# final report

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## Opportunities with terahertz and millimeter waves

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# Executive summary

This document looks at the opportunities for using Terahertz and Millimeter waves as measurement tools within the meat industry to enable more benefits to be derived. The development of commercial applications at these wavelengths is the last to be tackled of all of the Electromagnetic spectrum. This is mainly as a result of not having the physical hardware to be able to do it. This is now changing and technology is racing ahead to catch up with many major institutions, in Australia and around the world, now dedicating their best people to research in this area.

The areas of opportunity range from measurement of the temperature of outer space to measuring the skin to detect signs of skin cancer earlier than when they are identified now to heat rays that can make the skin feel extremely hot. The latter technology is finding use in crowd and terrorist control and this particular machine is displayed on the font cover of this report.

Whether this technology can bring a benefit is yet to be determined since the research is in its infancy but there is a very high probability that it will.
From what has been gleaned from this work, it is recommended that MLA begin an active dialogue with organisations in Australia at the Adelaide University Terahertz-wave group (another name for Terahertz waves) and continue dialogue with the CSIRO at their Wireless Technologies Laboratory at Epping, NSW.

It is also recommended that MLA give consideration to attending a Terahertz Wave Conference in Pasadena in California in September with a view of gaining a higher level of technical knowledge and begin a networking process to find out what research is going on around the world.

In a strange twist of fate, the reasons that triggered this project, that being an article regarding Raytheon's "Active Denial", heat ray system, has now switched back to the forefront as one of the opportunities. As this report was being finalised a chance conversation with a CSIRO team member at the Wireless Laboratories, suggested that what Raytheon had advised as to how the system worked was perhaps not the whole story. The reasons for this can only be speculated upon, but reasons of US national security would be prominent. The CSIRO researcher suggested that the Technology that Raytheon use is based on a "Gyrotron", a device for generating and focusing large Terahertz energies. Raytheon suggested that the "active Denial" heat ray system only created the "sensation" of being hot with it influencing only the nerve endings and that this technology could not be used to achieve what we had in mind. The CSIRO however, has suggested that they have heard of 2 people being physically burnt by the system and that their knowledge of how a Gyrotron works would support the theory that heating of the surface was indeed possible.
Sydney University's department of Physics has a Gyrotron in their laboratory and they are being approached to confirm or deny the potential opportunity.

These technologies may provide some potential opportunities to the Australian red Meat industry and should be pursued initially and an ongoing watching brief developed to keep abreast of the developments that are taking place.

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# 1 Introduction

This report was originally commissioned as a result of a chance article describing a process in use by the US military for Terrorist and crowd control; the Raytheon developed, “Active Denial System”. The article suggested that the technology could heat the surface of an organic object to painfully high temperatures in a matter of seconds using Terahertz wave radiation.

Such a system that could heat only the surface of the skin instantaneously and to painfully high temperatures for only a few seconds could have use in a meat processing plant for controlling the number of bacteria on the carcase surface. If the temperature of the carcase surface only could be raised to a high enough temperature for long enough to reduce the bacterial count but not so high a temperature that it causes any change to the underlying tissue, then this could have significant benefits for shelf life and other meat quality and health aspects.

As the research progressed it was found that this was not to be the case. Contact with Raytheon suggested that technology only acted on the nerve endings and gave only the sensation of high temperatures on the skin surface, contrary to many of the early research findings.

This article raised the interest of MLA staff and the brief was broadened to include a review of similar technologies that are available using Terahertz waves and what applications they might have to the Australian meat industry.

MLA had already had some experience with Electromagnetic waves in this non-ionising region having undertaken a project with the CSIRO using the nearby Millimeter wave system. This project was attempting to measure the subcutaneous fat depth of a carcase based on the amount of reflected energy from the millimeter wave that was bouncing off the fat /lean interface. The results of this trial were non convincing and further work needed to be done to determine the true capability.

This has not yet occurred because of a change of CSIRO staff but the process was beneficial in that it was to make MLA aware of the potentials that the radiation in this part of the electromagnetic spectrum may have. There are possibly applications using this technology to be able to measure safely, things that cannot be measured automatically with existing technology.

It had also been hoped that the sensing technologies in this region of the electromagnetic spectra (Terahertz and millimeter) may have been able to detect carcase contaminants such as hair, ingesta feces, and urine. Unfortunately the research suggests that the technology is yet to be tested in these areas to detect such items and in fact very little research in measuring organic things has occurred apart from Cancer research in the medical world. The technology does however, offer great promise of being able to detect such contaminants with each contaminant emitting its own spectral signature that is potentially detectable in the Terahertz region of the electromagnetic spectrum.

# 2 Background

Millimeter-wave and Terahertz-wave frequencies (f > 100 GHz) remain one of the most underdeveloped frequency ranges, even though the potential applications in remote sensing, spectroscopy, plasma diagnostics, and communications are obviously great. This is because the millimeter wave and far-infrared frequency range falls between two other frequency ranges in which conventional semiconductor devices are usually operated. One is the microwave frequency range, and the other is the near-infrared and optical frequency range. Therefore, a large gap exists from 100 GHz to 10 THz in which very few devices are available to detect such frequencies.

The National Academies Press web site[1] reveals the following:-

> *"While the parts of the millimeter-wave region of the electromagnetic spectrum have been extensively investigated since Bose in the 1800s, the region above 100 GHz is one of the least-explored ranges of the electromagnetic spectrum. Until relatively recently, it was difficult to generate and detect terahertz radiation efficiently. Recent advances in both electro-optic and radio-frequency (RF) techniques have enabled the undertaking of new investigations. These investigations have been directed toward two applications of importance to aviation security. The first is to produce imagery of passengers and baggage that takes advantage of the ability to penetrate clothing and other non-metallic coverings. This application is intended to find objects such as knives, guns, and explosives by detecting their shapes through the concealment. A second, more advanced application is intended to be able to classify materials, which also may be concealed, by observing their differential absorption or reflectance of radiation—in effect, spectroscopy. Recent data have shown that solid explosives do exhibit some repeatable spectroscopic features in the spectrum above 800 GHz that may be used to differentiate them from other solids."*

Until relatively recently, it was difficult to generate and detect terahertz radiation efficiently. Recent advances in both electro-optic and radio-frequency (RF) techniques have enabled the undertaking of new investigations. These investigations have been directed toward two applications of importance to aviation security. The first is to produce imagery of

## 2.1 What are Millimeter and terahertz Waves

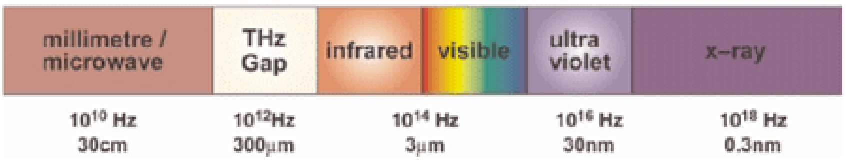
The expression "Millimeter wave" and "Terahertz wave" are basically interchangeable. The terahertz refers to the number of cycles per second or "Hertz" that the waves vibrate at and the "millimeter" part refers to the wavelength which is approximately 1 mm.

Terahertz radiation is non-ionizing electromagnetic radiation in the frequency from 0.1 to 10 THz or $1x10^{11}$ to $1x10^{13}$ hz (Terra Hertz = $10^{12}$ Hertz or cycles per second) and corresponds to wavelengths between 30 µm and 1mm These waves occupy a portion of the electromagnetic spectrum between

[1] http://books.nap.edu/openbook.php?record_id=11826&page=16

infrared and microwave radiation. Terahertz radiation is also called, terahertz waves, terahertz light, Terahertz-waves, T-light, T-lux and THz

Millimeter waves are I the range from 30- 300 Giga Hz ($3x10^{10}$ -$3x10^{11}$ They are therefore at the bottom end of the terahertz range, closer to the microwave region. .




Like Microwaves, Millimeter and Terahertz waves are affected by atmospheric conditions with much of the energy being absorbed by the atmosphere and are therefore not good for stable signal strength over long distances.

Terahertz waves are intrinsically safe since they are “non-ionising”, non invasive and non destructive. Unlike far more energetic X-rays, Millimeter-waves and Terahertz-waves do not have sufficient energy to "ionize" an atom by knocking loose one of its electrons. This ionization causes the cellular damage that can lead to radiation sickness or cancer. They share with microwaves the capability to penetrate a wide variety of non-conducting materials and can pass through clothing, paper, cardboard, wood, masonry, plastic, ceramics and other items such as fog clouds. It will not penetrate water or metals.

These qualities make terahertz devices one of the most promising new technologies for airport and national security and other potential uses. Unlike today's metal or X-ray detectors, which can identify only a few obviously dangerous materials, checkpoints that look instead at Terahertz-wave absorption patterns could not only detect but also identify a much wider variety of hazardous or illegal substances. All objects emit Terahertz electromagnetic radiation as “black- body” radiation but the total intensity emitted by all frequencies is less than one millionth of a watt per square centimetre[2]

The region above 100 GHz ($1x\ 10^{11}$ Hz) is one of the least-explored ranges of the electromagnetic spectrum

Terahertz waves can be compared to the Laser. When the laser was first seen by the public in the James Bond film, Gold finger, few people would have imagined that Lasers would be used 25 years later to scan the barcode for the price of groceries at a supermarket check out or burn off subsurface tattoos or form the basis of high speed computing. Terahertz waves will probably prove to be something similar in their wide variety of beneficial applications.

[2] http://physicsworld.com/cws/article/news/16414

# 3 Benefits and opportunities of Terahertz-Waves

Terahertz waves are beginning to become more and more widely researched and their potential applications continues to grow.

Whilst the knowledge of Terahertz-waves has been around for some time, their development has been slowed because of the limited amount of hardware that can detect and measure the Terahertz-wave output from a given body

"Many materials used in everyday life are highly transparent in the terahertz region, while others absorb the radiation in very characteristic ways. We can therefore use Terahertz radiation to see through materials such as clothes or plastic film and to analyse other materials using spectroscopy. In solids, weak non-covalent interactions between molecules can be observed, which can provide information about their crystalline structure; and metals are opaque at THz frequencies, so they can also be easily identified[3]"

In recent years Terahertz, Time-domain Spectroscopy (TDS) has been developed which provides a powerful tool for material identification. This development would not have been possible without advances in femtosecond lasers. A femtosecond laser is a laser which emits optical pulses with duration below 1 ps (ultrashort pulses), i.e., in the domain of femtoseconds (1 fs = $10^{-15}$ s) and these very high frequencies were needed to be able to generate the Terahertz-waves.

TDS is sensitive to the effect of material on both amplitude and phase of Terahertz radiation and has been able to deliver much more information than was available with conventional analysis.

Applications in organic products has only recently begun to accelerate. One of the benefits of Terahertz rays are that the can penetrate the body by almost half a centimetre. This coupled with the ability to measure different moisture contents mans that there potential many applications for agriculture and medical applications.

Recent research has seen applications now enable doctors to better detect and treat certain types of cancers, especially those of the skin and breast, The dental industry is also using this technology to generate images of their patients' teeth

Terahertz radiation puts much less energy into biological tissue than x-rays, and terahertz medical imaging systems can be tuned to highlight specific types of tissue such as skin cancers. Because terahertz waves can penetrate plastic and cloth, they can be used to detect concealed objects. Terahertz radiation is also capable of detecting chemicals like toxic gases and explosives

Among the challenges to making terahertz sensing and imaging applications more practical is finding ways to direct the waves to specific targets. Researchers are working to develop terahertz wave guiding devices that are similar to the waveguides used to channel microwaves and light waves.

[3] http://physicsworld.com/cws/article/indepth/33680

## 3.1 Issues with terahertz-Waves

The biggest issue with Terahertz-waves is:-

### 3.1.1 Water Vapour

Terahertz-waves are interfered with by water or water vapour. This is one of the reasons that Terahertz-waves are not used for communications , since their transmission through the atmosphere is variable, depending on humidity.

But this can be used as a strength enabling them to discriminate between objects of variable water content such as meat and fat.

### 3.1.2 Cost speed and complexity.

The systems are expensive because Terahertz-waves are not easy to generate. The frequencies required are too high for production by semiconductor devices and too low to be produced by solid state lasers of the femtosecond lasers used to cerate the radiation are costly although there is a push to reduce their cost. New algorithms need to be developed to increase the speed of the application which is in its infancy.

### 3.1.3 Limited Research

Because this is a new field and the detection of Terahertz and Millimeter waves has not been possible, the applications of their use and benefits are still in their infancy. Almost every major university worldwide is doing some form of research into Terahertz waves but there are few which have well developed technology although this is now raidly increasing. Only recently have commercial hardware system become available and only from a few vendors. Generally the vendors that are supplying equipment are companies that had a close relationship with an academic institution that was leading the research.

## 3.2 How are They Used

Terahertz waves are now finding applications in a wide range of applications, many which are still being discovered and unfortunately there has been little work undertaken in the biological area apart from medical applications with the detection and treatment of cancers.

There are two types of uses generally, passive and no passive.

In a passive system the Terahertz waves are collected by a Terahertz receiver. All objects are emitting background Terahertz waves, and some emit more than others and each item emits waves at their own frequency. The receiver can be tuned to receive waves that are close to a particular frequency of interest,

Non passive systems are where the object is bombarded with Terahertz waves of a particular range of spectral frequencies and the detector is receiving whatever os reflected. It can be compared to taking a photograph without a flash (passive) or with a flash with the camera “tuned” to receive the highr energy level of light.

## 3.3 Uses for Terahertz Waves and Millimeter waves include”

### 1. Astronomy

Radio Astronomy from high peaks where the attenuation is minimal and if used on large Millimeter Arrays. Very accurate measurement of atmospheric Temperature and temperature distributions can be achieved.

### 2. Explosive Detection

The ability of terahertz waves to identify a specific signature of a material means that it is ideally suited for use in Aviation baggage screening and even personal security screening.

### 3. Aviation Landing Systems

Potential exists to use Terrahertz waves to “see” through clud and enable aircraft to be able to land in poor weather conditions. The waves generated are safe to use around the public and do not damage any sensitive electronic machinery which is different from Microwaves and X-Rays. Research is still needed to develop the technology to overcome the absorption issue with water vapour. This may be overcome by more powerful generators.

### 4. Telecommunications

As a high speed telecommunications device in the 38.6-$0.0 GHz range and high speeds of up to 2.5 Gbits/ sec can be achieved over distances less than 2 km. In the 60- 100 GHz range, significantly higher transmission rates can be achieved and 10 Gbits is planned. The Millimeter wave has the ability to be focussed into thin beams and therefore interference an be minimised despite there being multiple beams in operation in close proximity.

The shorter wave lengths permits the use of smaller Antennae and the potential for very high bandwidths which could lead to a replacement for Fiber optic cables.

### 5. Security Screening

Recent developments have seen this wavelength wave being developed into security screening systems. This particular wavelength is able to penetrate organic materials such as clothing without penetration or exposing the skin to harmful ionising radiation.

There are significant privacy regulations that are still being overcome and better systems and protocols developed to cope with this.

More recent developments of the Technology have been applied to transmitting the waves over greater distance and scanning a larger area which would allow security workers to scan a large number of people without them being aware of this action.

Terahertz radiation can penetrate fabrics and plastics, so it can be used in surveillance, such as security screening, to uncover concealed weapons on a person, remotely. This is of particular interest because many materials of interest, such as plastic explosives, have unique spectral "fingerprints" in the terahertz range. This offers the possibility to combine spectral identification with imaging. Passive detection of Terahertz signatures avoid the bodily privacy concerns of other detection by being targeted to a very specific range of materials and objects.

### 6. Scientific use and imaging:

Spectroscopy or the interaction between radiation and matter, in terahertz radiation could provide novel information in chemistry and biochemistry. This is the area where detection of carcase contaminants is has the greatest opportunity of success.

Recently developed methods of Terahertz time-domain spectroscopy (THz TDS) and Terahertz tomography have been shown to be able to perform measurements on, and obtain images of, samples which are opaque in the visible and near-infrared regions of the spectrum. The utility of THz-TDS is limited when the sample is very thin, or has a low absorbance, since it is very difficult to distinguish changes in the THz pulse caused by the sample from those caused by long term fluctuations in the driving laser source or experiment. However, THz-TDS produces radiation that is both coherent and broadband, so such images can contain far more information than a conventional image formed with a single-frequency source.

### 7. Manufacturing:

Many possible uses of Terahertz-wave sensing and imaging are proposed in manufacturing, quality control, and process monitoring. These generally exploit the traits of plastics and cardboard being transparent to terahertz radiation, making it possible to inspect packaged goods.

### 8. Medical imaging:

Terahertz radiation is non-ionizing, and thus is not expected to damage tissues and DNA, unlike X-rays. Some frequencies of terahertz radiation can penetrate several millimeters of tissue with low water content (e.g. fatty tissue) and reflect back. Terahertz radiation can also detect differences in water content and density of a tissue. Such methods could allow effective detection of epithelial cancer with a safer and less invasive or painful system using imaging.

Some frequencies of terahertz radiation can be used for 3D imaging of teeth and may be more accurate and safer than conventional X-ray imaging in dentistry.

# 4 Hardware suppliers

There were several companies identified that were producing commercial systems using the frequencies of Terahertz-waves. The companies uncovered are listed below it a brief description of their products.

## 4.1 Terraview

TeraView Limited, is the world's first and leading innovator of 3-D imaging and spectroscopic systems which exploit the properties of terahertz to characterise a wide range of materials.

Their technology creates spectroscopic information and 3D images with unique spectroscopic signatures not found at other wavelengths. The technology also produces faster results than X-ray and enables non-destructive, internal, chemical analysis of tablets, capsules and other dosage forms.

TeraView's vision is to make terahertz technology affordable, accessible, and ubiquitous in everyday life.

TeraView was spun-out of Toshiba Research Europe in April  TeraView maintains close links with the Cavendish Laboratory at the University of Cambridge, where modern terahertz technology was pioneered in conjunction with the team at TeraView, and where Professor Pepper our founder, has held the position of Professor of Physics since 1987.

The Company manufactures a range of equipment and software, one of which is their proprietary TPI™ platform that can be configured to meet a variety of end-user needs.

## 4.2 Insight Product Co.

Insight Product Co. specializes in the design, engineering, and manufacturing of millimeter, sub-millimeter, and IR sources, frequency synthesizers, detectors, and mixers.

They custom design and produce millimeter and sub-millimeter systems based on the customer's specific needs and have devices are currently applied in astronomical research, material investigation, spectroscopy, mixers/receivers testing, EPR, NMR/ MRI, plasma diagnostics, Gyrotron experiments.

## 4.3 Microtech Instruments

http://www.mtinstruments.com/index.htm

Microtech Instruments manufacture and distributes Terahertz (THz) components and systems. Committed to innovation, Microtech collaborates with leading research institutions and companies around the world.

Contact Details
Megan Misiti, Sales Manager
E-Mail: sales@mtinstruments.com
Tel: (541) 683-6505
Fax: (541) 610-1825
Mail: 858 West Park Street, Eugene, OR 97401, USA

## 4.4 Zomega Terahertz Corporation

http://www.zomega-terahertz.com/

Zomega Terahertz Corporation is focused on developing and deploying Terahertz-based technology solutions for both the public and private sector. They produce both pre-designed and custom systems for Time Domain Spectroscopy (TDS) and CW applications in both point measurement and imaging modalities, true turnkey operation and integration into larger systems requiring THz capabilities. They also collaborate with the Center for Terahertz Research at Rensselaer Polytechnic Institute to push the frontiers of Terahertz science and commercialize new technologies.

## 4.5 Virginia Diodes, Inc.

http://www.virginiadiodes.com/

Virginia Diodes, Inc.

979 Second St. SE Suite 303

Charlottesville, VA 22902, 22902-6172

Ph: 434.297.3257, FAX: 434.297.3258 info @ virginiadiodes.com

## 4.6 Terahertz-wave Science

http://www.Terahertz-wavescience.com/

Ray Science is seeking to revolutionize the way skin cancer is diagnosed and ultimately cured by introducing a new platform of portable scanning devices that can be used in medical offices, skin care clinics, and other non-hospital locations; such as on-site skin cancer screening stations. Terahertz-wave Science's platform is being developed using non-invasive terahertz radiation, which is emerging as a safe, accurate and economical option to other scanning alternatives. The Terahertz-wave Science value proposition resides in building an economical technology that will address the widespread need for early skin cancer diagnosis in a cost effective manner.

The company's THz technology is also suitable for dental imaging, numerous pharmaceutical applications, wellness industry applications and postal securit

Terahertz-wave Science, Inc. Accelerator Centre

Waterloo Research & Technology Park

Suite 5B - 295 Hagey Boulevard

Waterloo, Ontario N2L 6R5

Toll Free: 877.605.0507 Fax: 519.513.2421 Email: info@Terahertz-wavescience.com

## 4.7 Institute for Development Commercialization of Advanced Sensor Technology (IDCAST)

http://www.idcast.com/default.aspx

DCAST, the Institute for the Development and Commercialization of Advanced Sensor Technology is a world-class center of excellence in remote sensing and CBRNE sensing technology. Established by a $28 million State of Ohio Third Frontier Grant, IDCAST brings remote sensor and CBRNE sensor technology to market. Through innovative collaborations of Academia, AFRL, and Industry IDCAST conducts game-changing sensor research.

It seems to be an amalgamation of Dayton, Toledo , Ohio, Wright State and Cincinnati universities in Ohio as well as others who are working oncommercialisation.

I belive this organisation may be worthy of follow up.

For more information email : Larrell.Walters@IDCAST.com

444 East Second St.

Dayton, OH 45402

# 5 What Research is Being Done?

There is significant research being done in the Millimeter-wave and Terahertz-wave area all around the world and in many Academic iInstitutions. In Australia there is a very active group called the "Terahertz-wave" group and are attached to the School of Physics at the University of Adelaide. The research they are conducting is limited in the tissue and organic area but they are interested to undertae work in this area.

The other universities that are doing active research of note are Cambridge and Leeds Universities in the UK, Rice University in Houston to name a few. Whether their research is applicable or they have an interest in the areas that MLA would like to investigate were unable to be determined within the scope of this document.

The following non Acadenmic organisations are actively doing research in more applied fields of endeavour:-

## 5.1 Rensselaer Polytechnic Institute

Rensselaer Polytechnic Institute

The research at Rensselaer is focused on the generation and detection of free-space THz beams with ultra-fast optics and electro-optic crystals. Intrinsic advantages to electro-optic detection include: non-resonant frequency response, large detector area, high scan rate and low optical probe power. Using a chirped optical probe pulse to read THz imaging in an electro-optic crystal allows for the measurement of a THz wave at an unprecedented data acquisition rate.

The Appendix includes a PDF file; THz Wave Technology and Application which demonstrates the vast capability of this organisation and they deserve a follow up in the future.

110 Eighth Street, Troy, New York 12180-3590 USA

## 5.2 USDA Agricultural Research Srevice

The US Department of Agriculture (USDA) through its' Agricultural Research Service has been undertaking significant research into the detection of Faecal matter particularly on Chickens. The following website link lists a number of research papers that have been published since 1998.

http://www.ars.usda.gov/Services/docs.htm?docid=9840

http://ars.usda.gov/pandp/people/people.htm?personid=3249

A number of the More relevant papers, and particularly thos applying to using Multispectoral Lser Interference have been included electronically with this report.

## 5.3 Jefferson National Research Laboratories.

The Jefferson Laboratories are a major Physics research centre with their own particle accelerator. Research is conducted in a wide range of areas.

The reason for the interest is that they have developed a large energy T-Wave generator . Whilst this is in its Infancy, this organisation and in Particular

Gwyn Williams, Basic Research Program Manager, would be worthy of making contact and exploring any opportunities for basic fundamental research that Terahertz waves may deliver. The higher energy terahertz unit allows a greater range of testing.

His further details are:-

gwyn@mailaps.org ph. 757 269-7521 (fax: 757 269-5026)

12000 Jefferson Ave

Newport News, VA 23606

Key People to Contact

General Business/Commercial: Jim Boyce, Technology Transfer Manager
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Michael J. Kelley Applied Research Program Manager
mkelley@jlab.org
757 269-5736 (fax: 757 269-5755) 12050 Jefferson Ave MS 6A
Newport News, VA 23606

# 6 Upcoming and Relevant Conferences

There are a number of relevant conferences on terahertz and Millimeter technology coming up within the next 12 months. Full details and internet references of a wide range of relevant conferences is identified in the Appendix un Conferences.

The ones identified as the most beneficial fo a representative of MLA to attend in the short term are:-

1. The joint 33rd International Conference on Infrared and Millimeter Waves and 16th International Conference on THz Electronics "Terahertz for Life" will be held at the campus of the California Institute of Technology in Pasadena, California, USA, between September 15th-19th, 2008. A list of the onference topics has also been included in the Appendix and there are a large number of presenations and posters covering a wide range of topic. The topic heading and précis have been included in the appandox to sho the large range and scope of research an potential applications athat are under research.

2. SPEC 2008: Shedding Light on Diseae: Optical Diagnosis for the New Millenium, which is being held in Sao Jose dos Campos, Sao Paulo, Brazil October 25- 29, October, 2008. This conference seem to have a more "biological" influence where the conference description includes:-

   -Concepts and overview of biomedical vibrational spectroscopy in medicine

   -Biomedical vibrational spectroscopy and imaging of single cells

   Drug-cell interaction studied by vibrational spectroscopies

   -Pathogens and infectious diseases

   -Vibrational clinical chemistry, analysis of bio-fluids

   -Raman, THZ-laser, NIR and MID-IR spectroscopies

   -Surface Enhanced Raman Spectroscopy (SERS)

   -Coherent Anti-Stokes Raman Spectroscopy (CARS)

   -Near-field infrared and Raman micro-spectroscopy

   -Dentistry

   -Other spectroscopic techniques

For conference details see:-

dollowinghttp://www.thznetwork.org/wordpress/index.php/archives/525

# 7 Where To Next?

This research has identified a number of things:-

1. There is an intrinsically safe technology in Terahertz waves that has high possibility of having commercial applications within the Australian, meat industry.

2. There a many researchers who have experience in these areas of research that can be tapped into to help deliver technology that will bring benefits to the industry and one of these key research groups is in Adelaide in Australia.

3. There are several relevant conferences in the short term which could be used as a way of developing the understanding and knowledge needed to see the opportunities that may be available to bring benefits to the industry and to develop key relationships with researchers and potential solution providers.

4. There are some Academic Institutions that are leading the field in various areas of Terahertz-wave research and are worthwhile exploring collaborative relationships further.

5. There are several commercial Companies that are manufacturing Terahertz-wave equipment on a commercial basis and would be worthy of making contact to explore the opportunities of developing specific equipment for the meat processing industry.

It also should be remembered that this technology is a sophisticated high technology area at this stage of its development and little is known by people within MLA or their advisors. It will take time for the understanding to be assimilated and understood and where the areas of benefit to the industry will be found. A structured approach to gain this understanding is therefore proposed.

## 7.1 Project Task list

The following tasks are recommended as the next steps in understanding where Terahertz and Millimeter waves can possibly bring a benefit to the meat industry.

- Meet with the CSIRO group who undertook the initial fat depth trials using Millimeter Waves and explore further opportunities.

- Meet with the Adelaide University School of Electrical and Electronic Engineering school and in particular the Terahertz-wave Group.

- This dialogue has already begun and it should be explored further and expanded to involve a greater number of researchers so that the opportunities may be more easily identified along with areas of promising research.

- Attend the joint 33rd International Conference on Infrared and Millimeter Waves and 16th International Conference on THz Electronics “Terahertz for Life” at the California Institute of Technology in Pasadena, California, USA, between September 15th-19th, 2008.

The goals of attending this conference would be to:-

- Learn what the latest research has identified
- Network with relevant organisations to learn who the key academic researchers are along with the innovative solution providers who would be the best fit to undertake collaborative joint research.

While in California and if not covered by attendance at the Pasadena Conference, meet with the Terahertz-wave researchers at the Stanford University who are undertaking work with Terahertz waves and tissue measurement[4] . Stanford University also has a close relationship with this area of research with other universities in the Bay area.

- Meet with the key researchers at Daniel Mittleman, Rice University, Houston, USA
- Meet with Giles Davis in the School of Electronic and Electrical Engineering at the University of Leeds and Edmund Lindfield at the Cavendish Lab at the University of Cambridge, UK
- Develop an Industry paper detailing the areas of opportunity and the expected industry benefits that would be delivered if successful and a detailed research plan for two of the most promising identified opportunities.
- Meet with Industry groups to confirm the interest and formulate a path forward form there is any.

[4] http://news-service.stanford.edu/news/2006/june14/laser-061406.html

## 7.2 Estimated Costs of Such a Plan

The costs of undertaking this next phase are estimated to be $73,000:-

| Terahertz Wave - Phase 1 Cost Etimates | | Air Travel | Accommodation days | Accommodation | Other Travel Costs | Meals | Consulting costs | Miscellaneous | Sub Totals |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Meet with the CSIRO Sydney | $300 | 0 | $0 | $200 | $20 | $1,500 | | $2,020 |
| 2 | Meet with the Adelaide University School of Electrical and Electronic Engineering school and in particular the Terahertz-wave Group. | $800 | 2 | $500 | $200 | $250 | $3,500 | $100 | $5,352 |
| 3 | Attend Conference on Infrared and Millimeter Waves at the California Institute of Technology in Pasadena, | $17,000 | 4 | $1,000 | $150 | $1,000 | $6,000 | $1,500 | $26,654 |
| 4 | Meet with the Terahertz wave researchers at the Stanford University | $300 | 2 | $500 | $250 | $150 | $2,000 | $200 | $3,402 |
| 5 | Meet with the key researchers at Rice University | $800 | 3 | $750 | $100 | $1,150 | $2,000 | $100 | $4,903 |
| 6 | Meet with G D; University of Leeds and EL Cavendish Lab at the University of Cambridge, UK | $500 | 3 | $750 | $100 | $200 | $3,000 | $200 | $4,753 |
| | Meet With the USDA ARS re work being done in contaminant detection in chicken with Terahertz-waves | $300 | 2 | $500 | $100 | $100 | $2,000 | $100 | $3,102 |
| 7 | Develop an Industry paper detailing the areas of opportunity and the expected industry benefits that would be delivered if successful and a detailed research plan for two of the most promising identified | $0 | 0 | $0 | $0 | $0 | $4,000 | $100 | $4,100 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | opportunities. | | | | | | | | |
| 8 | 9. Meet with Industry groups to confirm the interest and formulate a path forward form there is any. | $3,300 | | $0 | $100 | | $2,500 | | $5,900 |
| | Subtotal | $23,300 | 16 | $4,000 | $1,200 | $2,870 | $26,500 | $2,300 | $60,186 |
| | Contingency at 20% | $4,660 | | $800 | $240 | $574 | $5,300 | $460 | $12,037 |
| | Totals | $27,960 | | $4,800 | $1,440 | $3,444 | $31,800 | $2,760 | $72,223 |

# 8 Conclusions

The conclusions that can be drawn from the research include:-

- Terahertz and millimetre radiation offers possibly some opportunities to bring benefit to the Meat Industry.
- There are lots of possibilities for this area to provide benefits mto the red meat industries.
- Areas of identifiable possibility include :-
- Contaminant detection of type and location on carcases on the slaughter floor.
- Fat depth measurement or overall carcase subcutaneous fat depth
- Meat quality and eating assessment on the hot carcase
- Moisture content - possibility in trim sorting into cartons and remove manual sorting for specific Chemical Lean levels based on trim moisture component
- Dimensional imaging of carcases
- Confirmation of broken bags

Little applied research has been done in the organic arena and even less specifically on meat and many further opportunities potentially exist but are yet to be identified.

Any research will be significantly easier now because of the availability of high speed and higher energy radiation sources and the greater availability of people doing research in this area

It is believed that the potential is sufficiently great that MLA should make the investment to at least undertake Tasks 1 and 2 and then assess if the balance are worthy of continuing.

# 9 Appendices

The following Files are attached electronically

- Photon08.pdf – Call for papers for Europs Premier Conference in Optics and Photonics- Ausgust 08
- Basic_science.pdf – Overview of TeraNova's work in basic sciences
- Ngrant.pdf – a PDF of a powerpoint document entitled "Bringing Space Down to Earth – A review of Microwave Spinoff Technologies and Applications
- Science_thz_1.pdf – Article from "Science" VOL 297, 2nd August 2002 – Brainstorming Their way to An Imaging Revolution
- Thruvision t4000productbrief4.12..07lr.pdf - Product brochure of Thru vision Airport Screening System uing terahertz Waves
- Recentadvances.pdf – Recent Advances in terahertz Imaging
- Nature2.pdf – Terahertz power , Mark Sherwin
- 2006 yang95-4-4496BiosystemsEngineering.pdf - 83Development of Fuzzy Logic Based Differentiation Algorithm and Fast
- Line-scan Imaging System for Chicken Inspection
- 2006Yang49(1)245-257TransASABE.pdf – Simple MultiSpecttral Image Analysis For Systematically Diseased Chicken Identification
- 2007Liu81-412-418JFoodEngr.pdf - Development of simple algorithms for the detection of faecal contaminatants on apples from visible/near infrared hyperspectra; reflectance imaging.
- 2007Chen2-549-552NSTI-Nanotech.pdf - Development of SERS Spectroscopy for Routine and Rapid Identification of *Escherichia Coli* and *Listeria Monocytogenes* on Silver Colloidal Nanoparticles1
- 2006Kim60(10)1212-1216ApplSpec.pdf - Fluorescence Characteristics of Wholesome and Unwholesome Chicken Carcasses
- 2006Ding45(4)668-677AppliedOptics.pdf - Two-color mixing for classifying agricultural products for safety and quality
- 2005Yang49(2)255-271CompElecInAgric.pdf - Systemically diseased chicken identification using multispectral images and region of interest analysis

- 2005Lefcourt48(4)1587-1593TransASAE.pdf - Detection Of Fecal Contamination In Apple Calyx By Multispectral Laser-Induced Fluorescence
- 2005Yang69(2)225-234JFoodEngr.pdf - Development of multispectral image processing algorithms for identification of wholesome, septicemic, and inflammatory process chickens
- 2005Kim71(1)85-91JFoodEngr.pdf - Automated detection of fecal contamination of apples based on multispectral fluorescence image fusion
- Terahertz imaging_New steps toward real life applications.pdf - Terahertz imaging - new steps toward real-life applications –
- Millimeter-wave Terahertz and Infrared Devices.pdf -Millimeter-wave Terahertz and Infrared Devices.pdf- Millimeter-wave, Terahertz, and Infrared Devices
- Trrahertz Imaging.pdf - Terahertz Imaging For Drug Detection & Large-Scale Integrated Circuit Inspection
- TerahertzTechnologyLecture.pdf - Terahertz Technology M. S. Shur ECSE, Physics, and Broadband Center Rensselaer Polytechnic Institute, Troy, N Y USA - 85 pages
- THz08brochure.pdf – Brochure and call for papers for the IRMMW – Terahertz For Life Conference in Pasadena California,15-19 September 2008
- Lin_2008_spie_6840.pdf - Gas recognition with terahertz time-domain spectroscopy and spectral catalog: a preliminary study
- Tri-Fold_NLHumanEffects.pdf - Non-Lethal Human Effects
- Active denial System Presentation_Directed Energy Weapons_London_2.pdf - Active Denial System; Active SystemAdvanced Concept Technology Demonstration; Advanced Demonstration NonNon--Lethal Application of Directed EnergyLethal Energy - Brochure
- ADS_media_day_release.pdf - ADS_media_day_release.pdf - Joint Non-Lethal Weapons Program (JNLWP) Public Affairs Media Release
- Silent Guardian_cms04_017939.pdf - Raytheon Brochure -Silent Guardian™ Protection System
- 1-22-07%20SPIE%20Photonic%20West.pdf - THz Wave Technology & Applications

## 9.1 Appendix 1 Organisations Undertaking Research into terahertz Waves

### Australia

### University of Adelaide- Adelaide Terahertz-wave Group

The University of Adelaide seems to be the major institution outside the CSIRO that are Conducting active research into the T-Wave and Millimeter wave range. They would be the foirst organisation to begin to explore the opportunities of the potential benefits of T-Waves to the Australian red meat industry.

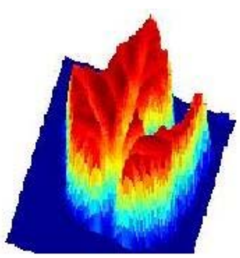
Personal communications with Dr Bernd M Fischer PhD, Australian Postdoctoral Fellow of the Adelaide Terahertz-wave group suggested (see email copy below) that there had been little work undertaken with organic materials apart from the security area and none that he is aware of in red meat.

The University of Adelaide Home | Faculties & Divisions| Search

School of Electrical & Electronic Engineering

THE UNIVERSITY OF ADELAIDE AUSTRALIA

Home > The School > Current Students > Future Students > Research Activities >



http://www.eleceng.adelaide.edu.au/thz/ourpeople.htm

School of Electrical & Electronic Engineering

Room N107. Engineering North Building

THE UNIVERSITY OF ADELAIDE SA 5005

Work on Terahertz-waves in Adelaide first began in 1997. On award of a large ARC grant in 1999, we developed Australia's first Terahertz-wave imaging program. In 2005, we won a major infrastructural ARC grant, to develop the world's first laser-based Terahertz-wave user facility. We currently run a range of Terahertz-wave research programs mainly in the areas of biosensing, security and short-path communications.

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Terahertz-wave Research Projects

THz Biomolecular Detection

THz radiation can probe biomolecular conformation and large-scale structure, whereas infrared spectroscopy only probes local structure. This project is aimed at exploiting THz spectroscopy to probe the conformation of biomolecules and the dependence on process stress. The elucidation of fundamental mechanisms of THz interaction with biomolecules will lead to improved methods of biomolecular fingerprinting. This will enable investigation of processing of biomolecular self-assembly and the classification of viral biothreats. This will impact on applications in the area of defence, security, pharmaceutical processing. **Investigators:** Sam Mickan, Shane Cloude and Derek Abbott. **Collaborators:** Anton Middelberg, Xi-Cheng Zhang, Giles Davies, Edmund Lindfield and Peter Uhd Jepsen.

THz Signal Classification

THz Package Inspection/3D Imaging for Security

THz Communications for Multimedia

The communications concept exploits the broad wireless bandwidth available with operation at 60 GHz through to THz frequencies, but recognises the costs of components and the limited propagation distances. Operating in broadcast mode (with a high cost at the transmitter end) transmitting at over 1 GBit/sec using CDMA for multi-chanelling within rooms, could open up new options. Users can move freely with their wireless enabled (low cost receivers) multimedia devices. The return channel could be at 2.5 GHz, as only a low rate would be required. This architecture exploits the advantages of THz or 60 GHz (high bandwidth at no regulatory cost), avoids the disadvantages of high cost components and limited propagation length to meet a potentially high market demand. The aim of the project is to examine the technical and economic feasibility of such a system. A potential application is in a high bandwidth wireless connection to virtual reality goggles'. **Investigators:** Reg Coutts, Neil Weste and Derek Abbott. **Collaborators:** Dan van der Weide.

THz Detection of Cancer

The early detection of skin cancers is critical with respect to treatment and patient survival. Biopsy techniques that are currently employed for such diagnoses are invasive, time consuming and costly. A TeraHertz (THz) imaging system potentially provides a fast and non-invasive way to detect and diagnose skin cancer by imaging the target area at different depths below the skin surface. While there is proof of concept that THz can distinguish cancerous and normal tissue, the mechanisms underlying this differentiation are not well understood. As yet it has not been shown whether THz can be utilised to discriminate malignant and benign skin disease, or different skin cancer types. This study will establish if THz spectroscopy is able to detect skin cancers and differentiate between tumours at various stages of tumourgenesis. **Investigators:** Tamath Rainsford, Sam Mickan, Derek Abbott. **Collaborators:** Tim van Doorn, David Findlay, Ross A. McKinnon, Stephen Scammel.

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## Personal Communication With Adelaide Terahertz-wave Group

Dear Greg,
it's been nice talking to you on Thursday.

As I was saying then, there hasn't been much published about interaction of THz radiaton (Terahertz-waves) and human/animal tissue.
Some of the earlier publications that might be of interest are:

- -Micro-spectroscopy and imaging in the THz range using coherent CW radiation, S Mair et al, 2002, Phys. Med. Biol., 47, 3719-3725

- -Far-infrared signature of animal tissues characterized by terahertz time-domain spectroscopy, Optics Communications, 259, Issue 1, Pages, 389-392 ,Mingxia He, Abul K. Azad, Shenghua Ye and Weili Zhang

As I mentioned before, there has not been much done in this field, and in particular all the studies performed so far we are more aiming for medical applications rather than quality control or anything like that.
Therefore, I am not able to say if there is a potential of Terahertz-waves for applications in the meat industry or not, but I am sure that some quite easy experiments could at least give some indications.

We have here at the National Terahertz-wave facility in Adelaide several different Terahertz-wave spectroscopy setups running and also some students who could perform such experiments. I am happy to show some people around in the labs and also give a shot introduction talk if there was some interest for that. I will be overseas for the next three weeks but have time after that.
Dr Bernd M Fischer PhD
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The Adelaide Terahertz-wave group
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or all Publications from Adelaide University and others on T-Wave topic see this web site.

https://www.eleceng.adelaide.edu.au/groups/thz/wiki/index.php/Terahertz-wave_Virtual_Library#2007_Publications

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### Adelaide Terahertz-wave Group Conference Articles

From Traywiki

Jump to: navigation, search

Introduction

Below are the links to our Terahertz-wave group conference publications that are maintained on this wiki page. The wiki concept is exploited, for the purpose of quickly updating the information with ease. To return to the previous page, click the "back" button on your browser or to return to the Terahertz-wave group Homepage scroll down to the links at the bottom of this page.

2008

[1] H. Lin, W. Withayachumnankul, B. M. Fischer, S. P. Mickan, and D. Abbott, "Gas recognition with terahertz time-domain spectroscopy and spectral catalog: a preliminary study," *Proc. of SPIE*, Vol. 6840, Art. No. 68400X, 4 Jan. 2008.

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[3] W. Withayachumnankul, B. M. Fischer, S. P. Mickan, and D. Abbott, "Removal of water-vapor-induced fluctuations in Terahertz-wave signals: A preliminary study," *Proceedings SPIE Noise and Fluctuations in Photonics, Quantum Optics, and Communications, Florence, Italy*, vol. 6603, art. no. 660323, 2007.

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[6] B. Fischer, H. Helm, and D. Abbott, "Biosensing with Terahertz-wave spectroscopy," *Biophotonics 2007: Optics in Life Science*, Ed. Jürgen Popp, Gert von Bally, Vol. 6633, 13th July 2007, Art. No. 66331D, 2007.

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[10] H. Lin, B. Fischer, S. Mickan, and D. Abbott, "Review of THz near-field methods," *Proceedings Smart Structures, Devices, and Systems III*, Ed. Said F. Al-Sarawi, Vol. 6414, Art. No. 64140L, 11 Jan. 2007.

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H. Lin, W. Withayachumnankul, B. M. Fischer, S. P. Mickan, and D. Abbott, "THz time-domain spectroscopy uncertainties", *Proceedings IRMMW-THz, Cardiff, UK*, pp. 222-223, 2007.

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[14] M. Franz, B. M. Fischer, D. Abbott, and H. Helm, "Terahertz study of chiral and racemic crystals," *Infrared Millimeter Waves and 14th International Conference on Terahertz Electronics*, IRMMW-THz 2006, *Joint 31st International Conference*, p. 230, 18-22 Sept 2006.

[15]W. Withayachumnankul, B. M. Fischer, S. P. Mickan, and D. Abbott, "Thickness determination for homogeneous dielectric materials through THz-TDS," *Infrared Millimeter Waves and 14th International Conference on Teraherz Electronics,* IRMMW-THz 2006, *Joint 31st International Conference,* p. 48, 18-22 Sept 2006.

[16] B. Ung, J. Balakrishnan, B.M. Fischer, B. W.-H. Ng, and D. Abbott, "Substance detection for security screening using Terahertz imaging technology," *Infrared Millimeter Waves and 14th International Conference on Teraherz Electronics,* IRMMW-THz 2006, *Joint 31st International Conference,* p. 447, 18-22 Sept 2006.

[17] J. Balakrishnan, B. M. Fischer, S. P. Mickan, and D. Abbott, "Novel Terahertz-wave liquid spectroscopy via double modulated differential time-domain spectroscopy," *Infrared Millimeter Waves and 14th International Conference on Terahertz Electronics,* IRMMW-THz 2006, *Joint 31st International Conference,*p. 446, 18-22 Sept 2006.

[18] I. Jones, T. Rainsford, B. M. Fischer, and D. Abbott, "THz fingerprinting of biomolecules supported by Ab Initio molecular modelling," *Infrared Millimeter Waves and 14th International Conference on Teraherz Electronics,* IRMMW-THz 2006, *Joint 31st International Conference,* p. 442, 18-22 Sept 2006.

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See Also

Adelaide Terahertz-wave Group Journal Articles

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### International

Rutherford Appleton Laboratory (RAL) in Oxfordshire.

Rice university Houston TX.

http://www-ece.rice.edu/~daniel/?

Welcome to the Mittleman group home page, in the ECE Department at Rice University. Our research interests are two-fold. Some of our work involves the generation and detection of single-cycle pulses of far-infrared radiation, which is accomplished with ultrafast laser pulses. This field, a subset of what is commonly known as *ultrafast optoelectronics*, is interesting because these far-IR (or *terahertz*) pulses access a range of the electromagnetic spectrum which is relatively unexplored. Others in the group study the properties of photonic crystals. These are materials with dielectric functions that vary periodically in space. This variation endows the crystals with unusal properties due to the strong diffraction of electromagnetic radiation. Please contact Dr. Mittleman if you have any questions or comments.

News: Check out the Virtual Journal of Terahertz Science and Technology!
News: Our article in *Rep. Prog. Phys.* is one of the feature articles of 2007.
News: OTST 2009 web site!

Research interests: THz spectroscopy and imaging, photonic crystals

Group members, phone list, meeting schedule

Publications from our group

Terahertz Links - a compendium of groups using THz time-domain spectroscopy

Home page for ELEC 262, Waves and Photonics

Home page for ELEC 569, Ultrafast Optics

Houston LEOS Chapter home page

Optics Express editor login

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### University of Leeds Faculty of Engineering

University of Leeds School of Electronic and Electrical Engineering

This department at the University of Leeds has been undertaking a wide range of research into Terahertz waves. In particular there have been several paers written on the topics of :-

“Electrical protein detection in cell lysates using high-density peptide-aptamer microarrays.

Terahertz spectroscopy of explosives and drugs”

The main researcher seems to be Professor AG Davies:- Chair of Electronic and Photonic Engineering, Director of the Institute of Microwaves and Photonics, Deputy Head of School and Director of Research

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Research activities

“My research interests include the development of terahertz science and technology, and the use of biological processes for nanotechnology.For further information, and for a complete publications and research grants list, please see my personal home-page (link below)”

Professor Davies has also contributed to a chapter of a book with a topic entitled “*Molecular and organic interactions” in a book “*Terahertz Frequency Detection and Identification of Materials and Objects”

His department has 9 research students conduction further research in the area of Terahertz waves. He lived in Australia from 1992-1995 as a an Australian Research Council Postdoctoral Fellow at the University of New South Wales.

Professor Davies has also been involved in Far Infrared Spectrosopy, Computer Tommography, X-Ray dose reduction, and a generic technique to generate large linear, branched, and/or circular DNA macromolecular complexes. He seems to have an interesting blend of physics and specialised imaging with the biological unsdertsanding that would bring benefit to this area of research within the Meat industry

The University of Leeds would be well worth following up for future investigations.

### Cavendish Laboratory University of Cambridge

### Jefferson National Research Laboratories.

http://www.jlab.org/visitors/

The Thomas Jefferson National Accelerator Facility (Jefferson Lab) is funded by the U.S. Department of Energy's Office of Science with strong support from the City of Newport News and the Commonwealth of Virginia. As a user facility for scientists worldwide, its primary mission is to conduct basic research of the atom's nucleus at the quark level.

With industry and university partners, Jefferson Lab also has a derivative mission: applied research for using the Free-Electron Lasers based on technology developed at the lab to conduct physics experiments. Additionally, as a center for both basic and applied research, Jefferson Lab reaches out to help educate the next generation in science and technology.

Jefferson Lab is managed and operated for the DOE by the Jefferson Science Associates, LLC. JSA is a limited liability corporation created by Southeastern Universities Research Association and Computer Sciences Corp. specifically to manage and operate Jefferson Lab.

The Jefferson Laboratories are a major Physics research centre with their own particle accelerator. Research is conducted in a wide range of areas.

From their website (http://www.jlab.org/visitors/)

“The Thomas Jefferson National Accelerator Facility (Jefferson Lab) is funded by the *U.S. Department of Energy's* *Office of Science* with strong support from the *City of Newport News* and the Commonwealth of Virginia. As a user facility for scientists worldwide, its primary mission is to conduct basic research of the atom's nucleus at the quark level.

With industry and university partners, Jefferson Lab also has a derivative mission: applied research for using the Free-Electron Lasers based on technology developed at the lab to conduct physics experiments. Additionally, as a center for both basic and applied research, Jefferson Lab reaches out to help educate the next generation in science and technology.”

Breakthrough at Jefferson Lab:terahertz Light (Terahertz-waves) –Nontechnical Summary

An experiment at the U.S. Department of Energy's Thomas Jefferson National Accelerator Facility in Newport News, Va., has shown how to make highly useful terahertz light, or Terahertz-waves, tens of thousands of times brighter than ever before. (View articles in the popular and scientific press.)

This latest spinoff from Jefferson Lab's main mission of nuclear physics research lights the way toward a number of prospective benefits, including:

better detection of concealed weapons, hidden explosives and land mines,

improved medical imaging and more productive study of cell dynamics and genes,

instant "fingerprinting" of chemical and biological terror materials in envelopes, packages or air,

better characterization of semiconductors, and

widening the frequency bands available for wireless communication.

Researchers from Jefferson Lab and two other Department of Energy laboratories - Brookhaven National Laboratory in Upton, N.Y., and Lawrence Berkeley National Laboratory in Berkeley, Calif. - sent a beam of electrons at nearly the speed of light through a magnetic field. That caused the electrons to radiate Terahertz-waves at a trillion cycles per second—the terahertz frequency that gives Terahertz-waves their name and that makes them especially useful for investigating biological molecules.

Invisible Terahertz-waves bear comparison with radio waves, microwaves, infrared light and X-rays. But unlike those much-used forms of radiated energy, Terahertz-waves have been little exploited—in part because no one knew how to make them bright enough.

Terahertz-waves are electromagnetic radiation of the safe, non-ionizing kind. They can pass through clothing, paper, cardboard, wood, masonry, plastic and ceramics. They can penetrate fog and clouds. Their wavelength—shorter than microwaves, longer than infrared—corresponds revealingly with biomolecular vibrations.

For over a decade, scientists worldwide have been pressing the study of terahertz light and looking for better ways to generate and use it. An Aug. 16, 2002, *Science* magazine article, "Revealing the Invisible," reported that "much research is being directed toward the development of Terahertz-wave sources and detectors, particularly for applications in medical imaging and security scanning systems." The Web site of Dr. Xi-Cheng Zhang, a Terahertz-wave expert at Rensselaer Polytechnic Institute, predicts that "the future 'killer application' ... will be in biomedicine."

Tochigi Nikon Corporation and Teraview—a Cambridge, England, start-up associated with Toshiba—have begun commercializing low-power Terahertz-wave systems. A few hospitals are testing comparatively dim Terahertz-waves for detecting skin cancer. Dr. Daniel M. Mittleman of Rice University says that for low-power Terahertz-waves, "perhaps the most promising applications lie in the area of quality control of packaged goods." He illustrates by showing how Terahertz-waves can check the raisin count in boxes of raisin bran.

Overall, though, Terahertz-waves still constitute a gap in the science of light and energy. They inhabit a region of the electromagnetic spectrum remaining to be better understood—and much better exploited. Now that a way to generate them at high power has been demonstrated, Terahertz-waves can potentially extend and add widely to the wave-based technologies that have defined the last century and a half, from the telegraph, radio and X-rays to computers, cell phones and medical MRIs.

