final report

Project Code: PRTEC.007

Prepared by: Philip Boyce, Kym MacRae ,Jeff Owen & Peter Ring

Food Science Australia

Date published: July 2004

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

AUTOMATIC CARCASS SPLITTER: Trial and Optimisation of Commercial/ Works Prototype

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

EXECUTIVE SUMMARY

The aim of this project was to develop a robot based prototype automated carcass splitting saw system suitable for installation in a commercial works. This report documents the final stages of development including a demonstration of the system for stakeholders at Food Science Australia's (FSA) Cannon Hill facility before installation and commissioning at Ralph's Meat Company in Seymour, Victoria.

An Aloka SSD-500 medical/veterinary unit, with a 3.5MHz linear probe was purchased and an acetyl probe cover developed, manufactured and trialled. A protective robot cover has also been developed and manufactured to assist in maintaining equipment life in the commercial abattoir. The final control system uses a National Instrument PXI primary controller which communicates with the ABB S4C robot controller and an external Linux ultrasound image analysis processor via RS232 serial protocols. Serial communications was selected as the most reliable and proven control communication scheme. In addition to the serial communication the primary control system is also responsible for general system inputs and outputs, and maintaining the Category 3 control system safety rating required for installation of this system for industrial trialling. The safety system has been audited and passed by an external consultant. After investigation and trialling the decision was made not to include carcass stabilising in the industrial installation as benefits from use did not justify the level of complexity required to fit the additional equipment.

The complete robot splitting system was successfully demonstrated processing beef cattle at Cannon Hill to stakeholders and the results accepted and documented. Following acceptance by the stakeholders the decision was made to proceed with commercial installation and commissioning.

During installation and commissioning at Ralph's Meat Company it was found that the hide-pulling operation caused subcutaneous bubbling between carcass fat and muscle layers, resulting in severe degradation of ultrasound images. This was investigated for both upwards and downwards hide-pullers with similar unusable ultrasound images found. Manually knifed hide removal was conducted at Ralph's and results confirmed the system integrity with that demonstrated at Cannon Hill.

Future options for consideration for this project include:

1. Addressing the hide pull process to reduce or eliminate the air bubbles
2. Removal or management of the air bubbles prior to or during scanning
3. Refining the image processing software to enhance the images

4. Terminating the project at this point
5. Sourcing or developing an alternative sensing technology including Xray, acoustic differentiation and mechanical guidance systems

These alternatives are presented in detail for discussion with stakeholders in the recommendation section of this report.

Table of Contents

Table of Figures

1. INTRODUCTION

This report documents the development and demonstration of the robotic automatic carcase splitter at Food Science Australia's Cannon Hill facility followed by the installation, commissioning and trialling of this commercial prototype at Ralph's Meat Company in Seymour, Victoria.

As this is the final report for this project it details the completion of work related to research objective activities 2, 3 and 4 of the contract. This includes testing and optimising of the system at Food Science Australia, including mechanical elements and software tuning; demonstration of the prototype system to MLA and stakeholders; and installation at a commercial plant for production trials. As such the commercial prototype system must use food grade materials and be acceptable for operation and maintenance by plant staff.

The research objective activities that were addressed in completion of this final milestone included:

- Development of the ultrasound probe protective cover.
- Integration of the ultrasound sensing analysis software, robot motion and primary control programs including error checking and manual operation.
- Carry out splitting trials on limited number of carcases.
- Trial of carcase stabilising device.
- Demonstration to MLA representatives and project partners.
- Steriliser.
- Safety issues.
- Transport and installation of commercial/ works prototype into participating processor site.
- Commission.
- Trial.
- Analysis of results and system performance.
- Report on final design, performance, and operation.
- Recommendations on future directions.

2. PROTOTYPE DESIGN/ DEVELOPMENT

The completion of the development for the Automatic Carcass Splitter prototype is documented below. This section details the system elements including improving the durability of the ultrasound probe and the robot in the abattoir environment; issues related to the control integration of the prototype both at Cannon Hill and during installation and commissioning at Ralph's Meat Company; and explanation of the safety and operational interface requirements to use this equipment in a commercial location.

2.1 ULTRASOUND DEVELOPMENT

A Shimadzu 35L medical ultrasound unit was used for the development of the imaging system for this project. As part of the system integration milestone, it was decided that this unit would be replaced for works trials as the 3.5MHz probes used with this unit are no longer readily available and this would lead to an unacceptable delay if the probe were to malfunction or be damaged. An Aloka SSD-500 medical/veterinary unit, with a 3.5MHz linear probe was selected. As contact with the ultrasound probe causes variation in carcase movement it is not possible to use exactly the same input data for both ultrasound units for scaled position comparison benchmarking analysis, however simulated trials and carcase trials from both systems on the robotic prototype showed comparable results.

Off the shelf ultrasound units of the type selected are supplied with a 2m long tuned cable. A cable of this length requires the fragile ultrasound unit to be mounted out on the robot arm where it is subject to vibration and violent motion. All attempts to find a manufacturer who would supply a longer cable were unsuccessful. Attempts to lengthen the cable on the original Shimadzu probe showed some promise, but significant signal degradation occurred and it was decided that the standard cable would be used. It was also decided that, rather than trying to lengthen the cable, future commercialising work would include remanufacturing the essential components of the ultrasound unit into a smaller, more robust industrial enclosure that would be mounted on the robot arm.

Figure 2-1 Ultrasound Mount

2.2 ULTRASOUND PROBE COVER

As detailed in Milestone 1, the ultrasound probes are quite fragile and are not designed to last in an abattoir environment with exposure to 848C hot water. While it would be possible to have a more robust custom probe developed and manufactured, it was decided that, at least for trialling and initial commercialising, a standard probe would be enclosed in a specifically designed housing.

Experimentation has shown that Acetyl, a hard engineering plastic, has excellent acoustic properties for this application. Accordingly, the final probe housing consisted of an aluminium “clamshell” around most of the probe, with an acetyl cover over the active face. This arrangement allowed the probe to be fully sealed against water and cleaning products, with all loads being carried by the housing and not by the probe. During assembly, all space around the probe in the aluminium section of the housing was filled with silicon sealant. This provided water proofing, thermal insulation and reduced shock and vibration to the probe. Standard medical ultrasound gel was used to fill the acetyl cover and provide an acoustic coupling between the probe and cover. There is a reservoir feature within the cover to allow for any flexing that may occur. The gel was chosen as it is made for the medical ultrasound applications, is water soluble and presents no health or contamination risk if leakage occurs.

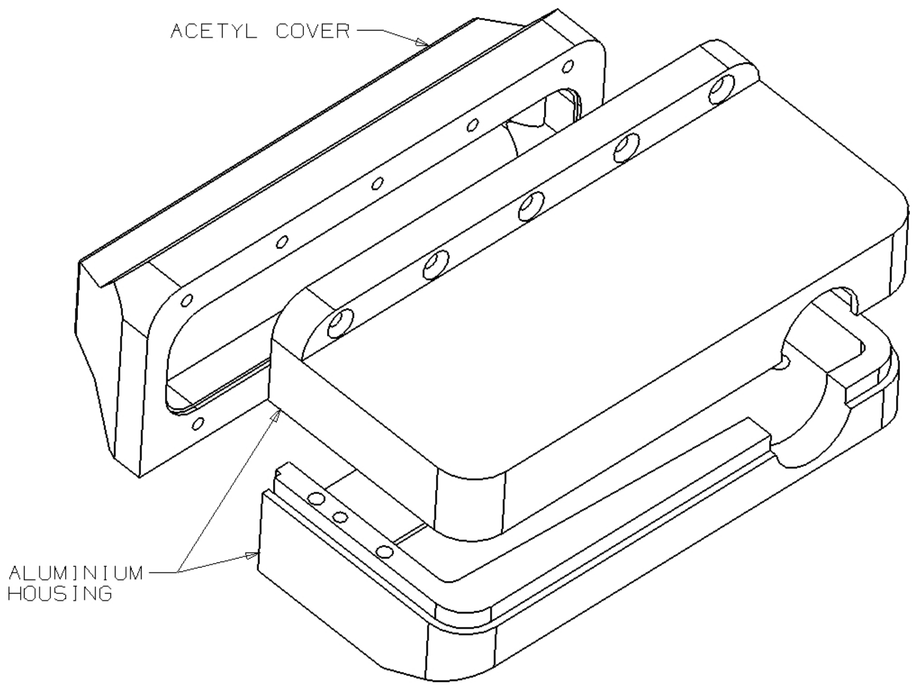

Figure 2-2 Probe Cover

Manufacture of the housing components was by CNC machining and allowed for low volume production for trialling and initial commercialisation without the high cost of injection moulding tooling. CNC machining also allows a commercialising company to readily adapt the housing design to suit different probes if required.

Placing any sort of cover in front of the probe attenuates the ultrasound signal. The high strength of the acetyl, and the design shape allowed the thickness of the front face cover to be kept to only 2 mm thick. As a result, losses are minimal and there was no discernable visual difference between images with and without the cover.

Ultrasound works by detecting an interface between different materials. Accordingly, the gel to cover interface produces a reflection that appears as a line parallel to the probe face. As well as this primary reflection, the ultrasound reflects back and forth a number of times resulting a series of parallel lines of diminishing intensity. As the distance between the probe and cover is minimal, these lines appear near the surface of the image and are eliminated by the software and have no detrimental effect on the result.

Throughout this project, ultrasound has sometimes produced unreliable images for a short distance in the region of the Coccygeal and Sacral vertebrae of lean cattle due to the probe only making contact with the protruding vertebrae. With the probe cover fitted, contact with the carcase in this region produced a “contact patch” in the parallel reflection lines. The imaging software was enhanced to recognise this contact and improve the cutting accuracy in this area.

Due to the high thermal conductivity of the aluminium housing, it is important that any sterilising cycle for the saw includes a cold wash that effectively removes the heat before it reaches the probe.

A total of over 150 scans on cattle have been performed with the enclosed probe with no obvious damage to the contact face or probe.

2.3 STABILISING SUBSYSTEM

As part of the integration milestone of this project, the “neck stretcher carcase stabiliser” was trialled at Cannon Hill. This unit rotated a set of jaws under the carcase and rose vertically until the neck was detected. The jaws then gripped the neck and pulled down. This steadied the carcase and allowed the ultrasound probe to be pushed firmly against the carcase for a more reliable coupling contact.

The height of the neck as detected by the stabiliser was utilised by the control program to determine the end of the cut.

By observation, it was determined that the stabiliser steadied the carcase as intended. However, when the carcase was released near the end of cut, it “bounced” on the pneumatic cylinder that held the probe against the carcase. It was believed that some refinement to the control program would address this instability.

In preliminary trials carried out at Cannon Hill, a leg spread of 800mm was used. To suit Ralph’s Meats, this was increased to 1200mm resulting in a significant increase in carcase stability.

For a stabiliser to not interfere with the splitting saw, it needed to be on the opposite side of the carcase. It must also be sterilised between carcases, and be clear of the “drip line”. A vertical range of over 1500mm is required. To meet these design requirements, the stabiliser had to be designed specifically for the location at Ralph’s Meats. After the stabiliser was manufactured, the layout at Ralph’s Meats was changed and the existing stabiliser needed a major redesign to fit in the new location.

Further trials were carried out at Cannon Hill without the stabiliser and it was decided that the improvement in stability did not justify the cost and space requirements. It was also decided that cost and space issues would impede commercialisation. The “neck stretcher” stabiliser is discussed further as part of the control section 2.7.1.1.7 Integration of the Neck Stretcher and Leg Spreader.

Figure 2-3 Neck Stabiliser Design

Figure 2-4 Pictorial View

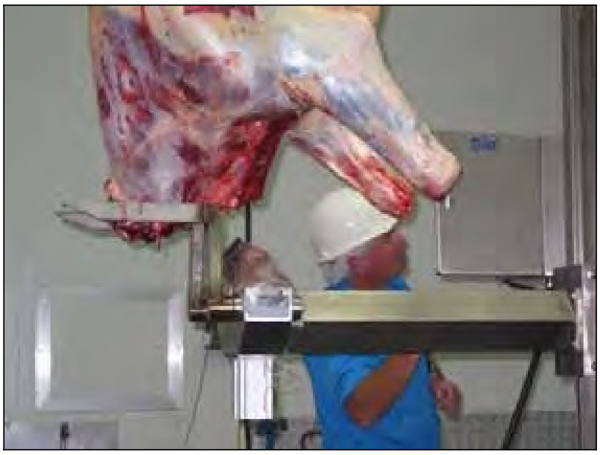

Figure 2-5 Side View

Figure 2-6 Trial

2.4 STERILISING SUBSYSTEM DESIGN

FSA engineers have prepared a specification and preliminary concept drawings for the saw steriliser. As the final design was dependant on the participating works installation Ralph's Meats, and their consulting engineering firm L. M. W. Engineering, have undertaken the final design and installation.

2.5 ROBOT PROTECTIVE COVER

Industrial robots used in an abattoir environment have to be protected from hosing and cleaning chemicals by waterproof bags. In many industrial applications, robots are protected by fabric covers, however in these applications the bags are manufactured in a number of sections that overlap to allow full movement. These types of covers are not suitable for the splitting saw application due to the high pressure hosing required during the cleaning of the slaughter floor.

For this application, it was necessary for the bag to also protect the ultrasound unit, motor and sensors of the extra movement axis. The bag also had to be quick and easy to be removed for maintenance and cleaning.

The bag was manufactured from a fibre reinforced vinyl fabric, with a full length zipper in the underside. To allow full movement without making contact with the carcase, a plastic template was first manufactured and adjusted for optimal fit. This template was then used to produce the final bag (see Figure 2-7).

Attachment of the bag at the saw end was by a stainless steel sheet metal shroud over the extra axis motor and sensors. The shroud has a circular collar that allows the bag to be secured with a clamp. Routine maintenance can be carried out by simply opening a short length of the zipper in the bag. More extensive maintenance requires the shroud to be removed from the end-effector.

The base of the robot was protected by a sheet metal cover with a baffled slew ring arrangement to attach the bag with a clamp.

A multi speed fan was used to inflate the bag to provide a positive air pressure to prevent water entering at the attachments and along the zipper. Inflation also prevented the bag snagging on the robot as it moved, and prevented condensation forming inside the bag.

