final report

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Prepared by: Peter Aust Phillip Boyce Andrew Finney Darryl Heidke
Kym MacRae Jeff Owen Peter Ring Ray White

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Meat and Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Development of X-RAY Sensing Technology

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EXECUTIVE SUMMARY

As outlined in the contract ‘Purpose and description’ two tasks have been selected for development under this project:

- Beef split saw sensor development; and
- Beef scribe saw quarter cut.

Some of the development issues faced during the initial stages of this project include: variation in industry population, the initial presentation of the beef spine to X-ray, and the limitations of the C-arm (i.e. imaging area and C-arm “throat”. Also, consideration was given to the method of demonstrating the project outputs to MLA and industry representatives.

Preliminary work tasks included determining the selected process task functional requirements and industry specification for the scribe saw quarter cut, image data capture of tasks identified for sensing development, and determining X-ray methodology. The latter involves a number of variables such as intensity, scan speed, and positional requirements.

In the initial stages of this project, it was decided to collect preliminary X-ray data from a sheep carcase. This supplied valuable information regarding the set-up of the X-ray, e.g. indexed still images appear to be more suitable than moving images. Information was also gathered with regard to the high voltage potential (HVP) settings that would be required. These trials provided a head-start to the task of using the X-ray on beef carcases. For all trials, the X-ray was mounted on the end of a robot arm.

The first task investigated was carcase splitting. An X-ray scan of a beef carcase was taken and an analysis results snapshot of the spine was compiled or “stitched” together. The data was analysed and initial software algorithms were developed that allow for some intensity adjustment, and initial spine positioning. For this trial, the X-ray was oriented with the receiver facing the outer surface of the spine. Laser distance measurements were made to determine the position of the carcase surface at the spine and at the X-ray receiver.

The method used separate analysis techniques for different areas of the carcase. These regions are defined as:

- Void – below the meat rail, but above the carcase
- Leg – between the opened legs
- Tail - across the aitch bone
- Back – between the tail and the neck
- Neck – from high on the shoulder to exiting the carcase

To investigate the second task (Quarter cut) the carcase was first split in the traditional manner. The system initially tracks the spine vertically until ribs are recognised. Once ribs have been established, their locations are recorded and counted as the system continues to track the spine towards the neck. Once the desired number of ribs has been recorded, the nominated rib is tracked in

discrete steps away from the spine until the limit of the C-arm is reached. In this manner, a pre-determined distance away from the spine on a desired rib can be located.

Once each image has been analysed for both vertebrae and rib locations, the images can be stitched together to give a historical map of the raw X-rays. Overlayed on this image is the spine analysis results and the rib location.

A survey of a number of regulatory bodies was also performed as these issues have a strong bearing on any proposed installation in a meatworks. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has a number of specific rules and regulations that stipulate the safety measures that need to be adhered to for installations in Government establishments. State government regulations are based on the ARPANSA documents and registration is required before any installation is made.

AQIS have indicated two areas to be addressed in considering the use of X-ray equipment to control automated meat processing equipment. They are:

- Cleaning/sterilising
- Ionising radiation.

The next stage of this project is to introduce this technology to the meat industry as a tool for identifying deep tissue features to control automatic devices. Meeting the controlling regulations will have a bearing on how this could be achieved.

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1. INTRODUCTION

The Development of X-ray Sensing Technology project is based on two selected tasks related to beef carcase processing. These tasks are Beef split saw and Beef scribe saw. The focus is on building sensing systems that will show proof of concept by utilizing existing equipment, such as the robot and X-ray machine, at Food Science Australia, Cannon Hill.

For the split saw, the location of the spine centre is sensed using real time X-ray image processing.

The sensor development for the scribe saw task focuses on identifying carcass features that lie within the carcass structure to allow the beef quarter cut to be performed. The carcass features that require sensing include:

- Identify the 13th rib, and then count down the ribs to identify the 10th rib.
- Identify region of interest of vertebrae joint adjacent to the 10th rib.
- Identify and track the edge of the 10th rib toward the brisket as far as the limits of equipment will allow.

To provide relative motion for the trials, the C-arm was removed from the X-ray unit and mounted onto the robot arm. For the split saw trials, a whole carcase was suspended within the throat of the C arm, while for scribe saw trials, a side of beef was suspended within the C arm.

For the split saw trials:

- Carcass suspended by meat rail with back surface facing the robot
- X-ray receiver facing carcass back/ featherbones
- C Arm movement vertical for carcass length

For the scribe saw trials:

- Beef side suspended with the splitting plane perpendicular to the X-ray beam direction
- X-ray receiver to the “outside” of the carcase
- C arm movement parallel to the slitting plain of the carcase

This aim of this project is the development of X ray sensing technology to progress automated control systems for the meat industry. This will enable further development of the existing automatic beef carcass splitting saw prototype and preliminary research into a beef side quarter cut system to be carried out.

2. LAB STUDIES - BEEF AND SHEEP (MILESTONE 1)

In “Milestone 1 - Laboratory Trials” investigations were conducted on sheep and beef carcasses to determine the X ray intensity and scan speed requirements that would enable image features to be analysed, to determine product cutting paths. Other tasks also carried out in milestone one were:

- the determination of an industry specification to automate the scribe saw quarter cut;
- the development of a temporary X ray equipment mounting rig that provided good quality imaging for beef carcass split saw and beef side quarter cut areas of interest. This allowed the image feature analysis work (milestone 3) to commence in parallel with milestone 2 work tasks; and
- the method of demonstrating the project research outcomes was developed along with identification of potential project hurdles and limitations documented.

Milestone 1 report is contained in Appendix A.

3. DEVELOP SENSING EQUIPMENT - MILESTONE 2

“Milestone 2 - Develop Sensing Equipment” hardware and equipment was developed and procured to control the X ray imaging unit, carcass and beef side and associated components to provide imaging along the spine of beef carcass to determine splitting saw control requirements and the regions of interest on a beef side to determine quarter cut paths.

The X ray imaging head was integrated with an industrial robot to provide stop start and continuous movement across the animal product imaging regions of interest. Preliminary results of image feature analysis are also included in the report.

Milestone 2 report is contained in Appendix B

4. IMAGE FEATURE ANALYSIS - MILESTONE 3

“Milestone 3 - Image feature analysis” contains all development details to identify the centreline of a beef carcass spine and the edge of bone detection on a side of beef by analysing X ray images of the target animal bone structure. The milestone 3 report details the imaging analysis approach, final saw cut determination and result reviewing software developed for beef carcass splitting. Spine and rib tracking, mapping of rib location and collating of results are also detailed for rib profile and position identification. Radiation safety requirements specific to installation into a processing facility is also detailed.

Milestone 3 report is contained in Appendix C

REFERENCES

[1] Aust P, Heidke D, MacRae K, White, R. *Investigation and Evaluation of Sensors for Adaptation to the Meat Industry – Milestone 1: Sensing Requirements for Beef and Sheep Slaughter Tasks & Milestone 2: Identify "Manual" Assist Sensing Techniques (PRTEC.032),* Food Science Australia. Cannon Hill, Qld., 2005

[2] *Development of Vision & Laser Sensing Systems Suitable for Beef and Sheep Slaughter Tasks (PRTEC.042)- Selected Beef & Sheep Tasks for Milestone 1,* Food Science Australia. Cannon Hill, Qld., 2006

APPENDIX A – MILESTONE 1

MONTHLY PROJECT UPDATE

Date: 17/12/2007

A.TEC.0058 DEVELOPMENT OF X-RAY SENSING TECHNOLOGY

1. Objectives

This report focuses on meeting the functional requirements of milestone 1 and the method the project outputs will be demonstrated to an MLA representative. This Food Science Australia project is progressing with work being carried out concurrently on a number of tasks.

Milestone 1 work tasks:

- Determine selected process task functional requirements and industry specification for the scribe saw quarter cut
- Image data capture of tasks identified for sensing development.
- Determine X-ray methodology.

2. Update

Milestone 1 - Lab Studies – beef & sheep
Due: 21/12/2007

As outlined in the contract ‘Purpose and description’ two tasks have been selected for development under this project:

1. Beef split saw sensor development; and
2. Beef scribe saw quarter cut.

Beef split saw sensor development

Initial development has been focused on the beef split saw sensor.

The development of an automatic beef carcass saw system was previously developed to reliably split beef carcasses within a ±3mm tolerance of the spine centreline. Part of this work has been carried out under the following projects:

Automatic carcass splitter PRTEC.007
Automatic beef carcass splitter – stage 2 PRTEC .029

As the work task requirements for this project are well understood no further investigation is being carried out into the work task process as part of this project.

To fast track the project it was decided to collect preliminary data from a sheep carcase delivered to the X-ray C-arm via a robotically mounted platen that was constructed for an internal Food Science Australia project (see Figure 1).

Figure 1 Left - Food Science Australia's robotically mounted platen; Right – X-ray C-arm

Examples of X-ray images from below the brisket region on the sheep carcase, captured at different X-ray intensities, are shown in **Error! Reference source not found.**.

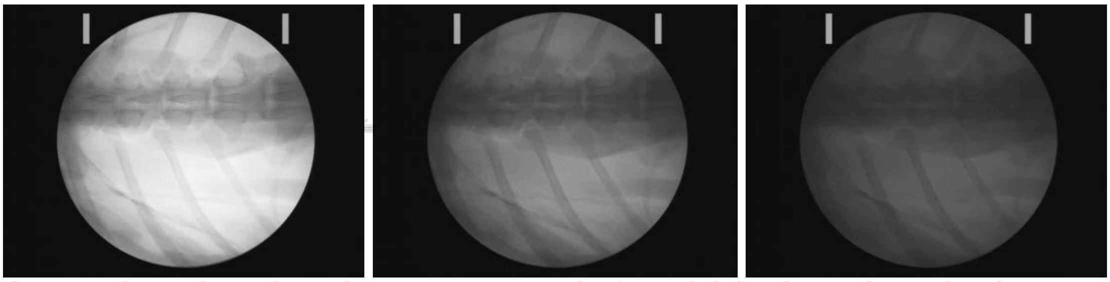


Figure 2 Sheep thoracic region - X-ray power: (Left to Right) 50kV, 54 kV and 56 kV

The sheep data was examined and clearly showed that the X-ray power required for clear imaging of the spine was very different in the muscled brisket region than that in the lumbar flank region. X-ray data was captured of both moving and still images and when considered it was decided that early indications favoured indexed still images for clarity over the continuous capture along the spine.

As the benefits of a sheep model as an approximation of X-ray data in beef had been utilised it was then decided that beef carcase data was required, particularly for examination through the beef brisket 'feather bone" region.

A temporary rig was developed, incorporating a forklift for vertical motion along a beef carcase that was suspended from a meat rail in the traditional industry configuration, to capture preliminary beef spine data.

Figure 3 Temporary X-ray rig

Figure 4 Carcase within X-ray forklift rig

Figure 5 Removed brisket

The brisket was opened to remove images of the brisket structure from the X ray of the back and feather bones. In a commercial unit a brisket spreading mechanism would ensure a clear view of the spine. X-ray data that was collected around the brisket/thoracic region is shown in Figure 6.

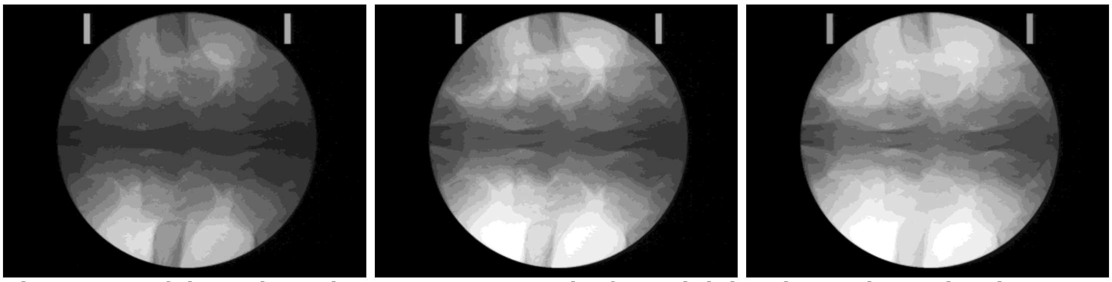


Figure 6 Beef thoracic region – X-ray power: (Left to Right) 62 kV, 68 kV and 70 kV

The data was analysed and initial software algorithms have been developed that allow for some intensity adjustment, and initial spine positioning along with an analysis to find the centre line of the featherbones and spine. A results snapshot has been compiled or "stitched" together from the analysis of continuous video and is shown in Figure 7.

