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LEAP4Beef DEXA and 3D Sensing evaluation for markers guiding TEYS Primal cut paths

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Abstract

The aim was the location of brisket, rib and spine cuts in a beef carcass for enabling beef automation.

Existing DEXA scanning technology for lean meat, fat and bone determination was modified in an attempt to provide accurate bone identification images for automation but hardware tuning and adjustments did not produce satisfactory results. However, removing the foreleg prior to scanning indicated satisfactory performance.

A number of technologies and analysis techniques were trialled and good candidates were identified for sensing the markers for each of the brisket cut, rib strip and spine cuts .

The sensing technologies employed included a combination of X-Ray and a colour camera.

The sensing of each of the cuts as defined in MLA project P.PSH.1199 Leap 4 Beef – DEXA cut information translation using carcass marking and verify proposed cutting and processing methods are suitable for TEYS production, enables automation solutions, with their associated value benefits from enhanced cut accuracy and labour saving.

Executive summary

The aim was to develop and validate sensing means in a beef carcass for the location of brisket and rib strip cuts, which are referred to as the un-obscured cuts. And the spine cuts, referred to as the obscured cuts.

Existing DEXA scanning technology for lean meat, fat and bone determination was modified in an attempt to provide accurate bone identification images for automation but hardware tuning and adjustments did not produce satisfactory results. However, removing the foreleg prior to scanning indicated satisfactory performance. It would seem plausible that LMY predictions could account for the missing foreleg.

A number of technologies and analysis techniques were trialled and good candidates were identified to identify the brisket and rib strip cuts.

A number of technologies and analysis techniques were trialled and good candidates were identified to locate the spine cuts.

It is proposed that this work will provide the following benefits to industry;

- Enable the automation of beef carcasses dismantling, as defined in MLA project P.PSH.1199 - LEAP4Beef DEXA cut information translation using carcase marking and verify proposed cutting and processing methods are suitable for TEYS production, and obtain value benefits from improved accuracy for cuts with value differential of adjacent portions and productivity.
- The work has proposed alternative tailored solutions for accurately locating skeleton features.

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1 Background

The current TEYS DEXA system has been optimised for establishing lean meat, fat and bone ratio's. It would be of benefit if the lean meat, fat and bone grading system could also sense the anatomical markers for the primal cuts. Previous work in this space includes the solution developed at Dinmore, where the sensing is DEXA, 3D scanner and colour image system. This work is disclosed in (Trieu, Ford, & Shirazi, 2016). The DEXA at Dinmore is setup to maximise contrast between bone and meat or fat. Energy levels are set such that the meat or fat is "over exposed" and further determination of properties is not possible.

The Ausmeat (AUS-MEAT, 2005) anatomical marker for the cranial end of the brisket cut, being the junction of the 1st rib with the sternum, is visible in the TEYS and Dinmore imaging system orientation – but not with the TEYS DEXA setup.

The research proposed in this project is to advance key technologies to automate all or part of the beef boning room.

Given the accurate sensing of the anatomical markers, either a system of mechanical fixturering the product from sensing to downstream automation or a vision re-referencing system is anticipated.

The topic here is the sensing of the markers required for the brisket, rib strip and cross cuts through the spine.

The cut strategy for automation was defined by consultation with TEYS specialists and formalised in the previous project (Thompson & Maunsell, 2020).

1.1 Significance for industry

The areas identified to potentially add value to the industry are;

1.1.1 Spine cuts

Increased value has been predicted in for example (Sweet, 2/8/2011) from achieving improved accuracy. It is stated that due to the differential value either side of a Longissimus dorsi cut, the value model is $0.72 per side per 5mm from the ideal cut plane.

1.1.2 Vertical brisket and rib strip cut

Increased value is predicted from the differential value of product either side of the vertical brisket and rib strip cut by achieving improved accuracy.

1.1.3 Additional opportunities

It is proposed that automation provides labour saving and productivity gains.

1.2 Background cut sequence and definitions

The previous P.PSH.1199 - LEAP4Beef DEXA cut information translation using carcase marking and verify proposed cutting and processing methods are suitable for TEYS production report (Maunsell, Kennedy, & Dickie, P.PSH.0911 LEAP 4 BEEF Detailed Design Stage 2 - Develop high level design and layout concepts, 2018) determined the cut sequence that has been used to determine the key requirements for the output of the sensing technologies.