During cleaning, the bag was inflated to allow it to be scrubbed while still on the robot.

A spray-on silicon was applied to the inside of the bag and allowed it to slide over the robot. This assists installation and removal of the bag as well as well as reducing wear while in use.

Figure 2-7 Cover Template

2.6 SAFETY SYSTEM

Consistent with the requirements of the Victorian State OHS (Plant) Regulations 1995, Food Science Australia staff has carried out a risk assessment hazard analysis for the installation and commissioning of the Robotic Split saw system at Ralph's Meat Company in Seymour.

The system installed at Ralph's was determined to require a category 3 control system (Standard EN954-1 Safety of Machinery- Safety Related Parts of Control Systems – Part 1: General Principles for Design). This means that no single fault in the system can lead to a loss of safety function. This category was determined as:

- **S2** : The result of an accident involving a bandsaw mounted on a robot could be serious, irreversible, and cause injury or death to a person.
- **F1** : The frequency or duration in the "danger zone" of a person would be seldom to quite often and /or exposure time is short. People who should be legitimately accessing the cell are cleaners, maintenance or project staff that should only be there for short time periods while using the proper procedures.
- **P2** : The possibility of avoiding the hazard in the event of a failure was considered to be virtually impossible.

A system resulting in a **S2/F1/P2** rating requires a **category 3** rated control system and associated safety cell.

The cell has also been designed to comply where practicable with the Australian Standards. In particular sections:

- AS 4024.1-1996 Safeguarding of machinery – General principles
- AS 4024.2-1998 Safeguarding of machinery – Installation and commissioning requirements for electro-sensitive systems: Optoelectronic devices
- AS 2939-1987 Industrial Robot Systems – Safe Design and Usage

Equipment used in the cell (including the robot, bandsaw, safety sensors and safety cell peripherals) also has manufacturer documented compliance with relevant design and safety standards. The robot adds an additional level of control via the use of a resident safety processor dedicated to the robot safety chain to ensure that robot operation is “safe” and emergency control is activated immediately at all times.

Points of interest about the safety cell included:

- The robot was enclosed in a fixed panel perimeter guard with two openings for the entry and exit so the carcases could be transferred in overhead along the meat rail. The openings were controlled by Sick MSL 3 beam light guards fitted in an angled horizontal position to prevent unauthorized access to the robot cell but enable the carcases to pass over the top of the light guards. The MSL 3 beam light guards are protected from the harsh environment of the slaughter floor in situ inside clear acrylic tubes, and a further guard was mounted slightly above each MSL unit to protect against physical damage.
- To maximise the safety of any operators using this equipment it was decided to have 2 operator panels. The main panel contained the manual positioning functioning keys as well as the “Emergency Stop” and “Start” buttons; these were also located on the secondary panel. To start automatic operation of the system both operators must activate the “Start Auto” buttons with the robot in the correct position after conducting a visual inspection that the robot cell is vacant. Residual risk of a person being left inside the safeguarded space during restart was minimised by a pre-start warning consisting of flashing light and ensuring that 1 operator cannot operate both panels as they are located at the entry and exit sides of the cell and there is a time for activation constraint built into the system. The main panel also had a keyed isolation switch restricting operation to authorised trained personnel.

Figure 2-8 Safety Cell at Ralph's Meat Company (Note: Main control panel)

- A major issue of installing a robot on a commercial slaughter floor was space. Ralph's installation did not meet all the recommendations outlined in the standards as the distance between the restricted space and the fixed guard was less than 450mm. However, the risk of crushing between the robot and the guard was minimised by prevention of entry to the cell and by the anti-collision system supplied as part of the robot control software. Whilst the anti-collision system is a software system and is not safety rated, it minimises the risk of the robot crashing against any fixed object. Hard stops were fitted to the base of the robot to also restrict the robot movement, preventing potential collision with guarding.
- Integration of the saw motor must also comply with category 3. Two in-line force-driven safety contactors isolate the saw motor, one fitted with an overload unit to protect the motor. The relays' control signal was supplied by the primary control unit. The contactors were then monitored by a SICK UE43 safety relay with overall category 3 protection provided by the relay.

During installation and commissioning a full safety audit of the system was conducted by an external safety consultant. RiskPlant Consultants were engaged to carry out an independent review of the safety systems to ensure compliance with AS 4024 and AS 2939. They confirmed that an appropriate category 3 control system has been implemented for compliance with AS 4024.1-1996 Safeguarding of Machinery. A report certifying compliance of the system with all safety requirements has been received from RiskPlant Consultants and is available for all relevant parties.

Legislation for this equipment required a risk assessment hazard analysis to also be conducted by Ralph's staff and any identified risk managed before the system could be operated. To assist in this a partial system function demonstration was conducted for plant OH&S staff.

Figure 2-9 Light curtains

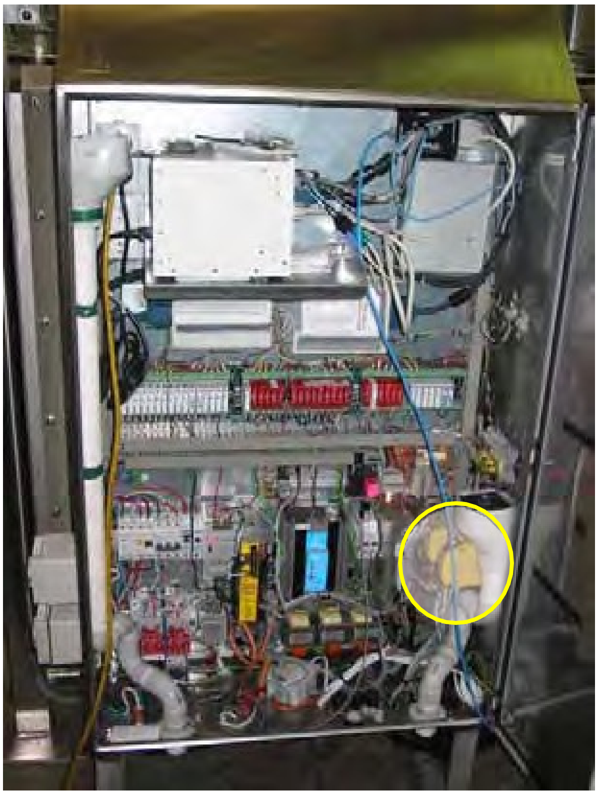

Figure 2-10 Inside slaughter floor control cabinet showing location of safety relays

2.7 CONTROL SYSTEM

2.7.1 LABORATORY PROTOTYPE AT FSA CANNON HILL FACILITY

2.7.1.1 Integration Challenges for the Control System

The robotic carcase splitter no longer uses ABB's Webware product to communicate between an external, remote, primary controller and the robot controller (S4C).

In theory, high speed communication between a National Instruments (NI) PXI controller (the primary controller for this application) and the robot controller should be possible. Unfortunately, communication between the S4C and the PXI was affected by unpredictable data stream halts which meant the system configuration discussed in Milestone 2 is not valid. The communication problems had the added effect of creating significant pauses ranging from 200 milliseconds to 13 seconds on the PXI controller, which in turn caused loss of control of the traverse motor, PXI image processing and the robotic cutting path. Investigation, both internally and by suppliers who have access to a deeper level of the robot software, has revealed no conclusive explanation for this fault.

The encountered pauses were not identified to be directly related to the S4C-PXI link at the time of testing the control system using Webware for communications and the PXI to do the image processing. The image analysis performed by the PXI used newly developed software (alternative algorithms), unproven in this application and as such would require testing to develop to the "accuracy" level of the Linux imaging software and was identified as a possible cause of the pauses, leading to a low level of team confidence in using this imaging system. For that reason it was decided to revert back to the proven image analysis system developed under the Linux environment by CSIRO's CMIS department.

Milestone 2 outlined that NI has available prototype, beta-tested versions of their Labview product on a Linux platform (which would enable the proven vision analysis software to be integrated with minimal changes) however this alternative was not pursued as there was limited documentation and support existing in an accessible form for project staff of this pre-release commercial product.

The final system used involved the main PXI primary controller communicating to both the S4C robot controller and the Linux imaging computer using RS232 serial protocols. The primary control system – controlling communications and general inputs and outputs – utilised a PXI computer with a Windows based operating system. The vision analysis was performed on a secondary Linux based computer with serial communications to the primary controller. Communications to the S4C robot controller was done with serial communications as this was chosen as the most reliable and proven solution. See Figure 2-11 for a system overview.

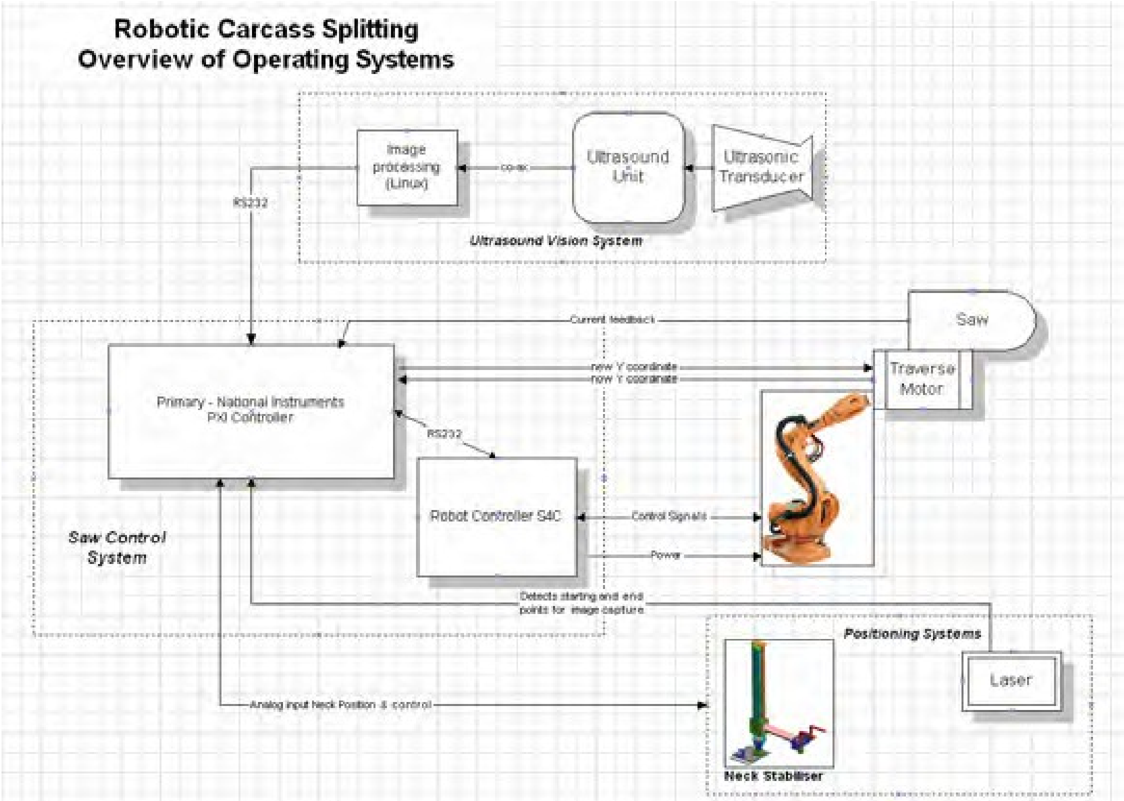

Figure 2-11 System Overview

2.7.1.1.1 Robot Communication

A balance was found on the amount of information that could be passed between the S4C and the PXI allowing pseudo real-time control of the splitting system during the cut. By reducing the amount of data that had to be transmitted at any time, maximum utilisation of the reduced bandwidth (relative to what was available when using Webware) could be achieved. Communication was at 9600 baud. This bandwidth allowed a pseudo real-time robot data update every 100 milliseconds. The data transmitted between the PXI controller and the S4C is summarised in the following table, Table 1 Transmitted Data.

Table 1 Transmitted Data

Data sent by the PXI controller	Data replied by the S4C controller
During the cutting routines	
New vertical location New horizontal location New end effecter angle Vertical cutting speed Horizontal movement speed Cut routine control Communications checking data	Current robot program routine name Present robot vertical location Present robot horizontal position Communications checking data
During manual driving routines	
Error code Reaction code Communications checking data	Current robot program routine name Communications checking data
At all other times	
Routine control data Communications checking data	Current robot program routine name Communications checking data

2.7.1.1.2 Imaging Computer Communication

Control of the imaging computer was done using serial string to a Pearl command line interface on the Linux computer. The information sent to the Linux computer was in the form of text strings to start or stop the image analysis, or to request information about the present desired cut position. The imaging program would be started at the beginning of each cut, and halted by the PXI control computer at the end of the cut. The information passed from the imaging computer as a reply to the PXI controller poll was the offset of the centre of the desired cut as determined by the process ultrasound image. Communications was performed at 19200 baud rate to increase the bandwidth of the data link.

2.7.1.1.3 Cutting Path Control performed by the PXI Controller

During the cut routine which starts at the tailbone position and ends as the saw cuts through the neck the position of the saw was controlled by the PXI controller.

The speed of the saw was controlled by allowing small movements of the robot (from 1 to 5mm steps) to drive to a new destination.

The vertical speed of the saw was limited by the current draw on the saw motor. A current draw increase indicated more material to cut, so the vertical speed was reduced. This reduces the stress on the blade due to material not being cleared by the carcase “opening up” or forcing the blade sideways into the cut. By reducing the saw vertical movement as the current increases, the load on the blade decreases, enhancing the life of the saw blade. The maximum vertical cutting speed was restricted to 150mm/sec from results of earlier prototype work examining saw blade dynamics in bone, but test cuts were normally performed at speeds ranging from 60 mm/sec to 120mm/sec.

The traverse (sideways) movement of the saw was determined by the centre of the backbone as analysed from the ultrasound image. The amount of difference between the actual and desired of the traverse position determined the angle that the saw blade was set at to “attack” the carcase. The greater the difference in the two positions, the greater the angle of attack. Previous trialling of the splitting saw system determined that appropriate angles of attack are 0.0°, ±1.5° and ±3.0°, to allow the blade to cut into - and not be guided down the side of - the featherbones. This angle movement was communicated to and actioned by the robot.

The speed of the traverse movement was limited by the downward speed of the saw and the required angle of attack. Sideways movement speed was usually under 2mm / second during testing.