Jefferson Lab's Gwyn Williams conceived and led the experiment, which took place during 2001. Dr. Williams and his colleagues announced the work in the article "High-power terahertz radiation from relativistic electrons" in the Nov. 14, 2002, issue of the international science journal Nature. (View this and other articles in the popular and scientific press.)

Dr. Williams is a photon scientist, a researcher of light. But Jefferson Lab's main mission is nuclear physics, the study of the atom's core. Nuclear physicists visiting from across the country and around the world probe nuclei with beams of electrons from Jefferson Lab's huge superconducting accelerator. Williams joined Jefferson Lab in 2000 to conduct research with a smaller, unique adaptation of that accelerator: the world's first high-powered "free-electron laser."

The U.S. Navy funded the laser's construction to investigate the science and technology of high-power laser beams whose precise wavelength can be selected. It's over 200 times more powerful than any other wavelength-tunable laser—and the Navy is funding an upgrade to still higher power. The laser is "driven" by the same small superconducting electron accelerator that Williams and his colleagues used for their demonstration of bright Terahertz-waves.

Before that experiment, no other method of generating terahertz light had yielded more than a thousandth of a watt in power. But they extracted tens of thousands times more. "Think of a candle and then think of a floodlight," says Williams.

But no matter how bright they are, Terahertz-waves can't penetrate metal or water. So they can't be used to inspect cargo containers on arriving ships or to diagnose conditions deep inside the human body. "Nevertheless," says Williams, "the growing awareness of Terahertz-waves' usefulness is like what happened a century ago with X-rays—only Terahertz-waves will have a much wider range of applications. The task now is to develop those uses individually."

And that's exactly what he and his colleagues are about to do. Dr. Williams is planning a program of further research to develop and demonstrate practical applications of terahertz light.

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### University of Utah

The University of Utah have an active Physic Department who are undertaking Tarahertz wave research particularly as it is appled to high speed computing. Whisl this does not apply to the biological area that is the area of interest for this project, the fact that they are actively undertaking research suggests that they should be considered for further consideration.

One of the major researchers in this field is Professor Valy Vardney. According to a Blog by Professor Vardeny he :-

" is an experimental physicist interested in transient and steady state optical, electronic and spintronic properties of organic semiconductors in the time domain from femtoseconds to minutes. In his laboratory Prof. Vardeny synthesizes a variety of semiconducting polymers and grows various single crystals from pi-conjugated oligomers and molecules. Using a variety of pulsed laser excitations he studies the transient response of photoexcitations in doped and undoped semiconducting polymer films, molecular organic crystals, fullerenes, single walled nanotubes and dielectric and metallic photonic crystals."

His details are :-

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University of California, Santa Barbara

The following recent abstract from the Proceeding of the International Society for Optical Engineering illustrates that the University of Santa Barbara in California is undertaking some relevant research on tissue using Terahertz waves. A followup of the key researchers would be one of the next steps.

Proc. SPIE / Volume 6949 / THz Technology and Methodology

THz imaging based on water-concentration contrast

Proc. SPIE, Vol. **6949**, 69490D (2008); DOI:10.1117/12.785337

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Conference Location: Orlando, FL, USA
Conference Title: Terahertz for Military and Security Applications VI

Conference Chairs: James O. Jensen, Hong-Liang Cui, Dwight L. Woolard, R. Jennifer Hwu

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Terahertz medical imaging has emerged as a promising new field because of its non-ionizing photon energy and its acute sensitivity to water concentration. To better understand the primary contrast mechanism in THz imaging of tissues, the reflectivity of varying water concentrations was measured. Using a pulsed THz reflective imaging system, a 0.3 mm thin paper sample with varying water concentrations was probed and from the measured data a noise equivalent delta water concentration (NE$\Delta$WC) of 0.054% was derived. The system is based on a photoconductive pulsed source and time-gated waveguide-mounted Schottky diode receiver. It operates at a center frequency of 500 GHz with 125 GHz of noise-equivalent bandwidth and at a standoff of 4 cm, the imaging system achieved a spot size of 2.2 mm. The high water sensitivity of this system was exploited to image burned porcine (pig) skin models in reflection using differences in water content of burned and unburned skin as the contrast mechanism. The obtained images of the porcine skin burns are a step towards the ability to quantify burn injuries using THz radiation. -*The International Society for Optical Engineering.*



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**Stanford University**
http://news-service.stanford.edu/news/2006/june14/laser-061406.html

Stanford Report, June 8, 2006

Researchers 'lase' a trail to early detection of breast tumors

BY ADITI RISBUD

Researchers: Seongsin Kim and Allison Kurian

A novel laser engineered to home in on tiny tumors may someday enhance early detection of cancers in breast, skin and other tissues, researchers report. Using a high-frequency laser to probe tissue biopsies from mice, a team of scientists at Stanford, the University of Neuchatel in Switzerland and the University of California-Davis has developed an experimental technology that ultimately may bring higher resolution and fewer risks than mammography and magnetic resonance imaging (MRI).

"If there's a safer, newer way of imaging that could combine the current technologies, it would be very promising for studying cancerous tissues," says Stanford research associate Seongsin Kim, who holds a doctorate in electrical engineering. "Considering research efforts have increased recently, I would expect the technology to come to market within the next five years."

Allison Kurian, a medical doctor who is an instructor in the Division of Oncology and conducts clinical research in hereditary breast cancer through the Stanford Cancer Genetics Clinic, says, "A new kind of imaging could give us a new tool for clinical studies and distinguishing between tumors and normal tissue."

Conventional imaging technologies for detecting breast tumors include mammography, which uses X-rays, and MRI, which uses strong magnetic fields. But neither of these techniques is ideal. Mammograms often miss smaller tumors and can expose women already at high risk for developing cancer to radiation. Conversely, MRI scans that detect alterations in tissue can produce false positives, leading to unnecessary biopsies.

In lasers, a higher frequency means smaller tumors can be detected, Kim says. Terahertz lasers are energetic enough to resolve features five times smaller than MRI and 50 times smaller than mammography. Data from the Centers for Disease Control and Prevention indicate screening to detect cancerous tumors—while they are still small—could prevent 16 percent of deaths associated with breast cancer in women over age 40.

This terahertz technology, says Kurian, "might fill a gap in imaging breast tissue for women who are at highest risk."

The type of laser used in this study, called a quantum cascade laser, allows researchers to tune the laser to a desired frequency. This lets scientists explore a range of medical applications, says Kim, including tumor detection.

In a typical laser, a crystal such as a ruby is used to provide a fixed output frequency. But in a quantum cascade laser, the crystal has been engineered to contain different layers of materials. In the case of the terahertz laser, each layer within a crystal of aluminum gallium arsenide is chemically distinct. The result is a laser that can emit light in a 'cascade' to allow unparalleled imaging capabilities while providing less exposure to radiation than mammography.

To test the laser's abilities, the researchers obtained 2-millimeter-thick pieces of liver, fat, muscle and tendon from mice and scanned the tissues for 30 minutes each with the laser. They also tested healthy and cancerous liver tissue from the mice. By measuring the difference between absorbed and transmitted power through these tissues, the researchers could distinguish features that differentiate healthy from cancerous tissues. Such 'differential absorption' provides higher contrast and resolution compared to optical imaging.

Eventually, says Kurian, "we want to get to the point where we have something that is feasible for medical imaging, such as a handheld device like [that used in] ultrasound." The scan speed for such a device would have to be improved for use in a medical setting, she says.

The study, titled "Biomedical terahertz imaging with a quantum cascade laser," appeared in the April 14 issue of *Applied Physics Letters*, and drew together engineers and doctors in a multidisciplinary collaborative effort. Stanford's Interdisciplinary Translational Research Program (ITRP) funded the study. ITRP is a joint effort of the Beckman Center for Molecular and Genetic Medicine, the [Medical] Dean's Office and the Virginia and D.K. Ludwig Fund for Cancer Research.

Stanford researchers Kim, visiting scholar Fariba Hatami and Electrical Engineering Professor James Harris teamed up with Kurian, Oncology and Genetics Professor James Ford and applied physics graduate student Douglas King. The technology for the cascade laser stemmed from previous research by co-authors Giacomo Scalari, Marcella Giovannini, Nicolas Hoyler and Jerome Faist at the University of Neuchatel, Switzerland. Faist invented the cascade laser with colleagues at Bell Laboratories in 1994. Co-author Geoff Harris at the University of California-Davis contributed to greater understanding of the tissue characteristics.

"We see women at the highest risk for cancer, so they are highly motivated and most in need of new technology," says Kurian. "It's an exciting new possibility."

Aditi Risbud is a science-writing intern at Stanford News Service.

### Other Terahertz Research Groups and Facilities

Source:- http://www.rpi.edu/~zhangxc/linkshome.htm

Oklahoma State University Ultrafast Terahertz Research Group

Terahertz Research at Cavendish Laboratory, University of Cambridge

Teravision Project, a Terahertz Research Collaboration Funded by the European Commission

University of Strathclyde, Terahertz to Optical Pulse Source (TOPS) Facility Homepage

Terahertz Physics in Freiburg

Terahertz Imaging at STARTIGER

Kawase Initiative Research Unit

University of Michigan, Center for Ultrafast Optical Science (CUOS)

University of California, Santa Barbara Center for Terahertz Science and Technology

Semiconductor Physics Institute, Terahertz Technologies and Nanostructures Research

Institute of Physics, Academy of Sciences of the Czech Republic Laboratory of Terahertz Spectroscopy

Mittleman Group at Rice University

Perdue University Ultrafast Optics and Optical Fiber Communication Laboratory

University of Maryland Ultrafast Optoelectronics Laboratory

The Schmuttenmaer Group at Yale

The University of Reading Terahertz Laboratory

Terahertz Photonics Group at Oxford

Photonics and Optoelectronis Group at Ludwig-Maximilians-Universität Munich

Ultrafast Processes Research Group at Universität Innsbruck

Ultrashort Pulse Spectroscopy and Terahertz Physics at Johann Wolfgang Goethe Universität

Femtolab at Aarhus Universitet

Research for Terahertz Optoelectronics, Japan

Terahertz group at New Jersey Institute of Technology

## 9.2 Appendix 2 Upcoming Conferences

### General

http://www.thznetwork.org/wordpress/index.php/archives/category/conferences-etc

International Conference on Advanced Infocomm Technology ( ICAIT 2008)

Monday, July 28th, 2008

[ July 28, 2008 to July 31, 2008. ] Shen zhen, China, on 28-31 July 2008

2008 China-Japan Joint Microwave Conference

Wednesday, September 10th, 2008

[ September 10, 2008 to September 12, 2008. ] September 10-12, 2008, Shanghai University, Shanghai, China

IRMMW-THz 2008

Monday, September 15th, 2008

[ September 15, 2008 to September 19, 2008. ] The joint 33rd International Conference on Infrared and Millimeter Waves and 16th International Conference on THz Electronics "Terahertz for Life" will be held at the campus of the California Institute of Technology in Pasadena, California, USA, between September 15th-19th, 2008.

SPIE Europe Security and Defence

Monday, September 15th, 2008

[ September 15, 2008 to September 18, 2008. ] This meeting crosses the divide between fundamental optical science and the application of the underpinning technologies in advanced defence and security systems. Cardiff, Wales, United Kingdom.

2008 E-MRS Fall Meeting

Monday, September 15th, 2008

[ September 15, 2008 to September 19, 2008. ] Warsaw, Poland. September 15-19, 2008.

FACSS 2008

Sunday, September 28th, 2008

[ September 28, 2008 to October 2, 2008. ] 35th FACSS, Grand Sierra Resort, Reno, NV, Sept. 28 - Oct. 2, 2008

EOS Annual Meeting 2008 - TOM 2: Terahertz - Science and Technology

Monday, September 29th, 2008

[ September 29, 2008 to October 2, 2008. ] The EOS Annual Meeting 2008 features seven topical meetings and an education workshop from 29 September to 02 October 2008 in Paris, France.

International Workshop "THz Radiation: Basic Research and Applications" (TERA 2008)

Thursday, October 2nd, 2008

[ October 2, 2008 to October 4, 2008. ] October 2 - 4, 2008

Alushta, Crimea, Ukraine

SPEC 2008: Shedding Light on Disease: Optical Diagnosis for the New Millenium

Saturday, October 25th, 2008

[ October 25, 2008 to October 29, 2008. ] Sao Jose dos Campos, Sao Paulo, Brazil. October 25-29, 2008

EuMW 2008: 38th European Microwave Conference 2008

Tuesday, October 28th, 2008

[ October 28, 2008 to October 31, 2008. ] The 38th European Microwave Conference (EuMC) that will be held in Amsterdam, The Netherlands, from 28 to 31 October, is the core of European Microwave Week 2008, the largest event in Europe dedicated to microwave electronics.

APS March Meeting

Monday, March 16th, 2009

[ March 16, 2009 to March 20, 2009. ] March 16-20, 2009 Pittsburgh, PA

Photon 08 – UK 26-29 August 2008, Edinburgh Conference Centre Herriot Watt University, UK

The is conference encompasses the Optics Photonics Division Conference, The Quantum Electronics Conference, an Industry Technology Progtamme, and an exhibition and tutorials.

There is a special section dedicated to Terahertz Waves.

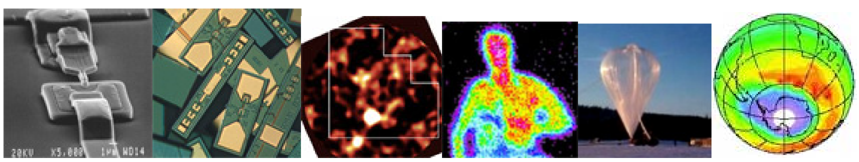
See their website www.photon.org.uk as well as the procure in the attached PDF filephoton08.pdf

## International Conference on Infrared, Millimetre and Terahertz Waves, California, USA September 15-19th. 2008

This conference is the most appropriate Conference in the near term whereby significant knwoldege of the applications of these technologies, and the areas of potential research could be gleaned in one location.

Below are listded all of the conference details as are the synopsis of the Papers and Posters to be delivered and presented. Whils this is an exhaustive list it has been included to show the great vlume of research being undertaken and the diversityof topics being researched. The highlighted areas show some potential definite areas of interest to MLA.

IRMMW-THz




International Conference on Infrared, Millimeter, and Terahertz Waves

http://www.irmmw-thz.org/

HOME

The International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), begun in 1974, is the oldest and largest continuous forum specifically devoted to the field of ultra high frequency electronics and applications. In 2004 the original conference series - International Conference on Infrared and Millimeter Waves (IRMMW) joined up with the International Conference on THz Electronics to form the Joint 29th International Conference on Infrared and Millimeter Waves and the 12th International Conference on Terahertz Electronics (IRMMW-THz 2004). In 2008 the conference name was shortened to the 33rd International Conference on Infrared, Millimeter, and Terahertz Waves, keeping the same general acronym: IRMMW-THz 20XX.

The IRMMW conference and its long standing accompanying monthly publication, The Journal of Infrared, Millimeter and Terahertz Waves, were among the very first scientific outlets for the burgeoning field of far infrared components and instruments that arose in the mid 1970s. The scope of the conference extends from millimeter wave devices, components and systems to far-infrared detectors and instruments, and encompasses micro- and nano-scale structures to large-scale accelerators and Tokamaks and their applications.

The international organizing committee is composed of world-recognized experts from eleven countries. The conference typically alternates between the USA, Asia and Europe on a three year cycle. Past conferences have been supported by US agencies such as IEEE, APS, DOE and DoD and dozens of local societies within the hosting countries. In 2003 both the IRMMW and THz Electronics conferences were held sequentially in Japan. Total attendees for both events was 520 registrants from 18 countries with 340 submitted papers. After 2003 the two conferences joined and attendance in 2004 (Karlsruhe, Germany) exceeded 450 scientists from 28 countries with over 400 contributed papers. The 2005 conference in Williamsburg, Virginia, hosted 300 scientists from 23 countries with more than 375 contributed papers. In Shanghai, China in 2006 more than 550 papers were submitted representing 28 countries and regions, the largest venue in recent memory. The 2007 conference in Cardiff, Wales, UK has just ended with more than 430 participants from 18 countries and 550 submitted papers.

Sandwiched between the optical on the short wavelength side and radio on the long wavelength extreme, the Terahertz or Far-Infrared has long been considered the last remaining scientific gap in the electromagnetic spectrum. Due to the historic role the IRMMW conference has played in bridging this gap by bringing together international researchers in many diverse fields - from space science to nuclear fusion - and recently chemistry and biology, the organizing committees would again like to reach out to scientists in adjacent fields who can benefit from recent developments in the far-IR.

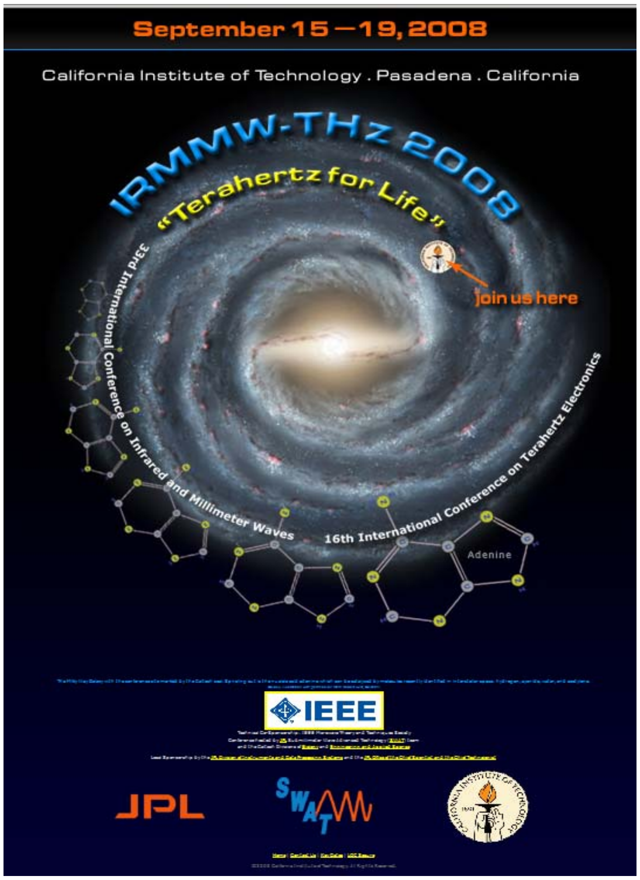
In the last few years interest in terahertz imaging and spectroscopy from the biology, security, ultra-fast chemistry and health science communities has grown exponentially as new instrumentation and techniques have begun to make their way into many laboratories world-wide. This is especially the case in Europe and Japan, both of which have thriving cross-disciplinary programs supporting new applications in this frequency domain.

As a consequence the conference organizing committees have significantly expanded the scope and the participating research communities. They have now included a special focus on terahertz techniques and applications, including both the traditional radio frequency domain, and the new fast pulse time domain approaches to generating, detecting and using high frequency energy. The conference offers the attendee a chance to hear and participate in a wide range of topic areas that span all aspects of Infrared, Terahertz and Millimeter-Wave (IR, THz, and MMW) technology and applications from quantum physics, chemistry, and biology to radio astronomy, plasma physics and security.

Over the coming years we are looking forward to very well attended and internationally supported cross-disciplinary conference venues that will set IRMMW-THz up as the pre-eminent conference for information exchange in the "Terahertz Gap”.

IRMMW-THz 2008 will be held on the campus of the California Institute of Technology in Pasadena, California, USA from September 15-19th.

http://www.irmmw-thz2008.org/




IRMMW-THz 2009 will be in Busan, Korea between Spetmber 21-15. IRMMW-THz 2010 is scheduled for Rome, Italy from September 6-10.

### Major Topical Areas

The following is a representative list of topics typically covered at the conference:

New IR, THz and MMW applications in Biology and Medicine

IR, THz and MMW Imaging, especially biomedical applications

Ultra-fast Components and Measurements in Chemistry and Physics

IR, THz and MMW Astronomy, Atmospheric and Environmental Science Applications

IR, THz and MMW Spectroscopy, Instrumentation and Material Properties

IR, THz and MMW Applications in Security and Defense

MMW Telecommunication and Industrial Applications

Ultra High Speed MMW Digital Devices

MMW and Submillimeter-Wave Radar and Communications

MMW systems, Transmission Lines and Antennas

Gyro-Oscillators and Amplifiers

Free Electron Lasers and Synchrotron Radiation

Plasma Diagnostics

Novel devices and Instruments for IR, THz and MMW applications

THz Devices, Components and Instruments; Frequency and Time Domain.

IR, THz, and MMW Sources, Detectors and Receivers

IR, THZ and MMW Future Applications, Markets and Directions

NEWS

**NEW**
The IRMMW-THz 2008 REGISTRATION and accommodations sites are open. The deadline for ABSTRACT submissions has passed. Paper selection and assigned slotting is now complete. Authors will be notified of their submission status on May 16th. Final papers are due on June 30th.

550 abstracts were received from 33 countries and 478 papers have been scheduled for oral and poster sessions. 54 Keynote talks were also solicited and speakers are now listed on the conference website.

Regular Registration continues through June 30th.
A complete guest program has also been arranged with registration for specific events/activities available on May 17th.

**Late Registration begins July 1**.

**NEW**
The International Journal of Infrared and Millimeter Waves has been renamed as:

Journal of Infrared, Millimeter, and Terahertz Waves (IRMMW-THz) in keeping pace with the conference.

CONTACT US Inquiries should be directed to:

Peter Siegel - Jet Propulsion Laboratory and California Institute of Technology

phs@caltech.edu

## 9.3 APPENDIX 3 Conference Abstracts

Accepted Abstracts as of 6/19/2008, 8:45 PM

| ID | Session | Type | Corresponding Author | Title |
|---|---|---|---|---|
| 1719 | M2G1 | keynote | Adam, Aurele | Terahertz Near-Field Measurements of Small Metal Structures |
| 1624 | W2B2 | oral | Afsar, Mohammed | The use of Microwave, Millimeter Wave and Terahertz Spectroscopy for the Detection, Diagnostics and Prognosis of Breast Cancer |
| 1308 | M5D26 | poster | Agusu, La | Design of Gyrotron FU CW V for Accurate Measurement of Positronium Energy Level |
| 1312 | T5D26 | poster | Agusu, La | Development of Gyrotron FU CW IIA for 600 MHz and 300 MHz DNP-NMR Experiments at the University of Warwick |
| 1403 | W4B4 | oral | Ahn, Yeong-hwan | Terahertz Electromagnetic Interference Shielding Using Single-Walled Carbon Nanotube Flexible Films |
| 1528 | R5D10 | poster | Ahn, Kwang Jun | Vector Field Mapping of THz-Electromagnetic Wave Transmitted Through Quadruple Holes |
| 1737 | W5D18 | poster | Akalin, Tahsin | THz Long Range Plasmonic Waveguide in Membrane Topology |
| 1740 | T4G5 | oral | Akalin, Tahsin | Directional Beam Pattern from a Double Metal Quantum Cascade Laser with a TEM-Horn Antenna |
| 1287 | R5D18 | poster | Al-Naib, Ibraheem | Improved Terahertz Sensors Based on Frequency Selective Surfaces For Thin-film Sensing |

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| 1413 | F2A1 | keynote | Alberti, Stefano | Status of the Development of the 2MW, 170GHz Coaxial Cavity Gyrotron for ITER |
| 1752 | T4A1 | keynote | Allen, S James | Exploring Novel Terahertz Detectors and Sources with the UCSB Free-Electron Lasers |
| 1226 | W5D39 | poster | Alves, Savio | Terahertz Plasmonic Device Modeled by Computational Electrodynamics |
| 1513 | M3G1 | keynote | am Weg , Christian | Fast Active THz Camera with Range Detection by Frequency Modulation |
| 1136 | M4B1 | oral | Andrianov, Alexander | Spectroscopy of THz Radiation Induced by Impact Ionization of Shallow Acceptors in Ge |
| 1665 | M5D3 | oral | Arbab, M. Hassan | Measurement and Application of Incoherent Terahertz Scattering Using Time-Domain Spectroscopy |
| 1650 | W3K2 | oral | Arbabi, Amir | A Terahertz Plasmonic Metamaterial Structure for Near-Field Sensing Applications |
| 1681 | M3G4 | oral | Ariyoshi, Seiichiro | Terahertz Imaging with a Two-dimensional Array Detector Based on Superconducting Tunnel Junctions |
| 1687 | T5D42 | poster | Asada, Masahiro | Sub-THz RTD Oscillators Integrated with Planar Horn Antennas for Horizontal Radiation |
| 1384 | T3B2 | oral | Ashida, Masaaki | Ultrabroadband THz Wave Detection Using Photoconductive Antenna |
| 1623 | W2B1 | keynote | Ashworth, Philip | An Intra-operative THz Probe For Use During The Surgical Removal of Breast Tumors |
| 1717 | R3K2 | oral | Atakaramians, Shaghik | Porous Fiber: A New Low Loss, Low Dispersion Waveguide For THz Transmission |

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| 1742 | M4G5 | oral | Attenkofer, Klaus | Using Coplanar Wave Guides To Excite Molecular Motions In The Frequency Range Of 10-1000GHz |
| 1461 | T5D3 | poster | Awano, Teruyoshi | Coherent Excitation in Superionic Conductors |
| 1467 | W5D3 | poster | Awano, Teruyoshi | THz Spectroscopy of Superionic Conducting Glasses |
| 1431 | R5D39 | poster | Awasthi, Yogendra | Analysis of Microstrip Transmission-Line on an Anisotropic Substrate |
| 1321 | M5D11 | poster | Baaske, Kai | Inspection of Glass-Fiber Reinforced Composites with a Continuous Wave THz Imaging System |
| 1683 | T3A3 | oral | Baik, Chan-Wook | Comparative Analysis on DRIE and LIGA Fabrications for Millimeter-Wave Backward-Wave Oscillators |
| 1486 | W5D42 | poster | Bakunov, Michael | Optimizing Two-Dimensional Tilted-Front Laser Pulses for Efficient Terahertz Generation |
| 1536 | W2K3 | oral | Banik, Biddut | Catadioptric Dielectric Lens for Imaging Applications |
| 1661 | M5D40 | poster | Bardeen, James | 3D Modeling of An Active Antenna Array |
| 1636 | R3B4 | oral | Bayat, Khadijeh | Polarization Selective Terahertz Photonic Crystal Slab Waveguide |
| 1618 | M3K3 | oral | Bean, Jeffrey | Long Wave Infrared Detection Using Dipole Antenna-Coupled Metal-Oxide-Metal Diodes |
| 1583 | R5D42 | poster | Beck, Alexandre | Terahertz Photomixing in InP/InGaAs UTC-PD Integrated with TEM Horn Antennas |
| 1552 | W3G2 | oral | Benz, Alexander | Quantum-Cascade Photonic Crystal Laser |

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| 1712 | M5D43 | poster | Berger, Vincent | Barrier breakdown in a THz QWIP |
| 1423 | W5D33 | poster | Beringer, Matthias | Towards a 4 MW 170 GHz Coaxial Gyrotron Resonator Design |
| 1212 | W2A3 | oral | Bernard, Jean-Philippe | PILOT: Measuring the FIR Polarization of the Diffuse Inter-stellar Medium |
| 1627 | T4B4 | oral | Bevan, John | Fast Sweep Solid State Spectrometer for SubTHz and THz Frequency Ranges |
| 1759 | W3B5 | oral | Bevan, John | Co-axially Configured Supersonic Jet Spectrometer for Submillimeter Investigations of Non-covalent Interactions |
| 1750 | F2K1 | keynote | Blake, Geoffrey | THz Spectroscopy in the Lab and at Telescopes |
| 1615 | W3G3 | oral | Bluem, Hans | Compact, Scalable THz Source |
| 1457 | M2B2 | oral | Bocquet, Bertrand | Single Living Cell Analysis by THz BioMEMS |
| 1581 | W5D43 | poster | Bodrov, Sergey | Efficient Optical-to-Terahertz Conversion of Femtosecond Laser Pulses Propagating Along a Sandwich Structure with Thin LiNbO3 Core |
| 1590 | T5D40 | poster | Bohn, Matthew | Alternative Explanation of Free-Induction Decay |
| 1260 | M4G1 | keynote | Bonn, Mischa | Charge Carrier Dynamics In Semiconductor Nanostructures Determined By Terahertz Time-Domain Spectroscopy |
| 1449 | M2A4 | oral | Bratman, Vladimir | Terahertz High-Harmonic Gyrotrons and Gyro-multipliers |
| 1668 | M2K2 | oral | Brown, Elliott | Milliwatt THz Average Output Power from a Photoconductive Switch |

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| 1744 | M4B4 | oral | Brown, Elliott | High-Resolution THz Transmission and Birefringence Measurements in Ferroelectric LiNbO3 |
| 1485 | F2K4 | oral | Brueckner, Claudia | Broadband Antireflective Structures for the THz Spectral Range Fabricated on High Resistive Float Zone Silicon |
| 1768 | T5D34 | poster | Bruneau, Peter | Metal Machining of THz Split-Block Waveguides with Micron Precision |
| 1367 | T4A2 | oral | Brunel, Louis Claude | Time Domain Electron Paramagnetic Resonance in the THz Frequency Range: Towards Recording Movies of Proteins in Action with UCSB's FELs |
| 1318 | R4K3 | oral | Burnett, Andrew | Broadband Terahertz Time-Domain Spectroscopy of Drugs-of-Abuse Mixtures and 'Street' Samples |
| 1176 | R5D43 | poster | Cao, J | Numerical Simulation of Extraction Barrier Width Effects on Terahertz Quantum Cascade Laser |
| 1228 | M5D53 | poster | Cauffman, Stephen | Gyrotron Efficiency Reductions Due to After-Cavity Interactions |
| 1253 | T3B1 | oral | Chakkittakandy, Reshmi | Quasi-Near Field Terahertz Time Domain Spectroscopy |
| 1393 | R5D41 | poster | Chang, Tsun-Hsu | Excitation of a Pure TEmn Mode at Low Terahertz Region |
| 1395 | R5D26 | poster | Chang, Tsun-Hsu | W-band TE01 Gyrotron Backward-wave Oscillator with Distributed Loss |
| 1396 | R5D51 | poster | Chang, Tsun-Hsu | Frequency Tunable Gyrotron Using Backward-wave Components |

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| 1761 | F2G2 | oral | Chattopadhyay, Goutam | Deep Reactive Ion Etching Based Silicon Micromachined Components at Terahertz Frequencies for Space Applications |
| 1705 | W4K5 | oral | Chebotarev, Andrey | THz Detection by Correlated 2D Electron Systems |
| 1404 | W5D51 | poster | Chen, Xiaohui | Comparative Study of Coaxial Bragg Reflector with Windowing Technique |
| 1595 | T2B2 | oral | Chen, Huanyu | Dielectric Measurement of Small Volume Liquid Samples Using Dielectric Image Guide in mm-Wave Range |
| 1540 | M5D44 | poster | Choi, Won Jun | Investigation of Subband Structure of Quantum Dot Infrared Photodetector |
| 1185 | T5D53 | poster | Chu, Kwo | Nonlinearly Driven Oscillations in the Gyrotron Traveling-Wave Amplifier |
| 1408 | T5D36 | poster | Chusseau, Laurent | A New THz Passive Radial Polarizer |
| 1747 | W2G4 | oral | Cooper, Ken | Penetrating 3D Imaging Radar at 4 and 25 Meter Standoff Range |
| 1606 | R3G5 | oral | Crowe, Thomas | Multiplier-based Sources of Terahertz Power |
| 1363 | M2G4 | oral | Cunningham, John | Sub-Wavelength Imaging of Terahertz Dielectric Permittivity Using Planar Resonant Circuits |
| 1458 | M4B2 | oral | Cunningham, John | Terahertz Vibrational Absorption Resonances Observed Using On-chip Terahertz Circuits |
| 1619 | R2A4 | oral | Dai, Jianming | Toward Standoff Distance Terahertz Wave Sensing |
| 1704 | T4G4 | oral | Danylov, Andriy | Terahertz Sideband-Tuned Quantum Cascade Laser Radiation |

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| 1441 | T4G3 | oral | Darmo, Juraj | Optical transitions mapping in terahertz QCL |
| 1304 | T4G2 | oral | Davies, Alexander | Terahertz Frequency Quantum Cascade Lasers Operating up to 178 K with Copper Metal-Metal Waveguides |
| 1670 | T3G3 | oral | Davoudi, Bahar | Comparison of Terahertz Pulsed and Continuous-Wave Imaging Techniques |
| 1262 | W1P1 | plenary | De Lucia, Frank | Why the Submillimeter? Why Has It Taken So Long? |
| 1671 | T4B1 | keynote | Demers, Joseph | A High Signal-to-Noise Ratio, Coherent, Frequency-Domain THz Spectrometer Employed to Characterize Explosive Compounds |
| 1418 | T4B3 | oral | Deninger, Anselm | Tunable CW THz Source with High-Precision Frequency Control |
| 1358 | T5D11 | poster | Denisov, Alexander | Passive 8 mm Microwave Imaging System for the Observing the Neighborhood Situation |
| 1448 | M5D27 | poster | Denisov, Gregory | Design and Test of New Millimeter Wave Notch Filter for Plasma Diagnostics |
| 1453 | R5D50 | poster | Denisov, Gregory | Modeling of Dynamic Effects in a Laser-Driven Semiconductor Switch of High-Power Microwaves |
| 1468 | T2A1 | keynote | Denisov, Gregory | Multi-Frequency Gyrotrons for Plasma Fusion Installations |
| 1472 | W4U4 | oral | Denisov, Gregory | Development in Russia of 170 GHz Gyrotron for ITER |
| 1512 | R4A2 | oral | Denisov, Gregory | Efficiency Enhancement of Gyrotron-Based Systems for Technological Applications |

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|---|---|---|---|---|
| 1547 | R2A1 | keynote | Dhillon, Sukhdeep | Terahertz Transfer onto a Telecom Optical Carrier |
| 1709 | W3G4 | oral | Dhillon, Sukhdeep | Spectral Gain Narrowing in Terahertz Quantum Cascade Lasers |
| 1306 | R5D3 | poster | Dietze, Daniel | THz Ellipsometry in Theory and Experiment |
| 1634 | W4U2 | oral | Domier, Calvin | Next Generation ECE Imaging: Status and Plans for TEXTOR |
| 1526 | W5D26 | poster | Donaldson, Craig | A 10kW W-Band Gyro-BWO Using a Helically Corrugated Waveguide |
| 1635 | W3A4 | keynote | Drouin, Brian | Submillimeter Wave Spectroscopy and the Search for Life on Planets |
| 1128 | M5D52 | poster | Duan, Zhaoyun | Theoretical Investigation into Cerenkov Radiation in an Anisotropic Double-Negative Medium |
| 1245 | T3B3 | oral | Dudley, Richard | Linearity of Terahertz Time-domain Spectrometers |
| 1179 | M5D19 | poster | Dumbrajs, Olgierd | Electron Dynamics in the Process of Mode Switching in Gyrotrons |
| 1629 | M5D4 | poster | Dutta, Jyotsnamoy | Electrically Active Defects and Dielectric Loss in Silicon Carbide |
| 1135 | W5D44 | poster | Dvoretsky, Sergei | The Second Generation of Focal Plane Array on the Basis of Design MCT MBE |
| 1360 | T2G3 | oral | El Fatimy, Abdelouahad | Room Temperature Terahertz Imaging by a GaAs-HEMT Transistor Associated with a THz Time Domain Spectrometer |
| 1505 | W3K1 | keynote | Elezzabi, Abdulhakem | Terahertz Plasmonic Random Metamaterial |

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| 1234 | R2A2 | oral | Ellrich, Frank | 200 Hz Rapid Scan Fiber-coupled Terahertz Time Domain Spectroscopy System |
| 1236 | W5D15 | poster | Ellrich, Frank | Thin-Film Measurements with THz-Radiation |
| 1166 | M5D35 | poster | Esmaeilzadeh, Mahdi | Self–Fields and Their Effects on Electron Orbits in a Three-Dimensional Helical Wiggler Free-Electron Laser |
| 1167 | T5D35 | poster | Esmaeilzadeh, Mahdi | Effects of Reversed-field on Electron Chaotic Orbits in a Helical Wiggler Free-Electron Laser |
| 1332 | W5D35 | poster | Esmaeilzadeh, Mahdi | Effects of Self-Fields on Growth Rate in a Free-Electron Laser with Planar Wiggler Magnetic Field |
| 1369 | M3A2 | oral | Essen, Helmut | A High Performance 220-GHz Broadband Experimental Radar |
| 1374 | R4K2 | oral | Essen, Helmut | A 3-D Millimeterwave Luggage Scanner |
| 1344 | W5D36 | poster | Faizabadi, Edris | Electronic Charge Pumping in Quantum Nanoring under Pulsed Signals |
| 1611 | W5D40 | poster | Faizabadi, Edris | Vacancy Effects on Optical Gap in Nanolayer GaAs in The Presence of Spin Orbit Interaction |
| 1381 | R2B4 | oral | Feil, Thomas | Studying Protein Dynamics in Aqueous Solutions through Linear and Non-linear THz Spectroscopy |
| 1608 | T2A2 | oral | Felch, Kevin | Recent Test Results on a 95 GHz, 2 MW Gyrotron |
| 1153 | R2B3 | oral | Feldman, Yuri | Human Skin as Arrays of Helical Antennas in the Millimeter and Submillimeter Wave Range |
| 1370 | W3K3 | oral | Fisher, Lorna | High Power Masers based on 2D periodic |

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| | | | | structures: From the GHz to THz Frequency Range |
| 1535 | M5D28 | poster | Flamm, Jens | Characterization of Windows for Fusion Applications using a D-Band Network Analyzer |
| 1391 | T5D27 | poster | Fliflet, Arne | Design of a Multi-kW, 600 GHz, Second-Harmonic Gyrotron |
| 1529 | T2G4 | oral | Friederich, Fabian | Development of a Hybrid THz Camera Using Frequency-Stabilized Two-Color Laser Radiation |
| 1420 | M4G2 | oral | Frischkorn, Christian | Ultrafast Electron Relaxation Dynamics In Laser-Ionized Gases Observed With Time-Resolved THz Spectroscopy |
| 1599 | W5D16 | poster | Frischkorn, Christian | Ultrafast Changes In The Far-Infrared Conductivity Of Carbon Nanotubes |
| 1178 | T2G1 | keynote | Fukunaga, Kaori | Terahertz Imaging for Analysis of Historic Paintings and Manuscripts |
| 1556 | T4K4 | oral | Gallant, Andrew | Micromachined terahertz waveguides with embedded metal rods |
| 1628 | T2G2 | oral | Gallerano, Gian Piero | THz-ARTE: Non-Invasive Terahertz Diagnostics for Art Conservation |
| 1679 | T5D19 | poster | Gholipour, Alireza | Optimization of A Sinuous Antenna for Coupling Enhancement in Azimuthally Polarized Surface Plasmon Waves |
| 1146 | W5D19 | poster | Ghosh, Sidhartha | Performance Characteristics of a Reflector Ultra Wideband Impulse Radiating Antenna |
| 1551 | M5D37 | poster | Ginzburg, Naum | Terahertz Band Bragg Reflectors |
| 1189 | W5D11 | poster | Gitlin, Mikhail | Real-Time Shadow Projection Millimeter- |

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| | | | | Wave Imaging Using Visible Continuum from a Slab of the Cs-Xe DC Discharge |
| 1654 | M4G4 | oral | Glancy, Paul | Dielectric Response Of Suspended Nucleotides At Terahertz Frequencies |
| 1126 | M2A1 | keynote | Glyavin, Mikhail | Generation of kW Level THz Radiation by the Gyrotron with Pulsed Magnetic Field |
| 1432 | T5D28 | poster | Glyavin, Mikhail | Design of Gyrotron FU CW VI for 600 MHz DNP-NMR experiment |
| 1159 | W2A1 | keynote | Goldsmith, Paul | Submillimeter Spectroscopy - Water, oxygen, and Other Key Species for Life |
| 1621 | R5D16 | poster | Golovachev, Sergey | High Precision Registration Of Optical Picosecond Impulses Responses In Case Of Their Propagation In Natural And Artificial Environments |
| 1188 | R5D19 | poster | Gong, Yandong | Air-core Bandgap Terahertz Fiber with Wider Bandwidth |
| 1127 | M5D54 | poster | Gorshunov, Boris | Modern Techniques of Terahertz-Subterahertz Spectroscopy of Solids |
| 1187 | T5D31 | poster | Gorshunov, Boris | Terahertz conductivity of Si and of Ge/Si(001) heterostructures with quantum dots |
| 1151 | W3A1 | oral | Griffin, Matt | The Herschel Space Observatory |
| 1730 | F1P2 | plenary | Griffin, Robert | High Frequency Dynamic Nuclear Polarization in Solids and Liquids: Why Two Electrons Are Better Than One |
| 1722 | W2G1 | keynote | Grossman, Erich | THz Microbolometers for Imaging Applications |
| 1364 | M4A4 | oral | Gunuganti Venkat, | Imaging Fourier Transform Spectroscopy |

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| | | | Sudhakar Rao | Using an Uncooled Microbolometer Array |
| 1706 | M5D20 | poster | Guo, Fangmin | Low-loss porous silicon substrates for microwave and millimeter applications |
| 1450 | R5D40 | poster | Hadjiloucas, Sillas | Subspace and Wavelet-Packet Algorithms for de-noising and classifying broadband THz transients |
| 1587 | R2B1 | keynote | Han, Haewook | Terahertz Near-field Imaging of Biomolecular Nanostructures |
| 1592 | R3B3 | oral | Han, Haewook | Highly Birefringent Terahertz Plastic Photonic Crystal Fibers |
| 1251 | T4K2 | keynote | Hartnagel, Hans | Heterostructure Equivalence of Step-Recovery Diodes for Ballistic and Diffusive Electron Resonance - a New Concept for THz Signal Generation |
| 1244 | R5D52 | poster | Hasek, Tomasz | Photonic Crystals for on-off Switching of Sub-terahertz Electromagnetic Waves |
| 1204 | M2B1 | keynote | Havenith, Martina | The THz Dance of the Protein with the Water |
| 1392 | R5D44 | poster | He, Zhihong | Study of Optimal Cavity Length in Optically Pumped D2O Gas THz Laser Based on the Semi-Classical Density Matrix Theory |
| 1454 | M5D45 | poster | He , Jian | Simulation About the Semiconductor Double Wavelength External Cavity Laser for the Generation of Tunable Terahertz Waves with Compact Structure |
| 1508 | T2B1 | keynote | He, Yunfen | The Role of Structure in the Protein Dynamical Transition |
| 1538 | T5D37 | poster | He, Jian | Theoretical analyses and numerical simulation about photo-mixing process in InGaAs with antenna structure for CW |

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| | | | | terahertz generation |
| 1733 | W4A1 | keynote | Hegmann, Frank | Terahertz Spectroscopy of Ultrafast Carrier Dynamics in Nanomaterials |
| 1676 | M3K4 | oral | Hesler, Jeffrey | The Development of Quasi-Optical THz Detectors |
| 1545 | T2A4 | oral | Hidaka, Yoshiteru | Effects of After Cavity Interaction in a 1.5 MW, 110 GHz Gyrotron |
| 1410 | W2A2 | oral | Hindle, Francis | Long Path Length cw-THz Spectrometer using a Multipass Cell |
| 1667 | T5D45 | poster | Hong, Sung-Min | The Millimeter-Wave Detector Using Vanadium Oxide with Planar Structure Antenna |
| 1767 | R5D36 | poster | Hor, Yew Li | Fabrication of metamaterials in THz region using ink jet system and characterization using THz-TDS |
| 1155 | T5D4 | poster | Hou, Bihui | THz Spectrum of KDP Crystal |
| 1156 | W5D4 | poster | Hou, Bihui | THz Spectrum of Cr3+:LiSrAlF6 Crystal |
| 1309 | W5D37 | poster | Hu, Min | Interaction of Electron Beam-Surface Plasmon in Planar Structures |
| 1387 | R5D37 | poster | Huarong, Gong | The Design of 1KW Ka-band Folded Waveguide Traveling-Wave Tube |
| 1339 | R3G2 | oral | Hübers, Heinz-Wilhelm | Terahertz Raman Laser Based on Silicon Doped by Phosphorus |
| 1518 | M3B1 | keynote | Hübers, Heinz-Wilhelm | Progress towards a 2.5-THz Solid State Heterodyne Receiver with Quantum Cascade Laser and Hot Electron Bolometric Mixer |

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| 1649 | W5D45 | poster | Hurlbut, Walter | Improved Performance of Hybrid Electronic Terahertz Generators |
| 1267 | M2A3 | oral | Idehara, Toshitaka | THz Gyrotrons - FU CW Series for High Power THz Technologies |
| 1270 | W5D28 | poster | Idehara, Toshitaka | A THz Gyrotron FU CW III with a 20T Superconducting Magnet |
| 1506 | R5D27 | poster | Illy, Stefan | Enhanced Transversal Collector Sweeping for High Power CW Gyrotrons |
| 1180 | R5D35 | poster | Ilyenko, Kostyantyn | Free-Electron Laser with Resonant Pumping |
| 1462 | R5D4 | poster | Ioachim, Andrei | Correlation of Structural and MW-MMW Dielectric Properties with Vibrational Modes in BaX1/3Ta2/3O3 Complex Properties |
| 1120 | T3K1 | keynote | Itoh, Tatsuo | Metamaterials for RF Applications |
| 1638 | T3A4 | oral | Ives, Robert | Advanced Cathode Research |
| 1640 | R5D28 | poster | Ives, Robert | Magnetron Injection Gun Measurements |
| 1641 | M5D41 | poster | Ives, Robert | Implementation of Computer Optimization for Design of Electron Guns |
| 1231 | T5D20 | poster | Jeon, Tae-In | Enhanced Coupling Property using a Conical Metal Wire Waveguide in the Terahertz Frequency Range |
| 1200 | M5D29 | poster | Jiao, Chong-Qing | Preliminary Design of a Stable, Second harmonic, 1MW, Ku-Band Gyro-TWA |
| 1239 | M5D5 | poster | Jin, Yun-Sik | Terahertz Time Domain Spectroscopy of Petroleum Products and Organic Solvents |
| 1240 | W3B4 | oral | Jin, Yun-Sik | Rotary Optical Delay Line for High Speed |

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| | | | | Scanning of Terahertz Pulse |
| 1248 | T5D29 | poster | Jin, Jianbo | Improved Quasi-Optical Launcher for Coaxial Cavity ITER Gyrotron |
| 1446 | T5D5 | poster | Jin, Biao-Bing | Study of THz Spectrum of a-Lactose Monohydrate |
| 1323 | R4G3 | oral | Joerdens, Christian | Terahertz Generation with an 830 nm All Semiconductor Femtosecond Laser System |
| 1325 | W5D20 | poster | Joerdens, Christian | Dielectric Fiber Based Splitters, Couplers and Endoscopes for sub-THz Frequencies |
| 1327 | T5D41 | poster | Joerdens, Christian | Effective Permittivity and Scattering Model for the Evaluation of the Leave Water Status |
| 1390 | M5D1 | poster | Jones, Inke | THz Spectroscopy of Protein Complexes |
| 1347 | F2A2 | oral | Joye, Colin | A Wideband 140 GHz, 1 kW Confocal Gyro-Traveling Wave Amplifier |
| 1341 | W3B2 | oral | Kadlec, Filip | Modulators of THz Radiation Based on SrTiO3 Epitaxial Thin Films |
| 1409 | T5D1 | poster | Kadlec, Filip | Determination of the Influence of Dialysis on the Human Skin Water Content by Means of THz Spectroscopy |
| 1243 | R5D45 | poster | Kang, Lin | A Room Temperature NbN Bolometer for Terahertz Detection |
| 1674 | M5D46 | poster | Kang, Chul | Fine Tuning of Terahertz Generation in Fan-out Type Periodically Poled Lithium Niobate Using Femtosecond Laser Pulses |
| 1694 | W2G2 | oral | Kangaslahti, Pekka | Millimeter Wave Synthetic Thinned Aperture Radiometer |

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| 1664 | W5D5 | poster | Kania, Patrik | Millimeter Wave Spectroscopy of Titanium Monoxide and Titanium Dioxide |
| 1130 | M5D15 | poster | Kapilevich, Boris | THz Characterization of Lossy Materials Using Multi-Layers Measuring Cell |
| 1139 | T3K2 | oral | Kapilevich, Boris | Noise versus coherency in mm-wave material characterization |
| 1673 | W4K4 | oral | Karasik, Boris | Ultra-Sensitive Hot-Electron Nanobolometers for THz Astrophysics |
| 1575 | T3B4 | oral | Karpowicz, Nicholas | Terahertz Time-Domain Spectroscopy with Continuous Coverage of the Entire Terahertz Range |
| 1600 | M3K2 | oral | Kasalynas, Irmantas | The Response Rate of Room Temperature Terahertz InGaAs-based Bow-Tie Detector with Broken Symmetry |
| 1680 | M2G3 | oral | Kawano, Yukio | On-Chip Near-Field THz Imaging Probe Integrated with a Detector |
| 1682 | F2B2 | oral | Kawano, Yukio | Highly Sensitive and Frequency-Tunable THz Detector Using Carbon Nanotube Quantum Dots |
| 1738 | W4K1 | keynote | Kazemi, Hooman | Antenna-Coupled Direct Detectors for Millimeter-wave and Submillimeter-wave Focal Plane Arrays |
| 1572 | W3B1 | keynote | Keilmann, Fritz | Asymmetric Comb-FTIR for Characterizing Metamaterials |
| 1574 | M2G2 | oral | Keilmann, Fritz | Nanoscale Infrared & THz Mapping of Conductivity |
| 1411 | W5D29 | poster | Kern, Stefan | Gyrotron Mode Competition Calculations: Investigations on the Choice of Numerical |

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| 1412 | M5D38 | poster | Kern, Stefan | Theoretical Study of 174 GHz Operation of the W7-X 1 MW, 140 GHz Gyrotron |
| 1479 | R5D29 | poster | Kern, Stefan | After Cavity Interaction in Gyrotrons: On the Influence of Different Models for Non-uniform Magnetic Fields |
| 1711 | W2B3 | oral | Kesari, Kavindra | 50 GHz Microwave Exposure Effect of Radiations on Rat Brain |
| 1666 | T5D2 | poster | Khan, Golam | Identification of Pollutant Gases from an Atmospheric Mixture Using High Resolution Dispersive Fourier Transformation Spectroscopy |
| 1378 | T5D46 | poster | Kikuchi, Kenichi | Broadband Scanning Spectrometer with Heterodyne SIS (Superconductor-Insulator-Superconductor) Receiver |
| 1148 | M3K5 | oral | Kim, Sangwoo | Room Temperature Terahertz Detection Based on Plasma Resonance of Electrons in an Antenna-Coupled GaAs MESFET |
| 1401 | W5D46 | poster | Kim, Jung-Il | Particle-In-Cell Simulation of 100 GHz Reentrant Linear Magnetron |
| 1491 | M2G5 | oral | Kim, D. S. | Terahertz Wave Focusing at Localized Surface Plasmon Resonance |
| 1499 | R5D11 | poster | Kim, D. S. | Poynting Vector Mapping of Terahertz Wave Transmission through Metallic Grating |
| 1500 | R5D20 | poster | Kim, DaiSik | Terahertz Wave Transmission Through Extreme Subwavelength Apertures |
| 1509 | R5D46 | poster | Kim, Sungil | The First Experimental Results of mm-Wave Generation by Photomixing |

