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World Best Industry Practice in Objective Prediction and Management of Dark Cutting in Beef Cattle in Meat Processing Facilities

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Contents

Executive Summary

Findings

- World strategies for the control of dark cutting in beef cattle are:
  a) Management of the factors that produce dark cutting in beef cattle,
  b) Sorting of groups of beef cattle based on animal history, and
  c) Sorting of individual beef cattle based on physiological or behavioural indicators.

- Information from international sources indicates that Australia is foremost in industry-wide schemes for the management of dark cutting. This is due to the activities of Meat and Livestock Australia (MLA) and adoption by the beef industry of schemes such as Meat Standards Australia (MSA), MSA-like stress management strategies and the use of educational packages such as "Preventing dark cutting in livestock" (MLA).

- No industry-wide, organised, dark cutting management systems were found in the USA, Canada, UK or continental Europe.

- In spite of Australia having the World Best Industry Practice in pre-slaughter stress management, a small, but economically very significant, proportion of cattle continue to present for slaughter in a stressed condition.

- Sorting schemes based on animal history allow the assessment of groups of cattle prior to slaughter and will supplement stress management strategies. However, they will not eliminate a small residual of dark cutters because of individual animal variation and such schemes will be economically difficult to implement because of the cost of remediation of groups of cattle.

- A method of assessing and managing pre-slaughter stress in individual animals will reduce the incidence of dark cutting below the level achievable by management or sorting alone.

- A predictive test for dark cutting must be non-invasive, quick, automated and directly linked to the physiological causes of dark cutting.

- The only technology for the physiological assessment of individual pre-slaughter stress that was found being developed in the USA, Canada, UK, continental Europe or Australia was infrared thermography.

- US patent, 5,595,444 "Method for detecting poor meat quality in groups of live animals", outlined the essential elements for the physiological prediction of dark cutting using infrared thermography but this method did not predict individual dark cutters.

- The Canadian group that developed the thermography patent is continuing their research into the method and has progressed towards a commercially viable technology.

Recommendations

1. That the MLA continues promoting pre-slaughter stress management strategies such as the "Preventing dark cutting in livestock" package and the MSA technology.

2. That the Australian Meat Processors Corporation (AMPC) develops and promotes group-sorting schemes based on animal history. Such methods could provide a computerised assessment of the probability of a mob having a high incidence of dark cutting. It could be used by processors before accepting consignments of cattle.

3. That the AMPC/MLA undertakes research into the prediction of dark cutting in individual animals. The most promising technology for this purpose at the moment is infrared thermography as being developed by the Agriculture and Agri-Food Canada (AAFC) group in Lacombe, Canada.

4. That the AMPC/MLA negotiates a commercial arrangement with the AAFC group to establish a stake in their technology. Such an arrangement might include direct financial support of the project, sponsorship of Australian participation in the project (eg. Travel Grant), and/or support for complementary projects in Australia.

5. That the AMPC/MLA adopts minimum performance criteria for individual assessment methods such as thermography. Suitable tolerances would be 90% accuracy in correctly identifying stressed cattle and 99% accuracy in correctly identifying unstressed cattle. At these levels of performance, the Australian beef industry would save more than A$45M annually because of reduced losses from dark cutting.

6. That the AMPC/MLA support research to evaluate the most effective and economic diversionary strategies for cattle identified as having a high probability of dark cutting.

7. That the AMPC/MLA support research to evaluate the effectiveness of combined strategies for the management of dark cutting.

8. That the AMPC/MLA support research into alternative technologies for the assessment of physiological stress in individual animals. These could be useful in the prevention of dark cutting and in other applications where the assessment of stress would be useful (eg. live export). Faecal cortisol may be a useful predictive test for dark cutting if a quick, non-laboratory method of analysis can be devised.

The Issue

The AMPC/MLA and the Australian Beef Industry are well aware of the economic costs of dark cutting and pre-slaughter stress. Consequently, justification for studies into dark cutting will not be addressed in detail in this report.

The proportion of cattle presenting for slaughter in a stressed state is highly variable and the data are not freely available as most meat processors regard the issue as commercial-in-confidence and will not allow reporting. Published accounts present a wide range of incidence levels from <1% to 40% with common values in the 5-20% range[1,2,3]. The cost of downgrading is reported to be $0.45 or $0.50 per kilogram of carcase weight and the total overt cost to the Australian industry is estimated at more than $36M per year. This cost doesn't include the economic cost of disaffected customers who consume substandard product.

History of dark cutting research and management

The study of the underlying causes of dark cutting and, subsequently, the causes and management of pre-slaughter stress by the national and international beef industry has a decades-long history. Much of the local effort has been supported and promoted by the MLA and its predecessors. A definitive report produced by the AMLRDC in 1989 summarised world knowledge to that date[4]. The report presented the mechanism of development of dark cutting and left no doubt regarding the links between pre-slaughter stress, glycogen depletion, pH and dark cutting. This is knowledge which does not have to

[1] Stevenson, C. R., Knee, B. W., Philpotts, A. C. and Warner, R. C. 1996. Investigation of dark cutting in beef carcases. *Proc. Aust. Soc. Anim. Prod.* **21**, 147-150.
[2] Taylor, C. 2000. Dark cutting at what cost? *Beef Improvement News* **July/August 2000**, 28-29.
[3] Weber, K. 1995. pH audit could lead to "preferred" producers, carriers. *Beef Improvement News* **November 1995**, 20.
[4] Dark Cutting in Cattle and Sheep. Proceedings of an Australian Workshop. August 1988. Ed. S. U. Fabiansson, W. R. Shorthose and R. D. Warren. AMLRDC, 1989, Sydney.

be revisited and will not be repeated in this report. Since the 1989 report, only two major advances have been made in the knowledge and management of dark cutting.

The Cooperative Research Centre for Cattle and Meat Quality (CRC) established the post-slaughter pH-temperature window for guiding the application of electrical stimulation[5] and the Meat Standards Australia (MSA) program successful demonstrated industry guidelines for pre-slaughter handling of cattle to minimise stress. Both these advances are described in the AMPC/MLA Processing and Product Innovation package[6], "Preventing Dark Cutting in Livestock", which is arguably, based on personal communications with world authorities (listed in the Appendices), World Best Industry Practice in dark cutting management.

Current research

Causative factors and indicators

Recent research into the prevention of dark cutting has continued studies on the effects of known related factors such as handling, breed, sex, transport, age, mixing, fasting, cold, heat, dehydration, supplements, electrolytes and pre-slaughter feeding on glycogen levels, pH and dark cutting (ABOA and other sources). Current thinking is that, with better understanding of these factors, better management practices can be adopted to minimise dark cutting via schemes such as MSA.

It is possible that better knowledge of animal history may be used to systematically predict the dark cutting status of groups of cattle before slaughter. Opinion is that such sorting strategies are unlikely to reduce overall dark cutting below 1-2% of slaughtered animals but they will be very useful in areas, or at times, where dark cutting rates are above this level. In Canada, the application of such a sorting system, the Kansas State University

[5] Hwang, I. H., Hearnshaw, H., Shaw, F. D. and Thompson, J. M. 1998. The interaction between the type (high or low voltage) and time (3 or 40 minutes post-stunning) of electrical stimulation on beef. *Proc. 44th ICOMST, Barcelona* **44**, 1052-1053.
[6] Preventing Dark Cutting in Livestock. 2000. Meat and Livestock Australia, Sydney.

sorting system, reduced dark cutters from 1.3% to nil[7]. However, it is not clear what diversionary corrective measures may be economically applied to groups of cattle that are judged to have a high probability of dark cutting. For abattoirs, it would be useful to apply the sorting system before consignment.

Immunisation to prevent dark cutting has been considered (Dr Ron Hoskinson, personal communication). A continuing area of interest is pre-slaughter feeding to elevate pre-stress muscle glycogen levels. Post-stress glycogen levels and post-slaughter residual glycogen levels[8] are also an area of continuing study.

A worldwide search of the literature and personal communications with international researchers has revealed no novel approaches to the prevention of dark cutting.

Invasive and behavioural indicators of stress and metabolism

An area of past and current interest is the study of indicators of the stress or metabolic status of pre-slaughter animals based on various biochemical, physiological and behavioural measurements. Circulating stress hormones, blood metabolites and enzymes are common targets that require invasive procedures such as collection of blood samples. Live animal muscle glycogen measurement, which requires muscle biopsy, is extremely invasive. Some measurements of thermogenesis, where thermometers are applied to the animal, disturb the animal and so can be regarded as invasive.

Assessment of stress using behaviour for the purpose of prediction of dark cutting is not well established, requires expert staff and is time consuming. The only approach that offers limited viability is the video taping of individual animals in lairage and individual assessment by expert staff (Dr Carol Petherick, personal communication). Acute stress is relatively easy to recognise. It is indicated by behaviours such as adopting various postures, trembling, vocalisation, frenzy, aggressiveness and defaecation[9]. Chronic stress is difficult to assess using behavioural criteria and it may be masked by adaptation in behaviour[9]. Such behavioural observations may be further complicated by the phenomenon

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[7] Basarab, J. A., Brethour, J. R., Zobell, D. R. and Graham, B. 1999. Sorting feeder cattle with a system that integrates ultrasound backfat and marbling estimates with a model that maximizes feedlot profitability in value-based marketing. *Can. J. Anim. Sci.* **79**, 327-333.

[8] Immonen, K. and Puolanne, E. 2000. Variation of residual glycogen-glucose concentrations at ultimate pH values below 5.75. *Meat Science* **55**, 279-283.

of learned helplessness where the animal copes with stress by not responding to stimuli. Stress may be indicated by the absence of normal self-maintenance or comfort behaviours such as grooming. The absence of play is also indicative of stress as is non-conformity to group activity patterns such as eating, resting and rumination. Therefore, while it is possible to assess stress using behavioural observations, the area is complex and requires expert attention.

In the context of an industrial situation where animal handling must be minimised, and test result turnover must be maximised, all of these invasive, laboratory-based and expert observational strategies are not viable as technologies for the individual management of dark cutting.

Non-invasive and remote indicators of stress

Literature searches (see Appendices for sources of information) find reports of some non-invasive indicators of stress that have shown promising results. These are heart rate (remote monitoring), faecal cortisol, salivary cortisol, salivary enzymes, tympanic temperature (remote monitoring) and infrared thermography. The Cooperative Research Centre for Cattle and Meat Quality is undertaking studies of real time ECG and remote body and skin temperature (sensors) measurements (Dr Drewe Ferguson, personal communication). Heart rate, tympanic temperature and salivary analyses, although good measures of stress, are too immediate to be useful in the context of dark cutting since an animal may have been stressed some three days before slaughter and still be in a state of depleted muscle glycogen. Faecal cortisol metabolites[10,11,12] reflect previous stress and provide some integration of the effect over time so they could be useful in the context of dark cutting. However, the analysis of the faecal cortisol metabolites is a laboratory test and thus too slow for useful industrial application.

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[9] Friend, T. H. 1991. Behavioural aspects of stress. *J. Dairy Sci.* **74**, 292-303.
[10] Palme, R., Robia, C. Messmann, S., Hofer, J. and Mostl, E. 1999. Measurement of faecal cortisol metabolites in ruminants: a non-invasive parameter of adrenocortical function. *Weiner Tierarztliche Monatsschrift* **86**, 237-241.
[11] Stead, S. K., Meltzer, D. G. A. and Palme, R. 2000. The measurement of glucocorticoid concentrations in the serum and faeces of captive African elephants (Loxodonta africana) after ACTH stimulation. *J. South African Veterinary Medical Association* **71**, 192-196.
[12] Tesky-Gerstl, A., Bamberg, E., Steineck, T. and Palme, R. 2000. Excretion of corticosteroids in urine and faeces of hares (Lepus europaeus). *J. Comparative Physiology - B* **170**, 163-168.

Some effort spent on developing a quick faecal cortisol metabolite test could be productive.

The industrial requirement in predicting dark cutting is for an automated, or semi-automated, technology that is not invasive, is quick and measures a physiological response that is directly linked to dark cutting. Subsequent sections in this report strongly suggest that infrared thermographic analysis may meet all these requirements.

Livestock stress management standards and systems

Australia

Recently, the MLA has produced a comprehensive educational package outlining the management of pre-slaughter stress[6]. This package is based on MSA research and other experience. Opinion is that this package represents the current World Best Industry Practice for management of dark cutting (personal communications see Appendices). The package, and its history and development, are well known within the AMPC/MLA and the Australian Beef Industry and will not be further discussed here. Individual meat processors and large retailers have in-house standards and systems for quality assurance, some of which include management strategies that minimise dark cutting. These are based on the well-known factors that cause dark cutting (previous section) and do not need elaboration here. Opinion is that none of these systems will reduce the incidence of dark cutting to zero and the most likely best result is something around 1-2% incidence dark cutting (various sources, personal communications).