The in / out contouring motion of the saw in relation to the carcass was determined by a linear sensor attached to the parallelogram on the ultrasound mount. The total movement of the parallelogram was approximately 70mm. During the cutting path, the ideal location of the parallelogram was at 35mm; this allowed the pressure applied by an air cylinder (also attached to the parallelogram) to apply the desired pressure of the ultrasound probe onto the carcase surface.

The speed of in / out moment for the saw is controlled by how far the parallelogram is sitting from centre – the further the parallelogram is from the centre, the faster the robot forward movement becomes.

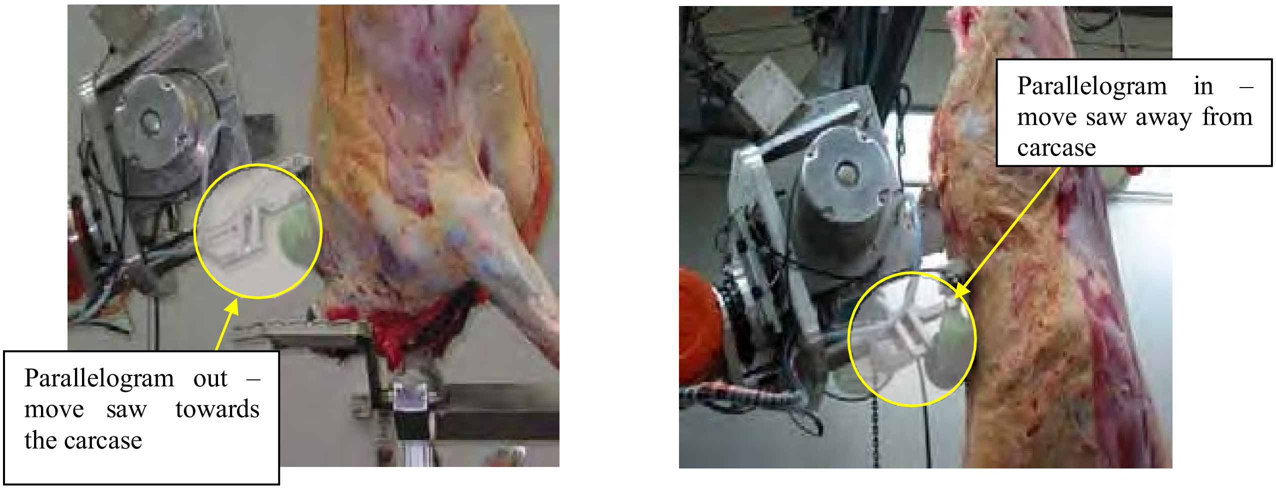

Figure 2-12: The parallelogram on the frame holding the ultrasound head determined how the saw moved towards or away from the carcase

2.7.1.1.4 Traverse Movement and Cut Angle Control

The traverse motor controlled the sideways movement of the saw with the total traverse movement restricted to +/- 35mm from the centre line of the ultrasound and centre of the leg-spread. The position of the saw along the traverse axis is determined by the PXI controller using feedback from the ultrasound image analysis.

At the end of each split the traverse position was recalibrated by performing a travel to one of the limits of the travel, then returning to the centre of travel. This removes any inaccuracies of the position of the traverse systems that may have occurred due to creep.

Figure 2-13: The traverse motor controlled the movement of the saw from side-to-side and was part of the robot end-effector

2.7.1.1.5 Robot Movement Control

Figure 2-14 illustrates the outline of the cycle paths for the robot splitting system. The movement path for sterilising is not shown for simplicity. Gross saw movements are done by the industrial ABB IRB6600 robot. This means that any movements of the saw not during cutting are to pre-determined locations controlled by the program in the S4C robot controller corresponding with the PXI primary controller. The robot is capable of movement speeds up to 5 metres per second. During the cutting routine the robot was controlled vertically and horizontally (in and out) by locations transmitted by the PXI controller.

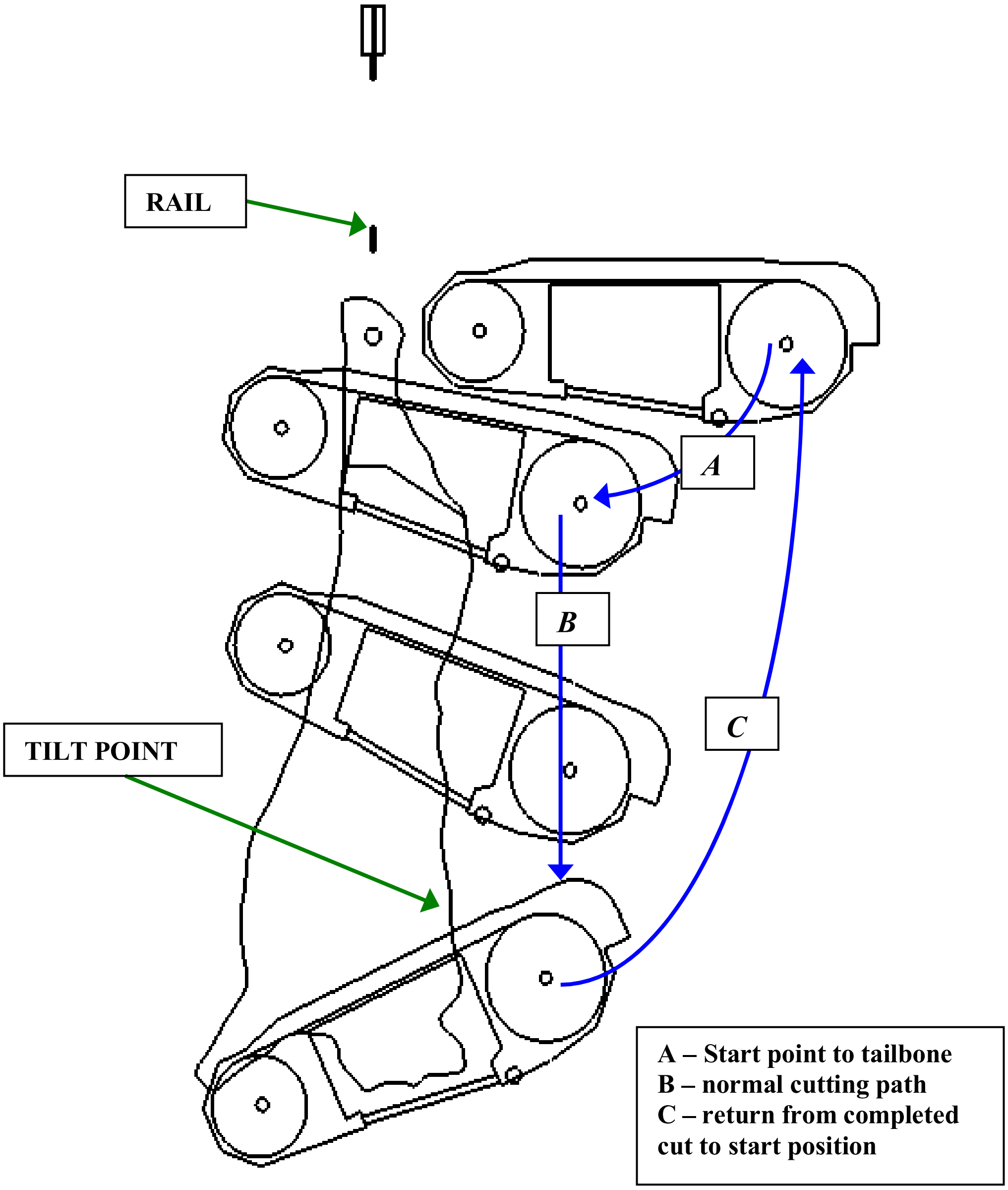

Figure 2-14: Schematic showing the outline of the saw path as delivered by the robot. Each of the major cycle paths are indicated.

The following table indicates how the robot was controlled.

Splitting saw path	***Controlled by***	***Notes***
A – from start point to tailbone	Main PXI controller delivers the location of the tail bone. The speed and path taken to the tailbone was controlled by the S4C controller during that movement	The saw must be delivered under the rail and a gradual tilt from the horizontal performed while cutting the aitch bone
B – Normal cutting path	The PXI controller delivers information on saw angle, vertical and horizontal speed and the location that the saw must be driven to. The sideways movement of the saw totally controlled by the PXI computer, the position determined by the feedback from the imaging computer. During the tilting of the saw from above to below horizontal through the shoulder, the cutting speed was controlled by the S4C controller, before cutting path control was returned to the PXI computer.	Vertical speed is restricted by the current draw of the saw. Vertical speed was restricted to a maximum of 150mm/s. Traverse movement was restricted by the vertical speed and determined by the angle of the parallelogram holding the ultrasound head.
C – return to start point after cutting	After exiting the carcase the saw path was controlled by the S4C controller driving to a number of set points (eg sterilising position).	Sterilising became part of the return path. The saw was delivered into a (simulated) sterilizer. The sterilising water was to be controlled by the S4C controller to meet AQIS requirements. Maximum speed of delivery during these paths was set to 5 metres per second.

2.7.1.1.6 Tail bone measurements

The exact location of the tailbone was required for the automatic spitting system, so that the ultrasound head could be placed accurately on the back surface of the carcase as close to the top of the coccygeal vertebrae as possible. This allowed image processing of the ultrasound image to commence as soon as contact with the carcase was made, thus allowing tracking of the backbone as soon possible, improving speed of saw position correction and minimising potential for soft-siding.

It was determined that damage to the ultrasound head was highly likely if was placed inside the anal cavity and dragged over the vertebrae. If the ultrasound head did not arrive very close to the carcase before contact was made, valuable cycle time could be lost in making contact with the carcase. For these two reasons the position of the tailbone needed to be determined as accurately as possible.

At FSA in Cannon Hill, the location of the tailbone was determined by profiling the contour of the back of the carcase using a Banner LT3 laser distance-gauging sensor. The LT3 was set to have a better than 2mm resolution over 3 metres using a class 2 laser.

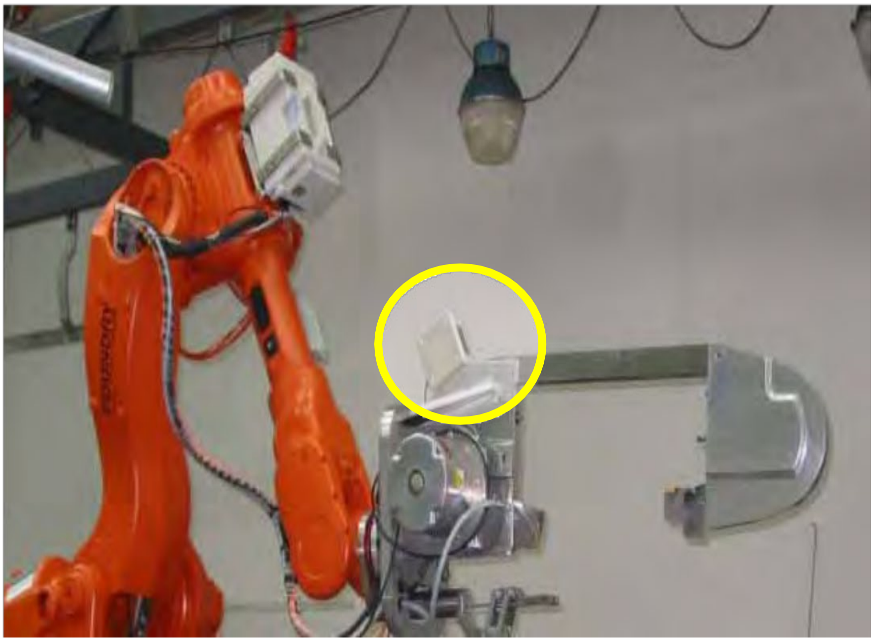

Figure 2-15: The Banner LT3 laser used to determine the tail bone position is mounted on top of the saw

The vertical movement required to plot the contour was provided by mounting the laser on the back of the saw and programming the robot to perform a vertical movement while keeping the laser horizontal (see Figure 2-16). The vertical measurements were sent from the robot to the main PXI controller every 5mm. The horizontal measurements were acquired from the laser measurements.

A dominant feature in the contour is created just above the coccygeal vertebrae by the removal of the anus. A large increase in the horizontal distance is encountered as the laser reference point changed from the external surface the internal carcase surface. The laser measurement slightly prior to this feature, along with the robot vertical distance at the same point gave a reference for the control system to use as the tail bone (or start of cut) position.

The major drawback of using the this method to locate the tailbone was the time required to plot the contour, then position the saw ready to begin cutting. During testing, this process could take 10 to 15 seconds.

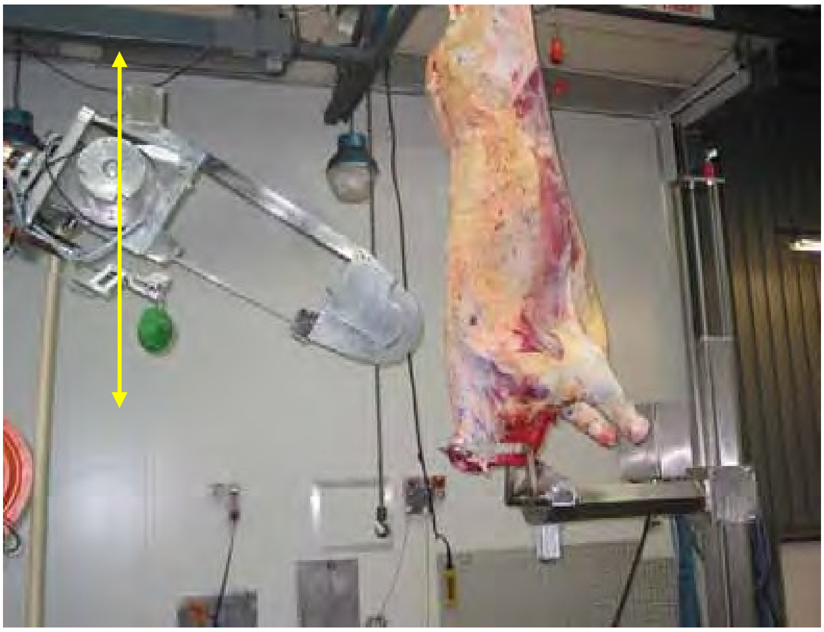

Figure 2-16: The robot moves the saw in a vertical line to allow the laser to determine the profile of the back of the carcase

2.7.1.1.7 Integration of the Neck Stretcher and Leg Spreader

At FSA Cannon Hill initial trials were done using the leg spreader designed for previous portions of this project and a specially designed neck stretcher.