In this project, sensing technologies required to view obstructed marker positions (those that do not lie on the external surface of the carcase) were investigated.

Given the likely difference in requirements for different processors it would be ideal for the vision sensing system to be adaptable to variations in processing methods. Therefore, the sensing development was based on the proposed Teys cut sequence and other industry automation solutions.

2 Project objectives

- Apply tuning to the DEXA scanner to enhance contrast for bone identification while maintaining sufficient signal to derive lean meat yield (LMY).
- Scan beef carcase sides with DEXA and 3D through the Rockhampton DEXA system
- Visually assess the data and images to ascertain:
    - All the un-obscured cut markers and paths can be identified on the sensing output images and a location in 3D space can be determined for them.
    - All the obscured cut markers can be visually identified in the DEXA image with sufficient clarity that it is likely that either a prediction model or additional sensing will be capable of identifying their location in 3D space.
    - If there is modification to the existing DEXA & 3D profile cell required, a proposal of the modifications is to be made (and tested if achievable in the proposed budget and timeframe)
    - Or an alternative cut location method to be identified.

If this development is successful, it is to provide a basis to conduct work in identifying if a prediction algorithm or sensing method should be assessed and hence have a high level of confidence that the proposed “single scanning cell” concept is viable or if an additional/alternative approach is required.

3 Methodology

3.1 Defining the markers required to place the brisket and rib strip cut lines

The rib cuts begin by defining the brisket cut line and then a parallel rib strip cut line towards the spine.

3.1.1 The intersection of the 1st rib and the sternum

This point is defined as per the AUSMeat brisket cut definition. It lies along the caudal edge of the 1st rib, where the rib intersects with the sternum.

It is not easily determined from X-Ray images, especially on larger animals, due to occlusion by scapula and foreleg.

3.1.2 The intersection of the 1st rib and the spine

The point that the caudal edge of the 1st rib intersects with the spine will be required to ensure there is sufficient room to fit the desired rib strip width.

3.1.3 The intersection of the 11th rib and the reflection of the diaphragm

This point is defined as per the AUSMeat brisket cut definition, being the intersection of the 11th rib and the diaphragm reflection.

3.2 Defining the markers required to adjust the vertical rib cuts

The vertical rib cuts are well specified using the 1st rib and sternum junction and a predefined rib strip width. However, these cuts may require adjustment if the proposed cut position were to cut into the spine. Determining the location of the intersection between ribs and spine will be important in determining if, and by how much, these vertical cuts need to be adjusted.

3.3 Defining the markers required to place the spine-cut lines

The cross-cuts/spine cuts are places to separate the chuck, rack and loin sections.

3.3.1 The intersection of the specified side of the specified rib and the spine

Determining the location of the intersection between ribs and spine will be required to place the spine cuts. The chosen rib will likely change to accomodate producer and consumer requirements.

3.4 Investigating sensing technologies

Accurately determining the key marker positions in the vision sensing data is the primary goal of the vision system. This is often a difficult task, made more difficult by the natural variation in carcase size, colour and structure.

A number of vision sensing technologies were investigated as to their suitability for use in determining the position of the key markers. Preference was for non-X-ray technologies or technologies that would facilitate a modular X-ray scanning cell for beef carcase sides.

3.4.1 X-ray imaging

Scott Technology have previously installed a LMY DEXA machine in Teys, Rockhampton with the hope that this could become the base for the automated cutting system.

There is one key difference between the Dinmore and Rockhampton DEXA X-ray installation. The Rockhampton installation has been setup to produce optimal LMY data and the Dinmore installation for optimal bone images.

In this project we have looked into the viability of using the existing Rockhampton DEXA system to provide cut data and any modifications that might be required to the machine or processes to enable this to be possible. We attempted to tune the existing DEXA system to improve bone identification in X-ray images while retaining all information required for LMY analysis.

3.4.2 Colour imaging

Colour imaging allows traditional vision sensing software to perform fast feature detection. An external coordinate system calibration (and additional 3D surface data) would allow data from the 2D colour images to be used in the same coordinate system as other 3D and X-ray data.

Some surface features, e.g. the diaphragm reflection, are essentially invisible to X-ray and so external camera technology would be needed to identify them. Where possible, colour and greyscale images were used to try and identify surface features.

