Final report

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Advanced Carton Inspection DEXA X-Ray Machine with Extended Analytics

Final Report - Public Version

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Abstract

The correct packing and inspection of cartons is important to processors and consumers. Cartons that are under-filled or packed incorrectly may become crushed creating a safety hazard, adding unnecessary freight cost and possible damage to plant/product. Cartons that contain incorrect product specification or contain contaminant may attract a discount or be rejected and at worst case cause a risk to consumers.

Scott Automation and Robotics recently completed a project investigating the use of DEXA technology to profile product inside closed cartons. A proof of concept system was successfully created and trialled.

Some preliminary trials to determine the chemical lean (CL) content of boxes has been conducted and shows a high level of confidence that CL will be able to be measured with the DEXA based hardware configuration.

DEXA has been shown to be effective when scanning boxes as a method of detecting contaminant within product including such contaminants as foreign material and bone. This has been shown using the Scott DEXA X-Ray contamination machine platform.

With the ability to measure these carton traits an opportunity exists to build a carton scanning system that can provide both real-time control and reporting as well as historical reporting to the processor to ensure that cartons are reliably filled with the correct CL, packed efficiently and are free of contaminant and so that processors can measure and trend the performance of their operations.

Besides, there will be some improvement on contamination detection by developing a new computer hardware platform, updating the software framework, implementing a new contamination detection algorithm, improvements to detector degradation, utilising DEXA hardware and coding, utilising more accurate calibration methods, and improved safety.

Based on the outcomes from the first stage carton fill and CL developments and the proven contaminant detection technology of the Scott contamination inspection machinery this project will combine the functionality of DEXA X-ray technology, carton fill inspection, contaminant detection, CL measurement and statistical analysis + reporting that can provide immediate feedback to operators and historical data to the processor to identify issues such as long-term inefficient use of carton space, CL packing performance and contaminant events.

At the conclusion of this project a production ready machine with the above functionality will be developed and demonstrated.

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1. Milestone Description

1.1. Milestone objective

Milestone 2: Order Materials and build Prototype machine ready for trialling.

Milestone 3: Trialling Machine at Scott Facility and Meat Facility.

Milestone 4: Demonstration and Final Report.

1.2. Background / Previous Research and Development

Scott has had a number of enquiries from industry regarding a recognised requirement to monitor the fill rate of cartons. This is due to a number of reasons. Firstly, cartons that are under-filled or packed incorrectly are at risk of being crushed when stacked. This can cause product damage resulting in losses. When this occurs within a shipping container, it can also pose a safety risk as the integrity of the stack has been compromised. Furthermore, identifying the consistent under filling of cartons presents an opportunity for improved efficiency and financial gains. These not only lie in costs associated with materials but also, more significantly, those related to logistics.

Figure 1: The cartons of meat which collapsed due to low carton fill and not well distributed inside the box.

Currently there is no way to monitor how a carton has been packed once the lid has been placed. As part of a stage 1 project Scott developed and built a proof of concept system using DEXA technology. This system was able to successfully calculate the fill-rate within a carton and flag those which fall below a certain threshold. It also checks for the existence of voids inside the carton which may present a significantly increased risk of crushing. The system was demonstrated with a number cartons filled with various arrangements of bone-in and boneless primals.

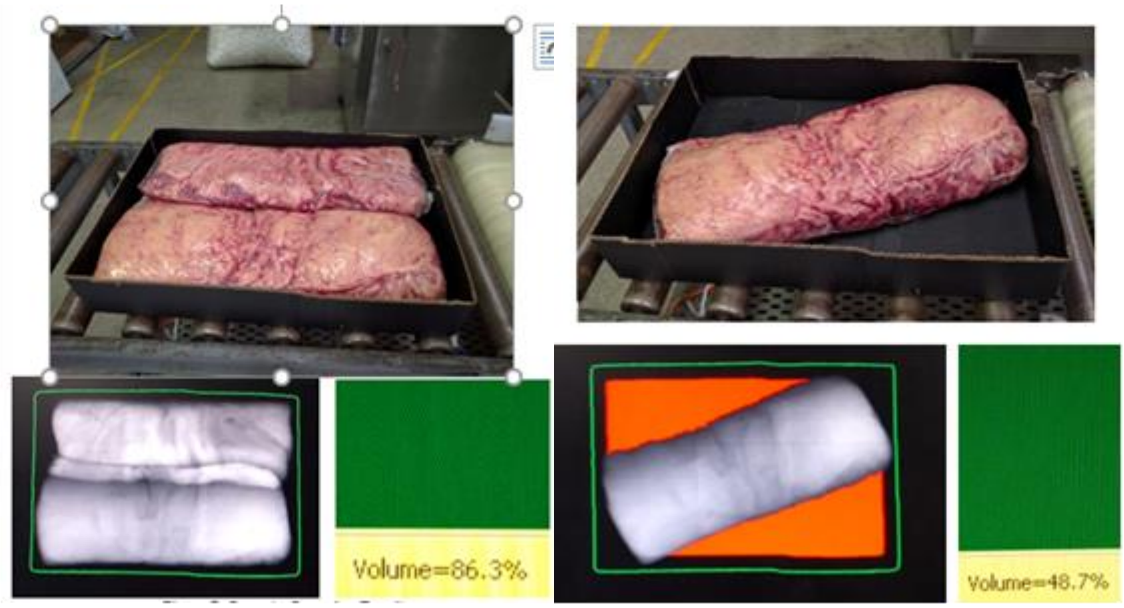


Figure 2: Meat boxes tested for carton fill.

CL or Chemical Lean: It is well understood within industry that a great deal variability can exist with CL levels when cartons are packed based on visual CL evaluation. This variability attracts a great deal of lost value to the processor and ultimately the value chain in lost opportunity and in supply claims.

One of the key enablers for DEXA carton profiling is the calibration of the system to measure bone and soft tissue quantities. It is feasible to extend this to differentiate between fat and lean and therefore to calculate chemical lean (CL). This was also investigated with promising results. It is therefore proposed that CL calculation be investigated further.

There are currently systems which measure chemical lean using x-ray. One key short coming of these systems is the lack of reporting capabilities. It has been identified that the following reporting functionalities would be highly beneficial to processors in Australia; a real-time display placed in the packing area would give packers immediate feedback on performance and allow them to modify as necessary, the logging of data to files or a database to allow historical trend data to be used for process optimisation. The ability to perform such customer reporting would be valuable for all functions of the machine.

Finally, x-ray technology is already used extensively for the purposes of contamination detection in cartons. This functionality could also be built into the machine to allow checking of cartons for contaminants while also assessing fill rate and packing structure. Contaminant data would be recorded to provide historical event history for business performance measurement.

1.3. Project objectives

DEXA has been shown to be effective when scanning boxes as a method of detecting contaminant within product including such contaminants as foreign material and bone. This has been shown using the Scott DEXA X-Ray contamination machine platform. The objective of these two milestones are to design, manufacture a prototype platform with DEXA technology to be able to measure carton fill %, detect contaminant, measure CL and generate online reporting.

1.4. Methodology

The following workflow was identified for executing the project:

1. Pilot trials and initial system design
2. Purchase, manufacturing of hardware, installation and commissioning
3. Software programming for hardware implementation
4. Scan of phantoms and Calibration of x-rays
5. Algorithm development for carton fill calculation
6. Factory trials testing
7. Further trials

1.5. Success in meeting the milestone

In order to have internal FAT the system, samples were taken in different sized meat cartons with various fill orientations. The boxes were filled with a combination of striploins and shortloins which had their volumes estimated using CT scan images. The system was set up to flag voids of a certain size or if total fill percentage was below a threshold. The system also checked with meat cartons and samples of different contaminants. The system also is developed for measurement of CL (in progress).

2. System Prototype

To achieve objective of this project, an X-Ray Inspection platform was designed and built with DEXA detector sensing, and enough X-Ray power/intensity to be able to find the optimum point required.

It was also decided to do following changes to previous X-Ray Inspection Systems and apply to new changes to this project:

The computer hardware system was updated for greater computing power, improved communication abilities, and occupy a smaller footprint.

All previous algorithm coding was upgraded to allow greater functionality and flexibility for future development of this system by adding/changing modules.

New calibration objects were also designed and constructed in a way to improve the accuracy of the calibration process.

The conveyor belt system was designed for standard width meat cartons and runs at a speed of 0.3 metres per second.

Figure 3: XR8000 inspection prototype platform with an upgraded detector inside.

Figure 4: XR8000 inspection prototype platform with an upgraded detector inside.

2.1. Design and Manufacturing of Soft and Hard Tissue Phantom:

DEXA images are in fact two separate images that contain the X-ray interaction with an object from different parts of the X-ray spectrum, denoted by the low energy (LE) and high energy (HE) images. If these parts are significantly different, then it's possible to transform the two X-ray images into thickness images of two, and only two, materials. The calibration process was optimised to allow the raw x-ray data to be converted into accurate lean, fat, and bone measurements. A key part of this process was the design and construction of specially designed calibration objects.

It should be noted that the X-ray properties of Fat and Lean are very similar, so the difference between the signals of the two DEXA images are very small. Since these small differences are mapped into large variations in thicknesses, and consequently CL, the X-ray imaging system must be extremely temporally stable. Otherwise considerable variation in CL values can arise from the repeated scans of the same carton. Considerable effort has been invested and, as a result, the required consistency of measurement has been achieved.

3. Contaminant Inspection

3.1. Background

Manufacturers need X-ray inspection systems in order to protect their brands as a poor quality product will damage their reputation with consumers and their future business. The quality of products needs to be controlled and verified on the production line and incorporating X-ray inspection into a business, whether in the food, beverage or pharmaceutical industry, is one of the most effective ways to safeguard against potential issues. Reducing the risk of poor quality products will also help manufacturers to increase their profitability as they avoid unnecessary and costly product recalls. Manufacturers are aware that they need to remain successful in a highly competitive and increasingly global marketplace and to achieve this they must ensure that their products meet the quality standards that their customers demand.

With an X-ray inspection system, manufacturers can identify contaminants such as metal, stone, glass, dense plastics and calcified bone. They can also reduce overall maintenance and ownership costs as many systems now combine the jobs that would normally need more than one machine. For example, in addition to contaminant identification, current X-ray systems can carry out recipe management. X-ray inspection systems can also simultaneously perform in-line quality checks such as measuring mass, counting components, identifying missing or broken products, monitoring fill levels, inspecting seal integrity, and checking for damaged products and packaging. With one machine carrying out several tasks, line maintenance and operations costs can be reduced.

3.2. Contaminant Inspection for Generated X-ray Image

An X-ray image is generated using the data captured from detectors. Here, two different post-processed x-ray images are compared for contaminant detection. Image processing algorithms are used to detect the contaminant (if any) inside the X-ray image. There are several challenges to detect contaminant in X-ray images. These include but not limited to noise, size, shape, orientation, contrast, background texture, etc. In addition, suppressing noise in X-ray images is a key challenge as contaminant detection of small objects may not be possible. This section details the contaminant detection algorithms developed and implemented in this inspection machine. These steps are as follow: image pre-processing, applying image processing tools, and contaminant identification.

3.2.1. Image Pre-processing

After capturing the data from X-ray detector, the images undergo pre-processing. This converts raw X-ray yield images to X-ray transmission images. Figure 5 shows an acquired image plus the images produced after pre-processing has occurred. It can be seen that this improves the contrast in the dark area and small contaminants are easier to see.

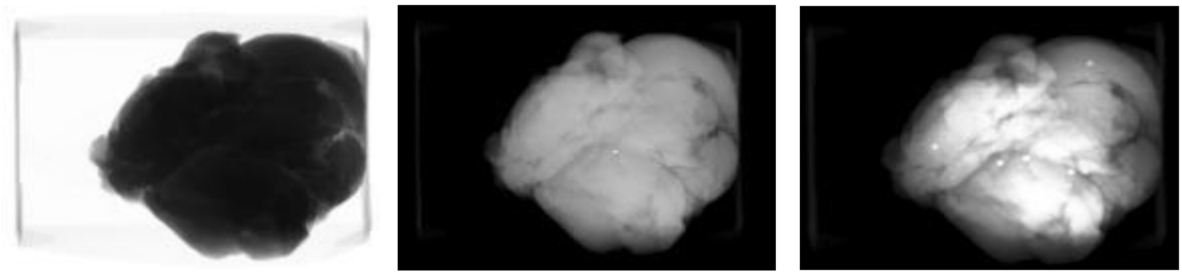


Figure 5: Left to right: Original 2-D transmission image (Meat with 90% Lean), and post-processed images. The bright white spots are contaminants.

The main purpose of pre-processing the image is to linearise the image contrast making it amenable to the plethora of techniques that have evolved in the field of image analysis. The techniques implemented to detect contaminants are described in the following sections.

Before proceeding to these descriptions, some images are shown of the system during contamination detection and CL trials.

3.2.2. Image Processing Tool

To detect contaminants, it's necessary to discriminate between background and foreground pixels in an image. In this case, the background is the meat texture and the foreground is the contaminant. There are several techniques to extract foreground from background in the image. If the background is plain and uniform, simple global thresholding easily extracts the foreground from background. However, in reality, the background can include several textures and edges which make global thresholding ineffective. Since the contrast of contaminants in x-ray images aren't always sharp, more advanced techniques are required for contaminant detection.

More complex image processing tools were utilised to allow more robust contaminant identification. These tools can extract useful structural information from images and dramatically reduces the amount of information to be processed. The general criteria for feature detection are:

- Detection of features with low error rate, which means that the detection should accurately catch as many features shown in the image as possible.
- The features detected from the operator should accurately localize on the centre of the feature. A given feature in the image should only be marked once, and where possible, image noise should not create false positives.

Figure 6 show x-ray images and their features. It can be seen that the contaminants are clearly defined. However, the edges around the border are also detected. This would cause an issue and send false alarm to contaminant inspection. To overcome this, a novel ranking technique was developed to discriminate between features.