The leg spreader could be lowered into the gap between the rollers, and then opened out to spread the legs.

The PXI controlled and monitored:

- Up and down of leg spreader
- In and out of spreading arms.

The neck stretcher was also controlled by the PXI controller.

Control for the neck stretcher consisted of:

- Rotation in and out of column
- Pressure drive to raise the jaw arm
- Linear drive feed back to monitor the height of the jaw arm (tempersonic sensor)
- Ultrasonic sensor for non contact detection of the neck
- Open and closing of jaws
- Brake control on vertical drive cylinder

The integration of the leg spreader involved the following sequence:

1. Deliver the carcase
2. Lower the leg spreader
3. Open the leg spreader
4. Rotate the neck stretcher to under the carcase
5. Drive the jaw arm up
6. Detect the neck
7. Apply the vertical cylinder brake
8. Close the jaws
9. Release the brake
10. Apply downwards force
11. Start and progress the cut until the jaw release point
12. Slow the vertical cutting speed of the saw
13. Release the jaws
14. Allow the jaws to drop out of the way
15. Rotate the column out of the way
16. Allow the vertical speed of the cut to increase until the cut is finished
17. Close the leg spreader
18. Raise the leg spreader

Knowing the height of the tailbone and the height of the neck, a location down the carcase was chosen as a point to change the cutting angle of the saw to allow better cutting through the shoulder and neck regions.

One of the problems encountered was the slowing of the cut speed at step 12. If the saw cutting speed halted or got too slow when the neck stretcher released the carcase, the carcase had tendency to swing away from the saw. This was caused by a combination of the ultrasound parallelogram pressure pushing the carcase, and there being a reduced amount of product for the saw blade to cut. The partially cut carcase was also more flexible and moved more easily. The robot tried to compensate and chased the carcase forward. However during that time the carcase had swung back and the saw now had product to grab and pulled the carcase harder towards itself further compressing the ultrasound parallelogram. The robot/ control system overcompensates, tries to move away from the carcase, but by then the parallelogram is pushing the carcase away, and a resonant frequency starts to take effect causing the carcase to move out of control.

The size of the carcase effected how much of a problem this became: longer carcases were more of a problem than shorter carcases (ie carcass release point is further from the meat rail).

Limiting the minimum downward speed and selecting a balance of when to disengage the neck stretcher had to be found, to allow enough time to get the neck stretcher safely out of the way of the saw path. To help alleviate some of the problems encountered with the carcase swinging during the saw tilt, and during the neck release, the speed of the in / out movement was reduced at the saw tilt point.

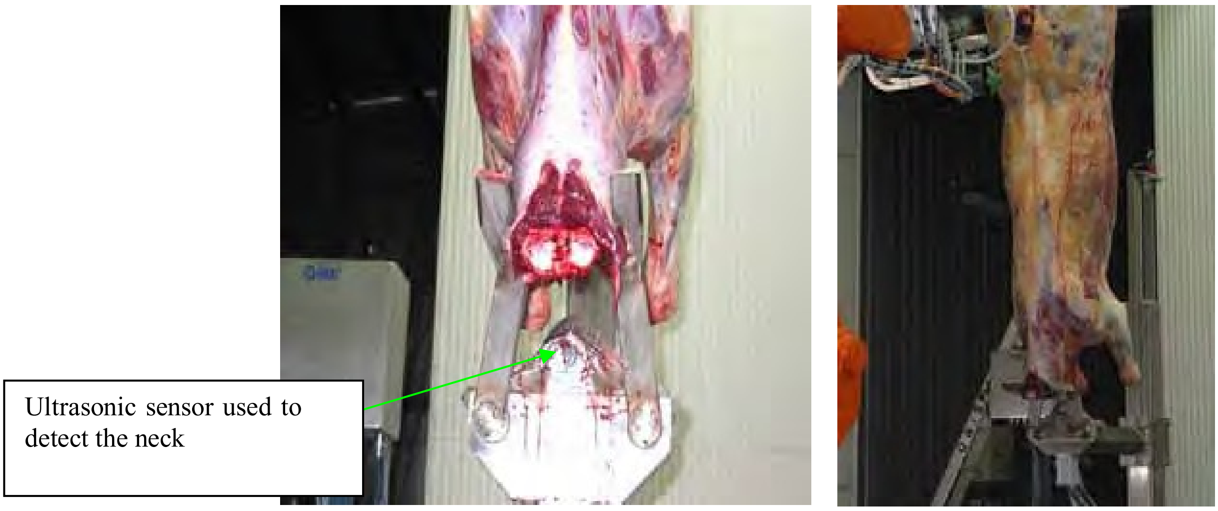

Figure 2-17: The neck stretcher in place showing the ultrasonic sensor used to detect the bottom of the carcase and the jaws pulling the carcase down during the cut

Trials were performed without the neck stretcher, and for the majority of cases it was determined that having the neck stretcher gave insufficient advantage over not having the neck stretcher for the amount of extra control that needed to be integrated.

Not having the neck stretcher also had the added advantage of not having to find the room for more equipment on the slaughter floor, and reducing the amount of equipment that had to be sterilised.

Figure 2-18: Pictorial of the neck stretcher

2.7.1.1.8 "Manual" Robot Control

The system has been designed to be operated on the slaughter floor from a single control panel with limited number of buttons to drive the robot to a number of set locations.

Figure 2-19:The primary operator panel provides the operator interface on the slaughter floor

Although two operators are required to put the splitting system into fully automatic control, there are three safe locations for the robot.

They are:

- Home – up high, ready to move the saw to the tailbone position
- Park – a resting position for the saw, used for a cleaning position
- Service – a position used for operations such as changing the saw blade

When the splitting system was in the “manual” drive mode the S4C controller was in “auto” mode (ie the robot controller is running a program in automatic mode). To avoid confusion the S4C controller modes – auto, step or manual – shall not be addressed in this report. “Manual” and “Automatic” modes refer to the splitting system only.

Saw movements to the safe locations were manually controlled by continually pressing the desired safe location button of the robot.

The movement to the safe location was done at a slow speed so that if anybody was inside the cell they had time to get out of the way of the robot. The person driving the robot was at all times able to see inside the cell to prevent people trying to enter – this was done to cover safe operating procedures. The button for the safe location must always be pressed during the movement or the robot will stop.

The movement of the robot to a safe location was determined by the current location of the saw. For example, if the saw has cut halfway down the carcase and the blade breaks, then it would need to reverse out of the carcase, then move to one side before moving down to a service position.

The safe locations for the saw were arbitrarily set at the FSA slaughter floor. The final positions are site dependent, but the moving methodology remains the same.

2.7.1.1.9 Test facility cycle times

At FSA Cannon Hill the cycle time of the cut was not a high priority, although it was addressed. The more important issue in this case was to get the cycle paths correct and prove the ultrasound imaging. During testing the cycle time was around 90 seconds. This included:

- ► Operating the leg spreader
- ► Operating the neck stretcher
- ► Using the robot to locate the tail bone

- Performing the cut
- Driving the robot to a (simulated) sterilising position and holding for 6 seconds
- Returning the saw to the starting position.

In the production environment, some of these processes were changed and sped up to reach production speeds.

2.7.2 INSTALLATION AND COMMISSIONING

The automatic splitting saw system was installed in a category 3 safety cell on the Ralph's Meats slaughter floor.

Figure 2-20: Automatic splitting system installed at Ralph's Meats in a category 3 safety cell.

The site installation required the main PXI control computer, robot and ultrasound unit to be situated on the slaughter floor. The S4C robot controller and imaging computer were located in a clean room adjacent the slaughter floor.

Due to a minimum production cycle time of around 56 seconds, the determining of the carcase features - tail bone location and neck height – had to be gathered differently to reduce the system cycle time. The leg spreader used on the production line was also a different format to the one used at FSA in Cannon Hill.

2.7.2.1 Tail bone measuring

The LT3 laser used to determine the profile of the back of the carcase, and hence the tailbone position, was moved from the end-effector saw mounting to a specially built vertical displacement arrangement at the station before the cutting station.

This allowed time for the carcase to stop swinging after transport and allow accurate measurements to be taken without encroaching on the time required for a full cutting cycle, thus saving around 10 to 15 seconds.

Figure 2-21: Location of tail bone measurer at Ralph's Meats. The tailbone measurement is done at the station prior to cutting

To perform a correct tail bone measurement, the path of the laser needed to go as close as possible to the centre of the back of the carcase and through the middle of the hole created by the anal cavity. The tailbone measurements were only initiated when the saw had arrived at the tailbone of the preceding carcase. Although the legs were not stretched at the tailbone station, it was determined that the extra height of the tailbone due to the stretch was negligible.

During initial trials it was found that the there were new and old sections in the carcase delivery chain. This reflected a variation of stopping positions for the middle of the carcase of up to 200mm. This was not suitable for using an automated tailbone measuring system. Ralph's Meats altered the method for halting that section of the chain and the stopping position of the carcases was improved to be better that +/- 25mm of a designated point.

2.7.2.2 Neck Height Measurements

The neck height or lowest point of the carcase was used to determine the lowest part of the cut and the height at which to tilt the saw down.

The neck stretcher developed and used in the system at Cannon Hill was not used at Ralph's Meats. Instead a SICK Multi Line Grid (MLG) system was used to determine the neck height. The MLG used consists of a light grid set at 50mm spacing, measuring 300mm below the base of the robot to 900mm above the robot base. This equated to approximately 600mm to 1800mm above the floor. No animals encountered during testing were higher than 1800mm off the floor.

The lowest neck height that could be accounted for by the automated cutting process - including a saw tilt through the neck - was 300mm below the robot base. Any lower caused the bow of the saw to touch the floor. Any animal 300mm below the robot base was determined to be a large bull which was not common during normal processing. It was agreed these animals be manually cut using the existing splitting saw.

The neck height of the carcase was measured as the animal moved along the chain and entered the splitting saw cell. Measuring the neck height at an earlier point along the chain meant this operation did not impose on the cycle time required for the splitting saw.

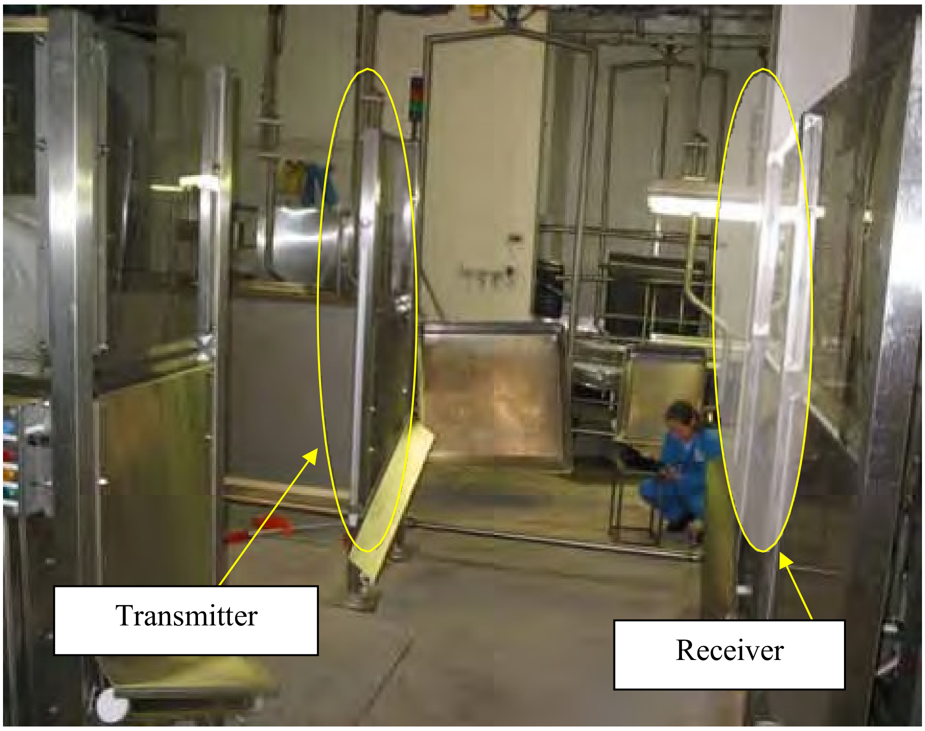

Figure 2-22: The neck height is measured as the carcase enters the splitting saw cell

2.7.2.3 Leg spreader

The leg spreader developed for the plant at Ralph's meats used only a single pneumatic cylinder. This cylinder actioned a set of opposing arms that provided the leg spread required to lift the carcase rollers off the indexing chain fingers and centre the carcase on the cutting line of the robot.

The location of the leg spreader (open or shut) was provided by a single proximity sensor detecting the leg spreader shut position. This differed from the leg spreader used at the FSA Cannon Hill facility which had 4 solenoid and 4 feed back sensors to 1 solenoid and 1 feedback signal in the production environment.

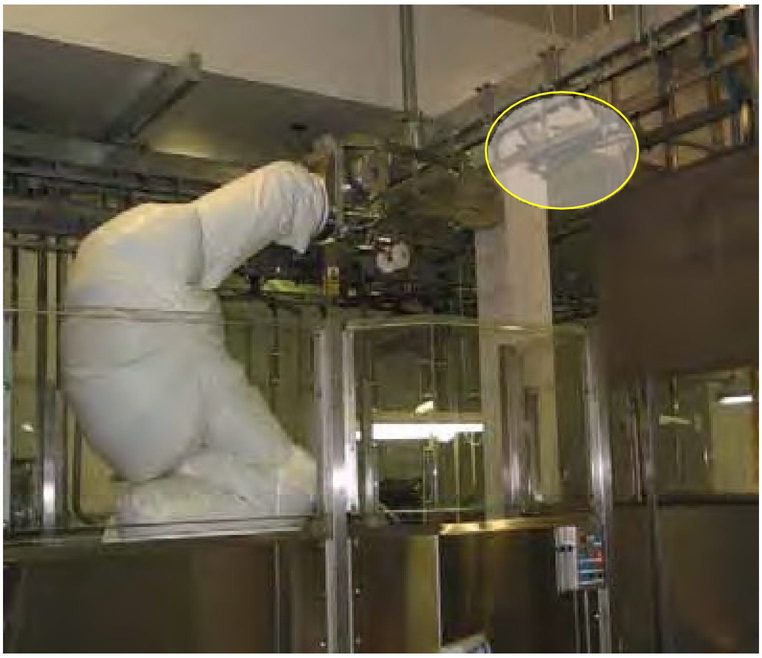

Figure 2-23: The leg spreader at Ralph's Meats comprises of a set of opposing arms controlled by a single cylinder

2.7.2.4 Integration to plant production line

2.7.2.4.1 Chain index hold

The splitting saw system provided a signal that is interfaced to the exiting production line to stop the chain. The "chain index hold" signal was a voltage free relay provided to prevent the existing indexing chain moving when the splitting saw system was not ready.