A variety of 3D colour cameras (structured light, colour stereo, time-of-flight) can be used to produce overlaid colour and 3D position information

3.4.3 Convolutional Neural Networks (CNNs)

Convolutional Neural Networks (CNNs) have been reviewed.

The way that the networks are developed/trained introduces difficulties in predicting their potential for success for a new task. CNNs typically require a significant number of manually labelled images, taken with essentially identical hardware (e.g. image size, image quality and lens distortion) and physical configurations (viewpoint, lighting and scaling) as the final setup. Consequently, getting confidence that a completed system will perform with the required accuracy and repeatability requires some amount of extrapolation.

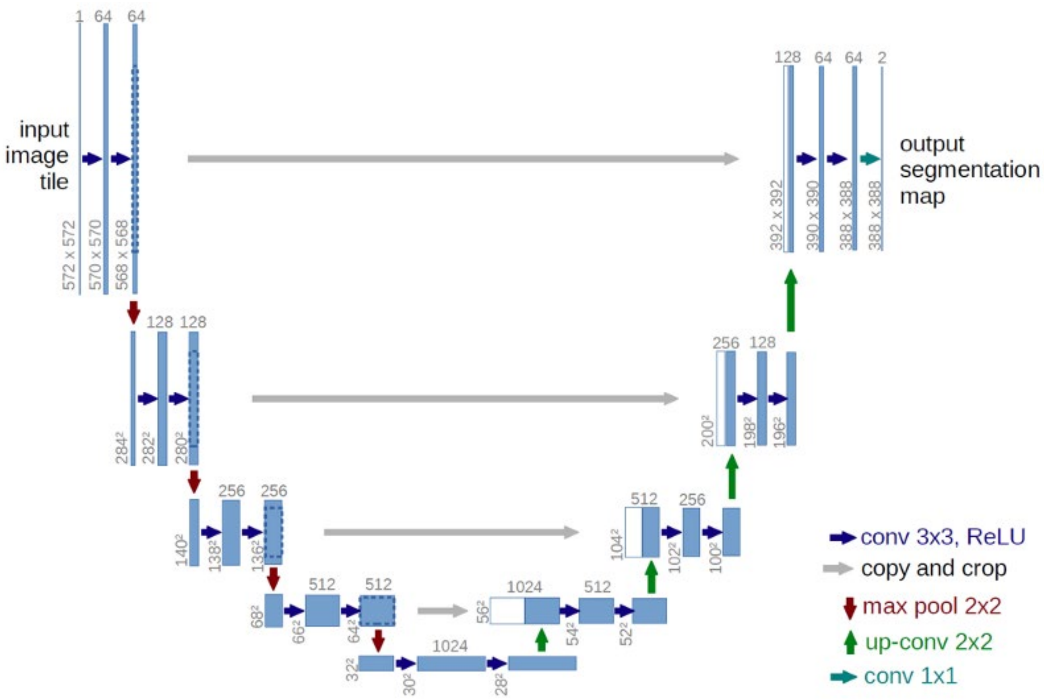

Fig. 1: U-Net architecture used for CNN segmentation

3.4.4 Backscatter X-ray systems

Additional technologies that might allow sub-surface feature detection were investigated. A standard X-ray system involves an X-ray source on one side of an object and a detector on the other side of the object as shown in Fig. 4.

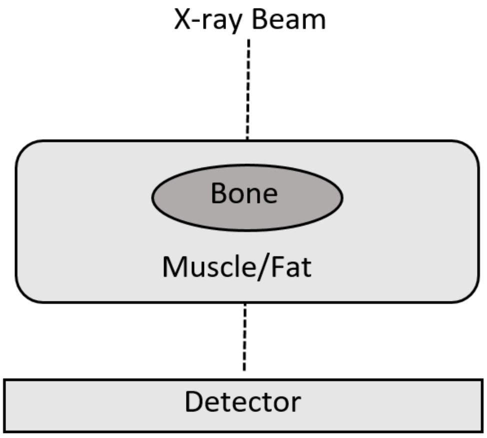

Fig. 2: A standard X-ray system depends on the absorption and transmission of some of the incident X-rays

In contrast a backscatter X-ray system has the X-ray source and detector on the same side of the object, as shown in Fig. 5.