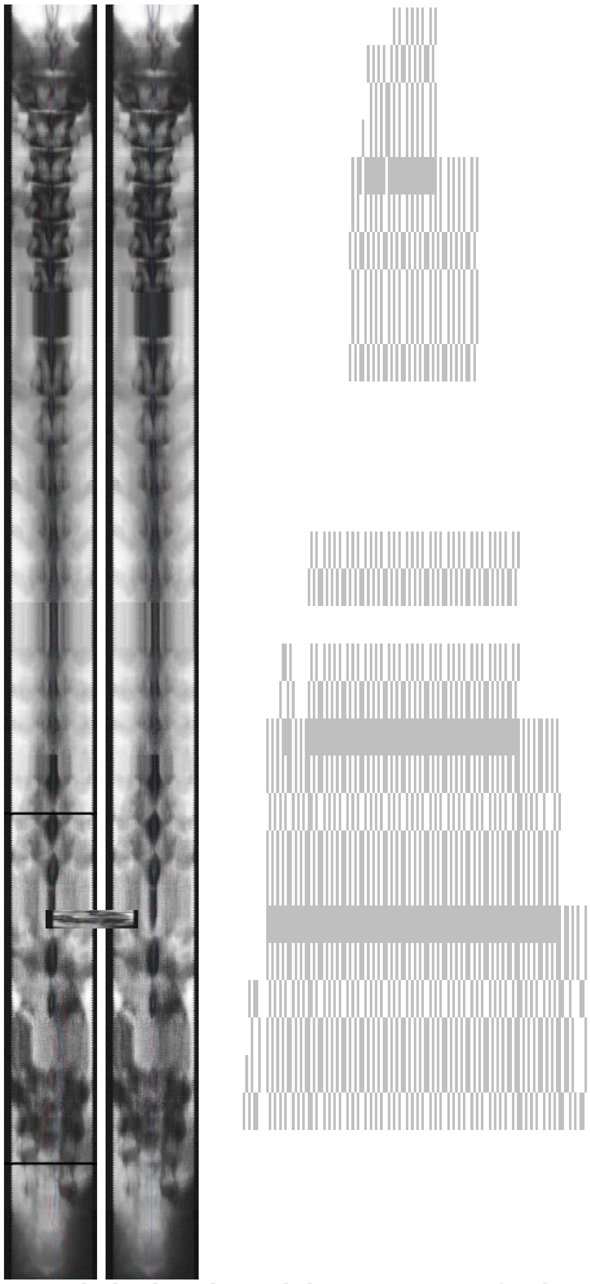


Figure 7 Left - Complete "stitched" spine; Right – Close up of spine portion showing preliminary image analysis

Beef scribe saw quarter cut

As part of beef boning operations, carcass sides are often separated into fore and hind quarters prior to individual primal cuts being separated from the skeletal frame.
Separation of beef sides into different fore and hind arrangements is commonly carried out, depending on the client specification for the shape of primal cuts. One Rib, Two Rib and Three Rib hind quarters are the most commonly practised separation positions.

In separating the fore from the hind quarter, the joint adjacent to the identified rib that will form the edge of the hind quarter is marked with a scribe through the spine and feather bone. The saw cut is usually positioned perpendicular to the spine and the cut is commenced along the line of the cartilage between vertebrae.

The fore and hind beef quarters are then separated by a knife cut that commences at the mark provided by the scribe saw and the meat is severed between the ribs, following the profile of the rib bone in the direction of the brisket.

Using the temporary X-ray rig mentioned previously (Figure 8) the same beef carcase used for the spine analysis development was split and imaged. Data has been compiled in X-Y dimensional, multi intensity grid for examination. An example of this is shown in Figure 9, which shows a series of X-ray images taken in a horizontal slice across the beef brisket.

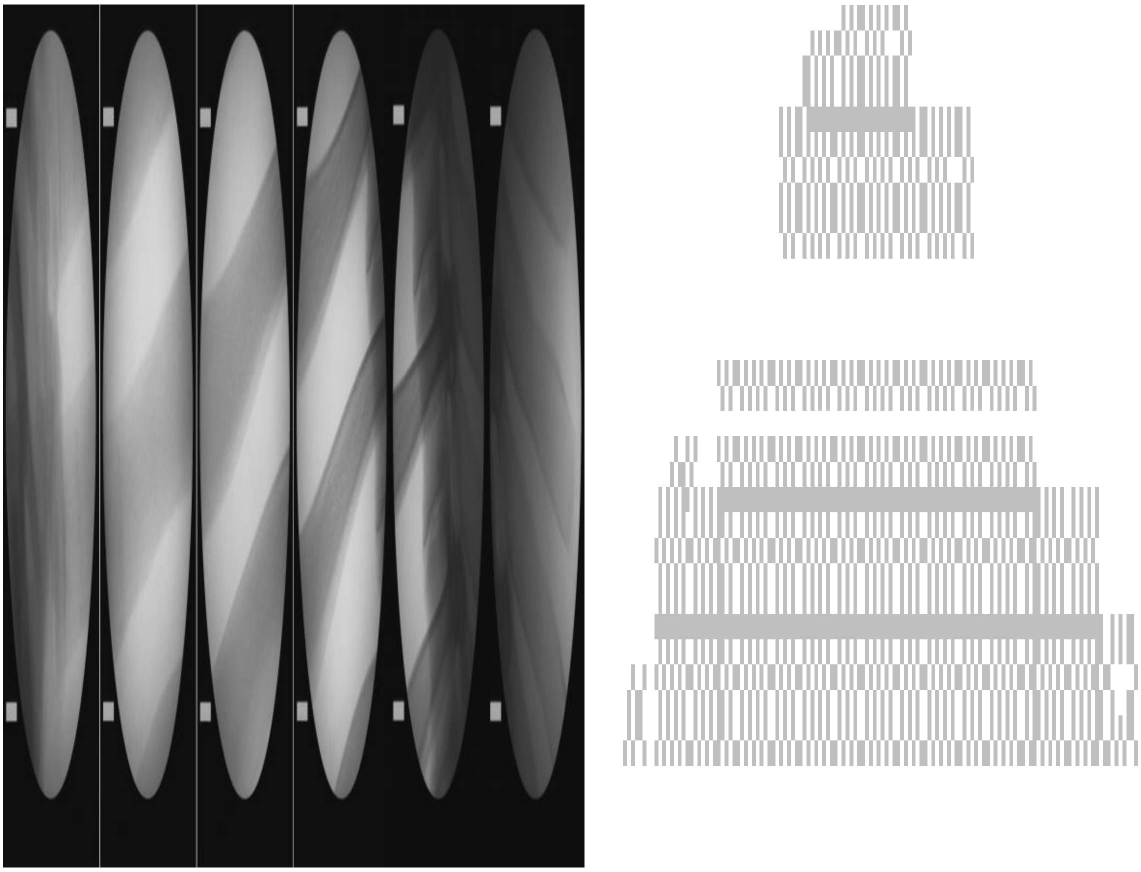


Figure 8 Beef scribe saw quarter cut X-ray arrangement

Figure 9 Beef rib region – Horizontal section at 52 kV X-ray power

Future Work – Demonstration approach

Milestone 4 requires a demonstration of beef sensing tasks at FSA Cannon Hill Laboratory.

In order to effectively move the X-ray unit across the target areas of beef carcasses, the C arm X-ray imaging head is required to be robot mounted. The planned approach to demonstrate the developed sensing systems for the split saw and quarter cut is to control the X-ray C arm to align and maintain the centre of image “crosshairs” to centreline of measured cutting position when moving across the carcass.

Distance from the sensor to the carcass surface will be measured by a laser distance pointer.

- Setup 1 – image carcass – demonstrate split saw control system.
- Setup 2 – manually split carcass, image side of beef & demonstrate quarter cut control system.

Split Saw

- Carcass to be suspended by meat rail with the carcass spine facing the robot
- X-ray receiver to be facing carcass back/ featherbones
- C Arm movement to be vertical z for carcass length & x for side movement – no y movement

Quarter Cut

- Beef side for quarter cut to be positioned similar to the split saw carcass position
- X-ray arm to be in a similar orientation as for the split saw
- C arm movement to be x side and z vertical movement to follow the rib bone – no y movement
- Laser distance measurement will determine the position of the carcass surface from the X-ray receiver.

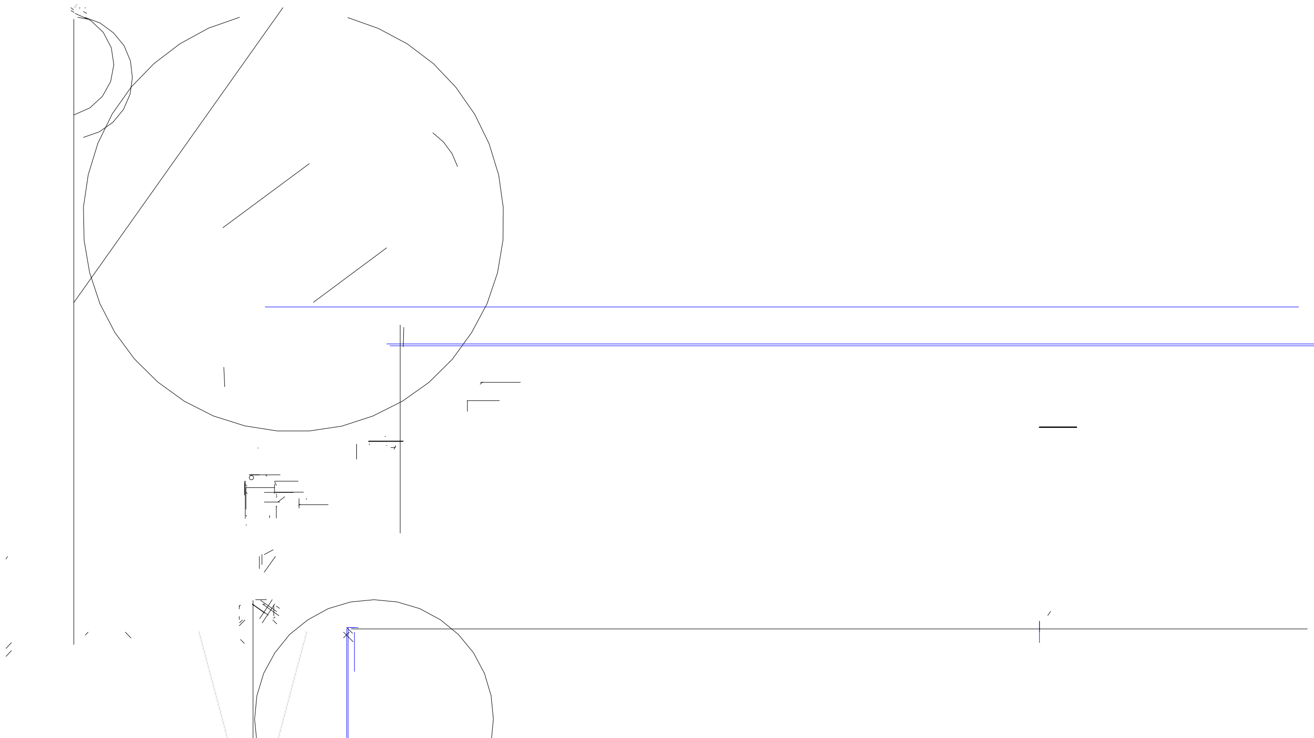


Figure 10 C arm X-ray robot mounting arrangement

4. Potential Hurdles / Limitations

- Variation in industry population
- Initial presentation of spine to X-ray
- C-arm limitations – imaging area and c-arm “throat”
- Method of demonstrating the project outputs to MLA and industry representatives.

5. Project Schedule

Milestone 2 - Develop Sensing Equipment
Due: 31/1/2008

Milestone 3 - Image Feature Analysis
Due: 30/4/2008

Milestone 4 - Demonstrate X-ray sensing tasks
Due: 13/6/2008

APPENDIX B – MILESTONE 2

5. MONTHLY PROJECT UPDATE

Date: 5/3/2008

A.TEC.0058 DEVELOPMENT OF X-RAY SENSING TECHNOLOGY

6. Objectives

Food Science Australia have completed the tasks required for Milestone 2 – "Develop sensing equipment" of this project and have also progressed Milestone 3 – "Image feature analysis" this will enable testing of the developed sensing equipment to commence in the near future on the beef split saw and the beef scribe saw quarter cut sensor development. Work progress on individual tasks is detailed below under the individual milestone headings.

7. Update

Milestone 1 was completed on 17/12/2007. When carrying out these tasks, acceptable images were obtained to develop preliminary sensing software for the split saw and quarter cut tasks via a temporary X-ray rig that incorporated a forklift for vertical motion. This has enabled software to be developed for the identified tasks to the point where further trialling is required to obtain more data before software development can be progressed.

Milestone 2 tasks have now been completed and this comprises the main body of this report.
Trialling of the X-ray sensing system will now commence to facilitate the completion of the sensing system software development as listed in Milestone 3 of this project – preliminary results are also include here.

Milestone 2 - Develop Sensing Equipment
Due: 31/1/2008

The objectives of Milestone 2 are as follows:

- Develop carcass handling /restraint equipment.
- Develop / modify X-ray sensing equipment.
- Develop / modify robotic accessories
- X-ray image data capture for feature analysis

The general arrangement of the sensing equipment to develop and demonstrate the stipulated tasks is as follows:

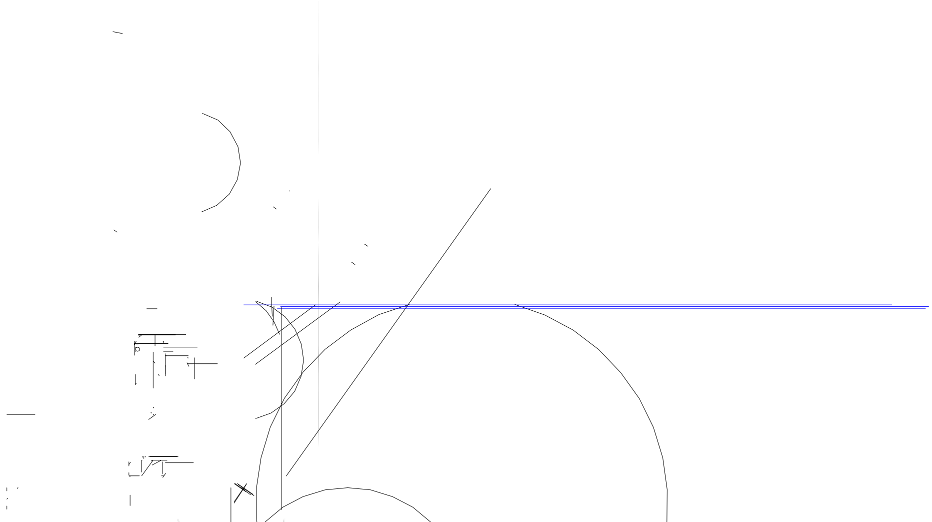


Figure 1 C-arm X-ray robot mounting arrangement relative to wall and meat rail (bottom of image)

Develop carcass handling / restraint equipment.