International

Research reports in the USA and Canada typically refer to dark cutting rates of one percent or less[7,13]. Industry reports refer to levels up to two percent[14]. These relatively low levels, compared to Australia, appear to be due to the feeding regime and the production system adopted in North America rather than any organised industry-wide management system for

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[13] Kriekemeier, K. K., Unruh, J. A. and Eck, T. P. 1998. Factors affecting the occurrence of dark cutting beef and selected carcase traits in finished beef cattle. *J. Anim. Sci.* **76**, 388-395.
[14] National Cattlemen's Beef Association, Research Summaries, Product Enhancement (www.beef.org).

reducing dark cutting. The factors related to dark cutting identified in the USA are the same as those recognised in Australia. In the 1991 National Beef Quality Audit, dark cutting was only the 10th most important concern for processors and the 7th for consumers in the USA. In the UK, frequencies of dark cutting are up to 5% for steers, up to 10% for heifers and up to 15% for bulls[15]. A recent survey at one abattoir in the UK had frequencies of 2.6%, 2.5% and 6.5% for steers, heifers and bulls, respectively (anon, personal communication). No beef industry in either North America or Europe has a systematic program for industry-wide management of dark cutting (personal communications, see Appendices for contacts). Any advances made in Australia will put the Australian beef industry further ahead of international competitors in the development and adoption of dark cutting management systems.

Legislative and regulatory performance benchmarks

Research

Experimentation with cattle will be subject to approval by the local Animal Experimentation Ethics Committee. Any experimentation and validation with infrared thermography of beef cattle that is outside normal production practices will require approval.

Operations

Disclaimer: The following is not legal advice. It is the opinion of the authors, and others with whom they have consulted, none of whom are legally qualified. No claim is made by the authors as to its validity. Users of the proposed technology should seek their own legal advice.

It appears that thermography will not contravene the current Queensland legislation (Animal Care and Protection Act 2001 and Animals Protection Act 1925) or the Australian Model Code of Practice for the Welfare of Animals. Thermography will not exempt the works from any regulatory requirements currently in force with regards to meat processing or animal welfare.

The thermography procedure does not impact on the animal directly and only a minor increase in handling may be required. Some restraint may be required but this will fall well

[15] Zerouala, A. C. and Stickland, N. C. 1991. Cattle at risk for dark cutting have a higher proportion of oxidative muscle fibres. *Meat Science* **29**, 263-270.

within normal practice. It is unlikely that there will be any public or animal activist objection to the use of infrared thermography as the procedure does not differ from the simple process of taking a video image of the animals. The technology is familiar to the public as it has received media exposure in its medical usage with humans and in leisure activities such as the assessment of outdoor heaters by the television show, Burke's Backyard.

The case for individual objective measurement

The principal strategy in dark cutting management in use to date is the adoption of best practice pre-slaughter handling and management procedures including pre-slaughter feeding strategies. While better pre-slaughter handling of cattle alleviates some stress-induced problems, it is neither 100% effective nor does it provide the opportunity for remedial action for animals that are stressed in spite of the efforts made. Practical and economic considerations restrict the application of this strategy to groups of cattle.

A scheme which incorporates stress minimisation management is MSA. Figures on dark cutting are not publicised so it is difficult to assess the impact of MSA management strategies on dark cutting. Very early figures on 1112 steers collected during the development of MSA gave an incidence of high pH (above 5.8) of 7.5% but it is not clear what management these cattle had received. It is expected that MSA cattle would have a much lower incidence today. Published results of industry performance in dark cutting management are variable with individual lots ranging from 0% to 40% with values commonly in the 5 - 20% range[1,2,3]. It may be reasonable to assume that well managed cattle would give an incidence at the lower end of this range, possibly 2 - 5%.

At a 5% overall incidence level of dark cutting, the slaughter of 7.52M cattle producing 1,952M kg of meat (ABS figures for 1999-2000) with a discount of A$0.50 per kg would result in an annual cost to the industry of more than A$49M which is in good agreement with other estimates (A$36M pa based on $0.45 discount and unknown slaughter numbers[2]). If pre-slaughter management can reduce the incidence to 2%, then the annual saving would be of the order of A$29M. However, the cost of implementing an MSA pre-slaughter management strategy is not negligible and there is a shift from a principally processor cost to a combined processor and producer cost.

A refinement to the pre-slaughter management approach is the sorting of mobs of cattle based on objective assessment and evaluation of all factors affecting dark cutting. The assessment is computerised and is used to predict the probability of a certain level of dark cutting in a group of cattle. Pre-slaughter assessment and sorting of cattle for probability of dark cutting based on treatments and behaviour of groups will miss individuals who are outliers in the group. The procedure could possibly reduce dark cutting to the 1-2% incidence level in Australia (anon, personal communication) although overseas experiments with group sorting, where incidence rates started very low, produced a zero incidence of dark cutting[7]. The problem of what to do with mobs that are assessed as having a probability of high levels of dark cutting remains. Within any group there will be a range of individual responses to management and treatments so that any sorted group selected for slaughter will contain animals that will cut dark, say 1%, and any sorted group selected for remediation will contain animals that would not have cut dark if slaughtered, say 90%. It would be uneconomical to feed a large group of cattle simply to eliminate a proportion, say 10%, of dark cutting. From the processors' point of view, an assessment prior to taking the cattle would be useful but this would be a complicated issue.

Advances beyond the reductions in dark cutting produced by the pre-slaughter handling and group sorting strategies will be made by the individual identification of stressed cattle, pre-slaughter, so appropriate remediation can be applied to individual animals. With the identification of individual highly stressed animals, individuals can be diverted to rest and feeding, thereby recovering the value of costly inputs such as 90 days grain feeding. Other, less highly stressed, animals can be categorised for differing management with regards to electrical inputs during processing so that the maximum amount of high quality meat can be produced. The most effective and most economical diversions and treatments can be studied and implemented after a method of individually identifying stressed animals is developed.

After the application of stress minimisation management and, possibly, some group sorting of cattle, the base level of dark cutting may be around 1%. Individual assessment can be applied to this base level for improved economic performance. Even if the individual procedure is only 90% effective in identifying stressed animals then the residual incidence of dark cutting, on a base of 1% dark cutting, will be 0.1% (ie. 0.10 x 1%) which, using the same procedure to calculate costs above, would reduce the total cost to the Australian industry of dark cutting to $1M pa. If it was 99% effective then the total cost to industry would be reduced to a mere $0.1M pa.

For individual objective assessment to be economical it is necessary to minimise the incidence of cattle mistakenly identified as potentially dark cutting. As the abattoir will have already taken delivery of the cattle, the critical factor in costs is the error rate in incorrectly identifying non-dark cutters as stress affected. If this error rate is 1% then 75,000 cattle (0.01 x 7.52M) would unnecessarily be remediated which could involve up to 3 days feeding in lairage. Costs include handling, lairage space and feed. At a cost of $30 per animal for remediation, the total remediation cost of about $2.25M still means there would be a saving of $7M - $8M for the industry beyond the savings produced by pre-slaughter management and sorting alone. The total savings of all three dark cutting management strategies will be over $45M pa allowing for costs and unnecessary remediation.

The minimum specifications for performance for any technology used to individually identify dark cutters should be:

(a) Incorrectly identifying stressed as unstressed - less than 10%

(b) Incorrectly identifying unstressed as stressed - less than 1%

Any performance in excess of the above would be welcome but care must be taken that the extra costs of development and operation do not exceed gains from lowered dark cutting and remediation costs. A reduction of (a) from 10% to 1% would save $0.9M pa and a reduction of (b) from 1% to 0.1% would save $2M pa.

Physiology of post-stress recovery

Stress

The physiological effects of stress in cattle, both during the stress period and during the recovery period, are highly individually variable[16]. The physiological responses of cattle to stress are similar to those of other mammals with transient changes in behaviour, thermogenesis, respiration, vascular function, cardiac function and hormone production[15,17,18,19,20]. The situations that trigger rapid glycogen depletion[21] are the same as those that cause energy expenditure and thermogenesis. While the identification of stress at the time it is occurring may be predictive of future dark cutting, the industrial situation is that cattle are usually in a post-stress recovery period at slaughter. Indicators are required which estimate the severity of previous stress and the extent of recovery from that stress. The two promising indicators that have been identified are faecal cortisol metabolites[10,11,12] and changes in thermogenesis[24]. The faecal cortisol metabolite method suffers from lack of a suitable assay method and this could be a future research project.

Post-stress recovery

Post-stress recovery in humans and other mammals cannot be related directly to cattle. While post-stress recovery takes several days in cattle, the post-stress recovery period in other mammals is short, with muscle glycogen levels being repleted within minutes[20]. During stress additional heat is produced and blood vessels are dilated so this heat can be carried to the surface and removed by radiative, convective and evaporative loss[22,23]. In

[16] Hahn, G. L., Chen, Y. R., *et al*.,. 1992. Characterizing animal stress through fractal analysis of thermoregulatory responses. *J. Therm. Biol.* **17**, 115-120.
[17] Grandin, T. 1997. Assessment of stress during handling and transport. *J. Animal Science* **75**, 249-257.
[18] Cooper, C., Evans, A. C. O., Cook, S. and Rawlings, N. C. 1995. Cortisol, progesterone and beta-endorphin response to stress in calves. *Can. J. Anim. Sci.* **95**, 197-201.
[19] Shaw, F. D. and Tume, R. K. 1992. The assessment of pre-slaughter and slaughter treatments of livestock by measurement of plasma constituents - A review of recent work. *Meat Science* **32**, 311-329.
[20] Lister, D., Gregory, N. G. and Warriss, P. D. 1988. Stress in meat animals. In "Developments in Meat Science" (Ed. R. Lawrie). pp. 61-91. Elsevier Applied Science. London.
[21] Tarrant, P.V. 1988. Animal behaviour and environment in the dark cutting condition. In "Dark Cutting in Cattle and Sheep. Proceedings of an Australian Workshop. August 1988". (Ed. S. U. Fabiansson, W. R. Shorthose and R. D. Warren). AMLRDC, 1989, Sydney.
[22] Blaxter, K. L. 1962. The energy metabolism of ruminants. Hutchinson Scientific and Techn. London.

cattle, regionalised vascular dilation is seen during heat loss and regionalised vascular contraction is seen during periods of heat retention and/or dehydration. In cattle the post-stress recovery period is long with muscle glycogen repletion taking up to three days[20]. During this period it is possible that thermogenesis is reduced and heat loss is minimised by localised vasoconstriction[24,25]. If the stress is associated with dehydration, then this may also alter the blood flow pattern as seen in humans[26]. Vasoconstriction and low skin temperature is seen in cattle in haemorrhagic shock[27]. Therefore, it is possible that the degree of vasoconstriction, as evidenced by the dermal heat loss pattern on selected parts of the cattle body, is indicative of the degree of previous stress and the extent post-stress recovery.

Infrared thermography

It is proposed to visualise the heat loss pattern of post-stress cattle using infrared thermography. Infrared thermography is widely used in industrial situations (power industry, railways) and in human and veterinary medicine. A summary of Medical Infrared Digital Imaging (MIDI - also known as Thermography) was supplied by Pip McCahon (Medical Infrared Digital Imaging Pty Ltd, Unit 6 Southern Cross House, 9 McKay Street, TURNER ACT 2612) and is presented in the Appendices.

The only published reports of infrared thermography technology used in identifying previously stressed cattle are reports of thermographic studies of stressed cattle published by one group in Canada[24,25]. The 1995 report clearly shows colder dorsal surface temperatures and less complex emission patterns in previously stressed animals. This effect may be due to lower metabolic heat production and reduced heat loss from the skin. However, the altered emission patterns strongly suggest a changed blood flow, probably

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[23] Webster, A. J. F. 1973. Heat loss from cattle with particular emphasis on the effects of cold. In "Heat Loss from Animals and Man". (Ed. J. L. Monteith and L. E. Mount). Ch. 10. Butterworths. London.
[24] Tong, A. K. W., Schaefer, A. L. and Jones, S. D. M. 1995. Detection of poor quality beef using infrared thermography. *Meat Focus* **Nov 1995**, 443-445.
[25] Schaefer, A. L., Jones, S. D. M., Tong, A. K. W. and Vincent, B. C. 1988. The effects of fasting and transportation on beef cattle. 1. Acid-Base-electrolyte balance and infrared heat loss of beef cattle. *Livestock Production Science* **20**, 15-24.
[26] Gonzalez-Alonso, J, Calbet, J. A. L. and Neilsen, B. 1999. Metabolic and thermodynamic responses to dehydration-induced reductions in muscle blood flow in exercising humans. *J. Physiol.- London* **520**, 577-589.
[27] Kalita, D., Lahon, D. K., Dutta, B. and Pathak, S. C. 1998. Clinical manifestations of haemorrhagic shock in bull calves. *Indian Vet. J.* **75**, 1032-1033.

vasoconstriction, caused either the need for reduced heat loss due to lowered thermogenesis[22] or because of dehydration[26]. No published evidence of lower metabolic rates during recovery from stress could be found. If the effect is primarily due to dehydration, associated with other causes and effects of stress, then rehydration will restore normal heat emissions but not necessarily muscle glycogen levels. The underlying problem of depletion of glycolytic potential can only be remedied by glycogen repletion, which will take longer than rehydration. As long as dehydration and metabolic stress are closely correlated, the technology will be useful but caution will be required.