This was required for instances such as when the saw may have been completing a cut and the leg spreader may have been open when the chain wanted to move on. The leg spreader had enough resistance to actually cause the indexing line motor to overload if it was still in place.

2.7.2.4.2 Start of process signal

The existing production line provided a signal to the system's PXI controller indicating that the chain had reached the start point, ready to start a new cycle.

This signal has to be buffered for the instances when the chain may have moved less than 100mm and was manually stopped by a slaughterman elsewhere on the line. In this case the signal was provided to the PXI twice. This was accounted for by inserting a software timer that did not allow start signals less than 10 seconds apart.

This start of process signal could then be used to initiate a splitting cycle if a carcass had been previously detected. If a carcass had not been previously detected then the tailbone and neck height measurements were also initiated by this signal.

2.7.2.5 Safety Cell Integration

To install the automatic splitting system in a commercial plant it needed to meet all relevant safety standards. One of the requirements was that the control system needed to have a category 3 rating.

Some of the requirements to reach this rating were:

- the saw be protected by 2 safety contactors
- the robot S4C controller required full safety chain connection to both inputs of its twin safety chain comparison monitor
- the safety cell must be isolated from person entry

.

Figure 2-24: The safety cell entry is protected at entry and exit by light curtains

Should any of the safety systems have been triggered, then they had to be reset by the PXI controller when a reset signal was initialled on the main control panel.

This involved:

1. Firstly resetting any triggered interface
   This simply required any obstructions to be removed (e.g. stop somebody standing in the light curtain)

2. Reset the light curtains
   This was hard wired into the reset switch on the main control panel

3. Reset S4C safety chain signal
   This involved sending a 30msec relay pulse to the S4C controller

4. Return the S4C controller to automatic mode
   A second pulse had to be sent to the S4C controller after the first with a pre-determined time delay

5. Reset the safety relays for the saw.
   This was always done prior to starting the cut, so as not to allow the saw to run or start prematurely when there was a possibility of somebody being within the splitting saw cell.

2.7.2.6 Operator interface panels

The splitting saw system operator interface on the slaughter floor consists of two control panels.

The reason for having two slaughter floor control panels was to meet safety requirements. This meant two people were located at the entry and exit of the safety cell, and those operators using visual inspection could ensure that there are no people inside the cell before the splitting saw was placed into the automatic cutting mode.

Figure 2-25: The Primary and secondary slaughter floor control panels provide the operator interface in the harsh environment of the slaughter floor

The primary slaughter floor control panel has the operator interface to allow “manual” driving of the splitting saw as well as the interface for resetting the splitting saw. The secondary control panel has only an emergency stop button and automatic mode start button.

Figure 2-26: The primary slaughter floor control panel is located at the exit of the safety cell

The buttons are as follows:

- Emergency Stop (both operator control panels)
  - Used to perform an emergency stop on the system. Also performs a break on the dual safety chains to implement an emergency stop at the S4C robot controller.

- Home
  - If the splitting system were in “manual” mode holding this button would drive the saw to the high starting “home” position ready to start a cutting cycle.

- Park
  - When the splitting system is in “manual” mode holding this button would drive the saw to a position that allowed easy cleaning of the system. At Ralph’s Meats this was determined to be a position with the saw horizontal, near the floor, under the rail.

- Service
  - When the splitting system is in “manual” mode holding this button would drive the saw to a position that allowed the saw blade to be changed. At Ralph’s Meats this was determined to be a position approximately 45 degrees to one side of the cutting line, with the saw vertical and inside the safety cell, away from the normal path of the carcases so as not to interrupt production.

- Manual / Auto
  - This pair of buttons changed the splitting system into manual or automatic mode. To perform a normal cutting cycle the system had to be in “auto” mode. To drive the robot into the “Home”, “Park” or “Service” positions the splitting system had to be in the “manual” mode.

- Clear Errors
  - This button resets the light curtains at the entry and exit of the safety cell when pressed. All software stoppage errors (saw error / communications errors) are also then reset. When the button is released a set of timed signals is transmitted to the S4C controller to reset the robot errors (caused by a break in the safety chain for example) then to place the S4C controller back into automatic mode.

- Start Auto (both operator control panels)
  - This button is present on both operator panels as two people must press the buttons only if the safety cell is confirmed by sight to be void of people. The two buttons must be simultaneously activated less than 30 seconds apart. If one button is held constantly on for more than 30 seconds then it must be released and pressed again (this was done to prevent a single person jamming the button in on one panel, then pressing the button on the other panel at will).

- Run / Continue
  - If the saw is located within a carcase, then the cut will be continued from the last position (in the case of a light curtain being accidentally broken, for example).
  - If the saw was in the home position then the system will be primed to start an automatic cutting cycle

Indicator lamps located at the edge of the robot cell gave the operator feed back on the state of the splitting saw system:

- Halted (Red)
- Ready (Amber)
- Run (Green)

Combinations of the lamps have different meanings, summarised in the table following.

Table 2 Indicator Combinations

RED	AMBER	GREEN	Meaning
ON			General fault – system halted
FLASHING	FLASHING		In manual mode
	FLASHING		System clear of errors Both “Start Auto” buttons have been pressed correctly Waiting for “Continue / Run” button to be pressed
	FLASHING	FLASHING	System ready to start a cutting cycle
	FLASHING	ON	In cutting cycle

2.7.2.7 Physical communications to robot and imaging computer

The PXI controller tying the system together was located in the cabinet on the slaughter floor at the rear of the robot. The imaging computer was physically situated in an isolated room 30 metres from the robot safety cell. This was done because it was the closest available room that would protect the computers from the harsh environment of the slaughter floor. The installation required that the cables - including the video signal from the top of the robot - go to the main PXI controller inside the slaughter floor cabinet. Cables then travelled to the roof and on to the isolated room. The robot control cables travel directly to the S4C controller also in the isolated room.

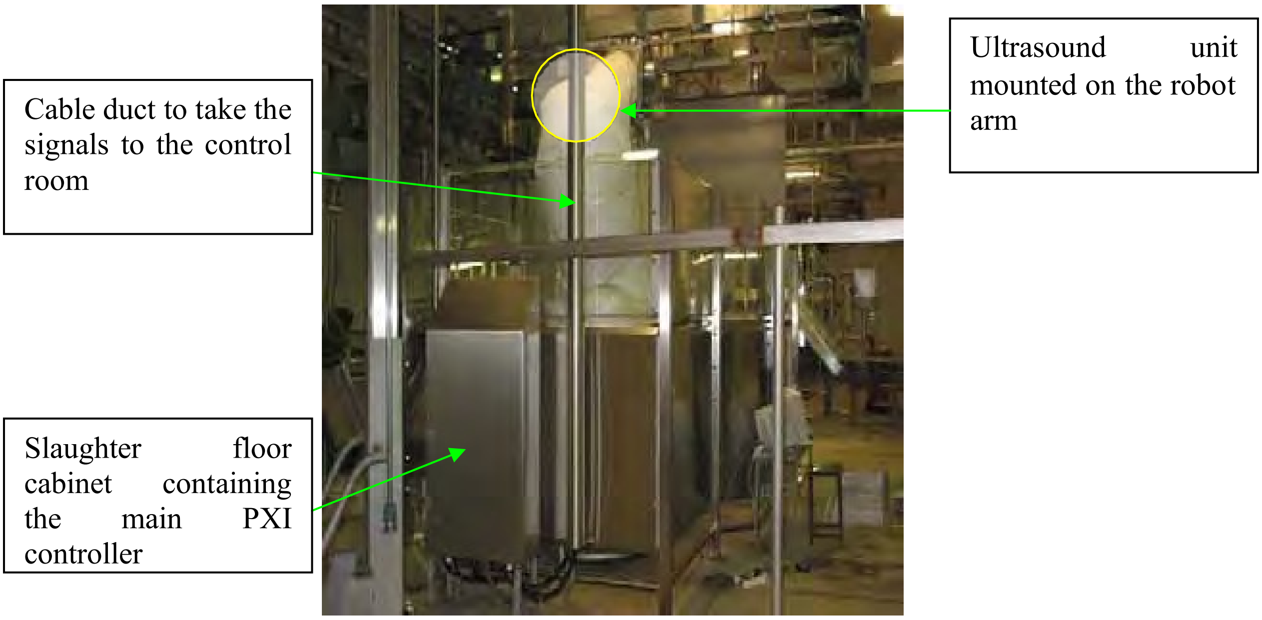

Figure 2-27: Location on the slaughter floor of component that interfaced to the control room

Figure 2-28: Inside the control room electronic components could be protected from the harsh environment of the slaughter floor. Later the screen and keyboard for the PXI controller would also be located in this room

2.7.2.8 Production Cycle Times

Ralph's Meats production cycle time during testing was around 65 seconds, but at times it could be as low as 56 seconds.

The production installation allowed for the splitting cycle time to be reduced over the Cannon Hill demonstration via performing some system operations in parallel. Ten to fifteen seconds was saved by moving the tailbone measurements to the station prior to the cutting station, and taking the neck measurement in-line. Not having to use the robot to move the laser for tailbone measurements allowed the start position of the cut to be refined requiring less time to place the ultrasound probe at the tail bone position.

These factors allowed the automated cutting cycle time to be reduced to around 45 seconds for an 1800mm long carcase. This did not however include time required for sterilising.

Further time reductions could be obtained by further refinement of the travel path after exiting the carcase and before delivering the saw to the start position. Additional refinement of the delivery of the ultrasound to the tailbone could save between 5 and 8 more seconds. Refining the tilt of the saw through the shoulder could save further time if required.

2.7.3 TECHNICAL USER INTERFACE

As part of this project a technical user interface providing information on the status of the splitting saw system was developed. The user interface panel was a graphical display similar to most standard windows operating system software. Figure 2-29 and Figure 2-30 show this technical operator panel.

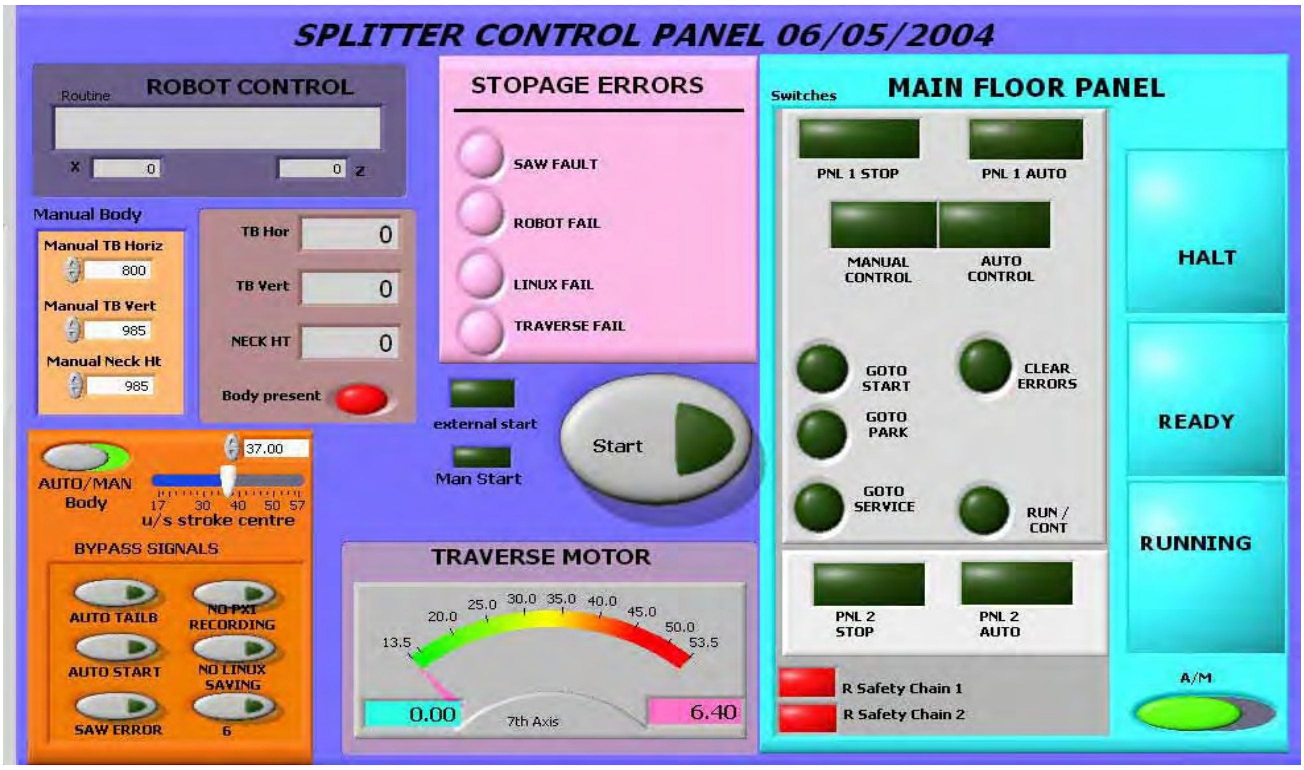

Figure 2-29: Technical user interface for the main PXI control unit

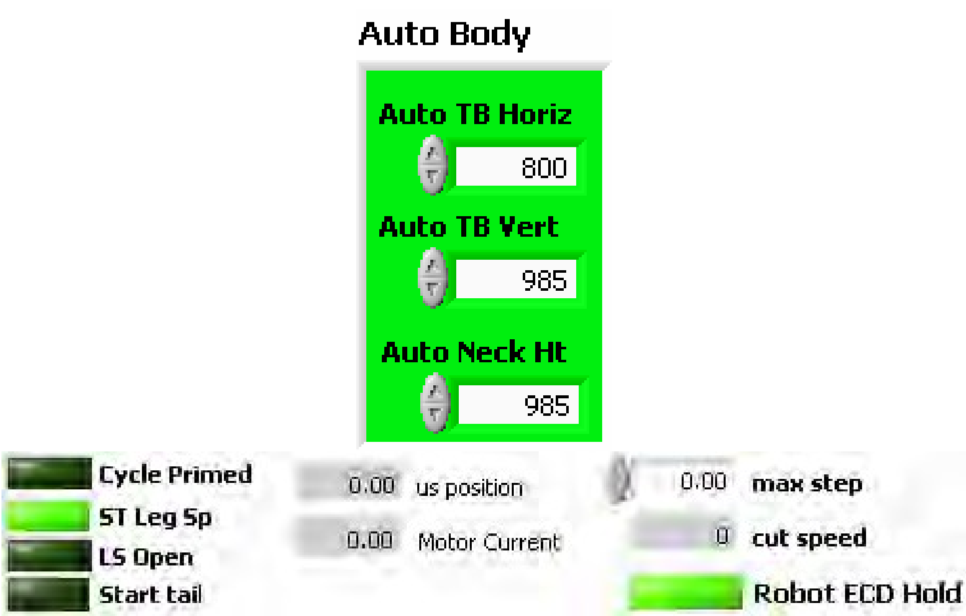

Figure 2-30: Additional information provided by the technical user interface

2.7.3.1 Robot Control Section

Information provided at all times:

