final report

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MEXA Detector and Software Development – Stage 1

Final Report

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Abstract

A multi-energy x-ray (MEXA) detector was purchased and installed in a test rig. Software was written to communicate with, and evaluate data from, the detector. A number of trials were performed to investigate its ability to perform objective carcase measurement and imaging of difficult regions of the carcase. A comparison with DEXA was provided where possible. Trials were performed to demonstrate the performance of the detector. It was shown that MEXA will likely outperform DEXA for objective carcase measurement and imaging, although a key factor will be developing a robust and accurate way to pre-process the spectral data and calibrate the system. During this project we have developed strategies on how to accomplish this but it is a task which is more complex than it is for DEXA and requires further work.

Executive Summary

A multi-energy x-ray (MEXA) detector was purchased by SCOTT and installed in an x-ray testing rig. Software was written to communicate with, and obtain data from, the detector. This software will be re-usable for all future work. A number of scans were performed to evaluate the technology in the context of red meat industry applications – specifically objective carcase measurement (OCM), and automation. The MEXA detector operates in a different fashion to a DEXA detector and therefore cannot be considered as simply an upgraded version of the latter. It has its own particular benefits and shortcomings which need to be assessed. Furthermore, as the MEXA detector produces much more information, more complex data analysis techniques are required (as with hyperspectral imaging data).

Scans of samples were also obtained with a DEXA detector and high-level comparisons made between the two technologies.

It was demonstrated that the MEXA detector is more sensitive at larger tissue depths than the DEXA detector. It was shown that the MEXA detector should be able to resolve fat:lean information effectively and at thicknesses above the capabilities of DEXA. It was similarly shown that the MEXA detector should produce better images of bone structure.

Given the large amount of data generated, the calibration process is significantly more complex than the methods currently used for DEXA. Developing such calibration methods for the MEXA data is therefore something that lies outside the scope of this stage 1 technology evaluation project.

Given the positive results encountered in this project, it is recommended that a stage 2 project continue the work completed here.

Table of Contents

1 Background

This project will evaluate the application of multi-energy detectors. A multi-energy x-ray (MEXA) detector, together with a SCOTT x-ray generator and tube, will be used to provide multiple energy measurements at each pixel.

There are limitations with the current DEXA approach that warrants investigation of additional detectors.

2 Project objectives

2.1 Objective 1:

Acquire the detector and interface boards and install them into SCOTT x-ray R&D room.

2.2 Objective 2:

Develop new MEXA x-ray pixel information interrogation software.

2.3 Objective 3:

Pass various beef and lamb parts through the system and report on the results.

3 Introduction

SCOTT have utilised x-ray technology extensively over the past 10+ years. Single energy x-ray (SEXA) imaging was first used for lamb primal cutting and then weight apportioning. When attempting to image beef carcases however, it was found that the greater thicknesses and larger weight variations presented a significant issue for single-energy x-ray. DEXA was then implemented successfully by using separate high-energy and low-energy hardware to construct a consistent, high-contrast image of the bone structure for beef sides. This enabled a commercial beef rib cutting system to be built. More recently, DEXA using a single, sandwich-style detector, has been implemented for lean meat yield objective carcase measurement (OCM) of lamb and beef.

While a significant improvement over SEXA, DEXA possesses its own shortcomings. The thickest areas of large beef carcases are still difficult to image consistently, even with DEXA. Similarly, while DEXA can be used to differentiate and measure fat and lean, the differences between these tissues is very slight and accuracy drops significantly as thickness increases above approximately 150mm.

MEXA may provide an opportunity to improve upon what is achievable with DEXA. However, there are significant differences between the technologies. SEXA and DEXA detectors operate by accumulating all incident photons over a certain amount of time and providing a reading. This style of detector is referred to as a photon integrating detector. In SEXA, an x-ray source emits photons through an object to a detector. Thinner/less dense areas will allow more photons through which will result in larger signals compared to thicker/denser areas of the object. The result is a single-energy x-ray image. Different materials interact differently with x-rays at different energy levels. At a very basic level, taking x-ray images at two different energy levels makes it possible to differentiate between, and measure the composition of, two different materials in any given pixel. This can be achieved in two different ways – by having separate source-detector pairs for the low-energy and high-energy images; or by having one high-energy source and a detector which has two layers, to obtain low-energy and high-energy data simultaneously. Using this data, bone can then be differentiated from soft tissue to enable automation; or amounts of fat and lean, and bone and soft tissue can be calculated to perform OCM. As it still utilises a photon integrating detector (just at two energy levels now, instead of one), DEXA can therefore be seen as an extension of SEXA technology.