The development of the X-ray sensing system thus far does not require it to have direct contact with the beef carcass or carcass side so carcass restraint equipment should not be necessary. The current equipment design also allows meat product to be transported and handled using standard meat rail & rollers while achieving reasonable presentation. However, repositioning of the carcass and/or beef side may be required to maximise the spine / rib imaging area coverage, hence any modification to achieve this and carcass contact restraint if required will be carried out on an "as needs" basis during the imaging trials.

Develop / modify X-ray sensing equipment and robotic accessories

In order to achieve the demonstration approach outlined in Milestone 1 project update the X-Ray sensing equipment needed to be integrated with the robot, as shown in Figure 2, so the path of the spine and ribs could be tracked during imaging of the beef carcass or side.

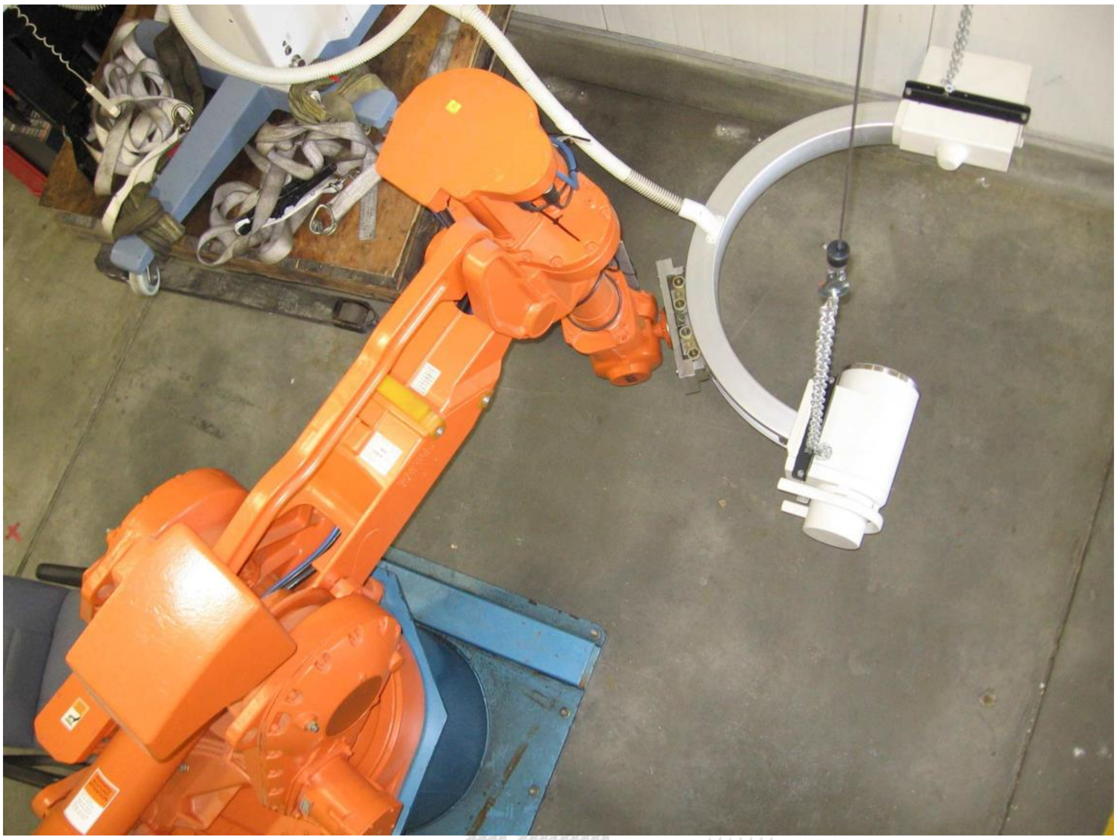


Figure 2 X-ray C-arm - robot mounting arrangement from above

Figure 2 shows the C-arm unit mounted onto the robot.

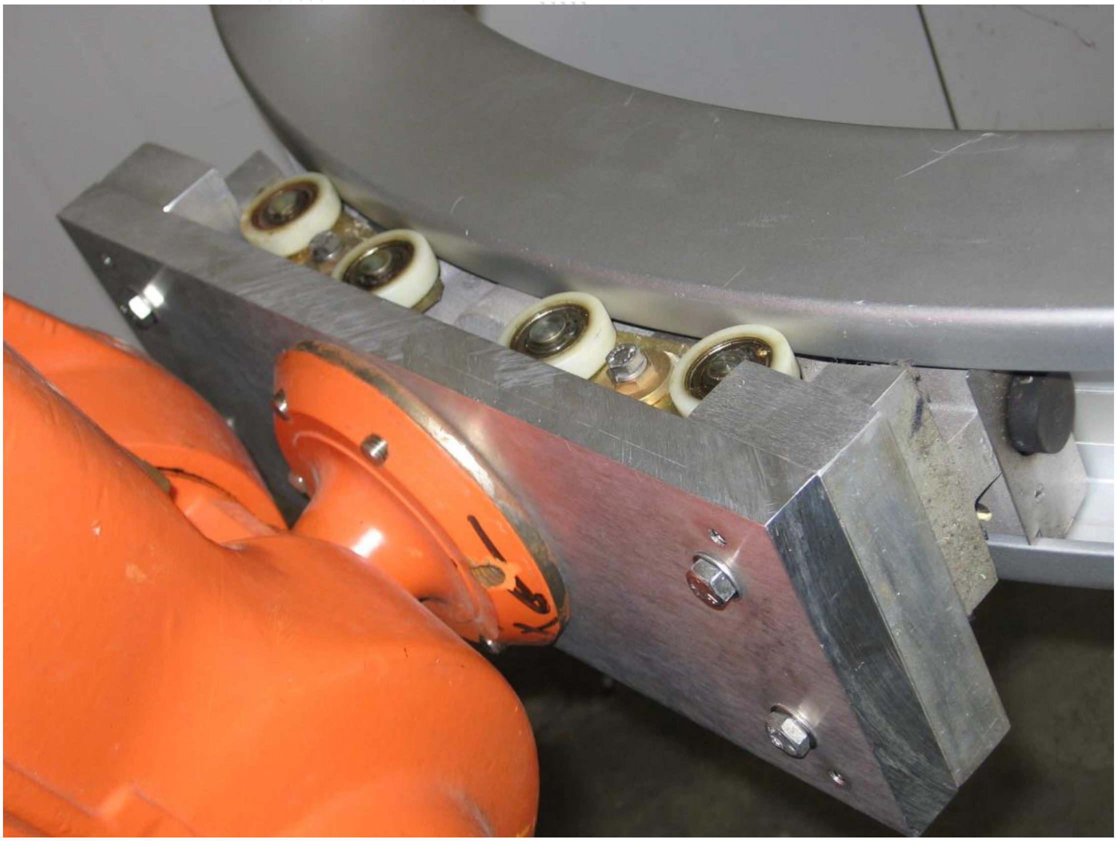


Figure 3 Adaptor plate

The X-Ray C-arm has been mounted onto the robot arm by an adaptor plate shown in Figure 3. The adaptor plate also incorporates an adjustment and brake system to allow the C-arm X-ray unit to be repositioned on the robot head.

Figure 4 C-arm support mechanism

As the mass of the C-arm greatly exceeds the maximum weight capacity of the robot arm, supplementary support of the C-arm is required. Controls to prevent movement outside of the working area are also required to prevent damage to the robot or the X-ray imaging system.

Due to the mass of the C-arm being four times greater than the maximum load capacity of the robot in the extended position, additional support was provided by two 35-45Kg adjustable spring tension units. This equipment was mounted above the overhead meat rail structure and fixed by brackets to the X-ray camera and emitter.

Movement of the C-arm will be controlled by the robot in the vertical Z plane and horizontal X plane (parallel with the meat rail). There will be no robot movement in the horizontal Y plane, allowing the X-ray head to be positioned at a fixed distance from the centre of the meat rail. The developed system can provide image scanning capability over a two metre vertical travel distance (Z direction) commencing 880mm below the meat rail. Horizontal (X direction) travel movement is also available; however practical imaging in this direction is restricted by the shape of the C-arm.

X-ray image data capture for feature analysis
Data capture for feature analysis was carried out as part of milestone 1 using a temporary rig incorporating the C-arm X-ray unit mounted onto a fork truck. The

capability to capture data at an early stage in the project has allowed feature analysis work to proceed in parallel with the sensing equipment development.

Milestone 3 - Image Feature Analysis
Due: 30/4/2008

Work tasks on Milestone 3 have commenced. Objectives for this milestone include:

- Develop image algorithms for identified tasks
- Trial X-ray sensing system at Food Science Australia
- Investigate AQIS, APANZA and other regulatory body requirements.
- Develop recommendations for future work and requirements required to implement next project development stage

Preliminary image analysis and algorithm progress has been achieved for the beef split saw sensor development to identify the carcass spine for splitting. This information was shown at the International Meat Automation Conference (iMAC) on the 28th of November, 2007. Figure 5 shows the results from the preliminary detection and vector direction algorithms.

Figure 5 Beef Split aphorism sensor development preliminary image analysis results

Preliminary image analysis and algorithm development has also been carried out for the beef scribe saw quarter cut task. The image in figure 6 shows the software determination of the rib positions and tracking a single rib.

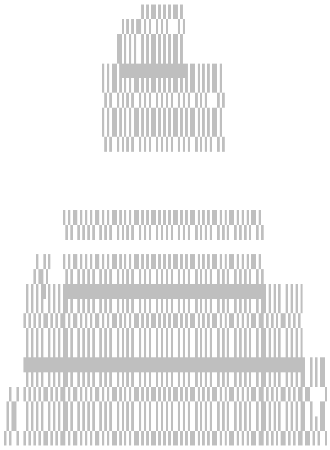


Figure 6 Beef scribe saw quarter cut preliminary image analysis results

Further data is now required to progress the preliminary software algorithms.

8. Potential Hurdles

Remaining potential hurdles from those discussed in the Milestone 1 update report potential are currently listed as:

- Variation in industry population
- Initial presentation of spine to X-ray
- C-arm limitati[redacted]aging area and c-arm “throat”

Although it is not possible to accommodate all available variation in a proof of concept prototype the project has now progressed to a Milestone 3 and additional trialling can commence to improve the robustness of current imaging algorithms for both the beef split saw sensor development and the beef scribe saw quarter cut. As detailed in this milestone update report the design of robotically mounted X-ray sensing equipment has included consideration of minimising limitations caused by the C-arm and presentation of the spine to the x-ray sensor in the laboratory setting.

No additional potential hurdles have been identified at this stage.

9. Project Schedule

Milestone 1 - Lab Studies – Beef & Sheep
Due: 21/12/2007 **Completed 17/12/2007**
Milestone update report submitted and accepted by D Doral (MLA).

Milestone 2 - Develop Sensing Equipment
Due: 31/1/2008 **Submitted 06/03/2008**
Completed and discussed in this milestone update report. D Doral (MLA) notified of potential delay in milestone completion date.

Milestone 3 - Image Feature Analysis
Due: 30/4/2008 **Under development.**
Preliminary development results discussed in this report.

Milestone 4 - Demonstrate X-ray sensing tasks
Due: 13/6/2008

APPENDIX C – MILESTONE 3

6. MONTHLY PROJECT UPDATE

Date: 3/6/2008

A.TEC.0058 DEVELOPMENT OF X-RAY SENSING TECHNOLOGY

10. Objectives

Food Science Australia has completed the tasks required for Milestone 3 – "Image Feature Analysis". This milestone entails the development of image algorithms for the selected tasks (beef carcase splitting and scribe saw quartering) and recommendations for implementing the tasks into a commercial processing plant. The progress of the work on individual tasks is detailed below under the individual milestone headings.

11. Update on Milestones

Milestone 1 was completed on 17/12/2007. While carrying out these tasks, acceptable images were obtained enabling the development of preliminary sensing software for the split saw and quarter cut tasks via a temporary x-ray rig that incorporated a forklift for vertical motion. This has enabled software to be developed for the identified tasks to the point where further trialling is required to obtain more data before software development can be progressed.

Milestone 2 was completed on 5/3/2008. The x-ray equipment has been modified and mounted on the end of an industrial robot enabling further data to be collected.
Trialling of the x-ray sensing system has commenced to facilitate the completion of the sensing system software development as listed in Milestone 3.