- Current subroutine of the S4C controller program

Information provided during the cut only:

- Current robot end effector X position (in/out location) relative to the robot base
- Current robot end effector Z position (vertical position) relative to the robot base

2.7.3.2 Manual Body / Auto Body / Body Parameters Sections

Information provided for all three windows:

- TB Horiz – the horizontal distance measure by the laser from the laser head to the outer most surface of the carcase at the tail bone position
- TB Vert – the vertical distance from the rail to the tailbone
- Neck Ht – the height of the neck relative to the base of the robot

During testing, the body parameters required for cutting could be manually inserted to enable testing without a carcass present. This was done by typing parameters into the "Manual Body" window.

The automatic tail bone and neck height measuring system values was shown in the "Auto Body" window.

The choice of using the automatic or manually entered values was selected in the "System Bypass" window.

Body parameters passed to the splitting system then determined if a body would be present for cutting. If no body was present, then an automated cutting sequence would not be initiated.

2.7.3.3 System bypasses Section

During testing of the system it was found to be an advantage to bypass certain aspects of the splitting saw feed back. For example, when only the ultrasound image was being tested and no cutting was being performed a saw fault would occur (broken blade condition). To allow the system to operate under the error condition the saw error was required to be bypassed.

The available bypasses were:

- **AUTO/MAN Body** – allows selection of automatically determined or manually entered body parameters.

- **u/s stroke centre** – the parallelogram on the ultrasound mount has a total stroke length of 70mm. Normally the centre of this stroke (35mm) would be where the parallelogram would sit during a cut cycle. It was desired to be able to easily adjust this position during testing to determine the results of an altered centre point.
- **AUTO TAILB bypass** –this was used when the tailbone measuring system is not activated.
- **AUTO START bypass** – this was used when the start of cutting cycle is not to be taken from the production line start signal.
- **SAW ERROR bypass** – this was used when the errors on the saw are to be ignored.
- **NO PXI RECORDING** bypass – the PXI controller could record data during the cutting process for evaluation after the cut. This information included such data as saw angle, vertical speed and actual/desired traverse position. During normal production this information was not required for every animal, so the saving of the data could be bypassed.
- **NO LINUX SAVING bypass** – similarly the image processing computer could save information on how the ultrasound image are processed. During normal production this information did not need to be saved.

2.7.3.4 Stoppage Errors Section

To monitor system integrity an indication as to why the system may have stopped was shown in this window. All of these errors caused the splitting system to stop any automated cutting process.

The stoppage errors were as follows:

- SAW FAULT
  - The saw would fault out if a saw blade breaks or if the saw jams
- ROBOT FAIL
  - The communications to the robot had failed
- LINUX FAIL
  - The communications to the imaging computer had failed
- TRAVERSE FAIL
  - The traverse motor had failed

2.7.3.5 Traverse Motor Section

The sideways movement of the traverse motor could be monitored by a twin needle indicator. One needle showed the desired position of the traverse motor (controlled by data sent from the imaging computer during a cut), and the other needle showed the actual position. Most of the traverse movement during a cut was +/- 20mm of the centre line, so the displayed scale was reduced to 33.5mm +/-20mm rather than +/- 30mm of maximum travel.

2.7.3.6 Main Floor Panel Section

Information on the status of the operator panels was shown in this window for diagnostic purposes. Each indicator reflected the condition of the switches on the two operator panels – when the switch was pressed, the indicator lit up.

Additional information is given on the status of the two safety chains that control the emergency stops for the S4C controller.

2.7.3.7 Additional technical user interface indicators

Other indicators on the technical user interface include:

- **External start / Manual start** – indicates where the start of cut cycle was initiated from
- **Start** – an interface provided so that a cut cycle can be initiated at the technical user interface
- **Cycle Primed** – indicates that the start signal from the production line was correct and a cut sequence is available
- **ST Leg Sp** – the leg spreader sequence had started
- **LS Open** – the leg spreader was in the open position
- **Start Tail** – The tailbone measurement system had been started automatically
- **Us position** – the current stroke position of the parallelogram holding the ultrasound probe
- **Motor Current** – the current draw of the saw motor
- **Max step** – operator input used to define the maximum cutting (vertical) speed
- **Cut Speed** – the current cutting (vertical) speed
- **Robot ECD Hold** – indicates the PXI is holding the S4C controlled in manual mode

2.7.3.8 Fault management

The main PXI controller monitor the splitting saw system and will stop an automated splitting sequence if a major failure occurs. These include:

- A saw fault
- Loss of image analysis
- Robot communications failure
- Traverse motor failure

2.7.3.8.1 Saw Fault

Broken blades in the saw were detected due to a very low current draw on the saw motor. A “jammed” motor was detected by a high current draw on the saw motor (this instance was also protected by overloads on the motor contactor). Either of these cases indicates a problem with the saw and caused a shutdown.

2.7.3.8.2 Loss of imaging computer

Without the results from the image processing computer, the centre line of the cut could not be determined and thus a correct split could not be performed.

The imaging computer was controlled by text strings sent serially from the PXI to a Pearl line command system. The Linux computer normally sat ready in the line command mode prepared to run the imaging program. Once the imaging program was being run the PXI controller could poll the program to see if it was running. Should the program not give the correct response a set of commands were sent to the Linux computer to cause and exit and restart of the imaging program. The process of trying to get the imaging program into a healthy state was repeated up to 5 times before a failure on the imaging computer was flagged.

2.7.3.8.3 Robot Failure

The desired location of the robot – and hence the saw – was controlled during the cut by the PXI controller. The desired destination in “manual” mode was also controlled by the PXI controller data string.

Communication to the robot was achieved by serial communications to a background program operating on the S4C controller. Should failure of this communication link occur, then the robot could not be controlled.

2.7.3.8.4 Traverse Motor failure

The traverse motor controls the sideways motion of the saw.

During rest (when the saw was not being moved during a cut or a calibration movement), the saw was “rocked” +/- 0.02mm from the centre point of travel. Should this movement stop for more than 1.5 seconds, then a traverse motion error was flagged.

3. RESULTS/ DISCUSSIONS

3.1 LABORATORY TRIALS

A selection of the results from trials conducted at Cannon Hill as part of research objective activity 2 of the contract is shown below. Input data for the complete system was in the form of ultrasound images and plots showing the trial results are generated from system data collected by the National Instruments unit which is the primary controller in this system.

Figure 3-1 Trial 18-11-03 @ 11:09 Ultrasound Image

Figure 3-2 Trial 25-11-03 @ 9:04 Ultrasound Image

Figure 3-1 and Figure 3-2 show ultrasound image data from trials conducted at Food Science Australia. The trial on the 25th of November was the system demonstration for Meat and Livestock Australia.

As discussed in the Milestone 1 report the ultrasound image frames were clipped, filtered then processed to produce a data profile that was representative of all the information contained within each frame. A Gaussian curve was then fitted to the data and used to predict the centre of the spine object captured by the ultrasound. A reasonable amount of processing was built into the program to be able to reliably fit the Gaussian curve to the data. If the Gaussian curve could not be fitted the frame was rejected as invalid. Other criteria for rejection included:

- Spine position could not be more then a given measure (approx 25mm) from the centreline of the leg spread (the physical spine cannot deviate greater then this measure therefore data must be false)
- Difference distance between current and previous spine position must be less then specified criterion (Physical spine cannot alter by greater then approx 10mm therefore data false)
- Look for specific features that are inherent in an ultrasound scan of carcase spine but that generate false data (eg. two spine "shadows" or "blobs" which is not possible ➔ this was generally filtered out via the Gaussian curve).

The imaging analysis then selected the path with the least variation as it represented the best estimate of spine position. This also controlled the amount of variation that was allowed in the analysis. The program's maximum frame analysis rate is only slightly below that of the frame grabber (25 images/ sec). The program was also reasonably robust against sporadic "salt and pepper" noise inherent in industrial environments.

It is possible to reconstruct a full spine trial image as an artefact of the imaging analysis process. These "projections" are only useful for data and display purposes as the actual trial and analysis occurs in real time. The top image of Figure 3-3 and Figure 3-4 shows the "raw" data with the saw path overlayed. The bottom image shows the projected saw path with the retained "processed" image frames. It has been found that the strength of this program was in predicting what frames to reject.