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| 1533 | M5D21 | poster | Kim, Dai-sik | Surface Plasmon Polariton Generation on Metal Surface: From Nano-optical to Terahertz Frequency Regime |
| 1677 | M5D17 | poster | Kim, Kyoungsik | Tailored Focal Length Of The Sub-Wavelength Slit-Groove-Based Metamaterials In THz Regime |
| 1379 | R5D5 | poster | Kitagishi, Keiko | Instrumentation of Terahertz Time-domain Spectroscopic System Including Two Kinds of THz-radiation Source |
| 1230 | T2B3 | oral | Kiwa, Toshihiko | Redox Reactions of Enzymes Measured by Terahertz Chemical Microscope |
| 1342 | M3A3 | oral | Kleine-Ostmann, Thomas | 300 GHz Channel Measurement and Transmission System |
| 1465 | T3G2 | oral | Knab, Joseph | Near-Field THz Imaging and Characterization of an Array of Sub-Wavelength Circular Apertures |
| 1193 | M3B3 | oral | Knyazev, Boris | Single Channel and Real-Time Imaging Attenuated Total Reflection Spectrometers for THz range |
| 1194 | T5D12 | poster | Knyazev, Boris | Real-Time Terahertz Speckle Photography and Speckle Interferometry with a Free Electron Laser |
| 1272 | R2K2 | oral | Kohjiro, Satoshi | A 0.2-0.5 THz Heterodyne Receiver Based on a Photonic Local Oscillator and a Superconductor-Insulator-Superconductor Mixer |
| 1625 | W5D12 | poster | Kong, Xiangyu | Miniature Substrate Lenses for Millimeter-Wave Imaging |
| 1351 | M5D6 | poster | Korolev, Konstantin | Permittivity of Highly Absorbing Oxide |

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| | | | | Ceramics in Millimeter Waves |
| 1340 | T3A5 | oral | Kory, Carol | 650 GHz Traveling Wave Tube Amplifier |
| 1405 | R5D12 | poster | Krebs, Christian | Material Scanner in the Lower THz |
| 1713 | T3A1 | keynote | Kreischer, Kenneth | Operation of a Compact, 0.65 THz Source |
| 1235 | T5D6 | poster | Krumbholz, Norman | A Fiberstretcher Operating as an Optical Delay Line in a Fiber-coupled THz Spectrometer |
| 1483 | T2K2 | oral | Krumbholz, Norman | THz Spectroscopy for the Inline Control of Polymeric Compounding Processes |
| 1213 | T4A5 | oral | Kubarev, Vitaly | Modulation Instability and Three Mode Regimes of Novosibirsk Terahertz Free Electron Laser |
| 1451 | M3A1 | keynote | Kukutsu, Naoya | 10-Gbit/s Wireless Link Using 120-GHz-Band MMIC Technologies |
| 1249 | R2G5 | oral | Kurabayashi, Toru | Sub-Terahertz Imaging for Construction Materials |
| 1726 | W3B3 | oral | Kuznetsov, Sergey | Electroformed Metal Mesh THz-Filters for Selecting Harmonics of NovoFEL Radiation |
| 1727 | T5D21 | poster | Kuznetsov, Sergey | Theoretical Optimization of Metal Mesh THz-Filters for Selecting Harmonics of NovoFEL Radiation |
| 1743 | M3B4 | oral | Kuznetsov, Sergey | Double Effective Band-Pass Submm-Filters Based on Anisotropic Resonant Meshes |
| 1280 | T5D17 | poster | Lai, Ying-xin | Multimode Conversions in an Overmoded Coaxial Bragg Resonator |

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| 1715 | W3A2 | keynote | Lambert, James | In Situ Gas Sensing Instruments for Planetary Science |
| 1580 | M4K3 | oral | Lampin, Jean | Integrated Horn Antenna for THz Photomixing in LTG-GaAs |
| 1756 | F1P1 | plenary | Lange, Andrew | Cosmic Background and Space Science at THz Frequencies |
| 1426 | M5D47 | poster | Lee, Kitae | Terahertz Radiations on Target Materials Irradiated by an Ultra-intense Laser Pulse |
| 1493 | T5D38 | poster | Lee, Sun-Goo | Optimization of Photonic Crystal Interfaces for High Efficiency Coupling of Terahertz Waves |
| 1565 | T4G1 | keynote | Lee, Mark | Integration of Terahertz Quantum Cascade Lasers with Lithographically Micromachined Waveguides |
| 1254 | M5D30 | poster | Lei, wenqiang | RF Cavity Simulation of 0.3THz 400W Gyrotron Oscillator |
| 1699 | R3G3 | oral | Leotin, Jean | AlP/GaP Quantum Wells for Implementing Intersubband Devices in the 30-60 µm Wavelength Region |
| 1417 | T5D47 | poster | Lewis, Roger | Emission of Terahertz-Frequency Electromagnetic Radiation from Indium Phosphide under Excitation by Short Pulses of Near-Infrared Radiation |
| 1477 | F2A4 | oral | Li, Fengping | The Design of a 390 GHz Gyrotron Based on a Cusp Electron Gun |
| 1492 | M5D13 | poster | Li, Chao | A Novel Design of Focal Plane Array in PMMW Imaging System |
| 1612 | W5D38 | poster | Liang, Tianran | Quasi-Optical Notch Filters for Plasma |

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| | | | | Imaging Applications |
| 1584 | T5D13 | poster | Lim, Mee-hyun | Perturbation Analysis of Terahertz Confocal Microscopy |
| 1605 | R5D15 | poster | Lin, Hungyen | Binary Gas Mixture Classification with Terahertz Time-Domain Spectroscopy and Spectral Catalog: A Preliminary Study |
| 1734 | R1P1 | plenary | Litvak, Alexander | High Power Gyrotrons: Development and Applications |
| 1191 | R2G3 | oral | Liu, Lei | A 585 GHz Annular-Slot Antenna Coupled Two-Dimensional Focal-Plane Array Utilizing Twin-HEB Devices |
| 1250 | W5D41 | poster | Liu, Guo-Sheng | Efficient explicit FDTD method with unconditional stability |
| 1290 | T5D30 | poster | Liu, Diwei | Coupled-mode Theory of Coaxial THz Gyrotron with Two Electron Beams |
| 1314 | R3A1 | keynote | Liu, Shenggang | A Sub-Wavelength Holes Diffraction Radiation Array |
| 1414 | W5D13 | poster | Liu, Delian | Texture Segmentation Based Anomaly Detection in Remote Sensing Images |
| 1273 | W5D21 | poster | Llombart, Nuria | Study of Cylindrically Periodic Dielectric Waveguides at Submillimeter Waves |
| 1763 | T4K3 | keynote | Llombart, Nuria | High Efficiency Submillimeter-Wave Imaging Array |
| 1675 | W5D32 | poster | Lok, Lai Bun | Measurement and Modeling of CPW Transmission Lines and Power Dividers on Electrically Thick GaAs Substrate to 220GHz |
| 1647 | R5D13 | poster | Lopez-Garcia, | Passive Millimeter-Wave Imaging System |

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| | | | Benjamin | Using a SIW Antenna |
| 1121 | R5D21 | poster | Lu, Zhigang | Study on Power Extraction using a Dielectric-Loaded Rectangular Waveguide |
| 1610 | T5D52 | poster | Lu, Xiaofei | Terahertz Generation from gases |
| 1233 | R3K4 | oral | Lucyszyn, Stepan | REconfigurable Terahertz INtegrated Architecture (RETINA) |
| 1232 | W5D30 | poster | Luo, Jirun | A Harmonic Multiplying Gyrotron Traveling Wave Amplifier at Ka Band Developed in IECAS |
| 1530 | F2B3 | oral | Lusakowski, Jerzy | THz Detection by Field Effect Transistors: Antenna and High Magnetic Field Effects |
| 1371 | R2G1 | keynote | Lynch, Jonathan | Low Noise Radiometers for Passive Millimeter Wave Imaging |
| 1494 | W5D1 | poster | Ma, Yong | THz Differential Spectroscopy of Rhodopsin |
| 1550 | R4A3 | oral | Machavaram, Kartikeyan | Studies on a 170 GHz, 1.0-1.3 MW, CW Conventional Cavity Gyrotron |
| 1229 | R2B5 | oral | MacPherson, Emma | The Effects of Formalin Fixing on Terahertz Properties of Biological Samples |
| 1754 | R4G1 | keynote | Maestrini, Alain | In-Phase Power Combining of Submillimeter-wave Multipliers |
| 1399 | M5D22 | poster | Majumdar, Payal | Closed-form Dispersion Models of Slot-Line with Conductor Thickness |
| 1511 | M4A2 | oral | Maki, Ken-ichiro | Terahertz Beam Steering and Frequency Tuning by using the Difference Frequency Mixing |

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| 1356 | W4B1 | oral | Maleck-Rassoul, Rysvan | Differentiation of Structurally Related Compounds Using Terahertz Spectroscopy |
| 1357 | R4K4 | oral | Maleck-Rassoul, Rysvan | Study of Two Sporulated Bacillus Species by THz Time Domain Spectroscopy |
| 1531 | W5D17 | poster | Mandal, Pankaj | De-exciting Rydberg Atoms Using a Half-Cycle THz Pulse Train |
| 1443 | T4B2 | oral | Mangeney, Juliette | 2 Port Vectorial THz Electro-Optic Sampling System |
| 1452 | M4K4 | oral | Mangeney, Juliette | CW generation up to 2 THz by ion-irradiated InGaAs photomixer driven at 1.55 µm wavelengths |
| 1764 | T3A2 | oral | Manohara, Harish | Vacuum Microelectronics Applications Using Carbon Nanotube Cathodes |
| 1237 | R4G5 | oral | Martl, Michael | Terahertz Subwavelength Waveguide Emitters |
| 1760 | W4A3 | oral | Matsko, Andrey | Photonic Front-end for Millimeter Wave Applications |
| 1317 | W5D47 | poster | Matsuo, Hiroshi | Design of Superconducting Terahertz Digicam |
| 1337 | M2K4 | oral | Matthäus, Gabor | Micro Lens Coupled Large Area Photoconductive Switch for Powerful THz Emission |
| 1672 | W4U1 | keynote | May, Timothy | Coherent Synchrotron Radiation Measurements in the THz Region at the CLS Far Infrared Beamline |
| 1195 | M2K3 | oral | McCaughan, Leon | Highly Efficient Terahertz Generation via a Continuously Phase Matched Difference Frequency Generation in a Nested Waveguide Structure |

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| 1542 | M5D39 | poster | McStravick, Michael | Helically Corrugated Waveguides for Compression of Microwave Pulses |
| 1516 | M5D14 | poster | Mencagli, Benedetta | THECAMAP: Terahertz Camera for Medical Applications |
| 1438 | M5D12 | poster | Meziani, Yahya Moubarak | Room Temperature Generation of Terahertz Radiation from Dual Grating Gate HEMT's |
| 1428 | R3A2 | oral | Michel, Georg | Numerical Analysis of Complex Mirror Transmission Lines |
| 1469 | R5D30 | poster | Michel, Georg | ECRH Antennas and In-Vessel Components for the W7-X Stellarator |
| 1527 | T2K3 | oral | Mitsudo, Seitaro | Development of a 300 GHz Material Processing System |
| 1163 | W1P2 | plenary | Mittleman, Daniel | A Terahertz Waveguide with Attenuation in the dB/km Range |
| 1524 | R4K5 | oral | Miura, Makoto | Numerical Analysis of Biased GaAs/AlGaAs Intersubband Raman Laser |
| 1316 | T5D14 | poster | Mizuno, Maya | Penetration Monitoring of Fixation Solution into Tissues Using Millimeter Waves |
| 1333 | R5D47 | poster | Molter, Daniel | A Pump Enhanced ns-OPO for THz Generation |
| 1579 | T5D18 | poster | Moon, Kiwon | Iterative Image Method for Apertureless THz Near-field Microscope |
| 1656 | M5D48 | poster | Morozov, Dmitry | Ultasensitive TES Detectors for FIR Space Astronomy |
| 1644 | R4B4 | oral | Morris, Christopher | Tunable Terahertz Absorption of InGaAs Quantum Post Nanostructures |

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| 1422 | R3G4 | oral | Mouret, Gael | Frequency Measurement In THz Domain By Using Femtosecond Laser Frequency Comb |
| 1459 | T4A3 | oral | Müller, Ralph | First Commissioning Results in the IR/THz Range at the Electron Storage Ring Metrology Light Source |
| 1735 | F2B4 | oral | Müller, Ralf | Towards Traceable Radiometry in the Terahertz Region |
| 1688 | R5D1 | poster | Murakami, Hiroshi | Terahertz Spectroscopy of Protein in Water |
| 1346 | R3A3 | oral | Nagel, Michael | Influence of Copper-Oxide Surface Coverage and Roughness on Terahertz Slit Waveguides Fabricated by Spark Erosion |
| 1324 | R2A5 | oral | Nakamura, Ryotaro | Precise Frequency Measurement of Sub-THz Test Source Referring to as Terahertz Frequency Comb |
| 1588 | W5D6 | poster | Nakayama, Kazuya | Determination of FIR Laser wavelength Using Precise Refractive Index Measurement Method of Optical Etalon |
| 1440 | W5D52 | poster | Nashima, Shigeki | Generation of intense terahertz radiation from laser-produced plasma of metal foil target |
| 1559 | R4B5 | oral | Neshat, Mohammad | Echo Cancellation in Pulsed Terahertz Integrated Circuits |
| 1478 | T3G1 | keynote | Neto, Andrea | On the Potentials Of Connected Arrays for Wide Band and Wide Angle Scanning Applications |
| 1653 | W2A4 | oral | Ngo, Mai | Clear-Air Backscattering Returns from the Lower Atmosphere Using High-power, High-resolution Millimeter Wave Radar |

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| 1173 | T5D48 | poster | Nikoghosyan, Anahit | Generation of Terahertz Radiation in Waveguides Partially Loaded with Nonlinear Crystal |
| 1703 | M5D31 | poster | Niu, Xinjian | 94GHz Second-Harmonic Gyrotron with Complex Cavity |
| 1154 | M2A2 | oral | Nusinovich, Gregory | Frequency-Quadrupling Gyrotrons |
| 1548 | R4A5 | oral | Ogawa, Isamu | A Frequency Tunable Gyrotron, Gyrotron FU CW IV |
| 1475 | T3K3 | oral | Olbrich, Peter | Circular Photogalvanic Effect Due to Quantum Interference in the Terahertz Radiation Absorption |
| 1480 | R3B5 | oral | Olbrich, Peter | Terahertz Photocurrents in Heterostructures with One-Dimensional Lateral Periodic Potential |
| 1359 | T2A5 | oral | Olstad, R.A. | Progress on Design and Testing of ITER ECH&CD Transmission Line Components |
| 1313 | W5D48 | poster | Ortolani, Michele | Homodyne Mixing at 150 GHz in a High Electron Mobility Transistor |
| 1691 | R4B2 | oral | Padilla, Willie | Metamaterials for the Terahertz Gap |
| 1558 | R5D31 | poster | Pagonakis, Ioannis | Parametrization Technique for the Preliminary Gun Design of the EU 170GHz 1MW Conventional Cavity Gyrotron for ITER |
| 1255 | T5D22 | poster | Park, Ikmo | A Terahertz Yagi-Uda Antenna for High Input Impedance |
| 1278 | R5D48 | poster | Park, Jaehun | Linac Based fs-THz Program at PAL |
| 1514 | M5D2 | poster | Park, Gun-Sik | Terahertz Imaging of Paraffin-embedded Epithelial Cell of Rat using Pulsed and CW THz |

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| | | | | Systems |
| 1669 | W5D27 | poster | Park, Gun-Sik | High Power THz Radiation from a Cylindrical Grating Structure Using a High Current Relativistic Electron Beam |
| 1678 | W5D22 | poster | Park, Gun-Sik | THz Multi-frequency Resonance Filter |
| 1684 | W2B5 | oral | Park, Gun-Sik | Response of Nanometer-scaled Water Layer to High-power THz Wave |
| 1701 | M5D49 | poster | Park, Gun-Sik | Effective Surface Plasmon Mediated Sub-millimeter Smith-Purcell FEL |
| 1568 | R5D6 | poster | Parrott, Edward | Understanding the Catalytic Activity of Heat Treated Carbon Nanofibres: Investigation of Their Dielectric Properties at THz Frequencies |
| 1573 | T3K5 | oral | Parrott, Edward | Probing Solids Through THz Spectroscopy: Differentiation of Chiral and Racemic Forms of Isostructural and Non-isostructural Cocrystals |
| 1582 | M4B5 | oral | Parrott, Edward | Using Terahertz Time-Domain-Spectroscopy to Follow the Kinetics and Mechanism of Cocrystal Formation |
| 1211 | T5D49 | poster | Pasour, John | Low-Voltage, Sheet-Beam MMW Amplifiers |
| 1129 | M5D7 | poster | Pathak, Nagendra | Dispersion and Attenuation Characteristics of Suspended Microstrip Line on Multilayer Lossy Silicon Substrate at 60 GHz |
| 1525 | R3B2 | oral | Paul, Oliver | Bulk Negative Index Metamaterial Operating at THz Frequencies |
| 1265 | W4B5 | oral | Peale, Robert | Far Infrared Spectroscopy of Mineral Particles |
| 1266 | W5D49 | poster | Peale, Robert | Tunable InGaAs/InAlAs/InP Far-IR Detector |

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| | | | | Based On Plasmon Resonance |
| 1748 | M3B2 | oral | Pearson, John | Spectroscopic Detection, Fundamental Limits and System Considerations |
| 1326 | W2B4 | oral | Peltek, Sergey | FEL THz Irradiation Approach for the Biochip Production Standardization |
| 1607 | W4K2 | oral | Perera, Unil | III-V Based Room Temperature THz Detectors |
| 1439 | R5D49 | poster | Petukhov, Vladimir | THz TE CS2 Laser |
| 1564 | F2B1 | keynote | Pfeiffer, Ullrich | A CMOS Focal-Plane Array for Terahertz Imaging |
| 1198 | T2B5 | oral | Pickwell-MacPherson, Emma | A Pilot Study of Terahertz Pulsed Imaging of Osteoarthritis |
| 1277 | M2B3 | oral | Pickwell-MacPherson, Emma | Characterizing Rat Tissue Samples Using Terahertz Pulsed Imaging |
| 1482 | R5D22 | poster | Plaum, Burkhard | Numerical optimization of smooth wall and corrugated horn antennas |
| 1544 | R3A4 | oral | Plaum, Burkhard | Numerical and Experimental Investigations of a Diplexer for Power Combination and Switching of High-power Millimeter Waves |
| 1380 | T5D7 | poster | Png, Gretel | Orientation Dependence of THz Scattering from Cylindrical Strands |
| 1741 | F2G1 | keynote | Popovic, Zoya | Micro-fabricated Micro-coaxial Millimeter-wave Components |
| 1143 | W5D31 | poster | Porodinkov, Oleg | Polarization THz Spectroscopy in High Pulsed Magnetic Fields in Voigt and Faraday Geometries |

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| 1561 | W5D7 | poster | Prabhu, Shriganesh | THz Spectroscopy of ZnTe and GaSe |
| 1241 | T3G5 | oral | Pradarutti, Boris | Multichannel THz Line Detection by a Microlens Array Excited Photoconductive Antenna Array |
| 1646 | M3K1 | keynote | Prober, Daniel | Terahertz Resonances and Bolometric Response of a Single-Walled Carbon Nanotube |
| 1537 | M5D23 | poster | Qin, Han-lin | An Objective Discrimination Model for Triangle Orientation Discrimination Threshold Measurements |
| 1541 | W5D14 | poster | Qin, Han-lin | Total Variation regularization Based Infrared Dim and Small Target Background Suppression Algorithm |
| 1651 | W5D2 | poster | Radford, Simon | The Cornell Caltech Atacama Telescope (CCAT) |
| 1663 | R5D2 | poster | Radford, Simon | CASIMIR: The Caltech Airborne Submillimeter Interstellar Medium Investigations Receiver |
| 1655 | F2G4 | oral | Rahman, Nahid | Broadband Complex Permittivity Measurements of Microwave Interconnects and Bonding Materials |
| 1421 | M4A1 | keynote | Raisanen, Antti | Micro-fabricated High-impedance Surface for Millimeter Wave Beam Steering Applications |
| 1731 | M2K1 | keynote | Rana, Farhan | Graphene Terahertz Sources and Amplifiers |
| 1515 | R2K5 | oral | Rea, Simon | A 320-360 GHz Sub-Harmonically Pumped Image-Rejection Mixer for Earth Observation Applications |
| 1227 | M2A5 | oral | Read, Michael | Demonstration of a THz Pulse Gyrotron |

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| 1736 | W2K1 | keynote | Rebeiz, Gabriel | Planar Antennas for THz Applications: A Review |
| 1322 | T4B5 | oral | Roehle, Helmut | 1.5 µm Wavelength All-Fiber Terahertz Time-Domain Spectrometer |
| 1444 | W4G1 | keynote | Roeser, Hans-Peter | Electrons at Schottky Barrier in Presence of Strong Coherent THz Radiation |
| 1119 | T1P1 | plenary | Rosen, Arye | The Role of Engineering Principles in the Medical Utilization of Electromagnetic Energies: Examples |
| 1118 | T1P2 | plenary | Rutledge, Dave | Hubbert's Peak, The Coal Question, and Climate Change |
| 1546 | T5D23 | poster | Ryu, Han | Increasing the Input Impedance of a Folded Dipole Antenna for Continuous-wave Terahertz Photomixers |
| 1521 | W4U5 | oral | Rzesnicki, Tomasz | Recent Experimental Results on the 170 GHz, 2 MW Coaxial Cavity Pre-Prototype Gyrotron for ITER |
| 1389 | W2K2 | oral | Saeedkia, Daryoosh | Optical Scanning Techniques for Characterization of Terahertz Photoconductive Antenna Arrays |
| 1207 | F2A3 | oral | Saito, Teruo | Operation Improvement of CW 300 GHz Gyrotron FU CWI |
| 1209 | M5D32 | poster | Saito, Teruo | Development of a Sub Terahertz High Power Pulse Gyrotron for Collective Thomson Scattering |
| 1502 | R5D17 | poster | Saito, Shingo | Phase Shift Measurement of the THz Wave with Laser Displacement Sensor |
| 1695 | R4A1 | keynote | Sakamoto, Keishi | High Power Gyrotron Development for Fusion |

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| | | | | Application |
| 1299 | M3G2 | oral | Salhi, Mohammed | Confocal THz Imaging Using a Gas Laser |
| 1132 | W5D23 | poster | Salman, A. Oral | Millimeter Wave Radiator _ Electric Current Source: Sinusoidal PCB Strip and Microstrip Antennas |
| 1220 | M3A4 | oral | Samoska, Lorene | A G-Band Multi-Chip MMIC T/R Module for Radar Applications |
| 1206 | T5D32 | poster | Scherer, Theo | Experimental and Theoretical Thermal Analysis of CVD Diamond Window Units for the ITER Upper Launcher |
| 1553 | W3A3 | Keynote | Schieder, Rudolf | Mid-Infrared Observations with the Tuneable Heterodyne Infrared Spectrometer "THIS" |
| 1765 | W4G5 | oral | Schlecht, Erich | New 600 GHz Balanced and Subharmonically Pumped Mixers with Reduced LO Power and State-of-the-Art Performance |
| 1601 | W4G4 | oral | Schoenherr, Daniel | Optical Mixing in THz Schottky Diodes |
| 1284 | W4G2 | oral | Schuer, Jan | A 4th Harmonic Schottky Diode Mixer - Facilitated Access to THz Frequencies |
| 1263 | M5D18 | poster | Sengupta, Suranjana | Study of Terahertz Emission from Bulk Ga[x]In[1-x]As Crystals Photoexcited by Femtosecond Laser Pulses |
| 1739 | R1P2 | plenary | Seracini, Maurizio | Infrared, Millimeter, and Terahertz Waves: New Innovations and Applications for Cultural Heritage |
| 1257 | T5D39 | poster | Shchegolkov, Dmitry | A Proposed Measurement of the Reverse Cherenkov Radiation Effect in a Metamaterial-Loaded Circular Waveguide |

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| 1214 | M5D50 | poster | Shepelev, Andrey | Heavy-ion irradiated GaAs crystals for high-efficient generation of terahertz radiation |
| 1219 | W2A5 | oral | Shepelev, Andrey | Extremely Bright Astrophysical Objects Excited by THz Radiation: Do They Operate in a Maser Regime? |
| 1293 | R5D7 | poster | Shimizu, Naofumi | Active Gas Sensing with Sub-terahertz Waves Reflected from a Wall |
| 1430 | R5D38 | poster | Shimozuma, Takashi | Propagating Mode Analysis and Field Reconstruction in the Corrugated Waveguides of a High Power Electron Cyclotron Heating System |
| 1591 | T4K1 | keynote | Shin, Young-Min | MEMS-Fabricated Micro Vacuum Electron Devices (micro-VEDs) for Terahertz (THz) Applications |
| 1723 | R3K1 | keynote | Shur, Michael | Plasma Wave Terahertz Electronics |
| 1350 | R5D23 | poster | Singh, Ghanshyam | Design Considerations to Improve the Performance of a Rectangular Microstrip Patch Antenna at THz Frequency |
| 1406 | M5D24 | poster | Singh, Ghanshyam | Nano-Antenna for Optical Resolution Using Plasmonic Material as Substrate |
| 1442 | T5D24 | poster | Singh, Himanshu | Closed-From Model of Shunt Capacitance and Inductance of Microstrip Step Discontinuity |
| 1221 | T5D50 | poster | Sizov, Fedir | Narrow-Gap Semiconductor as the All-Ware Detector from Near IR to MM Wave Regions |
| 1762 | F2K2 | oral | Skalare, Anders | Radiometers for Exploration of Moons of the Outer Planets |
| 1175 | W5D24 | poster | Smirnova, Evgenya | Design and Fabrication of a 100 GHz Channel-Drop Filter |

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| 1617 | M4A5 | oral | Smith,III, Charlie | SU-8 Micromachining process for Millimeter and Submillimeter-wave Waveguide Circuit Fabrication |
| 1637 | W2K5 | oral | Smith,III, Charlie | A Comparison of the Gaussian Coupling Efficiency for Three Types of Terahertz Horn Antennas |
| 1554 | M5D8 | poster | Sobakinskaya, Ekaterina | Effect of Stochastic Fields on Spectrum of Two-level Quantum Systems |
| 1642 | F2G3 | oral | Somjit, Nutapong | Novel RF MEMS Mechanically Tunable Dielectric Phase-shifter |
| 1424 | T2B4 | oral | Son, Joo-Hiuk | Terahertz Dynamics of Electrolytes in Aqueous Biological Media |
| 1464 | M3G3 | oral | Son, Joo-Hiuk | Nanoparticles Contrast Agents for Terahertz Medical Imaging |
| 1192 | R4B3 | oral | Sorolla, Mario | Negative Refraction Demultiplexer Metamaterial for Millimeter Waves |
| 1563 | R5D24 | poster | Sorolla, Mario | Millimeter and THz Extraordinary Transmission Hole Arrays |
| 1633 | T5D8 | poster | Spencer, Locke | The Effects of Beamsplitter Emission in a Balanced Fourier Transform Spectrometer |
| 1208 | W2G3 | oral | Stanko, Stephan | Active and Passive mm-Wave Imaging for Concealed Weapon Detection and Surveillance |
| 1622 | T2K4 | oral | Stoik, Christopher | Nondestructive Evaluation of Aircraft Composites Using Terahertz Time Domain Spectroscopy |
| 1702 | W4B2 | oral | Stringer, Mark | THz Spectroscopy Through a High-Pressure Combustion System |

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| 1386 | R5D32 | poster | Sun, Haiyan | Influence of Reflections of the Output Port on Beam-Wave Interaction |
| 1338 | R5D14 | poster | Sunaguchi, Naoki | THz-wave tomographic imaging: An approach via CT reconstruction from limited projections |
| 1657 | W5D8 | poster | Sundaram, S | Terahertz Transmission Spectroscopy of Chalcogenide Glasses |
| 1487 | W5D50 | poster | Suvorov, Evgeny | Investigation of THz Radiation Generation in a Laser Spark of Axicon Discharge |
| 1745 | T2G5 | oral | Suzuki, Toshitatsu | Microscopic Structure Imaging with Phase Analysis at 60GHz Band |
| 1571 | W3K4 | oral | Swift, George | Negative refracting materials at THz frequencies |
| 1300 | T3G4 | oral | Takayanagi, Jun | High-resolution terahertz tomography using 17-fs ultrashort-pulse fiber laser |
| 1197 | M3B5 | oral | Tani, Masahiko | Coherent Anti-Stokes Raman Scattering Spectroscopy in Terahertz Region Using Chirped Optical Pulses |
| 1281 | M5D33 | poster | Tatematsu, Dr. | Feasibility Study of Collective Thomson Scattering in LHD Plasma Using a 400 GHz Frequency Gyrotron |
| 1567 | R3A5 | oral | Tax, David | Measurement of Mode Conversion Losses in ITER Transmission Lines |
| 1373 | R3B1 | keynote | Taylor, Antoinette | Active Terahertz Metamaterials |
| 1519 | R2B2 | oral | Teranaka, Masato | Millimeter Wave Irradiation and Invasion into Living Bodies using AR Waveguide Vent Antennas and Gyrotron |
| 1279 | W3G5 | oral | Terashima, Wataru | Investigation of Quantum Cascade Laser |

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| | | | | based on III-Nitride Semiconductors in the THz Frequency Range |
| 1242 | R4G2 | oral | Theuer, Michael | Pump Beam Diameter Dependent Terahertz Generation from Surface Emitters – Experiment and Simulation |
| 1437 | W4G3 | oral | Thomas, Bertrand | Design of an 874 GHz Biasable Sub-Harmonic Mixer Based on MMIC Membrane Planar Schottky Diodes |
| 1460 | W4A2 | oral | Tissafi, Bouchra | Effect of InGaAs Surface States and Interfaces on the Photo-generated THz Pulse Shape |
| 1696 | R5D8 | poster | Toacsan, Mariana | InN Thin Films Deposition by rf Magnetron Sputtering |
| 1160 | M4G3 | oral | Tochitsky, Sergei | Narrow-band Terahertz Pulses Generated by Difference-Frequency Mixing of CO2 Laser Lines |
| 1161 | W4U3 | oral | Tochitsky, Sergei | Megawatt Power Seeded FEL Amplifer Tunable in the 0.5-9THz Range |
| 1660 | M5D9 | poster | Toda, Mitsuru | Sub-THz Wave Magnetic Resonance Force Microscopy with a Gyrotron |
| 1224 | W4A5 | oral | Torcedo, Jojit | Terahertz Time-Domain Spectroscopy of D2O |
| 1578 | T5D9 | poster | Torosyan, Garik | Fano Profiles in Transmission Spectra of THz Radiation through Periodic Metallic Structures |
| 1271 | T5D33 | poster | Torrezan, Antonio | Design of a Broadband Continuously Tunable Continuous-Wave 330-GHz Gyrotron Oscillator for Enhanced Nuclear Magnetic Resonance |
| 1632 | W2G5 | oral | Trischman, James | Inverse Synthetic Aperture Radar Imaging at |

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| | | | | 580 GHz |
| 1569 | M5D25 | poster | Trukhin, Valeriy | Generation of Terahertz Radiation by the Large-Aperture Photoconductive Antenna |
| 1274 | R2A3 | oral | Tsurumachi, Noriaki | Enhancement of Optical Rectification for THz Amplification in One-Dimensional Photonic Crystals |
| 1335 | M5D51 | poster | Uchida, Takashi | Antenna-Coupled GaAs SBD Detectors for 100 GHz Band Radiation |
| 1570 | M5D36 | poster | Ulrich, Schade | THz Performance of the Infrared Beamline at BESSY |
| 1725 | W3G1 | keynote | Unterrainer, Karl | Terahertz Quantum-Cascade Lasers: Time Domain Spectroscopy and Micro Cavity Effects |
| 1631 | T3K4 | oral | Urban, Stepan | Microwave Spectra of Fluoroformyloxyl and Fluorosulfate Radicals |
| 1566 | R2K3 | oral | Uzawa, Yoshinori | Development of the 787-950 GHz ALMA Band 10 Cartridge |
| 1560 | M4B3 | oral | Vaks, Vladimir | Generation of High Stable Wide-Range THz Radiation for Precise Frequency Measurements |
| 1721 | M4K1 | keynote | van Driel, Henry | THz Emission from Transient Electrical Currents Injected into Semiconductors via Optical Quantum Interference |
| 1771 | | poster | Vernon, Ronald | A High-Efficiency Four-Frequency Mode Converter Design with Small Output Angle Variation for a Step-Tunable Gyrotron |
| 1302 | W2K4 | oral | Vieweg, Nico | Enhanced Emission From THz Antennas Made of Low-Temperature-Grown GaAs with |

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| | | | | Annealed Contacts |
| 1383 | M4K5 | oral | Vodopyanov, Konstantin | THz Source Based on Resonantly-Enhanced Difference Frequency Generation in Periodically-Inverted GaAs |
| 1362 | R2G2 | oral | Voltolina, Francesco | Low Cost Thermopile Detectors for THz Imaging and Sensing |
| 1320 | R5D9 | poster | Vystavkin, Alexander | Method for Characterization of a Submillimeter Wave Receiving Elements with a TES Bolometer Using a Temperature Swept Blackbody |
| 1288 | T2A3 | oral | Wagner, Dietmar | Recent Progress with the New Multi-Frequency ECRH System for ASDEX Upgrade |
| 1199 | M4K2 | oral | Wakatsuki, Atsushi | High-Power and Broadband Sub-Terahertz Wave Generation Using a J-band Photomixer Module with Rectangular-Waveguide Output Port |
| 1174 | R4K1 | keynote | Wallace, Harry | A Method for Analyzing Active Submillimeter-Wave Imaging System Performance |
| 1397 | M2B4 | oral | Wallace, Vincent | Using Terahertz Pulsed Imaging (TPI) to Identify Colonic Pathology. |
| 1190 | R5D33 | poster | Wang, Hui | Analysis of the Dispersion Characteristics of Gyro-TWT with Axially Periodic Dielectric and Metal Loading |
| 1757 | R2K4 | oral | Ward, John | Sensitive Broadband SIS Receivers for Microwave Limb Sounding |
| 1766 | R3G1 | keynote | Ward, John | Tunable Broadband Frequency-Multiplied Terahertz Sources |
| 1407 | M5D34 | poster | Winnerl, Stephan | Terahertz Vector Beams |

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| 1470 | W4A4 | oral | Withayachumnankul, Withawat | Optimization of Material Thickness for THz-TDS |
| 1264 | M5D16 | poster | Wohnsiedler, Sabine | Influences of Real-World Conditions on Terahertz Stand-Off Detection: Simulation and Experiment |
| 1368 | T2K5 | oral | Wylde, Richard | Toolroom CAD Technologies Applied to the Manufacture of QO Systems |
| 1372 | M4A3 | oral | Xin, Hao | Investigation of THz Thermal Emission from Electromagnetic Crystals |
| 1626 | W4B3 | oral | Xin, Hao | High Frequency Characterization of Carbon Nanotube Films |
| 1259 | M2K5 | oral | Xu, Haiyong | Terahertz Planar Varactor Sideband Generator Array |
| 1522 | R2K1 | keynote | Yagoubov, Pavel | First Light From the Superconducting Integrated Receiver on Board Terahertz Limb Sounder TELIS |
| 1375 | T5D16 | oral | Yamashita, Masatsugu | Observation of Semiconductor Test Circuits with Defects using the Laser THz Emission Microscope |
| 1366 | R4A4 | oral | Yan, Ran | Analytical Theory of Low Frequency Oscillations in Gyrotrons |
| 1158 | M5D10 | poster | Yang, Bingxin | THz Spectrum and Ionic Polarizability of PbB4O7 Crystal |
| 1532 | W3K5 | oral | Yang, Bin | Quasi-optical Measurements of Magnetic Materials at Frequencies above 490 GHz |
| 1298 | M3A5 | oral | Yasui, Takeshi | Real-time, Terahertz Impulse Radar Based on Asynchronous Optical Sampling |

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| 1577 | W4K3 | oral | Yngvesson, Sigfrid | Microwave and Terahertz Detection in Bundles of Single-Wall Carbon Nanotubes |
| 1196 | R4G4 | oral | Yu, Nan Ei | Tunable Terahertz Generation in Periodically Poled Structures Using Femtosecond Laser Pulses |
| 1310 | W5D34 | poster | Yuan, Xuesong | Calculation and Design of an Experimental Verification of Coaxial Gyrotron with Two Beams |
| 1585 | M3G5 | oral | Zaghloul, Amir | Three-Dimensional Interferometric Imaging at Terahertz Frequencies Using Three-Dimensional Spiral Arrays |
| 1648 | T4A4 | oral | Zaks, Benjamin | Single Shot High Resolution FEL Wavemeter |
| 1586 | F2K3 | oral | Zannoni, Ric | The Bias II Feedback System: Understanding and Improving Stability in NbN HEB Terahertz Receivers |
| 1576 | M5D42 | poster | Zeitler, J. Axel | Modelling the Effect of Proton Hydrogen Positions and Temperature on the Lattice Dynamics Calculations of THz Spectra of Benzoic Acid |
| 1117 | M2B5 | oral | Zhadobov, Maxim | Numerical and Experimental Approaches to Millimeter-Wave Dosimetry for in vitro Experiments |
| 1177 | T3B5 | oral | Zhang, Cun-lin | Material Identification using Terahertz Reference-free Spectroscopy and Imaging |
| 1297 | R3K3 | oral | Zhang, Yaxin | Terahertz Radiation with Cylindrical Mimicking Surface Plasmons Wave Structure |
| 1305 | T5D51 | poster | Zhang, Kaichun | Study of Terahertz Extended Interaction Oscillator |

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| 1307 | R5D34 | poster | Zhang, Huibo | Nonlinear Analysis of Gyro-TWT Amplifier with Helical Interaction Waveguide |
| 1311 | T5D25 | poster | Zhang, Jin | A Novel Design of an Ortho-Mode Transducer at 150 and 225 GHz - Clover Detector RF Design |
| 1435 | T5D10 | poster | Zhang, Dongwen | Terahertz Spectra of GaSe: Fundamental and Two-Order Phonon Processes |
| 1474 | R2G4 | oral | Zhang, Yan | Polarization Information for Terahertz Imaging |
| 1732 | R4B1 | keynote | Zhang, Xiang | Metamaterials: from THz to Optical Frequencies |
| 1686 | W5D25 | poster | Zheng, Hong-Xing | FDTD and PSTD Simulations for W-Band Linear Tapered Slot Antenna |
| 1689 | R5D25 | poster | Zheng, Hong-Xing | Hybrid FDTD/PSTD Simulation for Ultrawideband Microstrip Antenna |
| 1348 | W5D10 | poster | Zhou, Lei | Search for the Core Materials of THz Liquid-Core Fibers |
| 1602 | T2K1 | keynote | Zimdars, David | Rapid Time Domain Terahertz Axial Computed Tomography for Aerospace Non-Destructive Evaluation |
| 1471 | T5D15 | poster | Zrazhevsky, Alexey | Thermal Portraits of Objects in the MM and IR Wave Bands |

# EOS Topical Meeting on Biophotonics - TOM 1

Upcoming Events » EOS Topical Meeting on Biophotonics - TOM 1

EOS Events

Date: 29th September 2008 - 2nd October 2008
Location: Paris-Nord Villepinte, Parc d'expositions et Centre de Conventions - Paris, France

This topical meeting is part of the EOS Annual Meeting 2008 and will be held from 29 September - 02 October 2008.

Synopsis

The Topical Meeting on Biophotonics covers two main areas, nano-biophotonics and biosensors.

Nano-biophotonics combines the fields of photonics and nanotechnology for applications in the biomedical sciences. This meeting aims to cover optical imaging, sensing and activation methods, operating down to the single molecule level. It will include advanced imaging modalities ranging from confocal and multiphoton microscopy to far- and near-field optical super-resolution techniques such as STED, PALM and scanning optical probe methods. Genetically engineered, quantum dot, SERS, SPR and FRET probes provide an important view into the nano-world where conventional imaging falls short, while spectral, lifetime and polarisation imaging can provide information at a molecular level. Finally, we would like to consider optical control at the nano-level realized by optical trapping or by photo-activation of bio-molecular species.

In the last two decades, an increasing interest has been devoted by the scientific community to the study of optical biosensors and biochips. The results carried out have shown the tremendous and potential applications that such devices can find in many areas, such as genomics, proteomics, medical diagnostics, pharmacology, health care, environmental monitoring, food analysis, agriculture, defence, and security. As a consequence, the industrial investments in these fields are pushing the biosensing market, that is growing at an increasing rate. The conference provides an international forum for the presentation of new ideas on basic concepts, surface functionalization procedures, transducing mechanisms, configurations and realization technologies to be exploited in the optical biosensing field. Contributions concerning the growing possibilities offered by the micro- and nano-technologies in the integration of optical biosensors with microfluidics and opto-electronic circuits on the same bio-chip are welcome.

## Topics

Principles and applications of optical biosensors and biochips

Micro- and nano-system technology for optical biosensors and biochips

Bio-opto-fluidics devices and systems

Optical microsensors and chips for genomics and proteomics

Novel configurations based on photonic crystals and resonant cavity structures

New signal transduction technologies

Natural and synthetic receptors for optical biosensors

Label-free optical biosensors

Near field optical microscopy

Far field super-resolving microscopy

Raman and flourescence techniques

Plasmon enhancement

Optical trapping and manipulation

Photoactivation and photoswitching

Photonic force techniques

Molecular, genetically-engineered and nano-particle probes

Abstract Submission and deadlines

The deadline for submission of abstracts has been extended to Monday, 16 June 2008 at 12 noon (CET).

Notification to authors: 10 July 2008

Prospective authors are invited to submit their abstract in one of the listed topics. The abstract shall cover a minimum of half a page and a maximum of two pages and shall be submitted online with the responsible author's contact data. The EOS guidelines for abstracts can be downloaded at www.myeos.org/abstractguidelines.
Should you work with Latex-files, please click here to download the guidelines and the template.

### Chairs

Gert von Bally, Westfaelische Wilhelms-Universitaet, Muenster, Germany

Ivo Rendina, IMM – National Council of Research, Naples, Italy

Mark Neil, Imperial College London, United Kingdom

Programme Committee

Francesco Baldini, IFAC - National Council of Research, Florence, Italy

Luca De Stefano, IMM – National Council of Research, Naples, Italy

Kishan Dholakia, University St. Andrews, United Kingdom

Emmanuel Fort, Université Paris Diderot, Paris, France

Rainer Heintzman, King’s College, London, United Kingdom

Jiri Homola, Academy of Sciences, Prague, Czech Republic

Paul Lambeck, University of Twente, Enschede, The Netherlands

Frances Ligler, Center for Bio/Molecular Science & Engineering, Washington, USA

Juergen Popp, Friedrich-Schiller-Universitaet, Jena, Germany

Carsten Schultz, EMBL Heidelberg, Germany

Vinod Subramaniam, University of Twente, The Netherlands

Plenary Speaker

Brian Mac Craith, Dublin City University, Ireland

Invited Speakers

Dorus Gadella, University of Amsterdam, The Netherlands

Guenter Gauglitz, Eberhard-Karls Universitaet, Tuebingen, Germany

Martina Havenith, Ruhr-Universitaet Bochum, Germany

Laura Lechuga, Microelectronics Institute of Madrid, Spain

Dmitri Petrov, ICFO - Institute of Photonic Sciences, Castelldefels, Spain

Tuan Vo-Dinh, Duke University, Durham, Unites States

Industrial Workshop "Biophotonics Business: Opportunities and Challenges for European Companies"

The new Biophotonics Business workshop will have a special structure:

First, a set of presentations of leading experts from industry will be invited to set the stage concerning biophotonics business, market outlook and challenges. Participants will then divide into working groups to address key issues concerning the successful transfer of ideas to products. Finally, everyone will participate in a final session to hear and to discuss the results from each working group.

Workshop Program Committee

Marie-Jöelle Antoine, Opticsvalley, Palaiseau, France

Gert von Bally, Westfaelische Wilhelms-Universitaet, Muenster, Germany

Carlos Dominguez, Microelectronics Institute of Barcelona, Spain

Andy Monkman, University of Durham, United Kingdom

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Vinod Subramaniam, University of Twente, Enschede, The Netherlands

Herbert Venghaus, Fraunhofer Institute for Telecommunications, Berlin, Germany

### Invited Speakers

Jean-Luc Ayral, FORCE-A, France

Frédéric Bruessin, Yole Développement, France

Peter Höjerback, Serstech AB, Sweden

Frank Stietz, Carl Zeiss AG, Germany

Thomas Zapf, Leica, Germany

This Workshop is co-organised with:

EPIC
European Photonics Industry Consortium

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URL: www.myeos.org

### Sub-Conferences

EOS Annual Meeting 2008

EOS Topical Meeting on Biophotonics - TOM 1

EOS Topical Meeting on Terahertz Science and Technology - TOM 2

EOS Topical Meeting on Nanophotonics, Photonic Crystals and Metamaterials - TOM 3

EOS Topical Meeting on Micro- and Nanoscale Photonic Systems - TOM 4

EOS Topical Meeting on Organic Photonics - TOM 5

EOS Topical Meeting on Nonlinear Optics: Materials, Devices and Spatio-Temporal Effects - TOM 6

EOS Topical Meeting on Dynamical Optics - TOM 7

EOS Workshop on Masters and PhD Education in Photonics

Sponsorship Opportunities

Call for papers!

The deadline for submission of abstracts has been extended to Monday, 16 June 2008 at 12 am.

Bottom of Form

Nanostructure design for surface-enhanced Raman spectroscopy -- prospects and limits [read more]

Electrically induced Bragg Reflectors in In/InGaAsP waveguides as ultrafast optoelectronic modulators [read more]

Application of Lippmann interference photography to data storage [read more]

High speed partial Stokes imaging using a ferroelectric liquid crystal modulator [read more]

Polarization sensitivity of optical resonant dipole antennas [read more]

Corporate member

# » Upcoming Events » EOS Topical Meeting on Terahertz Science and Technology - TOM 2

EOS Topical Meeting on Terahertz Science and Technology - TOM 2

EOS Events

Start: 29th September 2008

Location: Paris-Nord Villepinte, Parc d'expositions et Centre de Conventions - Paris, France

This topical meeting is part of the EOS Annual Meeting 2008 and will be held from 29 September - 02 October 2008.

Synopsis

The field of THz Science and Technology is growing at a tremendous speed, as evidenced by the exponentially increasing number of publications in this field and by the strongly increasing number of patents and applications. This topical meeting provides a platform on which the latest results in the generation, detection and use of THz radiation in science and technology can be presented and discussed. The meeting is for senior scientists and (under)graduate students alike. There will be two 45 minute-long Masterclasses, one given by Peter Uhd Jepsen, the other by Abdulhakem Elezzabi, which are especially aimed at the undergraduate/graduate student level.

### Topics

THz sources (QCL's, FELs, synchrotrons, etc.)

Detection of THz radiation (quantum dots, single photon detectors, time-gated, etc.)

THz plasmonics, metamaterials, photonic crystals

THz imaging

THz microscopy and microspectroscopy

THz integrated optics

THz applications (security, telecom, etc.)

THz-matter interaction (chemistry, solid-state physics, ultrafast spectroscopy, biology etc.)

Interactions between high-power THz radiation and matter

Remote sensing of gases and chemical / biological agents

Abstract Submission and deadlines

The deadline for submission of abstracts has been extended to Monday, 16 June 2008 at 12 noon (CET).

Notification to authors: 10 July 2008

Prospective authors are invited to submit their abstract in one of the listed topics. The abstract shall cover a minimum of half a page and a maximum of two pages and shall be submitted online with the responsible author's contact data. The EOS guidelines for abstracts can be downloaded at www.myeos.org/abstractguidelines.
Should you work with Latex-files, please click here to download the guidelines and the template.

How to submit an abstract

step 1: select your preferred Topical Meeting or workshop from the list above

step 2: click on the link submit an abstract

step 3: follow the instructions and fill in the required data

step 4: click on submit at the end of the page

step 5: your paper has been submitted sucessfully

JEOS: RP - Special publication offer

All attendees of the EOS Annual Meeting receive a 20% discount on the publication rate for the e-journal of the EOS: the Journal of the European Optical Society - Rapid Publications (JEOS:RP, www.jeos.org). The paper submitted to JEOS: RP must be an original contribution that is connected to one of the topical meetings and must be submitted no later than 01 December 2008. The special publication fee for attendees of this event is 280 euros (instead of 350 euros).

## Chairs

Paul Planken, Delft University of Technology, The Netherlands

Martin Koch, Technische Universitaet Braunschweig, Germany

Programme Committee

René Beigang, Technical University Kaiserslautern & Fraunhofer IPM, Germany

Jean-Louis Coutaz, Université de Savoie, Le Bourget du Lac, France

Daniel Dolfi, Thales Research & Technology, Palaiseau, France

Petr Kužel, Institute of Physics of ASCR, Prague, Czech Republic

Edmund Linfield, University of Leeds, United Kingdom

Daniel Mittleman, Rice University, Houston, USA

Ajay Nahata, University of Utah, Salt Lake City, USA

Masayoshi Tonouchi, Osaka University & Nanjin University, Japan

Alessandro Tredicucci, Scuola Normale Superiore, Italy

Plenary Speakers

Karl Unterrainer, Technische Universitaet Wien, Austria

Invited Speakers

Abdulhakem Elezzabi, University of Alberta, Edmonton, Canada

Frank Hegmann, University of Alberta, Edmonton, Canada

Rupert Huber, Universitaet Konstanz, Germany

Peter Uhd Jepsen, Technical University of Denmark, Lyngby, Denmark

Chiko Otani, Riken, Japan

Carlo Sirtori, Université Paris-Diderot, France

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EOS Workshop on Masters and PhD Education in Photonics

Sponsorship Opportunities

The deadline for submission of abstracts has been extended to Monday, 16 June 2008 at 12 am.

» read more

# International Workshop on Optical Terahertz Science and Technology 7-9 March 2009

http://conference.iqcd.ucsb.edu/OTST/

T-Waves General Information – Internet references

http://www.spacedaily.com/reports/Rice_Engineers_Demo_First_TRay_Endoscope.html

### Rice Engineers Demo First Terahertz-wave Endoscope

Houston TX (SPX) Nov 18, 2004

Rice University

6100 Main, Houston, Texas 77005-1827

Electrical engineers at Rice University in Houston have demonstrated the world's first endoscope for terahertz imaging, a discovery that could extend the reach of terahertz-based sensors for applications as wide-ranging as explosives detection, cancer screening and industrial and post-production quality control.

The research appears in the Nov. 18 issue of the journal Nature. It presents the emerging terahertz sensing industry with a unique new technology for transporting terahertz waves from a source and directing them at a particular target of interest.

"Our wave guide opens up a whole new class of capabilities because it offers a way to get terahertz energy into places it could never reach before," said lead researcher Daniel Mittleman, associate professor of electrical and computer engineering.

"Wave guide technology frees you to look around corners and get into tight places."

Terahertz waves, also known as T-waves or Terahertz-waves, fall between microwaves and infrared light in the least-explored region of the electromagnetic spectrum.

Metals and other electrical conductors are opaque to Terahertz-waves, but they can penetrate plastic, vinyl, paper, dry timber and glass like X-rays.

Unlike X-rays, Terahertz-waves are not hazardous radiation, and in some cases T-wave sensors can reveal not only the shape of a hidden object but also its chemical composition.

This unique combination of traits make T-waves perfect for applications like explosive detection, and several companies are already working on T-wave security applications, developing systems that can look inside people's shoes, bags and clothing for guns, bombs and contraband.

Terahertz-waves lie between microwaves, whose wavelengths measure from centimeters to millimeters, and light, with wavelengths measured in nanometers, or billionths of a meter.

The gap between - the so-called terahertz gap - contains wavelengths from 30 to 3000 microns, or 100 GHz to 10 THz when measured in frequency.

The terahertz gap has been called the "final frontier" of the electromagnetic spectrum because there's never been an easy or cheap way to either generate or measure Terahertz-waves, something that's only begun to change with the advent of new technology in the past decade.

The development of "wave guides" is a key element in the technical maturation of Terahertz-wave technology. Wave guides - like fiber optic cables for lasers and coaxial cables for microwaves - allow design flexibility because they move and direct energy where it's needed.

This is particularly useful if the beam generator is bulky or temperamental. Both fiber optic cables and coaxial cables work by confining the energy of the beam in a small space, causing it to propagate down the cable.