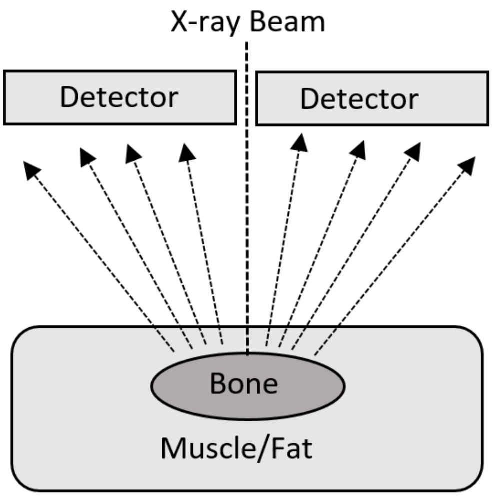

Fig. 3: A backscatter X-ray system depends on the Compton scattering of the incident X-rays

Backscatter X-ray systems utilise the Compton scattering) of the incident X-rays to generate an image rather than the amount of X-rays that make it through the target object. This means that the X-rays essentially go through the same amount of material twice, once going away from the detector and once going towards the detector. This is useful when looking for features embedded close to the surface of a substance but not if the features are embedded deep within a substance.

A number of possible backscatter X-ray systems were investigated as to their suitability for use in the sensing system.

3.4.5 Force-torque sensing

The use of force torque sensing for augmenting robotic movement paths is widely used in automation. Previous research (P.PSH.0736 – Lamb Boning Leap 2) has looked at the use of force torque sensing as a method to improve the accuracy of cut paths when driving a robotic knife. This technology could be used to improve the reliability and efficiency of cuts that look to trace along bone structures.