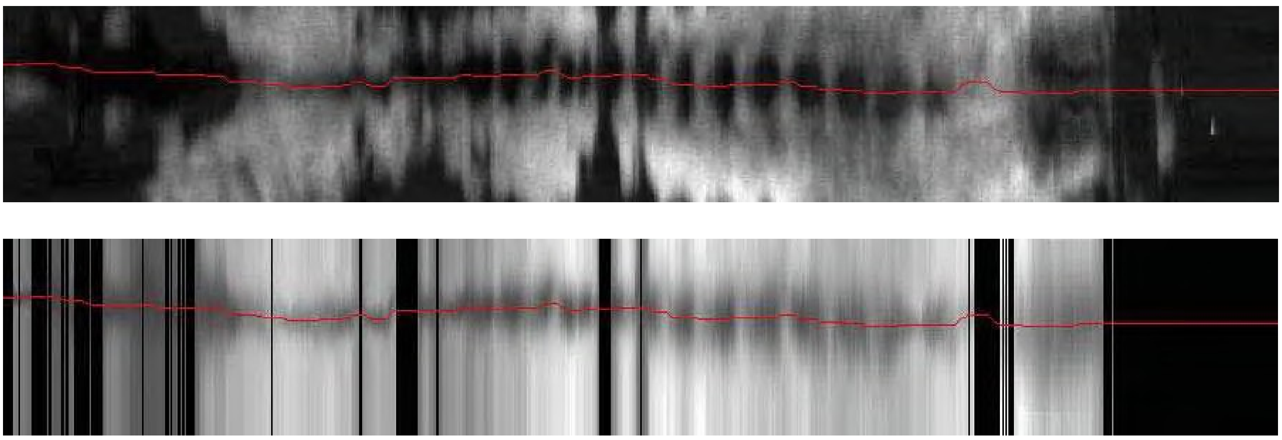

Figure 3-3 18-11-2003 @ 11:09 Projections

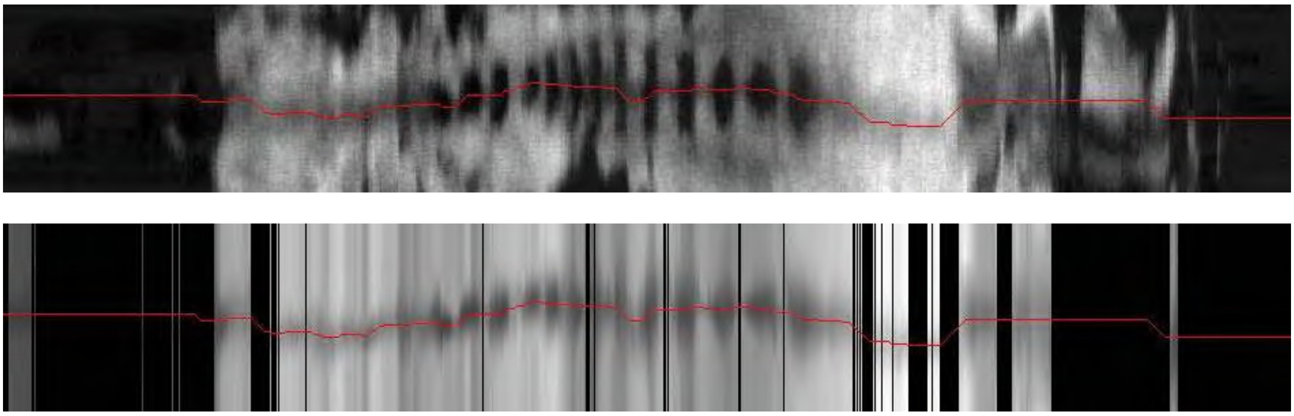

Figure 3-4 25-11-03 @ 9:04 Projections

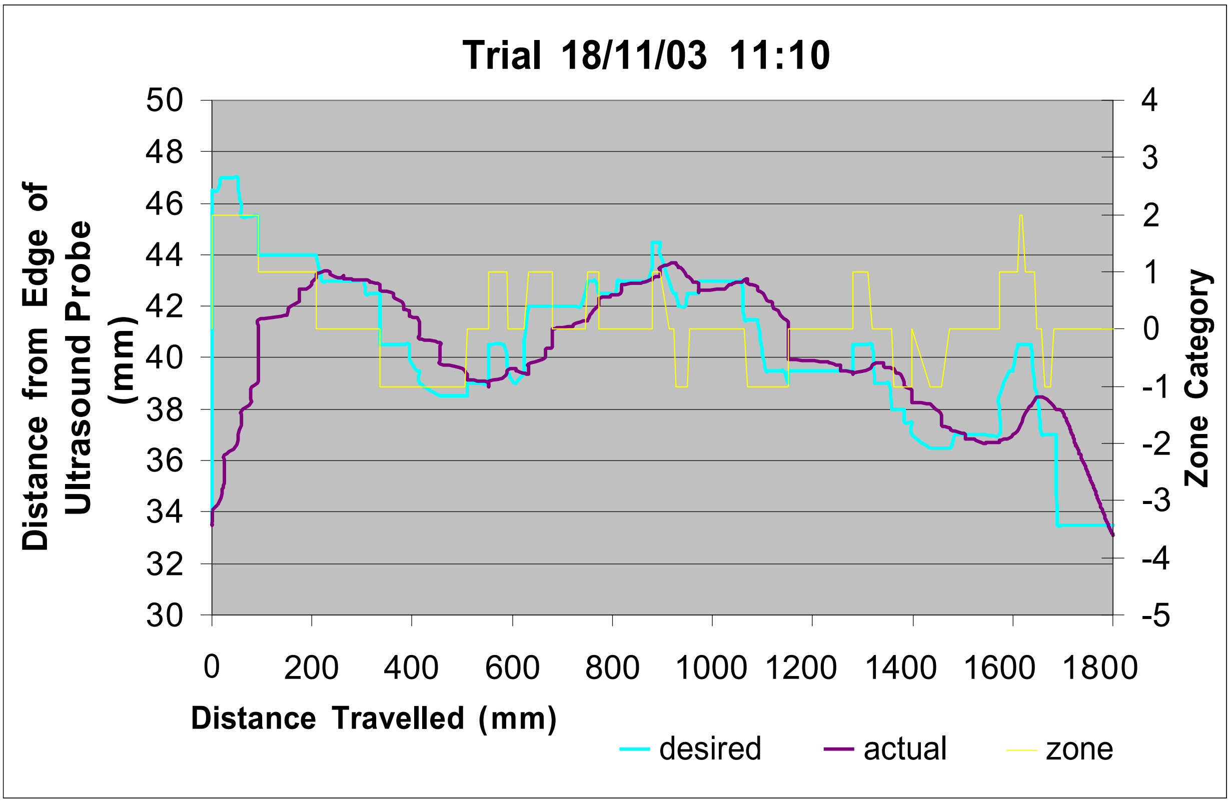

Figure 3-5 Trial 18-11-03 Data Plot

Figure 3-6 18-11-2003

Figure 3-5 and Figure 3-7 show examples of trial plots generated from the system data collected by the primary controller. The "desired" data represents the spine position as analysed by the imaging analysis software. The "actual" data was the saw position. "Zone" information was used to monitor whether the saw was moving to the left or right with a corresponding speed. In this way visual confirmation that the saw was tracking the spine position was possible. Note that there should be a slight lag in the response of the saw as it cannot move quickly horizontally without breaking the saw blade. "Distance travelled" was the distance the saw travelled from the tailbone.

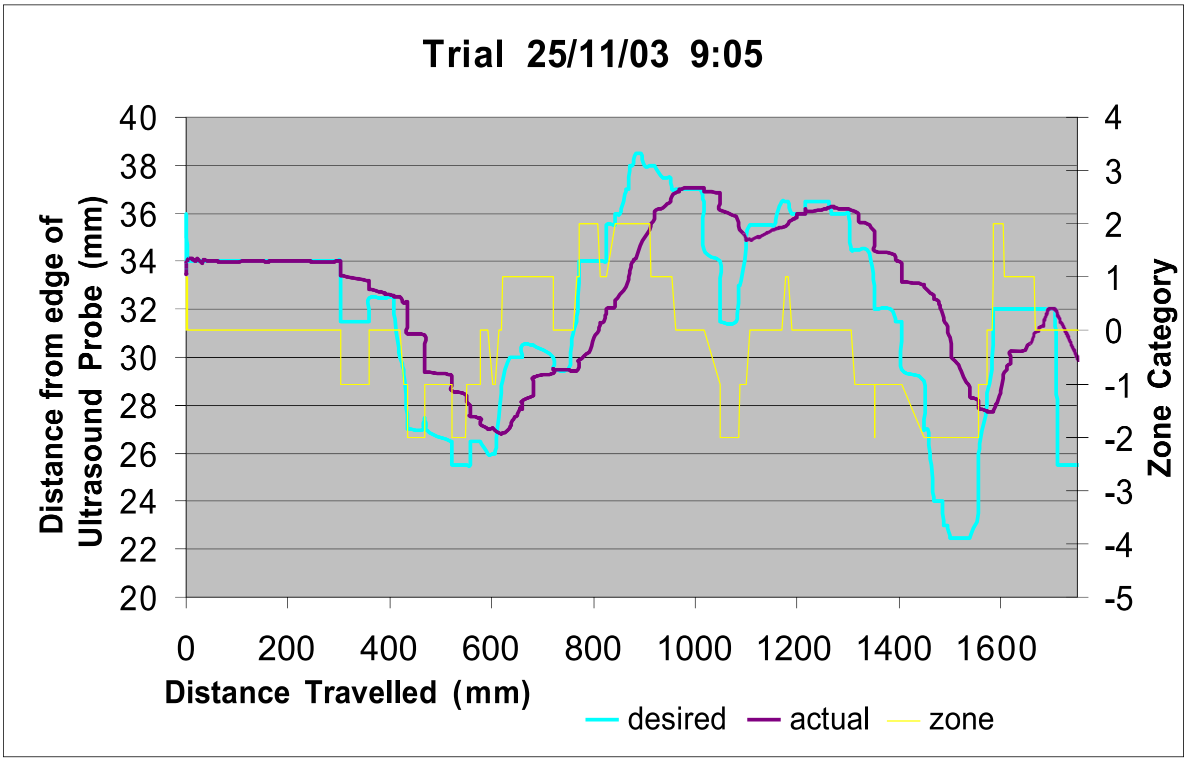

Figure 3-7 Trial 25-11-03 Data Plot

The final result of the system was comparable with previous prototype equipment developed by FSA for the splitting application which did not include the integration of an industrial robot. The system was demonstrated to MLA representatives and James Ralph and was accepted as being of an acceptable standard to commence the next stage of this project and proceed with the commercial site installation and testing.

3.2 SYSTEM ISSUES

The Automatic Carcase Splitter has been successfully demonstrated to both the MLA and James Ralph of the Ralph's Meat Company at Food Science Australia's Cannon Hill facility. Both of these project stakeholders expressed approval of the results that were achieved during these "Laboratory Prototype" trials. The carcases were prepared at Cannon Hill by a trained slaughterman using industry accepted procedures, however as the Cannon Hill Slaughter-floor is equipped to process small numbers of animals some slaughter operations vary from equivalent industry practice. Removing the hide from the carcase is one of these.

Figure 3-8 Upward Hide-puller at Ralph's (top)

Figure 3-9 Upward Hide-puller at Ralph's (bottom)

In plants processing large numbers of animals within minimal times (approximately 60 seconds cycle time for Ralph's) a hide pullers are used. Carcases at Cannon Hill are hand-skinned with a knife. An attempt was made by project staff to simulate downward hide pulling using a forklift which showed comparable results to knife prepared carcases. However, in view of developments during commissioning of the machine at Ralph's, it is believed that automatic hide pulling separates the fat layer from the underlying muscle tissue (Figure 3-8, Figure 3-9). Investigation indicated that "bubbling" occurs at the subcutaneous interface which causes interference to the transmission of ultrasound signals. The result is extremely poor ultrasound image quality very different from trials conducted at Cannon Hill.

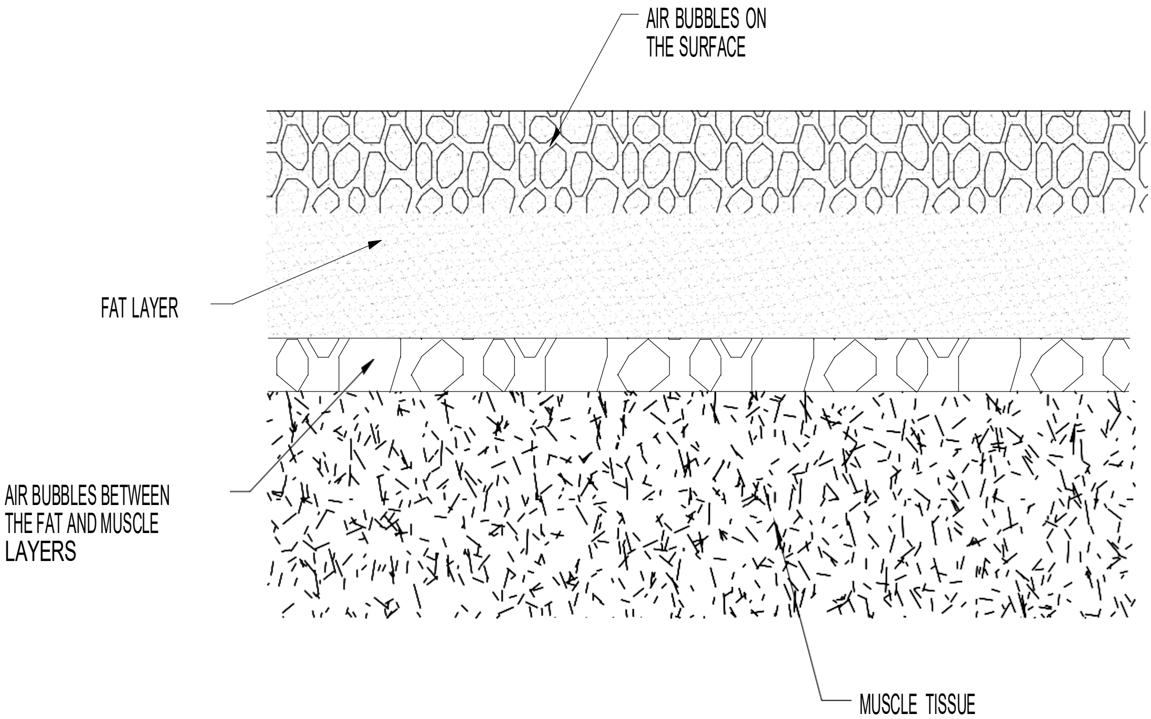

Figure 3-10 Profile Cross-section

To confirm the findings at Ralph's - using an upward hide puller - Food Science project staff conducted trials at a second commercial works that operates a downward hide puller. Again the subsurface bubbling occurred.

It was found that where bruising occurred a good ultrasound image was possible showing muscle tissue definition.

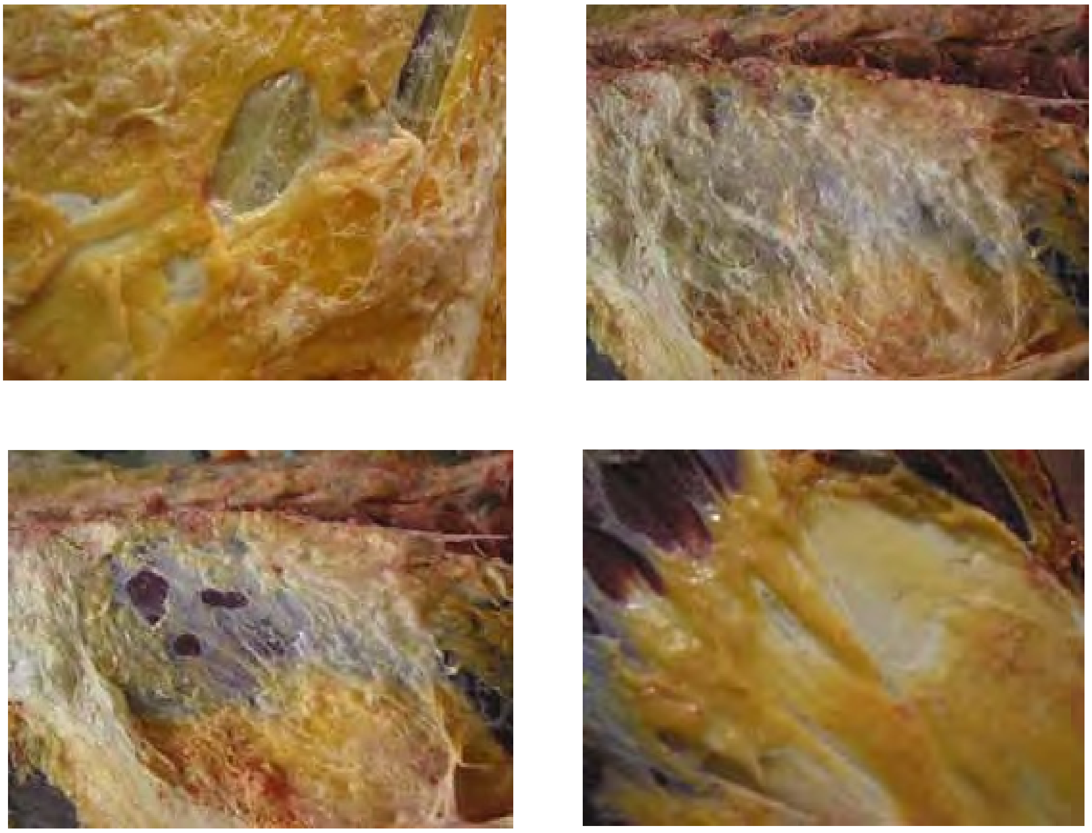

Figure 3-11Examples of "bubbling" on hide pulled carcases

3.3 ULTRASOUND

The ultrasound relies on a good coupling between the ultrasound probe face and the carcase surface. The ultrasound signals will not penetrate air and produce an image. It also needs soft muscle tissue to allow the carcase surface to conform to the shape of the ultrasound probe. Any of the above combinations of surface parameters, air bubbles, or the lack of soft muscle tissue will produce a poor ultrasound image to guide the saw.

Improvement to the ultrasound image was attained by increasing pressure from the ultrasound probe onto the carcase surface and improving the surface moisture content; but the image was not of an acceptable quality. Once the face of the ultrasound probe was against the featherbones (vertebrae protrusions), no further compression of the soft muscle tissue could occur. This restricted the ability of the ultrasound probe to have carcase surface conformation.