The MEXA detector is able to measure for each pixel, not just two different energy levels (as with DEXA), but multiple different energies. This is achieved through a different detection mechanism, where rather than lumping the signal from all the photons together, each individual photon is interrogated. As the photon arrives at the detector element, an electrical pulse is generated, the amplitude of which is proportional to its energy level. The photon's energy is thus determined and the result recorded along with the energies of the other incident photons within a given timeframe, providing a hyperspectral x-ray image. This is referred to as a multispectral photon-counting type detector. This offers the possibility of being more sensitive than DEXA, and thus operating better at larger tissue depths. Fat and lean possess very similar x-ray absorption characteristics and thus, while it is possible to measure fat and lean with DEXA, it is still rather challenging. Having extra data points along the x-ray absorption curve, as with MEXA, may enable more accurate measurement of fat and lean. There are however some key differences in performance and limitations that this style of detector has over integrating detectors. MEXA cannot be thought of as simply an upgraded version of DEXA, but as a different technology.

The aim of this project was to begin the process of assessing how MEXA technology can be used in red meat industry applications. A detector was purchased and programs developed to interface with, and obtain data from, the detector. Samples were scanned to provide a high-level assessment of the data obtained and evaluate what opportunities may exist for the technology.

4 Methodology

A multi-energy level detector was selected and purchased. It was housed and installed into an x-ray scanning rig. A program was then developed to communicate with the detector and allow data to be acquired. A basic data viewer was also created to visualise the data.

A number of scans were performed to assess the technology. Scans were taken to assess the MEXA detector's ability to perform OCM and enable automation. An attempt was also made to compare MEXA, as much as possible, with DEXA capabilities.

The MEXA detector is a photon counting detector. As photons hit the detector, their energy is calculated and stored. The data produced is thus a histogram of the number of photons counted for each energy range (bin of energies) in each pixel. As the technology is different to DEXA, it presents different considerations than an integrating detector when considering the data. These considerations were investigated as part of the trials performed.

5 Results and Discussion

5.1 Initial Assessment

Once the hardware was set up, software was written to communicate with the detector and enable data collection. This software allowed for different scan parameters to be applied, including number and size of energy bins. It also allowed the data to be visualised. Figure 1, Figure 2 and Figure 3 demonstrate some of these screens, including the scanning of a lamb rack.