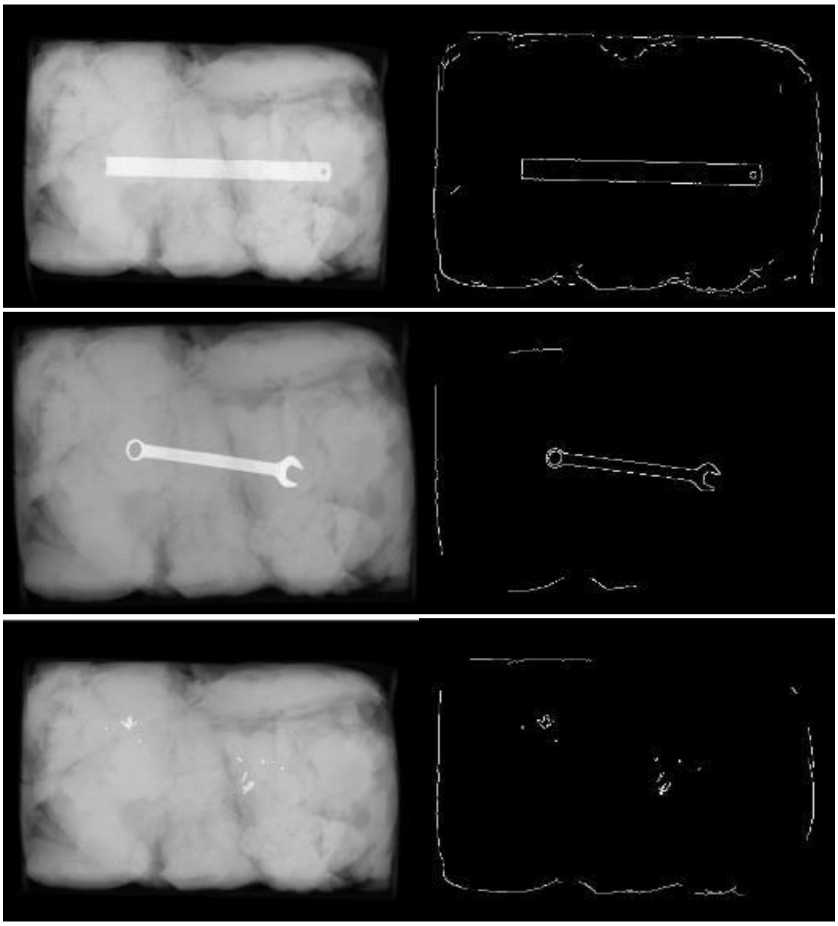


Figure 6: The meat image with contaminant (The stain steel ruler). The features detected after correctly setting the appropriate parameters.

After the initial features are identified, a ranking system is implemented to further isolate the contaminants of interest, as demonstrated in Figure 7.

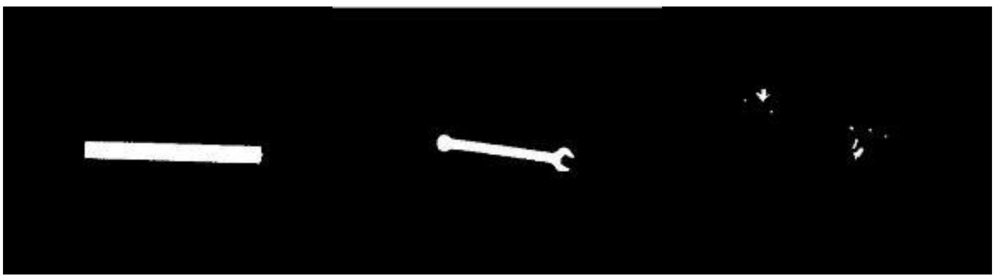


Figure 7: Ranking created from Figure 6.

3.2.3. Contaminant Inspection

The last step is to show where contaminants are located in a product. The image is annotated with red and either show it as an edge or filled in, as shown in Figure 8. Once detected, the alarm is sounded and the product can be deflected.

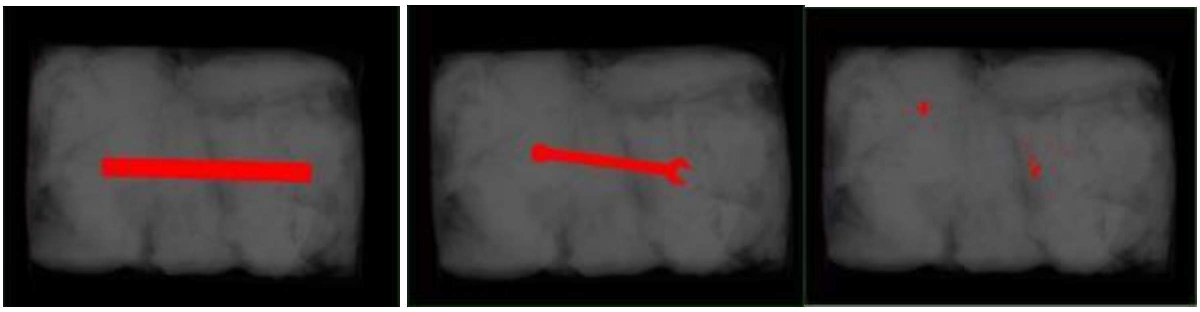


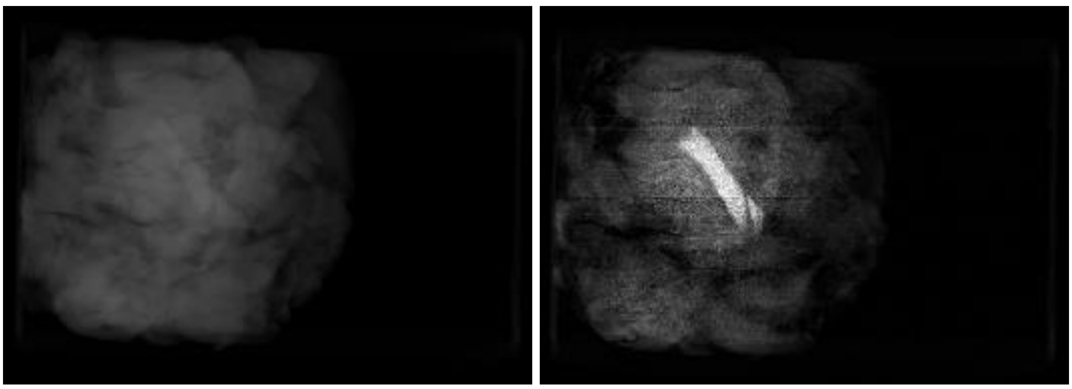
Figure 8: Contaminant labelled in red automatically.

3.2.4. Point Inspection

To retain the ability to detect such small, less prominent contaminants alternative detection methods and are included in the new software.

3.3. DEXA Contaminant Inspection

As described above, the two images from a DEXA scan can be converted into two alternative images based on the calibration. Any materials that have different X-ray characteristics to lean or fat (eg: many but **not** all contaminants) result in outputs from the calibration that are quite distinctive and provide a strong signature for contaminant detection. Figure 9 shows alternative x-ray images for various contaminants, the right-hand side images after being processed through a calibration procedure. As exemplified below, barely distinguishable contaminants in the uncalibrated image are very prominent and obvious in the calibrated image. Therefore, calibrated images can overcome the contrast issues for several types of contaminants which would improve accuracy in terms of false alarms for contaminant inspection.



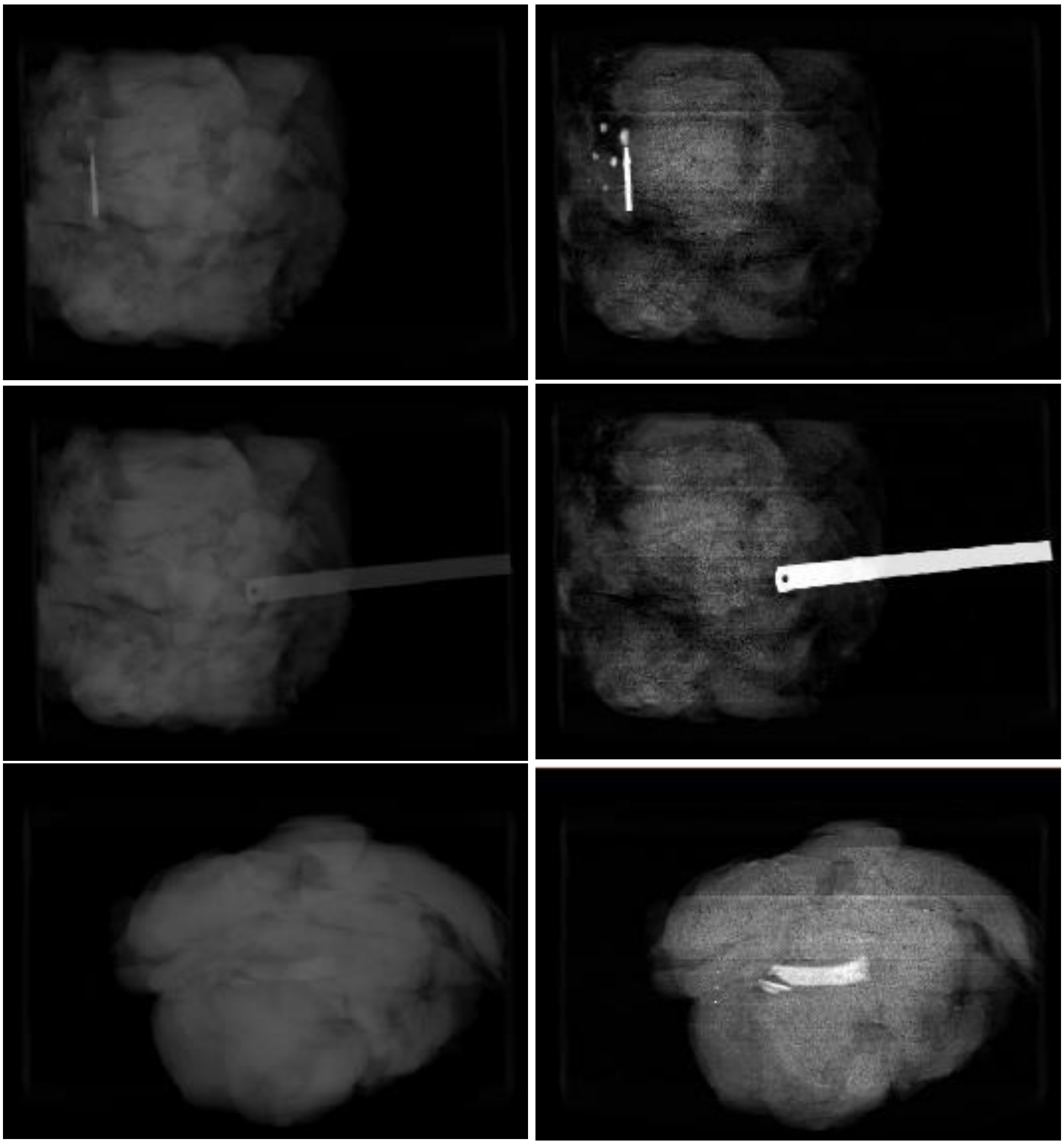


Figure 9: Left: Uncalibrated images with different contaminants including bones. Right: Calibrated images.

After generating the calibrated image, the technique described in section 3.2 is used to detect contaminants. The issue with calibrated images is not only is the contrast for contaminants improved, but the noise is amplified. This noise causes issues that can increase false alarms for contaminant detection. Post-processing is used to suppress this noise issue. Figure 10 demonstrates the contaminant detection before and after post-processing of the image.