Coaxial cables aren't good guides for T-waves because the metal sheath absorbs T-wave energy very quickly, and fiber optics don't transmit T-waves. By blending some aspects of both these technologies, Mittleman's team devised a system to guide T-waves in and out of a confined space.

This could prove useful for sensing applications that range from the mundane - scanning packages of cookies or cereal to make sure fruit and nuts are distributed evenly in every carton - to the space age - checking for defects under the insulation and heat shield of NASA's space shuttle.

In all T-wave applications today, the beam must be aimed directly from the wave generator at the spot to be sensed. Anything that needs to be scanned has to be moved in front of the beam.

Moving the beam isn't practical because the beam has to be fine-tuned each time it's set up, and worse, the whole apparatus is very sensitive to bumps and vibrations, which can easily knock the beam out of alignment.

Mittleman and his student, Kanglin Wang, stumbled upon the idea for the wave guide when they noticed T-waves were moving down a wire during an experiment on a new form of terahertz microscopy.

In follow-up experiments, they found they could move T-waves along a bare wire, direct those waves onto a surface, catch the reflected waves on another wire, carry those reflected waves back to a receiver and analyze the return waves to reveal information about the surface the original wave was shined upon.

"There are lots of places where T-waves would be handy but where they're difficult to use today," said Mittleman. "Free-space beams are notoriously temperamental - a shortcoming that's kept them off of some factory floors - and our endoscope technology has the potential to change that."

## Wire guides terahertz waves

http://www.trnmag.com/Stories/2005/030905/Wire_guides_terahertz_waves_030905.html

By Eric Smalley, Technology Research News

Terahertz radiation, which falls between microwaves and infrared light on the electromagnetic spectrum, is gaining attention from researchers because it shows great promise for medical imaging, chemical sensing and communications.

Terahertz radiation puts much less energy into biological tissue than x-rays, and terahertz medical imaging systems can be tuned to highlight specific types of tissue such as skin cancers. Because terahertz waves can penetrate plastic and cloth, they can be used to detect concealed objects. Terahertz radiation is also capable of detecting chemicals like toxic gases and explosives.

Among the challenges to making terahertz sensing and imaging applications more practical is finding ways to direct the waves to specific targets. Researchers are working to develop terahertz wave guiding devices that are similar to the waveguides used to channel microwaves and lightwaves.

Researchers at Rice University have come up with a particularly simple solution. They have shown that a piece of stainless steel wire nine tenths of a millimeter in diameter causes terahertz waves to propagate in the space around wire. "A very simple structure -- just a bare metal rod -- permits us to guide terahertz pulses around corners and into tight spots," said Daniel Mittleman, an associate professor of electrical and computer engineering at Rice University.

Previous efforts at developing terahertz waveguides focused on producing terahertz equivalents of the optical fibers that guide light or the metal tubes that guide microwaves, said Mittleman. Neither approach has panned out, he said. Fibers tend to absorb terahertz radiation and terahertz waves create electric currents that heat metal, a process that takes energy away from the terahertz waves.

The researchers' metal wire does not absorb terahertz waves, and its small surface area limits the current the waves produce, said Mittleman. Previous attempts at terahertz waveguides also tended to cause short terahertz pulses to spread out. The researchers' waveguide did not show any pulse dispersion for distances up to 24 centimeters, he said.

The waveguide could be used to image objects inside the body. To that end, the researchers made a terahertz endoscope from a pair of wire waveguides configured into a Y. One of the wires channels terahertz waves onto a sample and the other channels waves reflected by a metal plate positioned behind the sample to a detector.

The waveguide could also be used to detect substances inside containers. "If we take this straight piece of wire and dip it into a cargo container... then this becomes a dipstick sensor for trace gas analysis," said Mittleman. "Many different materials have specific chemical fingerprints in the terahertz range," he said.

Substances absorb or scatter different wavelengths of electromagnetic radiation in different ways, creating unique patterns. This makes it possible to identify substances and study their properties using light.

The researchers' prototype consists of a terahertz transmitter, an input coupler and a waveguide. The input coupler is a second piece of wire positioned perpendicularly to the waveguide with half a millimeter of space between the two wires. The terahertz transmitter focuses a beam at the intersection of the two wires, which causes terahertz waves to travel through the space around the waveguide.

The current method of getting the terahertz radiation onto the waveguide transfers less than one percent of the energy, according to Mittleman. "This is a big limitation because it means that the total energy we're starting with is very small," he said. The researchers are working on new method that should boost that to more than 50 percent, he said.

The researchers' waveguide could be incorporated very quickly into either of the two commercial terahertz medical imaging systems, said Mittleman. This would allow medical imaging of small areas inside the body.

Mittleman's research colleague was Kanglin Wang. The work appeared in the November 18, 2004 issue of *Nature*. The research was funded by the National Science Foundation (NSF), the Robert A. Welch foundation, and Advanced Micro Devices, Inc. (AMD).

Timeline: < 1 year
Funding: Government, Private, Corporate
TRN Categories: Optical Computing, Optoelectronics and Photonics
Story Type: News
Related Elements: Technical paper, "Metal Wires for Terahertz Waveguiding," Nature, November 18, 2004

**Rensselaer Polytechnic Institute**
110 8th St. Troy, NY 12180-3590

518-276-6000

### What is a Terahertz Wave?

The following article comes from the Rensselaer Polytechnic Institute in Trow NY, USA

http://www.rpi.edu/~zhangxc/about.htm

Terahertz (THz) waves, electromagnetic radiation in the frequency interval from 0.1 to 10 THz, is the next frontier in imaging science and technology. THz radiation, or THz waves, occupy a large portion of the electromagnetic spectrum between the infrared and microwave bands (in different units: 1 THz = 1 ps = 300 µm = 33 $cm^{-1}$ = 4.1 meV = 47.6$^{o}$K.). However, compared to relatively well-developed medical imaging at microwave and optical frequencies, basic research, new initiatives and advanced technology developments in the THz band are very limited. The THz band is a scientifically rich but technologically limited frequency band, since THz wave emitters and receivers are less developed, compared to its neighboring bands (microwave and optical). During the past decade, THz waves have been used to characterize the electronic, vibrational and compositional properties of solid, liquid and gas phase materials. It is a common belief that the future 'killer-application' of THz waves will be in biomedicine.

What is the Significance of a THz Wave?

Unlike common optical spectroscopes, which only measure the intensity of light at specific frequencies, the THz time-domain spectroscopic technique directly measures the THz wave's temporal electric field. Fourier transformations of this time-domain data gives the amplitude and phase of the THz wave pulse, therefore providing the real and imaginary parts of the dielectric constant without the use of the Kramers-Kronig relations. This allows precise measurements of the refractive index and absorption coefficient of samples that interact with the THz waves. Many rotational and vibrational spectra of various liquid and gas molecules lie within the THz frequency band, and their unique resonance lines in the THz wave spectrum allow us to identify their molecular structures. Raman spectroscopy directly uses the frequency domain to fingerprint the lattice vibrations. Similarly, THz wave spectroscopy describes molecular rotational and vibrational spectra from 10 GHz to 10 THz using the real and imaginary parts of the dielectric function, obtained by measuring the THz wave in the time-domain. This is not possible by any current optical or microwave technique.

Due to the diffraction-limit, the standard imaging resolution at 1 THz cannot be much smaller than 300 µm. This limits the spatial sensing or imaging of biological objects at the cell level. To overcome this limit, we propose to develop a near-field THz imaging technology by focusing the optical beams into an electro-optic crystal to generate (by optical rectification) and detect (by the electro-optic effect) the THz wave with sub-micron resolution. The imaging area of the biomedical tissue is comparable to the optical focal spot, and it is independent of the THz beam wavelength, $\lambda$. This near-field microscope will have a sub-wavelength spatial resolution better than 1/1000 $\lambda$ (or 0.5 µm @ 0.5 THz).

Our Previous Activities of the Rensselaer Polytechnic Institute

The research developments of THz wave science and technology at Rensselaer have been supported by the National Science Foundation, the Army Research Office, the Air Force Department of Scientific Research, the Department of Energy, the Research Corporation and Zomega Technology Corporation.

The research at Rensselaer is focused on the generation and detection of free-space THz beams with ultrafast optics and electro-optic crystals. The electro-optic THz system has demonstrated a linearity in a very large range ($10^6$) of the THz field < 2%, dynamic range > $10^7$, signal-to-noise ratio > $10^5$, a minimum pulse duration of 28 fs, a useful bandwidth form DC to 40 THz (8

μm), spatial, spectral, temporal 1D & 2D imaging, and a video rate or single-shot measurement capability. Intrinsic advantages to electro-optic detection include: nonresonant frequency response, large detector area, high scan rate and low optical probe power. Using a chirped optical probe pulse to read THz imaging in an electro-optic crystal allows for the measurement of a THz wave at an unprecedented data acquisition rate.

Terahertz imaging comes into view

http://physicsworld.com/cws/article/print/697

Physicists and industrialists are turning to terahertz radiation to provide cheaper, safer and more versatile ways of producing detailed images.

Imaging technology is becoming increasingly prevalent in our society. X-ray scanners are routinely used to examine luggage at airports, for example, and most hospitals are equipped with ultrasound scanners and magnetic resonance imaging machines. There is also a wealth of other less well known applications throughout industry. For instance, X-rays are used for package inspection, while the defects or voids in materials on production lines are often probed using microwaves or ultrasound.

In spite of their considerable success, X-rays, magnetic resonance imaging and ultrasound all have shortcomings. Many clinicians and non-medical users feel that fundamentally different physical principles are needed to provide safer and more cost-effective imaging techniques. And physicists are turning to other regions of the electromagnetic spectrum to address these issues.

Indeed, a cursory examination reveals that conventional imaging techniques only use the extreme ends of the electromagnetic spectrum: photons with energies greater than 30 keV for X-rays, and around 0.4 μeV for magnetic resonance imaging. The radiation between these extremes falls largely into the visible, infrared and millimetre or microwave regions.

In the April issue of Physics World[5] magazine, Don Arnone, Craig Ciesla and Michael Pepper at Toshiba Research Europe, Cambridge, UK, describe the advantages of Terahertz imaging.

Further reading

[5] http://physicsworld.com/cws/how-to-subscribe#11

D D Arnone *et al*. 1999 Applications of terahertz technology to medical Imaging *SPIE Proceedings* 3828 pp209219 P French 1999 Biomedical optics *Physics World* June pp4146 B B Hu and M C Nuss 1995 Imaging with terahertz waves *Optics Letters* 20 17161718 L E Larsen and J H Jacobi 1986 *Medical Applications of Microwave Imaging* (IEEE Press, New York) BUY: US / UK D M Mittleman, R H Jacobsen and M C Nuss 1996 Terahertz-wave imaging *J. Sel. Top. Quantum Electron*. 2 679 Q Wu Lu, T D Hewitt and X-C Zhang 1996 Two-dimensional electro-optic imaging of THz beams *Appl. Phys. Lett*. 69 1026

# Hardware Manufacturers

### Insight Product Company

From their website http://www.insight-product.com/


InsilInsigh t Product Company specializes in the design, engineering, and manufacturing of millimeter, submillimeter, and IR sources, frequency synthesizers, detectors, and mixers.

We custom design and produce millimeter and submillimeter systems based on the customer's specific needs.

In March 2007, Microwave & RF Journal wrote: "When a frequency synthesizer requirement calls for millimeter-wave signals, few firms can match the lineup offered by Insight Product Co. (www.insightproduct.com ) with models spanning 36 to 1250 GHz. The company's 120 to-180-GHz source, for example, provides more than 30 mW output power over that range and can be operated locally from the front-panel keypad or remotely under GPIB control. The company features three sources covering 370 to 535 GHz, 526 to 714 GHz, and 667 to 857 GHz with power levels from 4 to 15 mW." Frequency Synthesizers Fit Many Modular Formats

June 2nd, 2006, Mikhail Gershteyn, President of Insight Product Co. gave an invited presentation at the SURA (Southeastern Universities Reasearch Association) Terahertz Applications Symposium in Washington, D.C. entitled "Ultra-Stable Terahertz Frequency Synthesizers and Extremely Sensitive HEB detectors up to 70 THz".

On October 11, 2005, Insight Product Co. together with Moscow State Pedagogical University won a grant from U.S. Civilian Research and Development Foundation (CRDF) for "Technology Development of Hot-Electron Bolometer mixers for Terahertz applications."

In March 2005, Microwave & RF Journal wrote that Insight Product's frequency synthesizers are "Ideal for measurement and astronomy applications, these synthesizers can be equipped with optional AM and FM capabilities and GPIB remote control." Frequency Synthesizers Generate Clean  Signals

Insight Product Company has more than 15 years of serving some of the most prestigious scientific institutions, universities, and companies, including:

- NASA, Jet Propulsion Laboratory, USA
- NASA, Johnson Space Center, USA
- Harvard University, USA
- Massachusetts Institute of Technology, USA
- UCLA, USA
- Cornell University, NY, USA
- New York State University at Stony Brook, USA
- Friedrich-Alexander University at Erlangen-Nurnberg, Germany
- University of California, San Diego, USA
- Raytheon Company, USA
- Auburn University, Auburn, USA
- SRON Lab For Space Research, Netherlands
- National Institute of Standards and Technology, USA
- ETH Zurich, Switzerland
- North Carolina Central University, USA
- Seoul National University, Seoul, South Korea

Our devices are currently applied in astronomical research, material investigation, spectroscopy, mixers/receivers testing, EPR, NMR/ MRI, plasma diagnostics, Gyrotron experiments, etc.

Overview of Products

Millimeter and submillimeter wave sources:
-Solid-state sources (Gunn and Impatt) up to 280 GHz
-Tube-based sources (Backward Wave Oscillators, Magnetrons, Orotrons, Gyrotrons, and Gas Lasers) up to 2.5 THz

-Hybrid technology sources up to 1.25 THz. These new devices are a combination of tube-based or solid-state sources with frequency multipliers.

Frequency Synthesizers up to 1.25 THz with substantial output power.
Hot-electron bolometer mixers and detectors up to 70 THz.
Power Supplies for BWO sources.

**Contact:**


| | |
|---|---|
| E-mail: | InsightProduct@yahoo.com |
| Phone: | (617) 965-8151 |
| Fax: | (617) 965-2238 |

41 Dedham St. Newton, MA 02461-2133

USA

### Thruvision

www.thruvision.com

From Their website-

ThruVision is a privately funded startup and the world leader in the development and deployment of products based on passive terahertz imaging technology. ThruVision products are used to image concealed threat objects on moving people at a distance without illuminating the subject with any radiation and without revealing any anatomical detail.

ThruVision developed its proprietary technology by adapting space imaging technology originally developed at the Rutherford Appleton Laboratory (RAL), UK which began in 1985. Through a collaborative effort engineered by the European Space Agency (ESA) the space imaging technology was adapted for terrestrial applications. The company retains close links with both RAL and ESA as it develops next generation terahertz imaging products.

ThruVision headquarters is based in Abingdon, near Oxford in the United Kingdom. Most commercial, product development and support operations are conducted from this office.

Regional sales and support is also provided in North America, the Middle East and the Far East.

Thruvison have a stabdard Product, the T43000 system which is a security system designed to :-

Screen for a wide range of concealed objects including Metals, plastics, gels, explosives, composites, narcotics, currency and liquids.

Screen from a safe stand-off distance

Screen without introducing security ‘bottlenecks’ by screening people at various distances, as they move, with no eed for static person screening at a single point.

Safe and non-invasive

Totally passive screening technology. No privacy violation, anatomical details are not revealed.

This company would be worth discussing opportunites further since they already have a commercial product in operation.

ThruVision Ltd.,Central 127, No. 18,

Milton Park, Didcot, Oxfordshire,U.K.,OX14 4SA

Tel : +44 (0)1235 433130 Fax: +44 (0)1235 433140

Thru Vision will be exhibiting their equipment at the "Worldwide Exhibition of Internal State Security being held in Milipoli in Qatar on 17-19 November 2008.

See :- http://www.milipol.com/welcome.php?divers

## TeraView Ltd.

| | |
|---|---|
| Head Office | TeraView Ltd , Platinum Building<br><br>St John's Innovation Park, Cowley Road Cambridge, CB4 0WS UK |
| E enquiries@teraview.com<br><br>www.teraview.com | T +44 (0) 1223 435380<br><br>F +44 (0) 1223 435382 |
| Other offices on The US on East and West Coast | |

From Their Web site:-

"TeraView Limited, is the world's first and leading innovator of 3-D imaging and spectroscopic systems which exploit the properties of terahertz to characterise a wide range of materials.

Our patented terahertz technology creates spectroscopic information and 3D images with unique spectroscopic signatures not found at other wavelengths. It resolves many of the questions left unanswered by complementary techniques, such as optical imaging, Raman and infrared. Terahertz technology also produces faster results than X-ray and enables non-destructive, internal, chemical analysis of tablets, capsules and other dosage forms.

TeraView's vision is to make terahertz technology affordable, accessible, and ubiquitous in everyday life.

Two decades of experience

TeraView was spun-out of Toshiba Research Europe in April 2001 by its co-founders, Sir Michael Pepper (CSO) and Dr Don Arnone (CEO), to exploit the intellectual property and expertise developed in sourcing and detecting terahertz (1 THz= 33.3$cm^{-1}$) radiation, using innovative semiconductor technologies. Leading industry proponents of the technology sit on our Advisory Board, and TeraView maintains close links with the Cavendish Laboratory at the University of Cambridge, where modern terahertz technology was pioneered in conjunction with the team at TeraView, and where Professor Pepper, has held the position of Professor of Physics since 1987.

Uniquely, the Company has a wealth of experience in both the technology to generate, detect and manipulate terahertz light, as well as an extraordinary breadth and depth of knowledge in applications of the technology in different markets to solve real world problems for our customers. Both of these attributes are represented in our product offering to customers, as well as an impressive intellectual property portfolio that builds considerable value for the Company. The result is our proprietary TPI™ platform that can be configured to meet a variety of end-user needs.

Business model – solutions and support for end-users

TeraView seeks to exploit its TPI™ platform by working closely with select customers, and strongly supporting our products and their implementation with these customers. The Company is also dedicated to providing end-users with the benefit of both our technology as well as expertise in the manipulation of terahertz light. To this end, we seek to provide complete solutions to our customers' business issues, using the considerable experience of our engineering and applications support teams, who have considerable knowledge of the optimization of Terahertz to address the issues faced by our customers.

TeraView is currently working closely with major pharmaceutical customers to support implementation of our products in pharmaceutical drug formulation, product development and manufacturing. The Company also actively works with customers in the analytical instrumentation and defense sectors, including close support of government laboratories active in homeland security and other defense-related applications.

Where required, the Company is also dedicated to developing alliances with commercial partners targeted at specific market applications for sales to and support of end-users. The Company currently has alliances with global leaders in the analytical instrumentation market, security and defense, and medical markets to support work with customers in these areas.

The Company currently operates in Europe, as well as having an office and representatives in the US and North America. TeraView is also actively engaged with customers in Japan."

TerraView has developed a range of standard hardware and software applications that use the terahertz wave signature received from the product and interpret that signal for use in a range of industries. These industries are:-

| | |
|---|---|
| Pharmaceutical, | Determining Molecular Structures<br>Quality contol systems in Pharamceutical manufacture<br>Online Tablet inspection |
| Medical | Oral Health Skin Cancer Oncology |
| Securit | Chemical and Biological Detection<br>Personnel Screening<br>Explosive Detection |

## 9.4 Appendix 4 Original Articles on The Raytheon "Silent Guardian" Crowd Contol System

### Future of Crowd Control:- "Burning" Protestors

http://sydney.indymedia.org.au/node/36482

Posted April 12th, 2006 by Anonymous

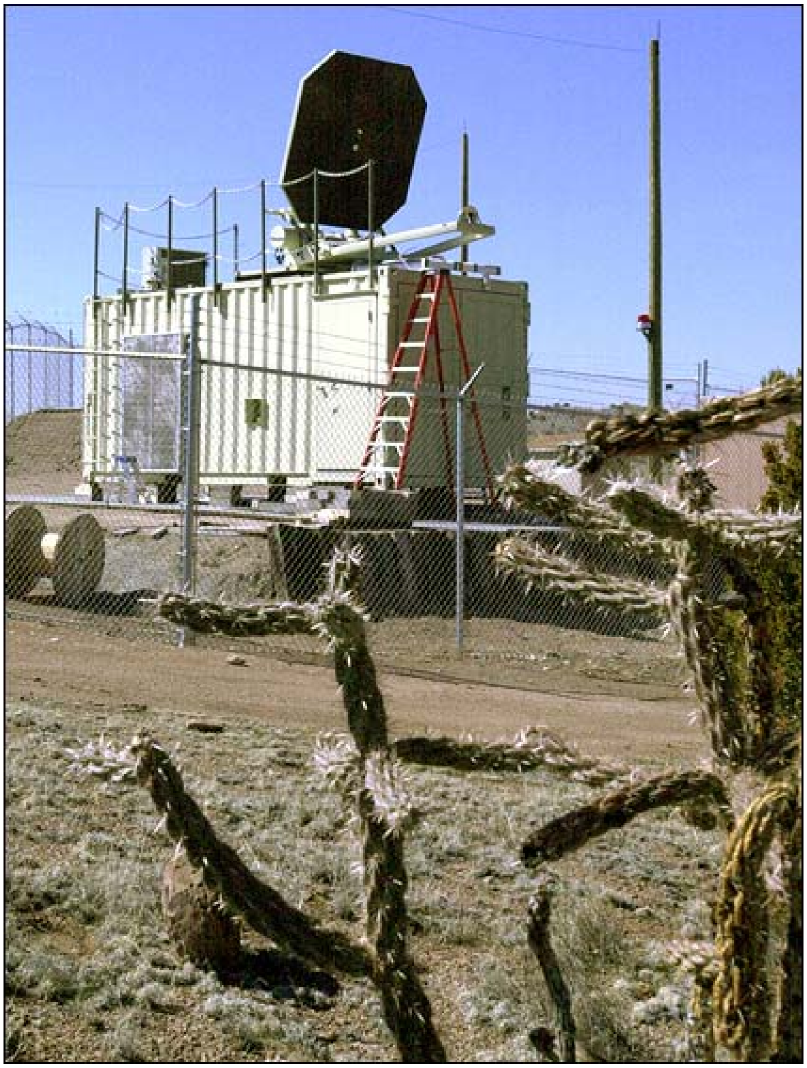
Doug Beason, the Deputy Director for Directed Energy at the Air Force Research Laboratory speaks about the future of crowd control:

What is Active Denial, the microwave weapon and how would it be used?

The Active Denial is actually not a microwave, but what they call a millimeter wave. Microwaves are 70 times larger than millimeter waves. The Active Denial system operates at about 100GHz, and what scientists discovered a few decades ago was that millimeter wave energy at about 100GHz is absorbed about a third of a millimeter into the human skin, and so it doesn't penetrate the body, but what happens is that this energy is perceived by the body as heat. The nerve endings perceive a near instantaneous increase in heat and in fact the effect is kind of like opening up a supercharged oven and feeling this heat all over your body.

Now what the body does when it experiences this is undergo something called the "flee effect"--the body just wants to get away from it; it wants to flee. When the person moves away from the millimeter waves that are causing this effect, the effect goes away, so what the military is doing now, it is investigating using this Active Denial effect as a way to what they call "assess intent."

The idea is that, as a crowd starts to descend upon an embassy, let's say, that at first you have loudspeakers broadcasting "stay away," and then when the crowd gets closer and closer, that you can expose the crowd very selectively to this Active Denial effect. If the people turn and run away, then you know that they perhaps didn't have the intent to storm the embassy, but if they turn around and start to come back again and then you again expose them to millimeter waves, then the intent is surely one that they want to take over the embassy. And so at that time, as they get closer and closer, you can use lethal force to stop it.



Now, you've actually experienced the Active Denial System.

Yes, I did. It was back in 2001, and it was when they had first approved Active Denial for human testing. It was one of the most amazing experiments that I have had the privilege to participate in. At the time they were just exposing people's backsides to the millimeter waves, because in very strict human protocol testing, you just want to take it one step at a time. At the time I had to jump out of the way of the beam within an extremely short amount of time and, even though I was scheduled for two more tests, I was kind of reluctant to go back and do that again because I still had the memory of what it felt like, even though I didn't show any signs of being exposed to it.

Now, before I underwent the testing, I did a lot of research, because I didn't want to do the testing without knowing what was happening. I did discover that because the beam was at the millimeter part of the electromagnetic spectrum that it wasn't energetic enough to cause any type of carcinogenic effects--that is, carcinogenic effects occur with exposure to UV radiation, because the UV radiation is energetic enough to ionize some of the cells that make up the human body, but millimeter waves are too low in energy to do this--in fact it's much, much lower than sunlight or even infrared radiation, and also the amount of time that it takes to produce the Active Denial effect is much, much less than any time that it would take to cause any physiological effects.

Active Denial could go to the battlefield any day.

So, in effect this works, to use science fiction terminologies, as a force field?

In fact, the joke was "phasers on stun"--you don't really stun people with this, but you can use a sweeping motion if you want to push people away as if you had a virtual force field there.

How much energy does this kind of system draw?

Active Denial has actually been put on a Humvee. I can't really say what the power levels are because that's classified, but you can actually drive around the Active Denial unit on this Humvee and have enough energy, so to speak, for missions that last a very long time--long enough to be of military significance. It's what we call a tactical system, that is, it's short-range, and remember I said an inherent advantage of directed energy is that it's really defensive because you cannot spread the Active Denial system over a large area, over a large crowd--it has to go from person to person to create this effect. You could sweep it back and forth, but you can't do it over a very large area--you can't imagine doing this over a city block or a city or anything like that.

## 9.5 Appendix 4 General Publications on T-Waves

### A technical Paper -Extreme Photonics

Field: Material/Biomaterial Science

Session Topic:

Extreme Photonics

Speaker:

Kodo Kawase/Nagoya University

Introduction

The terahertz (THz) wave region, bordered by the far-infrared and the millimeter waves, refers to the radiation within the approximate limits 0.3 THz – 10 THz, corresponding to wavelengths between 30 µm and 1 mm. While both sides of the spectrum have had a long history of research and development, leading to widely available sources, detectors, meters, and many additional devices, the THz range is still in its infancy, representing the last unexplored part of the electromagnetic spectrum. This delayed development was mainly caused by the difficulty of producing reliable and strong THz wave generators, as well as the unavailability of sensors that can conveniently detect this exotic radiation.

In recent years, however, several research groups have been able to fill the gap that once separated the radio waves and the light waves. Although still at a state-of-the-art level, sources, detectors, and specific optics have become less rare and more affordable. Research such as that carried out in our group has led to the development of various applications that used to be, not many years ago, simply unthinkable.

2. Properties of the THz waves

There are two key points around which much of the THz research and applications turn:

1) Spectral specificity: Most chemical substances present characteristic absorption features in the THz range. Such features are almost absent under 0.3 THz, in the millimeter and microwave region.

2) Transmission properties: A wide range of materials are transparent or partially transparent to THz waves. These materials generally become opaque as you go beyond 3 THz into the infrared.

The combination of these two properties is what makes THz radiation so interesting and unique for noninvasive inspection. You can see through packaging and identify the contents. The ability of the THz wave to pass through many packaging materials, such as paper and cardboard, textiles, plastics, wood, ceramics, semiconductors, dried or frozen materials, and so on, will allow the nondestructive and noninvasive inspection of mail packages in post offices, luggage and personal belongings in airports and border crossing points, and others.

Compared to the inspection techniques made possible by X-ray imaging, the THz radiation promises some advantages such as highly reduced risk of irradiation, increased image contrast to differentiate between various soft materials, and the possibility of chemical identification. This comes from the fact that the THz wave is more sensitive to the nature of the materials it passes through, being more selective than X-rays. By analyzing the frequency dependence of the transmission or reflection intensity, each substance presents a particular behavior, which allows what is called “fingerprinting,” that is, assigning a spectral characteristic to each chemical. Spectral fingerprints are essential in the process of identifying the chemicals in an unknown target.

Some materials limit the applicability of the THz waves, by being either highly reflective or highly absorptive. Metals for instance reflect most of the incoming THz radiation; this means that containers made of metal are opaque to THz probing. Another substance that blocks THz waves is water and materials containing a significant amount of water. This time the THz waves are stopped by a strong absorption; a layer as thin as 100 µm of water transmits about 10% of the incident power. The problem posed by metals and water is not limited to THz waves but is also common for the neighboring ranges of the electromagnetic spectrum, including the microwaves and the infrared.

Infrared radiation is also spectrally sensitive to chemicals and could be used for identification purposes. However, much fewer materials are transparent to infrared than to THz. Besides simple absorption, in many practical cases infrared radiation is strongly scattered by the target, which prevents its use for security applications. On the other side of the THz range, the millimeter waves have the disadvantage that they are generally not chemically sensitive, very few substances having fingerprint spectra in the millimeter range. In addition, for imaging applications, their longer wavelength translates into poor image resolution.

In exchange for the obvious advantages offered by the THz frequency range for nondestructive inspection, some practical drawbacks must be mentioned. The novelty of the field and the lack of a well-developed specialized industry lead to prohibitive prices for most devices used in this field. Much of the equipment used in THz research has large dimensions and weight, and special conditions have to be supplied, such as liquefied gasses, controlled temperature and humidity, and so on, which make it hard to implement THz systems in real-life applications. However, continuous research is being done to decrease the size and weight of the sources and detectors, as well as to make THz systems more accessible and less demanding of special conditions. On the other hand, novelty and inaccessibility represent an obstacle for the individuals and organizations that would attempt to pose a security threat.

Our group has been conducting research activities in several directions within the THz field. We introduced the THz-wave parametric generator as a widely tunable source, and we suggested a whole range of real-life applications. Among our research activities we can mention:

i) Noninvasive detection of illicit drugs using spectral fingerprints;

ii) Laser-THz emission microscope for semiconductor device inspection;

iii) Printable metal mesh sensor for DNA/protein chip.

iv) Real-time detection of micro-leak defects in the seal of flexible plastic packages;

v) Water content measurement in plants and seeds;

vi) Monitoring of the freezing state in food stuffs;

At the workshop, I would like to introduce several of our research results.

Acknowledgments

I would like to thank the following individuals for their valuable support: Adrian Dobroiu, Chiko Otani, Masatsugu Yamashita of RIKEN; Yuichi Ogawa and Shin'ichiro Hayashi of Tohoku University; Masayoshi Tonouchi of Osaka University; Hiroyuki Inoue and Tatsuyuki Kanamori of the National Research Institute of Police Science.

This work was partially supported by the Grant-in-Aid for the Scientific Research (18206009) from the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT). This work was also partially supported by the Asian Office of Aerospace Research and Development through Grant AOARD-06-4014.

# Apr 7, 2008 - The 'Measurement Fair' returns to Nuremberg

http://physicsworld.com/cws/article/indepth/33687

Visitors to the Sensor + Test 2008 exhibition and conferences in Nuremberg next month will be able to sample the wares of nearly 600 companies selling everything from the tiniest sensors based on nanotechnology to full-blown test and measurement systems for use in the automotive, aerospace and other industries.

Where the action is

New products on display at the exhibition — which will run 6–8 May — include what is claimed to be the world's smallest and most precise absolute pressure sensor. Produced by VTI Technologies of Finland, the device is said to consume only 6 μA of current, which means that it could be integrated within a wristwatch or mobile phone to allow such devices to function as precision altimeters.

Fibre–Bragg gratings

A number of firms will be exhibiting sensor technologies based on optical fibres, including Belgium's Fibre Optic Sensors and Sensing Systems. The firm offers a range of temperature, strain, displacement and pressure sensors that are all based on fibre–Bragg gratings. These are regions within an optical fibre with optical properties that are very sensitive to mechanical or temperature changes. Because such detection systems are based on the transmission of light — rather than electrical signals — they are immune to most electromagnetic interference, making them increasingly popular for use in cars and aeroplanes.

The exhibition also features an "Action Area" where more than 20 companies will offer hands-on demonstrations of their sensors and testing systems. Germany's Microtech Gefell, for example, will be demonstrating its "acoustic camera", which will be used to create images of the vibrational properties of vehicle engines. Future-Shape of Germany will invite delegates to try out its flooring and glass-pane products that have built-in sensors to help guide people with vision or mobility problems around their home. Stiegele Data Systems of Germany will be showing off its data acquisition and analysis software, which will be connected to a number of different sensors mounted on a mountain bike that will be ridden over a test course.

History of strain gauges

Delegates will also be treated to a history lesson on the invention and development of strain gauges in a retrospective exhibition sponsored by two German firms: ADDITIVE and imc Meßsysteme.

A little over 60% of exhibitors are from Germany, with most of the remaining firms hailing from the rest of Europe. Those coming from beyond Europe include more than 30 firms from North America and eight companies from China.

On your bike

Sensor + Test includes two major conferences: the 8th OPTO conference on research and development in optical and optoelectronic sensors and the 10th International Infrared Sensors and Systems Conference.

Both meetings will run 6–7 May and each day will kick off with joint plenary talks aimed at delegates to both conferences. On the first day, Holger Vogel of Germany's Carl Zeiss Optronics will talk about how to improve imaging systems by combining data from several different optical sensors. This will be followed by the second plenary talk by René Beigang, head of the ultrafast photonics and terahertz physics group at the Technical University of Kaiserslautern, Germany (see "The terahertz revolution"). Beigang will talk about the rapidly expanding field of terahertz sensing, which has been used by NASA to improve the safety of the space shuttle and could soon be used in airport security scanners.

Plenary talks

On the second day of the conferences, one plenary talk will be given by Georg von Freymann of the Center for Functional Nanostructures at Karlsruhe University, Germany. Von Freymann's research group is developing three-dimensional photonic crystals — materials comprising periodic nanostructures that have a number of distinct optical properties such as "optical band gaps". Von Freymann will talk about the prospects for using photonic crystals in optical sensor systems.

The OPTO conference will also include sessions on optical sources and modules, fibre-optic sensing and optical measurement technologies. In addition to several sessions devoted to thermal imaging and temperature measurement, the Infrared Sensors and Systems Conference will also include a session on the latest developments in sensors and arrays.

About the author

Hamish Johnston is editor of *physicsworld.com*

# Apr 7, 2008 - The terahertz revolution

http://physicsworld.com/cws/article/indepth/33680

Just a few years ago sensors operating at terahertz wavelengths were almost unheard of. Today, the technology is being used to improve the safety of the Space Shuttle, and could soon be used in airport-security scanners. Nadya Anscombe talks to René Beigang, head of the Ultrafast Photonics and Terahertz Physics Group at the Technical University of Kaiserslautern in Germany, about how terahertz radiation is being used to create a wide range of new test and measurement systems

What is so special about terahertz radiation?

Many materials used in everyday life are highly transparent in the terahertz (THz) region, while others absorb the radiation in very characteristic ways. We can therefore use THz radiation to see through materials such as clothes or plastic film and to analyse other materials using spectroscopy. In solids, weak non-covalent interactions between molecules can be observed, which can provide information about their crystalline structure; and metals are opaque at THz frequencies, so they can also be easily identified.

“Terahertz radiation is ideal for detecting non-metal objects hidden under clothing”

It is a non-ionizing radiation, which means that it is safe to use on humans. For example, at airports, it is ideal for detecting non-metal objects hidden under clothing. And, in the pharmaceutical industry, it could be used to perform chemical analysis of samples through containers such as blister packaging. No other region of the electromagnetic spectrum has these properties.

Why is there currently so much interest in this region of the spectrum?

The THz part of the spectrum is located between microwave and infrared radiation (100 GHz – 10 Hz) and has, until recently, not been easily accessible due to the a of efficient sources and detectors. Research in THz radiation is now benefiting from advances in other areas of physics, such as the development of lasers that can reliably produce femtosecond-long light pulsesand advances in non-linear optics — both of which can used to generate THz radiation. Now that good sources and detectors are available, companies and research groups have made impressive progress in developing products and applications utilizing this region of the spectrum.

What has been the most important technical advance in this area in the last few years?

The development of THz time-domain spectroscopy (TDS) — a powerful tool for material identification and chemical analysis — would not have been possible without advances in femtosecond lasers. The generation and detection scheme is sensitive to the effect of a material on both the amplitude and the phase of THz radiation. In this respect, the technique can provide more information than conventional Fourier-transform spectroscopy, which is only sensitive to the amplitude.

Are THz measurements being used today in industrial applications?

Yes, and the number is growing every day. But the industries that could make the most use of the technique — aerospace, defence and pharmaceutical — are notoriously cautious about adopting new technologies, making progress slow. Several companies have already launched passive THz cameras for use in airport-security systems and some are also developing active systems. For example, the UK companies ThruVision and QinetiQ have systems on the market.

Many people believe that THz technology has the potential to replace X-rays and metal detectors at airports, but I have my doubts. Security screening is a very challenging application because of scattering from clothing and the need to perform imaging and spectroscopy in real time. However, I think that the detectors will be a useful supplement to current screening techniques and I am that convinced we will find such systems at airports in the next few years.

Another UK company, TeraView, is exploring an interesting application in the pharmaceutical industry. The company claims that its system can be used to make high-speed measurements of the coating thickness of tablets while the pills are in random motion in a coating pan. For this application, the non-contact, non-destructive nature of the measurement technique is an advantage, plus it gives 3D and chemical information about the contents of tablets and capsules — something not normally possible with conventional monitoring techniques.

"NASA has used THz products developed by US-based firm Picometrix to examine the exterior of the Space Shuttle"

THz technology can also be used to detect defects in materials. For example, in the plastics industry it can be used to find air bubbles in extruded products, check the integrity of welded plastics and to monitor product thickness. NASA has used THz products developed by US-based firm Picometrix to examine the exterior of the Space Shuttle. THz measurements are used to detect flaws and poor adhesion in the sprayed-on foam insulation of the shuttle's external fuel tank. NASA is also evaluating the use of THz measurements to determine the integrity of the tiles on the shuttle's heat shield. As a shuttle ages, corrosion can form under the tiles potentially causing them to detach. By examining the layers that attach the tiles to the orbiter, NASA can determine which tiles to replace, and which tiles are still in good working order.

As it is safe to use on humans, THz technology can also, in principle, be used for medical imaging applications and in dentistry. Applications for this technology are endless.

Are there any problems with its use?

Yes, the radiation does have its limitations. Most polar molecules in the gas phase interact with THz radiation, which means that, in principle, it could be used to detect gases. However, the sensitivity of such techniques are not comparable with other, more established, methods of gas detection. The biggest problem for applications of THz radiation is water vapour, which interferes with measurements. This makes it challenging to use THz systems in outdoor settings.

What are the future innovations that are needed to help this industry develop and grow?

The main issues are cost, speed and complexity. THz systems are expensive because the femtosecond lasers used to create the radiation are very costly. The use of low-cost femtosecond fibre lasers, in particular at telecommunication wavelengths, should bring down the overall cost of systems. The use of continuous-wave devices based on electronic or optical generation may also reduce the cost considerably, although these systems cannot be used for all applications.

“In order to be useful in industrial applications, the systems have to become robust, compact and easy to use”

In order to be useful in industrial applications, the systems have to become robust, compact and easy to use. The time it takes to make measurements is another important issue that has to be addressed. In particular, for online process monitoring or security applications, new 2D measuring techniques have to be developed, including fast evaluation algorithms. The ongoing improvement of quantum cascade lasers as THz sources could enable more industrial usage of these systems.

As the technology has many different fields of application, it will not be possible to use a single THz system for all these applications simultaneously. Therefore, all the systems currently under development have their advantages and problems depending on the application being considered. To make most use of single systems, a modular set-up with flexible emitters and detectors is advantageous as it can be easily adjusted to a particular situation without changing the whole THz system. This is one route that many commercial companies and research institutes are following in order to make THz technology useable for different industrial applications.

Prof. Beigang will be making a plenary address on advances in THz technologies at the International Infrared Sensors and Systems Conference 2008 on Tuesday 6 May in Nuremberg, Germany.

About the author

Nadya Anscombe is a science and technology journalist based in the UK

# Feb 11, 2008 - Seeing the hidden fresco

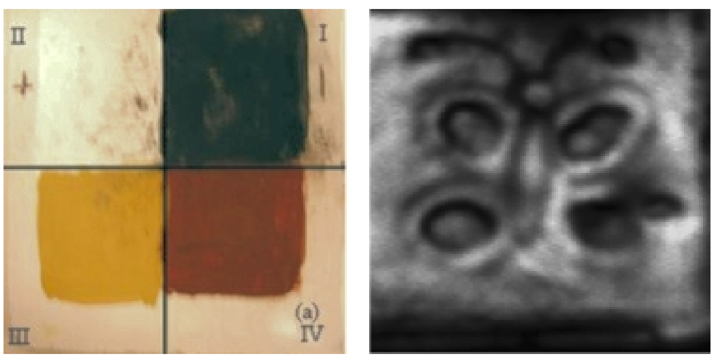
*The Battle of Anghiari*

http://physicsworld.com/cws/article/news/32833

Spread over a 16 m-wide wall in the Palazzo Vecchio town hall in Florence, Leonardo da Vinci’s *The Battle of Anghiari* is a magnificent fresco depicting two horse riders in combat. Also impressive are *la America Tropical* by the Mexican muralist David Alfaro Siqueiros in the Italian Hall in Los Angeles, and the numerous frescos adorning the ancient Hagia Sophia church in Bulgaria. Unfortunately no one can see these paintings: they are all hidden beneath a layer of plaster.

If studies by a team of scientists from the US and France continue to prove successful, however, then it could be only a matter of time before such frescoes, which have often been covered for religious or political motives, are exposed. Although plaster is opaque to visible light, in the much lower frequency terahertz ($10^{12}$ Hz) it all becomes clear. “Most non-polar, dielectric materials are transparent in the terahertz spectral range,” says Bianca Jackson, a physicist at Michigan University in the US. “Therefore, with enough power, terahertz can penetrate ‘infinitely’ thick, optically opaque materials such as concrete or wood.”

Jackson and her colleagues are collaborating with researchers from Picometrix — a photonics company based in Ann Arbor, Michigan — as well as the National Higher School of Advanced Techniques (ENSTA) and the Centre for Research and Restoration in the Louvre Museum, both in Paris. Their system involves scanning a pulse of terahertz light over a surface and then measuring how the amplitude of the reflected signal changes with time. Because materials have different dielectric properties, which determine how much light is reflected, these measurements can tell how dissimilar materials are layered on top of one another (*Opt. Commun.* 281 527). This makes it ideal for imaging frescos — a technique that won favour during the Renaissance in which pigments are painted into wet plaster.



A buried fresco (left) can be viewed with terahertz light (right)

No drawbacks

Although art historians regularly employ ultraviolet, infrared and Raman spectroscopy to examine the surfaces of murals, these techniques cannot probe deeper than a millimetre into plaster. On the other hand, X-rays and microwaves can penetrate many layers, but X-rays cannot distinguish between the layers and microwaves have a poor spatial resolution. Terahertz radiation has none of these drawbacks and, because it is non-ionizing, should not damage a painting either.

The Michigan team has already tested Picometrix’s “Terahertz-wave 4000” system on a graphite sketch of a butterfly imbedded in a 4 mm layer of plaster-of-Paris. After focusing the Terahertz-wave transceiver onto the back of the plaster, they found that they could make out the 2 mm wide graphite lines of the butterfly. The team is now planning to take the system next month to the St John the Baptist church in Vif, France, where there are believed to be many hidden frescoes.

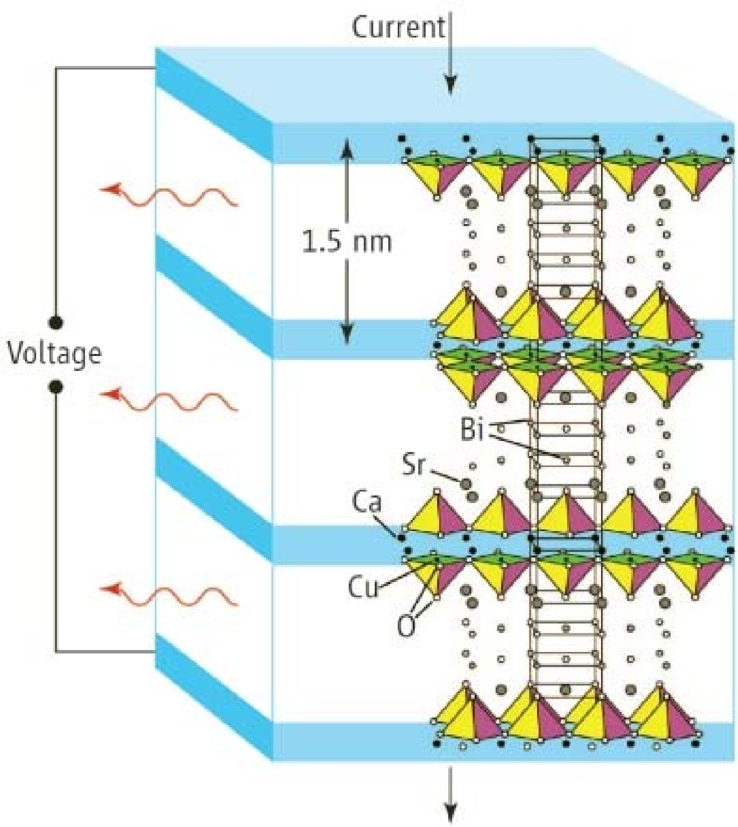
Irl Duling, director of terahertz business development at Picometrix, says that the company is already shipping the Terahertz-wave system to customers. “Terahertz-wave 4000 is the only full-featured, portable time-domain terahertz system.”

About the author

Jon Cartwright is a reporter for *physicsworld.com*

# Nov 23, 2007 - High-Tc superconductors plug 'terahertz gap'

http://physicsworld.com/cws/article/news/31957




Coherent radiation

Ulrich Welp at Argonne National Laboratory and colleagues have shown that the structure of the high-temperature superconductor "BSCCO" allows it to emit coherent terahertz ($10^{12}$ Hz) radiation. The structure, which contains alternating layers of superconducting $CuO_2$ (blue) and insulating BiO and SiO (white), acts like a stack of Josephson junctions. When a fixed voltage is applied across them, an oscillating current is set up that produces the radiation. Crucially, Welp's group have found that by matching the frequency to the resonant mode of the entire sample, all the Josephson junctions begin emitting in-phase — just like a laser. (Credit: *Science*) P.

Electromagnetic radiation in the terahertz range has a host of potential applications, from detecting explosives to diagnosing cancer. But sandwiched between microwaves and the infrared, terahertz radiation is not easy to generate — its frequencies are too high to be produced by semiconductor devices, yet too low to be produced by solid-state lasers. Researchers from the US, Turkey and Japan, however, have shown that this “terahertz gap” could be filled by exploiting the in-built Josephson junctions present in high-temperature superconductors.

Josephson junctions, which comprise two superconductors separated by a thin insulator, are well known for displaying odd quantum effects. In particular, applying a fixed voltage across a junction sets up an oscillating supercurrent, causing the junction to emit photons at a frequency matching the superconductor’s energy gap. In other words, Josephson junctions can produce electromagnetic radiation.

Unfortunately the energy gap in lab-made Josephson junctions, based on conventional superconductors such as niobium, is too small to produce terahertz radiation. Worse still, individual junctions do not generate much power. Researchers have tried rigging up arrays of junctions to boost the power, but it is difficult to synchronize the junctions to make a coherent beam of radiation in which all wavelengths are in-phase.

Layered structure

Ulrich Welp at Argonne National Laboratory and colleagues now claim that both of these problems can be solved with high-temperature superconductors. Unlike conventional superconductors, high-temperature superconductors do not need to be made into Josephson junctions because they naturally contain them throughout a unique layered structure. They also have comparatively large energy gaps that lend to producing radiation well into the terahertz range.

Crucially, however, Welp’s group have discovered a simple way to synchronize the phase of these “intrinsic” Josephson junctions in high-temperature superconductors to emit milliwatts of power (*Science* 318 1291). “A wide variety of sensing and imaging applications can be envisioned for terahertz radiation in this power range,” said Welp.

A wide variety of sensing and imaging applications can be envisioned for terahertz radiation in this power range

The researchers worked with the high-temperature superconductor $Bi_2Sr_2CaCu_2O_8$, also known as BSCCO, which has stacks of intrinsic Josephson junctions formed between interspersed layers of superconducting $CuO_2$ and insulating BiO and SrO. Applying a voltage across a BSCCO sample makes all of these intrinsic junctions emit electromagnetic radiation at a certain frequency — but not necessarily in-phase.

Similarly to a laser, the trick making the emission in-phase is to vary the voltage until the emitted frequency matches the resonant frequency of the cavity. At this frequency, the electric field cancels itself out in all but the in-phase mode, so that the junctions are “encouraged” to be synchronized. At first only a few junctions emit in-phase, but as more latch on the radiation intensifies, causing yet more junctions to resonate until finally the whole stack is in-phase.

Welp and colleagues fabricated samples of BSCCO with a height of about 300-µm. Such dimensions give a stack of some 200,000 intrinsic Josephson junctions, generating 0.5 µW of radiation at frequencies up to 0.85 THz. Welp told *physicsworld.com* that by optimizing the technique he hopes the power can be increased to 1 mW. This level of power could be used, for example, in airports to search for the spectral “fingerprints” of explosives, although he admitted that commercial devices using his group’s emitters are some way off. “Generally, the higher the available power, the better the signal-to-noise ratio is and the faster and more reliable active imaging and screening of people could be performed,” Welp said.

About the author

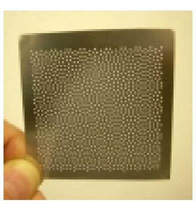
Jon Cartwright is a reporter for *physicsworld.com*

## Mar 29, 2007 - Quasicrystals are selective with terahertz light

http://physicsworld.com/cws/article/news/27453

Physicists in the US have found that they can transmit terahertz light at selective wavelengths by shining it onto a metal film perforated in an aperiodic, "quasicrystal" pattern. Until now, this sort of enhanced light transmission had only been achieved using holes in periodic patterns, and had not been wavelength selective. This discovery demonstrates that it may be possible to use quasicrystal hole arrays to make filters that can be tuned simply by being rotated (*Nature* 446 517).

Shine light through the large holes of, say, a kitchen colander and you get just a portion of it coming out the other side. Shine it through arrays of holes smaller than the light's wavelength, however, and almost all of it can be transmitted. This is thanks to the way photons interact with surface electrons, producing collective excitations known as "surface plasmon polaritons". Previously, enhanced transmission was thought only to occur in periodic holes in metal. But now Valy Vardeny and colleagues from the University of Utah have shown that the effect can be even more pronounced in aperiodic, "quasicrystal" arrays.



Quasicrystal holes

At a glance, quasicrystals look as though their pattern ought to repeat, but at closer inspection one finds that there are always subtle irregularities that preclude any of the translational symmetry that is found in normal crystals. Quasicrystals do, however, have rotational symmetry, meaning that at a certain number of intermediate points in a complete revolution their pattern will be the same.

Vardeny's team made different arrays of holes in 75-µm-thick stainless steel foil varying from quasicrystal to totally random patterns. They then shone light through the foils and measured the spectra of light emitted from the other side.

They found that the foils with random holes attenuated the light output fairly evenly over the spectra. The quasicrystal arrays of holes, on the other hand, let sharp peaks of the light's frequency pass through, which were directly related to the spacing between the holes in the structure. In addition, the precise transmission could be tuned by simply rotating the foil. For patterns that were neither well-defined enough to be termed quasicrystals, nor totally random – what Vardeny calls "quasicrystal approximates" – the transmission peaks were less prominent.

Vardeny told *Physics Web* that the foils could be developed as tuneable filters for use in communications. Terahertz radiation, which lies sandwiched between the microwave and infrared regions of the electromagnetic spectrum, is currently fairly underexploited, but could enable large amounts of data to be transmitted at high speeds. Vardeny's team is now looking at other aperiodic structures for use in the terahertz region.