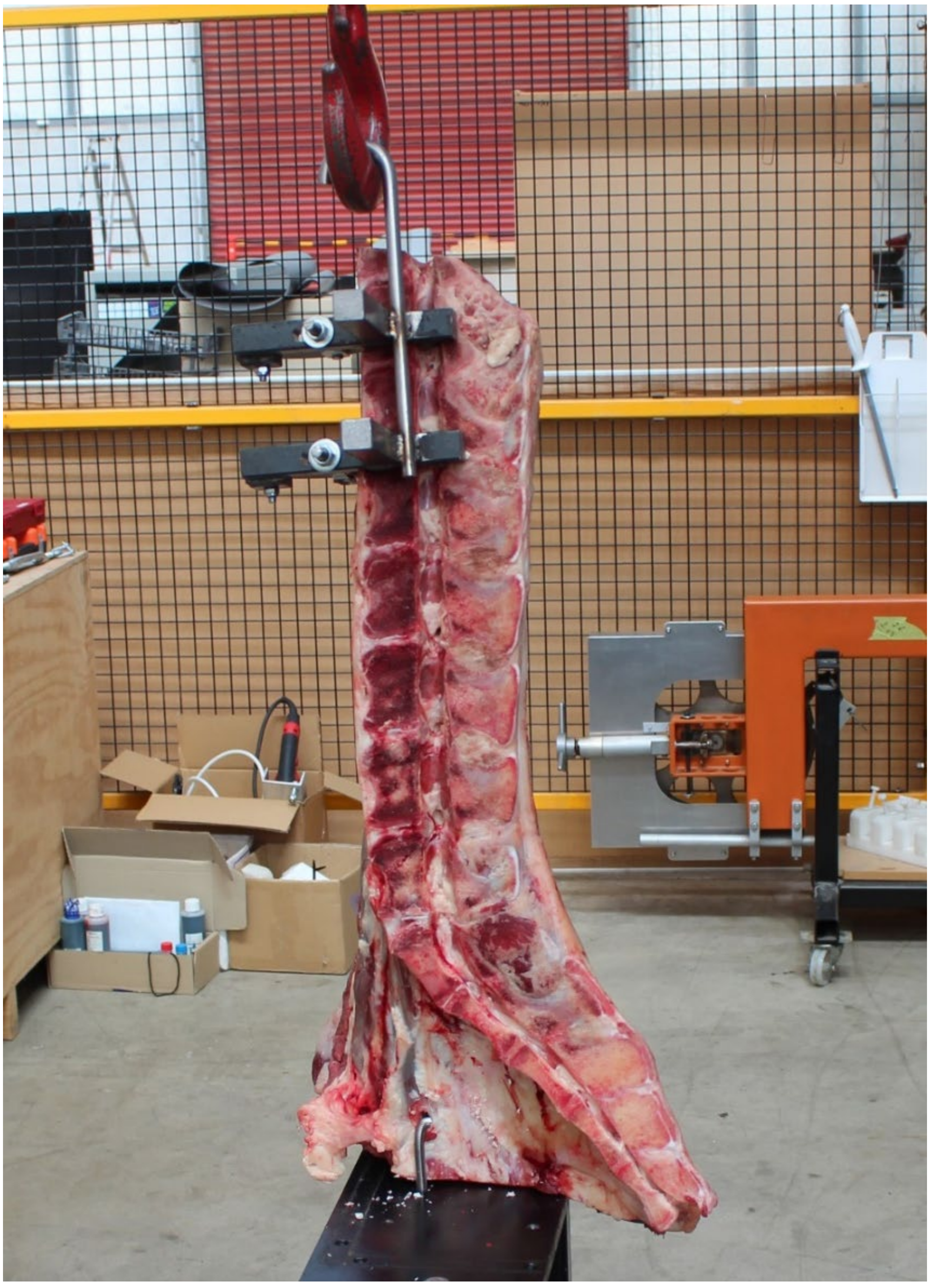

Fig. 4: Clamping setup for the rump and loin sections used in the workshop trials

Fig. 5: A load cell allowed control over the mechanical load applied to the spine during the cut

3.4.6 Correlation of anatomical features

As an alternative to the direct sensing of sub-surface key points we proposed using anatomical correlations to predict the position of these points from more easily sensed features. An investigation was proposed to determine how accurately the rib-spine junctions could be predicted from key points found on the exposed surface of the vertebrae.

4 Results

4.1 Suitability of LMY DEXA images for cut point detection

Removing the foreleg prior to X-ray imaging made a significant difference to image quality. If this process change is possible, it would undoubtedly improve the accuracy and reliability of the image analysis. The expectation would be that the correlation between whole carcase DEXA results vs foreleg removed DEXA results would be sufficiently high to predict from one to the other. Further testing would be required to validate this properly.

4.2 Identifying 1st rib and sternum intersection

A model was trained on 1120 X-ray images where the caudal side of the rib 1 intersection point could be identified with high confidence. The analysis error was reported as the difference in pixels..

A rough conversion from pixel error in the X-ray image to real world distance in mm was also calculated for comparison to other processes.

4.3 Identifying rib structures and intersections with spine

CNN segmentation for rib identification was completed successfully in a previous project P.PIP.0765 - Investigating neural network algorithms for imaging points of interest identification (Scott Nicholson, 2019). In the previous project only ribs 2-10 were identified.

4.4 Marker position re-referencing

The 2D colour images used in this investigation came from one of a pair of images from a 3D colour stereo camera. This meant that once the key point was identified in the 2D colour image, a 3D point could then be extracted from the surface point cloud data from the same 3D camera. This allows the orientation of the surrounding 3D surface to be determined and so the original cut points could be re-referenced with other important 3D information such as blade entry angle.

Fig. 6 and Fig. 7 show the key point can be identified even with moderate changes in scale, orientation, lighting, colour and structural changes between vision stations.