Milestone 3 - Image Feature Analysis

Due: 30/4/2008

Work tasks on Milestone 3 have been completed. Objectives for this milestone include:

- Develop image algorithms for identified tasks
- Trial x-ray sensing system at Food Science Australia
- Investigate AQIS, APANZA and other regulatory body requirements.
- Develop recommendations for future work and requirements to implement next project development stage

The general arrangement of the sensing equipment to develop and demonstrate the stipulated tasks is as follows:

6.1.3.0 Develop image algorithms for identified tasks

6.2.3.1 Beef Splitting

3.1.1 Overview

A system using x-ray images to track the centre of a beef spinal column has been developed using an x-ray C-arm unit attached to an ABB4400 robot located at Food Science Australia’s Cannon Hill laboratory.

The C-arm unit provides an x-ray image with a small viewing area of approximately 140mm in diameter. The features of the C-arm unit include:

- more real time information than line scan x-ray
- easier to control radiation risk as the focal beam is contained
- Capable of compensating for carcase movement during the cutting process

There were two methods of x-ray imaging used when gathering data: these are continuous and static.
It was determined that movement during the x-ray process causes “blurring” of the image, and the blurring increases as the speed increases with the current C-arm unit.
A pause in movement during the x-raying process produces the clearest image and was implemented by the robot pausing at successive locations.

The C-arm unit used during testing includes an automatic adjustment of the high voltage potential (HVP) for the x-ray source resulting in an automatic adjustment of the intensity of the x-ray image. This feature was used during the trials. The intensity of the images was also monitored in the analysis program for later implementation into an independent system. The automatic adjustment improved when the x-ray was stationary compared to when moving.

An earlier system using ultrasound required contact with the carcase before analysis could commence. Because the x-ray can produce data above the tail area, it is now possible to determine the centre of the aitch and tail bones to centralise the splitting saw without carcase contact and prior to starting the cutting process.

The method used separate analysis techniques for different areas of the carcase. These regions are defined as:

- Void – below the meat rail, but above the carcase
- Leg – between the opened legs
- Tail - across the aitch bone
- Back – between the tail and the neck
- Neck – from high on the shoulder to exiting the carcase

As the x-ray moves down the carcase the desired saw location can be displayed on the analysed image. Depending upon the quality of the analysis, a coloured rating can be set for displayed analysis cross hairs, allowing for an instant assessment as each frame is processed.

Figure 10: The quality of each image analysis can be shown by colour in the image

Once the individual x-ray image has been analysed, a portion of that image can be collated as part of a “stitched” x-ray image of the full spine. This allows for an overall verification of the analysis for the predicted carcase splitting line.

3.1.2 General Assumptions

Given the previous experience in automating a splitting saw system, it has been established that certain assumptions can be made.

1. The carcase can be approximately aligned to the centre of the saw by capturing the rollers on the meat rail. For these trials the carcase will be manually located into position.
2. The height of the tail (relative to the floor) can be established using a laser measurement system. The tail height will be entered manually during these trials.
3. The height of the neck (relative to the floor) can be established using a light measuring system, and hence the end of measured cut location can be established as a set height above the neck, or as a percentage of the carcase length between the tail and the neck. The neck height will be entered manually during these trials.

The parameters (Figure 11) entered manually during these trials would be automated in a commercial system.

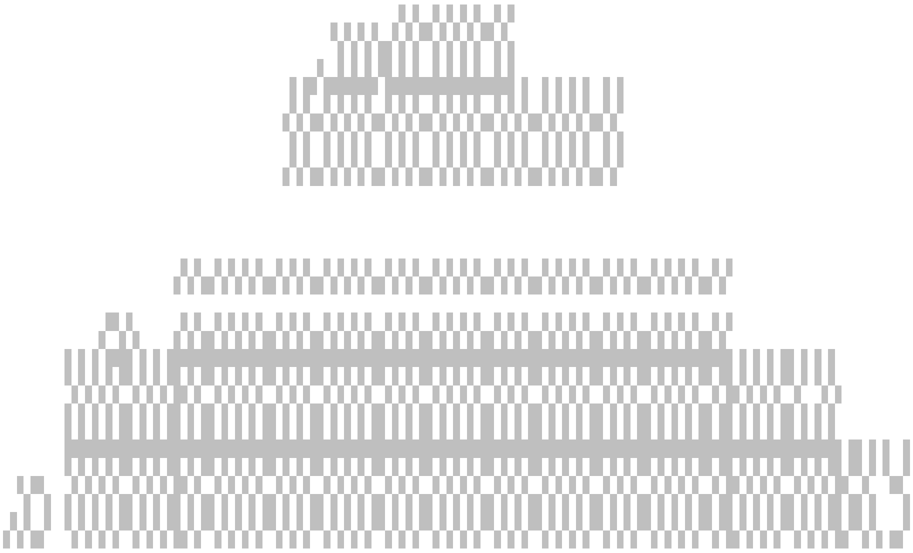


Figure 11: Information that can be gathered by already proven methods

3.1.3 Regions of Analysis

3.1.3.1 Void

This section is the region between the meat rail and the top of the carcase aitch bone where the legs can be captured in the x-ray image

Centring in this region would be done by mechanical methods, for example supporting the two rollers on separated stops. This could be a rough centring device, but it should establish an appropriate starting point.

The cut location in this region is determined as the centre of the image, and that location is held between analyses until the next analysis format is selected.

A sample analysis of this region can be seen in Figure 12. The product (legs) have not covered a predetermined portion of the image (defined by the blue line) so the cut position is held (indicated by a purple cross hair) in the centre of the image.

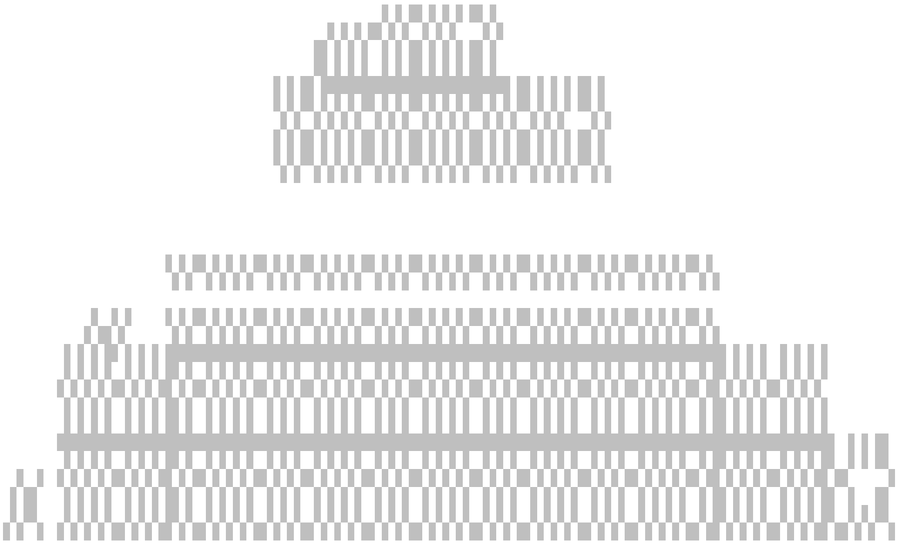


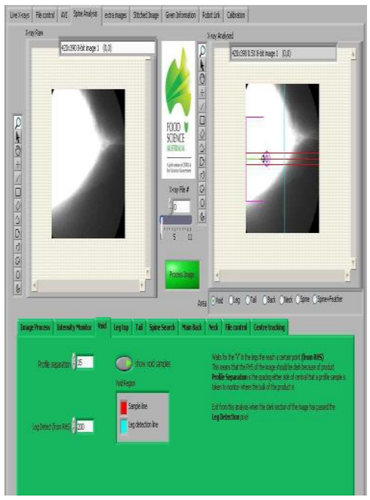
Figure 12: The cut location is defined as the centre of the image

In Figure 12 the software parameters “Leg Detect from RHS)” define the position specified to indicate there is enough of the leg within the image to commence analysing.

Analysis of this region changes to the next region either by monitoring the height of the carcase as the x-ray moves down, or by monitoring the amount of leg in the X-ray image.

3.1.3.2 Leg

The x-ray unit goes through the tops of the leg but still above the height of the anal cavity.



This analysis scans to find the centre of the legs, as shown by the “V” in

Figure 13.

The number of scans and spacing of the scans can be set by an operator. More scans require more processing time, but a more accurate result can be achieved.

The average of these samples is used to determine the “centre” or cut location when the saw blade starts to enter the carcase.

During this region the saw should not be cutting, but the blade being aligned to start cutting in as close a position to the centre of the carcase as can be reasonably established at this stage.

Figure 13: The cut location is defined as the averaged distance between the legs

Once the legs have moved beyond the x-ray image, (determined by finding less than the “minimum # centres to left”), the current centre is held and the saw is moved vertically while the “tail” analysis is implemented.

3.1.3.3 Tail

This is the region across the aitch bone.

The centre is established by the previous analysis and this location is held (shown by the purple cross hair in Figure 14) until the anal cavity is recognised (shown as the bright section in the image of Figure 15).

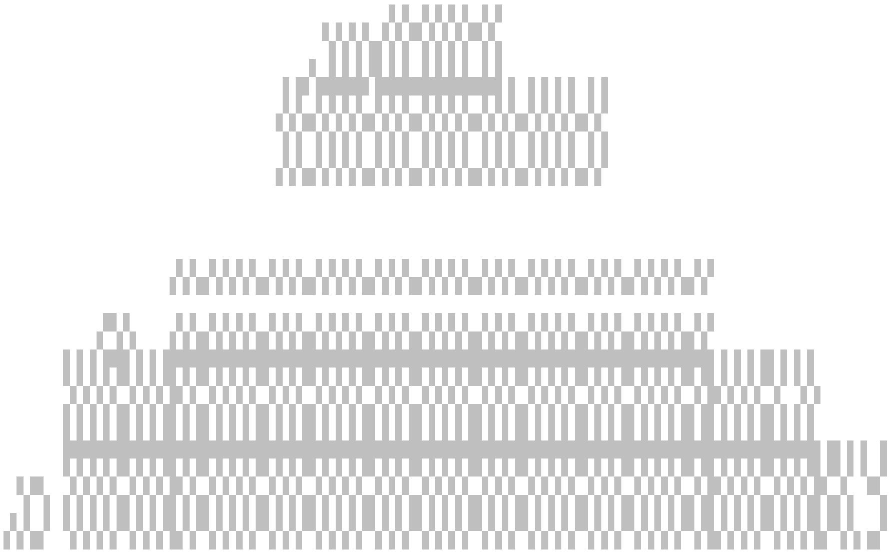


Figure 14: The analysis holds the previously established cut location initially

The animal may be hanging to one side, so further analysis is used to adjust the cut location. This adjustment is based on the location of the bright spot in the x-ray image created by the anal cavity, and is shown as the green cross hair in (Figure 15).

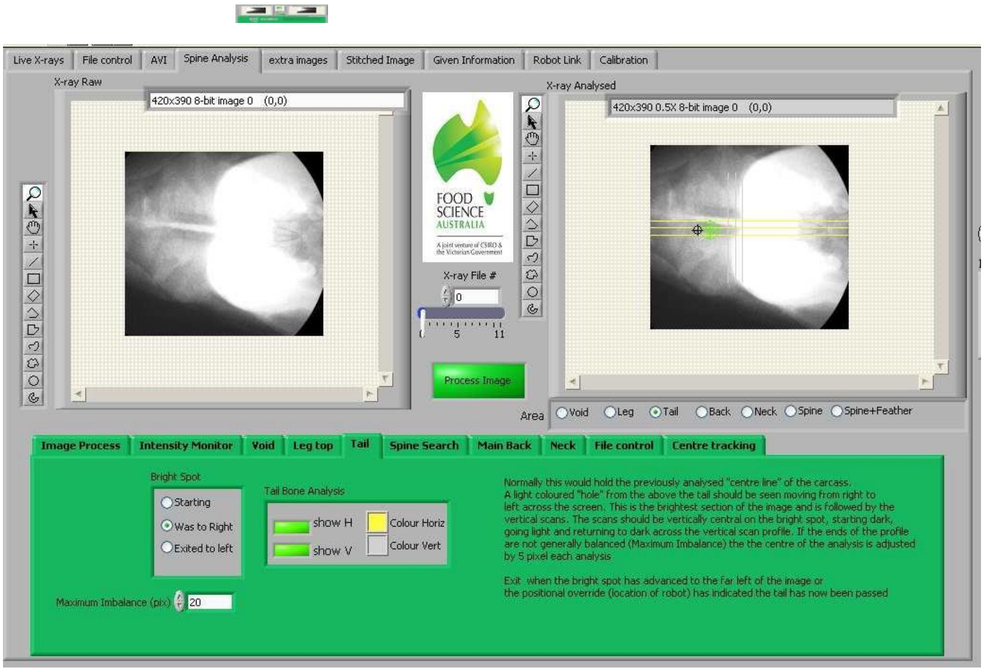
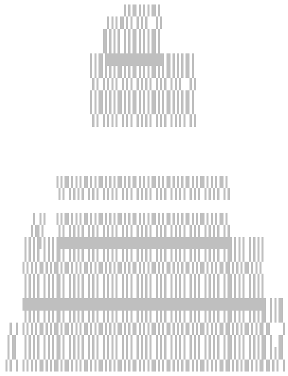


Figure 15: Once the anal cavity is recognised, the analysis re-establishes the centre of the carcase

This analysis ceases when the recognised anal cavity has left the image (to the left in Figure 15) or the height of the x-ray has gone below the previously established height of the tail (Figure 11).