The Canadian researchers at Lacombe Research Centre have taken a US patent on the thermographic assessment of potentially dark cutting cattle and other animals (Appendices; US Patent 5595444 Method for detecting poor meat quality in groups of live animals). The patent made a broad range of claims, which would cover most aspects of an implementation of this technology in meat works. The weak area of the patent was the mathematical handling of data from the thermographic image. The Lacombe researchers used a statistical approach where cattle were compared within a group and potentially stressed cattle were identified as those that were outside arbitrarily set limits. This identified about 20% of animals as requiring diversion. Alternatively, the operators could choose to eliminate a set proportion of animals (say 20%) which were at the extremes.

Using their preferred method, Example 4 of the patent described the pre-slaughter evaluation of 135 bulls. Thermography identified 104 bulls as potentially normal and 31 as potentially dark cutters. All 104 predicted as normal were indeed normal. Of the 31 predicted as dark cutters only 2 were dark cutters by objective measures and 2 were possibly dark cutters. Although it must be remembered that these numbers are not reliable for a commercial situation with large number of varied animals, this result gives a 100% success for elimination of dark cutters but incorrectly included 27 normal animals with the dark cutters giving an 80% success rate at identifying non-stressed animals.

The Lacombe group has continued to study the thermography technology. Most of their results are kept Commercial-in-Confidence. Personal communications and corporate information show that the group has studied the use of thermography for the assessment of stressed and sick cattle arriving at feedlots and on properties, for detection of mastitis and other diseases, and for sorting feedlot intakes into categories requiring different feeding regimes. They also studied at least 4 novel methods of analysing thermograms. A published poster shows results of using thermography for assessing stress in cattle after trucking (Appendices; Thermography after trucking poster). The poster also demonstrates the sophistication developed by the Lacombe group in applying the technology, adapting the apparatus and in automation by linking scanning to electronic identification of cattle.

The data analysis methodology shown in the 1995 paper and in the patent can be improved to achieve the minimum performance standards recommended above; ie. 99% accuracy in identifying normal animals and 90% accuracy in identifying dark cutters. The methodology is discussed in the next section. While the Lacombe group may have also progressed beyond their earlier methods, our effort could provide a novel aspect beyond their earlier claims and give a point of negotiation with the patent holders.

Technological Capacity

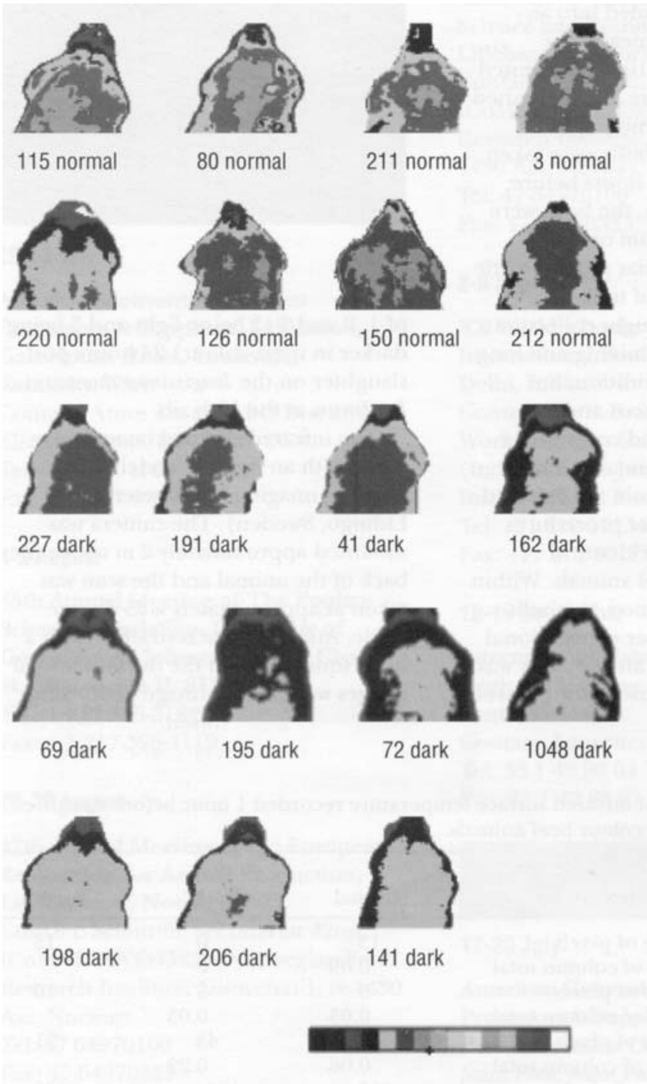
Thermal scanning technology

Preliminary research in Canada has identified infrared thermography as a potential technology for the identification of stressed cattle[24]. The technique is simple, non-invasive and cost effective. Analysis of the published thermographs indicates that simple algorithms could be developed that provide robust predictions of the potential for dark cutting (extremely stressed animals). Research would identify the potential for use of the technique for more refined categorisation of stressed cattle. The apparatus used in the 1995 Canadian study and in earlier studies[25], was very primitive compared to the technology available today. Current infrared imaging technology does not require cooling with liquid nitrogen, data output is enhanced and computing capacity has improved several fold. Usage is no more complicated than use of a normal video camera. The Lacombe group has progressed since then but it is not known what their apparatus consists of currently.

The proposed apparatus for any initial studies and for use by Australian Country Choice in a commercial setting is the AVIO TVS-600. A description of the apparatus has been extracted from company information and is presented in the Appendices.

Analysis of thermographs

The intellectual property of any independent Australian project will be the algorithms used to evaluate the data from each animal to predict stress status and ultimately a glycolytic potential. The Canadian published data[24] used a simple method of analysis that eliminated 70% of dark cutters and incorrectly rejected 10-20% of unstressed animals. The patent data correctly identified all the dark cutters but only identified 80% of the normal animals. As discussed earlier, acceptable minimum standards for performance would be 90% correct identification of dark cutters and 99% correct identification of normal cattle.



Using nineteen, scanned, poor quality, grey scale, published images from the 1995 Canadian study, the authors of this report devised a slightly more sophisticated algorithm which correctly identified all the dark cutters and only mistook one out of 8 normal animals. The procedure consisted of evaluation of standard transect for variability in temperature pattern. The procedure produced an index, a single number and a cut-off was chosen (7.9) such that all the normal animals were identified. Note, as discussed earlier it is more economically effective to correctly identify normal animals than it is to identify more of the dark cutters. This procedure made the evaluation independent of the absolute temperature of the animal thereby eliminating interferences from environmental conditions and animal irrelevancies such as hairiness. Again, within the constraints of having assessed just a few animals, 100% of normal animals were correctly identified and 63% of the normal animals were correctly identified. An alternative cut-off of the index (11) can give 100% reliability for identification of dark cutters but results in one normal animal (12.5%) being incorrectly identified.

Animal	Actual cutting	Index score	Predicted (cut-off 7.9)	Predicted (cut-off 11)
80	normal	13.5	normal	normal
3	normal	12	normal	normal
211	normal	14	normal	normal
115	normal	15	normal	normal
220	normal	8	normal	dark
150	normal	16	normal	normal
212	normal	14	normal	normal
126	normal	16	normal	normal
191	dark	9	normal	dark
227	dark	7.5	dark	dark
41	dark	8	normal	dark
162	dark	4	dark	dark
141	dark	3	dark	dark
206	dark	6	dark	dark
198	dark	6	dark	dark
69	dark	5	dark	dark
195	dark	10	normal	dark
72	dark	9	normal	dark
1048	dark	5	dark	dark

In the Canadian published result and Example 4 of the patent, the emphasis was on eliminating dark cutters completely. It needs to be emphasised that the economics indicate that it is more important to correctly identify normal animals than to eliminate all the dark cutters. This change of emphasis will make the mathematics of data analysis much more effective. Much more sophisticated algorithms based on fractals are available[15] and can be applied to digital data output available from modern infrared cameras.

Capital and operating financials

A system for managing dark cutting must incorporate a stress risk factor management system (MSA-like). A historical sorting system could be useful if done before consignment of cattle by producers to the abattoir. Finally, an individual physiological assessment method would be part of the system. Although these will work together and data will flow forward and back between them, each can be costed independently.

The financial situation with regards to implementing an infrared thermography strategy is dependent on licencing arrangements to be made with the Lacombe patent holders. Some fixed costs will be unaffected by these arrangements as the system will still require a camera, servicing and maintenance and data processing equipment. The system also involves extra handling of cattle and local remediation of affected cattle. The most efficient system will link to electronic ID. In the long term there will be some extra costs in feedback to the other management schemes (management and sorting) and to producers but these could be incorporated into existing or proposed feedback systems.

The following are indicative guesses/estimates. The costs are amortised over 5 years based on a 1% or 2% incidence of residual dark cutters after stress factor management and group evaluation of stock presenting to abattoirs. Costs are based on slaughter rate of 1,000 head per day for 240 days per year. This gives a total of 1.2M head slaughtered and 12,000 or 24,000 potential dark cutters diverted by the procedure.

Item	**Thermography cost/dark cutter**	
	1% base incidence	**2% base incidence**
EQUIPMENT AND FACILITIES		
Camera (purchase or lease, $90,000)	$7.50	$3.75
Maintenance contract for camera ($6,000)	$0.50	$0.25
Capital costs of support infrastructure ($30,000)	$2.50	$1.25
Data processing and reporting equipment ($30,000)	$2.50	$1.25
OPERATING COSTS		
Additional animal handling (1 additional employee)	$25.00	$12.50
Local remediation (feed each dark cutter for 3 days)	$30.00	$30.00
Total thermography cost per dark cutter	**$68.00**	**$49.00**
Loss due to dark cutting at $0.50/kg x 300 kg carcase	$150.00	$150.00
Saving per dark cutter using thermography	**$82.00**	**$101.00**

This is a very basic analysis of the costs. No account was taken of the loss due to normal cattle mistakenly diverted to remediation and the cost of patent licences. On the other side, no account is taken of the economic benefits of an overall better product going through the works.

Appendices

Persons and Organisations Consulted

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ARRIP (Rural research - in progress)
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CARRP (Rural research - completed)
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National Cattlemen's Beef Association (USA) (www.beef.org)
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Texas A&M University (http://meat.tamu.edu)
USDA (www.usda.gov)

Medical and Veterinary Thermography

The following is a summary of Medical Infrared Digital Imaging (MIDI - also known as Thermography) supplied by Pip McCahon of Medical Infrared Digital Imaging Pty Ltd, Unit 6 Southern Cross House, 9 McKay Street, TURNER ACT 2612.

Infrared Digital Imaging cameras measure and display visual images of infrared (IR) radiation emitted from the body and therefore provide a technique for photographically mapping the temperature of the body surface. Thermography is non-invasive, mobile and totally without risk to the patient or the operator. The temperature of the skin is influenced by the rate of the blood flow through the cutaneous vessels. Variation in skin temperature reflects changes in local tissue perfusion and tissue metabolism. Since tissue metabolism generally is constant, variation in skin temperature is usually the result of changes in local tissue perfusion. Defective vasomotor mechanisms in the peripheral and central autonomic nervous system are responsible for the changes in the temperature of the skin.

The following is an excerpt from The Proceedings 1996 Dubai Symposium Tracy A. Turner, DVM, MS, Dipl.ACVS.

Thermography is the pictorial representation of the surface temperature of an object[28,29]. It is a non-invasive technique that measures emitted heat. A medical thermogram represents the surface temperatures of skin making thermography useful for the detection of inflammation. This ability to non-invasively assess inflammatory change, makes thermography an ideal imaging tool to aid in the diagnosis of certain lameness conditions in the horse.

Heat is perpetually generated by the body, and it is dissipated through the skin by radiation, convection, conduction, or evaporation[29]. Because of this, skin temperature is

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[28] Purohit RC, McCoy MD: Thermography in the diagnosis of inflammatory processes in the horse. Am J Vet Res 1980; 41:11671172.

[29] Turner TA, Purohit RC, Fessler JF: Thermography: A review in equine medicine. Comp Cont Ed 1986; 8:855 860.

generally 5°C (9°F) cooler than body core temperature (37°C). Skin derives its heat from the local circulation and tissue metabolism[30]. Tissue metabolism is generally constant, therefore variation in skin temperature is usually due to changes in local tissue perfusion. Normally, veins are warmer than arteries because they are draining metabolically active areas. Superficial veins will heat the skin more than superficial arteries, and venous drainage from tissues or organs with a high metabolic rate will be warmer than venous drainage from normal tissues.