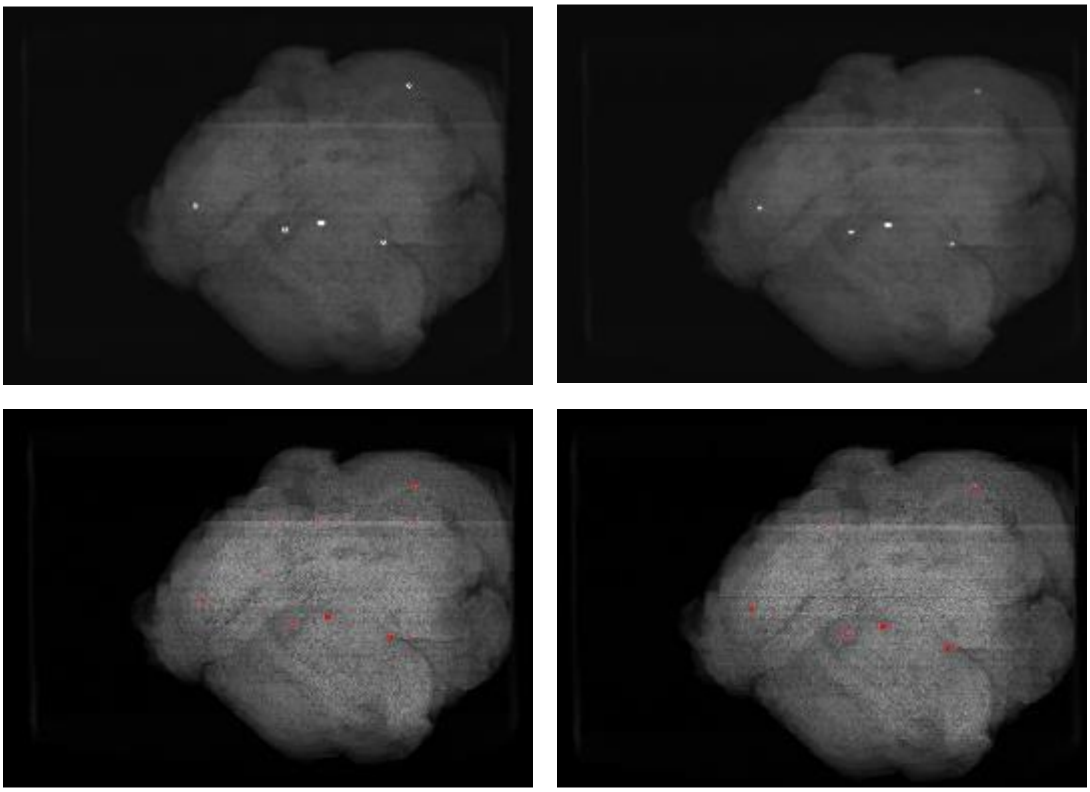
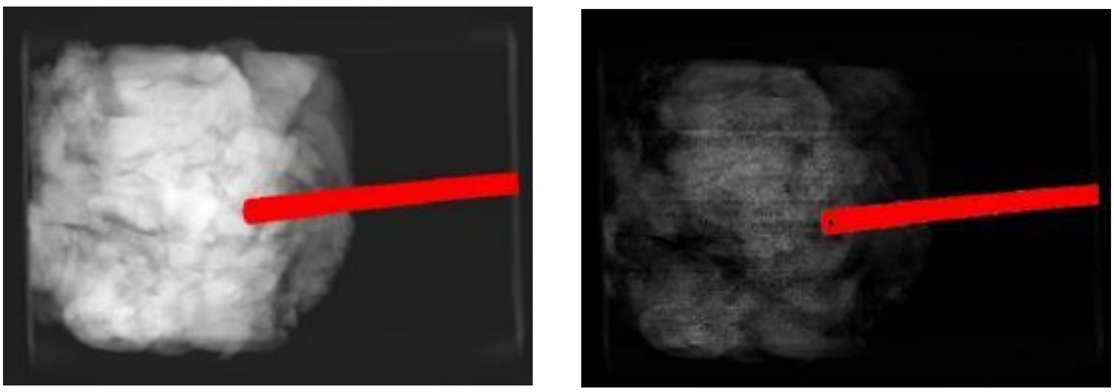
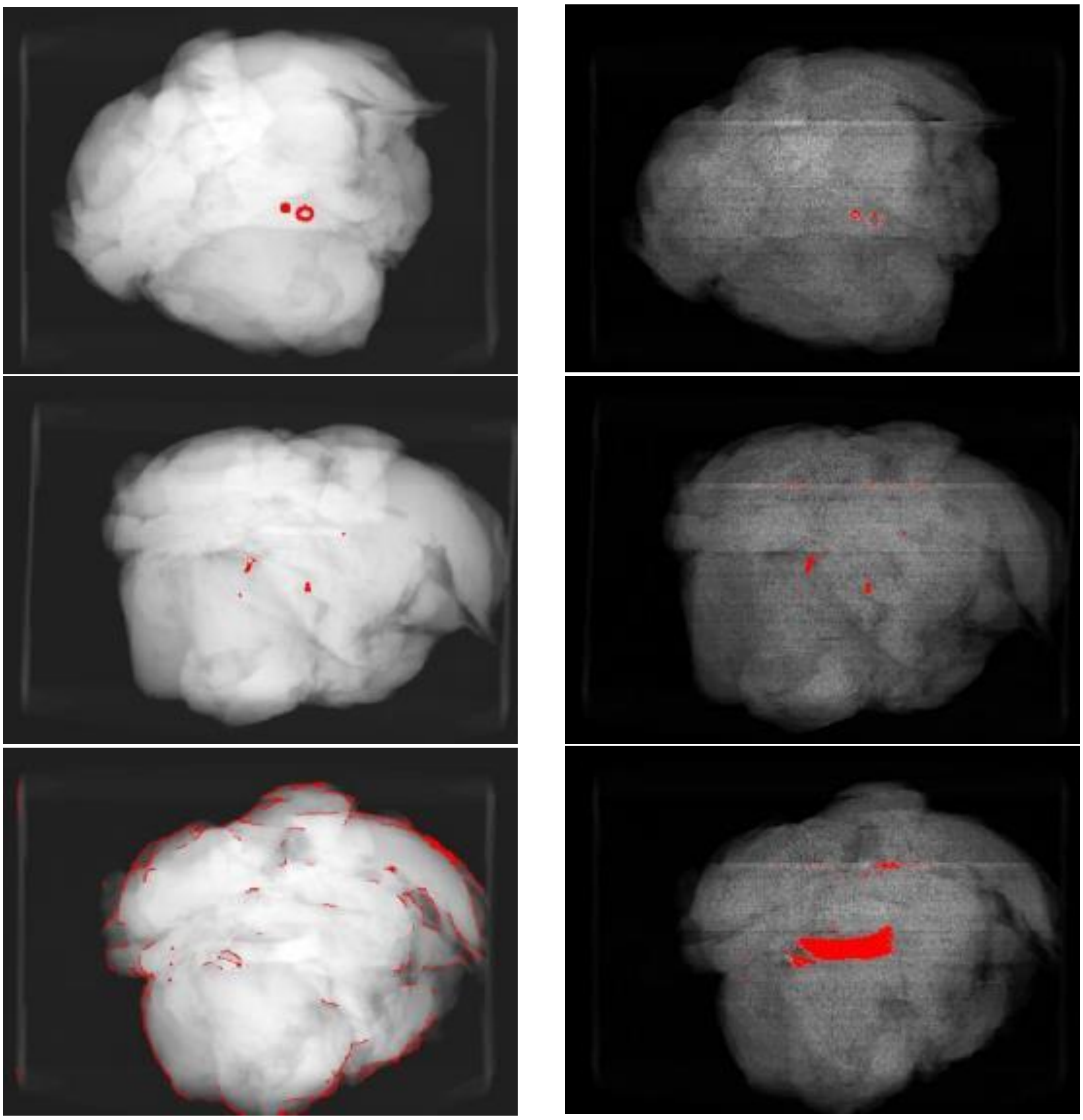


Figure 10: Left: enhanced calibrated image and its contaminant inspection. Right: Post-processing applied to calibrated image and its contaminant inspection..

3.4. Experimental Results

Images have been captured with the XR8000 X-ray machine for different contaminants inside boxes of meat. Also, different types of meat (65% and 90% CL) were scanned and both uncalibrated and calibrated images were processed to determine the robustness of the contaminant inspection algorithm. The results in Figure 11 show the technique can detect large contaminant in both images. However, for contaminants such as bones or rubber, the technique generates a false alarm in uncalibrated images. Therefore, contaminant detection for calibrated images has outperformed the uncalibrated images.





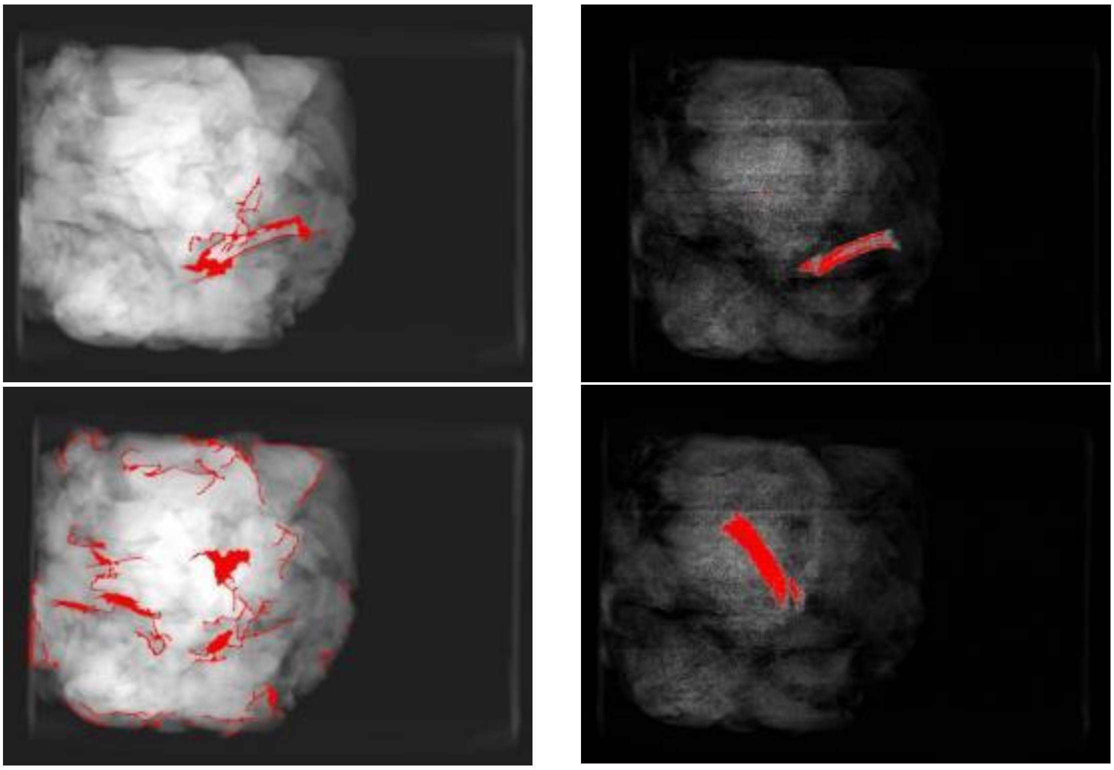


Figure 11: Contaminant inspection for Left: LE image and Right: Lean image.

3.5. Discussion

The contaminant detection from X-ray is a challenging problem due to several variations in material, size, scale, shape, etc. To verify the robustness of the contaminant inspection for meat processing, different type of materials with different size and shape has been used inside the meat box. The meat types used here is beef with 65CL and 90CL. The height of the box is 170mm. Both boxes have been scanned several times with and without contaminants inside to check the variation in contrast and robustness of the algorithm. The materials used as contaminants follow.

3.5.1. Bone

The bone was added inside the box of boneless beef meat as a contaminant. The box was scanned with X-ray machine and both uncalibrated and calibrated images are used for contaminant detection. The bone used is shown in Figure 12. After adding this bone randomly, the boxes was scanned and the results shown in Figure 13. It can be seen that the bone can be detected with 90% CL in uncalibrated image. However, with 65% CL, it is not possible to detect the whole bone. Furthermore, the sensitivity is less than 10% which makes it very sensitive to noise and background changes in contrast of the meat texture.

Figure 12: sample of bone (rib) used for contaminant inspection.

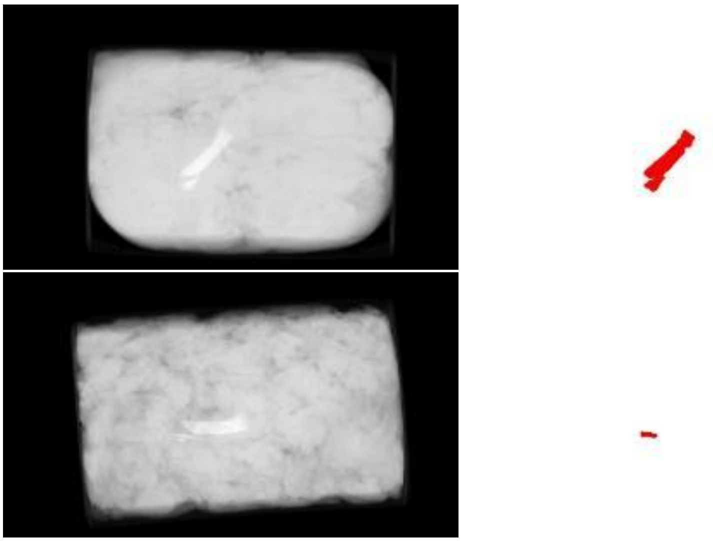


Figure 13: Uncalibrated image with bones added to box of meat with 90% CL for top row and 65% CL for bottom row.

Figure 14 illustrates contaminant detection with the calibrated image. It can be seen that for both 65% and 90% CL, the bone is detected accurately and the contrast of bone in calibrated images is higher than in uncalibrated images.

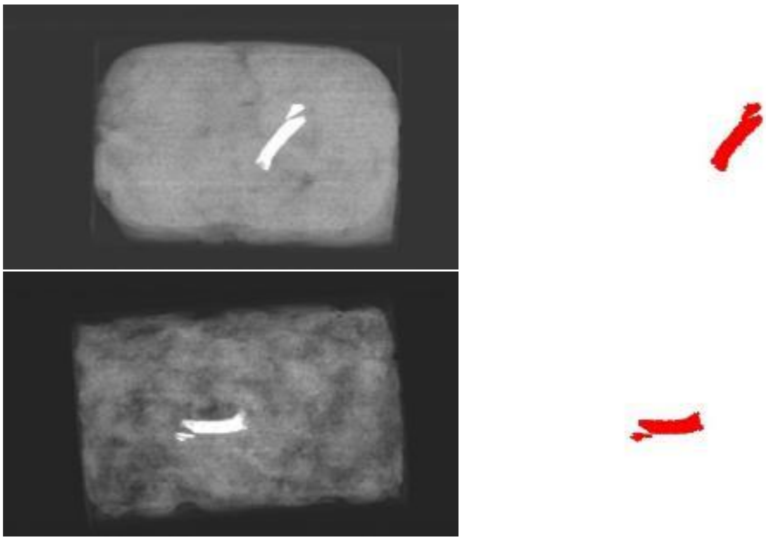


Figure 14: Calibrated images. Top row is 90% CL and bottom row is 65% CL.

3.5.2. Glass

Different types of glass were used for contaminant inspection in box of meat. Samples of glasses with different sizes are shown in Figure 15.

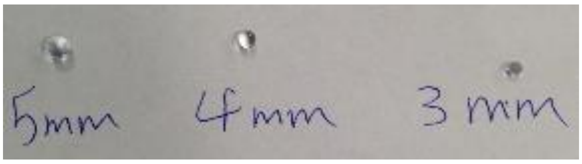


Figure 15: Glass samples used for testing the contaminant inspection.