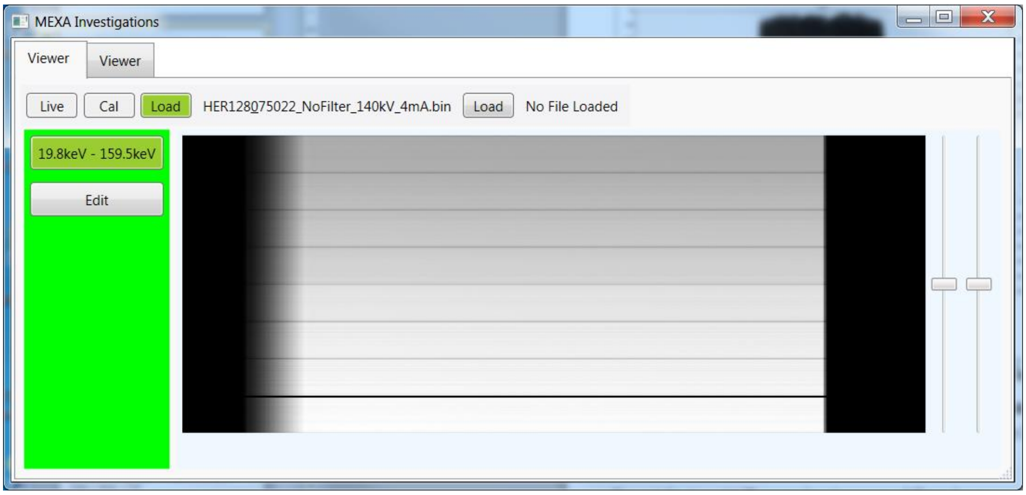

Figure 1 - MEXA data software

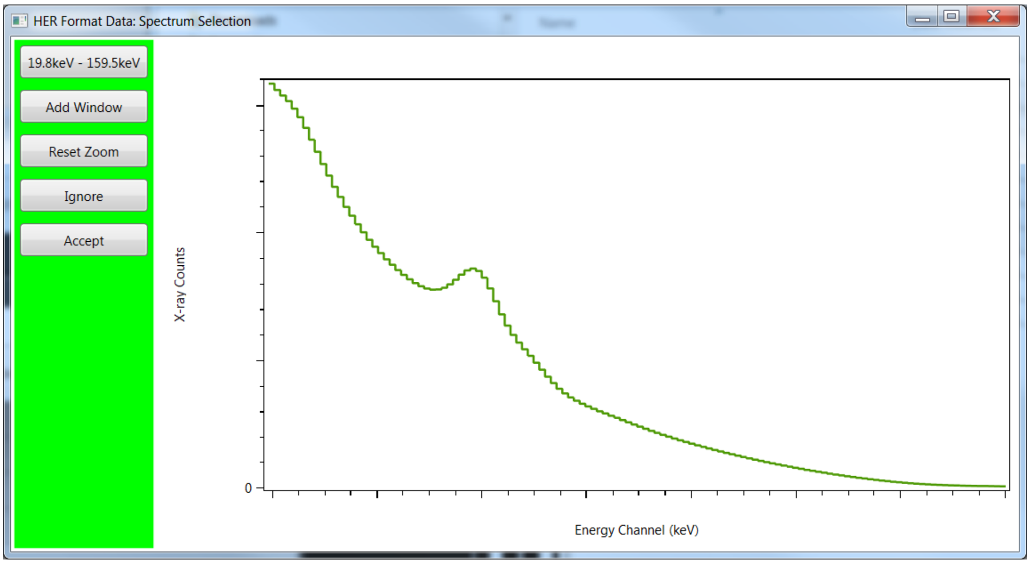

Figure 2 - MEXA data software (example)

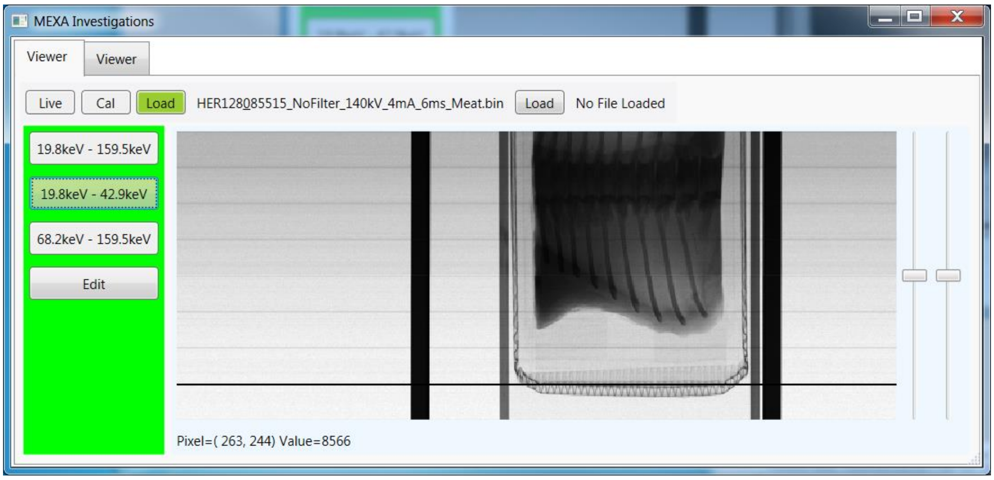

Figure 3 – MEXA data software (test scan of lamb rack)

As aforementioned, how the detector responded given different samples and scanning parameters was assessed in order to understand how to optimise the output, and how it compares to DEXA technology.

5.2 Transmission (vs DEXA)

Once the hardware and acquisition software were setup, a number of scans were performed. Transmission spectra were obtained for combinations of various thicknesses of lean, fat and bone tissue (**Error! Reference source not found.**). The same samples were then scanned with a DEXA detector. In analysing and comparing the transmission data for each, it was shown that the MEXA detector is more sensitive than the DEXA detector.