The circulatory pattern and the relative blood flow dictate the thermal pattern which is the basis for thermographic interpretation[29]. The normal thermal pattern of any area can be predicted on the basis of its vascularity and surface contour. Skin overlying muscle is also subject to temperature increase during muscle activity. Based on these findings, some generalizations can be made regarding the thermal patterns of a horse: the midline will generally be warmer[28,29], this includes the back, the chest, between the rear legs, and along the ventral midline. Heat over the legs tends to follow the routes of the major vessels, the cephalic vein in front and the saphenous vein in the rear.

On the dorsal view of the distal limb, the metacarpus (metatarsus), fetlock, and pastern appear relatively cool because the image recorded is away from the major blood supply. Thermographically, the warmest area in the distal limb is around the rich arteriovenous plexus of the coronary and laminar corium located proximally on the hoof wall. Normally, there is increased warmth between the third metacarpus and flexor tendons, following the route of the median palar vein in the foreleg and the metatarsal vein in the rear leg. Over the foot, the warmest area corresponds to the coronary band. From the palar (planter) aspect, the tendons are relatively cool and the warmest area is consistently between the bulbs of the heel along the midline.

Injured or diseased tissues will invariably have an altered circulation[29]. One of the cardinal signs of inflammation is heat which is due to increased circulation. Thermographically, the "hot spot" associated with the localized inflammation will generally be seen in the skin directly overlying the injury[28,29,31,32]. However, diseased tissues may in fact have a reduced

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[30] Love TJ: Thermography as an indicator of blood perfusion. Ann NY Acad Sci 1980; 335:429432.

[31] Bowman KF, Purohit RC, Ganjam UK, et al: Thermographic evaluation of corticosteroids efficacy in amphotericin B induced arthritis in ponies. Am J Vet Res 1983; 44:5154.

blood supply either due to swelling, thrombosis of vessels, or infarction of tissues[29,33]. With such lesions the area of decreased heat is usually surrounded by increased thermal emissions, probably due to shunting of blood.

In human medicine, thermography is performed under very controlled environmental conditions[32,34]. Unfortunately, in veterinary medicine this is not always possible, but even in the field standards can be followed so that reliable thermograms are produced[29]. Factors that must be controlled are motion, extraneous radiant energy, ambient temperature, and quantification of the thermogram.

Motion can be controlled by choosing the appropriate equipment and by immobilizing the horse in stocks. The latter also provides a safe working area for the equipment and personnel[29]. Stocks are not always available, but the use of chemical restraining agents to keep the horse from moving should be avoided because these drugs affect the peripheral circulation and cardiovascular systems. This could cause false thermal patterns to be produced. Thermal imaging equipment that produces an image in real time makes it possible to produce a motionless image. Real time thermography is a must in veterinary medicine. This equipment produces a thermal image almost instantaneously as compared to equipment that averages thermal images taken over a period from 19 seconds to 6 minutes to produce a visual readout. Consequently, motion is not only a potential source of error, it can be a real annoyance with this type of equipment. Telephoto lenses also allow the thermographer and equipment to maintain a safe distance from the horse while producing detailed thermal images. Other than for safety, distance is unimportant in producing a reliable thermogram. However, the closer the camera is to the object being scanned the more detailed the image. The author utilizes a camera object distance of 12 meters or simply includes the entire object of interest in the thermogram.

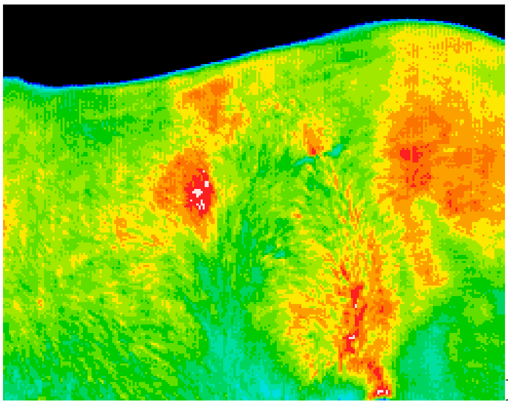
To reduce the effects of extraneous radiant energy, thermography should be performed under cover shielded from the sun[29]. Preferably, thermography should be done in darkness

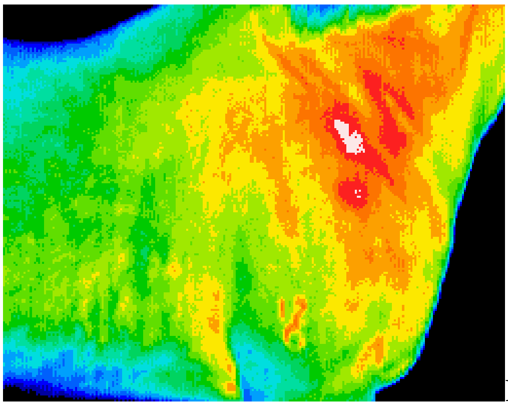
[32] Weinstein SA, Weinstein G: A clinical comparison of cervical thermography with EMG, CT scanning, myelography and surgical procedures in 500 patients. Proceedings Acad Neuro Musc Thermography 1985; 2:4447.
[33] Turner TA: Hind limb muscle strain as a cause of lameness in horses. Proceedings Am Assoc Eq Practnr 1989; 34:281286.
[34] Weinstein SA, Weinstein G: A review of 500 patients with low back complaints; comparison of five clinically accepted diagnostic modalities. Proceedings Acad Neuro Musc Thermography 1985; 2:4043.

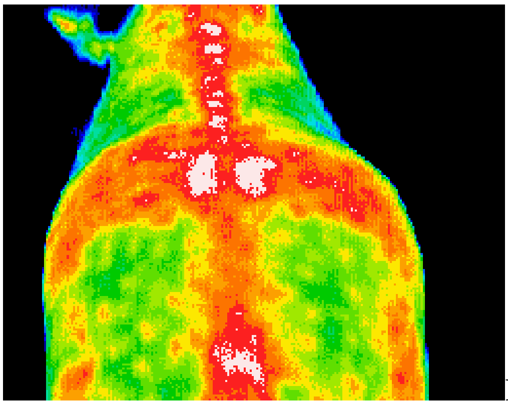
or low level lighting. Ideally, ambient temperature should tee in the range of 20°C (68°F) but any temperature below 30°C (86°F) is acceptable. Heat loss from sweating does not occur below 30°C, as radiation and convection are responsible for heat loss below that temperature. The thermographic area ideally should have a steady, uniform airflow so that erroneous cooling does not occur. Practically, the horse should be kept from drafts. Likewise, the horse should be allowed 10-20 minutes to acclimate to the environment or room where thermography is performed.

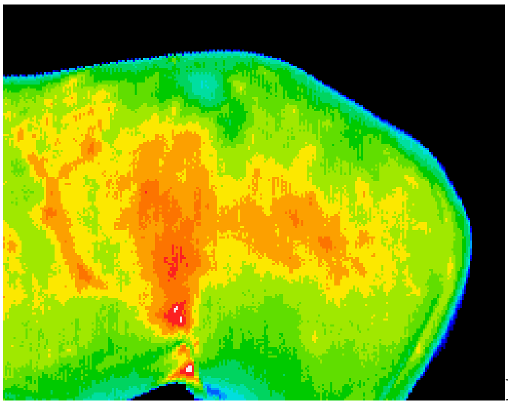
Quantification of temperature variations is important only to the degree the thermographer needs to differentiate if symmetrical areas are of similar temperature. For example, when assessing a thermal image, asymmetry of 1°C or more is significant and indicates possible pathology. To this effect, hair and hair length are important[29]. Hair insulates the leg and blocks the emission of infrared radiation. But, as long as the hair is short and of uniform length, the thermal image produced is accurate. The skin should always be evaluated for changes in hair length that may cause false "hot spots" in the thermogram.

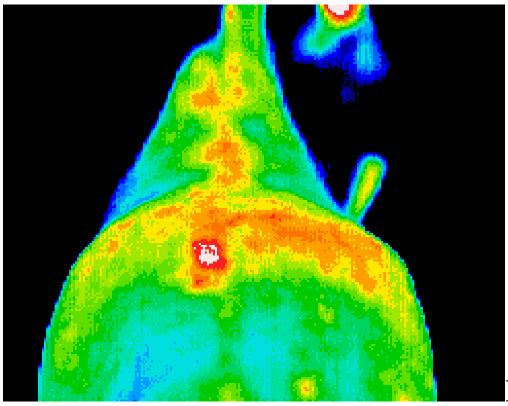
Multiple thermographic images of a suspect area should be made[32,34]. The area in question should be evaluated from at least two directions approximately 90° apart, to determine if a "hot spot" is consistently present. The horse's extremities should be examined from 4 directions (circumferentially)[29]. Some authors feel that 23 replicate examinations should be performed a minimum of 1 minute apart[32,34]. Significant areas of inflammation will appear over the same spot on each replicate thermogram. This technique is a simple way to have barnyard quality assurance.

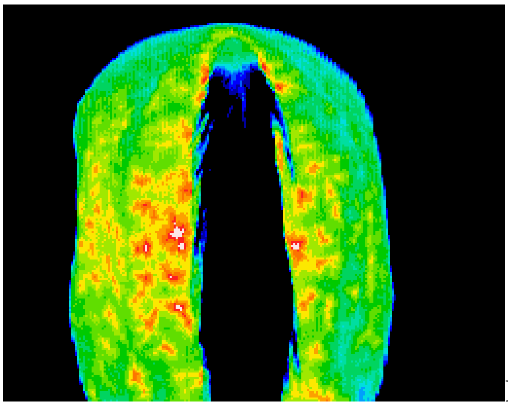

Left Flank of Horse showing inflamed Kidney


Right shoulder inflammation - horse


Posterior Dorsal View Horse


Left Flank/Hip Horse


Posterior Dorsal View - Horse


Posterior View Rump - Horse

US Patent 5595444

US Patent & Trademark Office Full Text Patent Search
5,595,444
Tong , et al. January 21, 1997

Method for detecting poor meat quality in groups of live animals

Abstract
The invention provides methods of detecting poor meat quality in live animals using infrared thermography. Animals from a group of live domestic animals such as cattle or swine are scanned to produce thermographic images. The images are then statistically analyzed to determine a measure of central tendency such as the mean temperature for each animal's image and for all of the images in the group. A measure of dispersion from the measure of central tendency, such as standard deviation is determined. Then, animals are rejected as having a high probability of producing poor meat quality if the measure of central tendency for that animal's temperature differs from the measure of central tendency for the group by more than 0.9 standard deviations. Alternatively a set percent of animals are rejected, preferably up to 20%, these being animals whose measures of central tendency differ the most from the measure of central tendency for the group. When mean temperature is used as a measure of central tendency, the method is preferably practised by rejecting animals whose mean temperature differs from the group mean temperature by more than 1.28 times the standard deviation for the group. The method is particularly useful in detecting high probability of poor meat quality in groups of animals in an antemortem environment which have mean temperatures significantly above or below the normal surface temperatures for unstressed animals.

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Intern'l Class: G01N 025/00
Field of Search: 374/45,124,4 99/493

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Parent Case Text

CROSS-REFERENCE TO RELATED APPLICATION
This is a Continuation-In-Part application Ser. No. 07/084,993, filed Jul. 2, 1993, now U.S. Pat. No. 5,458,418.

Claims

We claim:

1. A method for detecting those animals from a group of live domestic animals which have a high probability of producing poor meat quality, comprising:

scanning an area of each animal of the group of live domestic animals with an infrared camera to produce a thermographic image for each animal;

for each animal's thermographic image, determining a measure of central tendency for the temperature;

for the images from the group of live domestic animals, determining a measure of central tendency for the temperatures from all of the images; and

rejecting as animals having a high probability of producing poor meat quality, up to twenty percent of the animals, the rejected animals being those whose measures of central tendency differ the most from the measure of central tendency for the group.

2. The method as set forth in claim 1, wherein the measure of central tendency for the temperature determined for each animal's image and for the group images is a mean temperature.

3. The method as set forth in claim 2, wherein the mean temperature for each image is determined from an average pixel temperature for a consistent area of the animal scanned.

4. The method as set forth in claim 3, which includes the further step of, for the images from the group of live domestic animals, determining the standard deviation from the group mean temperature, and using the standard deviation to reject the up to twenty percent of the animals.

5. The method as set forth in claim 1, which includes the further step of, for the images from the group of live domestic animals, determining a measure of dispersion from the measure of central tendency for the group, and using that measure of dispersion to reject the up to twenty percent of animals.

6. A method for detecting those animals from a group of live domestic animals which have a high probability of producing poor meat quality, comprising:

scanning an area of each animal of the group of live domestic animals with an infrared camera to produce a thermographic image for each animal;

for each animal's thermographic image, determining a mean temperature;

for the images from the group of live domestic animals, determining a group mean temperature and a standard deviation from the group mean temperature; and

rejecting each animal as one having a high probability of producing poor meat quality if the mean temperature for that animal differs from the mean temperature for the group by more than 0.9 times the standard deviation.