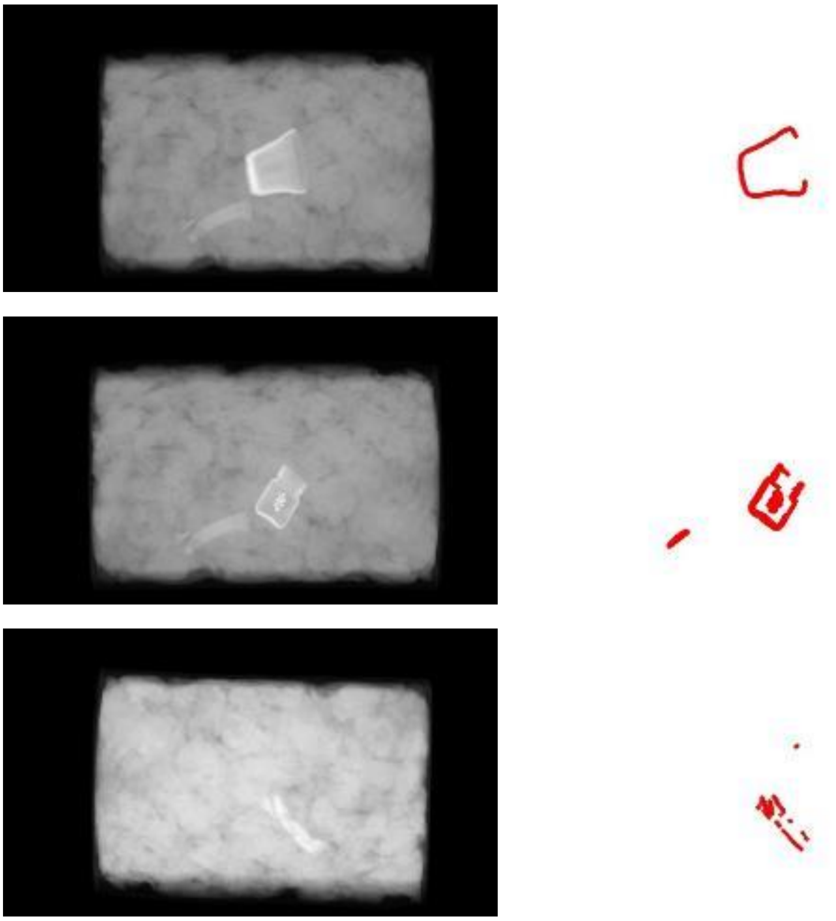


Figure 16: Contaminant inspection of uncalibrated image for glass with different sizes in 65% CL meat.

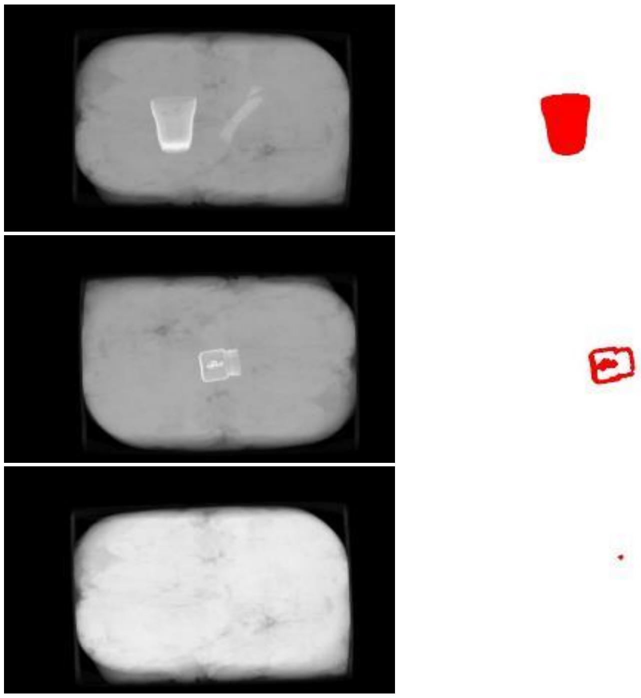


Figure 17: Contaminant inspection of uncalibrated images for glasses with different sizes in 90% CL meat.

From Figure 16 and Figure 17, it can be seen that detecting of large glass contaminant is possible in uncalibrated images with different shapes and size, but glass balls with less than 5 mm diameter can't be detected due to low contrast. Calibrated images are shown in Figure 18 and Figure 19. The glass has high contrast and is detected plus it's possible to detect smaller glass contaminants with 4mm diameter. The fact the bone is partially detected in the uncalibrated images emphasises the need to set algorithm parameters carefully, whereas with the higher contrast calibrated images this care is diminished.

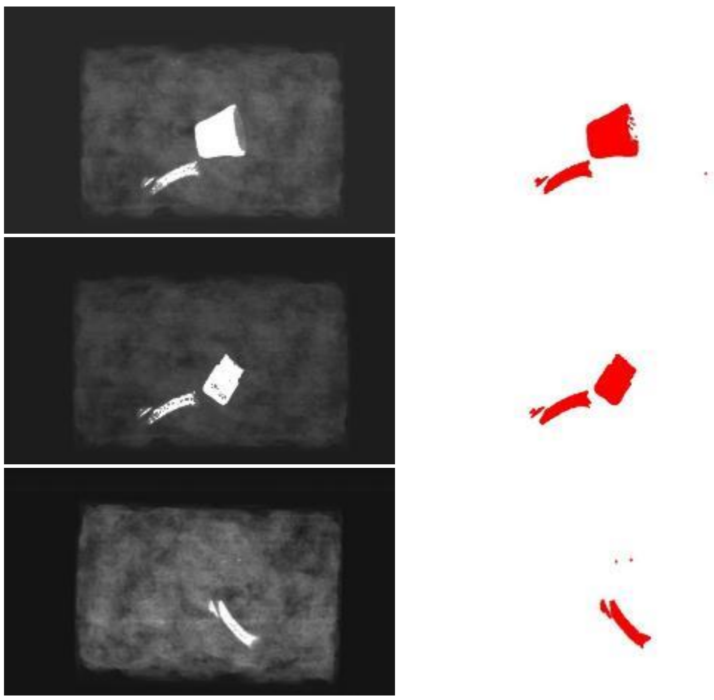


Figure 18: Contaminant inspection of calibrated image for glass with different sizes in 65% CL meat.

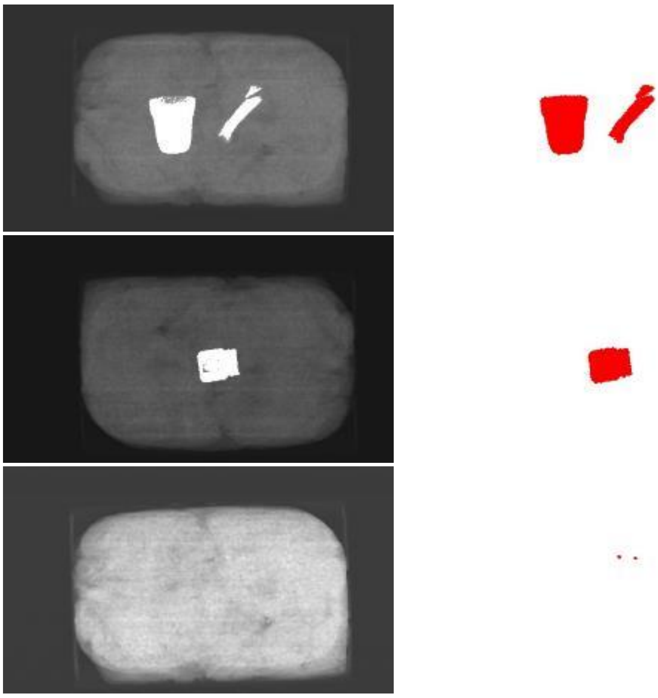


Figure 19: Contaminant inspection of calibrated images for glass with different sizes in 90% CL meat.

3.5.3. Basalt

Basalt is used as a contaminant for meat contaminant inspection. Figure 20 shows basalt with different sizes and shapes.

Figure 20: Basalt used for contaminant inspection.

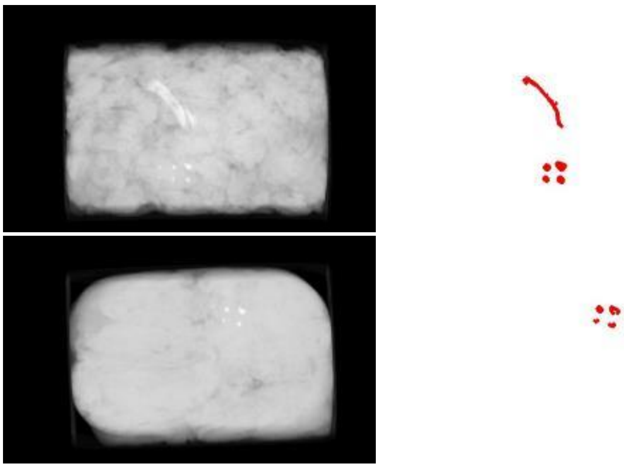


Figure 21: Inspection of uncalibrated image for basalt with different sizes in 65% (Top) and 90% (bottom) CL meat.

Figure 21 shows that basalt is detected in uncalibrated images, but only down to a size of 4.9 mm. Figure 22 show the 4.9 mm basalt detectable in calibrated images. In addition, the bone is also detected in the calibrated image with 65% CL.

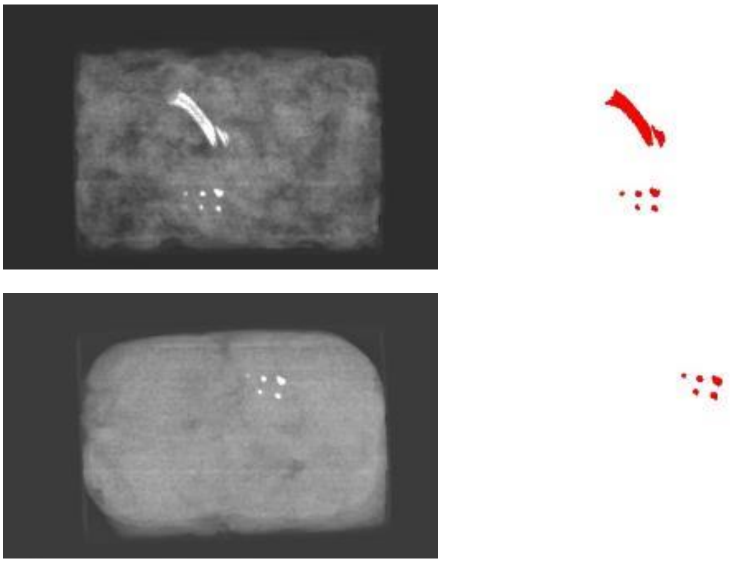


Figure 22: Inspection of calibrated image for basalt with different sizes in 65% (Top) and 90% (bottom) CL meat.

3.5.4. PVC Material

The PVC and UHDPE materials are used as a contaminant for meat contaminant inspection. Samples of these materials are shown in Figure 23. For uncalibrated images, it is not possible to detect less than 8mm size for PVC as shown in Figure 24. Furthermore, the bone is partially detected for 65% CL. For calibrated images, the PVC with 4mm can be detected and the bone is also clearly detected. Figure 25 shows the results for both 65% and 90% CL meat.

Figure 23: PVC used as contaminant inside the meat boxes.

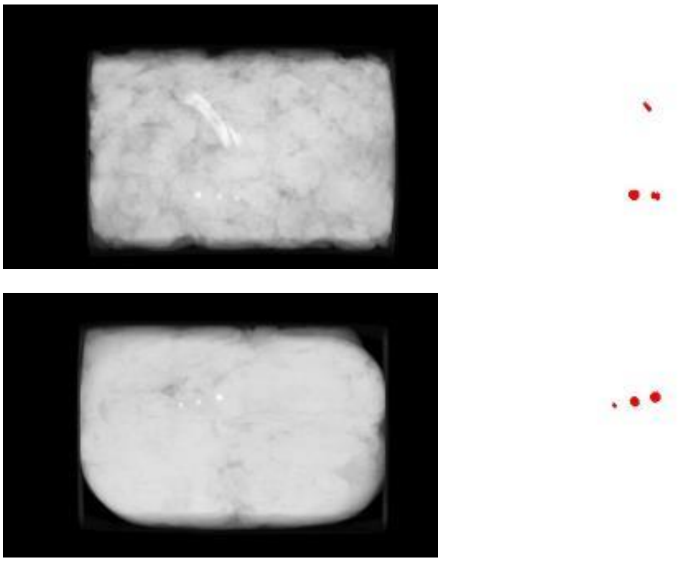


Figure 24: Contaminant inspection of uncalibrated images for PVC with different sizes in 65% (Top) and 90% (bottom) CL meat.

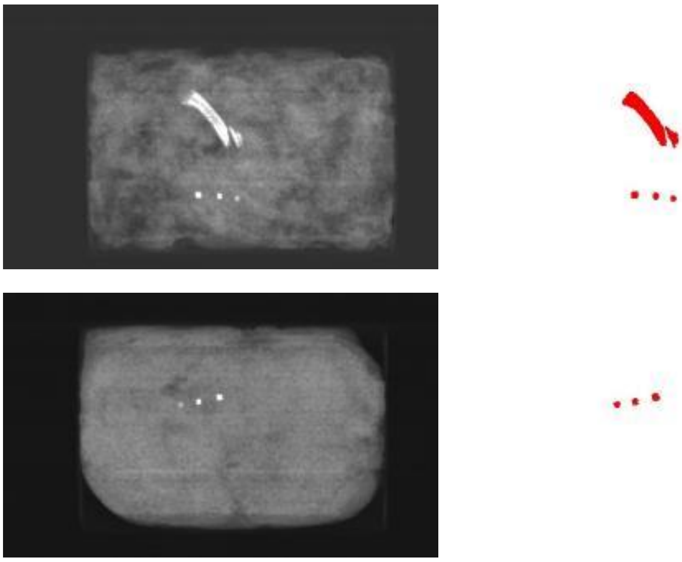


Figure 25: Contaminant inspection of calibrated images for PVC with different sizes in 65% (Top) and 90% (bottom) CL meat.