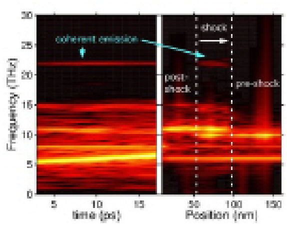
About the author

Jon Cartwright is a reporter for *Physics Web*

# Jan 17, 2006 - Crystals light up

http://physicsworld.com/cws/article/news/23977

Apart from lasers and free-electron lasers, there has not been a new way of producing coherent light for nearly half a century. Now, physicists in the US have found that coherent electromagnetic radiation can be generated in crystalline materials when they are subjected to a shock wave. The technique, which generates light in the terahertz region ($10^{12}$Hz), could provide a new tool for determining the properties of crystals (*Phys. Rev. Lett.* 96 013904).




Coherent light

Coherent light has a very narrow bandwidth and consists of photons that are all in phase with one another. Until now, however, all practical coherent light sources have been either lasers (which were invented in 1958) or free-electron lasers, which harness the radiation emitted by relativistic electrons. The new light source, proposed by Evan Reed and colleagues at the Massachusetts Institute of Technology and the Lawrence Livermore National Laboratory, is fundamentally distinct from these sources.

Using the Thunder parallel computer at the Lawrence Livermore Lab, the researchers performed a series of theoretical calculations and experimental simulations to observe what happens when a mechanical shock wave is generated inside a dielectric crystalline material, such as sodium chloride. They expected to observe only incoherent photons and "sparks" to be produced from the crystal, but to their surprise the researchers found weak yet measurable coherent light emerging from it with a frequency between one and 100 THz

According to the team, the shock wave makes large numbers of atoms in the crystal move in a synchronized way as it propagates through the lattice. This induces an oscillating dipole-like polarization in the material that produces the coherent radiation observed. The frequency of the emitted light is determined by the speed of the shock wave and the periodic lattice structure of the crystal, and not by the coherence of the source that generates the shock wave.

"To our knowledge, coherent light never has been seen before from shock waves propagating through crystals because a shocked crystal is not an obvious source to look for coherent radiation," explains Reed. "The light and radiation was in a portion of the electromagnetic spectrum that is not usually observed in these types of experiments."

The researchers say that the effect should be observed in a wide variety of crystalline materials, and plan to perform experiments to observe coherent radiation in the laboratory. Among a diverse range of potential applications, coherent light from a shocked crystal could be used as a diagnostic tool to determine atomic-scale properties of the shocked material.

About the author

Belle Dumé is science writer at *PhysicsWeb*

# Apr 14, 2005 - New transistor breaks speed record

http://physicsworld.com/cws/article/news/21993

A pair of physicists in the US has built the fastest ever transistor: one that can operate at a frequency of over 600 gigahertz. Developed by Walid Hafez and Milton Feng at the University of Illinois at Urbana-Champaign, the device is made from the semiconductors indium phosphide and indium gallium arsenide (*Appl. Phys. Lett.* 86 152101). The work demonstrates the feasibility of making transistors that can operate at frequencies of several terahertz, which could be used in ultrafast communications, high-speed computing, medical imaging and sensors.

The transistor

The new device is a so-called bipolar transistor, which is very different from the more well-known field-effect transistor. In it, electrons are injected from the "emitter" terminal, travel towards the "base" and are then received by the "collector", an arrangement that allows the device to work faster than a field-effect transistor.

Hafez and Feng have previously built a high-frequency bipolar transistor, but this earlier work focused on reducing the time it takes electrons to pass through the device by minimizing the device's vertical thickness. Their new research further increases electron speeds through the device by slightly varying, or "grading", the composition of the semiconductor layers. This, say the researchers, lowers the band gap in selected areas of the transistor and makes it easier for electrons to travel across the device.

The two physicists have shown their transistor can operate at a frequency of 604 gigahertz, a new record. However, according to Hafez, what is more important is that they have developed a technology that could be used to build transistors operating in the terahertz range. "Projections from our earlier high-frequency devices indicated that in order to create a transistor with a cutoff frequency of 1 terahertz, the devices would have to operate above 10,000 degrees C," he says. "By introducing the grading into the layer structure of the device, we have been able to lower the potential operating temperature for a terahertz transistor to within an acceptable range."

Devices operating at terahertz frequencies (the far infrared) could be used in communications applications or as sensors to detect toxic gases. They could also be used for medical imaging, since the radiation is long enough to penetrate skin and image what lies underneath.

The researchers' next step is to show that their devices can be assembled into circuits.

About the author

Belle Dumé is Science Writer at *PhysicsWeb*

# Apr 14, 2004 - Terahertz radiation targets skin cancer

http://physicsworld.com/cws/article/news/19343

Physicists in the UK believe that they have developed a technique that could be used to detect skin cancers and other epithelial tumours not visible to the naked eye. The technique, which relies on terahertz radiation, could be an effective and non-invasive alternative to the conventional medical imaging techniques used to diagnose these types of tumours (E Pickwell *et al.* 2004 *Phys. Med. Biol.* 49 1595).

85% of all cancers lie in the epithelium – that is, on or near the skin – but their small size can make them difficult to detect. Moreover, skin tissue must be surgically removed for analysis, which is both time consuming and invasive.

The technique developed by Emma Pickwell and colleagues at Cambridge University and TeraView could overcome these problems by exploiting the fact that water strongly absorbs radiation at frequencies between 0.1 and 3 terahertz. Since cancerous tissue tends to have a higher water content than healthy tissue, terahertz radiation could be used to differentiate between the two. Furthermore, the team have shown for the first time that terahertz imaging can be used *in vivo*.

Healthy skin contains about 70% water, so Pickwell and co-workers first developed a computer model that simulated the interaction of terahertz radiation with water. They tested the model by comparing its predictions with the results of tests on 20 healthy volunteers.

By measuring how terahertz pulses were reflected from skin on the forearms and palms of the volunteers, Pickwell and co-workers were able to distinguish between different types of skin, such as dry and normal skin. More importantly, they found that their simulation method was able to successfully model the interaction of terahertz light with normal skin.

“The success of applying the simulation to skin aids the understanding of the interaction of terahertz radiation with biological tissue,” Pickwell told *PhysicsWeb*. “Exploiting the differences in the response of terahertz light to normal and diseased skin may lead to terahertz imaging being used in hospitals as a clinical tool for identifying regions of cancer.”

About the author

Belle Dumé is Science Writer at *PhysicsWeb*

# Apr 10, 2004 - Bridging the terahertz gap

http://physicsworld.com/cws/article/print/19274

OVER THE last century or so, physicists and engineers have progressively explored and conquered the electromagnetic spectrum. Starting with visible light, we have encroached outwards, developing techniques for generating and detecting radiation at both higher and lower frequencies. And as each successive region of the spectrum has been colonized, we have developed technology to exploit the radiation found there. X-rays, for example, are routinely used to image hidden objects. Near-infrared radiation is used in fibre-optic communications and in compact-disc players, while microwaves are used to transmit signals from your mobile phone.

But there is one part of the electromagnetic spectrum that has steadfastly resisted our advances. This is the terahertz region, which ranges from frequencies of about 300 GHz to 10 THz ($10 \times 10^{12}$ Hz). This corresponds to wavelengths of between about 1 and 0.03 mm, and lies between the microwave and infrared regions of the spectrum. However, the difficulties involved in making suitably compact terahertz sources and detectors has meant that this region of the spectrum has only begun to be explored thoroughly over the last decade.

A particularly intriguing feature of terahertz radiation is that the semiconductor devices that generate radiation at frequencies above and below this range operate in completely different ways. At lower frequencies, microwaves and millimetre- waves can be generated by “electronic” devices such as those found in mobile phones. At higher frequencies, near-infrared and visible light are generated by “optical” devices such as semiconductor laser diodes, in which electrons emit light when they jump across the semiconductor band gap.

Unfortunately, neither electronic nor optical devices can conveniently be made to work in the terahertz region because the terahertz frequency range sits between the electronic and optical regions of the electromagnetic spectrum. Developing a terahertz source is therefore a frustrating business because it involves working in a region where established solid-state technologies fail. Nevertheless, researchers are fascinated by terahertz radiation, not least because it has many potential applications for sensing, imaging and spectroscopy across the physical, medical and biological sciences, and perhaps ultimately in communications too.

In the April issue of *Physics World* Giles Davies in the School of Electronic and Electrical Engineering at the University of Leeds and Edmund Linfield in the Cavendish Lab at the University of Cambridge, UK, describe the latest developments in this field

# Mar 19, 2004 - Femtosecond lasers aid frequency standards

http://physicsworld.com/cws/article/news/19219

The conversion of one optical frequency to another with an uncertainty of just 1 part in $10^{19}$ has been reported by a consortium of scientists from different standard institutes in the US, France and China. The demonstration suggests that the next generation of ultra-precise optical frequency standards will be able to be precisely replicated anywhere within a 100 terahertz bandwidth. (L-S Ma *et al.* 2004 *Science* 303 1843).

The work was a joint effort between the National Institute of Standards and Technology (NIST) in the US and the Bureau International des Poids et Mesures (BIPM) in France, along with scientists from East China Normal University (ECNU) in Shanghai and OFS Laboratories in the US.

At present, microwave frequency standards based on atomic transitions have an uncertainty of 1 part in $10^{15}$ while optical standards based on single ions are approaching 1 part in $10^{18}$. “Such an extremely stable and accurate standard is of little value if its frequency cannot be readily distributed to users and compared to those of other standards based on various atomic species operating at different frequencies,” say the authors.

The team believes that optical synthesisers based on femtosecond lasers can overcome the issues of reproducibility and accessibility. To back up this claim, the researchers compared four optical synthesisers: two made at NIST, one from BIPM and one from ECNU. All four synthesisers rely on a modelocked femtosecond laser to generate a comb of precisely-spaced frequencies.

Having compared the systems on 6 days over a 2 month period, the team suggests that the synthesisers are a reliable tool for optical frequency comparisons with uncertainties approaching 1 part in $10^{19}$ (equivalent to about 1 second in 320 billion years).

“Considering the very different designs of these synthesisers - broadband operation versus nonlinear microstructure fibre - it is notable that our data do not point to the existence of any fundamental limitations to the uncertainty,” say the scientists in their paper. “Our results appear to be limited mainly by noise of a technical nature - thermal and mechanical fluctuations - and total integration time.”

About the author

Oliver Graydon is Editor of *Optics.org* and *Opto & Laser Europe* magazine

# Mar 17, 2003 - Terahertz breakthrough at BESSY

http://physicsworld.com/cws/article/news/17134

Terahertz radiation can be used in applications as diverse as biological imaging and the study of semiconductors. However, beams created so far have been too weak to be used in spectroscopy because the terahertz waves were out of phase - or incoherent. Now Godehard Wüestefeld and colleagues at the BESSY synchrotron radiation source in Berlin have generated a steady-state beam of coherent terahertz radiation for the first time (M Abo-Bakr *et al.* 2003 *Phys. Rev. Lett.* 90 094801).

Synchrotron radiation is produced when bunches of charged particles, usually electrons that have been accelerated to close to the speed of light, are forced to move in a circular orbit by strong magnetic fields. The wavelengths produced can range from low-energy far-infrared radiation to high-energy X-rays. Terahertz radiation is found at the low-energy end of the spectrum and corresponds to wavelengths between about 1 mm and 15 microns.

Synchrotron radiation is usually incoherent because the bunches - which contain billions of electrons each - are longer than the wavelengths they are emitting. However, if the bunches could be made much smaller, the electrons would then emit in phase with each other and the radiation would be coherent. The electron bunches in the electron storage ring at BESSY are typically about 5 mm long, which is too long to produce coherent terahertz radiation.

Wüestefeld and co-workers therefore adjusted the magnetic fields in the storage ring to produce a special “low-alpha” mode in which the length of the bunches was comparable with the wavelength of terahertz radiation. The electrons in each bunch now behave as one giant particle and emit a beam of coherent rays.

The BESSY team was able to increase the power of the beam by a factor of $10^5$ when they used low-alpha optics. However, if the intensity is increased by too much the beam can become unstable.

About the author

Belle Dumé is Science Writer at *PhysicsWeb*

## Nov 14, 2002 - Power from terahertz beams

http://physicsworld.com/cws/article/news/16414

Terahertz beams are required in many scientific and technological applications, ranging from the imaging of biological materials to manipulating quantum states in semiconductors. However, existing terahertz sources have only been able to generate low-power beams. Now, Gwyn Williams, from the Jefferson Laboratory, and colleagues at the Brookhaven and Lawrence Berkeley National Laboratories in the US have created a beam that is several orders of magnitude more powerful than any existing source (GL Carr *et al.* 2002 *Nature* 420 153).

The terahertz region lies in the far-infrared region of the electromagnetic between about 300 GHz and 20 THz. All objects emit terahertz electromagnetic waves as “black-body radiation” but the total intensity emitted at all frequencies is less than one millionth of a watt per square centimetre.

The past decade however has seen a significant advance in the production of coherent broad-band terahertz beams. A common method of producing such a beam is to generate an electric field inside a high-resistance semiconductor. Typically, the average power of a beam generated by this method is less than $10^{-6}$ W. The beam can be used for high-resolution spectroscopy and some imaging techniques but it is of limited use, being of such low power.

Now Carr and co-workers have devised a new process in which bunches of electrons travel at nearly the speed of light, inside an accelerator at the Jefferson Laboratory in Virginia. They use a strong magnetic field to accelerate the electron bunches which emit a pulse of electromagnetic radiation lasting 500 femtoseconds. The pulse has a power peak of about 106 W and a peak frequency of 0.6 terahertz, although the detectable radiation continues up to several terahertz. When the electrons are generated at the maximum rate of 37 million each second, the average power reaches about 20 W. This is a 100,000 times higher than the power produced in previous terahertz beams.

“Of course producing and measuring the light is just a first step,” Larry Carr, a member of the group, told *PhysicsWeb*. “Most applications depend on coherent detection, so we need to develop this.” The Jefferson laboratory is already planning space for a terahertz laboratory in their Free Electron Laser facility.

Carr thinks it will be difficult to predict the most important applications for such a beam, although the team would like to use the large peak power to study advanced materials and devices, chemical reactions and biological processes. It could also be used for “full-field, real-time image capture” – in other words terahertz “movies”.

About the author

Belle Dumé is Science Writer at *PhysicsWeb*

## 9.6 Appendix 5 Research Being Undertaken

The research listed here is specific to particular organisations doing practical research into applcations. It does not include the research being undertaken bt the Academic instititions and their research has ben includedunder the heading "Organisations Undertaking Research into terahertz Waves"

# USDA Agricultural Research Service

The US Department of Agriculture (USDA) through its' Agricultural Research Service has been undertaking significant research into the detection of Faecal matter particularly on Chickens. The following website link lists a number of research papers that have been published since 1998.

http://www.ars.usda.gov/Services/docs.htm?docid=9840

http://ars.usda.gov/pandp/people/people.htm?personid=3249

A number of the More relevant papers, and particularly thos applying to using Multispectoral Lser Interference have been included electronically with this report.

Research Project: DEVELOPMENT AND IMAGING TECHNOLOGY FOR THE AUTOMATED ON-LINE INSPECTION OF POULTRY PRODUCTS

Below is a link to two research papers that have been included to demonstrate the type of research that is being undertaken by the USDA Agricultural Research Services.

http://ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=190423

**Title: REAL-TIME MULTISPECTRAL IMAGING APPLICATION FOR POULTRY SAFETY INSPECTION**

Authors

Park, Bosoon ,Lawrence, Kurt , Windham, William , Snead, Matthew

Submitted to: International Society for Optical Engineering
Publication Type: Proceedings/Symposium
Publication Acceptance Date: March 1, 2006
Publication Date: August 8, 2006
Citation: Park, B., Lawrence, K.C., Windham, W.R., Snead, M.P. 2006. Real-time multispectral imaging application for poultry safety inspection. International Society for Optical Engineering. 6070-7:1-10.

Interpretive Summary: For science-based poultry inspection system, the ARS imaging research group in Athens, Georgia has developed a real-time multispectral imaging system for fecal and ingesta contaminant detection on broiler carcasses for poultry industry. The industrial-scale system was able to calibrate imaging hardware and acquire and process images in real-time using a common aperture camera with three visible wavelength optical filters. The in-house image processing software was applicable for real-time image processing and analysis at pilot-scale imaging line. The test results of industrial-sacle real-time system demonstrated that the multispectral imaging technique was able to detect fecal contaminants with a commercial processing speed (currently 140 birds per minute). This industrial-scale imaging system can improve the FSIS poultry safety inspection program by incorporating scientific testing and efficacy of fecal detection during poultry processing.

Technical Abstract: Industrial-scale multispectral imaging system with real-time image processing software for on-line detection of poultry fecal and ingesta contaminants was developed. The software using Unified Modeling Language (UML) design approach was effective to develop real-time image processing software for on-line application. The UML models including class, object, activity, sequence, and collaboration diagram were developed. A window based real-time image processing software was consist twelve components, which represented classes and architectures. Based on the test at the pilot-scale poultry processing plant, the run-time of the software was fast enough to inspect carcasses on-line with 140 birds per minute. The imaging system was able to acquire high quality poultry images in real-time. The temperature increase inside enclosure was allowable (only 4 degree above ambient temperature) for long time operation in harsh environments. According to preliminary tests, the accuracy for fecal and ingesta contaminant detection was approximately 96%. Thus, the imaging system was reliable for in-plant trials.

Project Team

Lawrence, Kurt

Smith, Douglas - *Doug*

Windham, William - *Bob*

Park, Bosoon

Publications Publications

Related National Programs Food Safety, (animal and plant products) (108)

Last Modified: 06/25/2008

# Title: Detection of Ingesta on Pre-Chilled Boiler Carcasses by Hyperspectral Imaging

http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=190416

Authors

- Windham, William
- Heitschmidt, G - UGA
- Smith, Douglas
- Berrang, Mark

Submitted to: International Journal of Poultry Science
Publication Type: Peer Reviewed Journal
Publication Acceptance Date: December 28, 2005
Publication Date: January 20, 2006
Citation: Windham, W.R., Heitschmidt, G.W., Smith, D.P., Berrang, M.E. 2006. Detection of ingesta on pre-chilled boiler carcasses by hyperspectral imaging. International Journal of Poultry Science. 4(12):959-964.

Interpretive Summary: Undigested feed in the upper digestive tract of chickens, commonly referred to as ingesta, has been suggested as a source of bacteria. The two organs most likely to contain ingesta are the crop and gizzard and the crop contents have been observed to be a source of visible contamination on chicken carcasses when accidentally ruptured during commercial processing. The U. S. food safety performance regulations mandate that no visible fecal spots of any size can appear on carcasses at certain points in commercial processing. In this study, we used a camera and computer to detect visible ingesta from crop and gizzard contents on chicken carcasses and then determined the microbiological profile of the ingesta contamination. The camera system accurately detected all contamination on the carcasses. However, contamination of carcasses with ingesta did not change the microbiological profile. Based on the number of bacteria found, carcass contamination with visible ingesta does not appear to significantly increase total carcass bacteria.

Technical Abstract: The contents of the upper digestive tract (i.e. crop, proventriculus and gizzard) may serve as a source of carcass contamination during broiler processing. The crop as been identified as a source of Salmonella and Campylobacter on contaminated carcasses and is more likely to rupture than the ceca during commercial evisceration. The objective of this study was to determine the effectiveness of hyperspectral imaging for detecting ingesta contamination spots varying in mass from the crop and gizzard. Pre-chilled broiler carcasses were collected from a commercial processing plant. Crop and gizzard contents were also aseptically collected and enumerated for Campylobacter, coliforms, E. coli and total aerobic bacteria. Broiler carcasses were imaged and then contaminated with a spot of known mass (10,

50, or 100 mg) of crop or gizzard contents. Carcasses were then re-imaged. The imaging system correctly detected 100% of the crop and gizzard contents regardless of the mass or spot size. However, not every pixel associated with a given spot (contaminant ground truth) was detected. Detection of crop and gizzard content contaminant ground truth pixels averaged 72 and 53%, respectively. The mean number of bacteria in the crop contents were as follows: E. coli 4.0 log, coliforms 4.1 log, and total aerobic bacteria 5.7 log CFU/g of crop contents. Crop contents in the current study were Campylobacter negative. Applying crop contents in the amounts of about 9, 54, and 231 mg resulted in significant ($P<0.05$) increases in all bacterial population measured, with the biggest increase being noted for total aerobic bacteria. Gizzard contents contained only 4.6 log CFU/g of total aerobic bacteria. The total added bacterial load from contamination with known amounts of crop and gizzard contents did not significantly increase whole carcass counts of all bacteria enumerated. Based on these counts and numbers of bacteria found in gizzard, carcass contamination with visible ingesta does not appear to significantly increase bacterial load.

# Research Project: DEVELOPMENT OF TECHNOLOGY FOR AUTOMATED ON-LINE INSPECTION OF ANIMAL CARCASSES AND PLANT PRODUCE

http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=404205&showpubs=true

Location: Animal & Natural Resources

Publications

Development of Simple Algorithms for the Detection of Fecal Contaminants on Apples from Visible / Near Infraed Hyperspectral Reflectance Imaging - (Peer Reviewed Journal)

Liu, Y., Chen, Y.R., Kim, M.S., Chan, D.E., Lefcourt, A. M. 2007. Development of simple algorithms for the detection of fecal contaminants on apples from visible/near infrared hyperspectral reflectance imaging. Jrnl. of Food Eng. 81:412-418.

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Comparison of Visible and Near Infrared Reflectance Spectroscopy for the Detection of Faeces/ingesta Contaminants for Sanitation Verification at Slaughter Plants - (Peer Reviewed Journal)

Liu, Y.D., Chao, K., Chen, Y.R., Kim, M.S., Nou, X., Chan, D.E., Yang, C. 2006. Comparison of visible and near infrared reflectance spectroscopy for the detection of faeces/ingesta contaminants for sanitation verification at slaughter plants. Near Infrared Spectroscopy Journal. 14:325-331.

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Development of Fuzzy Logic-Based Differentiation Algorithm and Fast Line-Scan Imaging System for Chicken Inspection - (Peer Reviewed Journal)

Yang, C., Chao, K., Chen, Y.R., Kim, M.S., Chan, D.E. 2006. Development of fuzzy logic-based differentiation algorithm and fast line-scan imaging system for chicken inspection. Biosystems Engineering. 95(4):483-496.

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Development of Two-Band Color-Mixing Technique for Identification of Broiler Carcass Conditions - (Peer Reviewed Journal)

Chao, K., Chen, Y.R., Ding, F., Yang, C., Chan, D.E. 2007. Development of two-band color-mixing technique for identification of broiler carcass conditions. Journal of Food Engineering. 80(1):276-283.

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Fluorescence Characteristics of Wholesome and Unwholesome Chicken Carcasses - (Peer Reviewed Journal)

Kim, M.S., Chen, Y.R., Kang, S., Kim, I., Lefcourt, A.M., Kim, M. 2006. Fluorescence characteristics of wholesome and unwholesome chicken carcasses. Journal of Applied Spectroscopy. 60(10):1210-1216.

Systematic Approach for Using Hyperspectral Imaging Data to Develop Multispectral Imagining Systems: Detection of Feces on Apples - (Peer Reviewed Journal)

Lefcourt, A.M., Kim, M.S., Chen, Y.R., Kang, S. 2006. Systematic approach for using hyperspectral imaging data to develop multispectral imagining systems: detection of feces on apples. Computers and Electronics in Agriculture. 54:22-35.

Detection of Contaminants on Poultry Processing Plant Equipment Using Laser-Induced Fluorescence Imaging - (Peer Reviewed Journal)

Kim, M.S., Cho, B., Chao, K., Lefcourt, A.M., Liu, Y., Chen, Y.R. 2006. Detection of contaminants on poultry processing plant equipment using laser-induced fluorescence imaging. Key Engineering Materials. 321-323:1157-1162.

Line-Scan Machine Vision System for Online Poultry Carcass Inspection - (Abstract)

Yang, C.C., Chao, K., Chen, Y.R. 2006. Line-scan machine vision system for online poultry carcass inspection. BARC Poster Day 2006.

Simple Region of Interest Analysis for Systemically Diseased Chicken Identification Using Multispectral Imaging - (Peer Reviewed Journal)

Yang, C.C., Chao, K., Chen, Y.R., dKim, M.S., Early, H.L. 2006. Simple region of interest analysis for systemically diseased chicken identification using multispectral imaging. Transactions of ASAE. 49(1):245-257.

Hyperspectral Imaging Technique for Detection of Poultry Fecal Residues on Food Processing Equipment - (Proceedings/Symposium)

Cho, B.K., Kim, M.S., Chen, Y.R. 2005. Hyperspectral imaging technique for detection of poultry fecal residues on food processing equipments. Proceedings of SPIE Conf., Oct. 23-27, 2005, Boston, Mass. 5996:L1-L10.

Three-Color Mixing for Classifying Agricultural Products for Safety and Quality - (Peer Reviewed Journal)

Ding, F., Chen, Y.R., Chao, K., Kim, M.S. 2006. Three-color mixing for classifying agricultural products for safety and quality. Applied Optics. 45(15):3516-3526.

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Gabor-Wavelet Decomposition and Integrated Pca-Fld Method for Texture Based Defect Classification - (Proceedings/Symposium)

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Feature Extraction and Band Selection Methods for Hyperspectral Imagery Applied for Identifying Defects - (Proceedings/Symposium)

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Technique for Normalizing Intensity Histograms of Images When the Approximate Size of the Target Is Known: Detection of Feces on Apples Using Fluorescence Imaging - (Peer Reviewed Journal)

Lefcourt, A.M. and Kim, M.S. 2006. Technique for normalizing intensity histograms of images when the approximate size of the target is known: Detection of feces on apples using fluorescence imaging. Computers and Electonics in Agriculture. 50:135-147.

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Development of Hyperspectral Imaging Technique for the Detection of Chilling Injury in Cucumbers - (Proceedings/Symposium)

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Evaluating Uv-B Effects and Edu Protection in Soybean Leaves Using Fluorescence Emission Spectra and Fluorescence Images - (Peer Reviewed Journal)

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Two-Color Mixing for Classifying Agricultural Products for Safety and Quality - (Peer Reviewed Journal)

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Systemically Diseased Chicken Identification Using Multispectral Images and Region of Interest Analysis - (Peer Reviewed Journal)

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Characterizing Wholesome and Unwholesome Chickens by Cieluv Color Difference - (Peer Reviewed Journal)

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A Transportable Fluorescence Imaging System for Detecting Fecal Contaminants - (Peer Reviewed Journal)

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Kang, S., Kim, M.S., and Kim, I. 2004. Chicken Disease Characterization by Fluorescence Spectroscopy. Journal of Agri. and Biosys. Eng. 5(1):25-29.

Detection of Fecal Contamination on Apples Using Nanosecond-Scale Time-Resolved Imaging of Laser Induced Fluorescence - (Peer Reviewed Journal)

Lefcourt, A.M., Kim, M.S., Chen, Y.R. 2005. Detection of fecal contamination on apples using nonosecond-scale time-resolved imaging of laser induced fluorescence. Applied Optics. 44(7):1160-1170.

Ns-Scale Time-Resolved Laser Induced Fluorescence Imaging for Detection of Fecal Contamination on Apples - (Proceedings/Symposium)

Kim, M.S., Lefcourt, A.M., Chen, Y.R.. 2004. NS-scale time-resolved laser induced flourescence imaging for detection of fecal contamination on apples. In: Chen, Y.R., Tu, Shu-I., editors. Nondestructive Sensing for Food Safety, Quality, and Natual Resources. The International Society for Optical Engineering Conference, October 27-28, 2004, Philadelphia, Pennsylvania. p. 190-197.

Automated Detection of Fecal Contamination of Apples Based on Multispectral Fluorescence Image Fusion - (Peer Reviewed Journal)

Kim, M.S., Lefcourt, A.M., Chen, Y.R., Tao, Y. 2005. Automated detection of fecal contamination of apples based on multispectral flourescence image fusion. Journal of Food Engineering. 71(1):85-91.

Vis/nir Spectroscopic System for High-Speed Poultry Carcasses Inspection - (Proceedings/Symposium)

Chao, K., Chen, Y.R. 2004. VIS/NIR spectroscopic system for high-speed poultry carcasses inspection. In: Proceedings of the CIGR International Conference, Beijing, China. October 11-14, 2004 CDROM.

Development of Simple Algorithm for the Detection of Chilling Injury in Cucumbers from Visible/near Infrared Hyperspectral Imaging - (Peer Reviewed Journal)

Liu, Y., Chen, Y.R., Wang, C.Y., Chan, D.E., Kim, M.S. 2005. Development of simple algorithm for the detection of chilling injury in cucumbers from visible/near infrared hyperspectral imaging. Applied Spectroscopy. 59:136-143.

Development of Hyperspectral Imaging Technique for the Detection of Chilling Injury in Cucumbers: Part Ii. Image Analysis - (Peer Reviewed Journal)

(20-Sep-04)

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Safety Inspection of Cantaloupes and Strawberries Using Multispectral Fluorescence Imaging Techniques - (Proceedings/Symposium)

(31-Aug-04)

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Application of Multispectral Imaging for Identification of Systemically Diseased Chicken - (Proceedings/Symposium)

Yang, C., Chao, K., Chen, Y.R., Kim, M.S. 2004. Application of multispectral imaging for identification of systemically diseased chicken.(Abstract). ASAE Annual International Meeting. ASAE Paper No. 04-3034.

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Development of Multispecteral Imaging Processing Algorithms for Identification of Wholesome, Septicemia, and Inflammatory Process Chickens - (Peer Reviewed Journal)

Yang, C., Chao, K., Chen, Y.R. 2005. Development of multispecteral imaging processing algorithms for identification of wholesome, septicemia, and inflammatory process chickens. Journal of Food Engineering. 69(2):225-234.

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Detection of Skin Tumors on Chicken Carcasses Using Hyperspectral Fluorescence Imaging - (Peer Reviewed Journal)

Kim, I., Kim, M.S., Chen, Y.R., Kong, S.G., 2004. Detection of skin tumors on chicken carcasses using hyperspectral fluorescence imaging. Transactions of the ASAE. Volume 47(5): 1785-1792.

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Middleton, E.M., Kim, M.S., Krizek, D.T. 2004. Evaluating UV-B effects and EDU protection in soybean leaves using fluorescence emission spectra and fluorescence images. [abstract] Program and Abstracts, Annual Meeting, American Society for Photobiology, Seattle, WA, July 10-14, 2004. p.23.

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Kim, M.S., Lefcourt, A.M., Chen, Y.R., Kang, S. 2004. Hyperspectral and multispectral laser induced fluorescence imaging techniques for food safety inspection. Key Engineering Materials. Vols.270-273:PP.1055-1063.

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Chao, K., Chen, Y.R. 2003. High-speed poultry inspection using visible/near-infrared spectrophotometer. SPIE Proceedings entitled: Monitoring Food, Safety, Agriculture, and Plant Health. 5271:51-61.

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Dey, B.P., Chan, D.E., Chen, Y.R., Gwozdz, F.B. 2003. Spectroscopic detection of abnormality in chicken liver as an inspection tool. SPIE Proceedings entitled: Monitoring Food, Safety, Agriculture, and Plant Health. 5271:43-50.

Multispectral Fluorescence Imaging Techniques for Nondestructive Food Safety Inspection - (Proceedings/Symposium)

Kim, M.S., Lefcourt, A.M., Chen, Y.R. 2003. Multispectral fluorescence techniques for non-destructive food safety inspection. SPIE Proceedings entitled: Monitoring Food, Safety, Agriculture, and Plant Health. 5271:62-72.

Portable Multispectral Fluorescence Imaging System for Food Safety Applications - (Proceedings/Symposium)

Lefcourt, A.M., Kim, M.S., Chen, Y.R. 2003. Portable multispectral fluorescence imaging system for food safety applications. SPIE Proceedings entitled: Monitoring Food, Safety, Agriculture, and Plant Health. 5271:62-72.

Analysis of Hyperspectral Fluorescence Images for Poultry Skin Tumor Inspection - (Peer Reviewed Journal)

Kong, S.G., Chen, Y.R., Kim, I., Kim, M.S. 2004. Analysis of hyperspectral fluorescence images for poultry skin tumor inspection. Applied Optics. 43(2):1-10.

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Multispectral Laser-Induced Fluorescence Imaging System for Large Biological Samples - (Peer Reviewed Journal)

KIM, M.S., LEFCOURT, A.M., CHEN, Y.R. MULTISPECTRAL LASER-INDUCED FLUORESCENCE IMAGING SYSTEM FOR LARGE BIOLOGICAL SAMPLES. APPLIED OPTICS. 42(19):3927-3934. 2003.

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Automated Detection of Fecal Contamination of Apples by Multispectral Laser-Induced Fluorescence Imaging - (Peer Reviewed Journal)

LEFCOURT, A.M., KIM, M.S., CHEN, Y.R. AUTOMATED DETECTION OF FECAL CONTAMINATION OF APPLES BY MULTISPECTRAL LASER-INDUCED FLUORESCENCE IMAGING. APPLIED OPTICS. 2003.

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Analysis of Vis/nir Spectral Variations of Wholesome, Septicemia, and Cadaver Chicken Samples - (Peer Reviewed Journal)

CHAO, K., CHEN, Y.R., CHAN, D.E. ANALYSIS OF VIS/NIR SPECTRAL VARIATIONS OF WHOLESOME, SEPTICEMIA, AND CADAVER CHICKEN SAMPLES. APPLIED ENGINEERING IN AGRICULTURE. 2003.

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Analysis of Vis/nir Spectral Variations of Wholesome and Unwholesome Chicken Meat - (Proceedings/Symposium)

Chao, K., Chen, Y.R., Chan, D.E., Kang, S. 2003. Analysis of vis/nir spectral variations of wholesome and unwholesome chicken meat. ASAE Annual International Meeting. 19(4): 453-458.

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Assessment of Combined Effects of Elevated Tropospheric O3 and Co2 on Soybean under Well-Watered and Restricted Soil Moisture Conditions by Multispectral Fluorescence Imaging Techniques - (Peer Reviewed Journal)

KIM, M.S., MULCHI, C.L., DAUGHTRY, C.S., MCMURTREY III, J.E. ASSESSMENT OF COMBINED EFFECTS OF ELEVATED TROPOSPHERIC O3 AND CO2 ON SOYBEAN UNDER WELL-WATERED AND RESTRICTED SOIL MOISTURE CONDITIONS BY MULTISPECTRAL FLUORESCENCE IMAGING TECHNIQUES. CROP SCIENCE. 2003.

Chicken Disease Characterization by Fluorescence Spectroscopy - (Proceedings/Symposium)

(01-Aug-02)

Application of Hyperspectral Fluorescence Imaging for Detection of Skin Tumors on Chicken Carcasses - (Proceedings/Symposium)

(01-Aug-02)

Changes in Structure and Color Characteristics of Irradiated Chicken Breasts As a Function of Dosage and Storage Time - (Proceedings/Symposium)

(01-Aug-02)

Principal Component Regression of Near-Infrared Reflectance Spectra for Beef Tenderness Prediction - (Peer Reviewed Journal)

PARK, B., CHEN, Y.R., HRUSCHKA, W.R., SHACKELFORD, S.D., KOOHMARAIE, M. PRINCIPAL COMPONENT REGRESSION OF NEAR-INFRARED REFLECTANCE SPECTRA FOR BEEF TENDERNESS PREDICTION. TRANSACTIONS OF THE AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS. 43(3):609-615. 2001.

Project Team

- Chen, Yud-Ren - *Chen*
- Chao, Kuanglin - *Kevin Chao*
- Kim, Moon
- Lefcourt, Alan
- Delwiche, Stephen - *Steve*

Project Annual Reports

FY 2006

FY 2005

FY 2004

FY 2003

FY 2002

Publications Publications

Related National Programs Food Safety, (animal and plant products) (108)

Last Modified: 06/22/2008

# Research Project: DEVELOPMENT OF NEW AND IMPROVED SYSTEMS TO ENHANCE FOOD SAFETY INSPECTION AND SANITATION OF FOOD PROCESSING

http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=410502

Location: Food Safety Laboratory

Project Number: 1265-42000-013-00
Project Type: Appropriated

Start Date: Jan 23, 2006
End Date: Jan 22, 2011

Objective:
The first objective is to fine-tune the ISL poultry inspection systems for detecting pathophysiological abnormalities in poultry, with a goal of commercial implementation as part of existing or new poultry processing systems. The second objective is to continue development, evaluation, validation and refinement of techniques for detecting feces and defects on fresh fruits and vegetables, and to address problems of implementing new systems using these techniques, or integrating these techniques with existing systems already in commercial use or under development in other ARS facilities. The third objective is to develop, evaluate, and validate portable low-cost optical and opto-electronic devices for in situ identification of contamination sites for use by producer/processing operations with goals of commercial implementation and expansion to include use in other areas, such as cleaning and sanitation, and military food security.

Approach:
The ISL multispectral imaging system will be fine-tuned to meet the rigors of use in a processing plant. Detection algorithms for both the ISL Vis/NIR spectrophotometric system and the multispectral imaging system will be upgraded so that they are able to automatically compensate for changes in environmental conditions (seasonal, geographical, etc.) and feed affecting the poultry being processed. An automated control system that improves the integration of ISL detection systems with commercial operations will be developed. The ISL poultry inspection systems and a system being developed by ARS in Athens, Georgia to detect fecal contamination on poultry carcasses will be integrated. Development, evaluation, validation and refinement of techniques for detecting feces and defects on fruits and vegetables will be continued. Problems of implementing new systems that use ISL techniques, or integrating these techniques with existing systems in commercial use or under development in other ARS facilities, will be addressed. The laboratory results where reflectance and fluorescence imaging methods were successfully used to detect feces on apples will be the basis for the design of more practical systems. The results obtained for apples will be used to develop systems to detect feces on other fresh and fresh-cut produce. Portable/wearable imaging devices will be designed to assist inspectors by highlighting areas with thin contaminants, much of which would not be easily spotted by the naked eye. Optimal wavelengths for detection using visually enhanced direct viewing (e.g., binoculars), reflectance imaging techniques, or fluorescence imaging techniques will be established. These results will be used to design, construct, and validate inexpensive portable/wearable devices. The devices will be designed to detect the presence of animal fecal matter and then will be expanded to include detection of other organic materials that can harbor pathogen growth. Strategic inspection models in which data are shared among multiple inspectors using portable devices and integrated with wireless image/voice communication capabilities will also be developed. Results from the development of apple inspection systems will be used to develop systems to detect feces on other fresh and fresh-cut produce.

Project Team

Kim, Moon

Lefcourt, Alan

Delwiche, Stephen - *Steve*

Chao, Kuanglin - *Kevin Chao*

Project Annual Reports

FY 2007

FY 2006

Publications ◦ Publications

Related National Programs◦ Food Safety, (animal and plant products) (108)

Related Projects

- DEVELOP SPECTROSCOPY TECHNIQUES FOR DETECTION OF TRACE BACTERIA AND BIOLOGICAL TOXINS IN FOODS

DEVELOPMENT OF LINE-SCAN IMAGE ALGORITHMS FOR INSPECTION OF POULTRY CARCASSES

GRADUATE STUDENT ASSISTANCE IN DEVELOPING METHODS TO IMAGE WHOLE SURFACES OF APPLES AND FRUITS FOR SAFETY INSPECTION

- GRADUATE STUDENT ASSISTANCE IN THE DEVELOPING A PROTOTYPE SYSTEM FOR DETECTING APPLES CONTAMINATED WITH FECES

- DEVELOPMENT OF MULTISPECTRAL IMAGE-BASED ONLINE SAFETY INSPECTION METHODS FOR FRUITS AND VEGETABLES

Last Modified: 06/22/2008

# Research Project: DEVELOPMENT OF NEW AND IMPROVED SYSTEMS TO ENHANCE FOOD SAFETY INSPECTION AND SANITATION OF FOOD PROCESSING

You are here: Research /

Location: Food Safety Laboratory

2007 Annual Report

1a.Objectives (from AD-416)

The first objective is to fine-tune the ISL poultry inspection systems for detecting pathophysiological abnormalities in poultry, with a goal of commercial implementation as part of existing or new poultry processing systems. The second objective is to continue development, evaluation, validation and refinement of techniques for detecting feces and defects on fresh fruits and vegetables, and to address problems of implementing new systems using these techniques, or integrating these techniques with existing systems already in commercial use or under development in other ARS facilities. The third objective is to develop, evaluate, and validate portable low-cost optical and opto-electronic devices for in situ identification of contamination sites for use by producer/processing operations with goals of commercial implementation and expansion to include use in other areas, such as cleaning and sanitation, and military food security.

1b.Approach (from AD-416)

The ISL multispectral imaging system will be fine-tuned to meet the rigors of use in a processing plant. Detection algorithms for both the ISL Vis/NIR spectrophotometric system and the multispectral imaging system will be upgraded so that they are able to automatically compensate for changes in environmental conditions (seasonal, geographical, etc.) and feed affecting the poultry being processed. An automated control system that improves the integration of ISL detection systems with commercial operations will be developed. The ISL poultry inspection systems and a system being developed by ARS in Athens, Georgia, to detect fecal contamination on poultry carcasses will be integrated. Development, evaluation, validation and refinement of techniques for detecting feces and defects on fruits and vegetables will be continued. Problems of implementing new systems that use ISL techniques, or integrating these techniques with existing systems in commercial use or under development in other ARS facilities, will be addressed. The laboratory results where reflectance and fluorescence imaging methods were successfully used to detect feces on apples will be the basis for the design of more practical systems. The results obtained for apples will be used to develop systems to detect feces on other fresh and fresh-cut produce. Portable/wearable imaging devices will be designed to assist inspectors by highlighting areas with thin contaminants, much of which would not be easily spotted by the naked eye. Optimal wavelengths for detection using visually enhanced direct viewing (e.g., binoculars), reflectance imaging techniques, or fluorescence imaging techniques will be established. These results will be used to design, construct, and validate inexpensive portable/wearable devices. The devices will be designed to detect the presence of animal fecal matter and then will be expanded to include detection of other organic materials that can harbor pathogen growth. Strategic inspection models in which data are shared among multiple inspectors using portable devices and integrated with wireless image/voice communication capabilities will also be developed. Results from the development of apple inspection systems will be used to develop systems to detect feces on other fresh and fresh-cut produce.

3.Progress Report

In the past year, FSL scientists have developed various nondestructive sensing methodologies and systems for food safety, quality, and sanitation inspection. Applications were submitted for the following four patents: online inspection of chicken carcasses for wholesomeness, online multi-task inspection for safety and quality of fruits, a portable device for sanitation inspection of food processing equipment surfaces, and a method for detection of chemical and biological contaminants in foods. The hyperspectral/multispectral line-scan image-based chicken inspection system has been extensively tested at a Tyson Foods commercial chicken processing plant located in Cumming, Georgia, and is being transferred through an agreement to Stork-Gamco (Gainesville, Georgia) for commercial development. FSL collaborated with scientists from the Poultry Processing Research Unit, ARS, Athens, Georgia, for evaluations of line-scan hyperspectral imaging-based online inspection of chicken carcasses for fecal contamination. FSL scientists visited the PPRU, ARS in Athens, Georgia, to set up and test the hyperspectral line-scan imaging system for chicken carcasses on a processing line operating at a speed of 140 birds per minute. An agreement was developed with AHPharma, Inc. (Salisbury, Maryland) to make the portable sanitation inspection devices available to food processing industries at a low cost.

4.Accomplishments

Title: Automated On-line High-speed Wholesomeness Inspection of Chicken Carcasses. FSIS has been testing the HACCP-based Inspection Models Project (HIMP) in 20 volunteer plants that process young chickens in the U.S. To enhance food safety inspection of poultry carcasses, a line-scan hyperspectral/multispectral imaging system was developed and installed online in a commercial poultry processing plant, and demonstrated successful online sorting of wholesome and unwholesome birds for diversion to separate processing lines. Collaborating with Stork Gamco, Inc. (our CRADA partner) and poultry plant personnel, in-plant testing of the system was conducted in March and July 2007, during which over 100,000 birds were inspected. Inspection accuracies of 99.0 percent and 99.5 percent were achieved for unwholesome and wholesome birds, respectively. This inspection data was required for protocols prepared for submission to FSIS New Technology Staff by Stork Gamco to gain approval needed for commercialization of the system for food safety inspection use. This accomplishment is aligned with Problem Statement 1.2.2 (On-line Sensing Systems) of National Program 108.

Title: SERS Technique for the Rapid and Specific Detection of Pathogenic Bacteria. Rapid, accurate, and preferably routine methods for the identification of foodborne bacteria are increasingly important for both public health concerns and economic losses due to threats of bio/agro-terrorism and unexpected outbreaks of foodborne illness such as E. coli-contaminated spinach. Examination of SERS spectra for E. coli and L. monocytogenes cultures adsorbed on silver colloidal nanoparticles identified spectral bands at 712 and 390 cm-1 for use in simple band ratio algorithms to identify the bacterial cultures with 100 percent success and to assess binding effectiveness of the silver colloidal nanoparticles with time. This first report of characteristic SERS bands for E. coli and L. monocytogenes suspensions presents a simple method for bacterial detection that has potential for rapid, specific, and routine screening for bacteria in ready-to-eat food products, in manufacturing process control, and in monitoring of sanitation practices. This accomplishment is aligned with Problem Statement 1.2.9 (Food Security) of National Program 108.

Title: Hyperspectral Line-scan Imaging for Online Defect and Safety Inspection of Apples. We have recently developed a rapid online line-scan imaging system capable of both hyperspectral Vis/NIR reflectance and fluorescence in the Vis with UV-A excitation. The hyperspectral online line-scan system was evaluated to inspect apples for fecal contamination and defects at a processing line speed of over three apples per second. Results showed that fluorescence imaging (using a two-band ratio) could achieve detection of fecal spots on artificially contaminated apples with a 100 percent detection rate and no false positives regardless of the presence of defects. A NIR two-band reflectance ratio coupled with a simple classification method based on the mean intensity and homogeneity of the ratio achieved a 99.5 percent apple defect classification accuracy with a false positive rate of only 2 percent. The most significant and important outcome of this investigation is a line-scan inspection system that can potentially provide the capability for current sorting mechanisms, such as by size and color, as well as additional sorting for quality and safety attributes of food products. This line-scan based online imaging system offers great potential as a value-added dynamic inspection system due to its capability for multi-tasking to meet a variety of inspection objectives. This accomplishment is aligned with Problem Statement 1.2.2 (On-line Sensing Systems) of National Program 108.

Title: Apple Processing Technique to Allow Effective Detection of Contamination and Quality Issues. Lack of an effective and inexpensive method to appropriately orient fruit for imaging applications has hindered the development of optical technologies for sorting fruit. A method for orienting fruit, theoretically complex yet simple in practice, was developed based on inertial properties of the fruit. While rolling down a special track constructed of two parallel rails, apples jump to an "oriented" position after achieving sufficient angular velocity. Currently, apples are processed using conveyer belts with individual cups for apples. Potentially, the conveyer belts could be replaced by the much less expensive track with the added benefit that machine vision could then be used to sort apples for contamination and safety problems. This accomplishment is aligned with Problem Statement 1.2.2 (On-line Sensing System) of National Program 108.

Title: Application of Online Hyperspectral Reflectance and Fluorescence Line-scan Imaging for Citrus. A collaborative study was conducted between the FSL and the University of Florida to evaluate fluorescence and Vis/NIR reflectance line-scan imaging methods to detect canker disease on citrus fruits. FSL scientists designed and built a transportable hyperspectral imaging system capable of both fluorescence and reflectance, and conducted an experiment to determine potential means to detect canker disease on citrus fruits at the FSL laboratory. The University of Florida also duplicated the FSL hyperspectral/multispectral imaging methodologies and system developed by the FSL scientists for online safety and quality inspection of apples. This accomplishment is aligned with Problem Statement 1.2.2 (On-line Sensing System) of National Program 108.

5.Significant Activities that Support Special Target Populations
None

6.Technology Transfer

Number of new CRADAs and MTAs 3

Number of active CRADAs and MTAs 1

Number of invention disclosures submitted 3

Number of patent granted 1

Number of web sites managed 1

Number of non-peer reviewed presentations and proceedings 5

Number of newspaper articles and other presentations for non-science audiences 2

Review Publications

Chao, K., Chen, Y.R., Ding, F., Yang, C., Chan, D.E. 2007. Development of two-band color-mixing technique for identification of broiler carcass conditions. Journal of Food Engineering. 80(1):276-283.

Yang, C., Chao, K., Chen, Y.R., Kim, M.S., Chan, D.E. 2006. Development of fuzzy logic-based differentiation algorithm and fast line-scan imaging system for chicken inspection. Biosystems Engineering. 95(4):483-496.

Chao, K., Yang, C., Chen, Y.R., Kim, M.S., Chan, D.E. 2007. Fast Line-Scan Imaging System For Broiler Carcass Inspection. Jrnl of Sensing and Instrumentation for Food Quality and Safety. 1:62-71.

Lefcourt, A.M., Kim, M.S., Chen, Y.R., Kang, S. 2006. Systematic approach for using hyperspectral imaging data to develop multispectral imagining systems: detection of feces on apples. Computers and Electronics in Agriculture. 54:22-35.

Kim, M.S., Cho, B., Chao, K., Lefcourt, A.M., Liu, Y., Chen, Y.R. 2006. Detection of contaminants on poultry processing plant equipment using laser-induced fluorescence imaging. Key Engineering Materials. 321-323:1157-1162.

Kim, M.S., Chen, Y.R., Kang, S., Kim, I., Lefcourt, A.M., Kim, M. 2006. Fluorescence characteristics of wholesome and unwholesome chicken carcasses. Journal of Applied Spectroscopy. 60(10):1210-1216.

Liu, Y., Chen, Y.R., Kim, M.S., Chan, D.E., Lefcourt, A. M. 2007. Development of simple algorithms for the detection of fecal contaminants on apples from visible/near infrared hyperspectral reflectance imaging. Jrnl. of Food Eng. 81:412-418.

Liu, Y.D., Chao, K., Chen, Y.R., Kim, M.S., Nou, X., Chan, D.E., Yang, C. 2006. Comparison of visible and near infrared reflectance spectroscopy for the detection of faeces/ingesta contaminants for sanitation verification at slaughter plants. Near Infrared Spectroscopy Journal. 14:325-331.

Project Team

Kim, Moon

Lefcourt, Alan

- Delwiche, Stephen - *Steve*
- Chao, Kuanglin - *Kevin Chao*

Project Annual Reports

FY 2007

FY 2006

Publications Publications

Related National Programs Food Safety, (animal and plant products) (108)

Related Projects

- DEVELOP SPECTROSCOPY TECHNIQUES FOR DETECTION OF TRACE BACTERIA AND BIOLOGICAL TOXINS IN FOODS
- DEVELOPMENT OF LINE-SCAN IMAGE ALGORITHMS FOR INSPECTION OF POULTRY CARCASSES
- GRADUATE STUDENT ASSISTANCE IN DEVELOPING METHODS TO IMAGE WHOLE SURFACES OF APPLES AND FRUITS FOR SAFETY INSPECTION
- GRADUATE STUDENT ASSISTANCE IN THE DEVELOPING A PROTOTYPE SYSTEM FOR DETECTING APPLES CONTAMINATED WITH FECES
- DEVELOPMENT OF MULTISPECTRAL IMAGE-BASED ONLINE SAFETY INSPECTION METHODS FOR FRUITS AND VEGETABLES

Last Modified: 06/22/2008

# Research Project: DEVELOP SPECTROSCOPY TECHNIQUES FOR DETECTION OF TRACE BACTERIA AND BIOLOGICAL TOXINS IN FOODS

http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=410575

Location: Food Safety Laboratory

Project Number: 1265-42000-013-05
Project Type: Specific C/A

Start Date: Jul 27, 2006
End Date: Jun 30, 2009

Objective:
1) To develop the Surface Enhanced Raman Spectroscopic (SERS) method as a rapid and routine detection technique and 2) to fabricate and characterize SERS nanoprobe to provide localized and non-destructive SERS identification from surfaces of bulk samples with large spatial selectivity.