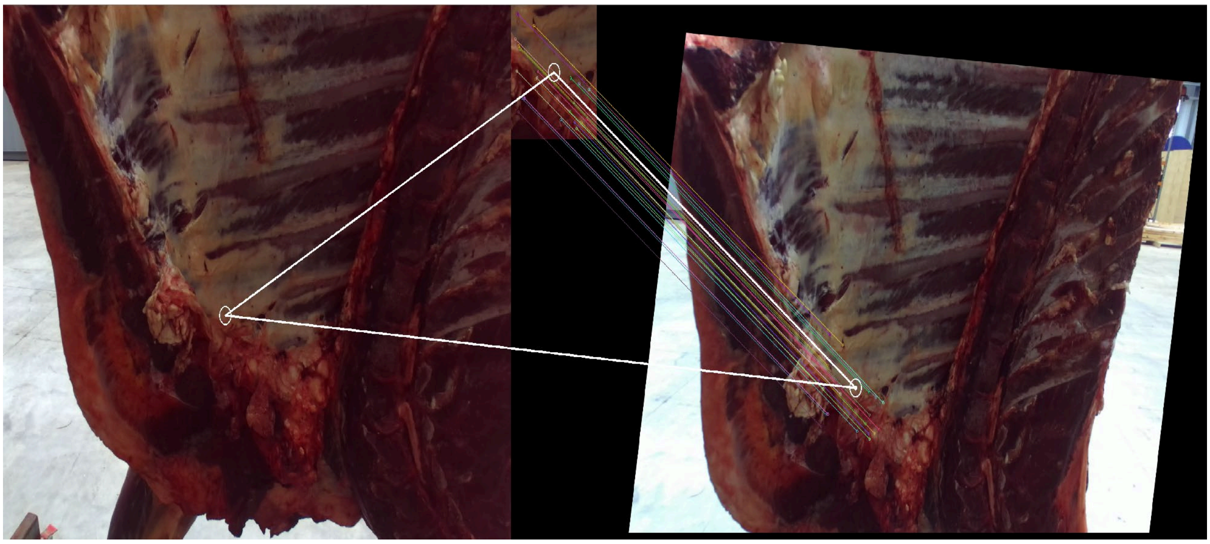

Fig. 6: Re-referencing via feature detection with scale, orientation and artificial structural changes

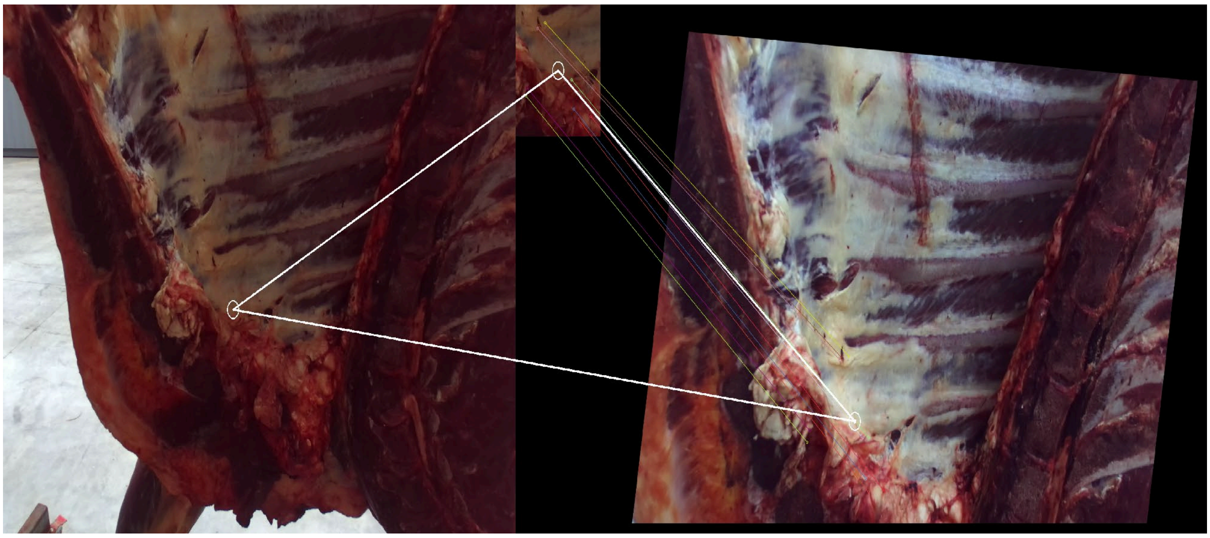

Fig. 7: Re-referencing via feature detection with scale, orientation, lighting, colour and artificial structural changes

Time constraints meant the results could only be assessed qualitatively, however the results were encouraging. Where the key point was clearly visible, the re-referencing seemed to perform as well as an expert human.

The re-referencing would attempt to identify the key point with only a section of the patch was visible in the image and even if the centre of the patch (the key point) was not visible. Significant changes between the original and the re-reference images, especially with orientation changes over 45 degrees, prevented accurate identification. This would suggest that surface markers could be re-referenced successfully, with good accuracy and reliability, if the carcase presentation was similar between the imaging and cutting stations.

4.5 Identifying the diaphragm reflection

A model was used to identify the area of the rib cage inside the diaphragm reflection. The original images were cropped and scaled to 400x400 pixels for analysis. The analysis achieved a 99.2% success rate in pixel classification over a sample of 50 sides, with each pixel roughly 3.42mm square.