3.1.3.4 Back

This is the main region of analysis and is used from the start of the tail bones to the set height above the neck.



During this analysis the centre of the backbone and featherbones are established to determine the centre of the spinal canal, and hence the cutting location.

As the x-ray unit travels through the brisket region, the brisket must be opened up so that the x-rays are not absorbed by the brisket material and also so the bones of the brisket are not included in the image analysis (Figure 16).

Figure 16: X-ray including brisket and spine bones

The x-ray image is initially analysed for the bulk of the backbone (Figure *8*). This establishes an “estimated” centre of the spine. This estimated centre is then used to initiate the featherbone analysis within the vertebrae.

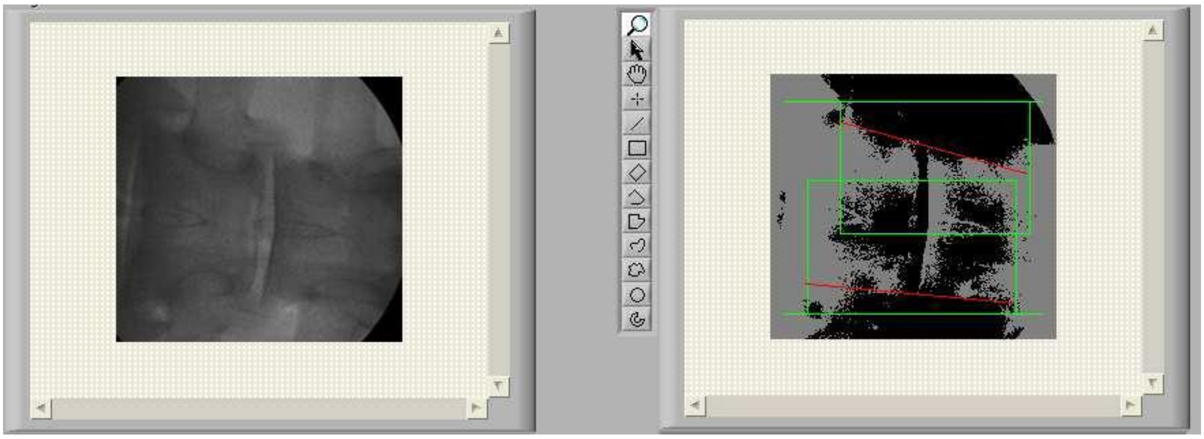


Figure 17: The bulk of the spine is located to establish the centre for featherbone detection

The detection of the featherbones is restricted by a number of parameters that can be set by an operator (Figure 18).

> The ***Centre Start (y)*** is based on the previously analysed spine centre and this is the assumed centre of the spine at the start of the analysis.
>
> The ***Expansion*** is the distance either side of the centre line that is used to search for feather bones. This should not extend to the full width of the vertebrae.
>
> The ***Scan Step*** is the spacing between scans used to look for the edges of the featherbones. The scans occur across the complete image (Figure 19). At each scan location the image is sampled several times to eliminate problems with noise within the image. The lower the *scan step*, the more sample scans are taken and the longer the processing time required.

Once the featherbones have been analysed, the results are assessed by their spacing (*Edge width limits*). Individual featherbone edges are assessed based on these limits and a score can be established based on the number of edges left. A minimum number of good edges (*Min Acceptance*) must be quantified to recognise a featherbone. If at any stage the analysis is rejected, the reason for that rejection is shown in "*Feather Bone Quality"*.

Figure 18: Parameters to define a featherbone

Once the initial analysis of the featherbone has been completed (Figure 19), there may still be some false positive edges being recognised. An approximation of the centre line of the featherbones is made (green line on Figure 20) to help reject the false positives.

Figure 19: The x-ray image is scanned for possible featherbone edges

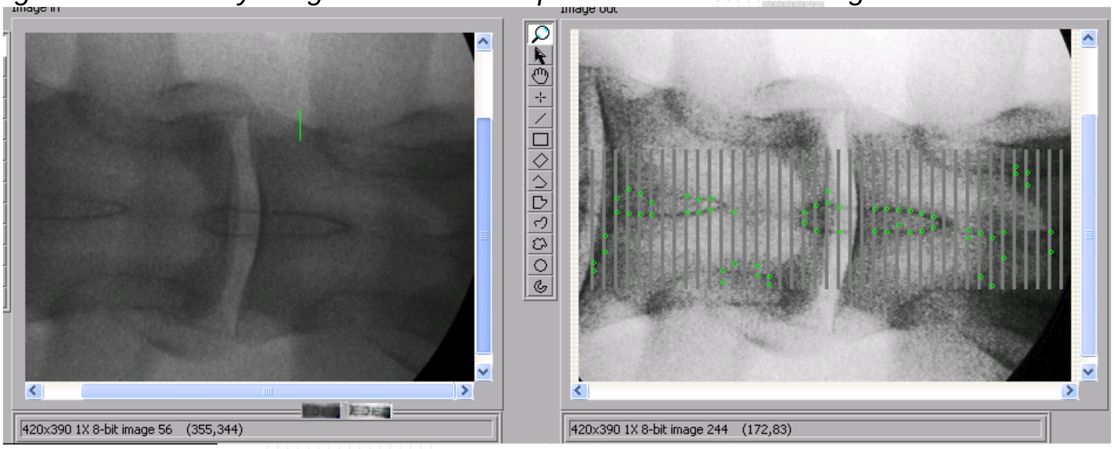


Figure 20: An approximated centre line is established based on raw analysed featherbone edges

A set of confirmed featherbone edges are evaluated by assuming the featherbone should be symmetrical around the estimated centre line (blue line in Figure 21).

An alternate analysis assumes the featherbone should remain within the limits of an average spacing, based on a combination of the average width of the vertebrae during the first pass analysis, and the predetermined minimum and maximum widths of a featherbone (Figure 22).

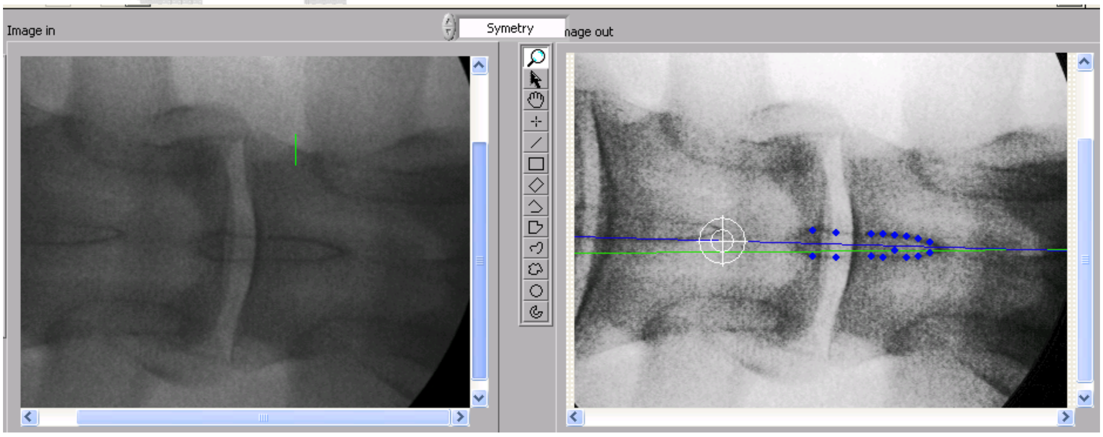


Figure 21: The edges are re-analysed based on the approximate centre and a more accurate centre is established

Figure 22: Alternate methods based on the estimated points around the centre line can produce more likely featherbone edges

Once the analysis of the featherbone has established enough edges, a line of best fit is used to determine the centreline of the featherbones based on the whole x-ray image and the centre can then be based on that line (white cross hair in Figure 21 and Figure 22). This is one further step that helps remove the influence of falsely detected featherbones.

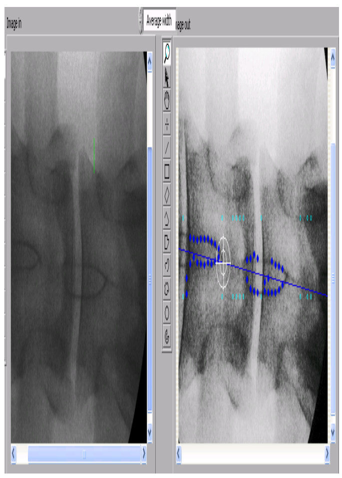
Should the featherbone analysis be rejected by the parameters of *Acceptance level* (Figure 18), then the "estimated" centre (based on the outer edges of the vertebrae in (Figure 8) can be used to locate the saw for that analysis.

If the featherbone analysis has passed all restrictions, then that centre can be combined with the "estimated" centre analysis, providing information on the twist of the animal (where the carcase is not hanging square in relation to the saw).

The analysis of the back region is completed when the x-ray reaches a pre-determined height above the neck.

3.1.3.5 Neck

The lower part of the carcase is defined as the neck. This is also the approximate region where the saw is rotated to change the cut angle in the carcase.



In this region the bone structure becomes very complex and the thickness of material that that the x-rays pass through increases dramatically.

It has been previously established that mechanical stabilisation of the carcase is sufficient to keep the saw in the centre of the neck bones. This stabilisation can either come from additional support arms or from the tri-pod support of leg rollers and the saw as it cuts.

In this region the last analysed centre of the backbone is held and the cut line is no longer adjusted.

3.1.4 X-ray Image intensity Monitoring

The intensity of the x-ray image is used to determine the high voltage potential (HVP) of the x-ray source. The higher the HVP, the higher the power of the x-ray beam, which means that either more tissue can be penetrated by the beam or for the same amount of tissue, the resulting image will appear "brighter". This analysis is performed for HVP adjustment in a final system.

A sample area within each x-ray image is analysed (*ROI Descriptor*, Figure 23) and the level of brightness of the image is assessed. The results are shown in graphical format by the *Intensity* gauge (Figure 23, Figure 24 and Figure 25).

If the HVP is too high the image contains blooming which cannot be recovered using image analysis and the information is lost. In Figure 23, the black needle in the *Intensity* gauge is off the scale indicating that the HVP should be turned down.

If the HVP is too low the image will be too dark and information can again be lost. In Figure 25, the black needle indicates an image is starting to get too dark and the HVP should be turned up. In this particular image the analysis still correctly determined the centre of the featherbone despite the bad presentation.