Approach:
1) To develop the SERS method as a rapid and routine detection technique, stability and consistency of silver SERS substrates with the storage time and fabrication batch as well as the interaction between toxin/pathogen and substrates will be examined first and 2) To develop innovative SERS nanoprobe, which could provide localized and non-destructive SERS identification from surfaces of bulk samples with large spatial selectivity.

Project Team

Chao, Kuanglin - *Kevin Chao*

Kim, Moon

Project Annual ReportsFY 2007

Related National Programs

Food Safety, (animal and plant products) (108)

Last Modified: 06/22/2008

# Research Project: DEVELOPMENT OF TECHNOLOGY FOR AUTOMATED ON-LINE INSPECTION OF ANIMAL CARCASSES AND PLANT PRODUCE

http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=187339

Location: Animal & Natural Resources

Title: Detection of Contaminants on Poultry Processing Plant Equipment Using Laser-Induced Fluorescence Imaging

Authors

- Kim, Moon
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- Chao, Kuanglin
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- Liu, Yongling - VISITING SCI., ISL, ANRI
- Chen, Yud-Ren

Submitted to: Key Engineering Materials
Publication Type: Peer Reviewed Journal
Publication Acceptance Date: May 1, 2006
Publication Date: October 1, 2006
Publisher's URL: http://www.scientific.net
Citation: Kim, M.S., Cho, B., Chao, K., Lefcourt, A.M., Liu, Y., Chen, Y.R. 2006. Detection of contaminants on poultry processing plant equipment using laser-induced fluorescence imaging. Key Engineering Materials. 321-323:1157-1162.

Interpretive Summary: There is a need for reliable optical sensing systems that can be employed in food processing plants for detection of contamination due to animal faeces and ingesta. We used a recently developed laser-induced fluorescence imaging system (LIFIS) to demonstrate the potential use of fluorescence techniques for detection of a range of diluted poultry fecal matter from various sections of the digestive tract, including gizzard, duodenum, small intestine, ceca, and colon, on processing plant equipment. The advantage of the current LIFIS is that it allows tunable excitation in the visible with the selection of interchangeable emission wavebands for multispectral imaging. Thus, both fluorescence excitation and emission parameters can be optimized (e.g., 415 nm excitation, and 580 and 630 nm emission bands) for detection of poultry fecal matter on the surfaces of processing plant equipment. The results showed that 1:5 and 1:10 diluted fecal samples could be detected with 100% detection rates at 580 and 630 nm emission bands regardless of feces types. Detection rates for 1:50 and 1:100 diluted samples at the 580-nm band were 96.0 and 89.3%, respectively, and those at the 630-nm band were 94.7

and 84.0%, respectively. Presented are sensing systems and methodologies useful to food scientists, engineers, regulatory government agencies (FSIS and FDA), and food processing industries.

Technical Abstract: Fluorescence techniques have demonstrated great potential for detection of the presence of fecal and other biological substances that can harbor pathogens. We used a recently developed laser-induced fluorescence imaging system (LIFIS) to demonstrate the potential use of fluorescence techniques for detection of a range of diluted poultry fecal matter from various sections of the digestive tract, including gizzard, duodenum, small intestine, ceca, and colon, on processing plant equipment. The use of the LIFIS allowed tunable excitation in the visible with selection of emission wavebands for multispectral imaging. Thus, both fluorescence excitation and emission parameters can be optimized (e.g., 415 nm excitation, and 580 and 630 nm emission bands). The results showed that 1:5 and 1:10 diluted feces samples could be detected with 100% detection rates at the 580 and 630 nm emission bands regardless of feces types. Detection rates for 1:50 and 1:100 diluted samples at the 580-nm band were 96.0 and 89.3%, respectively, and those at the 630-nm band were 94.7 and 84.0%, respectively. Even minute amounts of poultry fecal matter on processing plant equipment surfaces, not clearly visible to the human eye, could be detected.

Project Team

- Chen, Yud-Ren - *Chen*
- Chao, Kuanglin - *Kevin Chao*
- Kim, Moon
- Lefcourt, Alan
- Delwiche, Stephen - *Steve*

Publications Publications

Related National Programs

Food Safety, (animal and plant products) (108)

Last Modified: 06/22/2008

# Research Project: DEVELOP SPECTROSCOPY TECHNIQUES FOR DETECTION OF TRACE BACTERIA AND BIOLOGICAL TOXINS IN FOODS

http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=410575

Location: Food Safety Laboratory

Project Number: 1265-42000-013-05
Project Type: Specific C/A

Start Date: Jul 27, 2006
End Date: Jun 30, 2009

Objective:
1) To develop the Surface Enhanced Raman Spectroscopic (SERS) method as a rapid and routine detection technique and 2) to fabricate and characterize SERS nanoprobe to provide localized and non-destructive SERS identification from surfaces of bulk samples with large spatial selectivity.

Approach:
1) To develop the SERS method as a rapid and routine detection technique, stability and consistency of silver SERS substrates with the storage time and fabrication batch as well as the interaction between toxin/pathogen and substrates will be examined first and 2) To develop innovative SERS nanoprobe, which could provide localized and non-destructive SERS identification from surfaces of bulk samples with large spatial selectivity.

Project Team

- Chao, Kuanglin - *Kevin Chao*
- Kim, Moon

Project Annual Reports

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  Related National Programs

  Food Safety, (animal and plant products) (108)

Last Modified: 06/22/2008

# Research Project: DEVELOPMENT AND IMAGING TECHNOLOGY FOR THE AUTOMATED ON-LINE INSPECTION OF POULTRY PRODUCTS

http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=404158

Location:

2003 Annual Report

1.What major problem or issue is being resolved and how are you resolving it? Several deaths occur each year from public consumption of contaminated poultry and/or meat. This contamination by bacterial micro-organisms has led the public to require more careful inspection of meat and poultry. Such micro-organisms are most commonly found in the digestive tract of the animals and their excreted faeces. Potential contamination can occur when feces or ingesta is deposited on the surface of the carcass. A hyper spectral and multispectral imaging system has been built and a method, which can be used for further real-time processing application, has been developed for faecal and ingesta detection on meat surfaces.

2.How serious is the problem? Why does it matter?
Identification and separation of the birds contaminated by faeces and/or crop ingesta is very important to protect the consumer from a potential source of food poisoning. To protect the consumer, FSIS has a zero-tolerance regulation for faeces on poultry carcasses prior to the carcass entering the chiller. Identification and removal/cleaning of carcasses with contamination will also reduce further cross contamination during poultry processing. Regular machine vision systems are not effective in differentiating contaminated birds, because they have very limited spectral information which is necessary for positive identification. Therefore, new technology, such as hyper-spectral imaging or imaging spectroscopy, which gives spatial, spectral, and radiometric information, could identify fecal and crop ingesta surface contamination on poultry

3.How does it relate to the National Program(s) and National Program Component(s) to which it has been assigned?
This research directly supports National Program 108 in Food Safety (Animal and Plant Products). The project is under Post harvest Activities: 2.1 Methodology, with Priority Objectives: 2.1.1.7, Develop methods for the automatic identification of pathophysiological, abnormalities, lesions, fecal contamination, ingesta and processing damage on animal carcasses.

4.What were the most significant accomplishments this past year?
A. Single Most Significant Accomplishment during FY 2003: Broiler carcass contaminated with feces must be detected with a real-time imaging system capable of operating at processing-line speeds (140 birds per minute). In the pilot-scale processing plant at the Russell Research Center located in Athens Georgia, we installed an waterproof industrial-scale, real-time, transportable multispectral imaging system with a new common aperture camera and upgraded image processing software. The system can capture carcass images to detect fecal contamination at a rate of 140 birds per minute. The system will aid FSIS inspectors in detection of fecal spots on carcasses and help the industry meet the zero-fecal-tolerance mandate for visible fecal material.

B. Other Significant Accomplishments:

(1) The lowest possible detection level of fecal contamination must be established for the multispectral imaging system to determine its commercial feasibility and compliance with FSIS's zero tolerance policy for visible fecal contamination of broiler carcasses. A study was conducted by Poultry Processing and Meat Quality Unit scientists, B. Windham, K. Lawrence, B. Park, and D. Smith to determine the lowest detection limits on carcasses by imaging and conducting microbiological analyses on small spots of feces with known weights. The imaging system successfully detected even the smallest spot, and was more sensitive to detecting contamination than the microbiological methods at the smallest spot size. The imaging system could be applied commercially and should be acceptable to FSIS for in-plant fecal detection on carcasses.

(2) To determine the commercial feasibility and compliance with FSIS(s zero-tolerance policy for visible fecal contamination of broiler carcasses, the effectiveness of the ARS multispectral imaging system to detect contaminants inside a poultry carcass cavity must be explored. Poultry carcasses were halved and hyperspectral images of inside halves before and after contamination with cecal feces were collected by

Poultry Processing and Meat Quality Unit scientists, B. Windham, K. Lawrence, B. Park, and D. Smith to characterize the inside carcass features and determine the effectiveness of the imaging system. The imaging system successfully detected cecal contaminants inside the carcasses. The imaging system could be applied commercially for internal fecal contaminant detection of broiler carcasses.

5.Describe the major accomplishments over the life of the project, including their predicted or actual impact.
A method and imaging system for detection of fecal and ingesta contamination was developed and an international patent granted by the U.S. Patent and Trademark Office; Patent No. 6,587,575 Method and System for Contaminant Detection During Food Processing. The invention will impact industry by providing a technique to detect sources of potential food safety contaminates, by reducing subsequent slaughter plant stoppages resulting from contaminated carcasses, and by reducing the water usage within the plant.

6.What do you expect to accomplish, year by year, over the next 3 years?
This project will have completed a five year cycle in FY2005, so research for the next two years is outlined. In FY 2004, the imaging system will be installed and evaluated on a evisceration line in a commercial processing plant.

In FY 2005, methods and models will be developed to classify and identify type of individual contaminants. The output will be used for selective reprocessing of contaminated poultry carcasses.

7.What science and/or technologies have been transferred and to whom? When is the science and/or technology likely to become available to the end-user (industry, farmer, other scientists)? What are the constraints, if known, to the adoption and durability of the technology products?
A. Cooperative Research and Development Agreement (2-year) has been entered into with one of the largest manufactures of poultry processing equipment to aid in reducing to practice our method and system of contaminate detection. Patent 6,587,575 was licensed to the University of Georgia Research Foundation.

8.List your most important publications in the popular press and presentations to organizations and articles written about your work. (NOTE: This does not replace your peer-reviewed publications listed below).
Fine-Tuning Analytical Results. Sheldon,B., editor. Meat Processing. 2003. June. p. 102.

Lawrence, K.C., Windham, W.R., Park, B., Smith, D.P. Contaminant detection on poultry carcass surfaces. New Food Volume. 2002. v. 5. p. 21-24.

Wyvill, C. Computer Vision Technology: Ready for payback. Poultry USA. 2003. May. p. 24-32.

Review Publications
Park, B., Lawrence, K.C., Windham, W.R., Buhr, R.J. 2002. Hyperspectral imaging for detecting fecal and ingesta contaminats on poultry carcasses. Transactions of the ASAE.

Lawrence, K.C., Park, B., Windham, W.R., Mayo, C., Poole, G.H. 2002. Reflectance calibration of focal plane array hyperspectral imaging system for agricultural and food safety applications. Society of Photo-Optical Instrumentation Engineers.

PARK, B., LAWRENCE, K.C., WINDHAM, W.R., CHEN, Y., CHAO, K. DISCRIMINANT ANALYSIS OF DUAL-WAVELENGTH SPECTRAL IMAGES FOR CLASSIFYING POULTRY CARCASSES. COMPUTERS AND ELECTRONICS IN AGRICULTURE. 2002.

Windham, W.R., Park, B., Lawrence, K.C., Buhr, R.J., Smith, D.P. 2001. Selection of visible/nir wavelengths for characterizing fecal and ingesta contamination of poultry carcasses. [abstract] Near Infrared Spectroscopy International Conference Proceedings.

Park, B., Windham, W.R., Lawrence, K.C., Buhr, R.J., Smith, D.P. 2002. Imaging spectrometry for detecting feces and ingesta on poultry carcasses. Near Infrared Spectroscopy International Conference Proceedings.

Lawrence, K.C., Park, B., Windham, W.R., Mao, C. 2003. Calibration of a pushbroom hyperspectral imaging system for agricultural inspection. [abstract] Transactions of the ASAE.

Windham, W.R., Lawrence, K.C., Park, B., Buhr, R.J. Visible/NIR spectroscopy for characterizing fecal contamination of chicken carcasses. Transactions of the American Society of Agricultural Engineers. 2003. v. 46(3). p. 747-751.

Park, B., Lawrence, K.C., Windham, W.R., Smith, D.P. 2002. Assessment of hyperspectral imaging system for poultry safety inspection. International Society for Optical Engineering. 289:269-279.

Project Team

Lawrence, Kurt

Smith, Douglas - *Doug*

Windham, William - *Bob*

Park, Bosoon

Project Annual Reports

- FY 2006
- FY 2005
- FY 2004
- FY 2003
- FY 2002

Publications
- Publications

Related National Programs ◦ Food Safety, (animal and plant products) (108)

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# Research Project: DEVELOPMENT AND IMAGING TECHNOLOGY FOR THE AUTOMATED ON-LINE INSPECTION OF POULTRY PRODUCTS

**http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=190423**

Location:

Title: Real-Time Multispectral Imaging Application for Poultry Safety Inspection

Authors

- Park, Bosoon
- Lawrence, Kurt
- Windham, William
- Snead, Matthew

Submitted to: International Society for Optical Engineering
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Citation: Park, B., Lawrence, K.C., Windham, W.R., Snead, M.P. 2006. Real-time multispectral imaging application for poultry safety inspection. International Society for Optical Engineering. 6070-7:1-10.

Interpretive Summary: For science-based poultry inspection system, the ARS imaging research group in Athens, Georgia has developed a real-time multispectral imaging system for fecal and ingesta contaminant detection on broiler carcasses for poultry industry. The industrial-scale system was able to calibrate imaging hardware and acquire and process images in real-time using a common aperture camera with three visible wavelength optical filters. The in-house image processing software was applicable for real-time image processing and analysis at pilot-scale imaging line. The test results of industrial-sacle real-time system demonstrated that the multispectral imaging technique was able to detect fecal contaminants with a commercial processing speed (currently 140 birds per minute). This industrial-scale imaging system can improve the FSIS poultry safety inspection program by incorporating scientific testing and efficacy of fecal detection during poultry processing.

Technical Abstract: Industrial-scale multispectral imaging system with real-time image processing software for on-line detection of poultry fecal and ingesta contaminants was developed. The software using Unified Modeling Language (UML) design approach was effective to develop real-time image processing software for on-line application. The UML models including class, object, activity, sequence, and collaboration diagram were developed. A window based real-time image processing software was consist twelve components, which represented classes and architectures. Based on the test at the pilot-

scale poultry processing plant, the run-time of the software was fast enough to inspect carcasses on-line with 140 birds per minute. The imaging system was able to acquire high quality poultry images in real-time. The temperature increase inside enclosure was allowable (only 4 degree above ambient temperature) for long time operation in harsh environments. According to preliminary tests, the accuracy for fecal and ingesta contaminant detection was approximately 96%. Thus, the imaging system was reliable for in-plant trials.

Project Team

Lawrence, Kurt

Smith, Douglas - *Doug*

Windham, William - *Bob*

Park, Bosoon

Publications -Publications

Related National Programs Food Safety, (animal and plant products) (108)

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**Machine Vision Sees the Food Contaminants We Can't See**

Agricultural engineer Bosson Park,formerly with the Instrumentation and Sensing Laboratory, checks a light probe, which scans the chicken breast to determine its condition. (K7902-4)

Robotic cameras may one day stand between us and the danger of drinking fresh, unpasteurized juices contaminated with fecal bacteria. Scientists at the ARS Instrumentation and Sensing Laboratory in Beltsville, Maryland, are developing "machine-vision" systems that can detect contamination the human eye often can't see.

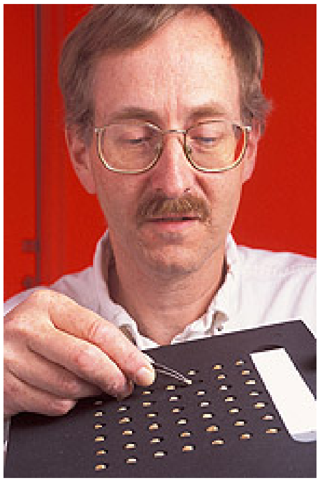
The issue of contaminated apple juice came to the forefront in recent years with major outbreaks of *Escherichia coli* O157:H7 infections in people who drank unpasteurized apple juice or cider. The *E. coli* presumably got into the drinks via the skins of apples contaminated with fecal matter. This can happen when apples drop to the ground in an orchard and land in deer droppings or livestock manure. Or a rainstorm can splash parts of cowpats or deer droppings onto low-hanging fruit. Various forms of *E. coli* are present in fecal matter—whether of cows, deer, or people—and some, like *E. coli* O157:H7, are harmful. About a million fecal bacteria—including *Salmonella*—can live in a gram of cow manure.

This newly upgraded hyperspectral imaging system, being used by biophysicist Moon Kim, takes pictures at different wavelengths simultaneously. Three-dimensional images are created from the process, and researchers can then choose the wavelengths best suited for spotting fecal contamination or cuts and bruises in agricultural products. (K9940-1)

When the apples are mashed, the *E. coli* becomes part of the mash and the juice. Fortunately, pasteurization kills all *E. coli*. But 2 percent of the fruit and vegetable juices sold in this country are unpasteurized, and that 2 percent accounts for an estimated 16,000 to 48,000 people sickened each year from bacterial or viral infections.

To identify fecal contamination early and quickly, Yud-Ren Chen, an agricultural engineer, and colleagues Kuanglin Chao, an agricultural engineer; Moon Kim, a biophysicist; and Alan Lefcourt, a biomedical engineer, are building a prototype "multispectral imaging" apple-inspection system. It uses reflectance from apples illuminated by halogen lamps in the invisible near-infrared and visible color light bands, as well as fluorescence techniques. It also detects dirt, fly specks, fungi, rot, and other diseases, all of which can cause fruit to harbor more bacteria, besides creating obvious quality problems.

Such systems are called machine-vision systems. They are quicker and more accurate than the human eye and don't require anyone to handle the fruit or cut it up.



Agricultural engineer Stephen Delwiche positions wheat kernels on a custom-designed tray in preparation for hyperspectral imaging for mold detection. (K9941-1)

Chen leads the diverse team that specializes in developing machine-vision systems using visible and near-infrared light. A mechanical engineer, an electrical engineer, a computer scientist, and a USDA Food Safety Inspection Service (FSIS) industrial engineer are also in the group. The Instrumentation and Sensing Laboratory is known for using cutting-edge technology and developing unique tools and technology to design equipment for commercial use.

For their latest project, the well-oiled team is testing machine vision on a commercial apple-sorting line. They are using a new digital spectral camera that is really several cameras in one. It can take pictures at different wavelengths simultaneously, creating multiple images. This once required two or more cameras, each with its own light filter. Using a hyperspectral imager, the team can find the wavelengths best suited to spotting fecal contamination or cuts and bruises that can harbor bacteria. Some wavelengths are chosen because of their identifiable relationships to photosynthetic pigments in apples.

Mechanical engineer Talaya James and agricultural engineer Yud-Ren Chen use a common aperture multispectral systemto detect apple bruises. They are checking on apples to evaluate the effectiveness of the detection algorithms.(K9938-1)

Hyperspectral Imaging

Biophysicist Kim came to ARS in 1999 from the National Aeronautics and Space Administration (NASA), where he used reflectance and fluorescence for remote sensing of vegetation from airplanes to check on the planet's environmental health. Using his NASA experience, Kim added a fluorescence capability to the Beltsville lab's existing hyperspectral imaging equipment. To detect fecal contamination, he is still sensing photosynthetic pigments from plants, but on a much smaller scale, now working barely 2 feet from his targets rather than several thousand.

Kim and Lefcourt, who came to Chen's lab in 2001, upgraded and modernized the lab's existing hyperspectral imaging equipment. The lab uses the hyperspectral system to design commercial inspection systems for poultry and produce.

The unique instrument, designed and hand-built by the Beltsville team using commercially available components, is called hyperspectral rather than multispectral because it can capture images at up to 256 different wavelengths. A multispectral system generally uses only 2 to 4 wavelengths.

Agricultural engineers Kuanglin Chao (left) and Yud-Ren Chen discuss poultry carcass images taken with a multispectral imaging system. (K9936-1)

"In the research stage, we use over 100 images at many different wavelengths," Kim says. "But it takes several minutes to scan objects at that many wavelengths. So hyperspectral imaging wouldn't be practical for commercial operations. But it is valuable because it lets us visualize images across a range of the spectrum. We can then choose a few optimal spectral bands that will get the job done with enough speed and accuracy when used in multispectral imaging systems." A multispectral imaging system can scan a whole object in a fraction of a second and is more suitable for real-time use in processing plants, Kim says.

Their latest hyperspectral imaging system has the newest "scientific-grade" imaging spectrograph and halogen and fluorescent lamps, all packaged in one unit that sits above a motorized positioning table where the apple is placed. The imaging spectrograph is connected to a computer. For reflectance sensing, visible to near-infrared light comes from quartz halogen bulbs connected to the unit through fiber-optic lines, while fluorescence imaging uses fluorescent lamps. ARS-developed computer software analyzes the hyperspectral images.

The imaging spectrograph scans a moving apple hundreds of times, each time sensing a line across the apple's surface. The light on each point on the line is spread out like a rainbow by the spectrograph, creating a three-dimensional image.

The positioning table lets the researchers run hundreds of scans of the apple surface, placing the apple in many different positions, while recording the exact position of the apple so a scan can be repeated later. Mathematical algorithms interpret the multiple images.

"The hyperspectral imaging system is versatile and has many research applications besides food safety," Kim says. Chen agrees that the lab's hyperspectral imaging equipment can be used in many disciplines and with a variety of agricultural products. For example, Stephen Delwiche, an agricultural engineer on the team, uses the equipment to test for fungal contamination of wheat kernels.

Or, says Lefcourt, "A color change in leaves can signal a problem like serious nutrient deficiency. Machine vision can spot the problem when it's still minor and causing slight color changes not visible to the human eye. There's no need to destroy the leaf to diagnose the condition."

"One of our lab's strengths is that we can study biological things such as chickens or apples in detail, from the smallest spot all the way up to the whole object," Lefcourt says. We can obtain a picture of the object with spectral signature information for each spot of its surface. This allows us to start with a concept of a problem, set up lab equipment to test the concept, assemble a prototype system to test it in an in-house pilot plant, and finally test it in a commercial environment.

"We use machine vision to find common patterns in wholesome agricultural objects, so that any anomalies—diseases, defects, or contamination—stand out. Similar machine-vision technology can be applied to detect tumors in chickens or fecal contamination or bruises on apples, or a fungus on a kernel of grain. Since natural objects are not uniform, we can't compare one spot on an object to another spot, but we can find common features among objects in the same class. We take pictures of whole objects with spectral signatures at each spot on these objects to detect anomalies and then figure out what the anomalies are."

### From Chickens to Apples

Chen first developed his machine-vision inspection techniques with chickens, which present more complex problems than apples. Apples are easier in part because they are more uniform in shape and surface texture than chickens. Still, there are uniformity problems, such as color differences from variety to variety and even within a single apple.

More than a decade ago, Chen and a team of engineers, working alongside FSIS scientists and veterinarians began developing a prototype of a four-camera multispectral imaging system and a near-infrared light probe for reflectance scans of chicken carcasses on the processing line. (See "Automated Chicken Inspection," *Agricultural Research*, May 1998, p. 4.)

"We use visible and near-infrared light bounced off various spots on a chicken carcass to find systemic problems," Chen says. The reflected light is analyzed by a computer using software and hardware combinations designed by Chen's team. Differences between light shining on the chicken and light reflected are due to variations in external skin color, texture, and chemical contents that are clues to problems.

"We use the multispectral imaging to view each carcass as a whole, so we can spot quality problems, such as undersize birds, as well as food safety-related problems, such as blood poisoning," Chen says. For chickens, he uses a green and a red filter to create an image. He found that these two light wavelengths were best for detecting physical and biological problems.

The equipment identifies definitely unwholesome carcasses for rejection and suspect carcasses requiring closer human inspection.

Automated Chicken Inspection Ready To Commercialize

The lab has a cooperative research and development agreement (CRADA) with Stork Gamco, Inc., of Gainesville, Georgia—one of the largest manufacturers of chicken-processing plant equipment in the world—to commercialize the system and move it into use among the nation's 300-plus poultry processing plants.

Chen's colleague Chao says that Stork Gamco will soon test the system in a chicken-processing plant under the most demanding situation—lines that move 140 birds a minute. Chen says the system could handle up to 180 birds a minute.

Chao says the new system will be contained in a box hung over the beginning of the processing line, right after the point where chickens are killed and defeathered. Its camera will send spectral images to a computer set up in another room.

Chao and colleagues, including Sukwon Kang, an agricultural engineer, updated the machine-vision system to its present user-friendly form, ready to leave the research bench for commercial development. The two redesigned the system to use the new camera, instead of multiple cameras that required additional mathematical adjustments to join separate images. They also changed the software from the DOS operating system to function in Windows, where users can easily navigate by clicking on graphic images.

"We recognize that the users—in this case the chicken processing plant employees—must be considered at every design stage," Chao says.

## The Time Is Right

Chao says the new system is ready to market at just the right time, when everything is in place for its success. FSIS is looking at machine vision as a way to help implement its Hazard Analysis and Critical Control Points system, which shifts more inspection responsibility to the processing plant. "This would free up inspectors so they have time to take a close, careful look at the birds the machine-vision system judges suspect," Chao says.

Also, the processing industry is moving to high-speed lines in response to a rising demand for poultry. The industry wants the highest feasible speeds for maximum efficiency, and they see machine vision as the way to make it possible while also improving inspection efficacy. Chao says that the high-speed lines separate into two or three more lines after the birds are killed, and more inspectors are added to meet USDA's requirement of a maximum speed of 35 birds a minute for each inspector.

### Robots Are Quick Learners

Chao stresses that machine vision requires occasional input from the inspectors to make assessments and adjustments. While the line is down for cleaning, the system can update itself based on this input. The system has to be more intelligent than one that inspects nonbiological products like bottle labels and caps. "The size and shape of each cap and the cap's label are all uniform, making variations easy to detect," Chao says. "Unfortunately, nature doesn't make chickens with anywhere near that much uniformity."

Chickens differ not only in size, but also in other key characteristics such as skin color and chemical composition. These change with each batch of chickens, depending on the feed they were raised on and the weather conditions they lived with.

Ironically, some uniformity for chickens may be found in their diseases. "Chickens are raised so closely together that a disease tends to spread through the flock," Chao says, "making it more likely that if one carcass has a disease, others in the batch may also."

The inspectors and plant veterinarians can teach the system based on their skills and experience and based on what they find as they inspect the birds rejected by the system. The system has another advantage: It keeps records on every chicken, and these records can later be used by the plant to alert poultry growers to conditions in particular batches of chickens.

Chen's system quickly diagnoses all physical or biological conditions that cause an inspector to remove a chicken from the processing line. It does not spot bacterial contamination, but the ARS Poultry Processing and Meat Quality Research Unit in Athens, Georgia, has signed a CRADA with Stork Gamco to use machine vision to spot contamination from "ingesta," partially digested food from the ruptured crops of chicken carcasses, and from fecal matter, both of which are associated with bacterial contamination.

The chicken plant of the very near future will likely have two new systems in place—one for the automated diagnosis of wholesomeness and one for fecal and ingesta contamination—combining the Beltsville and Athens machine-vision systems.

### From Apples to All Produce

In a similar way, apple-packing plants will have two or more systems in place. Some plants currently have automated ways to sort out undersized apples. The system Chen and his team are working on, when commercialized, would likely be merged with that system, along with others in the pipeline, including one by Renfu Lu, an ARS agricultural engineer in East Lansing, Michigan. He is developing an automated way to sort apples by quality, including deep internal bruises, as well as taste and firmness. Lu once worked in Chen's lab, as did Bosoon Park, now an agricultural engineer in the Athens lab.

Chen applied the experience and technology developed from his chicken work to detecting fecal contamination on apples. "We had to develop new technology for this application as well, but the work evolved from our success with chicken inspection," Chen says.

"We want 100 percent of the apples to be inspected as each passes the continuously operating lights and camera," Chen says. "We expect this system to be adaptable for use with all fruits and other produce."—By Don Comis, Agricultural Research Service Information Staff.

This research is part of Food Safety (Animal & Plant Products), an ARS National Program (#108) described on the World Wide Web at http://www.nps.ars.usda.gov.

To reach scientists featured in this story, contact Don Comis, ARS Information Staff, 5601 Sunnyside Ave., Beltsville, MD 20705-5129; phone (301) 504-1625, fax (301 504-1641.

"Machine Vision Sees the Food Contaminants We Can't See" was published in the August 2002 issue of *Agricultural Research* magazine.

### Automated Chicken Inspection

http://www.ars.usda.gov/is/AR/archive/may98/auto0598.htm

Contents

ARS agricultural engineer Yud-Ren Chen is developing a computer-directed scanning system that could help speed inspection of the nearly 8 billion chickens processed annually through federally inspected U.S. plants.
(K7898-4)

As chickens move down the processing line at speeds as high as 140 birds per minute, four cameras click away, followed by near-infrared and visible light scans of each bird.

Instantly, a computer decides whether a chicken has signs of defects or disease. If not, the bird continues down the production line. Otherwise, the computer directs the suspect carcass to a separate re-inspect line.

On the re-inspect line, birds get a closer examination by a human inspector because the automated system spotted signs--such as reddish or purplish skin or abnormally small body size--that suggested unwholesomeness.

That's the chicken plant of the near future, says Yud-Ren Chen, an agricultural engineer with the Agricultural Research Servicewho has led the group that designed and built the prototype. He says the increasing popularity of poultry products has made improved inspection even more important.

Chen's group will test their prototype this year at Tyson Food's poultry processing plant in New Holland, Pennsylvania.

"Almost 8 billion chickens go through federally inspected plants annually, compared to less than 3 billion 30 years ago," Chen says. "If you are going to increase productivity without sacrificing the accuracy of meat and poultry inspection, you have to use machine vision and other automated sensors."

Developed over the past 7 years, the prototype consists of four spectral cameras, a light probe, and a spectrophotometer--all linked to computers. When the chickens, on hooks dangling from a moving chain, pass through a light beam, the interruption triggers a fraction-of-a-second photo opportunity: One pair of cameras takes photos of the chicken's front; the other pair, its back. One camera of each pair uses a red filter; the other, a green one. This obtains images of the bird's front and back in two colors.

"The same physical condition--involving surface color and texture--shows up differently under different wavelength filters," says Chen. "We use two wavelengths for comparison, to be sure we don't miss anything."

Agricultural engineer Bosson Park uses a near-infrared and visible light probe to scan a chicken's skin and underlying breast area tissue, to determine its condition. (K7902-14)

Chen's group developed computer software that compares the images at different wavelengths, to determine if the bird is wholesome or not. Color differences can be caused by improper bleeding during slaughter or by blood-related diseases like septicemia. Skin textural differences can be caused by tears, bruises, or tumors.

The cameras also detect body size. Chen explains that an abnormally small chicken requires closer inspection because disease may have stunted the bird's growth.

After a chicken passes the cameras, it crosses another light beam, this one triggering a scan from about an inch away.

A light probe illuminates a portion of the chicken with both near-infrared and visible light. The chicken absorbs some of the light, but any that is reflected is analyzed by the spectrophotometer and computer using software developed by Chen's team.

Differences between light shining on the bird and light reflection are due to variations in external skin color and texture and to internal blood color and tissue composition. In the prototype, the probe can analyze properties deep beneath the chicken's skin, stopping only at the abdominal cavity.

A red light on the frame near the computer setup indicates rejection.

"The computer can also keep a record of the conditions of each bird on the line, ready for the inspector's review," Chen says.

Chen's group has tested the system in a chicken plant in West Virginia. All those tests used birds hung on a portable conveyor line brought to the plant--alongside, but not on, a real production line like the one at the Tyson's New Holland plant.

Leonard Payne, who manages the New Holland plant, has been looking forward to this first production-line test of Chen's automated system.

The automated inspection system compares pictures of each bird as viewed through a red filter and a green filter, to spot defective chickens. Here, agricultural engineer Yud-Ren Chen places a green filter on one of the lenses of the computerized, four-camera subsystem. (K7900-7)

Payne says machine vision would benefit the industry mainly through more consistency and accuracy. In most cases, wholesome birds differ obviously from unwholesome ones.

"Over 90 percent of the birds are unquestionably wholesome. Machine vision could quickly pass these birds on, while identifying those that require a second look to determine if a problem exists," says Payne.

"The federal inspectors and the assistants we provide are highly trained. But machine vision can free them to focus on the relatively few birds whose condition is not conclusive," he says. Payne sees machine vision, if it works as expected, as a win-win situation for consumers, inspectors, and the industry.

For Chen, an important part of the Tyson's test is to see how the system stands up to the high humidity of a commer
cial production plant.

"We want to see how long the prototype lasts in this environment, how much maintenance it'll need, and how accurate and consistent it is online," says Chen. "The prototype has an average accuracy rate of over 95 percent. We are continually improving this, and we achieved 100 percent accuracy in a recent test comparing the system's conclusions with those of a veterinarian."

"To maintain accuracy," he says, "the system occasionally needs retraining with special software. This adjusts the computer to recognize the normal skin color of different chicken breeds or chickens fed different rations, for example. Processing plant employees would do this retraining by running self-learning software while flipping switches to show the system chickens that are normal and chickens that are not."

Though this prototype can spot unwholesome birds, it can tell the reasons for condemnation only in cases of septicemia or improper bleeding. "But," notes Chen, "these two conditions account for over half of the carcasses removed from the processing lines."

Chen aims to expand the system's capabilities, along with incorporating advances in computer and sensor technology. He is also planning to test a new probe that will explore the whole chicken--still without touching it--and take color photographs of the abdominal cavity as well as the viscera. The color images would also be analyzed by the computer.

Ultimately, Chen wants the automated system to quickly diagnose every physical or biological condition that causes an inspector to remove chickens from the processing line. It cannot spot bacterial contamination, he explains, adding that many other scientists are busy developing tests for that.--By Don Comis, Agricultural Research Service Information Staff, 6303 Ivy Lane, Greenbelt, Maryland 20770, phone (301) 344-2748.

Yud-Ren Chen is at the USDA-ARS Instrumentation and Sensing Laboratory, 10300 Baltimore Ave., Beltsville, MD 20705-2350; phone (301) 504-8450, fax (301) 504-9466, e-mail

"Automated Chicken Inspection" was published in the May 1998 issue of *Agricultural Research* magazine. Click here to see this issue's table of contents.

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### University of Cambridge Physics Dept. UK.

Research into various aspects of Terahertz research is being undertaken in:-

- Explosives detection
- Space
- Imaging and Spectrosopy
- High frequency Microwave and Terahertz Receivers

- Electronics
- Applications of Terahertz and Millimeter Waves

# First Image from Revolutionary Terahertz-wave Camera; Sees through Fog, Clothing and into Deep Space

http://www.space.com/businesstechnology/technology/Terahertz-wave_camera_020613.html

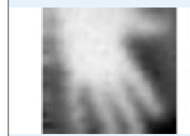
By Robert Roy Britt
Senior Science Writer
posted: 01:30 pm ET
11 February 2003

A project to develop a promising new astronomy imaging technique that can also denude a fully clothed human or see through thick fog has generated its first picture.

A so-called Terahertz-wave image of a human hand, taken through a 1/2-inch (15 millimeter) pad of paper, is the first product of the new terahertz camera. The technology is poised to revolutionize imaging in astronomy, medicine and airport security, proponents say.

The European Space Agency's project to develop the camera was first reported by *SPACE.com* last June. While largely unheralded, Terahertz-wave imaging does not appear to be pie-in-the sky. In fact, a camera built by a company called QinetiQ and working in similar millimetric waves already last year had demonstrated the ability to peer through clothes and reveal a concealed weapon, along with much of a person's body.

Images



A picture of a human hand, taken through a 1/2-inch (15 mm) pad of paper, is the first product of the new Terahertz-wave camera.

Derek Jenkins of the StarTiger team removes the first silicon machined wafer carrying the a terahertz array of sensors used in the new camera.

A fully clothed man imaged by a QinetiQ millimetric wave camera. Note the concealed gun. Terahertz-wave cameras are said to be similar but more powerful. Image used with permission.

The technique employs a little-studied but ubiquitous radiation. Detecting Terahertz-waves allows a camera to effectively see through smoke, walls and even clothing or bandages.

Low frequency versions of terahertz waves are known as millimeter waves, and they behave much like radio waves. At higher frequencies, the terahertz waves straddle the border between radio and optical emissions. The technology is sometimes referred to as quasi-optics.

Similar but less sensitive technology is already used to examine sea-surface temperatures from satellites. A future Terahertz-wave observatory might study the tails of comets, experts say, and the frequency could also shed new light on the early universe and how the first galaxies formed.

"Observations from space may be on the verge of a revolution with the possibility of looking into the terahertz frequency range," said Peter de Maagt, project manager for StarTiger, which stands for Space Technology Advancements by Resourceful, Targeted and Innovative Groups of Experts and Researchers.

Few formal studies of Terahertz-wave technology exist, but an article on the Web site of the journal *Nature* last year said these cameras could be "the next big wave" in imaging for everything from cells to stars. Scientists at the Rensselaer Polytechnic Institute in New York claim Terahertz-wave technology will speed computer memory and sharpen flat-panel displays.

To develop the technology quickly, StarTiger was created by the ESA. The project brought a group of researchers together for a few months, provided ample money and facilities, and encouraged development of new technology in a short period of time. The researchers started in June, created their first Terahertz-wave image last fall, and released one this week.

"When we started last June we set an ambitious goal: to build in four months the first compact submillimeter-wave imager with near real time image capturing using state-of-the-art micro-machining technology," said de Maagt. "We reached this goal when the first terahertz images were taken in September."

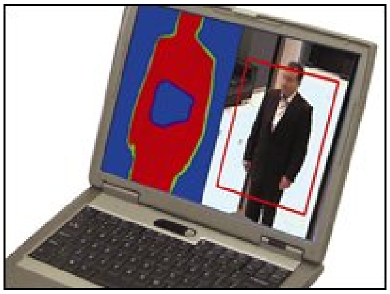
Terahertz waves are unique because they can pass easily through some solid materials, yet they can also be focused as light to create images of objects behind the obscuring material.

Terahertz imaging may soon become a standard medical diagnostic technique, researchers with StarTiger say. Terahertz-waves could provide an image that has X-ray-like properties without the use of potentially harmful radiation. It might be particularly useful to augment dental X-rays and for possible early detection of skin cancers.

Pilots might one day use terahertz imagers to generate a picture of what's ahead in heavy fog, StarTiger officials say. A higher resolution imager than currently developed would be needed for such a view.

The newly developed device is small enough to fit in a briefcase. A future version might one day be deployed to space to examine the early universe. If money were provided, a space-based Terahertz-wave camera could be deployed in two years, a StarTiger scientist said.

# Camera 'looks' through clothing



http://news.bbc.co.uk/1/hi/technology/7287135.stm

Last Updated: Monday, 10 March 2008, 11:47 GMT

All objects emit terahertz radiation

A camera that can "see" explosives, drugs and weapons hidden under clothing from 25 metres has been invented.

The ThruVision system could be deployed at airports, railway stations or other public spaces.

It is based on so-called "terahertz", or Terahertz-wave, technology, normally used by astronomers to study dying stars.

Although it is able to see through clothes it does not reveal "body detail" or subject people to "harmful radiation", according to the designers.

"It is totally and utterly passive - it receives only," said a spokesperson for Thruvision.

The portable camera, which has already been sold to the Dubai Mercantile Exchange and Canary Wharf in London, will be shown off at the Home Office scientific development branch's annual exhibition later this week.

Body glow

Unlike current security systems that use X-rays, the ThruVision system exploits terahertz rays, or Terahertz-waves.

This electromagnetic radiation is a form of low level energy emitted by all people and objects.

These are able to pass through clothing, paper, ceramics and wood but are blocked by metal and water.

The system works by collecting these waves and processing them to form an image which can reveal concealed objects.

"If I were to look at you in terahertz you would appear to glow like a light bulb and different objects glow less brightly or more brightly," said the firm's spokesperson.

"You see a silhouette of the form but you don't see surface anatomical effects."

In addition, the system does not involve any of the "harmful radiation associated with traditional X-ray security screening", according to the firm.

The company has made previous versions of the camera, but the T5000, as it is known, is the first that works both indoors and out.

The system exploits technology originally developed at the government owned Rutherford Appleton Laboratory (RAL) in Oxfordshire.

"Astronomers use Terahertz-wave cameras that can see through dust and clouds in space, revealing what lies beyond," explained Dr Liz Towns-Andrews, of the Science and Technology Facilities Council which runs RAL.

Other terahertz systems, developed by companies such as TeraView, are used to probe the structure of pharmaceutical compounds.

# New Terahertz-wave Source Could Improve Airport Security, Cancer Detection

Science News

www.sciencedaily.com/news

ScienceDaily (Nov. 27, 2007) — Going through airport security can be such a hassle. Shoes, laptops, toothpastes, watches and belts all get taken off, taken out, scanned, examined, handled and repacked. But "Terahertz-waves", a completely safe form of electromagnetic radiation, may reshape not only airport screening procedures but also medical imaging practices.

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Scientists at the U.S. Department of Energy's Argonne National Laboratory, along with collaborators in Turkey and Japan, have created a compact device that could lead to portable, battery-operated sources of Terahertz-waves, or terahertz radiation. By doing so, the researchers, led by Ulrich Welp of Argonne's Materials Science Division, have successfully bridged the "terahertz gap" – scientists' name for the range of frequencies between microwaves (on the lower side) and infrared (on the higher side) of the electromagnetic spectrum.

While scientists and engineers have produced microwave radiation using conventional electric circuits for more than 50 years, Welp said, terahertz radiation could not be generated that way because of the physical limitations of the semiconducting circuit components.

"Right around 1 terahertz, you have a range of frequencies where there have never been any good solid-state sources," he added. "You can make those frequencies if you are willing to put together a whole table full of expensive equipment, but now we've been able to make a simple, compact solid-state source."

Unlike far more energetic X-rays, Terahertz-waves do not have sufficient energy to "ionize" an atom by knocking loose one of its electrons. This ionization causes the cellular damage that can lead to radiation sickness or cancer. Since Terahertz-waves are non-ionizing radiation, like radio waves or visible light, people exposed to terahertz radiation will suffer no ill effects. Furthermore, although terahertz radiation does not penetrate through metals and water, it does penetrate through many common materials, such as leather, fabric, cardboard and paper.

These qualities make terahertz devices one of the most promising new technologies for airport and national security. Unlike today's metal or X-ray detectors, which can identify only a few obviously dangerous materials, checkpoints that look instead at Terahertz-wave absorption patterns could not only detect but also identify a much wider variety of hazardous or illegal substances.

Terahertz-waves can also penetrate the human body by almost half a centimeter, and they have already begun to enable doctors to better detect and treat certain types of cancers, especially those of the skin and breast, Welp said. Dentists could also use Terahertz-waves to image their patients' teeth.

The new Terahertz-wave sources created at Argonne use high-temperature superconducting crystals grown at the University of Tsukuba in Japan. These crystals comprise stacks of so-called Josephson junctions that exhibit a unique electrical property: when an external voltage is applied, an alternating current will flow back and forth across the junctions at a frequency proportional to the strength of the voltage; this phenomenon is known as the Josephson effect.

These alternating currents then produce electromagnetic fields whose frequency is tuned by the applied voltage. Even a small voltage – around two millivolts per junction – can induce frequencies in the terahertz range, according to Welp.

Since each of these junctions is tiny – a human hair is roughly 10,000 times as thick – the researchers were able to stack approximately 1,000 of them on top of each other in order to generate a more powerful signal. However, even though each junction would oscillate with the same frequency, the researchers needed to find a way to make them all radiate in phase.

"That's been the challenge all along," Welp said. "If one junction oscillates up while another junction oscillates down, they'll cancel each other out and you won't get anything."

In order to synchronize the signal, Argonne physicist Alexei Koshelev suggested that the stacks of Josephson junctions should be shaped into resonant cavities, which visiting scientist Lufti Ozyuzer of the Izmir Institute of Technology, Turkey, and graduate student Cihan Kurter then fashioned. When the width of the cavities was precisely tuned to the frequencies set by the voltage, the natural resonances of the structure synchronized the oscillations and thus amplified the Terahertz-wave output, in a method similar to the production of light in a laser.

"Once you apply the voltage," Welp said, "some junctions will start to oscillate. If those have the proper frequency, an oscillating electric field will grow in the cavity, which will pull in more and more and more of the other junctions, until in the end we have the entire stack synchronized."

By keeping the length and thickness of the cavities constant while varying their width between 40 and 100 micrometers, the researchers were able to generate frequencies from 0.4 to 0.85 terahertz at a signal power of up to 0.5 microwatts. Welp hopes to expand the range of available frequencies and to increase the strength of the signal by making the Josephson cavities longer or by linking them in arrays.

"The more power you have, the easier it is to adopt this technology for all sorts of applications," he said. "Our data indicate that the power stored in the resonant cavities is significantly larger than the detected values, though we need to improve the extraction efficiency. If we can get the signal strength up to 1 milliwatt, it will be a great success."

Collaborators on this research were Lutfi Ozyuzer, Alexei Koshelev, Cihan Kurter, Nachappa (sami) Gopalsami, Qing'An Li, Ken Gray, Wai-Kwong Kwok and Ulrich Welp of Argonne; Masashi Tachiki from the University of Tokyo; Kazuo Kadowaki, Takashi Yamamoto, Hidetoshi Minami and Hayato Yamaguchi from the University of Tsukuba; and Takashi Tachiki from the National Defense Academy of Japan.

The research was supported by DOE's Office of Basic Energy Sciences and by Argonne's Laboratory Directed Research and Development funds.

A scientific paper based on their research, "Emission of Coherent THz Radiation from Superconductors," appears in the November 23 issue of Science.

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# New Terahertz-wave Source Could Improve Airport Security, Cancer Detection.

DOE/Argonne National Laboratory (2007, November 27). *ScienceDaily*. Retrieved June 1, 2008, from http://www.sciencedaily.com/releases/2007/11/071126121732.htm

***Adapted from materials provided by DOE/Argonne National Laboratory.***

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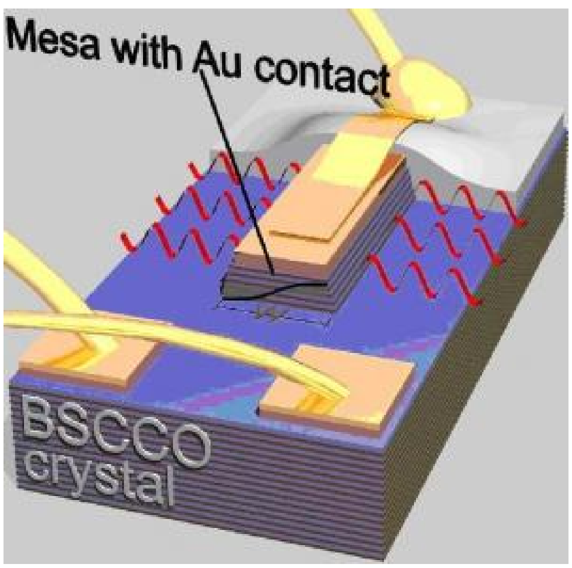


***Schematic of the terahertz-source, which was fabricated on the top of an atomically layered superconducting crystal. The applied current excites the fundamental cavity mode (solid half-wave) on the width w of the mesa, and high-frequency electromagnetic radiation is emitted from the side faces (red waves). (Credit: Image courtesy of DOE/Argonne National Laboratory)***



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Microwaves Could Bring Concealed Weapons To Light (Mar. 4, 2004) — Microwaves could provide a safe new way of finding hidden weapons and buried mines, thanks to UK research. Scientists are developing a microwave-based technique that can generate high-quality ... > *read more*

# Terahertz imaging comes into view

Apr 1, 2000

http://physicsworld.com/cws/article/print/697

Physicists and industrialists are turning to terahertz radiation to provide cheaper, safer and more versatile ways of producing detailed images.

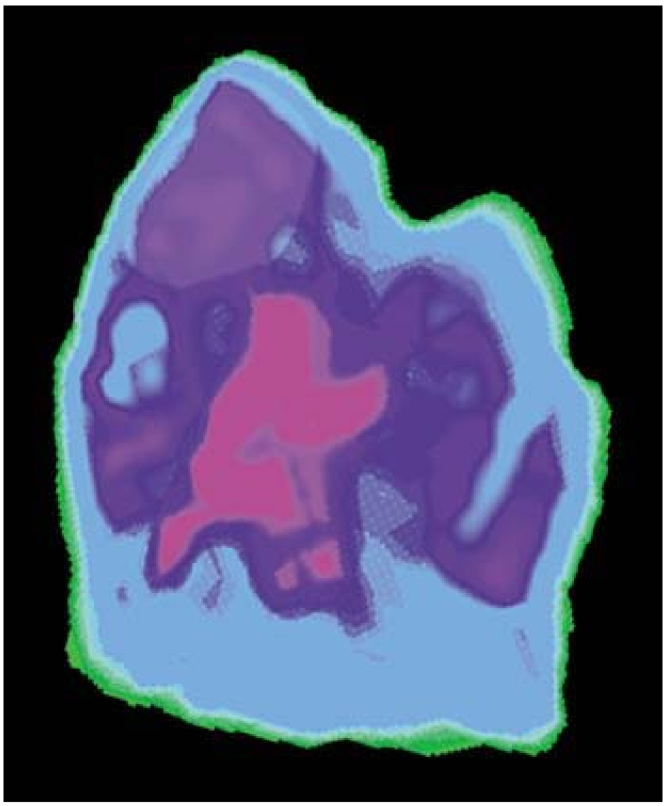

***Image of a human tooth formed from terahertz radiation. The data can be manipulated to provide different terahertz images, each containing different diagnostic information***.

Imaging technology is becoming increasingly prevalent in our society. X-ray scanners are routinely used to examine luggage at airports, for example, and most hospitals are equipped with ultrasound scanners and magnetic resonance imaging machines. There is also a wealth of other less well known applications throughout industry. For instance, X-rays are used for package inspection, while the defects or voids in materials on production lines are often probed using microwaves or ultrasound.

In spite of their considerable success, X-rays, magnetic resonance imaging and ultrasound all have shortcomings. Many clinicians and non-medical users feel that fundamentally different physical principles are needed to provide safer and more cost-effective imaging techniques. And physicists are turning to other regions of the electromagnetic spectrum to address these issues.

Indeed, a cursory examination reveals that conventional imaging techniques only use the extreme ends of the electromagnetic spectrum: photons with energies greater than 30 keV for X-rays, and around 0.4 μeV for magnetic resonance imaging. The radiation between these extremes falls largely into the visible, infrared and millimetre or microwave regions.

In the April issue of Physics World magazine, Don Arnone, Craig Ciesla and Michael Pepper at Toshiba Research Europe, Cambridge, UK, describe the advantages of Terahertz imaging.

## Further reading

D D Arnone *et al*. 1999 Applications of terahertz technology to medical Imaging *SPIE Proceedings* 3828 pp209219 P French 1999 Biomedical optics *Physics World* June pp4146 B B Hu and M C Nuss 1995 Imaging with terahertz waves *Optics Letters* 20 17161718 L E Larsen and J H Jacobi 1986 *Medical Applications of Microwave Imaging* (IEEE Press, New York) BUY: US / UK D M Mittleman, R H Jacobsen and M C Nuss 1996 Terahertz-wave imaging *J. Sel. Top. Quantum Electron*. 2 679 Q Wu Lu, T D Hewitt and X-C Zhang 1996 Two-dimensional electro-optic imaging of THz beams *Appl. Phys. Lett*. 69 1026

## Details on Raytheons' Active Denial System

http://www.dailymail.co.uk/sciencetech/article-482560/Run-away-ray-gun-coming--We-test-US-armys-new-secret-weapon.html

Raytheon brings heaTerahertz-wave weapon to market

http://www.eetimes.eu/industrial/202400400;jsessionid=AMKVQGZXV4PXYQSNDLPSKHSCJUNN2JVN?pgno=2

Peter Clarke
EE Times Europe
**10/09/2007 3:52 PM**

LONDON — Research into using the heating effect of millimeter waves as a weapon has been brought to market by the Missile Systems division of Raytheon Co. (Tucson, Ariz.) in a product called Silent Guardian. The heating effect of a beam of millimeter-wave energy can be used to induce an "intolerable heating sensation" according to Raytheon documentation.