3.5.5. Stainless Steel and Metal

The stainless steel ruler, needles, wrench and spheres with different are used as a contaminant for meat contaminant inspection. Figure 26 shows samples of these materials. Figure 27 and Figure 28 show that the large stainless steel contaminants can be detected in LE images. However, for needles it is not possible to detect less than 1.6 mm in diameter. In addition, the bone is not detectable due to low contrast when having large contaminant inside the box. For Lean images, it can be seen that the large objects with bone can be detected. For small stainless steel contaminants needles down to 0.7 mm in size are detected but for spheres it is not possible to detect less than 2mm diameters. This is expected as these tests were done using a 1.6 mm pitch detector.

Figure 26: Stainless steel and metals used for contaminant inspection.

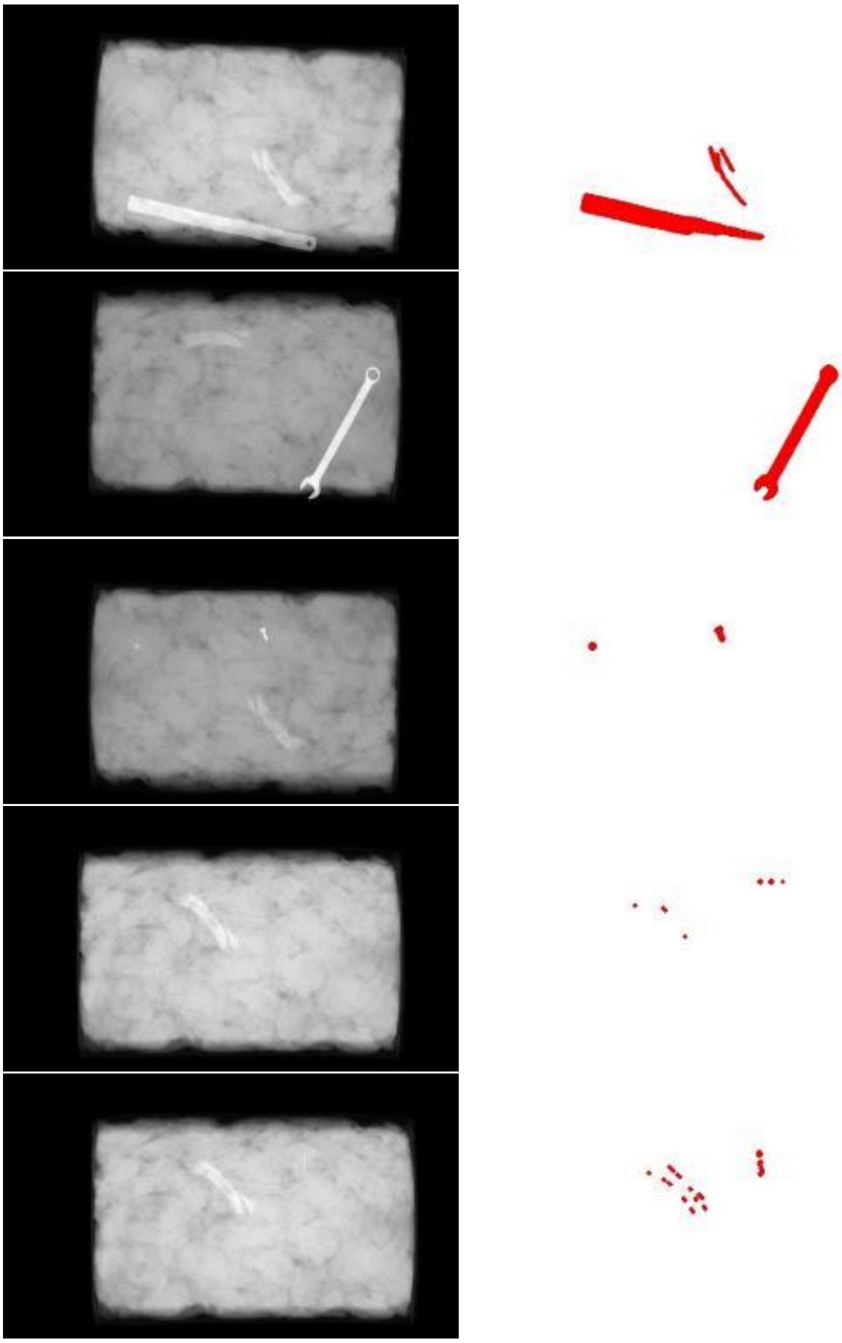


Figure 27: Contaminant inspection of uncalibrated images for stainless steel with different sizes in 65% CL meat.

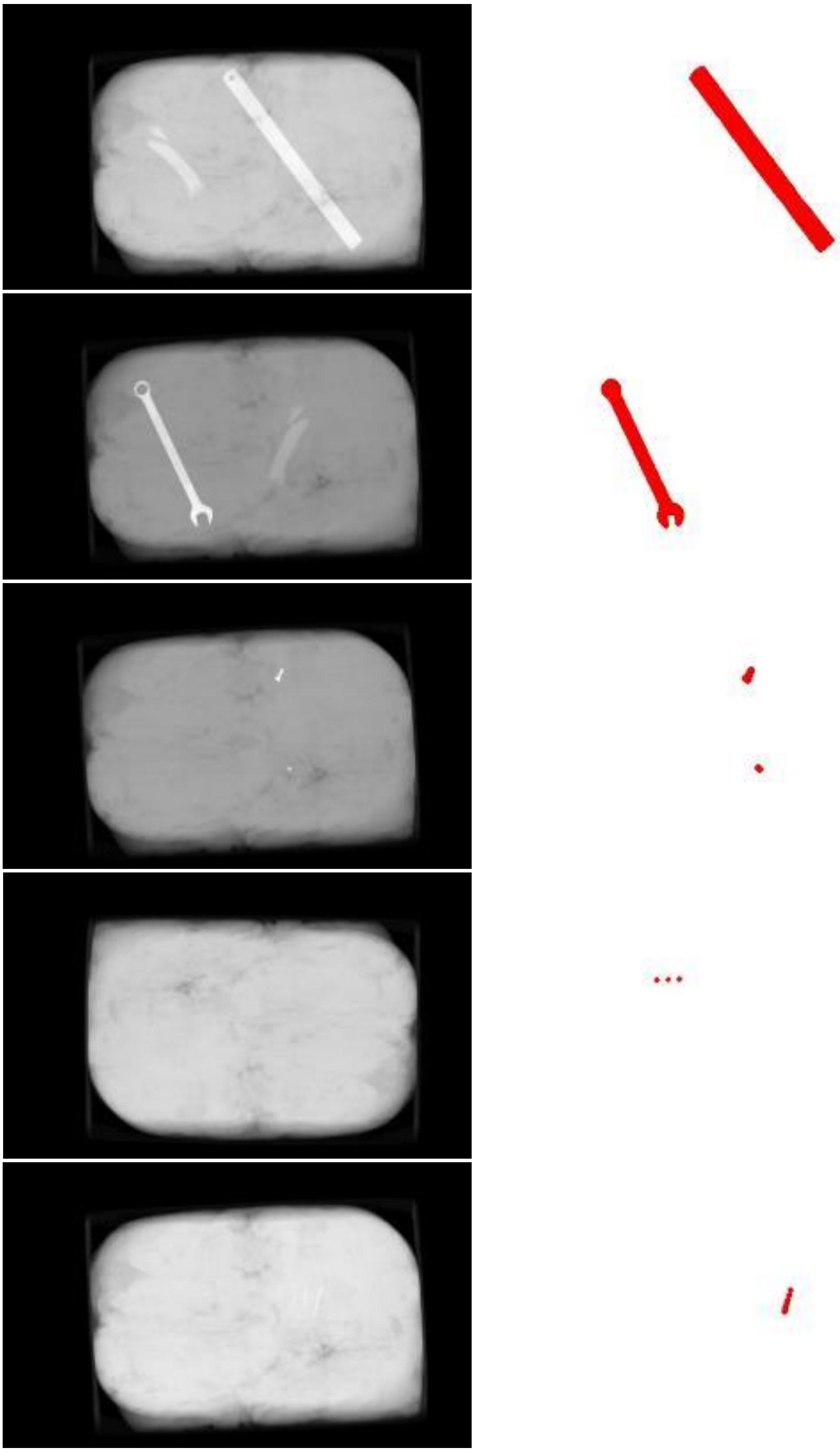


Figure 28: Contaminant inspection of uncalibrated images for stainless steel with different sizes in 90% CL meat.

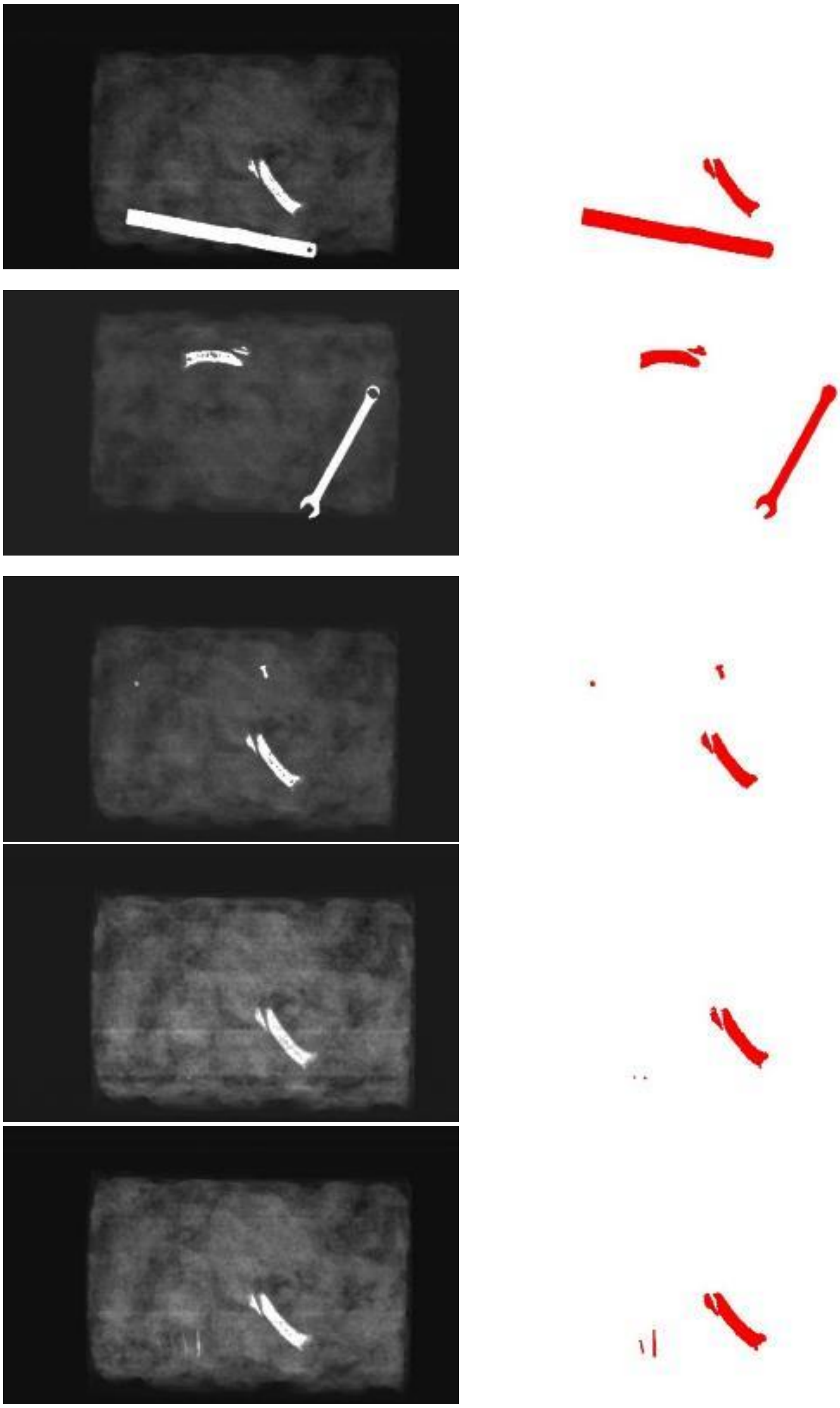


Figure 29: Contaminant inspection of calibrated image for stainless steel with different sizes in 65% CL meat.