7. The method as set forth in claim 6, wherein the mean temperature for each image is determined from an average pixel temperature for a consistent area of the animal scanned.

8. The method as set forth in claim 7, wherein the animals are live swine.

9. The method as set forth in claim 8, wherein the group of animals is a group having a mean temperature above or below 24.degree.-26.degree. C.

10. The method as set forth in claim 8, wherein the dorsal surface of the animal is scanned.

11. The method as set forth in claim 10, wherein the animal is scanned between the atlas vertebrae and the thoracic vertebrae.

12. The method as set forth in claim 10, wherein the animal is scanned between the atlas vertebrae and the cervical vertebrae.

13. The method as set forth in claim 10, wherein the animal is scanned in the intrascapular area between the atlas vertebrae and the cervical vertebrae.

14. The method as set forth in claim 7, wherein each animal is rejected if the mean temperature for that animal differs from the mean temperature for the group by more than 1.28 times the standard deviation.

15. The method as set forth in claim 14, wherein the animals are live cattle or elk.

16. The method as set forth in claim 15, wherein the dorsal surface of the animal is scanned.

17. The method as set forth in claim 16, wherein each animal is scanned between the atlas vertebrae to the thoracic vertebrae.

18. The method as set forth in claim 17, wherein the animals are cattle.

19. The method as set forth in claim 18, wherein each animal is scanned from the side.

20. The method as set forth in claim 19, wherein the scan includes one or more of the head, trunk and extremities of the animal.

21. The method as set forth in claim 18, wherein the group of animals is a group having a mean temperature above or below a temperature range of 28.degree.-32.degree. C.

22. The method as set forth in claim 7, wherein each animal is scanned in an antemortem environment.

23. The method as set forth in claim 22, wherein each animal is scanned within about 6 hours of a transport or within 24 hours of slaughter.

Description

FIELD OF THE INVENTION

This invention relates to methods for detecting poor meat quality in groups of live animals, and more particularly to the use of infrared thermography for such purposes.

BACKGROUND OF THE INVENTION

In domestic animals, handling and transport are known to be potent stressors (Stephens, 1980: and Kenny et al., 1987). Such stresses are often termed "antemortem stresses". These stresses have been documented to bring about changes in many physiological parameters including thermoregulation (Frens, 1975; and Houdas et al., 1975). It is also well documented that such factors as handling, mixing, and transport in the preslaughter environment (the "antemortem environment") are causative agents of poor meat quality (Jones et al., 1989; Jones et al., 1988; Warriss, 1986). Primarily affected are such quality attributes as colour, moisture holding capacity, pH, toughness and texture. If the stress is severe enough, the animal's energy supply is taxed, which in turn may lead to poor or degraded meat quality, such as dark, firm and dry (DFD) or tough meat in beef cattle, or pale, soft and exudative (PSE) meat in swine

The assessment of meat quality has always, by necessity, been done on post mortem analysis. To the inventors' knowledge, prior to their own invention, as set forth in U.S. application Ser. No. 084,993, filed Jul. 2, 1993, now U.S. Pat. No. 5,458,418. (PCT Application No. PCT Information=CA94/00383, published Jan. 12, 1995) there has never been a technology with a demonstrated capability to detect animals likely to produce poor meat quality. Arguably, the development or discovery of such a technology capable of predicting meat quality in live animals in the antemortem environment has significant value to the meat production industry, since preventative and restorative therapy can be initiated in those identified animals.

Infrared thermography (IRT) has been used in human medicine for some time for the diagnosis and study of such conditions as tumors and cardiovascular integrity (Clark et al.,

1972) as well as hyperthermia (Hayward et al., 1975). In domestic animals, IRT has also been found useful for diagnosing such conditions as vascular lesions in pigs (Lamarque et al., 1975) and leg injuries in horses (Clark et al., 1972).

The patent literature discloses the use of IRT for several purposes. U.S. Pat. No. 3,877,818 to Button et al., discloses the use of IRT for determining fat content in meat (post mortem). U.S. Pat. No. 3,948,249 to Ambrosini teaches 8 the use of an infrared detector for identifying a cow in heat. U.S. Pat. No. 5,017,019 to Pompei discloses the use of radiation detectors to measure temperature differentials in animals.

The inventors have been involved in previous studies using IRT with live animals. Initial studies by the co-inventors Jones, Schaefer and Gariepy suggested that IRT might be useful in identifying basic stress levels in cattle (Schaefer et al., 1987a, 1988) and in swine (Schaefer et al., 1987b; and Gariepy et al., 1987). The studies recognized that cattle having cooler surface temperatures as measured by IRT appear to have lower meat quality, while in pigs, poor meat quality was associated with very high surface temperatures. However, these studies fell short of teaching a method for reliably detecting the likelihood of poor meat quality in live animals.

There is a continuing need for a method of detecting, with acceptable accuracy, live animals susceptible to producing poor meat quality.

SUMMARY OF THE INVENTION

As set forth in their co-pending U.S. patent application Ser. No. 084,993, the inventors initially set out to develop a method for detecting poor meat quality in live animals with infrared thermography, by studying the anatomical sites and temperatures for different animals, along with the methods of analysing the thermographic data, so as to be sufficiently predictive of the relevant meat quality traits. By testing a large number of animals and breaking down the thermographic images by temperature zones, they discovered, surprisingly, that animals which went on to produce poor quality meat had infrared thermographs which were uncharacteristic in a particular test temperature zone. Compared to animals which produced high grade meat quality, the low grade meat quality animals were found to have thermographs which had higher proportions of the scan (measured by proportion of total pixel count) in temperature zones which were higher and lower than the test temperature zone. This discovery enabled the inventors to develop a reliable method for detecting for low meat quality in live animals.

The invention described in the inventors' earlier U.S. patent application extended to a method for detecting a high probability of producing poor meat quality in live domestic livestock, comprising the steps of:

(a) scanning the live animal with an infrared camera to produce a thermographic image;

(b) for cattle, determining the proportion of the scan falling within the test temperature range of 28.degree.-32.degree..+-.2.degree. C.;

(c) for swine, determining the proportion of the scan falling within the test temperature range of 24.degree.-26.degree..+-.2.degree. C.; and

(c) rejecting the animal as one having a high probability of producing poor meat quality if the proportion of the scan falling within the test temperature range is lower than that falling outside the test temperature range.

In further work relating to the present application, the inventors discovered that the above method could be improved to reject animals having a high probability of producing poor meat quality with greater precision, particularly when the animals were part of an "atypical" group of animals. Atypical groups of animals were discovered having infrared temperature profiles which were considerably hotter or colder than the normal surface temperatures for animals of that species. For domestic cattle, that normal temperature is about 28.degree.-32.degree. C., while for swine, that normal temperature is about 24.degree.-26.degree. C. In the antemortem environment, such animals arrive as groups, such as a truckload, having experienced similar environments in either or both of the origin feedlot or farm, and the type and extent of antemortem stress conditions, such as time and extent of transport. Such groups of animals were discovered to have group mean temperatures, which, although different from the normal surface temperatures, did not necessarily indicate a very high incidence of poor meat quality. In such circumstances, the method of the inventors' earlier patent application might reject the entire group of animals as having a high probability of producing poor meat quality. While this was not incorrect, because animals in these groups on a whole had a higher probability of producing poor meat quality compared with groups which had a more normal mean temperature, the inventors set out to determine whether a more precise prediction of poor meat quality could be achieved.

The inventors discovered that the thermographic images from these atypical groups of animals can be statistically analyzed in order to reject animals whose temperature differed significantly from a norm for the group, such as a group mean temperature. More particularly, the inventors discovered that animals having a high probability of producing poor meat quality can be more precisely detected if the animals are processed as a group of animals which have experienced a similar environment prior to scanning. Animals whose thermographic images vary significantly from the norm, as determined from a statistical measure of central tendency of the temperatures for the group, were discovered to contain a high proportion, if not all, of the animals which produce poor meat quality.

The most preferred measure of central tendency used for the thermographic images is the mean temperature, both for the image of each individual animal, and the images for the group. However, other measures of central tendency including median or mode may also be used. To assist in determining significant departure from the norm, a measure of dispersion from the measure of central tendency, such as standard deviation (SD), is preferably determined.

In accordance with the present invention, up to 20% of the animals are rejected as having a high probability of producing poor meat quality, the rejected animals being those whose measures of central tendency differ the most from the measure of central tendency for the group. Preferably, in rejection, an animal is rejected if its mean temperature differs from the group mean temperature by more than 1.28 times the standard deviation for the group. This effectively rejects the upper 10 percent and lower 10 percent of the outliers (i.e. animals whose mean temperatures are most distanced from the group mean temperature) from a bell shaped normal population curve, i.e. a standardized population of animals having a mean of zero and a standard deviation of 1.

The method of the present invention can be practised by rejecting a greater number or lesser number of outliers, say as much as 36 percent for stress sensitive groups, or only 5 percent for lower stressed groups. This is largely a matter of economics to be determined by the commercial meat packers. However, as will be evident to those skilled in the art, rejecting 20 percent as outliers if the poor meat quality animals are all within the upper and lower 5 percent, is inefficient. Generally, rejecting 5-20% as outliers is likely to be economical for most meat packers. The inventors have demonstrated that rejecting the upper and lower 10 percent as outliers (i.e. up to 20 percent) will likely include all of the dark cutters in a group of beef cattle and elk. If economics dictate, the method can be practised by rejecting only the upper and lower 5 percent as outliers (i.e. up to 10 percent, or animals whose mean temperature differs from the group mean by more than 1.65 SD). For swine, the inventors have demonstrated that rejecting up to 36% as outliers includes poor meat quality animals in groups predisposed to stress. In a normal genotype pig, rejecting up to 10-20% should be sufficient.

Broadly stated, the invention provides a method for detecting those animals from a group of live domestic animals which have a high probability of producing poor meat quality, comprising:

scanning an area of each animal of the group of live domestic animals with an infrared camera to produce a thermographic image for each animal;

for each animal's thermographic image, determining a measure of central tendency for the temperature;

for the images from the group of live domestic animals, determining a measure of central tendency for the temperatures from all of the images; and

rejecting as animals having a high probability of producing poor meat quality, up to twenty percent of the animals, the rejected animals being those whose measures of central tendency differ the most from the measure of central tendency for the group.

Although the method has been demonstrated for groups of animals having atypical temperature profiles, specifically beef cattle having a group mean temperature significantly below the normal 28.degree.-32.degree. C. temperature, it also has application for groups of animals having group mean temperatures above that norm. The method also has application for groups of animals having more normal temperature profiles, for example groups of animals having a group mean temperature in the normal temperature range for that animal species.

Furthermore, although the method has been demonstrated for groups of beef cattle, elk and swine, it has application for all live domestic animals. For swine, the method is particularly useful for groups of animals having a group mean significantly above or below the normal temperature range of 24.degree.-26.degree. C., although the method is also useful within that temperature range.

Furthermore, while the method of detection and rejection is based on a group of animals whose temperature distributions fit a normal bell shaped curve, the method also has application for groups whose temperature distributions are non-homogeneous, i.e. which are skewed toward either the higher or lower temperatures.

The term "domestic animals", as used herein and in the claims, is meant to include domestic ruminant and monogastric animals, including swine, horses, cattle (Bos taurus and Bos indicus) and domestic ungulates such as bison, sheep, lamb, deer, moose, elk, caribou and goats.

The term "thermographic image" as used herein and in the claims, is meant to include a scan output in the form of either or both of a visual image and corresponding temperature data. The output from infrared cameras used for infrared thermography typically provides an image comprising a plurality of pixel data points, each pixel providing a temperature data point which can be further processed by computer software to generate for example, mean temperature for the image, or a discrete area of the image, by averaging the data points over the number of pixels.

The term "group of live domestic animals" as used herein and in the claims is meant to include a minimum of three animals from the same or similar species of animal which have been subjected to the similar types and/or duration of antemortem stresses. Preferably a minimum of 10 animals comprise a group. More preferably, and more typically in the industry, a group of animals will include about 40 or more animals from one or more truck or train-car loads which have originated from one farm or feedlot, or which have originated from different farms/feedlots, but which have been transported a significant distance for a similar duration of time.

The term "measure of central tendency" as used herein and in the claims is a statistical measure of a point near the centre of a group of data points. Without limitation, the term includes the mean, median and mode. The mean temperature is the most preferred measure of central tendency used in the present method. For each animal's image, the mean temperature is determined from the average pixel temperature for a discrete area of that animal that has been scanned. Just by way of example, the area between the atlas and thoracic vertebrae in a dorsal scan of beef cattle may be the discrete area scanned. The mean temperature determined for each animal's image is the arithmetic mean of the pixel temperatures for the discrete area, identified as say the 70.times.90 pixels of the image in that discrete area. For the group of live domestic animals, the mean temperature is determined from the individual animal mean temperatures determined from the images taken of the consistent discrete area of the animals scanned.