However, observers have questioned whether the weapon is useful for its declared purpose, for controlling crowds and individuals in open ground, and have argued that it could be used more easily for torture. The obvious example of this is where a person is restrained and not able to get out of the way of the beam.

Research was conducted into the use of 95-GHz frequency waves as an antipersonnel "heat ray" against crowds and insurgents during the 1990s and was reported by *EE Times* in June 2001.

At that time the weapon, called "active-denial technology", had been in development for 10 years at the Air Force Research Laboratory (Kirtland, New Mexico), in tandem with the Joint Non-lethal Weapons Directorate of the Marine Corps. About $40 million had been spent developing the weapon, according to the Air Force Research Laboratory (AFRL). The technology was described as producing a heating effect in the top 1/64 of an inch of the skin.

According to reports at the time, a two-second burst of energy from the system can heat the skin to a temperature of 130° F. An AFRL fact sheet produced at that time said, "active-denial technology will not cause rapid burning, because of the shallow penetration of the beam and the low levels of energy used."

Now Raytheon has produced a datasheet on Silent Guardian saying that it has designed, developed and manufactured the technology.

The system's antenna emits a focused beam of millimeter wave energy. The beam travels at the speed of light and penetrates the skin to a depth of 1/64 of an inch, producing an intolerable heating sensation that causes the targeted individuals to instinctively flee or take cover," according to the Raytheon datasheet.

The beam size, whether it is a convergent focused beam or a divergent beam and the range, were all described as classified information in 2001. Raytheon has said in its datasheet that the beam is focused and illustrated it as being convergent. It describes the range as being in excess of 250 meters. The datasheet and a video of the Silent Guardian and its target-tracking could be found here when this story was first posted.

In 2004 it was reported that a version of the technology would be mounted on High Mobility Multipurpose Wheeled Vehicles (more commonly referred to as Humvees) and deployed by U.S. troops in Iraq (see September 2004 story).

However, it was pointed in the June 2001 *EE Times* article that countermeasures against directed energy weapons at millimeter-wave frequencies could be quite straightforward. The examples given then were covering up the body with thick clothes or carrying a metallic sheet, or even a trash can lid, as a shield or reflector. It remains unclear how the active-denial technology would work in rainy, foggy or sea-spray conditions where the beam's energy could be absorbed by water in the atmosphere.

A recent article in the *Daily Mail* has questioned the use of the Raytheon active denial system, pointing out that the system could be used for torture but is of questionable value as a means of controlling crowds or individuals. The *Daily Mail* article could be found here when this story was first posted.

## Active Denial System

https://www.jnlwp.com/ads.asp

The Active Denial System (ADS) provides a new non-lethal capability helping to fill the gap between the 'shout' and 'shoot' alternatives faced by our troops. It provides numerous advantages over existing non-lethal weapons, such as extended range and extremely small risk of injury, and it has the potential to provide a tremendous new capability for U.S. forces in support of today's complex missions.

The Active Denial Technology hardware demonstrator (ADS System 0) represented the first integration of the key technology elements such as the millimeter wave source, cooling system, and antenna, among other things. In 2001, ADS System 0 successfully demonstrated that the technology could achieve desired effects at distances beyond small arms range, and set the stage for the next evolution of the technology, ADS System 1.

In 2002, the ADS was designated an Advanced Concept Technology Demonstration, a formal Department of Defense process to rapidly move mature technologies into the hands of the warfighter for military evaluation. During the ACTD, ADS was integrated and packaged into a mobile configuration. The platform chosen for ADS System 1 was the High Mobility Multi-purpose Wheeled Vehicle (HMMWV).

The final phase of the ACTD, the Extended User Evaluation (EUE), concluded in September 2007. The EUE resulted in improvements in procedures and training of System 1. A more militarized version of ADS, known as System 2, was also developed under the ACTD. System 2 is the containerized version of the ADS that is transportable via a tactical vehicle.

Beginning in fiscal year 2008, under the Joint Non-Lethal Weapons Directorate sponsorship, the Air Force Air Armament Center, Eglin Air force Base, Fla., is leading a joint effort to bridge the transition from an ACTD to the establishment of a formal program of record.

- Human Effects Advisory Panel Report
- More ADS information
- ADS Media & Demonstration Day coverage

## Active Denial System-2

ADS System 1

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ADS System 1 and 2

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Microwave technicAl Articles

# Microwave beam weapon reportedly to be deployed in Iraq

http://www.eetimes.com/news/latest/showArticle.jhtml;?articleID=47900605

EE Times: Latest News

Peter Clarke

Silicon Strategies (09/21/2004 9:43 AM EDT)

LONDON — A beam weapon that uses the heating effect of microwaves to cause pain is to be issued to U.S. troops in Iraq, according to a report on the *Telegraph* Web site.

The supposedly nonlethal weapon, also called "active-denial technology," has been under development throughout the 1990s at the U. S. Air Force Research Laboratory (Kirtland, N.M.), in tandem with the Marine Corps' Joint Nonlethal Weapons Directorate, the report said.

The weapon uses 95-GHz energy to penetrate the skin to 1/64 of an inch, and hits water molecules in the skin to produce an intense burning sensation that stops when the transmitter is switched off or when the individual moves out of the beam.

The weapon has been cited as being particularly useful for crowd control and urban conflicts, although there thought to be counter-measures (see see June 6, 2001, story). "The skin gets extremely hot, and people can't stand the pain, so they have to move — and move in the way we want them to," the more recent report quoted Col. Wade Hall of the Office of Force Transformation as saying. The weapon is set to be fitted to armored vehicles already in Iraq. This would allow the microwave beam weapon to be deployed in 2005, the report said.

U.S. Army and Marine Corps units should receive four to six vehicles equipped with the microwave weapon, dubbed "Sheriffs," by September 2005.

The system includes a millimeter-wave energy source with waveguides to direct the energy to a dish antenna measuring about 3 x 3 meters, which forms a beam that can be swept across a battlefield or hostile crowd. Beam size, whether it is a convergent, focused beam or a divergent beam, and its range, were classified, although the beam has been reported to have a range of about 1 kilometer.

# Millimeter-wave energy to be used in a weapon

EE Times:

http://www.eetimes.com/story/OEG20010606S0072

Peter Clarke
EE Times (06/06/2001 2:02 PM EDT)

LONDON — Stories of the soldiers who operate the Arctic radar stations and stand in front of the transmitter to get warm will surely be repeated now that the U.S. Department of Defense has gone public with plans to use the heating effect of millimeter waves within a weapon.

The U.S. Marine Corps says it has developed a 95-GHz system as an antipersonnel "heat ray" and is conducting tests on animals and volunteers.

The supposedly nonlethal weapon, called "active-denial technology," has been in the works for the last 10 years at the Air Force Research Laboratory (Kirtland, N.M.), in tandem with the Marine Corps' Joint Non-lethal Weapons Directorate. About $40 million has been spent developing the weapon, according to the Air Force Research Laboratory (AFRL), although it could be nearly another decade before it is used in conflict. The earliest estimate for deployment is 2009.

The system includes a millimeter-wave energy source with waveguides to direct the energy to a dish antenna measuring about 3 x 3 meters, which forms a beam that can be swept across a battlefield or hostile crowd. The aim is to deter or drive off adversaries caught out in the open with a beam that inflicts pain without causing permanent damage.

According to an AFRL fact sheet, the 95-GHz energy penetrates 1/64 inch into the skin and produces an intense burning sensation that stops when the transmitter is switched off or when the individual moves out of the beam.

Top skin layer takes heat

"It works by heating the water molecules in the top 1/64-of-an-inch layer of the skin," said Marine Corps spokesman Maj. David Andersen.

According to reports, a 2-second burst from the system can heat the skin to a temperature of 130° F. Elsewhere, the AFRL describes the sensation as similar to touching an ordinary light bulb that has been left on for a while. "Unlike a light bulb, however," says the AFRL fact sheet, "active-denial technology will not cause rapid burning, because of the shallow penetration of the beam and the low levels of energy used."

Beam size, whether it is a convergent, focused beam or a divergent beam, and its range are all classified information.

"This is a beam that is going to be directed. It's not harmful to internal organs because it doesn't penetrate the skin beyond 1/64 of an inch," said Conrad Dziewulski, a spokesman for the directed-energy division of AFRL. "It will be swept across the battlefield or directed at an individual for a few seconds."

Dziewulski said the system was intended to protect military personnel against small-arms fire, which is generally taken to mean a range of 1,000 meters. Elsewhere, the system is described as having a range of 700 yards.

While early tests have been carried out using a fixed antenna, the military now plans to develop a mobile version of the system, otherwise known as Vehicle Mounted Active Denial System, or Vmads.

AFRL said Vmads could be mounted on a High Mobility Multipurpose Wheeled Vehicle (more commonly referred to as a Humvee). Later it could be mounted on other vehicles such as aircraft, helicopters and ships, officials said.

However, countermeasures against the weapon could be quite straightforward — for example covering up the body with thick clothes or carrying a metallic sheet — or even a trash can lid — as a shield or reflector. Also unclear is how the active-denial technology would work in rainy, foggy or sea-spray conditions where the beam's energy could be absorbed by water in the atmosphere.

The technology was developed by two Air Force Research Laboratory teams: one from the laboratory's Directed Energy Directorate at Kirtland Air Force Base, and the other from the Human Effectiveness Directorate at Brooks Air Force Base, Texas.

The Air Force's Electronic Systems Center at Hanscom Air Force Base, Mass., will manage acquisition of the Humvee Vmads system.

# Run away the ray-gun is coming : We test US army's new secret weapon

By MICHAEL HANLON

Last updated at 23:21 18 September 2007

Comments (23)

Add to My Stories

Modern face of warfare: The Silent Guardian

"Where do I put my finger? There ... OK? Nothing's happening ... is it on?"

"Yes, it's on. Move your finger a bit closer."

"Er ... ow! OW!" Not good. I try again. "OWWW!" I pull my hand away sharpish. My finger is throbbing, but seems undamaged.

I was told people can take it for a second, maximum. No way, not for a wimp like me.

I try it again. It is a bit like touching a red-hot wire, but there is no heat, only the sensation of heat. There is no burn mark or blister.

Its makers claim this infernal machine is the modern face of warfare. It has a nice, friendly sounding name, Silent Guardian.

I am told ***not*** to call it a ray-gun, though that is precisely what it is (the term "pain gun" is maybe better, but I suppose they would like that even less).

And, to be fair, the machine is not designed to vaporise, shred, atomise, dismember or otherwise cause permanent harm.

Oww! Michael Hanlon tries the Raytheon ray-gun

But it is a horrible device nonetheless, and you are forced to wonder what the world has come to when human ingenuity is pressed into service to make a thing like this.

Silent Guardian is making waves in defence circles. Built by the U.S. firm Raytheon, it is part of its "Directed Energy Solutions" programme.

What it amounts to is a way of making people run away, very fast, without killing or even permanently harming them.

That is what the company says, anyway. The reality may turn out to be more horrific.

I tested a table-top demonstration model, but here's how it works in the field.

A square transmitter as big as a plasma TV screen is mounted on the back of a Jeep.

When turned on, it emits an invisible, focused beam of radiation - similar to the microwaves in a domestic cooker - that are tuned to a precise frequency to stimulate human nerve endings.

It can throw a wave of agony nearly half a mile.

Because the beam penetrates skin only to a depth of 1/64th of an inch, it cannot, says Raytheon, cause visible, permanent injury.

But anyone in the beam's path will feel, over their entire body, the agonising sensation I've just felt on my fingertip. The prospect doesn't bear thinking about.

"I have been in front of the full-sized system and, believe me, you just run. You don't have time to think about it - you just run," says George Svitak, a Raytheon executive.

Silent Guardian is supposed to be the 21st century equivalent of tear gas or water cannon - a way of getting crowds to disperse quickly and with minimum harm. Its potential is obvious.

"In Iraq, there was a situation when combatants had taken media as human shields. The battalion commander told me there was no way of separating combatants from non-combatants without lethal force," Mr Svitak tells me.

He says this weapon would have made it possible because everyone, friend or foe, would have run from it.

In tests, even the most hardened Marines flee after a few seconds of exposure. It just isn't possible to tough it out.

This machine has the ability to inflict limitless, unbearable pain.

What makes it OK, says Raytheon, is that the pain stops as soon as you are out of the beam or the machine is turned off.

But my right finger was tingling hours later - was that psychosomatic?

So what is the problem? All right, it hurts, but then so do tear gas and water cannon and they have been used by the world's police and military for decades.

Am I being squeamish?

One thing is certain: not just the Silent Guardian, but weapons such as the Taser, the electric stun-gun, are being rolled out by Britain's police forces as the new way of controlling people by using pain.

And, as the Raytheon chaps all insist, you always have the option to get out of the way (just as you have the option to comply with the police officer's demands and not get Tasered).

But there is a problem: mission creep. This is the Americanism which describes what happens when, over time, powers or techniques are used to ends not stated or even imagined when they were devised.

With the Taser, the rules in place in Britain say it must be used only as an alternative to the gun. But what happens in ten or 20 years if a new government chooses to amend these rules?

It is so easy to see the Taser being used routinely to control dissent and pacify - as, indeed, already happens in the U.S.

And the Silent Guardian? Raytheon's Mac Jeffery says it is being looked at only by the "North American military and its allies" and is not being sold to countries with questionable human rights records.

An MoD spokesman said Britain is not planning to buy this weapon.

In fact, it is easy to see the raygun being used not as an alternative to lethal force (when I can see that it is quite justified), but as an extra weapon in the battle against dissent.

Because it is, in essence, a simple machine, it is easy to see similar devices being pressed into service in places with extremely dubious reputations.

There are more questions: in tests, volunteers have been asked to remove spectacles and contact lenses before being microwaved. Does this imply these rays are not as harmless as Raytheon insists?

What happens when someone with a weak heart is zapped?

And, perhaps most worryingly, what if deployment of Silent Guardian causes mass panic, leaving some people unable to flee in the melee? Will they just be stuck there roasting?

Raytheon insists the system is set up to limit exposure, but presumably these safeguards can be over-ridden.

Silent Guardian and the Taser are just the first in a new wave of "non-lethal" weaponry being developed, mostly in the U.S.

These include not only microwave ray-guns, but the terrifying Pulsed Energy Projectile weapon. This uses a powerful laser which, when it hits someone up to 11/2 miles away, produces a "plasma" - a bubble of superhot gas - on the skin.

A report in New Scientist claimed the focus of research was to heighten the pain caused by this semi-classified weapon.

And a document released under the U.S. Freedom of Information Act talks of "optimal pulse parameters to evoke peak nociceptor activation" - i.e. cause the maximum agony possible, leaving no permanent damage.

Perhaps the most alarming prospect is that such machines would make efficient torture instruments.

They are quick, clean, cheap, easy to use and, most importantly, leave no marks. What would happen if they fell into the hands of unscrupulous nations where torture is not unknown?

The agony the Raytheon gun inflicts is probably equal to anything in a torture chamber - these waves are tuned to a frequency ***exactly*** designed to stimulate the pain nerves.

I couldn't hold my finger next to the device for more than a fraction of a second. I could make the pain stop, but what if my finger had been strapped to the machine?

Dr John Wood, a biologist at UCL and an expert in the way the brain perceives pain, is horrified by the new pain weapons.

"They are so obviously useful as torture instruments," he says.

"It is ethically dubious to say they are useful for crowd control when they will obviously be used by unscrupulous people for torture."

We use the word "medieval" as shorthand for brutality. The truth is that new technology makes racks look benign.

Comments (23)

Here's what readers have had to say so far. Why not add your thoughts below?

The applications for this sound very 1984. With all that footage on youtube of people being tasered, I really don't like the way this could be used.

- Dave, UK, 20/9/2007 09:33

It could make open prisons very secure. That it will be used as an instrument of torture is in no doubt, now that it has been demonstrated the next version will be designed to penetrate to the heart and be a killing weapon.

- John Sizeland, Eccles on sea, Norfolk, England, 19/9/2007 12:41

What happens if I reflect or absorb the wave using lead or other materials?

- William Kerr, Leatherhead, England, 19/9/2007 12:25

http://www.defensetechbriefs.com/index.php?option=com_search&Itemid=99999999&searchword=%22millimeter+%22&submit=Search&searchphrase=any&ordering=newest

### 9. *Comment: heat ray is a focus for concern, - Will a convergent millimeter-wave beam - like a magnifying glass focusing the sun's rays - do more than sting?*

Peter Clarke

Page 1 of 2

EE Times Europe

(10/12/2007 5:34 AM EDT)

LONDON — The U.S authorities have taken more than 15 years to research the use of the heating effect of millimeter waves as an antipersonnel weapon, so plenty of due diligence should have been done that the Silent Guardian system brought to market by Raytheon Co. is both non-lethal and effective (see Oct. 9 story).

On the surface it seems like the stuff of science-fiction; a non-lethal directional heat ray that causes angry crowds to disperse and makes insurgents run for cover.

However, there are some things in the documentation of the heaTerahertz-wave weapon that suggests it is technology looking for a problem to solve and this observer has concerns over the further development and deployment of the system. One particular concern is that Silent Guardian uses a convergent, focused beam.

The pitch from Raytheon's datasheet on Silent Guardian is that the heaTerahertz-wave produces an "intolerable heating sensation" in the top 1/64 of an inch of the skin but that it "does not cause injury because of the shallow penetration depth of the millimeter wave." The datasheet also discusses a focused beam and shows a convergent beam coming from a millimeter-wave antenna.

However, what is not disclosed is the effect of the beam hitting the human eye or the effect of prolonged exposure. Also we are not told the energy density of the beam or what happens when that energy is focused to a point.

It is the same as the sun in whose parallel rays it can be pleasant to bathe.

But when those same rays are focused they produce dramatic heating effects. Using a magnifying glass to set fire to paper, grass and worse, is the thing most young people want to do immediately after using it to look at things.

According to reports from the Air Force Research Laboratory (Kirtland, New Mexico) in 2001, a two-second burst of energy from a millimeter wave system can heat the skin to a temperature of 130 degrees F. But what does a 10 second burst of energy do to the skin? Or one minute? And what is not clear from that account is whether that was measured with a divergent or convergent beam, because the information at that time was classified.

A divergent beam could be engineered for safety so that the closer protagonists came to the source the greater the energy flux and the more painful their exposure the millimeter waves. This would be a form of self-limiting device.

But a bigger concern is that after spending tens of millions of dollars in development - $40 million by AFRL up to 2001 the system just won't work very well.

Raytheon claims the Silent Guardian fills the gap between "shout and shoot" but the riotous, protesting insurgent masses may find thick clothing, balaclava helmets and gloves quite effective at nullifying the heat ray. They may find objects they can use as shields. They may even use other human beings as shields.

This emphasizes that the Silent Guardian is likely to be most effective where the victim is unable to cover his or her skin or move out of the way of the beam. As a result all that money will have been spent on a weapon that may I stress may not be good at its primary function, but that would be unsurpassed as a means of torture.

A series of mirrors used to collect and redirect sunlight to temporarily inconvenience marauding rioters, protesters, insurgents and opposing armies might not work on a cloudy day - but it has been used in warfare since biblical times. It is a lot cheaper to develop than a millimeter-wave heat ray system and may be equally effective.

## 10. Raytheon brochure

Raytheon

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Mission Systems Integration

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Community Relations

Ethics

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Features

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Photo Gallery

Tradeshow Calendar

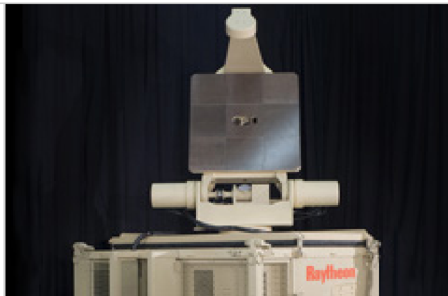
Executive Speeches

Media Contacts

Home > Products & Services > Silent Guardian Protection System

Products & Services Index

IDIQ Contract Vehicles




SILENT GUARDIAN™ PROTECTION SYSTEM

Product Data Sheet

PDF FORMAT

Silent Guardian Video(32 Sec)

The Silent Guardian™ protection system is a revolutionary less-than-lethal directed energy application that employs millimeter wave technology to repel individuals or crowds without causing injury. The system provides a zone of protection that saves lives, protects assets and minimizes collateral damage. Silent Guardian produces precise effects at longer ranges than current less-than-lethal systems and provides real-time ability to establish intent and de-escalate aggression. Various commercial and military applications include law enforcement, checkpoint security, facility protection, force protection and peacekeeping missions.

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http://www.raytheon.com/capabilities/products/silent_guardian/


## 11. PATENTS

## 12. US Patent 6587575 - Method and system for contaminant detection during food processing

http://www.freepatentsonline.com/6587575.html

US Patent Issued on July 1, 2003

Method and system for contaminant detection during food processing

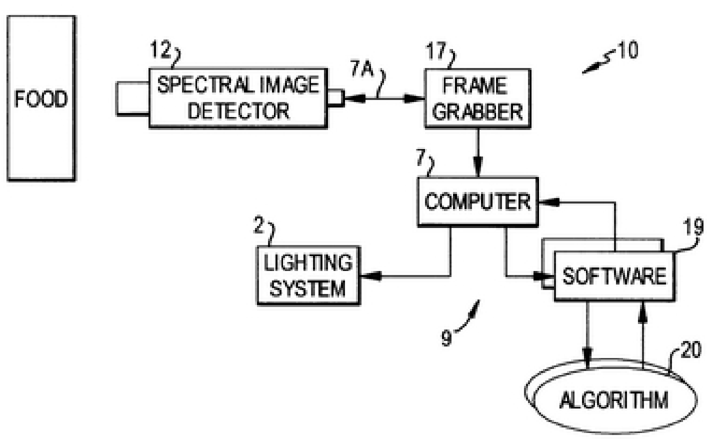
Document Type and Number:

United States Patent 6587575

Abstract:

Imaging systems, containing at least one charge-coupled device detector, are used for determining contamination of foodstuffs, such as for example, animal carcasses. Image processing algorithms allow for the identification of contaminants.

Representative Image:



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Application Number:09/779832

Publication Date:07/01/2003

Filing Date:02/09/2001

View Patent Images: Images are available in PDF form when logged in. To view PDFs, Login or Create Account (Free!) Referenced by:

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Primary Class:

382/110

International Classes:

*G01N21/31*; *G01N21/35*; *G01N33/12*; *G01N21/27*; *G01N21/94*; G01N33/02; G01N21/25; G01N21/88; G06K9/00

Field of Search:

250/461.2, 250/458.1, 382/110, 435/34, 250/339.09

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| | | | |
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| | | | |
|---|---|---|---|
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Claims:

We claim:

1. An imaging system for determination of contamination on food comprising: at least one charge-coupled device detector with an optical filter capable of collecting at least two discrete narrow-band images, a lighting system, a data processing unit operatively connected to said detectors for receiving images for analysis of the spectral properties of an image created by said detector, and a computer readable memory encoded with a computer program containing a detection algorithm based on mathematical analysis of selected key wavelengths of radiation detected by said detector wherein said selected key wavelengths are derived by using a calibration process including: (a) collecting spectra with a visible/near infrared monochromator by irradiating samples of uncontaminated food and pure contaminants representative of the types of contamination to be determined with visible/near infrared radiation and digitally recording reflectance intensity from about 400 nm to about 2500 nm in about 2-nm intervals, (b) transforming said spectra recorded in step (a) for each sample to $\log_{10}$, spectra in absorbence units, (c) transforming said $\log_{10}$ spectra with standard normal variety and detrending procedures to remove interferences of scatter, particle size, and variations in baseline shift and curvilinearity, (d) processing said transformed spectra in step (c) with at least one of Principal Component Analysis and Partial Least Squares regression for formation of scores and loadings, (e) comparing said scores with variations in Principal Components for selecting discrete Principal Components at which scores correlate with uncontaminated foods and contaminants, (f) evaluating loadings of said discrete Principal Components for extreme variations in absolute value to identify key wavelengths, (g) selecting images at key wavelengths identified in step f, and (h) calculating algorithm to detect contaminants.

2. The imaging system of claim 1 wherein said optical filter is selected from the group consisting of a line-scan spectrograph, a liquid crystal tunable filter, an acousto-optic tunable filter, and a narrow band-pass filter; wherein said filters are capable of collecting at least two discrete spectral images each taken at a different wavelength.

3. A method for identifying contamination on food comprising: (a) identifying key wavelengths by performing the following steps: (i) preparing samples of uncontaminated and pure contaminants representative of the types of contamination to be determined, (ii) collecting spectra of said samples, (iii) transforming spectra of said samples to $\log_{10}$ in absorbence units, (iv) transforming said $\log_{10}$ spectra with standard normal variate and detrending procedures to remove interferences of scatter, particle size, and variations in baseline shift and curvilinearity, (v) processing said transformed spectra in step (iv) with at least one of Principle Component Analysis and Partial Least Squares regression for formation of scores and loadings, (vi) comparing said scores with variations in Principal Components for selecting discrete Principal Components at which scores correlate with uncontaminated foods and contaminants, (vii) evaluating loadings of said discrete principal components for extreme variations in absolute value for identifying key wavelengths, (viii) identifying said key wavelengths based on the results of step (vii), (b) calibrating image wavelengths wherein said calibration includes selecting sensor binning to determine band numbers, imaging known wavelength standards to identify wavelength peaks and band numbers,

performing a non-linear regression on said wavelengths against said band numbers, and applying said regression to subsequent images, (c) creating hyperspectral or multispectral images of said samples, (d) selecting said images at said key wavelengths based on the results of step (viii), (e) applying algorithms using key wavelengths identified in step (viii) to form an image dataset for the identification of contamination.

4. A method for identifying contamination on food comprising: (a) identifying key wavelengths by performing the following steps: (i) preparing samples of uncontaminated and pure contaminants representative of the types of contamination to be determined, (ii) collecting spectra of said samples, (iii) transforming spectra of said samples to $\log_{10}$ in absorbence units, (iv) transforming said $\log_{10}$ spectra in absorbence units, (v) processing said transformed spectra in step (iv) with at least one of Principle Component Analysis and Partial Least Squares regression for formation of scores and loadings, (vi) comparing said scores with variations in Principal Components for selecting discrete Principal Components at which scores correlate with uncontaminated foods and contaminants, (vii) evaluating loadings of said discrete principal components for extreme variations in absolute value for selecting key wavelengths, (viii) identifying key wavelengths based on the results of step (vii), (b) calibrating image wavelengths wherein said calibration includes selecting sensor binning to determine band numbers, imaging known wavelength standards to identify wavelength peaks and band numbers, performing a non-linear regression on said wavelengths against said band numbers, and applying said regression to subsequent images, (c) creating hyperspectral or multispectral images of said samples, (d) selecting said images at said key wavelengths based on the results of step (viii), (e) calculating a ratio of two images at said two wavelengths to form a ratio image, (f) performing a masking procedure on said ratio image to reduce background noise, (g) applying histogram stretching to said ratio image to qualitatively identify contaminants in real-time, and/or (h) applying thresholding to said ratio image from step f to quantitatively identify contaminants in real-time.

5. The method of claim 4 further including transforming said log10 spectra with standard normal variate and detrending procedures to remove interference of scatter, particle size, and variations in baseline shift and curvilinearity.

6. The method of claim 4 wherein hyperspectral images are collected by a line-scan spectrograph with a charge-coupled detector.

7. The method of claim 4 wherein multispectral images are collected using an imaging device selected from the group consisting of a common aperture camera with at least two charge-coupled device detectors, at least one charge-coupled device detector with a liquid crystal tunable filter, at least one charge-coupled device with an acousto-optic tunable filter, at least one charge-coupled device with a line-scan spectrograph, and multiple charge-coupled device detectors with narrow band-pass filters.

8. The method of claim 4 wherein said ratio image is determined by dividing an image at a first key wavelength by an image at a second key wavelength on a pixel by pixel basis of said collected images from step (4*d*).

9. A method comprising: (a) preparing samples of uncontaminated food and pure contaminants representative of the types of contamination to be determined, (b) collecting spectra of said samples, (c) transforming spectra of said samples to $\log_{10}$ spectra in absorbence units, (d) processing said transformed spectra in step (c) with at least one of Principal Component Analysis and Partial Least Squares regression for formation of scores and loadings, (e) comparing said scores with variations in Principal Components for selecting discrete Principal Components at which scores correlate with uncontaminated foods and contaminants, (f) evaluating loadings of said discrete principal components for extreme variations in absolute value for selecting key wavelengths, and (g) identifying key wavelengths for identification of contaminants based on the results of step (f).

10. A process for detecting contamination on food comprising: (a) illuminating said food with a source of electromagnetic radiation having a predetermined spectral content, (b) detecting radiation from said source reflected by said food item in each of four predetermined wavelengths $\lambda_1$, $\lambda_2$, $\lambda_3$, $\lambda_4$, and generating a first data set comprising digital values indicative of reflected radiation intensity in each of said wavelengths; (c) processing said digital values according to an algorithm as follows I=(λ1-n)· · (λ3+λ4)λ3· (λ1+λ2)· wherein n is a constant integer; and I is an indication of fecal contamination.

11. The process of claim 10 wherein $\lambda_1$ is from about 750 to about 830 nm $\lambda_2$ is from about 450 to about 500 nm $\lambda_3$ is from about 500 to about 535 nm $\lambda_4$ is from about 550 to about 585 nm.

12. The process of claim 10 further comprising calculating, for each digital value in said first data set, mean and variance values, based on a set of proximate digital values, thereby creating a mean value data set and a variance value data set; adding said mean value and variance value data sets to create a final data set; determining presence or absence of contamination based on values in said final data set.

13. The process of claim 12 wherein said determining step comprises: comparing data values in said final data set to a predetermined threshold value; and determining presence of contamination based on results of said contamination.

14. A process for detecting contamination on food comprising: (a) illuminating said food with a source of electromagnetic radiation having a predetermined spectral content; (b) detecting radiation from said source reflected by said food in a plurality of predetermined wavelengths and generating a data set comprising signals indicative of reflected radiation intensity in each of said wavelengths; (c) processing said data set according to a predetermined mathematical function to generate a plurality of rule files comprising respective image files; (d) combining said rule files to generate a combined data set; (e) performing a texture analysis on said combined data set to generate spatially distributed mean and variance data; (f) summing said mean and variance data to yield output data; and (g) detecting contamination based on said output data.

15. The process of claim 14 wherein said predetermined mathematic function is defined by: cos-1· (∑i=1nb· ti· ri(∑i=1nb· ti2)1/2· (∑i=1nb· ri2)1/2) wherein nb=number of said predetermined wavelengths; t=detected reflected radiation value from said food for a defined wavelength; and

<r=reflectance value of a contaminant at said defined wavelength.

16. A method for determining contamination on poultry or livestock carcasses comprising: (a) obtaining poultry or livestock carcasses for which contaminants are to be determined, (b) creating hyperspectral or multispectral images of said carcasses, (c) selecting images at key wavelength, (d) applying an algorithm to detect contaminants from images selected in step (c), (e) applying masking to reduce background noise in images of step (d), (f) applying histogram stretching to images of step (e) to qualitatively identify contaminants, and (g) applying thresholding to images of step (e) or (f) to quantitatively identify contaminants in real-time.

17. The method of claim 16 wherein said algorithms are selected from the group consisting of a ratio of key wavelengths and a linear combination of key wavelengths.

18. A computer readable medium encoded with a computer program for detecting contamination on food by causing a computer to process image signals indicative of intensity of radiation reflected from said food in four wavelengths $\lambda_1$-$\lambda_4$, using an algorithm: I=(λ1-n)・ ・ (λ3+λ4)λ3・ (λ1+λ2)・ a wherein I is an indication of contamination.

19. An apparatus for detecting contamination on food comprising: (a) a plurality of sensors for detecting spatially distributed radiation reflected from a food at four wavelengths $\lambda_1$, $\lambda_2$, $\lambda_3$, and $\lambda_4$, and generating image signals indicative thereof; a computer; and a computer readable medium coupled to said computer for causing said computer to process said image signals using an algorithm: I=(λ1-n)・ ・ (λ3+λ4)λ3・ (λ1+λ2)・ wherein I is an indication of contamination.

20. A computer readable medium encoded with a computer program for detecting contamination on a food by causing a computer to process spectrally resolved image information indicative of intensity of radiation reflected from said food in a plurality of wavelength by performing the following steps: (a) calculating data sets in the form of rule files, using said spectrally resolved image information, comprising values of α wherein α=cos-1・ (∑i=1nb・ ti・ ri(∑i=1nb・ ti2)1/2・ (∑i=1nb・ ri2)1/2) wherein nb=number of bands of spectrally resolved image information; t=detected spectrally resolved image information values for an $i_{th}$ band; and r=spectrally resolved image information value for an $i_{th}$ band for a contaminant whose presence is to be detected. (b) combining said rule files to generate a combined data set; (c) performing a texture analysis on said combined data set to generate spatially distributed mean and variance data; and (d) summing said mean and variance data to yield output data indicative of contamination.

21. An apparatus for detecting contamination on food comprising: (a) a plurality of sensors for detecting spatially distributed spectrally resolved image information indicative of intensity radiation reflected from a food in a plurality of wavelength bands; (b) a computer readable medium coupled to said computer for causing said computer to process said image signals by calculating data sets in the form of Rule Files, using said spectrally resolved image information, using a formula α=cos-

1・ (∑i=1nb・ ti・ ri(∑i=1nb・ ti2)1/2・ (∑i=1nb・ ri2)1/2) wherein nb=number of bands of spectrally resolved image information; t=detected spectrally resolved image information values for an $i_{th}$ band, and r=spectrally resolved image information value for an $i^{th}$ band for a contaminant whose presence is to be detected; (c) combining said Rule Files to generate a combined data set; (d) performing a texture analysis on said combined data set to generate spatially distributed mean and variance data; and (e) summing said mean and variance data to yield output indicative of contamination.

Description

MICROFICHE APPENDIX

A Microfiche Appendix containing 1 Microfiche containing 71 frames is included.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to imaging systems for detecting contamination on foods. The imaging systems can be used, for example, for real-time detection of fecal and ingesta on meat and poultry carcasses which may be present when carcasses are being processed. The systems include both hyperspectral and multispectral imaging systems including apparatus, methods, and computer readable mediums.

2. Description of the Related Art

Microbial pathogens in food cause an estimated 76 million cases of human illnesses and up to 5,000 deaths annually, according to the Center for Disease Control and Prevention (Mead et al. Emerging Infectious Diseases 5(5) 607-625, 1999). In 1996, the USDA Economic Research Service reported that the annual cost of the food-borne illnesses caused by six common bacterial pathogens: Campylobacter spp., Clostridium perfringens, Escherichia coli O157:H7, Listeria monocytogenes, Salmonella spp., and Staphylococcus aureus; ranges from 2.9 billion to 6.7 billion dollars. The foods most likely to cause these illnesses are animal products such as red meat, poultry and eggs, seafood, and dairy products.

Contamination of meat and poultry in particular, with many bacterial food-borne pathogens, can occur as a result of exposure of the animal carcass to ingesta and/or fecal material during or after slaughter. Accordingly, in order to minimize the likelihood of such contamination, it has been necessary to examine each food item individually to detect the presence of contaminants. Historically, such inspection has been performed visually by U.S.D.A. inspectors, who examine each individual food item as it passes through the processing system.

With poultry, for example, in a modern poultry processing plant, carcasses are placed on shackles of a processing line conveyor system for dressing and inspection. Typically, such conveyors operate at speeds of up to 140 carcasses per minute, with a six inch separation between shackles holding carcasses. Even with multiple inspectors continuously performing such inspection, as little as two seconds are allotted for the inspection of each carcass.

During this inspection period, the inspector is required to check for evidence of eight different diseases as well as for certain quality characteristics, to verify that the chicken was alive when placed on the production line, and to check for evidence of ingesta or fecal contamination. Moreover, during a typical business day operating in two eight hour shifts, a productive poultry processing plant may produce as many as 250,000 processed chickens.

After slaughter, each carcass is examined for disease or evidence of contamination that would render all or part of the carcass unfit for human consumption. Currently the meat processing industry relies upon a variety of methods for the inspection of animal carcasses. These methods typically include human visual inspection, microbiological culture analysis, bioluminescent ATP-based assays, and antibody-based microbiological tests. Unfortunately, these procedures are labor intensive, time consuming, and do not meet the needs of the meat processing industry for an accurate high speed, non-invasive method that is amenable to inspection and real-time analysis.

It is apparent from this brief description that the historical inspection of meat carcases by human inspectors is problematic, and that it is poorly suited to the effective detection and elimination of contaminants in modern poultry processing plants. In particular, it requires the inspectors to make a subjective determination repeatedly. Such a system is prone to errors, which can lead to the entry of contaminated poultry products into the commercial distribution system.

In 1994, the Food Safety Inspection Service (FSIS) published a proposed rule, "Enhanced Poultry Inspection" (USDA, Proposed Rule, Fed. Reg. Volume 59, 35659, 1994) to clarify and strengthen the FSIS's zero-tolerance policy for visible fecal contamination on poultry carcasses. Prior to this rule, FSIS ensured removal of all visible fecal contamination subsequent to postmortem inspection through off-line reinspection, direct on-line observations by an inspector, and application of finished product standards (FPS). Any bird found to be contaminated with feces was set aside for rework or condemnation. The proposed Enhanced Poultry Inspection rule removed "feces" from the list of defects in the FPS.

Since the proposed rule was published, FSIS has adopted the Pathogen Reduction; Hazard Analysis and Critical Control Points (HACCP) Systems (USDA, Final Rule, Fed. Reg., Volume 61, 28805-38855, 1996). The Pathogen Reduction/HACCP system superceded the provisions of the Enhanced Poultry Inspection rule. However, FSIS determined that the zero fecal tolerance provision would complement the Pathogen Reduction/HACCP regulations. Therefore, FSIS finalized the zero fecal tolerance provision of the Enhanced Poultry Inspection proposal (USDA, Final Rule, Fed. Reg., Volume 62, 5139-5143, 1997).

The HACCP regulations require meat processing establishments to identify all food safety hazards likely to occur in a specific process, and to identify critical control points adequate to prevent them. Zero tolerance for visible fecal contamination is a standard that has been implemented by FSIS, forcing poultry processing plants to adopt some point in the evisceration process as a critical control point under HACCP regulations which can be achieved by control, and therefore, is consistent with the HACCP framework. If evisceration machinery is not adjusted properly, the digestive tract of the bird may be torn during evisceration and its contents may leak onto the carcass. In meat processing establishments, fecal contamination of carcasses is a food safety hazard because of its link to microbiological contamination and food borne illness (USDA, 1997, supra). Pathogens may reside in fecal material and ingesta, both within the gastrointestinal tract and on the exterior surface of animals going to slaughter. Therefore, without proper procedures during slaughter and processing, the edible portions of the carcass can become contaminated with bacteria capable of causing illness in humans. Preventing carcasses with visible fecal and ingesta contamination from entering the chlorinated ice water bath (chiller) is critical for preventing cross-contamination of other carcasses. Thus, the final carcass wash, before entering the chiller, has been adopted by many poultry processors as a HACCP system critical control point for preventing cross-contamination of other carcasses.

Compliance with zero tolerance in meat processing establishments is currently verified by visual observation. Three criteria are used for identifying fecal contamination (USDA, 1997, supra). These are color, consistency, and composition. In general, fecal material color ranges from varying shades of yellow to green, brown and white; the consistency of feces is usually semi-solid to paste; and the composition of feces may include plant material. Inspectors use these guidelines to verify that establishments prevent carcasses with visible fecal contamination from entering the chillers. me Visual inspection is both labor intensive and prone to both human error and variability. In addition, there has been a dramatic increase in water usage in most plants as a result of the zero-tolerance fecal standard. Plants have nearly doubled their previous water usage and nationwide the usage has increased an estimated 2 billion gallons (Jones, Poultry, Volume 6, 38-41, 1999).

Efforts have been made to develop automated or semiautomated visual inspection systems for detecting the presence of contaminants on food products during processing. Most systems utilize a technique in which the food item is irradiated with light having a frequency, for example, in the UV range, such that it causes the emission of fluorescent radiation upon striking fecal matter or ingesta. Fluorescent light emanating from the target food item is then measured and compared with a threshold value. If the light gathered exceeds the threshold, a signal indicative of the presence of fecal contamination or ingesta is generated. Such a system is disclosed for example in U.S. Pat. Nos. 5,621,215 and 5,895,921 to Waldroup et al., and U.S. Pat. No. 5,821,546 to Xiao et al.

U.S. Pat. No. 5,914,247 to Casey et al. discloses a fecal and ingesta contamination detection system which is based on the premise that the emission of fluorescent light having a wavelength between about 660 and 680 nm is indicative of the presence of ingesta or fecal material. Thus, carcases being processed are illuminated with UV or visible light (suitable wavelengths being between 300 and 600 nm) and the illuminated surface is then examined for the emission of fluorescent light in the 660 and 680 range. In a preferred embodiment, the intensity of such fluorescence in the 660-680 nm range is compared with that in the 600-620 range as a baseline in order to distinguish fluorescent light emissions of the carcasses themselves.

Visible and near-infrared reflectance (Vis/NIR) spectroscopy is a technique that can be used to detect contamination on foodstuffs. It is a nonconsumptive, instrumental method for fast, accurate, and precise evaluation of the chemical composition of agricultural materials (Williams, Commercial near-infrared reflectance analyzers. In Williams and Norris, eds., Near Infrared Technology in the Agricultural and Food Industries, Am. Assoc. Cereal Chem., St. Paul, Minn., 1987, pp. 107-142). The use of Vis/NIR spectroscopic techniques for classifying wholesome, septicemic, and cadaver carcasses have been reported by Chen and Massie (ASAE, Volume 36(3), 863-889, 1993) and Chen et al. (Appl. Spectrosc., Volume 50, 910-916, 1996b). These studies were conducted with a near-infrared reflectance (NIR) probe in contact with a stationary carcass. More recently, Chen and Hruschka (ASAE Paper No. 983047, American Society of Agricultural Engineers, St. Joseph, Mich., 1999) disclosed an on-line transportable Vis/NIR system (400 to 1700 nm) in which the probe was not in contact with the carcass and carcasses were moving at rates of either 60 or 90 birds per minute. Carcasses were classified as wholesome or unwholesome with an average accuracy of 94% and 97.5% when measured in room light and in the dark, respectively. On-line trials were conducted in a slaughter establishment where spectra of normal and abnormal carcasses were measured. The Vis/NIR system measured carcasses at a rate of 70 birds per minute and was able to classify the carcasses from the spectral data with a success rate of 95% (Chen and Hruschka, 1998, supra). The Vis/NIR method showed promise for separation of wholesome and unwholesome carcasses in a partially automated system. The use of the technique to detect fecal and ingesta surface contaminants on poultry carcasses has not been attempted in the processing plant.

Machine vision is a technology for automating production processes with vision capabilities. Even though machine vision has evolved into a promising technology for many agricultural product applications, such as grading or inspection, there are many factors to be considered in on-line applications: processing speed, reliability, and applicability for industrial environments (Sakar and Wolfe, Trans. ASAE, Volume 28(3), 970-979, 1985; Miller and Delwiche, Trans. ASAE, Volume 32(4), 1484-1490, 1989; Tao et al., Trans. ASAE Volume 38(5), 1555-1561, 1995; Steinmetz et al., Trans. ASAE, Volume 37(4), 1347-1353, 1994; Ni et al., ASAE Paper No. 933032, American Society of Agricultural Engineers, St. Joseph, Mich., 1993; Daley et al., Proc. SPIE, Volume 2345, 403-411, 1994). Image processing techniques have made machine vision research possible to identify and classify agricultural commodities in the spatial domain (Guyer et al., Trans. ASAE, Volume 29(6), 863-869, 1986) as well as in the spectral domain (Meyer et al., Applied Engineering in Agriculture, Volume 8(5), 715-722, 1992).

Machine vision techniques are feasible for grading and parts identification in poultry production (Daley et al., Proceedings of Robotics and Vision '88, Society of Manufacturing Engineers, Dearborn, Mich., 1988). Techniques for recognizing global or systemic defects on poultry carcasses with a color imaging system were reported by Daley et al. (1994, supra ) and Chin et al. (Experimental evaluation of neural networks for inspection of chickens. Research Report of Georgia Tech. Research Institute, 1993). However, this approach had a 90% accuracy for global defect classification and only a 60% accuracy for local defect classification (Daley and Carey, Color machine vision for defect detection: Algorithms and techniques, RIA International Robots and Vision Conf., 1991). Even though a color imaging system has the ability to extract the salient image features, this system was not successful for totally automated inspection because of low accuracy (Daley, Color machine vision for industrial inspection advances and potential for the future, Research Report of Georgia Tech. Research Institute, 1992).

Multispectral imaging technology has potential for food inspection application. Since biological materials at different conditions have different spectral reflectance characteristics, the status of materials could be identified based on their spectral images by selecting optimum wavelengths. Several spectral image processing algorithms have been developed to differentiate wholesome carcasses from unwholesome carcasses (Park and Chen, ASAE Paper No. 946027, American Society of Agricultural Engineers, St. Joseph, Mich., 1994a; Park et al., Trans. ASAE, Volume 39(5), 1933-1941, 1996a). Use of intensities, recorded in different spectral bands of a multispectral camera for segmentation, was effective for classification of poultry carcasses (Park and Chen, Trans. ASAE, Volume 37(6), 1983-1988, 1994b; Park et al., 1996a, supra). Multispectral imaging was used for detecting unwholesome conditions, such as septicemia, cadaver, bruise, tumor, air-sacculitis, and ascites, in poultry carcasses (Park et al., 1996a, supra). Park and Chen (1994b, supra) developed a prototype multispectral imaging system for detecting abnormal poultry carcasses, specifically, to determine the optimal wavelengths of multispectral filters for discerning septicemic and cadaver carcasses from normal carcasses, and to develop a discriminate function for separation of the abnormal carcasses with an accuracy of 93% for normal, 83% for septicemic, and 97% for cadaver carcasses.

Textural feature analysis of multispectral images has potential to discriminate wholesome carcasses from septicemic and cadaver carcasses with high classification accuracy of about 94% (Park and Chen, Trans. ASAE, Volume 39(4), 1485-1491, 1996). However, texture feature analysis would not be useful for an on-line system because of heavy computing time. To achieve real-time processing and analyzing of multispectral gray-scale images for on-line separation of septicemic, cadaver, tumorous, bruised, and other damaged carcasses from the wholesome carcasses, a neural network algorithm was found to be useful (Park et al., ASAE Paper No. 983070, American Society of Agricultural Engineers, St. Joseph, Mich., 1998b). Thus, image texture analysis is an important process in scene analysis because it partitions an image into meaningful regions. Lumia et al., (Pattern Recognition, Volume 16(1), 39-46,1983) described a method for discriminating texture classes based on the measurements of small regions determined by an initial segmentation of the image for categorizing homogeneous regions. Park and Chen (1996, supra) have reported that textural feature analysis of multispectral images containing Vis/NIR wavelengths based on co-occurrence matrices was feasible for discriminating abnormal from normal poultry carcasses at 542 nm.

Development of high speed and reliable inspection systems to ensure safe production of poultry processing has become an important issue. Two dual-wavelength vision systems were developed for on-line machine vision inspection of poultry carcasses (Chao et al., ASAE Paper No. 993118, American Society of Agricultural Engineers, St. Joseph, Mich., 1999). A real-time multispectral image processing algorithm was developed from neural network models with different learning rules and transfer functions for on-line poultry carcass inspection (Park et al., Journal of Agricultural Engineering Research, Volume 69, 351-363, 1998c). The classification accuracy with dual-wavelength spectral images was much higher than single wavelength spectral images in identifying unwholesome poultry carcasses (Chao et al., 1999, supra). Object-oriented software was developed for on-line image capture, off-line development of classification models, and on-line prediction of wholesome and unwholesome carcasses.

An extension of multispectral imaging is known as hyperspectral imaging which is also referred to as imaging spectrometry. Whereas multispectral imaging consists of measurements from two to about ten discrete wavelengths for a given image, hyperspectral imaging measures more than ten contiguous wavelengths, often many more. Like multispectral imaging, hyperspectral imaging is an imaging technique that combines aspects of conventional imaging with spectrometry and radiometry. The result is a technique that is capable of providing an absolute radiometric measurement over a contiguous spectral range for each and every pixel of an image. Thus, data from a hyperspectral image contains two-dimensional spatial information plus spectral information over the spatial image. These data can be considered as a three-dimensional hypercube which can provide physical and geometric observations of size, dimension, orientation, shape, color, and texture, as well as chemical/molecular information such as water, fat, proteins, and other hydrogen-bonded constituent as described above in other Vis/NIR research. Hyperspectral imaging is often used in remote sensing applications (Schowengerdt, The nature of remote sensing, In Remote sensing: Models and methods for image processing, San Diego, Academic Press, 1997, pp. 1-33), but is also being utilized in medical, biological, agricultural, and industrial areas as well (Lu and Chen, SPIE, Volume 3544, 121-133, 1998; Heitschmidt et al., SPIE, Volume 3544, 134-137, 1998; Levenson et al., SPIE, Volume 3438, 300-312, 1998; Lu et al., ASAE Paper No.993120, American Society of Agricultural Engineers, St. Joseph, Mich., 1999; Willoughby et al., SPIE, Volume 2599, 264-272, 1996).

Since the detectors used to measure hyperspectral data are two-dimensional focal plane arrays (FPA), while hyperspectral data are three-dimensional, there must be a technique to collect all the data. The two primary techniques for collecting hyperspectral images are collecting two-dimensional spatial images while sequentially varying a narrow bandwidth of incident energy, or collecting full spectral information of a line-scan image while sequentially varying the position of the line scan (Wolfe, Introduction to imaging spectrometers, SPIE Optical Engineering Press, Bellingham, Wash., 1997; Fisher et al., SPIE, Volume 3438, 23-30, 1998; Hart and Slough, SPIE, Volume 3389, 139-149, 1998). The first technique can typically be demonstrated with either an acousto-optic tunable filter (AOTF) or a liquid-crystal tunable filter (LCTF) in front of a FPA where a two-dimensional spatial image is captured at successive wavelengths. The latter technique is usually implemented in remote sensing as either a push-broom or whisk-broom scanner where a line-scan spectrometer is positioned in front of the FPA so that the FPA successively captures one spatial dimension and one spectral dimension as the scanner or image travels normal to the line-scan direction (first spatial dimension). With each technique, the successive images must be combined to build a hypercube of data for a given image. Each technique has advantages and disadvantages that dictate their use in varying applications. LCTF and AOTF systems can rapidly collect images at discrete wavelengths, which can be easily varied. However, they are better suited for stationary objects to avoid image shifting between discrete wavelength measurements. Push-broom and whisk-broom systems are better suited for moving objects but cannot measure at discrete wavelengths.

Hyperspectral imaging has recently been used to explore the feasibility of detecting defects and contaminants in poultry carcasses (Lu and Chen, 1998, supra; Heitschmidt et al., 1998, supra). Lu et al. (1999, supra) demonstrated that taking a second-derivative of the reflectance value could qualitatively distinguish between four normal carcasses and four cadaver, four septicemia, and three tumorous carcasses. Heitschmidt et al. (1998, supra) contaminated two carcasses with fecal material and were able to qualitatively identify the contaminants with principal component analysis (PCA). However, the time required to perform the PCA was over 40 minutes for a single carcass. Image ratios (wavelength ratios) were also examined. No specific wavelengths were identified as significant for detecting fecal contamination with the limited sample population.