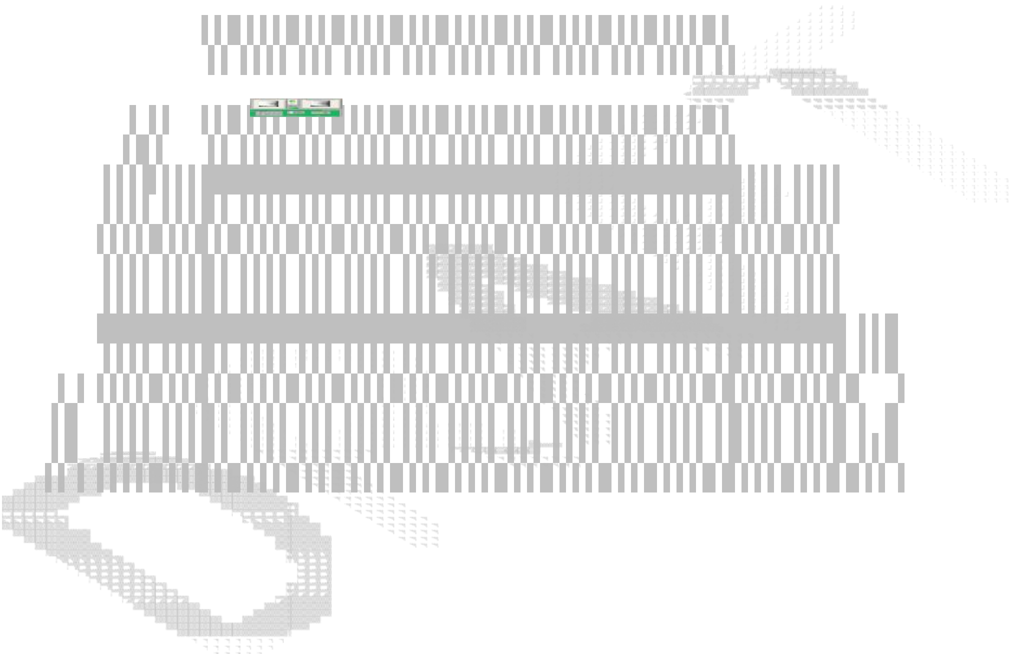


Figure 23: HVP is too high - increased difficulty in analysis

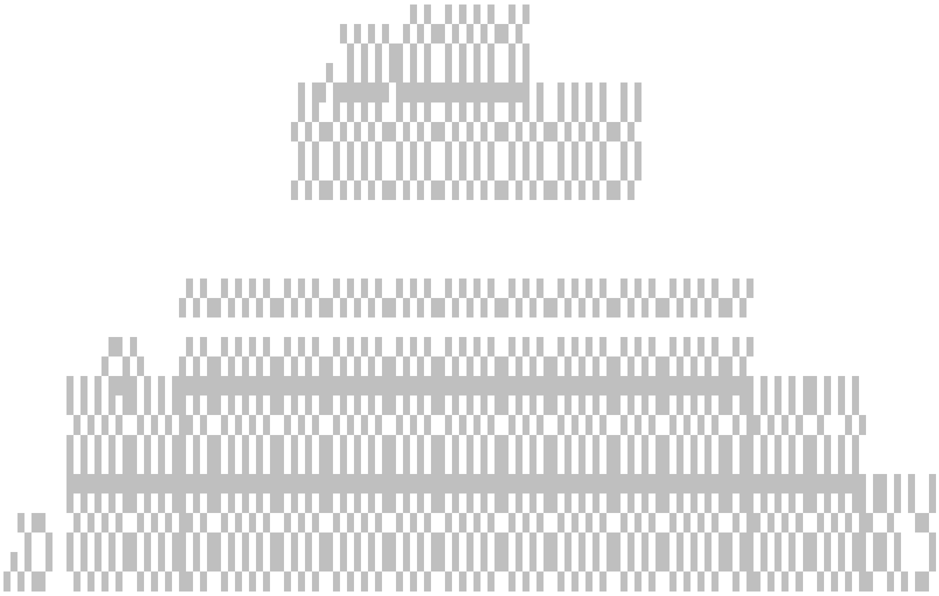


Figure 24: HVP and image intensity within range

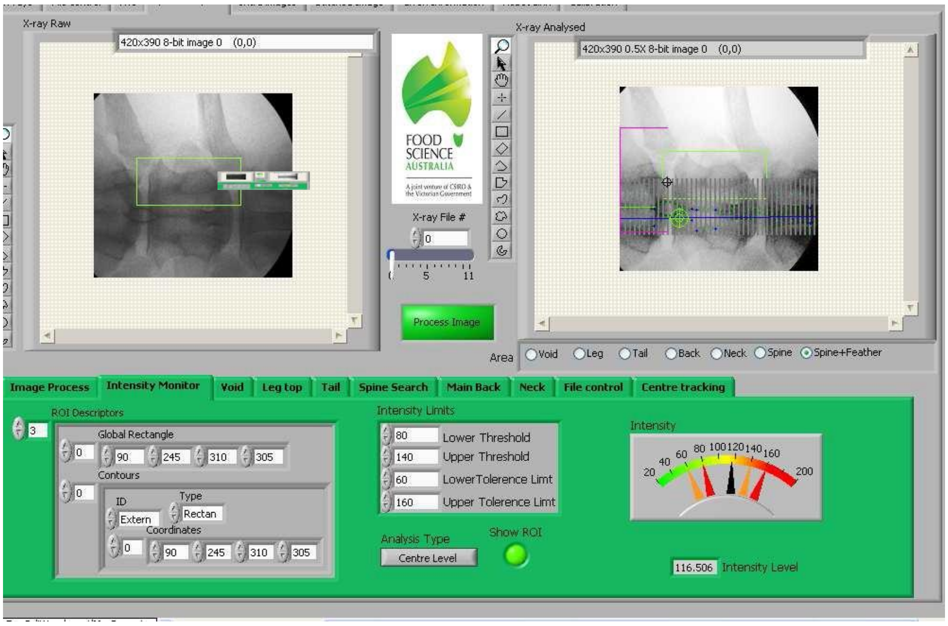


Figure 25: HVP too low - increased complexity of analysis

3.1.5 Final Saw Position (Weighting of Analysis)

As the x-ray is moved to a new position, a live x-ray image is used for analysis. During the live x-ray feed noise and intensity adjustments can vary the results of an individually analysed frame of the image feed. For this reason several x-ray images are analysed at each position and an averaging routine is used to establish the location of the spine over those images. This location is shown by the larger green crosshair in (Figure 26).

As more images are analysed, historical data based on the last 5, 10 or 20 results is used to establish a “historically based centre” to locate the cutting blade. This is shown by the smaller black crosshair in (Figure 26). This is used in a way such that the control system does not try to move the saw blade in too large a step across the spine, potentially causing damage to the cutting blade and also moving the carcase.

Large movements between x-ray locations are highly likely during the splitting operations due to carcass movements when a bone is completely cut and carcase stresses change. Large movements in cutting location may also be encountered when a separated (broken) spine has occurred in the hide removal process.

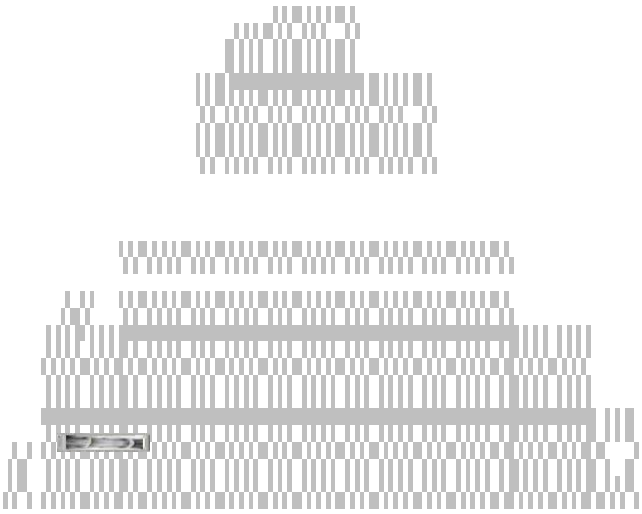


Figure 26: The difference between instant and historically based spine cut location

3.1.6 Result Reviewing

To evaluate how the analysis has performed during a carcase scan, a portion of each analysed image can be stitched to previous analysed images, ultimately producing a collation of scans of the full spine (Figure 27).

The carcase used to gather the data in this image was hung on two different length rollers and this produced a curve in the spine as it hung.

The resulting analysis shows each individual centre point (green/red) and the cut trend line (black).

Should there be any problem with any individual analysis, the green cross hair will change colour based the condition of the analysis. Hence the crosshair in the third segment is blue, indicating the centre location is “held” at the same location as previously analysed because there is not enough good image information to determine the feather bone centre at that location.

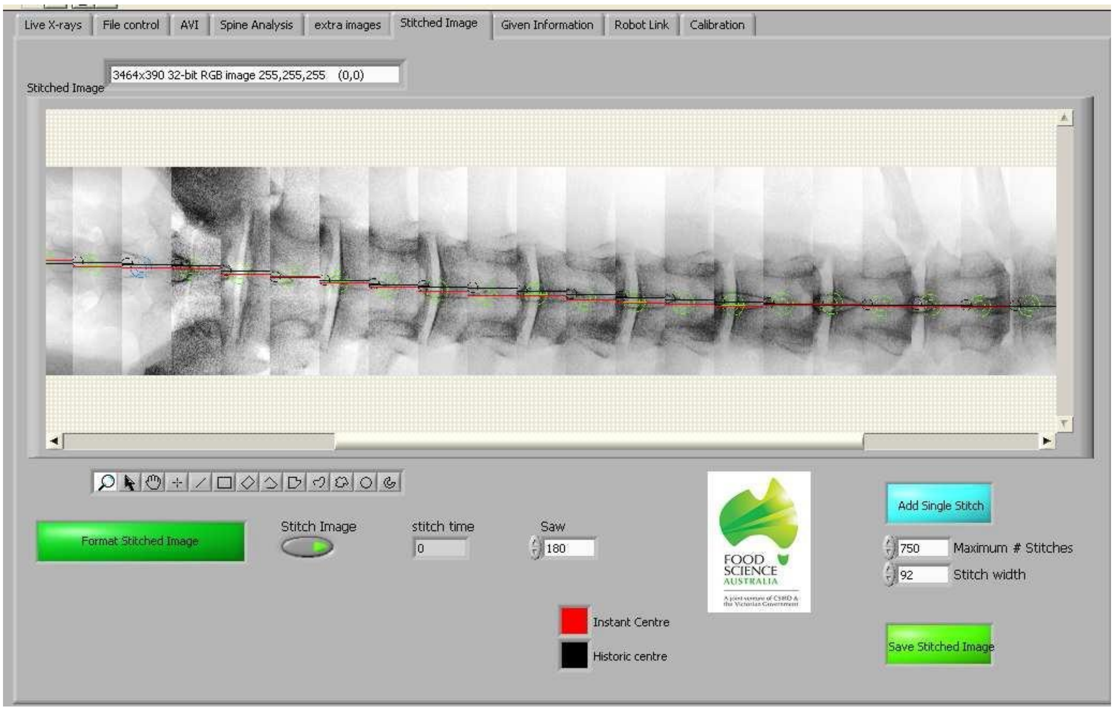


Figure 27: Partials of the analysed image can be stitched together to allow the overall cut to be analysed

6.3.

6.4.

6.5.3.2 TRACKING RIBS IN SIDES

3.2.1 Overview

Hardware used to track the location of a particular rib within a carcase side included the small area x-ray unit (C-arm) located at Food Science Australia at Cannon Hill (Figure 28). This system was used to prove the efficacy of small area x-ray for this application.

The C-arm unit has been mounted on a robot allowing for easily implemented automated movements in two dimensions. It was found during tests that slight variation in distance from the product to the x-ray image intensifier module (Figure 19) did not cause focusing problems, and hence the C-arm did not need to be moved in the third dimension.

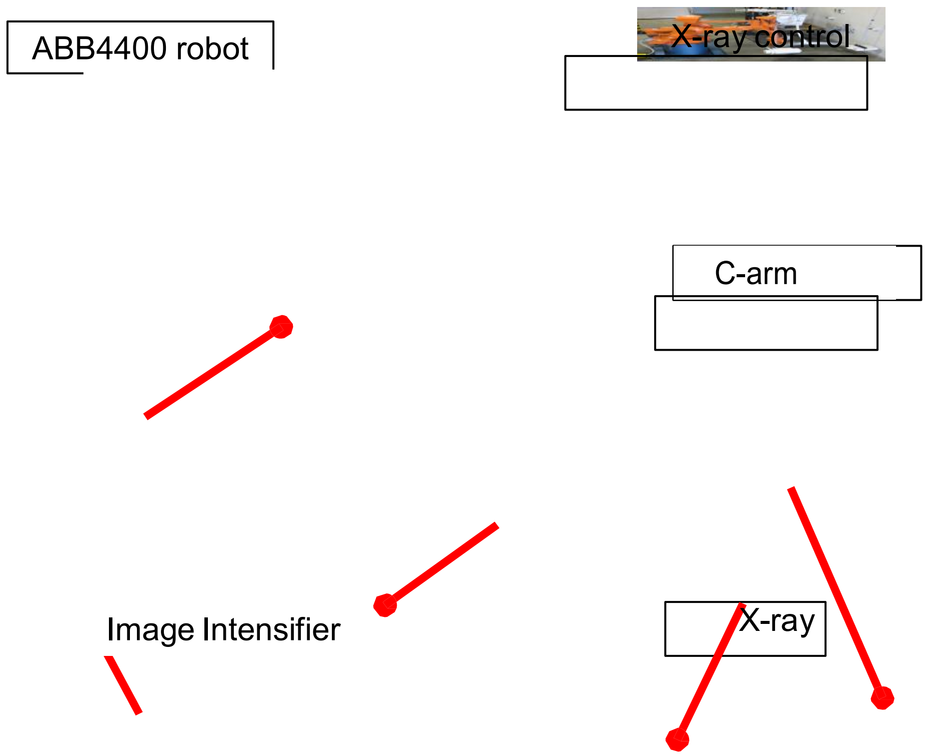


Figure 28: C-arm mounted on the ABB4400 robot

Using this method reduces the amount of equipment required for final implementation, helps control the radiation risks and reduces the amount of radiation required to obtain an x-ray image. However, during these tests, the weight of the C-arm (90kg) secured to the end of the robot limited the speed of movement of the system.

During tests a side of beef was located within the “C” of the x-ray unit. The C-arm was first located such that the vertebrae were located within the x-ray image, below the hip in the lumbar region. This is a gross placement to start the tracking process.

The system initially tracks the spine vertically (Figure 29) until ribs are recognised. Once ribs have been established, their locations are recorded and counted as the system continues to track the spine towards the neck. Once the desired number of ribs has been recorded, the nominated rib is tracked away from the spine until the limit of the C-arm is reached. In this manner, a pre-determined distance away from the spine on a desired rib can be located.

Figure 29: Tracking the vertebrae, looking for the correct rib

A coarse location is provided by the position of the robot arm. A fine location within the x-ray image provides an offset to that location to give the exact location (fine position) of the point along the rib. The distance the x-ray unit is away from the product is determined by a single point laser measurement referenced below the image intensifier unit.

The analysed position of the spine and ribs can be shown diagrammatically by overlaying those reference positions on the raw image; as seen in Figure 30.