5.3 Objective Carcase Measurement

5.3.1 Ability to differentiate between fat and lean (vs DEXA)

In order to extract fat and lean measurements from x-ray data it is vital to establish the relationship between the x-ray data and the fat:lean content. This is not a simple task and depends upon many variables. Moreover, the differences in the x-ray signals created by differences in the fat:lean content are very subtle and extreme care is necessary in the design and calibration in order to produce accurate and repeatable chemical lean measurements.

The results of calibration can be used to determine the range over which useful fat:lean measurements can be made. In observing the absorption characteristics of different tissues, it can be shown that DEXA's accuracy diminishes rapidly above 150mm (at which point modelling methods become more important to providing measurements).

MEXA is more complex because instead of two measurements per pixel in an image, we now have many. Extracting the optimal information from such rich data requires considerable work in developing a suitable calibration methodology. When evaluating the data obtained by the MEXA detector however, the same limitations are not present in the data. We can therefore be optimistic about the likelihood of MEXA delivering better performance that DEXA. It was also found that there is a clear difference in the data between fat and lean tissue, further reinforcing the detector's ability for fat:lean discrimination and measurement.

5.3.2 Scans of meat samples

Scans were performed of meat samples. The x-ray data were then analysed to provide a high-level demonstration of how the MEXA detector differentiates fat and lean tissue. Two sirloin steaks were acquired and scanned (Figure 4). Figure 5 shows the result of the scan. Two regions of interest (ROIs) were selected – an area of fat and an area of lean. The spectra for all the pixels in each region was then combined to demonstrate a 'fat' response and a 'lean' response. The responses for the two tissues are consistent with theoretical data. It was shown that the fat and lean are able to be differentiated, and where the key differences occur.

Figure 4 - Sirloin samples for MEXA scanning.

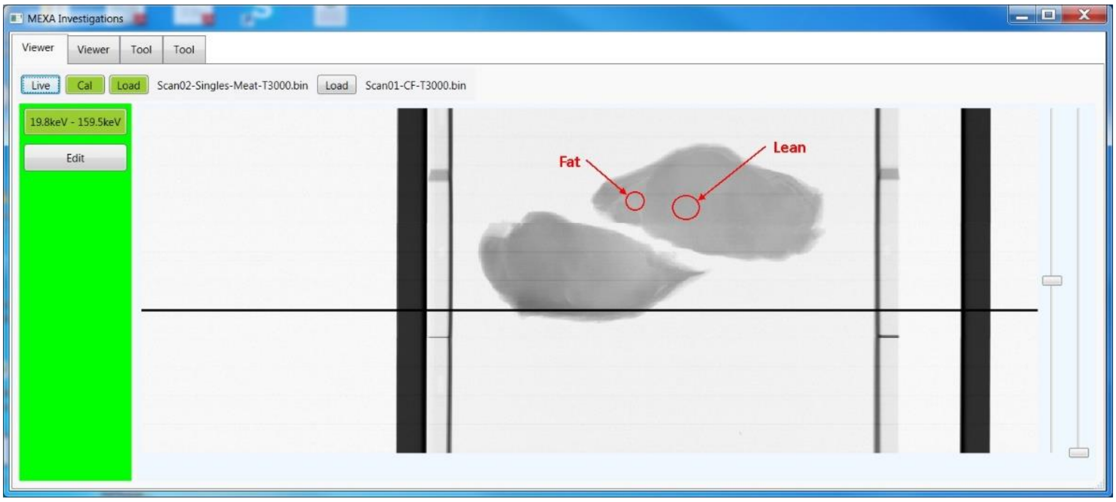

Figure 5 - Pixel selection from meat scan for fat:lean discrimination.

5.3.3 Conclusion

It can be seen that MEXA demonstrates a clear ability to differentiate between fat and lean, and should do so with better accuracy and at larger thicknesses than a DEXA detector. As there is much more information available than with a DEXA detector, the optimal calibration of a MEXA system to perform these measurements requires a novel approach.