Hyperspectral imaging is an extremely useful tool to throughly analyze the spectra of inhomogeneous materials that contain a wide range of spectral information. It can be an effective technique for identifying surface contaminant on poultry carcasses. At the current time though, it is not suitable for on-line identification of fecal contamination because of lengthy image acquisition and processing times.

SUMMARY OF THE INVENTION

It is therefore, an object of the present invention to provide imaging systems and methods for detecting contamination on foods.

Another object of the present invention is to provide improved processes and apparatus for detection of contamination on a food item, which achieves enhanced accuracy and dependability in positively identifying contaminants.

Another object of the present invention is to provide processes and apparatus which can reliably detect contaminants at a speed which is compatible with the rate at which a food is processed on a production line.

A still further object of the present invention is to provide real-time automated food inspection systems which can quickly and accurately identify contaminated food items in a food processing line.

This and other objects and advantages are achieved by the imaging systems according to the invention, in which digital imaging sensors, such as multispectral or hyperspectral imaging camera units are used to collect reflectance data from a food source on which contamination is to be detected. Reflectance data gathered by the imaging system are then processed in a digital computer using specially derived algorithms for enhancing the detection of contamination.

The theoretical development of algorithms which are used for this purpose is based on the difference between spectral reflectance of contaminants versus that of uncontaminated food. The assumption is made that a mathematical combination of remotely sensed spectral bands could be used to identify contaminants. The results generated by such a combination of spectral bands corresponds to the amount of contaminants in a given image pixel.

There are two categories of algorithms that have been developed for use in the detection of contaminants. The first is a ratio of key wavelengths or bands that are determined. The purpose behind using a ratio is to alter the reflectance measurements of spectral bands using an illumination independent function, which will augment the spectral values for the contaminant while diminishing the values for the food source or background.

Examples range from a simple ratio of two wavelength images, to a ratio of multiple wavelength image combinations, such as ##EQU1##

where $\lambda_1$, $\lambda_2$, $\lambda_3$, and $\lambda_4$ are images at four key wavelengths, and x is a constant. Another example in the ratio category would be the well-known normalized difference vegetative index (NDVI).

The second category of algorithm is defined as a linear combinations of wavelengths. The linear combinations category can range from a combination of two wavelengths ($\lambda_1$ +$\lambda_2$), to a linear combination of wavelength ratios, such as: ##EQU2##

where $\lambda_1$, $\lambda_2$, $\lambda_3$, and $\lambda_4$ are images at four key wavelengths, and w, x, y, and z are constants. This category also includes previously published remote sensing algorithms such as the Mahalonobis Distance and the rule file generation of the Spectral Angle Mapper. These formulas may need to be combined with a known filter for optimum results. Once an equation has been used, it may be necessary to apply any of a number of imaging filters to the resultant data set, either for clarity, to sharpen results, or even to limit the error. Some examples of these are low pass, high pass, median, gaussian, laplacian and texture filters.

Further objects and advantages of the invention will become apparent from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

The claim of this patent contains at least one drawing executed in color.

FIGS. 1a (Front view), 1b (Side View), and 1c (camera assembly) show a schematic of an imaging system 10 including a means for obtaining spectral images 12-SensiCam camera containing at least one charge-coupled device detector 1A with spectrograph 1C, and lens assembly 1B; two quartz-halogen line lights 2B; fiber-optic cables 2A, power supply 2C for lighting; power supply 4 for detector 1A; battery backup 5; computer monitor 6, computer 7, and interface cable 7A. FIG. 1d is a schematic diagram which shows the components of a multispectral contaminant detection system according to one embodiment of the present invention.

FIG. 2 is a flowchart for the detection of contaminants on food such as feces and ingesta on the poultry carcasses with Vis/NIR monochromator (2.1-2.5) and hyperspectral imaging system 10 (2.6-2.17).

FIG. 3 is a flowchart for the detection of contaminants on food such as feces and ingesta on poultry carcasses with a multispectral imaging system where key wavelengths have already been determined.

FIGS. 4a and 4b illustrate a digital filtering technique common to two embodiments of the present invention.

FIG. 5 is a graph showing Vis/NIR reflectance average spectra from a scanning Vis/NIR monochromator of uncontaminated hard (#5.1) and soft (#5.2) scalded poultry carcass skin and pure feces from duodenum (#5.3), ceca (#5.4), and colon (#5.5) samples of poultry viscera.

FIG. 6 is a graph showing discrimination of uncontaminated hard and soft scalded poultry carcass skin (#6.1) from duodenum (#6.2), ceca (#6.3 ), and colon (#6.4) feces by Principal Component Analysis of Vis/NIR reflectance spectra.

FIG. 7 is a graph showing Principal Component Analysis loadings for Principal Components 1 (#7.1), 2 (#7.2), and 4 (#7.3) as a function of wavelength.

FIG. 8 is a graph showing a non-linear cubic regression model for spectral calibration of the hyperspectral imaging system 10 with a binning of 4 by 2.

FIG. 9 shows a color composite and images of poultry carcasses contaminated with feces from duodenum, ceca, and colon locations of viscera at selected spectral wavelengths acquired by hyperspectral imaging to demonstrate image quality and spectral-image differences.

FIGS. 10a-e show a color-composite image (FIG. 10a) and spectral images (FIGS. 10b-e) from image system 10 which correspond to key wavelengths capable of identifying fecal contamination as determined from a Vis/NIR monochromator.

FIGS. 11a-f show the ratio images at key wavelengths that identify feces (duodenum, ceca, and colon) and ingesta contaminants on a poultry carcass. FIG. 11a is a 517-nm image divided by 434-nm image. FIG. 11b is a 565-nm image divided by 434-nm image. FIG. 11c is a 628-nm image divided by 434-nm image; figure d is a 565-nm image divided by 517-nm image. FIG. 11e is a 628-nm image divided by 517-nm image. FIG. 11f is a 628-nm image divided by 565-nm image.

FIG. 12a shows a hyperspectral color-composite image for the identification of fecal and ingesta contaminants on a poultry carcass. The image shows blood hemorrhage (#12a.1) and fecal contaminant in the wing shadow (#12a.2).

FIG. 12b shows a ratio image (565-nm image divided by 517-nm image) for the identification of fecal and ingesta contaminants on a poultry carcass. The blood hemorrhage (#12b.1) is not identified while the fecal contaminant in the wing shadow (#12b.2) can be identified easily.

FIGS. 13a, b, and c are ratio images to show a masking procedure to eliminate background noise from algorithm-processed images. FIG. 13a shows an unmasked image (565-nm image divided 517-nm image). FIG. 13b shows a masking template from a image at 565 nm. FIG. 13c shows the image of FIG. 13a after the masking template (FIG. 13b) was applied.

FIGS. 14a-b show a ratio image (565-nm image divided by 517-nm image) before and after histogram stretching of the masked ratio image to qualitatively demonstrate the effectiveness of the histogram stretching routine. FIG. 14a shows a ratio image, after the masking procedure, with contaminants somewhat visible in white. FIG. 14b shows a ratio image, after the histogram stretching procedure, with contaminants clearly visible in white. #14b.1-contaminant below the tail, #14b.2-row of duodenum, #14b.3-row of ceca, #14b.4-row of colon contaminant, and #14b.5-row of ingesta contaminants.

FIGS. 15a-f show graphs of contaminated and uncontaminated poultry carcasses for validation of the ratio-image algorithm before and after the masking and threshold procedures for identification of fecal and ingesta contamination. The figure shows a clean carcass (FIG. 15a), clean carcass with masking procedure applied to eliminate background (FIG. 15b), clean carcass after masking and threshold procedures (FIG. 15c), carcass with contaminant (FIG. 15d), contaminated carcass with masking procedure applied to eliminate background (FIG. 15e), and contaminated carcass after masking and threshold procedures (FIG. 15f).

DETAILED DESCRIPTION OF THE INVENTION

Hyperspectral and multispectral imaging are imaging techniques that combine aspects of conventional imaging with spectrometry and radiometry. These techniques are capable of providing an absolute radiometric measurement over a contiguous spectral range for each and every pixel of an image. Data from an image contain two-dimensional spatial information as well as spectral information at each location in the spatial domain. These data can be considered as a three-dimensional hypercube (or data cube) which can provide physical and/or chemical information of a material under test. This information can include physical and geometric observations of size, orientation, shape, color, and texture, as well as chemical/molecular information such as water, fat, and protein.

Generally, for detecting contamination on food, such as for example animal carcasses, testing is conducted at one or more stations along the processing line, during transport along the line, or soon after completion of slaughter. For the purposes of this application, contamination of animal carcasses is to include but not be limited to, digestive tract material including fecal contamination, ingesta contamination, crop contents, bacterial contamination, etc. At the testing stations, the carcasses may be imaged with a hyperspectral or multispectral imaging system at any contiguous or discrete wavelengths of radiation from about 400 to about 2500 nm emitted therefrom and detected as described herein below. Because processing facility practices vary with the particular meat producing animal, specific locations for testing along the processing line will vary. For instance, the typical processing line for poultry include the following steps in order: the bird is suspended by the legs in a shackle, electrically stunned, bled via a neck cut, hard or soft scalded, defeathered, decapitated, and eviscerated (usually by mechanical means), and chilled in chlorinated ice-water baths. On the other hand, beef harvest procedures differ significantly, and include the following steps: the animal is inspected, rendered unconscious, shackled, hoisted, exsanguinated and placed onto a moving rail. The carcass is then skinned (primarily through the use of mechanical hide pullers) and the head is removed for postmortem inspection of wholesomeness. Prior to evisceration, the brisket is split and the esophagus and anus are loosened (these may be tied to prevent fecal and ingesta contamination of the carcass). The abdominal cavity is then opened with a vertical incision through the abdominal muscles and the internal organs (excluding the kidneys) and the entire gastrointestinal tract are removed onto a conveyor for postmortem inspection and further processing. The eviscerated carcass is then split into halves, cutting longitudinally through the spinal column, and inspected for wholesomeness. Once inspection is complete (passed), the carcass sides are mechanically washed (which may include a steam pasteurization step to minimize microbial contamination), weighed, and chilled for 24 to 48 hours before fabrication into primal and subprimal cuts and subsequent shipment. Pork harvest procedures are similar to beef, with the exception where the skinning step in the beef process is replaced by a hair removal process in pork that leaves the skin on the carcass. Scalding the carcass in hot water to loosen the hair follicles, mechanically removing the hair, singeing to remove any residual hair, and subsequently washing and rehanging the carcass accomplish this. Evisceration is similar to beef and pork carcasses are split into sides through the spinal column; however, the skin and soft tissue are left intact at the anterior end of the carcass. Inspection, washing, and chilling procedures are also similar to beef. In some instances, pork carcass may be deboned while warm, ground with other ingredients such as spices, and rapidly chilled to refrigeration temperatures. Testing may be conducted during or upon completion of any of the above-mentioned steps.

In one example, beef or pork carcasses can be inspected for contamination prior to chilling of the sides or carcass usually within approximately 2-3 minutes after splitting or in less than 10 minutes of initiation of harvest, depending on the species. Other sites for inspecting may include after skinning, after evisceration, and(or) after splitting. Poultry carcasses can be inspected for contamination after defeathering and/or evisceration. For quality control, poultry may also be inspected following removal from chilled chlorinated ice-water baths.

Imaging systems 10 (FIG. 1d) include a means for obtaining spectral images 12, a lighting system 2, and data processing unit 9. One embodiment of the present invention includes a hyperspectral imaging system 10 (FIGS. 1a-c). Hyperspectral imaging system 10 includes at least a means for obtaining spectral images 12, such as for example at least one charge-coupled device detector 1A; lighting system 2, and data processing unit 9. The means for collecting spectral images 12 for the purposes of this embodiment, includes at least one charge-coupled device 1A, a lens assembly 1B, and a line-scan spectrograph 1C. It further includes a power supply 4 and a battery back-up 5.

Device 1A can be a high resolution detector, such as for example, a Charge-Coupled Device detector (CCD). Examples of a charge-coupled device detector include, for example, a SensiCam 370 KL Camera (Cooke Cooperation, Auburn Hills, Mich.); an Orca 100 Digital CCD Camera system (Hamamatsu, Bridgewater, N.J.); a SpectraVideo 16-bit Digital (PixelVision, Inc., Beaverton, Oreg.); etc.

Line-scan spectrograph 1C has a nominal spectral range of from about 400 nm to about 900 nm and attaches to the CCD detector 1A for generating line-scan images. Lens assembly 1B includes a 1.4/17-mm compact C-mount lens such as, for example, a Xenoplan (Schneider, Hauppauge, N.Y.); Nikkor (Nikon Inc., Melville, N.Y.); and attaches to spectrograph 1C.

Another embodiment of the present invention includes a multispectral imaging system 10. Multispectral imaging system 10 includes a means for obtaining spectral images 12, a lighting system 2 and a data processing unit 9. In this embodiment, a means for obtaining spectral images 12 for a multispectral imaging system includes a common aperture camera having two or more detectors, such as two CCD detectors, for simultaneously acquiring multispectral images. The camera utilizes a wavelength-separating prism, a dichroic filter, to split broadband light, which enters the camera through the lens, into at least two independent optical channels. The degree of specific spectral separation between optical channels depends upon the dichroic filter and the subsequent trim filter properties. Specifically, the separation is a function of the desired key wavelengths as determined by the calibration model for the specific food and its associated contaminants, their proximity to each other, and the bandwidth of the trim filters. The wavelength separating prisms or filters contain different dichroic coatings on different faces of the prism which determines the performance of the camera. The optical trim filters, between the prism exit plane and the detectors, determine the spectral bandwidth reaching the detectors and are designed such that the central wavelength corresponds to one of the key wavelengths. As a result of this process, two or more spectral images are obtained simultaneously. By way of example, a common aperture camera system with two detectors is described. Common aperture cameras with three or more detectors are also feasible. These cameras would result in simultaneously acquiring three or more spectral images.

It is of course possible to achieve similar means for obtaining spectral images 12 by using multiple digital imaging devices, such as CCD devices, each having its own filter, for isolation of a preselected wavelength band. Another means for obtaining spectral images 12 is at least one charge-coupled device detector containing area scan filters, such as for example, a liquid crystal tunable filter, an acousto-optic tunable filter, etc. The bandwidths for these filters are specified according to the type of data to be collected. The determination of the bandwidths needed is well within the ordinary skill in the art in light of the detailed description of the present application. The at least one charge-coupled device detector with filters has to be capable of collecting at least two discrete spectral images.

The image signals provided by the means for obtaining spectral images 12 are input to a computer 7 via a known frame grabber 17, such as, for example, a 12-Bit PCI interface board (Cooke Company, Auburn Hills, Mich.; National Instruments, Austin, Tex.). The frame grabber 17 assembles the data into respective image frame files. These data are then processed by the computer 7 according to one of the different processes, including differing processing algorithms 20 and method steps, depending on the nature of the production line processing the food. The end result of such computer analysis is the generation of a qualitative analysis such as a "contaminated/uncontaminated" determination for each unit of food that passes in front of the means for obtaining spectral images or a quantitative determination to determine, for example, types and/or size of contamination.

The theoretical development of algorithms 20 which are used for this purpose is based on the difference between spectral reflectance of contaminants versus that of uncontaminated food. The assumption is made that a mathematical combination of remotely sensed spectral bands could be used to identify contaminants. The results generated by such a combination of spectral bands corresponds to the amount of contaminants in a given image pixel.

There are two categories of algorithms that have been developed for use in the detection of contaminants. The first is a ratio of key wavelengths or bands that are determined. The purpose behind using a ratio is to alter the reflectance measurements of spectral bands using an illumination-independent function, which will augment the spectral values for the contaminant while diminishing the values for the food source or background.

Examples range from a simple ratio of two wavelength images,to a more complex ratio such as: ##EQU3##

where $\lambda_1$, $\lambda_2$, $\lambda_3$, and $\lambda_4$ are images at four key wavelengths, and x is a constant. Another example in the ratio category would be the well-known normalized difference vegetative index (NDVI).

The second category of algorithm is defined as a linear combination of wavelengths. The linear combination category can range from a combination of two wavelengths, ($\lambda_1$ +$\lambda_2$), to a linear combination of wavelength ratios such as: ##EQU4##

where $\lambda_4$, $\lambda_2$, $\lambda_3$, and $\lambda_4$ are images at four key wavelengths, and w, x, y, and z are constants. This category also includes previously published remote sensing algorithms such as the Mahalonobis Distance and the rule file generation of the Spectral Angle Mapper. These formulas may need to be combined with a known filter for optimum results though. Once an equation has been used, it may be necessary to apply any of a number of imaging filters to the resultant data set, either for clarity, to sharpen results, or even to limit the error. Some examples of these are low pass, high pass, median, gaussian, laplacian and texture filters.

Both the hyperspectral and the multispectral systems require lighting system 2. Lighting system 2 includes an illuminator with at least 2400 lux (lumen/$m^2$) intensity and excitation wavelengths between about 400 and about 2500 nm, such as for example, Fiber-Lite A240 (Dolan-Jenner, Inc., Lawrence, Mass.); lamp assembly 2B, for example quartz halogen line lights such as for example QF5048 (Dolan-Jenner, Inc.); lighting power supply 2C, and fiber-optic cables 2A.

Data analysis (Microfiche Appendix) is needed in order to determine particular types of contamination on foodstuffs. A calibration model correlates band numbers of the imaging system with actual wavelengths. Referring to FIG. 2, the first step is to collect spectra of pure contaminants and uncontaminated food with a Vis/NIR monochromator, for example, a NIRSystems 6500 monochromator (NIRSystems, Silver Spring, Md.) which has a spectral range from about 400 to about 2500 nm in about 2-nm intervals (FIG. 2, Box 2.1). Before each sample is measured, a standard ceramic tile, having high reflectance, is measured to provide standard reflectance values. The reflectance values of the samples and the standard are converted to log (1/R) values where R is reflectance. It is known to convert reflectance data representing log (1/R) values, wherein R is reflectance, which values vary approximately linearly with the concentration of the absorber. Generally, any suitable monochromator may be utilized, provided that the resulting spectra covers both visible and NIR regions. This means that the wavelength of visible light will be in the range of about 400 to about 780 nm, and NIR light will be in the range of about 782 to about 2500 nm.

After the data are converted to log (1/R), the next step is to transform the converted data with standard normal variate and detrending or multiplicative scatter correction to remove interferences of scatter, particle size, variation in baseline shift, and curvilinearity (FIG. 2, Box 2.2). Variation within individual Vis/NIR spectra is the result of three main sources: 1) nonspecific scatter of radiation at the surface of the sample; 2) variable spectral pathlength through the sample; and 3) chemical composition of the sample. Scatter is dependent on the physical nature of the sample particles and pathlength is largely dependent on sample particle size. There is a high degree of collinearity between data points in the log (1/R) spectra, which is a function of scatter and variable pathlength. The multiplicative combinations of these effects are unique to any one spectrum, and any corrections for these interference should be made on the same basis. These interferences can cause problems in quantitative and qualitative analysis and should be removed prior to calibration and analysis. Spectral measurements of pure contaminants and uncontaminated foodstuffs are transformed with standard normal variate and detrending procedures (Barnes et al., Appl. Spectrosc., Volume 43 (5), 772-777, 1989; herein incorporated by reference) to remove interferences of scatter and particle size, and variations in baseline shift and curvilinearity. The invention is not limited to any one specific mathematical transformation to remove these interferences. It has been found that NIR ratio techniques (Norris, Karl, U.S. Pat. No. 5,132,538; herein incorporated by reference), second derivative transformation, and multiplicative scatter correction (Geladi et al., Applied Spectrosc., Vol. 39(3), 491-500, 1985; herein incorporated by reference) show sufficiently similar corrections within the scope of the present invention.

After transforming the log (1/R) data, as described above, the transformed data is processed with Principal Component Analysis (PCA) for formation of scores and loadings (FIG. 2, Box 2.3). Examples of commercially available software for performing PCA analysis include Winisi, Infrasoft, Port Matilde, Pa.; Unscrambler, CAMO, Oslo, Norway; Grams/32, Galactic Industries Corp., Salem, N.H.; etc. Mathematical tools have been developed to help extract additional information from spectra. Chemometrics have been described as the application of mathematical and statistical methods to extract more useful information from chemical and physical measurements. Recent advances have lead to new data analysis systems and commercially available Vis/NIR instruments that use one or more chemometric methods for qualitative and quantitative analysis. Standard practices for chemometrics in infrared, multivariate, qualitative, and quantitative analysis are described elsewhere (American Society for Testing Materials (ASTM) Practice, E1655-94, 1995; ASTM Annual Book of Standards, West Conshohocken, Pa., Volume 3.06, 1995; both herein incorporated by reference). Principal Component Analysis (PCA) is one technique for identifying the underlying features of large data sets, and attempts to describe the variation in multi-dimensional data by means of a small number of uncorrelated variables. The underlying concepts and properties of PCA are described in Barton et al., (U.S. Pat. No. 6,114,699; herein incorporated by reference). Briefly, PCA is a variable reduction procedure. It is useful on a large data set with a large number of variables that are correlated to each other. Because of these intercorrelations, the observed variables can be reduced into a smaller number of artificial variables (principal components, eigenvectors, factors, or T-variables) that will account for most of the variance in the observed variables. Translated into principal components, the new coordinate system has fewer dimensions than the original set of variables, and the directions of the principal components describe the largest variations. The localization, or the coordinates of the samples related to the principal components, are called scores (Eigenvalues). The corresponding relationship between the original variables and the new principal components are called loadings (weights). The next step is to compare scores with variations in principal components to select discrete principal components at which scores correlate with uncontaminated foods and contaminants (FIG. 2, Box 2.4). The spectra of samples are analyzed by principal component analysis as described above, and scores and loadings are used to select key Vis/NIR wavelengths for discrimination between contaminated and uncontaminated foods. It has been found that partial least squares regression (Workman et al., Applied Spectrosc. Reviews, Volume 31(1&2), 73-124, 1996; herein incorporated by reference) can also be used for modeling the variance within spectra of pure contaminants and uncontaminated foods to identify key wavelengths (FIG. 2, Box 2.5). Once key wavelengths are identified for a particular food and its associated contaminants, these can be used in any embodiment of the present invention.

After key wavelengths are identified from the calibration model generated for a particular food and its associated contaminants, the systems of the present invention are ready to image foods for contamination. For hyperspectral imaging system 10, line scan images are collected (FIG. 2, Box 2.6). With hyperspectral imaging, all spectral wavelengths can be collected for every pixel of an object. Data are acquired with a high resolution CCD image detector, which is a two-dimensional focal-plane array sensor. Therefore, only two dimensions of an image can be collected at any given time. A typical embodiment is a single line-scan image which consists of spectral information for one spatial row. Line-scan images are taken while the food source is moving so that the successive line scans represent successive slices of the food source. Alternatively, the food source may remain stationary and the camera may move. Successive line-scan images are collected by computer 7 via a frame-grabber 17 that interfaces the CCD detector through interface cable 7A. Once the frame-grabber has stored line-scan images as data files in computer 7, they may be combined to create a full hyperspectral image that has two-dimensional spatial information as well as spectral information (FIG. 2, Box 2.7). This full hyperspectral image is sometimes referred to as a three-dimensional hypercube. The hyperspectral image is created through software which combines the individual line-scan image files into a single hyperspectral image file such as for example Hypervisual (Provision Technologies, Stennis Space Center, Miss.); Interactive Data Language (IDL)(Research Systems, Inc., Boulder, Colo.), etc. However, any software capable of creating a hyperspectral image is useful in the present system and is well within the ordinary skill in the art given the detailed description of the present invention.

The next step in the process is to choose sensor binning (FIG. 2, Box 2.8). The choice of hyperspectral imaging resolution is determined by the food source imaged, the minimum physical size of the contaminant, and the values of the key wavelengths determined from the Vis/NIR monochromator. The imaging resolution is a function of both the CCD detector dimensions and the binning selected during image capture. Binning describes the process where photons collected in adjacent pixels are summed together. For example, a binning of 4 by 2 applied to a CCD with 1280 by 1024 pixels would result in the summing of photons collected over eight adjacent pixels (two rows of four columns). The result would be line-scan images with an image resolution of 320 pixels (1280 divided by 4) in the spatial dimension and 512 pixels (1024 divided by 2) in the spectral dimension. The spectral dimension is sometimes referred to as the bands.

The hyperspectral imaging system requires a wavelength calibration so that the intensities at various band numbers will correspond to an actual wavelength. Thus, after wavelength calibration, the same key wavelengths, identified with the Vis/NIR monochromator (FIG. 2, Box 2.5 and described above), can be evaluated with the hyperspectral imaging system. The hyperspectral wavelength calibration equation was developed from separate hyperspectral image data (FIG. 2, Box 2.9) of spectral calibration lamps (Oriel Instruments, Stratford, Conn.) and lasers (Edmund Scientific, Barrington, N.J.) inserted into an integrating sphere (Optronic Laboratories, Inc., Orlando, Fla.; Labsphere, North Sutton, N.H.). The integrating sphere disperses the energy from the calibration lamps so that any image system looking into the integrating sphere observes a spatially uniform image. The calibration lamps must have precise distinct wavelength peaks across the wavelength range of the hyperspectral imaging system needing calibration. Determination of these is well within the ordinary skill in the art.

After imaging the spectral calibration sources, distinct wavelength peaks and their corresponding band numbers are identified (FIG. 2, Box 2.10) and for a given binning, regressed (FIG. 2, Box 2.11) against the corresponding image band numbers as follows:

$$\text{wavelength (nm)}=380.277+0.905+(4.369\times10^{-4})X^2-(4.356\times10^{-7})X^3 \quad (r^2=0.9999)$$

where X is the band number ranging from about 0 to about 511 (FIG. 2, Box 2.11). This wavelength calibration equation is independent of light intensity but is dependent on the individual CCD detector and will have different coefficients for different detectors and binning combinations. The wavelength calibration is then applied to all subsequent images of food (FIG. 2, Box 2.12). Given this detailed description of the present invention, it is well within the ordinary skill in the art to develop a calibration equation for a given sensor.

The next step is to select hyperspectral images (FIG. 2, Box 2.13) with the key wavelengths identified earlier (FIG. 2, Box 2.5). Then a ratio image is calculated where, in the simple case, the intensity of one image is divided by the intensity of a corresponding image at a different key wavelength on a pixel-by-pixel level (FIG. 2, Box 2.14). This allows for the generation of ratio images that are used to identify and locate contamination on the food source.

To further enhance an image, the image background is eliminated through a masking procedure (FIG. 2, Box 2.15). Histogram stretching is used to visually enhance the contaminants (FIG. 2, Box 2.16). Masking is a process where all pixel intensities below a minimum value are assigned to a fixed value (zero). Since the calculated ratio-image values vary (FIG. 2, Box 2.14) from about 0 to about 2, masking is performed on one of the original key wavelength images and then transferred to the ratio image by assigning all corresponding ratio image intensity values to zero. For example, the image at 565-nm has an intensity value of less than about 120 for the background. Thus, any pixels below the minimum value of 120 in the 565-nm image are assigned a value of zero in the ratio image, which removes the background.

Histogram stretching is a method to enhance the contrast of a displayed image. Typically, it is a linear stretching of the image intensity values to the full-scale display range (0 to 255 gray-scale) where the minimum image intensity value is assigned to a full-scale display value (255 for 8-bit gray-scale). However, for the masked ratio images, a histogram stretch is applied such that all image intensity values below a low threshold value are assigned a zero display value, and all those above a high threshold value are assigned a full display-scale value, with intermediate values assigned linearly proportional display values between the zero and full display-scale values. The method to this point would be suitable as a decision tool for food inspectors in the identification of the presence of contaminants.

Another alternative to histogram stretching is to use a threshold routine to quantitatively identify contaminants (FIG. 2, Box 2.17). The threshold routine changes all pixel intensity values below a given contaminant threshold value to zero. The contaminant threshold is chosen so that all pixels greater than the threshold value are identified as contaminants. This is applicable for real-time identification of food contamination in a processing line.

For the multispectral imaging system 10 embodiment, spectral images at least two wavelengths are collected (FIG. 3, Box 3.1) with a means for collecting spectral images 12 as described above. The spectral data is then analyzed using a software program 19 containing the necessary algorithms 20 and process steps. A software program 19 is stored in the memory of a computer 7 (FIGS. 1a-d).

One example of an algorithm 20 for a first step in analyzing the spectral data is to calculate a ratio image at two key wavelengths to detect contaminants (FIG. 3, Box 3.2). Multispectral wavelengths are first collected (FIG. 3, Box 3.1) at the key wavelengths as discussed above for the hyperspectral imaging embodiment. Then the image at one key wavelength is divided by the image at another key wavelength. When this type of calculation is used the next step, is to reduce the background noise by separating the contaminated foodstuff from its background with a masking procedure (FIG. 3, Box 3.3) as discussed above for the hyperspectral imaging embodiment. The fourth step, for this embodiment, separates the contaminants from the foodstuff with histogram stretching (FIG. 3, Box 3.6) for display or monitoring purposes (FIG. 3, Box 3.7) for qualitative separation, while the fifth step, for this embodiment, is a threshold procedure which quantitatively separates the contaminants from the foodstuff (FIG. 3, Box 3.8), as described for the hyperspectral imaging embodiment.

Another embodiment for analyzing spectral data is illustrated in FIG. 3 with a system as depicted in FIG. 1d which is used to detect contamination on poultry carcasses which have been hard scalded prior to removal of feathers. The carcass is illuminated by a light source 2 which provides a predetermined spectral profile. In this case, it has been determined that a light source corrected to about 5600K is particularly advantageous.

Data representing a multispectral image of light reflected from the target carcass are generated by the spectral image detector 12 in four wavelengths (FIG. 3, Box 3.1). In particular, it has been determined that the following four ranges of wavelengths are particularly advantageous for this purpose:

$\lambda_1$ =about 750-830 nm

$\lambda_2$ =about 450-500 nm

$\lambda_3$ =about 500-535 nm

$\lambda_4$ =about 550-585 nm

The image data generated (FIG. 3, Box 3.1) thus provide four reflectance values, each represented by a digital number (DN), for each pixel included in the acquired image--one such digital number for each of the frequency bands $\lambda_1$ -$\lambda_4$. These values are combined to generate a value I for each pixel (FIG. 3, Box 3.2), according to the following algorithm: ##EQU5##

wherein n is an integer constant. Subtraction of the constant n in the numerator as indicated in Equation 1, reduces the amount of background noise (FIG. 3, Box 3.3) by altering the DN values of the specified wavelength $\lambda_1$. The result of the above calculation, which is performed in computer 7 of FIG. 1d is the creation of an image file having a single DN value for each pixel.

The DN values generated are then filtered by a process referred to as "texture analysis" (FIG. 3, Box 3.4), which characterizes the image according to real variations in pixel brightness--that is, DN values--to generate two new output image files indicative of the mean and variance for pixels within a moving window of about a 3 by 3 pixel mask, as illustrated in FIGS. 4a and 4b.

FIG. 4a shows the manner of calculation of mean values in the texture analysis. For each window of nine pixels (about a 3 by 3 pixel set) a mean value of the DN values is determined.

For example, in FIG. 4a, three windows a, b, and c are indicated by brackets, with window a being enclosed by a heavy line. The mean of DN values in window a is about 4.2. Similarly, the mean value for window b, enclosed by a dashed line, is about 3.2, as also shown in the set of mean values. As the window is moved over the whole of the image file, a complete new image file of mean values is created. It is of course apparent that different sizes and shapes of windows can be used for this purpose.

The technique of calculation of a new image data set of variance values, shown in FIG. 4b, is similar to that used to calculate the mean values in FIG. 4a.

As is apparent, the performance of the texture analysis (FIG. 3, Box 3.4) yields two image data sets, representing the spatially distributed mean and variance values, respectively for the data values I (FIG. 3, Box 3.2). The mean and variance values are then added together to form a final output image.

Finally the output image is analyzed by computer 7 to determine whether ingesta or fecal contamination is present on the imaged carcass. This can be done, for example, by establishing a threshold value, IF which is indicative of contamination. In this case, calculated values in the final output image data are compared with a threshold value and a decision is made based on such comparison. For example, a positive contamination judgement (FIG. 3, Box 3.10) could be made if a single pixel value exceeds the threshold value,or a judgement of contamination could be made if a specified minimum number of values exceed the threshold; or a minimum number within a defined proximity. In a preferred embodiment, such a determination is made if the carcass has at least one pixel that exceeds the threshold (FIG. 3, Box 3.10); otherwise, the carcass is concluded to be contaminant free (FIG. 3, Box 3.9).

In another embodiment, for carcasses that are soft scalded, carcasses are illuminated by a 5600K color corrected light source 2 in the same manner as indicated in FIG. 1d. In this embodiment, however, three multispectral image-data sets are acquired by specral image detector 12 at the following key wavelengths, one image dataset per wavelength range:

$\lambda_1$ =about 497-537 nm

$\lambda_2$ =about 545-585 nm

$\lambda_3$ =about 608-648 nm

That is, DN reflectance values are determined for every pixel at each of the three wavelength ranges $\lambda_1$ - $\lambda_3$. Thus, each pixel is characterized by a spectral pattern or "signature" consisting of these three DN values--one for each wavelength range.

Next, an algorithm referred to as Spectral Angle Mapper is applied (FIG. 3, Box 3.2), correlating each of the acquired image-data sets λ with predetermined spectral signature values at the detected wavelength ranges $\lambda_1$, $\lambda_2$, and $\lambda_3$, for each of four types of ingesta/fecal contaminants, which differ only in their source within the digestive tract of the carcass prior to dressing; that is in particular, the stomach, the duodenum, the colon, and the ceca. The reflectance values for each of these types of contaminant at the key wavelength ranges varies in a characteristic fashion, and accordingly this characteristic pattern can be used to detect its presence. It is of course apparent that the greater the number of wavelength bands which is used to characterize both the target carcass and the types of contamination, the greater the precision of the correlation. However, it has been determined that the three wavelength range values indicated above are sufficient in practice.

In this embodiment, the Spectral Angle Mapper (SAM) algorithm is calculated (FIG. 3, Box 3.2). The Spectral Angle Mapper is a mathematical function which can be used to determine the degree of spectral similarity between the spectral values for each pixel in the acquired image data set and the corresponding spectral signature values for the four contaminants noted above. The formula for calculation of SAM is as follows: ##EQU6##

wherein:

$t_i$ =detected reflectance value of the target carcass in the $i^{th}$ band,

$r_i$ reflectance value of the predetermined spectral signature of a subject contaminant in the $i^{th}$ band; and

nb=number of bands i in the image.

In this case, since four different types of contaminants are to be detected, four values of α are calculated for each pixel--one for each of the respective reference spectra--resulting in four image data sets, referred to as Rule Files. By virtue of the SAM algorithm, the data in each of these Rule Files are indicative of the likelihood of contamination of the imaged carcass.

Next, the sum or product of all the Rule Files produces a new image file (FIG. 3, Box 3.2). Thereafter, processing for soft scald carcasses in FIG. 3 proceeds in the same manner as for hard scald carcasses as in FIG. 3. That is, a texture analysis is performed (FIG. 3, Box 3.4); the mean and variance values are combined; and contamination is determined based on the combined image data set (FIG. 3, Box 3.8-3.10).

The following examples are intended only to further illustrate the invention and are not intended to limit the scope of the invention which is defined by the claims. Poultry carcasses are used as a model system for testing the system of the present invention.

EXAMPLE 1

Live birds were obtained from a local broiler house, transported to the grow-out facilities at USDA-Agricultural Research Service in Athens, Ga. and held for about 4 days. The feeding regime was scheduled for meal feeding to provide a consistent amount of fecal material in the digestive tract among birds. Birds were stunned (12 VAC), bled for about 90 seconds, scalded at about 57.5° C. for approximately 2 minutes (e.g. hard scald), or about 53° C. for 50 seconds (e.g. soft scald), and picked. Hard scalding removes the skin cuticle resulting in a white carcass, whereas soft scalding leaves the cuticle intact resulting in a yellow carcass. In order to collect feces and ingesta, four replicates of 20 birds were processed and eviscerated to obtain fecal material from the duodenum, ceca, and colon portions of the viscera, and ingesta from the proventriculus and gizzard. Samples of skin were also taken from the breast. See Table 1 below for control variables and fixed values for digestive tract contents.

TABLE 1 Control Variables and Corresponding Fixed Values CONTROL VARIABLES VALUES Bird 6 week male Diet Corn/Soybean meal Feed Withdrawal 8 hours Water Withdrawal 4 hours

EXAMPLE 2

In order to collect Vis/NIR spectra from carcasses, pure feces from duodenum, ceca, colon and both hard and soft scalded uncontaminated skin were scanned with an NIRSystems 6500 monochromator (McGee, U.S. Pat. No. 4,969,739, herein incorporated by reference). Spectra were recorded from about 400 nm to about 2500 nm in about 2-nm intervals and analyzed from about 400 nm to about 900 nm. Samples of uncontaminated breast skin were presented in cylindrical sample cells (internal diameter-about 38 mm; depth-about 9 mm) with an optical quartz surface and a cardboard backing. Samples of pure feces were presented in cylindrical sample cells (internal diameter-about 38 mm; depth-about 0.1, 0.2, or 0.3 mm) with an optical quartz surface and a locking back. Each sample was scanned about 32 times, averaged and transformed to log ($1/R_1$), where R is reflectance. FIG. 5 is the reflectance spectra of uncontaminated poultry carcass breast skin (hard and soft scalded), and pure feces from different sites in the digestive tract. Samples 5.1 and 5.2 are uncontaminated breast skin subjected to hard and soft scald treatments, respectively. Samples 5.3-5.5 are pure feces from the duodenum (5.3), colon (5.4), and ceca (5.5).

A commercial spectral analysis program (NIRS3, Infrasoft International, Inc., Port Matilda, Pa.) was used to collect the spectra of pure contaminates and uncontaminated poultry carcass skin and for principal component analysis (PCA). The spectral data set (n=76 uncontaminated hard and soft scalded skin; N=42 duodenum; N=37 ceca; and N=25 colon) was transformed with standard normal variate and de-trending procedures to remove the interference of light scatter from the skin and differences in pathlength due to sample thickness. The spectra were mean centered and reduced by PCA. Translated into principal components, the new coordinate system has fewer dimensions than the original Vis/NIR data set, and the directions of the new coordinate axes (called principal components) were chosen to describe the largest variations.

The PCA algorithm creates scores, which represent the position of samples relative to the principal components. For each principal component, scores are derived by taking the sum across the spectrum of weights times the log (1/R) values. The corresponding relationship between the Vis/NIR spectra and the principal components are called loadings. Plots of loadings often resemble the spectra of samples and thus offer scope for interpretation. Four principal components were used in the PCA. The components explained about 99.8% of the Vis/NIR spectral variation. FIG. 6 shows a clear discrimination between uncontaminated skin and feces using principal components 1, 2, and 4. Principal component 1 (PC 1) was primarily responsible for the separation of uncontaminated skin (FIG. 6, 6.1 hard and soft scald), from duodenum (FIG. 6, 6.2), colon (FIG. 6, 6.3), and ceca (FIG. 6, 6.4). Uncontaminated skin had negative scores for PC 1, whereas pure feces had positive scores for PC 1. Loadings are the regression coefficients for each Vis/NIR wavelength for each principal component and indicate which wavelengths are dominantly influencing the discrimination. From PC analysis, four key wavelengths were identified for discrimination of uncontaminated skin from pure feces based on the loadings.

FIG. 7 shows the loadings for PC 1, PC 2, and PC 4 as a function of wavelength. Key wavelengths are identified by maximum loadings at about 565 nm for PC 1 (FIG. 7, 7.1), about 434 and 517 nm for PC 2 (FIG. 7, 7.2), and about 628 nm for PC 4 (FIG. 7, 7.3). These key wavelengths were selected and applied to hyperspectral images of uncontaminated and contaminated carcasses.

EXAMPLE 3

Spectral calibration was performed to correlate absolute wavelength data from known spectral light sources of Mercury Argon (HgAr) and Krypton (Kr) gas emission calibration lamps (Model 6035 and 6031, Oriel Instruments, Stratford, Conn., respectively), and Helium-Neon lasers, to the 512-hyperspectral image bands (1024 pixels with a binning of 2) obtained from the CCD detector la. FIG. 8 shows the data and the non-linear calibration for the hyperspectral imaging system 10, which was used to correlate the band numbers of the hyperspectral images to the actual wavelengths. The wavelength calibration equation for hyperspectral imaging system 10 is as follows:

Wavelength (nm)=380.277+0.905+(4.369×$10^{-4}$) $X^2$ -(4.356×$10^{-7}$)$X^3$ ($r^2$ =0.9999)

where X is the band number ranging from about 0 to about 511.

EXAMPLE 4

Immediately after processing, as in Example 1, carcasses, fecal, and ingesta samples were used for image acquisition. Carcasses were contaminated with feces from the duodenum, ceca, and colon, and ingesta with varying contaminate size and location. Carcasses were imaged in a shackle welded to a stainless steel rod, suspended across two stands. A laser beam was used to align fiber-optic line-light propagation to make light propagation on the carcasses as diffuse as possible. Light intensity and distribution on the carcasses were measured and optimized with a digital intensity meter (Mavolux 5032C, Gossen, Germany) before image data were collected. Carcasses were imaged with hyperspectral imaging system 10 with 4 by 2 binning and SensiCam™ software with the following control settings: actual image size of about 320 (horizontal) by about 340 (vertical) pixels spatial resolution, and about 512 wavelengths spectral resolution. The spectral resolution of hyperspectral images was approximately 0.9 nm. The exposure time and delay time of camera control during image acquisition were about 50 msec. and zero, respectively. Even though scanning time depends on the size of a carcass and image resolution, the average time to scan a whole carcass was about 34 seconds. Hypercube image files were created from line scan image data with HyperVisual software (ProVision Technologies, Stennis Space Center, Miss.), which converts 16-bit binary data into binary sequence mode data for hyperspectral image processing. First, hyperspectral images of uncontaminated carcasses were collected. Then, carcasses were contaminated with feces and ingesta varying in type of contaminant, contaminant spot size, and location on the carcass. Hyperspectral images and spectral image files were further processed, analyzed, and displayed using Environment for Visualizing Images (ENVI) software (Research Systems, Inc., Boulder, Colo.).

FIG. 9 shows spatial images at some selected spectral wavelengths acquired by the hyperspectral imaging system 10 to demonstrate image quality and spectral differences. The spectral images less than 400-nm wavelengths contained noise compared with others, because the grating diffraction efficiency of the system below about 400 nm is less than about 30% and the nominal spectral range of spectrograph is between about 430 nm to about 900 nm. The fecal (top three rows on carcass) and ingesta spots (bottom row on carcass) on each carcass were displayed distinctively up to about 517 nm. However, the spots of duodenum and ingesta began to disappear as the wavelengths increased beyond 517 nm. Feces from the ceca were clearly found over all the wavelength spectral images. Thus, spectral images selected from hypercube image data were useful for the identification of feces and ingesta contamination on the poultry carcasses.

EXAMPLE 5

Using the wavelength calibration from example 3, the key wavelengths of about 434 nm, 517 nm, 565 nm, and 628 nm, identified with the Vis/NIR monochromator, corresponded to band numbers 58, 143, 190, and 251. FIGS. 10a-e show an approximate color composite (Red: 634 nm; Green: 520 nm; Blue: 446 nm) image and four spectral images at key wavelengths (434, 517, 565, and 628 nm) of a poultry carcass contaminated with feces (duodenum, ceca, colon) and ingesta. Cecal feces were detected from the raw spectral images from the four selected wavelengths including the false color image. However, it was difficult to detect feces from duodenum and ingesta samples with the about 565 nm and about 628 nm spectral images. With a single wavelength image, uncontaminated dark areas in the leg and wing folds were incorrectly identified as contaminates.

Two wavelength ratio images were determined from the four key wavelengths above. Six ratio images were obtained from the combination of different key wavelengths as shown in FIGS. 11a-f. Among ratio images, the image at 565 nm divided by the image at 517 nm could identify feces (duodenum, ceca, and colon) and ingesta contaminants including colon feces located below the tail as shown in FIG. 11d. The ratio images of the image at 517 nm divided by the image at 434 nm (FIG. 11a), the image at 565 nm divided by the image at 434 nm (FIG. 11b), and the image at 628 nm divided by the image at 434 nm (FIG. 11c) show distinctive ceca (dark spots on the body) contamination. However, other contaminated spots of duodenum, colon, and ingesta were not readily apparent. Even though the image at 628 nm divided by the image at 517 nm (FIG. 11e) shows all the contaminated spots on the body, other white spots under the wings and the area between the legs caused false positive errors. Similarly, as seen on the image at 628 nm divided by the image at 565 nm (FIG. 11f), false positive contamination between the carcass legs were actually caused by skin cuticle or blood hemorrhages on the skin of the carcass.

Other contaminated carcasses showed this algorithm could detect contaminates of different sizes at different locations. As shown in FIG. 12, blood clot (FIG. 12, 12a.1) in the color composite disappeared (FIG. 12, 12b.1) after the image ratio algorithm was applied. In addition, this algorithm could detect fecal contaminant in the shadow of the wing fold (FIG. 12, 12a.2) in the composite image; (FIG. 12, 12b.2 in the ratio image). Thus, image-ratio algorithm, particularly 565-nm and 517-nm wavelengths, identified fecal and ingesta contaminants on the surface of poultry carcasses extremely well, while minimizing false positive contaminates.

EXAMPLE 6

The background of the original two-wavelength ratio image is noisier than the chicken body and contains no useful information. To eliminate the background, a masking procedure was implemented for further processing to segregate the ratio image of a carcass from the background. To build a masking template for each carcass (FIG. 13a), a single spectral image was selected from the 512-hyperspectral images. For example, a template (FIG. 13b) was created by thresholding an image at 565 nm. Intensities below a minimum thresholding value of about 120, which corresponded to the background, were then assigned a value of zero. FIG. 13c shows the ratio image after the masking procedure was applied. It was obvious that the masking procedure made the spots of contamination on the carcass more visually distinctive.

EXAMPLE 7

After eliminating the background noise with a masking procedure, a histogram stretching algorithm was used to separate feces and ingesta contaminates from a carcass as shown in FIG. 14a. Both linear and nonlinear histogram-stretching algorithms were tested. As shown in FIG. 14b, top center white portion of vent area indicates natural contamination of colon feces (FIG. 14, 14b.1); the second row represents duodenum (FIG. 14, 14b.2); third row represents ceca (FIG. 14, 14b.3); fourth row represents colon feces (FIG. 14, 14b.4); and fifth row represents ingesta contaminates (FIG. 14, 14b.5), respectively. From numerous ratio images of both hard and soft scalded carcasses, parameter values of histogram-stretching algorithm for the sample in FIGS. 14a and 14b were determined as follows: minimum input=about 1.28; maximum input=about 1.60; minimum output=about 0.75; maximum output=about 2.38. These parameter values force intensities below 1.28 to have a display value of zero, intensities between 1.28 and 1.60 to have display values that linearly vary from zero to full scale, and intensities above 1.60 to have display values at full scale.

EXAMPLE 8

The hyperspectral image processing algorithms (ratio of two-wavelength images) demonstrated in the previous examples were tested with sixteen poultry carcasses. As shown in Table 2 below, the histogram stretching algorithms were accurate for both the linear and nonlinear models. Even though threshold values of each sample varied slightly, the mean minimum and maximum input threshold values were about 0.76 (Standard Deviation (S.D.)=about -0.03) and about 2.29 (S.D.=about 0.25). For the linear model, the mean minimum and maximum values were about 1.25 (S.D.=about 0.05) and about 1.69 (S.D.=about 0.08), respectively. For the square-root model, the mean minimum and maximum values were about 1.39 (S.D.=about 0.06) and about 1.55 (S.D.=about 0.13), respectively.

The square-root model of histogram stretching performed perfectly for identifying fecal and ingesta contaminants. However, the linear model missed several contaminant spots (chicken sample #2, #3, and #7).

TABLE 2

Threshold values of histogram stretching for segregating feces and ingesta from chicken carcasses.

| | | | Output | | | | Number of Contaminants | |
|---|---|---|---|---|---|---|---|---|
| | Input | | Linear | | Square root | | Predicted | |
| Sample ID | Min. | Max. | Lower | Upper | Lower | Upper | Linear/Square | Actual |
| Chicken#1 | 0.77 | 2.62 | 1.20 | 1.88 | 1.34 | 1.38 | 9/9 | 9 |
| Chicken#2 | 0.77 | 2.03 | 1.28 | 1.80 | 1.38 | 1.46 | 8/9 | 9 |
| Chicken#3 | 0.76 | 2.22 | 1.20 | 1.80 | 1.30 | 1.94 | 7/9 | 9 |
| Chicken#4 | 0.72 | 2.28 | 1.26 | 1.60 | 1.36 | 1.56 | 10/10 | 10 |
| Chicken#5 | 0.80 | 2.10 | 1.20 | 1.70 | 1.36 | 1.46 | 9/9 | 9 |
| Chicken#6 | 0.75 | 2.33 | 1.28 | 1.60 | 1.36 | 1.46 | 11/11 | 11 |
| Chicken#7 | 0.74 | 2.01 | 1.26 | 1.60 | 1.30 | 1.40 | 6/8 | 8 |
| Chicken#8 | 0.80 | 2.30 | 1.20 | 1.70 | 1.46 | 1.56 | 12/12 | 12 |
| Chicken#9 | 0.74 | 2.46 | 1.30 | 1.70 | 1.50 | 1.60 | 14/14 | 14 |
| Chicken#10 | 0.74 | 2.06 | 1.34 | 1.70 | 1.46 | 1.56 | 16/16 | 16 |
| Chicken#11 | 0.76 | 2.14 | 1.20 | 1.64 | 1.41 | 1.51 | 16/16 | 16 |
| Chicken#12 | 0.74 | 2.51 | 1.30 | 1.64 | 1.44 | 1.57 | 14/14 | 14 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Chicken#13 | 0.73 | 2.18 | 1.20 | 1.68 | 1.40 | 1.50 | 13/13 | 13 |
| Chicken#14 | 0.80 | 2.96 | 1.30 | 1.66 | 1.36 | 1.50 | 12/12 | 12 |
| Chicken#15 | 0.80 | 2.13 | 1.28 | 1.60 | 1.40 | 1.60 | 12/12 | 12 |
| Chicken#16 | 0.73 | 2.34 | 1.20 | 1.74 | 1.44 | 1.66 | 16/16 | 16 |
| Mean | 0.76 | 2.29 | 1.25 | 1.69 | 1.39 | 1.55 | | |
| Std. Dev. | 0.03 | 0.25 | 0.05 | 0.08 | 0.06 | 0.13 | | |

EXAMPLE 9

FIG. 15 shows the comparison of intensity distribution between a clean and contaminated carcass to demonstrate the performance of the masking procedure and the threshold algorithm. As shown in FIGS. 15a-e, there were no readily apparent differences of the intensity distribution of the original ratio images between the clean (FIG. 15a) and fecal and ingesta contaminated (FIG. 15d) carcass. Masking makes the carcass outline apparent (FIGS. 15b and 15e), but little distinctive between the contaminated and uncontaminated carcass can be seen. After the thresholding algorithm was applied, intensities above the threshold are shown in FIG. 15c for the clean bird disappeared; whereas the peak intensities above the threshold in FIG. 15f indicated the spots of feces and ingesta on the carcass. Therefore, the threshold algorithm can be further applied for the automatic detection of fecal and ingesta contaminants on poultry carcasses in conjunction with masking and the optimum threshold parameter values.

The foregoing detailed description is for the purpose of illustration. Such detail is solely for that purpose and those skilled in the art can make variations therein without departing from the spirit and scope of the invention.

Index of the Elements

1A. Charge-Coupled Device Detector

1B. Lens Assembly

1C. Spectrograph

2. Lighting System

2A. Fiber Optic Cable

2B. Lamp Assembly

2C. Power Supply for Lighting

4. Power Supply for at least one Charge-Coupled Device Detector

5. Battery Backup

6. Computer Monitor

7. Computer

7A. Interface Cable

9. Data Processing Unit

10. Imaging Systems

12. Means for Obtaining Spectral Images

17. Frame Grabber

19. Software

20. Algorithm

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