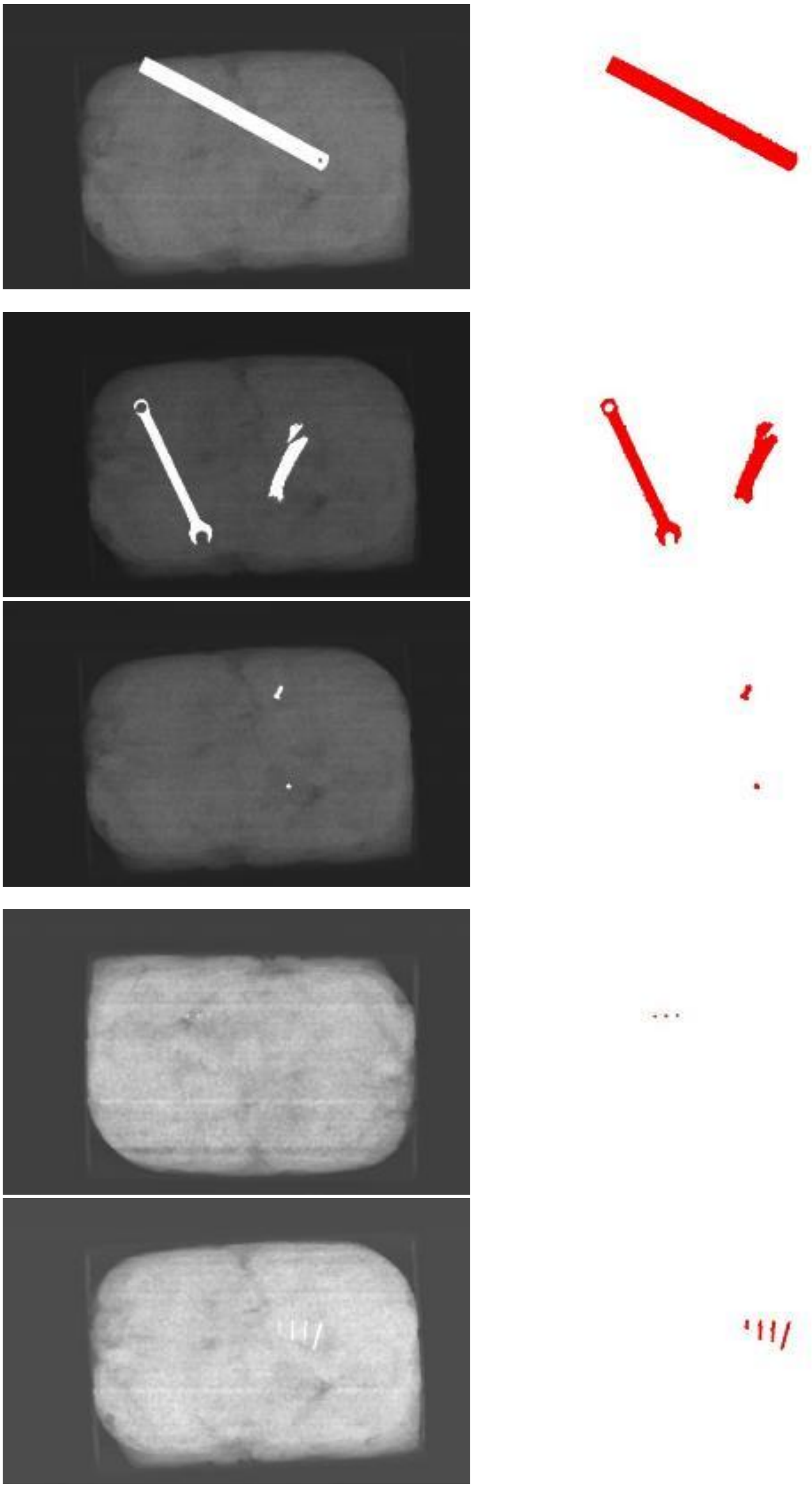


Figure 30: Contaminant inspection of calibrated images for stainless steel with different sizes in 90% CL meat.

3.6. Conclusion

The contaminant inspection algorithm in section 3.2 has been demonstrated for X-ray scans of boxed meat. Experimental results show that the contaminants are detected in both uncalibrated and calibrated images if the contaminant has high contrast compared to background. However, in many cases such as bones the contrast is too close to the background, as exemplified in the uncalibrated images. Calibrated images show better contrast of contaminants and therefore contaminants are easier to detect. In addition, this contaminant detection technique outperforms classic global thresholding.

4. Carton Fill Calculation

To measure the percentage carton fill, accurate calibrations are required. Since this work was achieved in a previous study, the same algorithm has been copied into the new XR8000 software. The examples below use the boneless X-ray images and calibrated images from the previous study but this time measured on the new XR8000 software.

The algorithm to calculate the percentage carton fill requires only one parameter – the box height. When a carton is scanned, an algorithm first identifies the width and length of the box. The data from the calibrated images are then processed to calculate the percentage carton fill within the carton.

Another algorithm analyses the values to identify the presence of any ‘voids’ in the carton – areas which have been under filled. Such areas represent a risk for the carton collapse when stacked. Similarly, the total fill percentage is interrogated. If voids are detected, they are highlighted on the x-ray image, an alarm is sounded and an output fired (which may actuate a diverter). Similarly, if the fill volume is too low, the entire area is highlighted, the alarm sounded and the output fired. The visibility of the highlighting on the image can be toggled by pressing a button on the machine, thus allowing the original x-ray image to be viewed if necessary.

Note a new approach has been investigated that calculates an overall box collapsibility factor. This is briefly discussed at the end of this section.

4.1. Internal Trials and Factory Acceptance Testing (FAT)

In order to FAT the system, samples were taken in three different sized cartons with various fill orientations. The boxes were filled with a combination of striploins and short loins which had their volumes estimated using CT scan images. The system was set up to flag voids of a certain size or if total fill percentage was below a threshold. In the former case, the voids are highlighted by a red box on the image. In the latter, a red box overlaps the entire image. In both cases, a flashing light and an audible alarm are sounded after a delay (which would also actuate a diverter downstream in a production environment). The outline of the box is traced in green. The fill volume was also reported on the screen for every scan.

Scan 1 –

Box dimensions (mm): 545 x 360 x 90
Product: Two striploins
The system reported a fill volume of 74.7%.
The estimated fill volume using the CT data from the striploins is 74%.
PASS – The system would pass this box as being within tolerance.

Figure 31: Scan 1 - Two striploins in 545 x 360 x 90 box

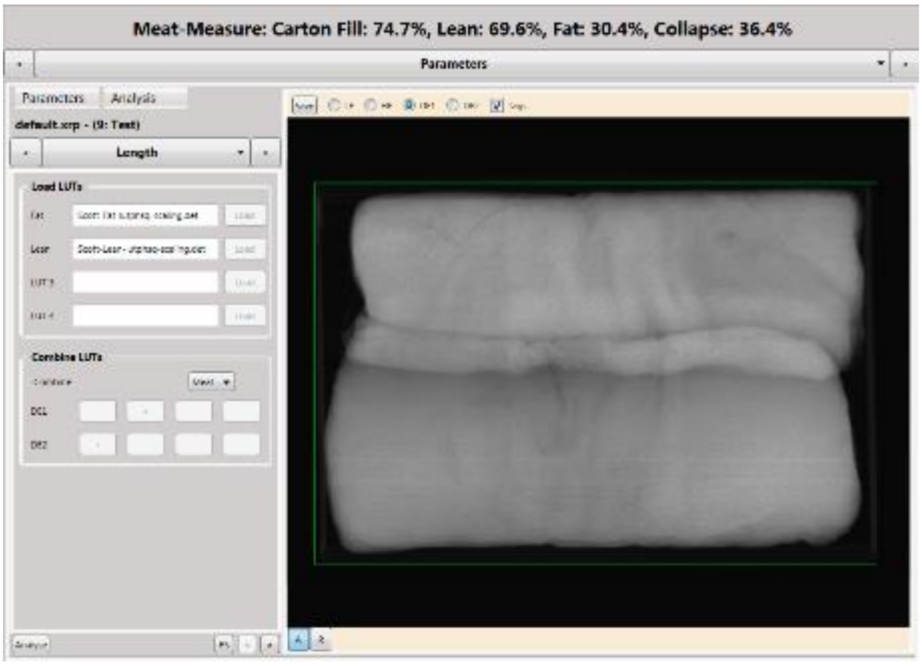


Figure 32: Scan 1 - Scanning Result

Scan 2 –

Box dimensions (mm): 545 x 360 x 90
Product: One striploin placed along one side.
The system reported a fill volume of 40.3%.
The estimated fill volume using the CT data from the striploin is 40%.
FAIL - The system would fail this box - the void on the side of the box was identified and flagged.

Figure 33: Scan 2 - One striploin in 545 x 360 x 90 box.

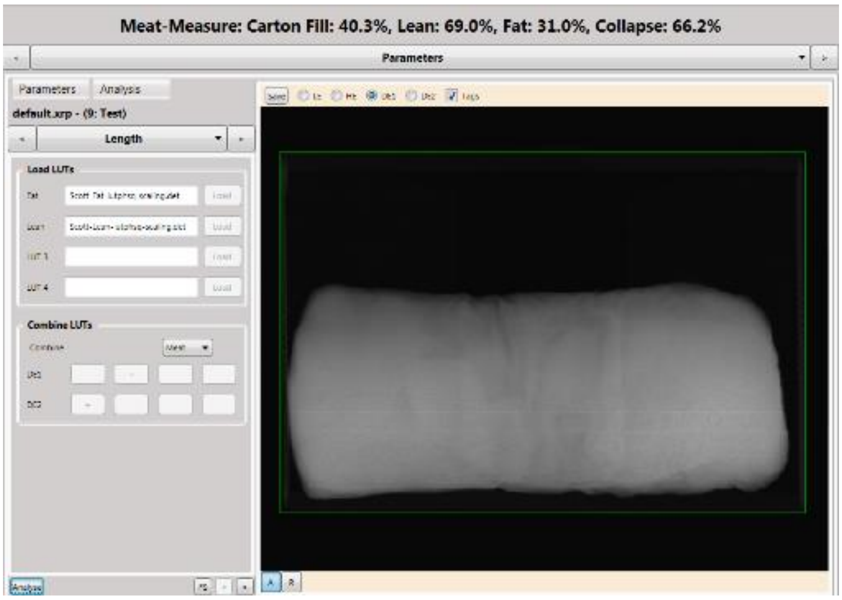


Figure 34: Scan 2 - Scanning Result.

Scan 3 –

Box dimensions (mm) : 545 x 360 x 90
Product: One Striploin placed diagonally across the box.
The system reported a fill volume of 40.5%.
The estimated fill volume using the CT data from the striploin is 40%.
FAIL - The system would fail this box - the voids on the corners of the box were identified and flagged.

Figure 35: Scan 3 - One striploin in 545 x 360 x 90 box.

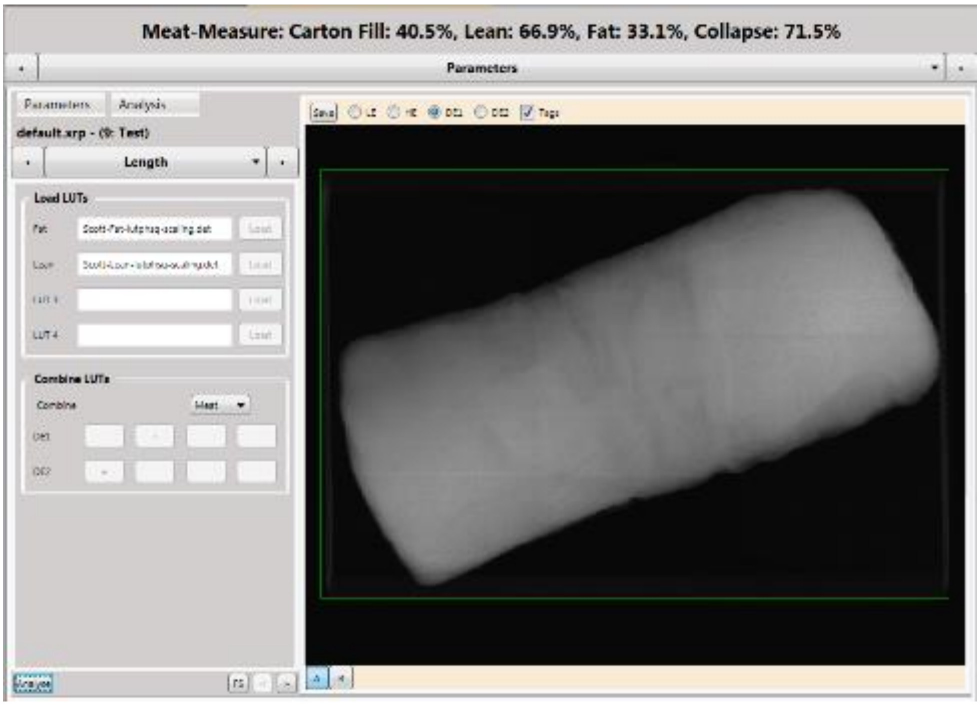


Figure 36: Scan 3 - Scanning Result.

Scan 4 – (Note, 170mm tall box)

Box dimensions (mm) : 585 x 320 x 170
Product: Two striploins side by side.
The system reported a fill volume of 37.4%.
The estimated fill volume using the CT data from the striploin is 41%.
FAIL – The system would fail this box - the box is under filled which has been identified and flagged.

Figure 37: Scan 4 - Two striploins in 585 x 320 x 170 box.

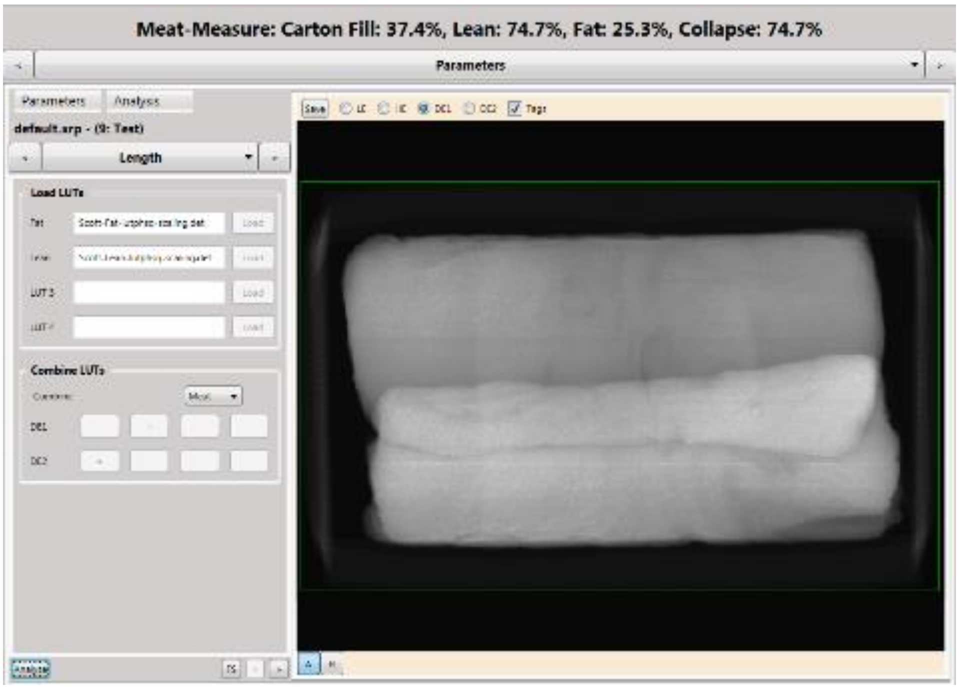


Figure 38: Scan 4 - Scanning Results.