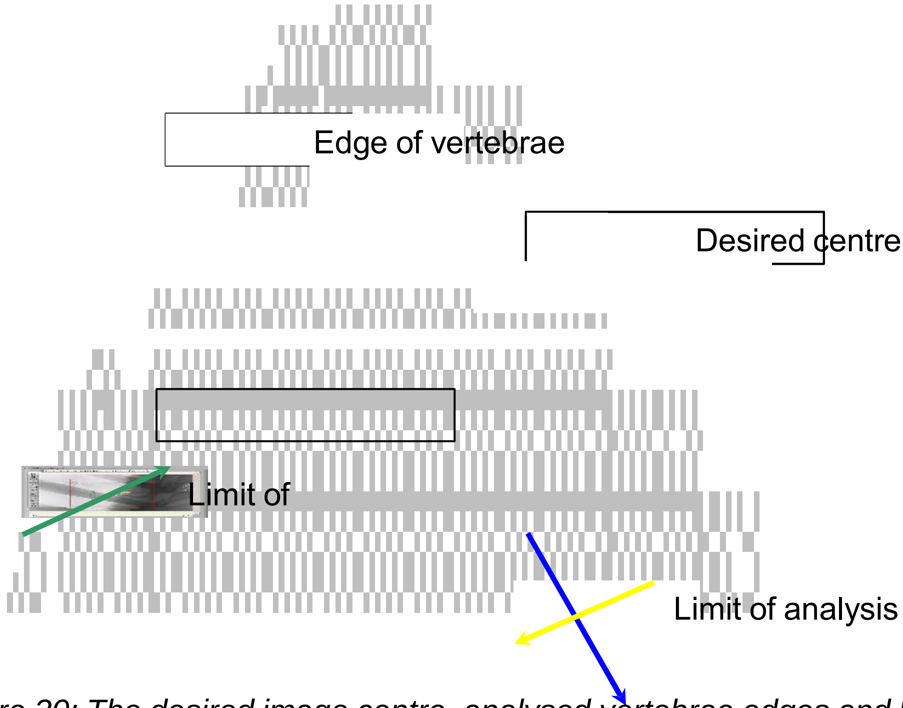


Figure 30: The desired image centre, analysed vertebrae edges and limits of rib can be overlayed on the raw image

3.2.2 Tracking the Spine

The spine is located in each image and it can be assumed that the spine will be the prominent feature that is mostly vertical in the image.

The analysis of the spine must pass criteria to confirm that the spine is being analysed. For example, should there be too much noise in the image, the analysis of the spine results in an angle that is not within the expected vertical range of a spine. If the vertebrae covers the whole of the image, or image was taken when tracking a rib away from the vertebrae, the verification can ignore or reject the spine analysis.

Once the edge of the vertebrae has been established, it can be marked on the raw image with a blue cross hair (Figure 31).

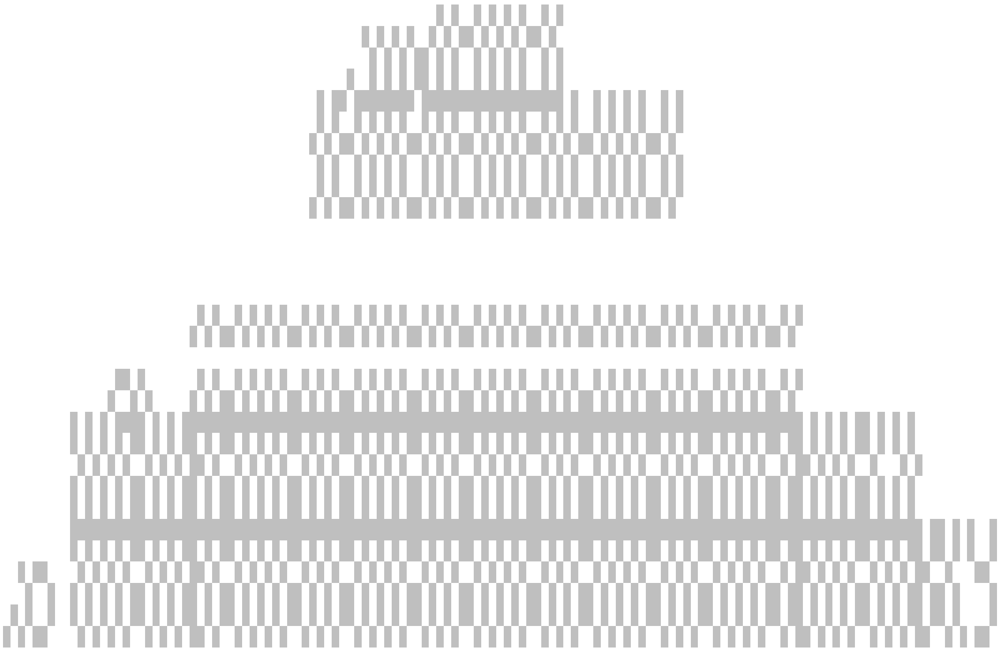


Figure 31: First analysis determines the location of the spine edge

The location of the next x-ray image is a set distance below the current location when the system is searching for the correct rib. The horizontal location is adjusted (Figure 38) by the distance required to keep the analysed spine location at the desired target centre (yellow crosshair in Figure 32).

Figure 32: Desired analysis centre

Once the desired rib has been located near the vertebrae, the location of the next x-ray position ignores the spine analysis and is altered by a set step away from the spine.

3.2.3Tracking the Rib

Each image is analysed to locate any possible ribs. The image is automatically adjusted based on the intensity and contrast to help remove noise in the image.

Because of the amount of noise encountered when separating the rib from the image, several scans of the rib are used and averaged to determine levels to automatically extract the ribs from the total x-ray image.

Each possible rib location (green oval in Figure 33) is analysed and accepted or rejected based on its location in the search area and the analysed vertical size of the rib.

Once a rib location has been confirmed its location is mapped for later referencing. To help avoid false positive detection of a rib, it should appear in several analysed images creating a large rib target in the rib map (Figure 34).

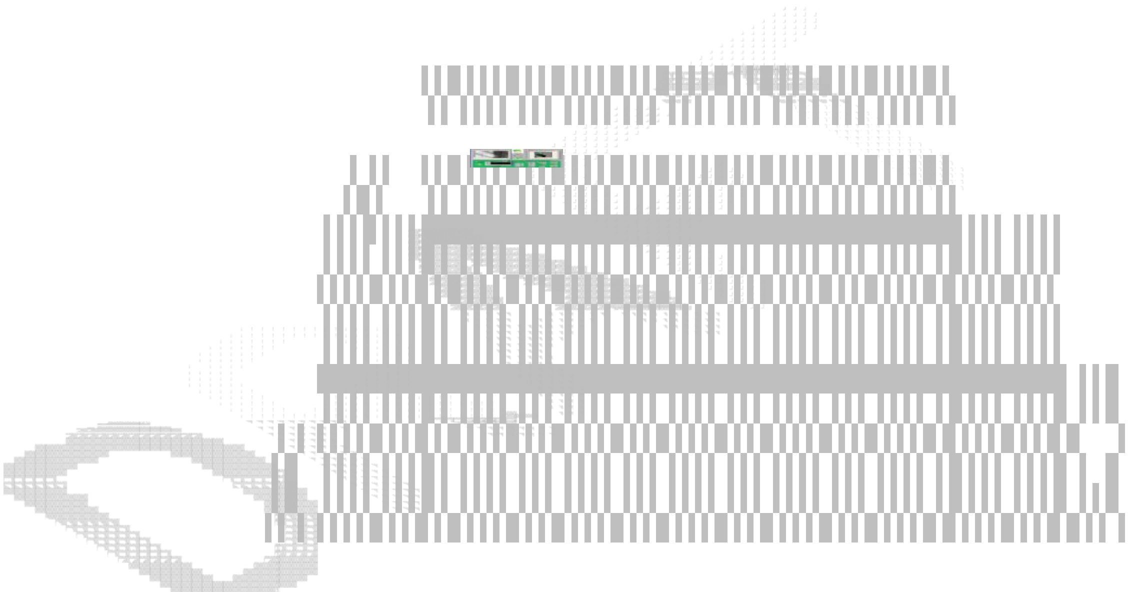


Figure 33: The limits of the ribs are analysed within the image

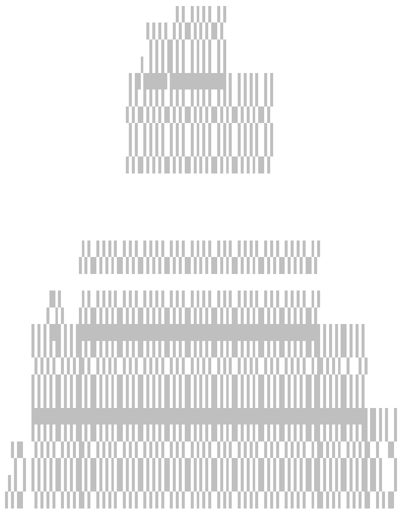


Figure 34: Located ribs are mapped and counted in real time

Only ribs that have been identified in several analyses are used to count the number of ribs from the starting point. The desired rib can be selected using the *Track Rib #* option (Fi[redacted]re 35). This is the rib number down from the top of the carcase as it hangs. The number of identified ribs is also tracked in the *# ribs* display.

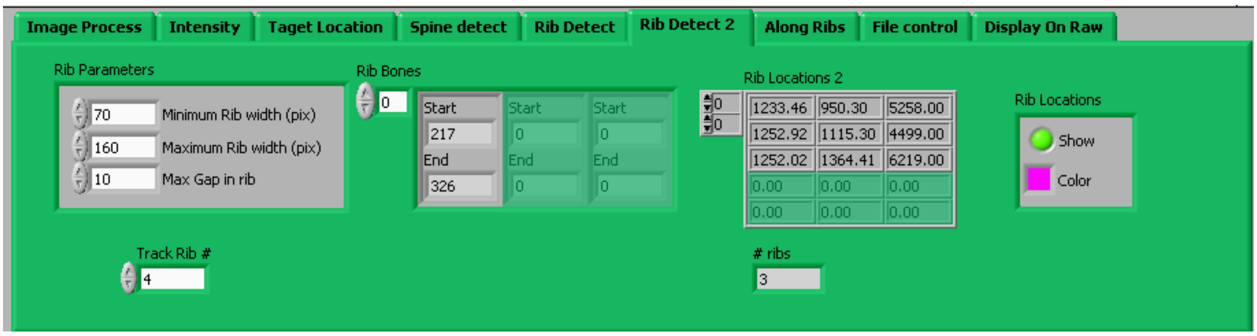


Figure 35: The desired rib can be selected by the "Track Rib" option

From the starting point below the hip, until the required rib is found, the rib analysis is only used to identify and count ribs. In this region the location of the next x-ray is not influenced by the rib analysis, it is moved down in discrete steps.

Once the desired rib has been found, the x-ray unit is moved in discrete steps away from the spine. Similar to the early positioning using the spine analysis, the location of the next x-ray vertically is influenced by the amount of distance required to keep the present rib centred on the desired target location (Figure 32).

The movement away from the spine is then limited by the maximum distance of 700mm from the inside of the C-arm to the outside of the image intensifier. This is shown in Figure 36.

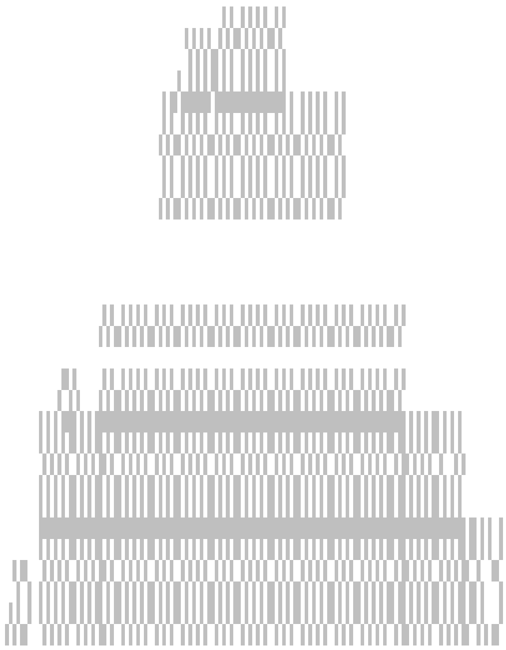


Figure 36: Physical limits of test system

3.2.4 Collating Results

Once each image has been analysed for both vertebrae and rib locations, the images can be stitched together to give a historical map of the raw x-rays. Overlayed on this image is the spine analysis results (blue cross) and the rib location (pink circle) as shown in Figure 37.

These images allow for a final visual assessment of how the bone structure was tracked within the side of beef.

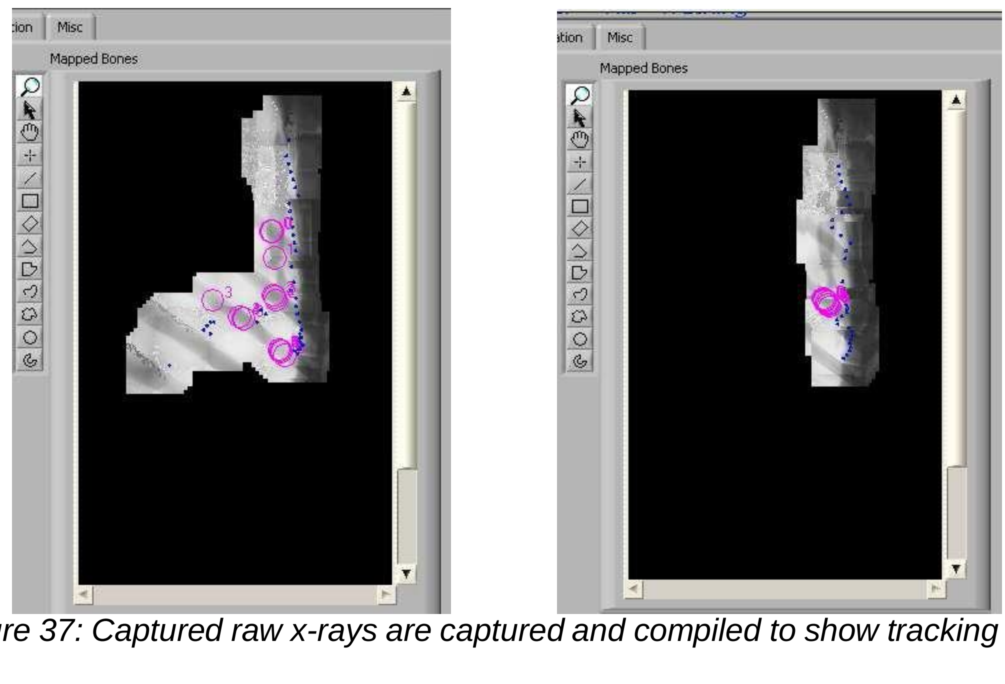


Figure 37: Captured raw x-rays are captured and compiled to show tracking of ribs

3.2.5 Location Control

As previously discussed in *3.2.2 Tracking the Spine* and *3.2.3Tracking the Rib* the location of the next x-ray is based on the results of the present image analysis.