The term "measure of dispersion" as used herein and in the claims is meant to include statistical measures of spread from the measure of central tendency for the group. Preferred measures of dispersion when the measure of central tendency is the mean, include variance, standard deviation and coefficient of variation. Most preferred is "standard deviation". Definitions of these statistical terms may be found in standard statistic texts, one such text being Steel, R and Torrie, J, 1980 2d edition, Principles and Procedures of Statistics, A Biometrical Approach, McGraw-Hill, New York, which definitions are incorporated herein be reference.

The term "standard deviation" as used herein and in the claims is the positive square root of the variance for the group, the variance being the arithmetic mean of the squares of the deviations of the individual values from their arithmetic mean. For a group of live domestic animals, wherein the measure of central tendency being used for each individual animal's image is the mean temperature (.mu..sub.i), and wherein the measure of central tendency being used for the group of all the animal images is the group mean temperature (.mu..sub.g), then the standard deviation (SD) for a group of n animals is: ##EQU1##

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the inventor' previous patent application, the method of detection with infrared thermography was proven effective in detecting animals having a high probability of producing poor or degraded meat quality on subsequent slaughter. There, in a test group of 54 bulls, the method proved to be greater than 80% effective in advance detection of dark cutting. This is a very high accuracy rate. Once animals were detected, they could be treated to improve meat quality. For instance, a composition for such a method of restoring degraded meat quality and improving carcass yield loss is disclosed in U.S. application Ser. No. 08/084,989 filed Jul. 2, 1993 by Jones et al., now U.S. Pat. No. 5,458,418.

Infrared thermography equipment (camera, analytical software) is known in the art. Preferably, animals, or relevant anatomical sites, are scanned at relatively close range (1-3 m) at an angle between about 45.degree.-90.degree. from the horizontal surface of the animal.

Software is available for analysing the thermographic images produced from the camera. An exemplary software package is Viewsoft (Version 2.0 Viewscan Ltd., Concord, Ontario, Canada). In the inventors' previous application the images were preferably analyzed to determine the proportion of a scan that fell within a particular temperature range (ie. proportion of total pixels of a defined area which fell within a particular temperature range). The same or similar software can be used in the practise of the method of the present invention to calculate the statistical measures of central tendency and dispersion.

Preferred conditions of scanning were reported in the inventor's previous patent application, and are applicable to the method of this invention, including, for different animal types, the relevant anatomical sites, the type of scan view, and the timing of the detection.

For all live domestic cattle, scanning is preferably conducted within about 6 hours of transport or within 24 hours of slaughter. Scanning after 6 hours of transport may still be conducted, however, the stressed animals having cooler or warmer thermographs than the normal range, will be generally cooler, making detection somewhat less precise. However, for animals which are held in lairage preslaughter, the method is preferably practised within 24 hours of slaughter.

For cattle and elk, a dorsal view is most preferred. This is likely also the most accessible and economical view. However, side views are also efficacious. The most revealing anatomical site is the dorsal surface between the atlas and thoracic vertebrae. However, side views of trunk, head and extremities are also efficacious.

Scanning swine by infrared thermography showed that a dorsal view is most preferred. The most revealing anatomical sites include the dorsal area between the atlas and thoracic vertebrae, most preferably including the intrascapular area between the atlas and cervical vertebrae.

While the IR detection method of this invention is preferably practised with computer data analysis of the statistical measures, it is also amenable to displaying the images, in order to provide the operator with a more immediate "feel" for the data, as it is being collected. Distinctive colours or grey tones may be assigned by computers to the test temperature ranges of the scan and to the non-test temperature ranges (preferably every 1.degree.-2.degree. temperature range has a different colour). The thermographs are displayed on a computer monitor, such that a human operator can determine if the animals are generally warmer or cooler than the norm.

The practise of the method of the present invention will differ from one commercial packing plant to another, depending on the overall automation level available or desirable. Generally, the groups of live domestic animals arrive at the plant in truckloads of about 40 or more animals. Each animal of the group is scanned with the infrared camera positioned to view a relevant, discrete and consistent anatomical site. The digitalized data output from the camera is used to determine the mean temperature for each animal's image, the mean temperature for the group of animal images, and the average deviation, or more preferably the standard deviation. Animals are rejected after comparing the individual animal mean temperature with the group mean temperature. Animals whose mean temperature differs from the group mean by more than about 0.9 standard deviations, or more preferably, by more than 1.28 standard deviations are rejected as animals having a high probability of producing poor meat quality. To facilitate the locating and separating of the rejected animals, each animal may be marked or tagged prior to scanning. Bar code tags may be advantageously used, since this allows for automated rejection by running the animal through a bar code scanner. Alternatively, animals are rejected as the 5-36%, most preferably as the 10-20%, whose mean temperatures differ the most from the group mean. Any measure of dispersion from the group mean can be used in this determination, including variance and coefficient of variation, but most preferably standard deviation.

The method may be practised by scanning less than the entire group of animals, for example 10 or more animals, in order to determine the initial statistical basis for rejecting the animals. The remaining animals in the group could then be scanned and virtually immediately rejected in accordance with the animal's calculated mean temperature. With computer analysis, the statistical analysis for the group can be continuously, and virtually instantaneously updated with each animal scanned. While this continuous method may be less precise, at least for the early animals scanned, it is less time consuming in that the animals may be rejected in a single scan once the group statistics were established. For very large feedlots a group of live animals may comprise hundreds of animals. A first truckload of these animals, comprising for example 45-50 animals, can suffice to determine the group mean and standard deviation as the basis for rejecting animals from the remaining truckloads.

Rejected animals likely to produce degraded meat quality may be isolated for later treatment or lower sale value.

The method of the invention is illustrated in the following non-limiting examples. The first three examples illustrate the method of the inventors' previous patent application, but are repeated here to illustrate the applicability of IR thermography to different animal species, scanning different anatomical sites and the like. Although the method of the present invention differs from that of Examples 1-3, certain aspects of the examples are applicable. Preferred embodiments of the method of the present invention is illustrated in Examples 4-6.

EXAMPLES

In Examples 1-3 the inventors developed infrared thermographic detection technology under simulated management and transportation practices normally experienced by market cattle. For example, a producer may transport cattle directly to an abattoir. Alternatively, a producer may transport cattle to an auction mart, and leave them overnight in lairage for sale the next day. After sale, the animals might be shipped again to a feedlot or to an abattoir, where they might be left again overnight. Thus the timing between the feedlot, transport and slaughter might be anywhere from an hour to several days. The timing affects the thermographic image of the animal.

EXAMPLE 1

This example reports early work with cattle using infrared scans taken as total animal side views just prior to stunning. In this example, 30 steers and 21 heifers (1 to 1.5 years old) were penned separately, fasted for 24 hours, and divided into three treatment groups. The control group, Treatment 1, was not mixed by sex before being transported 3 km to the research centre. Including time in lairage, the animals were off feed for 24 hours. The second group, Treatment 2, was mixed by sex and transported for 320 km (6 hours) prior to a lairage period of 18 hours. Animals were off feed for 48 hours altogether. The third group, Treatment 3, was treated the same as Treatment 2, except that the animals received an additional 320 km (6 hours) of transport and were in lairage for another 18 hours. They were off feed for a total of 72 hours. Following the lairage period, animals were stunned and slaughtered at the Research Centre where carcass composition and meat quality were analyzed.

Infrared pictures or scans were taken of each animal just prior to stunning. The infrared thermal images (scans or thermographs) were taken with an Agema model 782 camera (AGA, Lidingo, Sweden). Subsequent resolution and printing of the individual thermographs was accomplished using Viewscan software (Viewscan Ltd, Concord, Ontario, Canada) as set out below.

The video signal from the camera was converted to digital data with a A/D converter before being processed by a computer as follows. The image was saved as a raw, uncalibrated data file. The area of the image itself was divided into 7140 pixels or pieces of information. The raw pixel data was digital data proportional to voltage signals from the IR camera. In order to analyze the thermograph, the digital data was converted to temperature data using a calibration procedure with the Viewsoft software. After calibration, the pixels were displayed in fifteen different colours plus a background colour, representing fifteen temperature ranges of 1.2.+-.0.2.degree. C., ranging from 15.0 to 32.0.degree. C.

The Viewsoft software allowed for analysis of the pixel data by different zones or by the entire image. Seven zones were identified as: Zone 0--whole image, including background, Zone 1--whole body of animal excluding background, Zone 2--trunk of the animal excluding extremities, Zone 3--front trunk from the shoulders to the midline, Zone 4--back trunk from the midline to the tail, Zone 5--head and neck, and Zone 6--extremities, including legs and tail. The following information was obtained for each zone using the Viewsoft software: absolute pixel counts and pixel counts as a percentage of the total pixels in the zone falling into each temperature range; maximum and minimum temperatures in the zone; the overall range of temperatures in the zone; the median, the mean, and standard deviations of temperatures in the zone; the total area of the zone (in pixels); and the area of the zone as a percentage of the total image area. The temperatures were grouped into larger temperature ranges to analyze the data. The four temperature ranges were: (1) 10.0-18.0, (2) 18.0-23.0 (3) 23.0-28.0 and (4) 28.0-36.0. The temperatures in each body zone were grouped into the four ranges. The number of pixels falling into each range was expressed as a percentage of the total number of pixels in that zone.

Since heat loss from the body surface may vary with location on the body, the thermograph of the animal's body was divided into three zones for analysis, the trunk, the head, and the extremities. In each body zone, the area covered by each temperature range was expressed as a percentage of the total visible area.

The three treatments resulted in different thermographic patterns. The animals with the greatest degree of transport stress had the greatest proportions of pixels counts in the cooler ranges.

The cattle with the greatest level of stress also showed altered meat quality traits observed as objective colour and shear values. The meat quality assessment was conducted according to the methods described by Jones et al., 1988. The cattle with the most degraded meat quality were those which had received the greatest stresses. The meat quality data is set out in Table 1.

TABLE 1

Effect of transport and handling in market weight cattle on the objective colour and shear values (toughness)

Meat Quality Value	Treatment 1	Treatment 2	Treatment 3
Shear (kg)	5.08 a	6.75 b	8.23 b
Colour			
L*	38.03 a	36.73 b	36.02 b
a*	18.50 a	17.88 ab	17.27 b
b*	14.25 a	13.14 b	12.88 b

Note:
a,b $P < 0.05$
(*C.I.E. colour system)

EXAMPLE 2

This example is included to demonstrate the efficacy of the method of the present invention in detecting poor meat quality in swine using infrared thermography. The IR scans were taken with a Thermovision 750 Serial #1066 camera with a 7 and 0 degree angle lens. Temperature measurements were made with a Taylor 9200 digital thermometer fitted with either a type J surface contact probe or an Exergen Microscanner to facilitate videorecording and electronic capture. Viewsoft version 2.00 software was used to analyze the thermographs.

Trial 1

Both barrows and gilts were used in this experiment. Two IRT scan procedures were used on the pigs. The first IRT image (A) was made of the pigs as they left their home pens. At this time the pigs were not mixed and were unstressed. The second image (B) was made of the pigs after they had been mixed with unfamiliar pigs and moved around the barn. This mixing and moving of pigs is common in the industry and constitutes a stress to the animals. The thermal images of the pigs were taken while the animal was in a small holding pen (squeeze). The animal was viewed from above and behind at a distance of approximately 0.7 meters with the 20 degree lens. The most revealing and useful angle scans were taken of the back and head enfilading at the spine at an angle of more than 45 degrees from the horizontal. The images were interfered in the neck or cervical region by a crossbar, visible in the thermographs.

The thermographs of 4 animals, with colours or grey tones assigned to temperature ranges were analyzed. It was evident that the animals receiving the greater stress had temperatures elevated above the 24.degree.-26.degree. C. range in the dorsal surface, specifically between the atlas and the cervical vertebrae, including the intrascapular area. The temperatures range in the thermographs was 21.7.degree.-28.1.degree. C., with 0.5.degree. C. increments. The blue and purple temperature ranges were between 22.7.degree. and 24.1.degree. C. The black and dark green ranges were between 24.1 and 25.0. The light green ranges were between 25.0 and 25.9. The yellow range was between 25.9 and 26.4. The orange, bright purple and red ranges were between 26.4.degree. and 28.1.degree. C. With grey tones, the cooler temperatures were assigned darker tones and the warmer temperatures were assigned gradually lighter tones.

Trial 2

The purpose of this trial was to confirm the site specificity of heat production as was suggested by the above trial. This trial also tested this specificity in pigs known to produce a high incidence of poor meat quality when subjected to antemortem stress. The degree of stress induced in the pigs in this trial was controlled by the direct manipulation of stress hormones (adrenergic agonists).

The pigs in this trial were genetically stress-susceptible or halothane positive pigs (H+phenotype, nn genotype) as defined by Sather et al., 1989. These pigs are known to produce a high incidence (80%) of poor meat quality traits, including pale colour, soft, texture, exudative or high drip-loss pork and low pH (Murray et al., 1986).