A table summarising the results is shown in Table 1. Feedback from the customer suggests that the levels of accuracy which have been achieved may already be sufficient for their requirements. In fact improvements to the algorithm have led to more accurate results.

Table 1: Reporting structure for XR8000.

Scan	Box Height (mm)	Samples	Comments	Exp Vol %	Reported Vol %
01	*90*	Both Striploins	Carton Full - **Pass**	73.9%	74.7%
02	*90*	High Marbled Striploin	One side filled - **Fail**	40.0%	40.3%
03	*90*	High Marbled Striploin	45 degree fill - **Fail**	40.0%	40.5%
06	*170*	Both Striploins	Underfill - **Fail**	41.0%	37.4%

4.2. Conclusions/Recommendations/Further Work

A carton fill profiling system utilising DEXA technology has been created by SCOTT and demonstrated. The system was able to accurately identify the fill volume in closed cartons and identify the existence of voids which may indicate a risk of crushing when stacked upon. While the accuracy levels demonstrated meet the customer's need, a number of opportunity areas exist to further improve accuracy based on the learnings acquired throughout the project. This functionality is provided on top of the primary use for the machine, which is contamination detection.

Two key features which would add significant value to the system would be the implementation of chemical lean (CL) calculation and high quality reporting. By upgrading the hardware, this accuracy can be further improved. Similarly, the addition of customer-specific reporting functionalities can be added to the system based upon their requirements.

A rudimentary investigation in generating a ‘box collapsibility’ factor has been done based on how the meat is distributed within the box and is weighed against a structural integrity model of the box. The factor is a percentage probability that the box will collapse, with 100% reserved for empty boxes.

5. Chemical Lean Analysis

This section introduces the concept behind and steps necessary to perform chemical lean (CL) analysis using dual-energy X-ray (DEXA) scans.

5.1. Background

Chemical lean is a numerical value that represents the crude fat content of a portion of meat. The value of meat trim is determined based on its CL which is used to price the meat product. Therefore, meat processors are under growing pressure to be able to guarantee their CL values. A number of different methods of determining the fat content of meat exist. The fundamental industry standard reference model is Soxhlet which is used to compare with other fat analysis methods. The most common techniques used by meat processors today are Anyl-Ray and NIR&NIT Spectroscopy. Although all these methods are capable of generating useable measurements of fat content in meat, they have several limitations including skilled labour, sampling error, delay and gaming.

By carefully calibrating an X-ray system, the CL in a box can be measured.

5.2. Linearisation

To measure the CL content of a box containing meat, careful linearisation of the X-ray detector is required. To ensure repeatable measurements, image stability is essential. A specialised calibration object was constructed to allow for accurate linearisation and enable stable image data to be obtained from the system.

The effectiveness in this approach is demonstrated in the graphs below. The top graphs show the response of each pixel and each step thickness in red. As the thickness of the calibration object increases, the curvature also increases – this curvature must be removed if the CL measurement is to be accurate. Also note the small pixel variations and peaks with respect to the ideal ‘green’ response due solely to the fan-beam geometry. The bottom graphs show the step wedge measurement after correction.

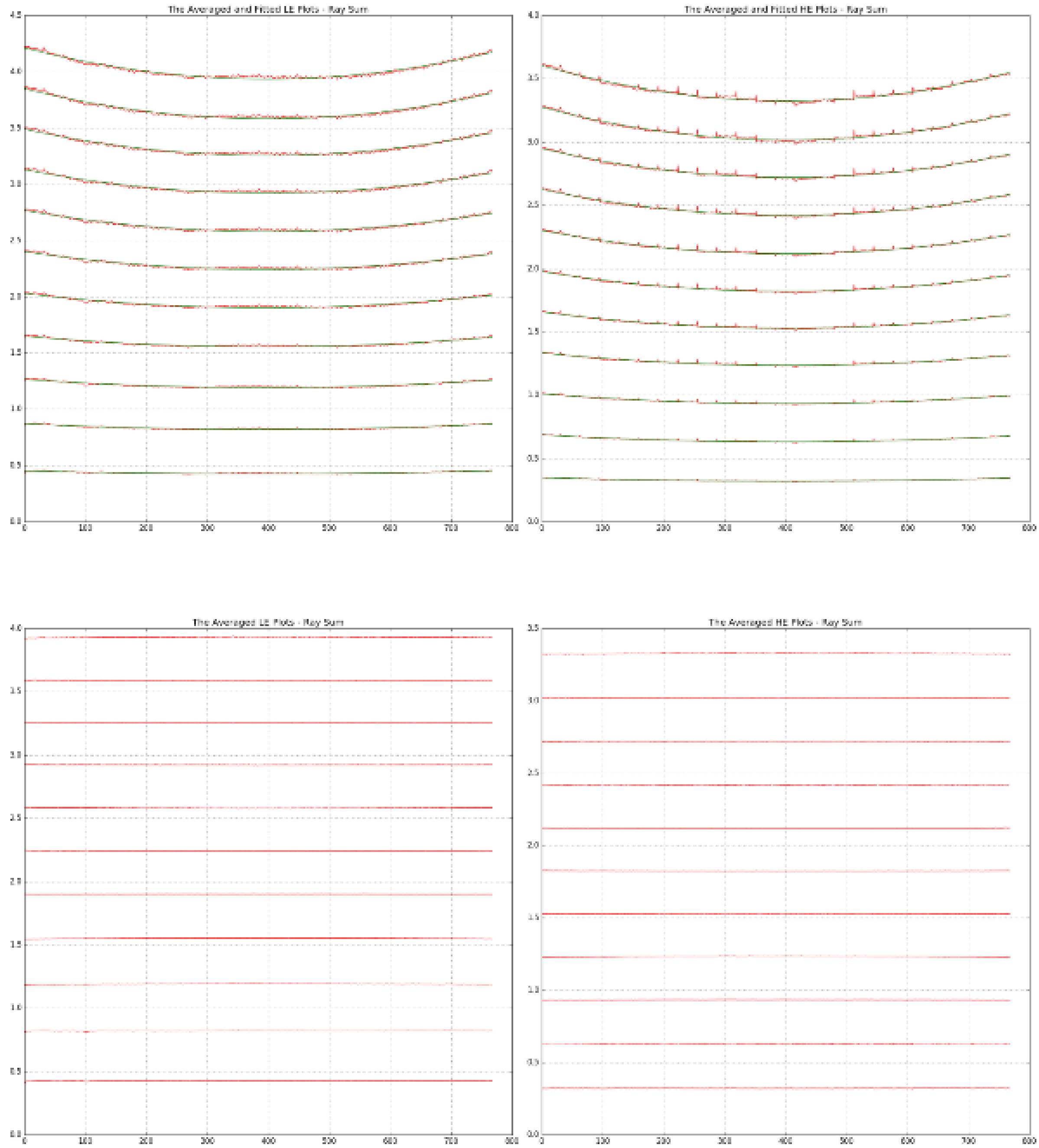


Figure 39: Linearisation calibration object response at every step for every pixel across the detector.

5.3. Calibration, Phantom Scanning and Image Stability

Calibration provides the thickness of lean and fat at each pixel in an image by non-linearly combining the 'low energy' and 'high energy' values at each pixel in a DEXA image. To enable this, a specially-designed phantom was constructed and scanned. The low-energy and high-energy values are extracted to generate the calibrations.

To ensure repeatability of these measurements, the stability of the machine is paramount. A number of mechanisms are employed to achieve this stability.

5.4. CL Analysis

With the calibration files, the tissue images are built from the DEXA data. Coupled with additional geometric attributes of the boxes, measurements of ‘Carton Fill’, ‘CL Content’ and ‘Box Collapsibility’ are assigned to each scanned box. The lean and fat data is generated by using these tissue images. The results are shown in Figure 41, Figure 42, Figure 43 and Figure 44. For each pixel the lean and fat has been calculated and lean only is the fraction of lean over total meat which is lean plus fat. It can be seen that the lean image for 90% CL has more contrast than 65% CL whereas the fat image is reversed.

Figure 40: Sample of /meat boxes used for CL analysis and carton fill.

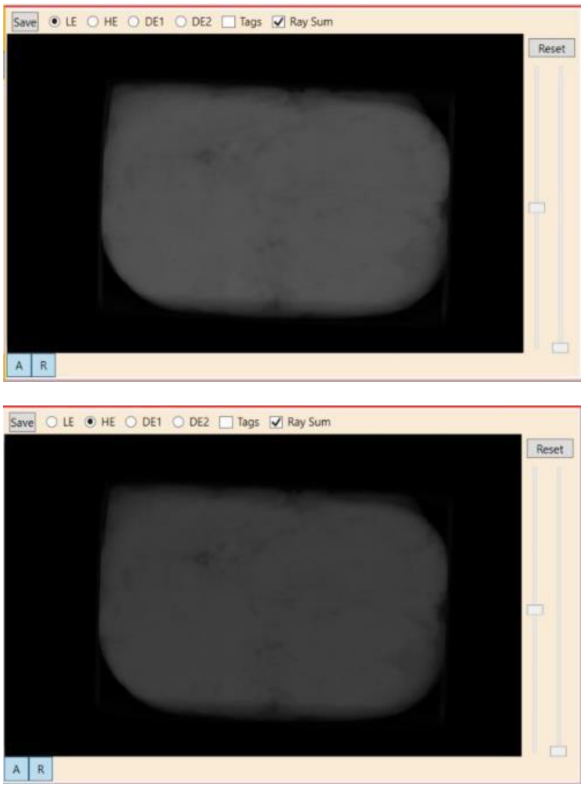


Figure 41: LE (top) and HE (bottom) images for 90% CL.

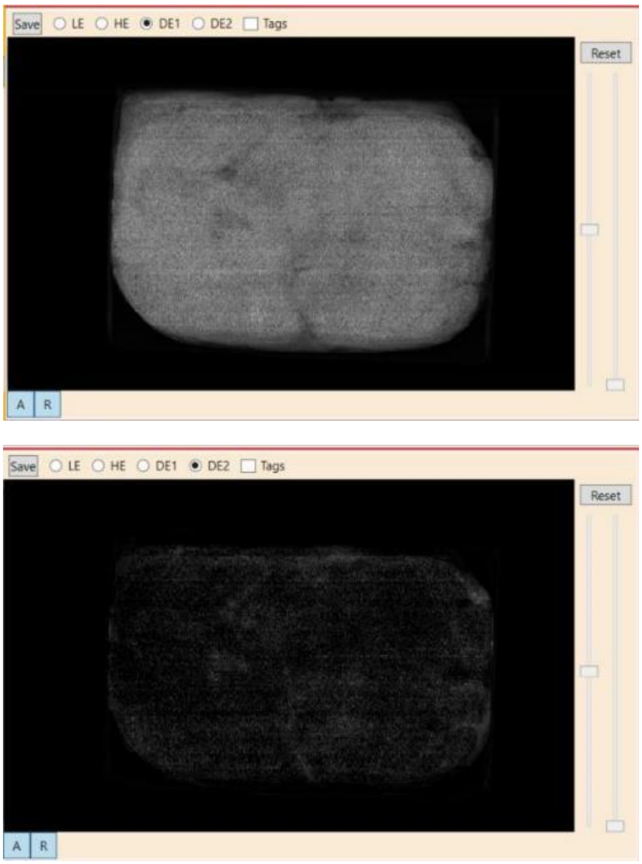


Figure 42: Lean image (top) and Fat image (bottom) generated from Figure 41.

Figure 43: LE (top) and HE (bottom) images for 65% CL.

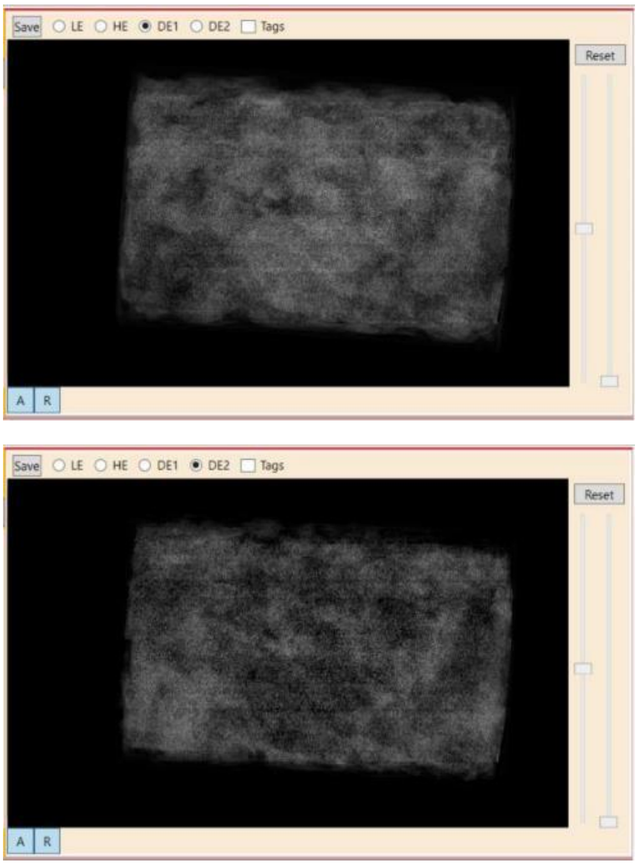


Figure 44: Lean image (top) and Fat image (bottom) generated from Figure 43.

6. Alternative Detector

The path to improving contaminant detection size limits whilst also performing CL has been started with the installation of an alternative detector. Below are some X-ray images comparing the scan of a tool set using the current pitch detector (top) and the alternative pitch detector (bottom) – take note of the enhanced image fidelity.