This adjustment can be seen at the completion of each analysis by an arrow indicating the direction of travel and the number of millimetres adjustment that will be implemented as shown in Figure 38.

Accompanying the position adjustment flags is information on how bright the image is and how the HVP needs to be adjusted, as described previously in *3.2.2Tracking the Spine* for splitting.

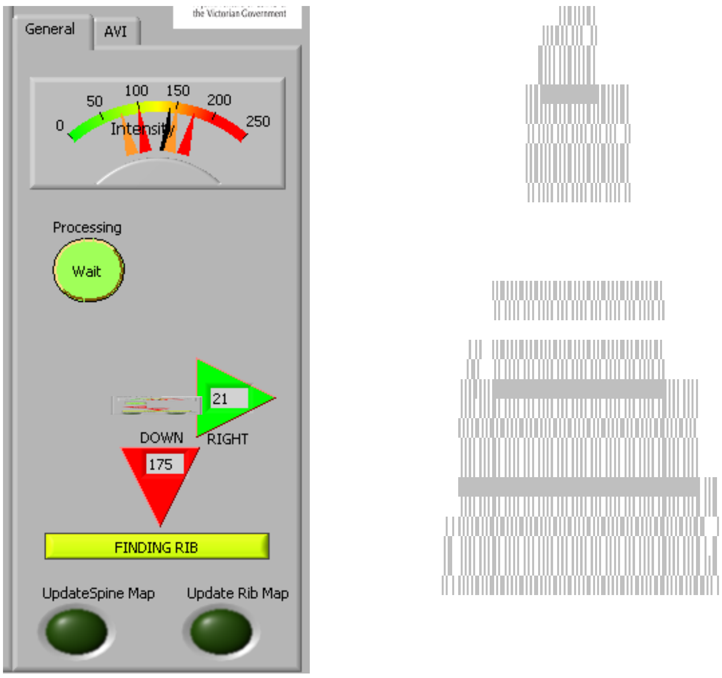


Figure 38: Image intensity and location for next x-ray is determined based on last image

The control of the robot to locate the C-arm for the next x-ray location can be seen in Figure 39. A serial string is transmitted to the robot containing the desired location in two dimensions. The robot replies allowing the actual position to be monitored and an x-ray initiated.

The positional information transmitted to the robot can be used to give the coarse location of the rib or spine in space.

The discrete movement steps described in *3.2.2 Tracking the Spine* and *3.2.3Tracking the Rib* are both set to be the same distance controlled by ***Track Step (mm)*** and the maximum movement allowed in any direction between x-rays is controlled by ***Move Limit (mm)***, both seen in Figure 39.

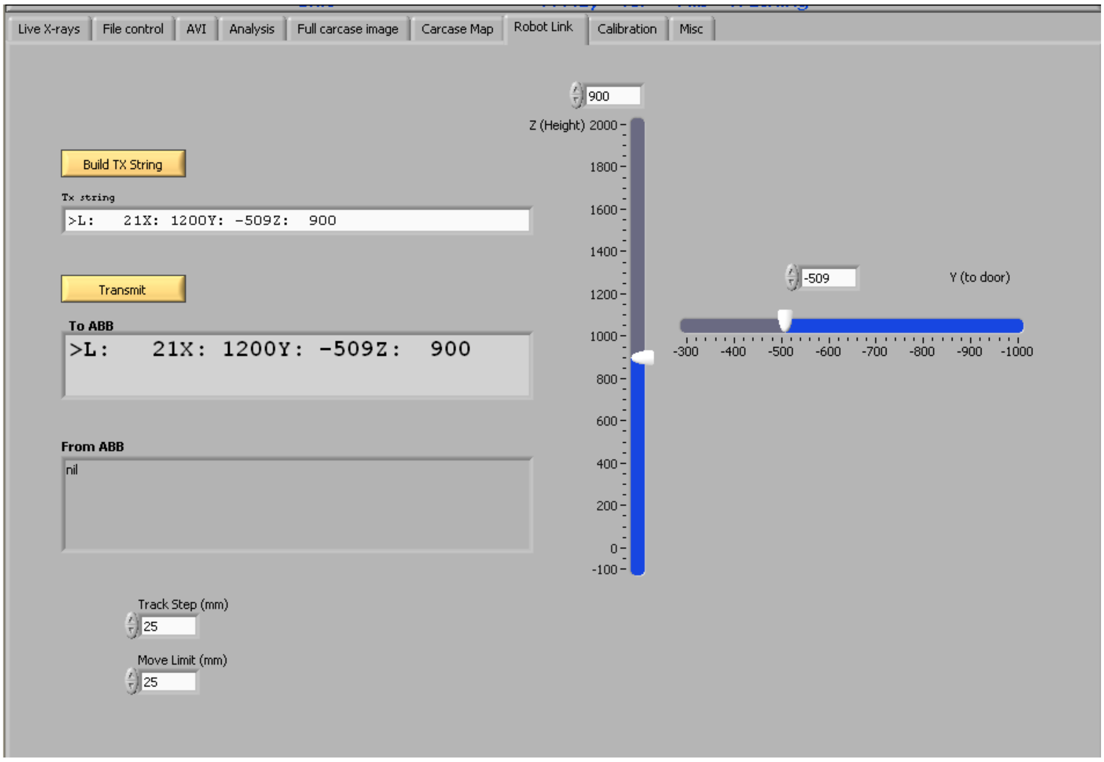


Figure 39: X-ray positioning is controlled in real-time

4.0 REGULATORY BODY RQUIREMENTS

4.1 RADIATION SAFETY REQUIREMENTS

The use of x-ray equipment in any Australian commercial environment is governed by particular regulatory bodies. In areas covered by federal government jurisdiction, registration with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is required. Two standards that need to be adhered to are the
"National Standard for Limiting Occupational Exposure to Ionizing Radiation [NOHSC: 1013 (1995)] and the "Code of Practice for Protection Against Ionizing Radiation Emitted from X-ray Analysis Equipment (1984) [RHS9]".

In other industries and agencies not directly under control by the Australian government, state "Radiation" legislation must be adhered to. In Queensland, the Division of Health and Medical Physics is the statutory authority. A quote from the "Guidelines for the Development of a Radiation Safety and Protection Plan for Diagnostic Radiography Practices", issued by the Queensland Government is as follows:

> The *Radiation Safety Act 1999* requires that a radiation safety and protection plan be developed for every radiation practice. This plan has been formulated for the purpose of ensuring that all diagnostic radiography practices are conducted as safely as possible and in compliance with the *Radiation Safety Act 1999* and the *Radiation Safety Regulation 1999*.

The x-ray unit planned for use in this project is a "controlled-beam" type. This mode has a lower overall output compared to the alternative "full-body" unit. Controlled-beam x-rays, similar to the unit applied at FSA, are in common use throughout Australia, for example in diagnostic clinics and surgeries. The x-ray beam will be directed to pass through the subject material (i.e. carcase) and on to a receiver, which will be coupled to the x-ray source by a rigid C-arm arrangement. This means that the x-ray radiation is always focused on the receiver, reducing the amount of extraneous radiation that can be emitted.

A fundamental guideline in the use of any x-ray system is the ALARA principle. This is the tenet that one should ensure that all exposure is kept "As Low As Reasonably Achievable". In practical terms, this means that appropriate shielding and protective equipment must be employed where monitoring indicates the need. This monitoring would be initially performed as part of a site assessment in the initial stages of installation, and also carried out on a regular basis according to the requirements of the relevant regulatory body.

The code of usage for x-ray equipment such as the proposed unit for this project specifies that the level of extraneous radiation being emitted in all directions is monitored. This is critically important in areas where there is any possibility of persons either being located or passing through. There are several different types of wall/shielding material that would be appropriate and recommendations would be made after a site assessment has been performed. Lead is a good absorber of radiation and a thickness of only a fraction of a millimetre is adequate; however steel of around 1 millimetre will also perform the same task. The thickness of the material will have a bearing on the efficacy of the shield. If through-vision is required at any locations, lead impregnated glass or polycarbonate can be used. Personal Protective Equipment (PPE) in the form of lead-lined aprons and gloves are available, but engineering controls, such as isolation, would be more appropriate.

The total body annual dose for radiation workers is limited to a maximum of 20 milliseverts (mSv) per year (<50 mSv in any one year with not more than 20 mSv/year averaged over 5 years), and the limit for the general public is 1 mSv per year. The radiation exposure levels of those in a specified radius from the unit would need to be continually monitored. ARPANSA would probably recommend a thermo luminescent dosimeter (TLD) be issued and worn by all exposed persons. These TLDs are sent away for measurement at regular stipulated intervals. The ARPANSA document: “Personal Radiation Monitoring Service and Assessment of Doses Received by Radiation Workers (2004) should be referred to.

For any industrial application, including the proposed FSA set-up at a meatworks, a site radiation officer would need to be appointed and suitably trained. This officer would then become known as what ARPANSA call “The Responsible Person” for the site. Among their responsibilities would be ensuring monitoring was performed correctly. The responsible person would also be in charge of keeping a precise record of usage of the x-ray machine.

4.2 AQIS REQUIREMENTS

AQIS have indicated two areas to be addressed in considering the use of x-ray equipment to control automated meat processing equipment. They are:

- Cleaning/sterilising
- Ionising radiation.

4.2.1 Cleaning/sterilising

Unlike the ultrasound sensor previously developed to control a beef splitting saw (PRTEC.007), an x-ray sensor is not required to be in direct contact with the carcase. However, to reduce the size and cost of the equipment, it needs to be in close proximity to edible product and this can result in incidental contact and therefore require sterilising. An alternative approach would be to consider a larger imaging plate and position it further away from the edible product. Depending on the application, the increased sensor cost may be offset by not requiring the complexity of full sterilising.

Trials during this project have shown that engineering plastics such as acetyl have little effect on x-ray imaging and could be used to produce a suitable environmental enclosure that would allow the x-ray sensor to be washed and sterilised. This approach was used for the ultrasound sensor referred to above and was successfully trialled.

4.2.2 Ionising radiation

Some countries that import meat do not allow meat products to be sterilised by irradiation. X-ray inspection systems are already in use and accepted due to the extremely low dose levels compared to x-ray sterilisation. According to an Australian manufacturer of x-ray inspection equipment, dose levels are $1x10^{-7}$ times the level used for sterilisation by irradiation. The x-ray source required for a sensing system suitable for an automated splitting saw and other processing tasks is likely to be of similar power to that required for inspection, and should be treated in a similar manner.

4.3 FUTURE DEVELOPMENT

The next stage of this project is to introduce this technology to the meat industry as a tool for identifying deep tissue features to control automatic devices.

A proposal has been submitted to AMPC and has approval and awaiting contractual arrangements.

The following is the approach and milestone requirements:

While X-ray technology has become increasingly common in industry, it still subjected to stringent regulatory control. As part of Milestone 1, the requirements of authorities such as the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), Work Safe Victoria and other regulatory bodies will be addressed.

Milestone 1: (CSIRO and X-ray equipment supplier)

1. Develop conceptual and preliminary designs for an X-ray sensing system based on the findings of the Stage 1 beef splitting saw X-ray sensing and control project.
2. The equipment and installation designs will be submitted to regulatory bodies (eg ARPANSA and Work Safe VIC) for preliminary approval.

GO / NO GO dependant on approvals being successful

Milestone 2: (CSIRO and X-ray equipment supplier)

1. Refine to detailed design of sensor
2. Purchase X-ray equipment and safety equipment
3. Development and manufacture of sensor arrangement
4. Undertake testing and further development at the CSIRO Cannon Hill facility.

Milestone 3: (CSIRO, Processing plant)

1. The x-ray sensor will be installed on the existing robotic processing plant splitting saw (saw removed).
2. Radiation shielding and OH&S requirements will be installed
3. Regulatory approval will be obtained
4. Trials carried out on sufficient carcasses to evaluate the suitability of the X-ray sensor to control an automated beef splitting saw

5.0 Project Schedule

Milestone 1 - Lab Studies – Beef & Sheep
Due: 21/12/2007 **Completed 17/12/2007**
Milestone update report submitted and accepted by D Doral (MLA).

Milestone 2 - Develop Sensing Equipment
Due: 31/1/2008 **Submitted 06/03/2008**
Completed and discussed in this milestone update report. D Doral (MLA) notified of potential delay in milestone completion date.

Milestone 3 - Image Feature Analysis
Due: 30/4/2008 **Completed.**
Milestone update report submitted.

Milestone 4 - Demonstrate X-ray sensing tasks
Due: 13/6/2008