The pigs were fitted with indwelling ear-vein catheters under aseptic conditions 24 hours prior to endocrine studies. On the day of experiments the pigs were anaesthetized with ketamine (Ketalar) at 20 mg per kg animal weight in accordance with guidelines established by the Canadian Council on Animal Care. It should be noted that ketamine anaesthesia was necessary in that a respiratory anaesthetic such as halothane would have induced malignant hyperthermia in these pigs. Following anaesthesia the pigs received an intravenous infusion of selected adrenergic agonists including dobutamine (Dobutrex, B1, 5.6 ug/kg/min for 30 minutes), and Clenbuterol (B2, 3.39 ug/kg/min for 30 minutes). In anaesthetized pigs, a series of sub cutaneous thermocouples (inserted approximately 2 cm) were placed along the spine from the cervical to the lumbar areas. These thermocouples were connected to a data-logger which recorded direct temperature readings every 30 seconds.

The results showed that a direct and controlled challenge of adrenergic agonists (stress hormones) in pigs known to produce poor quality pork was accompanied by an increase in the thermocouple temperature, particularly in the cervical (and occasionally lumbar but not thoracic) areas of the dorsal surface of the pig. This increase in temperature is consistent with the above trial showing IRT temperature increases in these same anatomical areas. The data also confirms that these thermal changes coincide with the production of poor pork quality, as the halothane positive pigs used in this trial are documented to produce approximately 80% poor pork quality.

EXAMPLE 3

This example illustrates an IR detection method using dorsal IR thermographs of bulls taken directly after transport. The camera and computer software were as in Example 1.

In this example data was collected on 54 crossbred yearling bulls weighing on average 500 kg. The animals had been raised on a conventional balanced silage-cereal grain diet with ad libitum access to water and iodized salt. The cattle were allocated to one of two treatments, balanced by breed and weight and designated as control or treated. The control animals remained on their normal diets and with familiar pen mates until the morning of the experiment. The cattle were then moved to a weighing facility, weighed, loaded onto a commercial cattle liner and transported a short distance (3 km) to the abattoir. The bulls were then unloaded into abattoir lairage pens, measuring approximately 3 m by 10 m for 1/2 to 2 hours before being scanned from above with an infrared thermography camera (as Ex. 1). The camera was placed approximately 2 m above the back of the animal and the scan was taken at approximately a 75 degree angle. Within 2 to 3 hours of being scanned, the animals were moved on into the abattoir premise and slaughtered as per conventional commercial practice.

The treatment animals were taken off of feed and water 24 hours before transport. In addition, the bulls were mixed from a minimum of 2 different and unfamiliar pens of cattle. These time off feed and mixing conditions are common in auction mart and some feedlot operations, and constitute a stress to the animals. The treatment bulls received one hour of transport following morning weight collections. Once unloaded in the abattoir/lairage area the infrared scanning and slaughter procedures were completed in an identical manner to the control animals. Meat quality data was assessed as per the Canadian grading system (Dark cutters grading B4, or formerly a grade of B2 prior to institution of the new beef grading system in 1993). The thermographs for 32 animals were analyzed as set out below.

For animals in this study, 11 temperature ranges in were examined. These ranges (.degree.C.) were as follows: 1=10.0-18.9; 2=18.9-20.8; 3=20.8-22.7; 4=22.7-24.6; 5=24.6-26.5; 6=26.5-28.4; 7=28.4-30.3; 8=30.3-32.2; 9=32.2-34.1; 10=34.1-36.0; 11=36.0-37.9.

Following statistical analysis of the data, it was learned that:

(a) greater than 80% of the treated cattle produced carcasses designated by the grading system as being B4 dark cutters;

(b) 40% of the pixel area from the control animals, but only 12% of the pixel areas of the treated animals, fell into temperature range 7;

(c) 30% of the pixel area of the control animals, but only 16% of the pixel area of the treated animals, fell into temperature range 8.

Animals within the temperature ranges 7 and 8, that is with higher pixel numbers in those ranges than outside those ranges were termed Group A. All of the animals in Group A proved to produce normal or non-dark cutting meat, with the exception of one animal, which proved to be a dark cutter. Groups B and C thermographs for animals outside the temperature ranges 7 and 8, that is with higher pixel counts outside the ranges than inside the ranges differed from the Group A thermographs. Group B thermographs were below (cooler than) the temperature ranges 7 and 8, while Group C thermographs were above (warmer than) the temperature ranges 7 and 8. All of the animals whose thermographs were in groups B and C proved to produce darker coloured meat (dark cutters) (with the exception of one animal (of the 24 in B and C)). By assigning colours or grey tones to the ranges, one is able to readily visually determine which animals are predominantly within or without the temperature ranges.

It is thus apparent that the majority of treated (stressed) cattle had a lower proportion of pixels in the ranges 7 and 8, and a higher proportion of pixels in the hotter or colder temperatures outside these ranges. Thus animals having a lower number of pixels in the temperature ranges 7 and 8 were more likely to be stressed and had a higher probability of poor meat quality.

EXAMPLE 4

The process of the present invention was demonstrated with a group of 135 live market weight beef cattle weighing about 500 kg each. The animals were scanned at a commercial packing plant after several hours of transport and/or lairage. The scans were performed in a manner similar to Example 1, using an Inframetrics 760 BroadBand camera (North Billerica, Mass.), with a 0.5.times.lens (40.degree. wide, 30.degree. vertical). The dorsal surface of each animal was scanned (5 ft from the surface) to provide a thermographic image. A rectangular area of each animal's image, approximately 70.times.90 pixels, starting at or near the thoracic vertebrae, was selected on each dorsal view of the digitized infrared thermographic image. The images were analyzed using TPI Image software (Ottawa, Ontario) on a Macintosh computer. The mean temperature of all pixels within this selected area was calculated for each of the 135 cattle. The group mean and standard deviation were calculated as 9.4.degree. C. and 1.2.degree. C., respectively. Animals were rejected as outliers likely to produce poor meat quality if their individual mean temperature differed from the group mean temperature by more than 1.28 times the standard deviation. The area under a bell shaped normal population curve (mean of zero and a standard deviation of unity) which is in the tails, differing from the mean by more than 1.28 SD, is 20 percent of the total area. Thus this method was chosen to reject as outliers, approximately the upper 10 percent and lower 10 percent (area under the curve) of animals from a standardized population having a mean of zero and a variance of 1. The two critical points for rejection were thus the group mean .+-.1.28.times. the calculated standard deviation, or 9.4+(1.28.times.1.2)=10.94.degree. C. and 9.4-(1.28.times.1.2)=7.86.degree. C. Thus, approximately 20 percent of the cattle, those with a mean temperature below 7.86.degree. C. and above 10.94.degree. C., were rejected as outliers that are likely to produce poor meat quality. The number of cattle rejected by this method from the group of 135 cattle was 31 (actual rejection percent was 23%).

After slaughter and meat grading as set forth in Example 1, (pH, Minolta color meter giving the CIE L*, a* and b* coordinates and carcass temperature measurements were recorded for the non-rejected cattle and the outliers. There were no dark cutting carcasses from the 104 non-rejected cattle. Of the 31 carcasses rejected as outliers, evidence from the objective quality measurements indicated that two of the animals had two or more objective measures (pH and a*, b*) that placed them in a dark cutting category. An additional two animals that were suspect of being in a dark cutting category on the basis of one of the measures (a*).

EXAMPLE 5

This example is included to demonstrate the IR thermographic detection method of the present invention with a group of 25 (n=25) market weight (92 kg) live swine.

The animals used in this experiment represented three genotypes normal, non-halothane gene carrier animals (denoted H--, n=8), heterozygote, halothane gene carrier animals (denoted H+-, n=9), and homozygote, halothane gene positive animals (denoted H++, n=8). Pigs carrying the stress susceptible gene (halothane gene) are known to produce a higher incidence of poor pork quality and are therefore a good research model for studying pork quality. The development of halothane gene lines as well as a description of their meat quality is described in detail by Sather and Murray, 1986, and Murray and Sather, 1989. Typically, pigs carrying the halothane positive gene produce pork displaying a higher degree of pale-soft-exudative properties, usually with a lower pH. Use of halothane positive pigs alloys a smaller population sample to be utilised and tested, however, the results from this experiment are predictive of the utility of the method in other swine populations. A description of pork quality is given in the publication by Agriculture Canada, 1984.

The animals used in this trial were raised at the Lacombe Research Centre, Alberta, Canada, on conventional swine diets and received a short transport and handling treatment (20 minutes) on a commercial livestock carrier before arriving at the Meat Research Centre abattoir, located at the Lacombe Research Centre. Infrared thermographs of the dorsal (back) area were collected within 1 hour of arrival at the abattoir, as described in Example 2. An Agema IRT camera (model 782, AGA, Lidingo, Sweden) and graphics package (IBM enhanced AT computer and Viewscan Software, Viewscan Ltd, Concord, Ontario, Canada) were used to collect and analyze the data. Mean temperatures were determined for each image and for the group of images. Standard deviation was also determined. The mean temperature for the group was 25.51.degree. C., and the standard deviation was 2.33. Following slaughter, pork quality was assessed on all animals using conventional methods as described in the Agriculture Canada 1984 publication.

The data and meat quality analyses are shown in Tables 2 and 3 below. In Table 2, animal identification numbers, genotypes (H--, H+-, H++), and mean dorsal temperatures from individual scans are given. Apparent from Table 2 is the observation that animals displaying the lowest and highest dorsal mean temperatures (approximately above and below 0.9 standard deviations of the group mean, representing 36% of the animals) are from either halothane positive or carrier genotypes. Only one of these outliers was a non carrier or non halothane positive pig. In other words, the upper and lower tails of a distribution curve for this data, representing the data points more than 0.9 standard deviations from the group mean included the animals known to produce higher incidence of poor pork quality attributes on a population basis. This is also supported by the comparison of average pork quality traits of the animals in the outlier tails with those of the normal pigs, not carrying the halothane gene, as shown in Table 3. Pigs displaying upper and lower temperatures had lower pH, higher shears (toughness), and greater drip loss than normal pigs.

It will also be noted from Table 2, that the distribution of the data points in this experiment are non-homogeneous, that is they are not evenly distributed from the mean. The halothane gene is known to predispose pigs to a condition of malignant hyperthermia which would cause more pigs to produce higher dorsal mean temperatures under stress, such as handling and transport (see Mitchell and Heffron, 1982). Thus, although the data is skewed toward the warmer temperatures, the rejection method of the present invention is operative, whether rejecting as a percentage differing from the group mean, or as a factor of the standard deviation.

This example thus demonstrates the method of the present invention by rejecting swine whose mean temperatures vary by more than 0.9 standard deviations from the group mean or the 36% outliers, as those animals likely to produce poor meat quality. In a population of non stress susceptible pigs, ie pigs not carrying the halothane gene, the proportion of animals falling into the outlier regions should be smaller, so the method might be practised economically by rejecting up to approximately 20% of the animals as outliers, or by rejecting the animals whose mean temperature differs by more than 1.28 standard deviations, or some other factor found to be economical.

TABLE 2

Distribution of Dorsal Infrared Temperatures, Animal ID and Genotype
For Pigs Used in The Current Study
Temp 19.0 20.0 21.0 22.0 23.0 24.0 25.0 26.0 27.0 28.0

Temp 19.0 21.0 22.9 23.6 24.8 25.0 26.6 27.4 28.0 degree.C.
ID 26404 25001 21602 30402 27101 21608 23902 23901 22202
Gene. H-- H+- H+- H-- H+- H++ H-- H-- H+-
Temp 22.8 23.0 25.8 26.6 27.7 28.2
ID 22506 25004 21504 27403 23603 21306
Gene.H++ H+- H++ H-- H+- H++
Temp 25.9 26.5 27.8
ID 22101 30209 21405
Gene. H++ H-- H++
Temp 25.2 26.8 27.5
ID 23502 22209 22408

Gene. H+- H+- H++
Temp 25.7 26.7 27.6
ID 28806 22601 24006
Gene. H-- H++ H+-
Temp 25.7
ID 25005
Gene. H--

TABLE 3

Meat Quality Traits in Normal Pigs and in Pigs Screened as Outliers (above and below 0.9 standard deviations of the mean) Based on Dorsal Infrared Temperatures.

Meat Quality Trait	Normal Pigs (H--, n = 8)	Lower Dorsal Temp (below 0.9 SD, n = 5)	Upper Dorsal Temp (above 0.9 SD, n = 4)
pH 45	6.26	5.98	5.85
pH unit	5.61	5.59	5.56
Shear	5.85	6.2	6.8
L*	50.2	51.4	51.1
a*	7.45	7.7	7.9
b*	2.1	2.9	2.7
Expressible Juice	5.27	5.14	5.84
Drip Loss %	2.11	2.95	3.09
Mean Dorsal Temp	25.1	21.7	27.9

EXAMPLE 6

This example illustrates the method of the present invention with a group of live elk animals (wapiti).