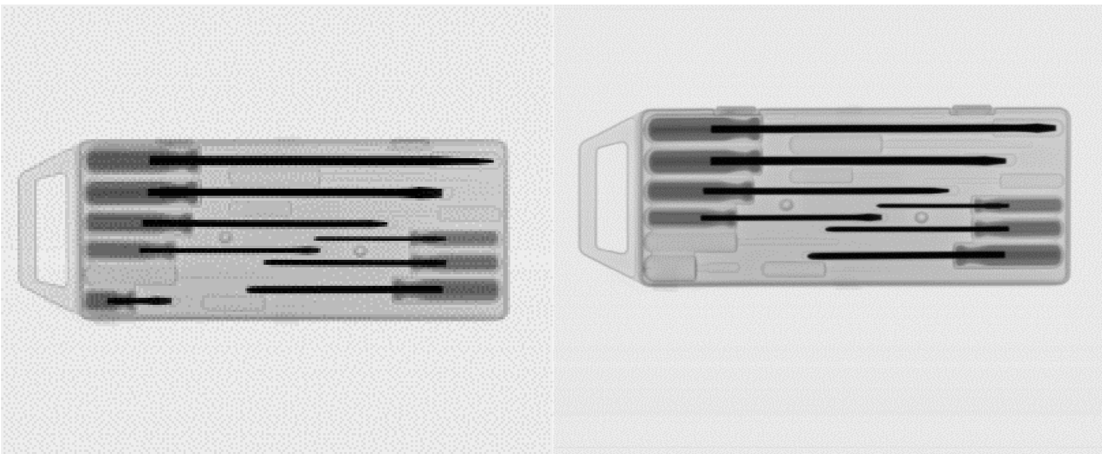


Figure 45: Comparison of LE images of a tool set between the original and alternative detector.

A light description of the issues encountered with the alternative detector is provided. Figure 46 shows the distribution of LE and HE measurements for a test scan. The left plot shows substantial overlap as the test object thickness increases. The right plot shows the average for each scan – there are a total of 20 scans. As can be seen, even over a period of 15 minutes, the average values also vary. Figure 47 shows the distribution of measurements taken of test objects. The left plot show substantial overlap. Again, the right plots show the average for each scan.

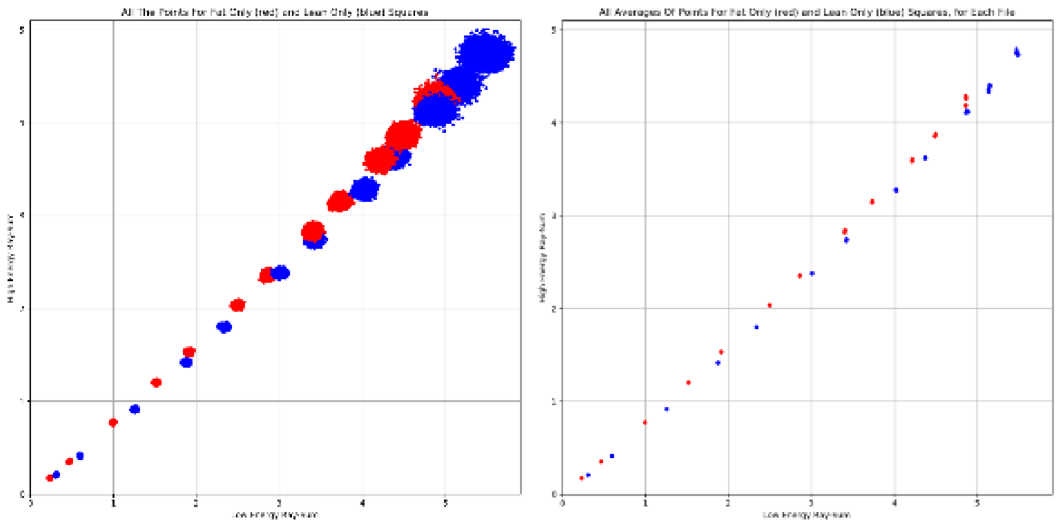


Figure 46: Pixel data from multiple scans of test objects. The left plots shows all the pixels and the right plots show the average of the pixels for each scan.

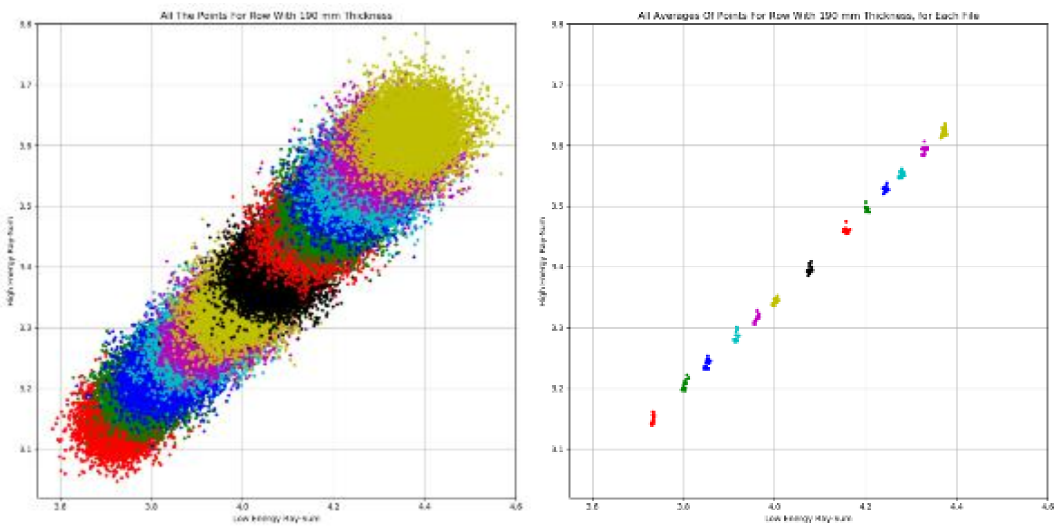


Figure 47: Pixel data from multiple scans of test objects. The left plots shows all the pixels and the right plots show the average of the pixels for each scan. The colour of each cluster / point represents a different test object.

The left plots of all figures exemplify that imaging a constant thickness can result in a multitude of X-ray values, hence making it very difficult to extract accurate data. Any noise in the measured images is greatly amplified. The right plots of all three figures show that even over a period of 15 minutes, the average values also vary. This has serious implications when generating stable calibrations.

6.1. Repeatability Tests

To test repeatability, boxes of meat were purchased. They were 160mm tall boxes and were certified as 65CL and 95CL boxes of meat.

The results are very repeatable, with a value of 98±1 for the 95CL box and a value of 55±1 for the 65CL box. Note that the final values have not been post-processed to give a final CL value (hence the discrepancy in baseline).

Two other measurements were also measured in this trial: the 'Carton Fill' and 'Box Collapsibility' measures as described in Section 4. They too demonstrate robust repeatability. It's important to note that the accuracy of these measurements also depend on the accuracy of the CL values.

6.2. Contaminant Detection

As stated above, the use of the alternative detector has increased the noise in LE and HE images to the extent the noise in calibrated images is too great for identifying very small contaminants. The updated contaminant detection algorithms were applied with the alternative detector to gauge its ability to identify a range of contaminants.

The main observation from these trials is very thin contaminants can be seen provided they are dense enough and are <u>also</u> long or thick.

7. Software Development

7.1. Overview

The software to control the X-ray inspection machine has been re-written from scratch. The new HMI possesses a 'Parameters' mode which allows the interrogation of previously collected images and allows a user to adjust parameters.

The layout of the HMI is as follows: On the left, Machine Alarms, if present, are shown. To the right of the Alarms and moving from top to bottom the following features are shown:

- The voltage and current of the X-generator, the status of the safety and gain shutters and a detector trace.
- A status message bar, in this case showing the carton fill, % lean, % fat and collapsibility factor of the currently loaded image.
- A drop down menu to select the state of the HMI. The available states are:
    - Production – frame for production mode, showing last acquired image, with an optional filmstrip of all acquired images and an overall summary of the boxes images during the production run.
    - Parameters – frame for users to adjust various acquisition parameters.
    - Configuration – a password protected frame to configure the machine.
    - Signals – view the states of the machine digital IO signals.
    - Messages – view the machine logging messages.

- This example shows the Parameters state of the HMI and is separated into further frames.
    - Parameter Selection – grouped into further frames that are discussed in section **Error! Reference source not found.**.
    - Image Exploration – frame to explore image, for example:
        - Selection of data channel to view.
        - Show tag information.
        - Ability to zoom into image.
        - Ability to adjust image contrast to accentuate features, such as contaminants.
    - Filmstrip – ability to load a group of previously scanned images. Additionally, can also add images as boxes are scanned during production mode.

7.2. Meat Inspection Parameters

To measure the carton fill, % lean, % fat and collapsibility factor, only a few parameters are required. They are:

- Calibration references
- Box Height

In addition, there are three alarms, which can trigger a box deflection. The alarms are for detecting when the carton fill, % lean or collapsibility factor are below a certain percentage.

Every time a carton fill, % lean, % fat and collapsibility factor are measured, they are shown on the status frame and are also logged to a database so a production run can be dynamically monitored from another location or a report can be generated at the end of the run.

7.3. Meat Inspection Report

The software stores all meat inspection results to a database. This allows for dynamic monitoring of a production run or for report generation at the end of the production run. The report structure is shown in Table 2. The examples of failed boxes are shown, two due to contamination and one due to insufficient meat in a box. The boxes can be deflected immediately after they are scanned by the machine.

Table 2: The report structure for boneless meat inspection.

Barcode	Date	Time	Carton Fill %	CL %	Fat %	Collapse %	Contaminant	Flag
111456770	21/05/2018	10:10:15	93	90	10	42	No	Pass
111456761	21/05/2018	10:10:16	94	66	34	41	No	Pass
111456752	21/05/2018	10:10:17	70	64	36	70	No	Fail
111456752	21/05/2018	10:10:18	92	65	35	42	No	Pass
111456783	21/05/2018	10:10:19	91	88	12	45	Yes	Fail
111456786	21/05/2018	10:10:21	90	80	20	41	No	Pass
111456781	21/05/2018	10:10:22	94	90	10	42	No	Pass
111456782	21/05/2018	10:10:23	93	65	35	40	Yes	Fail
111456792	21/05/2018	10:10:24	90	90	10	41	No	Pass
111456793	21/05/2018	10:10:25	93	65	35	40	No	Pass

Figure 48 shows an example HMI dynamically monitoring the meat properties of all the boxes that have been scanned during a production run.

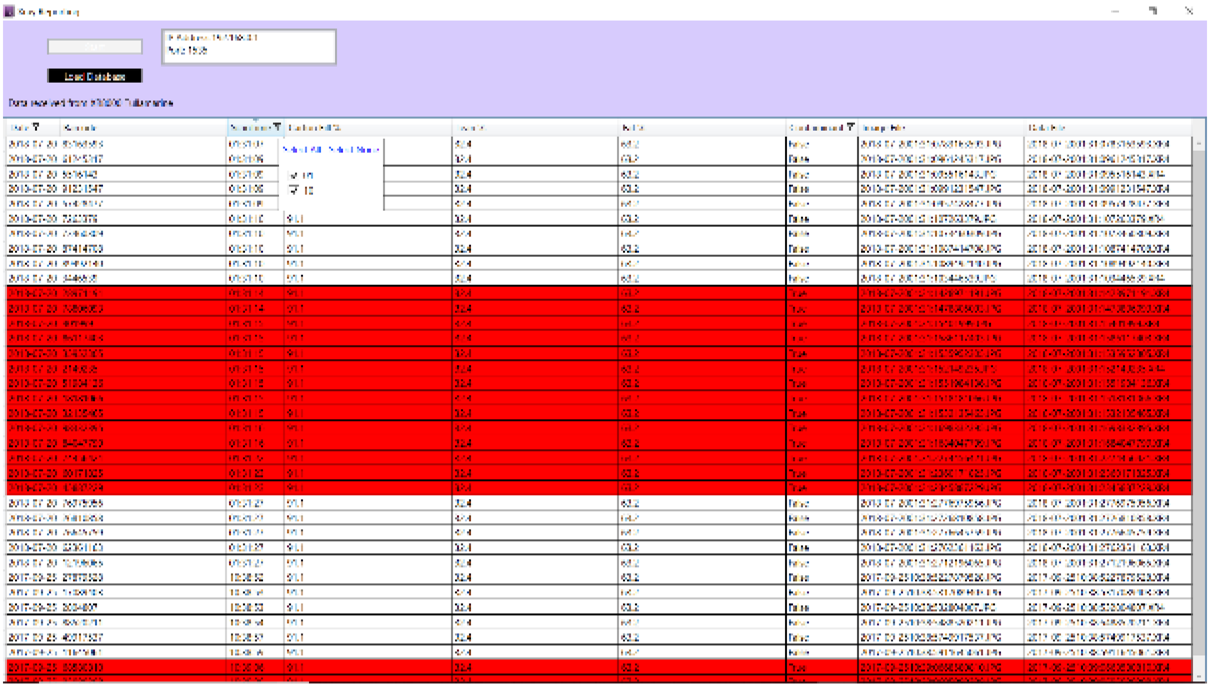


Figure 48: An example HMI for monitoring a production run.

7.4. Conclusion

The new HMI for selecting parameters for carton fill, chemical lean, box collapsibility and contaminant inspection has been shown. All the parameters have default values and the user can select between the ranges which are specified by the software. If the user sets a value outside of this range, it always reverts to the last valid value. The software can set parameters for various products and can load and save unique parameter sets.

8. Conclusion and Discussion

Novel techniques to enhance the inspection and detection of both small and large contaminants have been developed. The missed contaminant detection and false positives due to sensitivity settings and analysis technique has been addressed and resolved with two new proposed techniques. The Chemical Lean analysis repeatability has been demonstrated. The volumetric carton fill can show both filling and void areas with ability to accept or reject it. The preliminary box collapsibility can measure the likelihood a box will collapse. The software has this ability to detect contaminants, show the percentage of lean and fat, carton fill and box collapsibility of cartons in real time and can be deflected when certain criteria are measured. For software, a new graphic user interface has been developed, new features have been added for reporting of data and a complete re-write now allows for easy addition of new features as modules.