5.4 Cutting and Automation

5.4.1 Ability to differentiate between bone and soft tissue

DEXA imaging is currently used in red meat industry automation through the use of image processing algorithms. The goal regarding automation is to produce clear and consistent images in the areas of interest, with high contrast between bone and soft tissue. One particularly challenging area is the rib 1 costochondral junction for large beef carcases. This point defines one of the key cutting lines as per the AUS-MEAT specification. Of particular interest is whether MEXA imaging can provide clearer images and be able to directly identify challenging features such as the rib 1 junction.

Error! Reference source not found. to **Error! Reference source not found.** clearly demonstrate the spectra produced for varying amounts of bone and soft tissue, showing that discrimination between the two is possible. They also demonstrate that it is expected that MEXA will have greater penetrability than DEXA which should help in imaging challenging areas of the carcase. The precise magnitude of this improvement will depend on application-specific factors such as line-speed, pre-processing methods used on the spectral data, and how effectively the system can be calibrated.

Test samples were scanned to demonstrate the MEXA detector's ability to differentiate soft tissue and bone. The MEXA detector was also found to demonstrate improved penetrability. A lamb rack, sourced from a butcher, was used to get a preliminary assessment of what can be 'seen'. Figure 6 shows a simple transmission image of the data acquired. It is based on the total area under the spectral curve and therefore doesn't represent any spectral information – it is essentially a single-energy x-ray image. Four points were selected on the image. The spectra at each of these points showed the clear difference between the bone-containing points (vertebrae and rib) and the non-bone-containing points (folded meat and meat between ribs), demonstrating that the system is able to differentiate between bone and soft tissue.

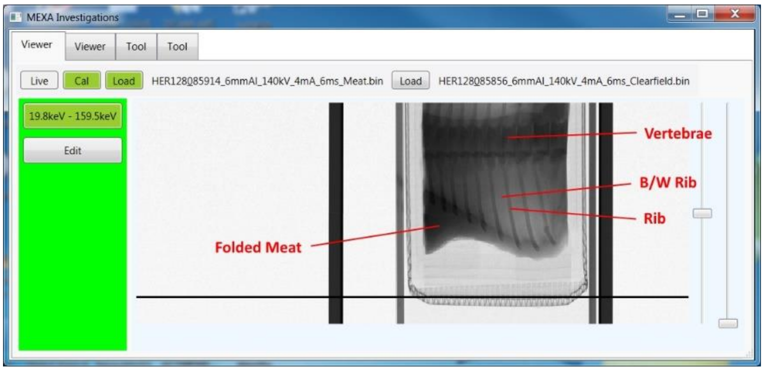

Figure 6 - MEXA transmission image of lamb rack with SCOTT software.

5.4.2 Calibration

As with OCM, the x-ray data needs to be calibrated for bone and soft tissue to optimise image contrast. The calibration of spectral data is more complex than the procedures currently used for DEXA data. A rudimentary calibration similar to what is used with DEXA was created for use in comparison of MEXA and DEXA meat scan results. This rudimentary calibration won't yield optimum images but will provide an indicative image of what is possible with MEXA. To obtain the optimal image quality achievable by the technology however, a complex calibration method utilising the full spectral information needs to be derived.

5.4.3 Meat scans

Two samples of beef brisket were sourced and scanned with both the MEXA detector, and a sandwich-style DEXA detector (Figure 7). A rudimentary calibration was applied to the MEXA data as outlined in section 5.4.2 to provide indicative images. Scans were also performed with slabs of meat placed over the rib 1 junction to simulate progressively thicker carcases.

Figure 7 – Beef brisket samples.

Figure 8 - Beef brisket scan with extra meat.

6 Conclusions and Recommendations

A multi-energy x-ray (MEXA) detector was purchased and installed in an x-ray testing rig. Software was written to interrogate the detector for data and to provide basic visualisation. This code will be directly transferrable to future systems. A number of trials were then performed to assess how the detector operates, particularly within the contexts of objective carcase measurement and automation. It was demonstrated that the MEXA detector is capable of outperforming DEXA for both applications. In order to calculate quantitative benefits to accuracy and depth penetration however, the MEXA data needs to be calibrated. Given the large amount of data generated, this process is significantly more complex than the calibration method currently used for DEXA. Developing a calibration method for the MEXA data is therefore something that lies outside the scope of this stage 1 technology evaluation project.

Given the positive results encountered in this project, it is recommended that a stage 2 project continue the work completed here.