4.6 Investigating potential backscatter X-ray systems

Rapiscan developed the first commercial backscatter X-ray systems in the mid-1990's and continue to be a dominant player in this market. Their systems cover a wide range of sizes, from small handheld devices to devices as large as a truck. These predominantly differ in voltage, penetration distance, and weight.

The key specifications, specifically those that relate to the requirements for use in process rooms, are shown in Table 1 below. The X-ray power levels would suggest they could be suitable for use in a meat-processing room with minimal shielding. The amount of muscle penetration would also suggest some of the systems could provide useable images for detecting the position of the ilium. However, the slow scan speeds required to generate clear images are generally too slow for a single unit to keep up with the processing rate at most plants.

	ZBV	AXISS	Portable	Handheld	Viken*
Energy (keV)	225	140	70	70	120
Power (W)	Not available	600	300	10	5
Steel Penetration (mm)	8	3 - 5	1 - 3	0	1-3
Muscle Penetration+ (mm)	62	34 - 57	35 - 104	N/A	14 - 42
Mass (kg)	Not available	135	70	3.9	3.7
Scan Speeds	45 - 277 cms^{-1}	2 – 15 cms^{-1}	Not available	15 cms^{-1}	15 - 30 cms^{-1}

Table 1: Key hardware specifications of potential backscatter X-ray systems

* Viken refers to the HBI-120 Handheld X-Ray Imager manufactured by Viken Detection and is the only model mentioned above not manufactured by Rapiscan.

+ The muscle penetration is based on the steel penetration numbers provided, scaled by the appropriate mass attenuation coefficients and densities for the given energies.

5 Discussion

5.1 Proposed sensing technologies

A number of promising sensing technologies have been investigated and an estimation for accuracy has been produced. All of the key markers can be identified by one or more technologies but with a varying degree of accuracy. Trade-offs between accuracy, speed and cost will need to be considered when automation solutions are proposed.

5.2 The proposed vision system sequence

A number of promising sensing technologies have been identified and these provide a number of options to automate the proposed cut sequence.

All options could potentially offer working solutions, but the level of accuracy will vary. Further research work that focuses on the cost-benefit analysis of the different processes would give an indication as to which strategy might offer the most sensible route forward. In general, the force torque sensing increases the amount of error tolerance in the sensing system.

6 Conclusions/recommendations

Existing DEXA scanning technology was modified in an attempt to provide accurate bone identification images but hardware tuning and adjustments did not produce satisfactory results. However, removing the foreleg prior to scanning made a significant difference to image quality and should allow LMY DEXA images to be used for bone identification. It would seem plausible that LMY predictions could account for the missing foreleg.

This project also aimed to further outline the requirements of a vision sensing system for determining:

- The surface markers for the brisket and rib-strip cuts
- The obscured markers for the spine and leg separation cuts.

Key requirements of the vision sensing system were identified:

- Identifying 1st rib and sternum intersection
- Identifying the intersection of 1st and 11th rib with the spine and sternum
- Identifying the intersection of 11th rib and the reflection of the diaphragm
- Re-referencing of surface markers between imaging and cutting stations
- Identifying the vertebrae positions to allow localised, optimal camera positioning
- Accurately identify the vertebrae gaps to guide spine cross-cut placement
- Accurately identify the lumbar-sacral vertebrae gap for placing the spine cut in the leg-separation process
- Determine the “low” point on the ilium crest and/or sense the ilium surface during cutting

A number of technologies and analysis techniques were investigated and produced good candidates to achieve the requirements for accurate automated cutting.

6.1 Spine Cuts

This project aimed to further outline the requirements of a vision sensing system for determining the obscured markers for the spine and leg separation cuts. Key requirements of the vision sensing system were identified:

- Accurately identify the vertebrae gaps to guide spine cross-cut placement
- Accurately identify the lumbar-sacral vertebrae gap for placing the spine cut in the leg-separation process

A number of technologies and analysis techniques were investigated and produced good candidates to achieve the requirements for accurate automated cutting.

Further research in this area would allow more optimal imaging and analysis techniques to be investigated.

7 Key messages

- The design of X-Ray systems for lean meat, fat & bone ratio determinations versus the finding of skeleton features require individual optimisation.
- X-Ray is required to locate the cranial end of the brisket separation cut as defined by AusMeat, as opposed to a camera and vision analysis techniques.
- Sensing of all the locators to perform brisket, ribset and spine cuts is possible with current technology and likely to provide accuracy benefits over current manual processes.

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