Twelve adult (2-6 year old, male) wapiti were used in the experiment. All animals received 4-6 hour transport to the Lacombe Research Centre prior to being held overnight in lairage. All animals received 0.5-1 kg of an electrolyte pellet pre-transport (NUTRI-CHARGE, trade mark of Agriculture Canada), and six of the animals were given an additional liquid electrolyte drink overnight at the abattoir preslaughter. The animals were scanned with IRT cameras, dorsal views, as set out in Example 3, immediately before slaughter. The wapiti were subsequently stunned by captive bolt, processed and meat quality was assessed on the Longissimus muscle.

Statistical analysis of the thermographic images, showed mean dorsal temperatures ranged from 28.2.degree.-33.5.degree. C., with a group mean of 31.1 and a standard deviation of 1.2 from the mean. The upper 10% (one animal) displayed a mean dorsal temperature of 33.49. The lower 10% (one animal) displayed a mean dorsal temperature of 28.21.

Meat quality analysis, showed a group average for pH of 5.80 (L.D. muscle or longissimus dorsi at 24 h post stunning), L* colour was 29.8, a* was 14.4, and b* was 5.4. The upper and lower temperature animals identified by IRT scans displayed pH, L*, a*, b* values of 5.82, 28.4, 12.9, 4.6 for the upper animal, and 5.73, 28.9, 13.5, 4.6 for the lower animal. Thus, the upper and lower temperature animals displayed darker coloured meat than the average and higher or lower pH values than the average.

Thus, by rejecting either the approximately 20 percent of the animals whose mean temperatures differ the most from the group mean, or by rejecting animals whose mean temperatures differ by more than 1.28 standard deviations from the group mean, the animals likely to produce poor meat quality were detected. In this example, the actual rejection rate was 17%.

All publications mentioned in this specification are indicative of the level of skill of those skilled in the art to which this invention pertains. All publications are herein incorporated by reference to the same extent as if each individual publication was specifically and individually indicated to be incorporated by reference.

Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it will be obvious that certain changes and modifications may be practised within the scope of the appended claims.

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Thermography Equipment

DESCRIPTION

Neo Thermo TVS-600 cameras are manufactured by AVIO (Nippon Avionics) in Japan and utilise the Raytheon detector module (320 x 240 pixel uncooled microbolometer FPA) with a sensitivity (NETD) of 0.15°C and measured temperature resolution of less then 0.1°C.

The camera is light-weight (about 2 kg without battery) and gives sharp images, capturing even the most subtle thermal anomalies. It is almost unaffected by sunlight, due to the 8 to 14 microns operation range.

INTUITIVE GRAPHICAL USER INTERFACE.

This outstanding feature simplifies operation. A joystick, located on the handgrip, controls an on-screen cursor providing Windows-like operation.

DIGITAL IMAGE STORAGE.

Up to 50 12-bit images, each with voice annotation can be stored on a supplied 10Mb mini PCMCIA card and easily downloaded into your computer for later analysis and report generation. Larger capacity cards can be used. Windows based and MS Office compatible software is easy to operate and infrared images together with temperature information can be readily exchanged with Word and Excel. File name can be adjusted on the screen to store the first 4 characters (letter-digit) for easy identification.

VOICE AND TEXT ANNOTATION.

A headset microphone is included in the standard package. It allows recording of voice notes to each image. In addition, it is possible to add written notes with the help of a simple text generator - up to 40 characters to each image. This feature is essential for noisy industrial environments, such as motor, compressor room, etc.

PROTECTIVE JACKET.

When working in harsh environments the camera together with operator’s hand will be well protected by an optional protective jacket, easily replaced if damaged. The protective jacket will enable the camera to work beyond the range of specified environmental conditions.

AVIO TVS-600 FEATURE SUMMARY

- An integrated 5-inch LCD display offers safety and easy-to-view high-resolution imagery even in bright sunlight.
- Easy-to-learn Windows-like interface with shortcuts to camera control functions on the screen makes AVIO TVS-600 easy to operate.
- Low power consumption
- Store voice notes with images in the standard wav format.
- Store up to 50 12-bit .IRI images or .TIF pictures on the standard 10-Mb PCMCIA memory card.
- An optional high-temperature filter extends AVIO TVS-610 temperature range up to 900°C or even to 1700C .
- AVIO TVS-600 ergonomic handgrip and light-weight make it easy and comfortable to use all day.

- Standard lithium-ion camcorder batteries make replacements inexpensive and easy to obtain, standard car battery chargers save time for charging the batteries when driving
- Sensitive to 8-14 micron wavelength of thermal radiation, the AVIO TVS-600 is less affected by solar reflections
- Interchangeable optics range from microscopic to telescopic lens.
- AVIO TVS-600 integrated 5-inch LCD display enables thermographers to work in a wide range of conditions. It can be rotated when inspecting equipment overhead or near the floor.
- Brightness Control – Enables you to adjust for a complete range of lighting conditions, from total darkness to bright daylight.
- Graphical User Interface (GUI) – Access camera functions via on-screen icons and status areas with the on-screen cursor.
- Multiple Spot Meters – Three spot meters provide accurate, direct temperature readout. Moving the spot meters is as simple as select and drag.
- Palette Selection – Choose from two colour and two grey-scale palettes.
- Isotherm – Instantly highlighting hot spot temperatures higher or lower than pre-set. 2 isotherms.
- Status Area – Displays current emissivity and ambient temperature.
- Main Menu – For advanced analysis and system settings.
- Power Saver button - Cuts off power from the display when closed.
- Prefix - When pre-set will appear on every image number for easy differentiation.
- Temperature profile
- RS 232 port on/off - Mouse, computer or modem communication
- Single or interval recording buttons
- Recall stored images button

SPECIFICATIONS

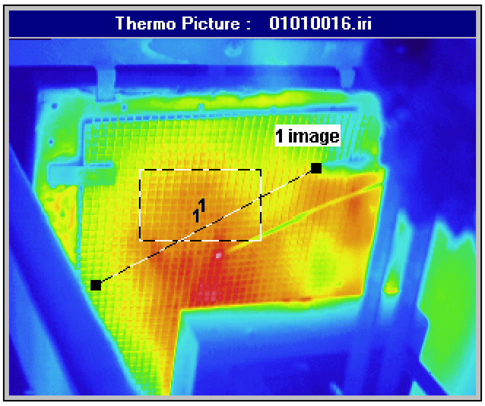
Model	TVS-610	TVS-620
Temperature range	-20°C to 300°C	-20°C to 900°C Extendable to 1700°C
Measurement accuracy	+- 2°C when the object temperature is 100°C or lower +- 2%C when the object temperature is 100°C or higher in the environment of room temperature	
Measured temperature resolution	0.1°C at 30°C Black Body	
Frame rate	30Hz	
Detector type	320 x 240 uncooled microbolometer	
Wavelength response	8-14 μm	
Field of view*	26°(H) x 19°(V)	
IFOV*	1.4 mrad (0.7 mrad when 70 mm lens used)	
Minimum focus*	30 cm	
Number of displayed pixels	320 x 236	
A/D conversion	12-bit full-range	
Ambient temperature correction	Auto and manual correction	
Camera display	5 inch colour low reflection active matrix LCD monitor	
Digital image file format	.iri, .tiff	
Audio file format	.wav	
Temperature range setting	Auto temperature range setting, manual temperature range setting	
Thermal image recording/playback	10-Mb Mini-PCMCIA card. Capacity of 50 12-bit images with voice annotations and playback function	
Video output	NTSC, PAL	
External interface	RS-232	

Power supply	Standard Lithium ion camcorder type battery, AC adaptor
Power consumption	15 W or less
Battery life	>1 hour WITH SUPPLIED BATTERY, LONGER - OPTIONAL
Dimensions	115 (W) x 220 (D) x 142 (H)
Weight	2 kg (excluding lens and battery)
Environmental Conditions WITHOUT PROTECTIVE JACKET	Temperature 0°C - 40°C Humidity Max.90%RH without dew condensation) Vibration 1.0 G (10-150Hz) Shock 50G (11msec)
* When 35mm standard lens is attached	

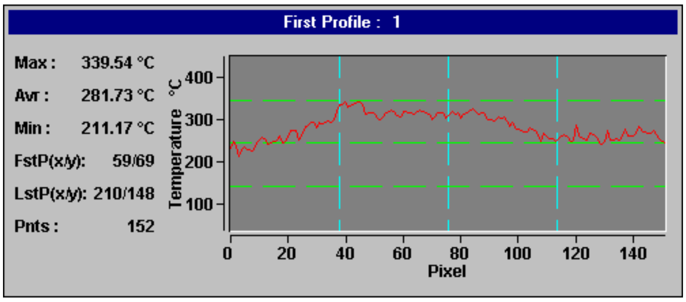
CALIBRATION AND SERVICE.
Due to high quality and reliability of AVIO TVS-610 and 620, the manufacturer does not recommend periodic recalibration. However, should a customer require so, the recalibration can be done in Japan.

Maintenance and service including temperature measurement check is not required, but can be provided by Selby Biolab. Certified Black Bodies are available in Selby's Melbourne Service Centre. Selby Biolab is selling and servicing infrared equipment since 1996.

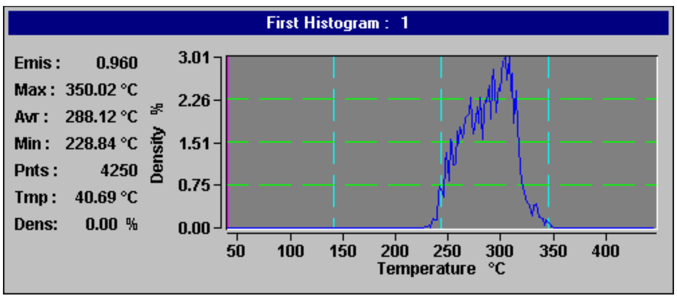
FEATURES EXAMPLES



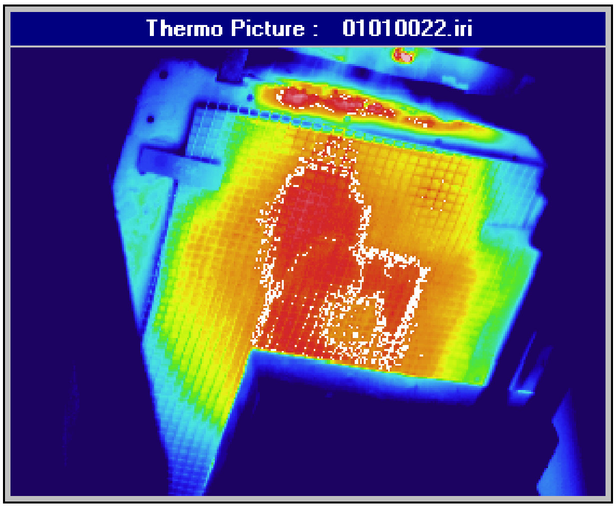
Thermal image of sample under test. I used a profile and histogram tools for temperature measurement.



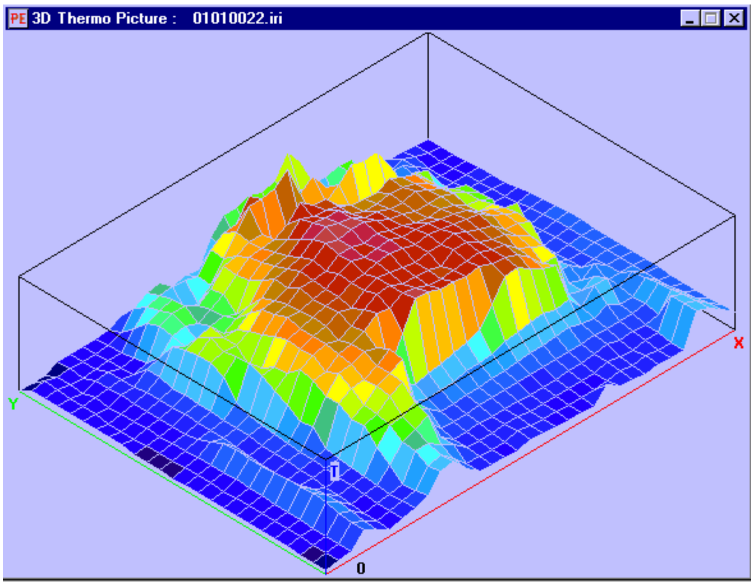
Temperature profile is a useful tool for identifying temperature distribution across a straight or broken line.



Histogram gives a much better representation of temperature distribution on the surface. Maximum, minimum and average temperatures from an area, which can be shaped as required. Besides, the graph shows density of temperatures in the area.



ISOTHERM is one of the best tools to use when accurate temperature measurement is required and temperature distribution picture is important. At this picture white colour belongs to isotherm which can be of a defined width and moved up and down the temperature scale.



3D image can be generated by the software.

Voice comments can be made to each image during a test; in noisy conditions there is an additional function for comment writing on the screen.

There are other features and options for specific tests, but they can be ordered later.

Thermography after trucking poster