During the commissioning of the Automatic Carcase Splitter at Ralph's, it was observed that the angle of the ultrasound probe was not being kept perpendicular to the surface while scanning the carcases with large protruding feather bones. The rollers were riding down the sides of the feather bones and changing the angle of the ultrasound probe. This was producing no image. To remedy this situation, the following modifications were made to the roller system:

1. Reduced the gap between the rollers. This caused the rollers to wedge the feather bones (vertebrae protrusions) and cause the ultrasound to lose all pressure and come away from the surface.
2. Trialled larger rollers. This caused the angle change at the top of the carcase and was unpredictable in the feather bone area.
3. Installation of plastic block between the rollers to prevent the rollers from riding down the feather bones. This produced a better result and maintained the correct angle of the ultrasound probe.

Carcases with the large feather bones had no soft tissue for the ultrasound to have a good coupling. Changes to the image analysis were made to include the contact shadow which improved the guidance of the saw.

3.4 TRIALS

4.4.1 TRIALS AT RALPH'S

Trials were carried out at Ralph's on 84 carcases with only 5 producing a usable ultrasound image. Four of these usable imagecarcasses had their hides removed manually. MLA hold a photo gallery of the trial images.

Following are examples of unusable ultrasound input images and the associated image projection from the same trial (Figure 3-12 and Figure 3-13). Note the dark "shadows" caused by air bubbles.

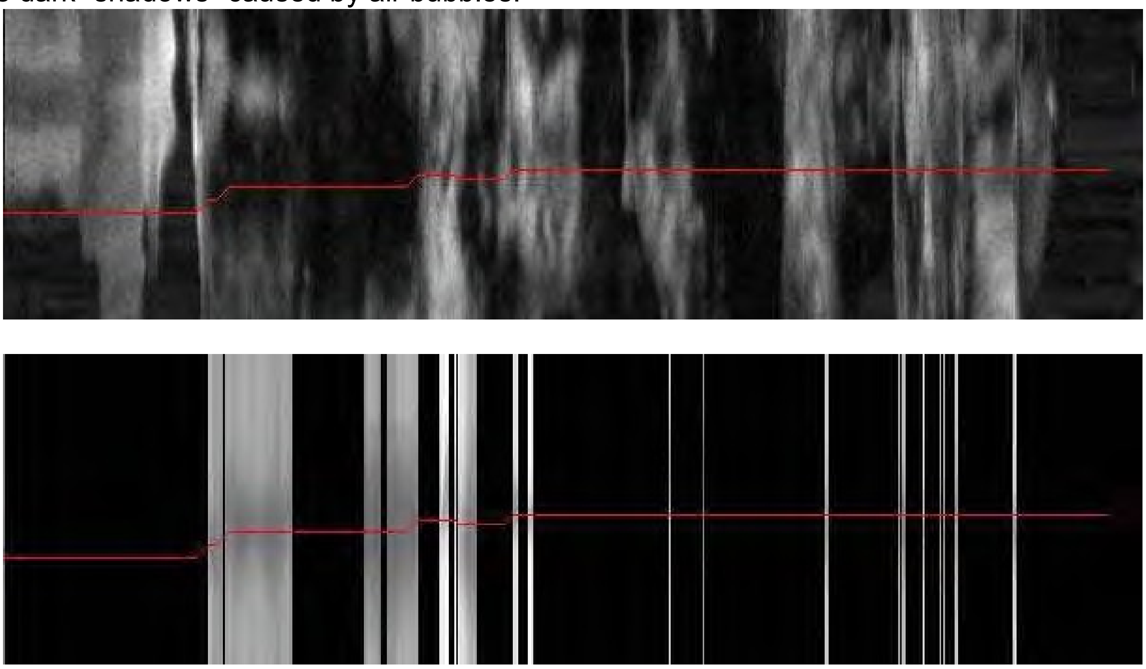

Figure 3-12 01-06-04 @ 10:31 Projection

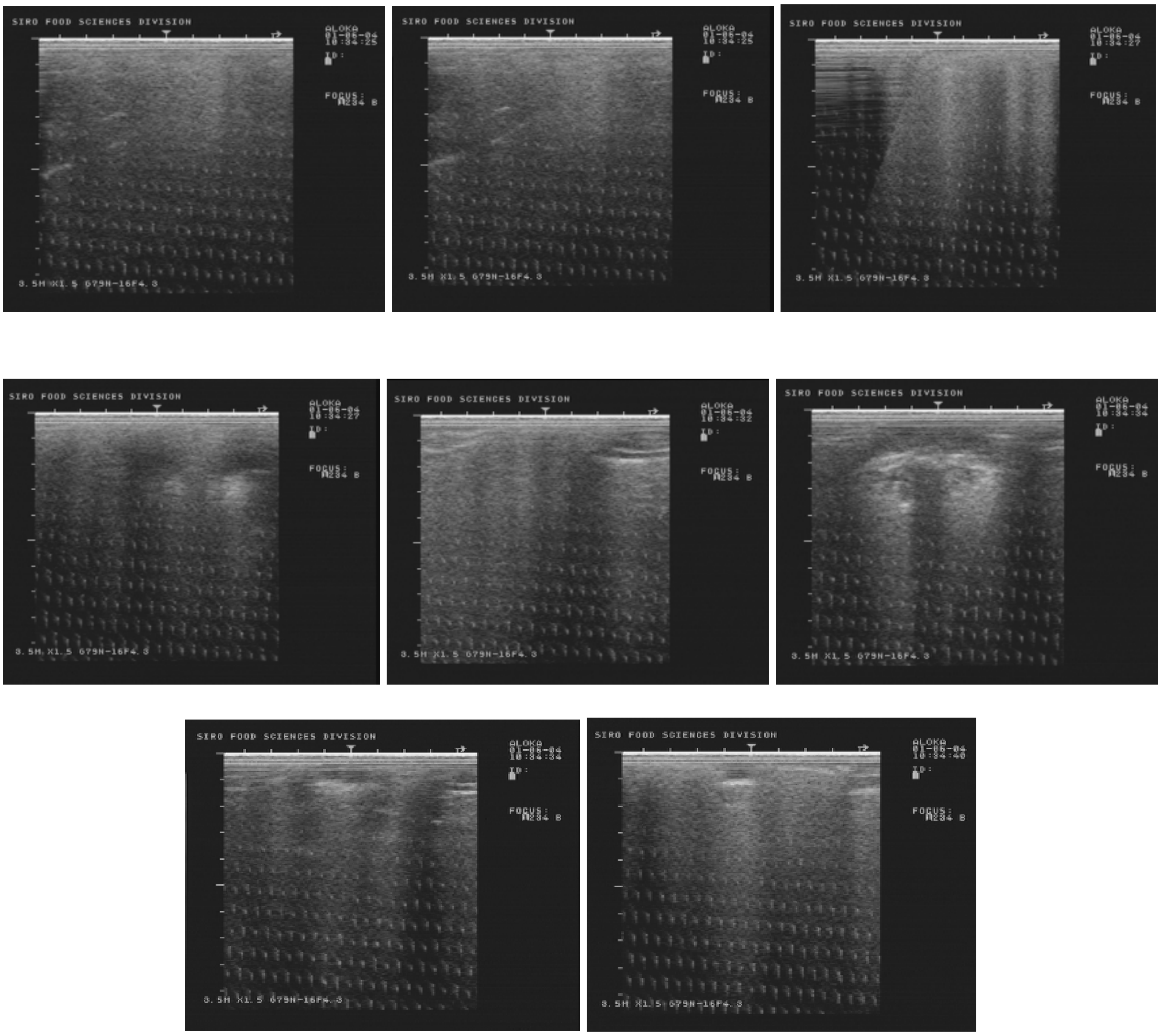

Figure 3-13 Ultrasound Images 01-06-2004 @ 10:31

During trialling extra water sprays were mounted underneath the ultrasound probe to wet the carcase surface (refer Figure 3-14). Spraying substantial amounts of water onto the carcase surface provided a better coupling for the ultrasound probe. Observations were made that the surface air bubbles tended to fill with water and provide the coupling for the ultrasound. Another advantage was that on lean carcases with large protrusions, the water would sometimes flood the area around the contact point of the ultrasound probe. This simulated soft tissue on both sides of the feather bones. However it could not be positively determined that the image was displaying the true centre of the feather bones when this occurred.

The splitting saw system was developed to account for all types of carcases and simulating soft tissue with water will not work with fattier or flat backed carcases. Any further work in this area would only benefit the lean carcases.

Figure 3-14: Water sprays were fitted below the ultrasound head to wet the carcase surface

Severe bubbling of the fat layer and surface tissue was occurring due to the hide pulling action. Further investigation showed that more bubbling was occurring in the subcutaneous tissue layers (see Figure 3-15 and Figure 3-16). This caused improper ultrasound signal coupling at the air/material interface producing an unusable image.

Figure 3-15 Fat Layer Separation

There was a clear indication that air bubbles and tissue separation was the difference between the hide pulled and the manually pulled carcases.

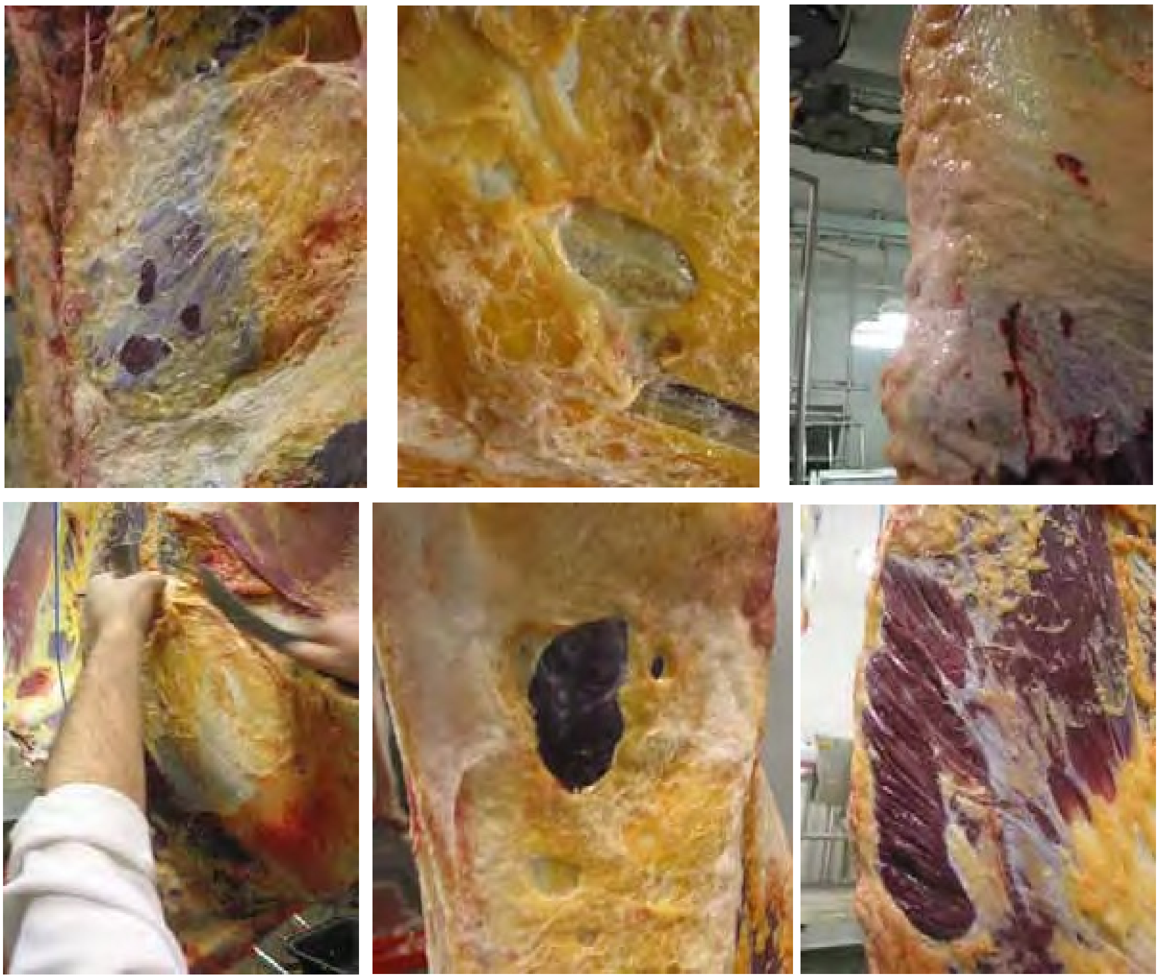

Figure 3-16 Examples of surface and subsurface bubbles and tissue separation

4.4.2 TRIALS AT VALLEY BEEF

A trial was carried out to evaluate the ultrasound unit and the effects of using a downward hide puller. 100 day grain fed animals were used for the investigation.

The ultrasound probe was manually applied to the carcase surface. Water was applied to the carcases, as the surface fat and tissue was drying and becoming ‘sticky’ making it difficult to drag the ultrasound probe down the length of the carcase by hand.

Figure 3-17Examples of the sample animals tested at Valley Beef

Surface bubbles were obvious and bubbles in the subcutaneous tissue could be felt on all of the carcases. The surface air bubbles did tend to burst or flatten under the ultrasound head but made little difference to the result.

This again produced an unusable image for most of the animals.

The hand scans were to be used as a benchmark only. Control over the angle, pressure and speed of the ultrasound head was variable when done by hand and had no resemblance to the controlled mechanical system.

20 animals were trialled and only 5 produced usable ultrasound images.

4. RECOMMENDATIONS

The original concept for this project was to utilise “off the shelf” medical/veterinary ultrasound technology to provide cost effective sensing for the real time control of a standard industrial robot. It was also fundamental to the concept that the technology be readily integrated into existing slaughter floors to facilitate commercialisation.

This approach was effective for trials carried out at FSA’s slaughter floor at Cannon Hill. Subsequent works trials at Ralph’s Meats have shown that the mechanical hide pulling process (upward hide puller) results in air bubbles in and under the subcutaneous fat layer of all carcases scanned. The bubbles result in an ultrasound image that was not usable for control sensing. Subsequent imaging trials at Valley Beef have shown that the gentler downwards hide puller results in a similar unusable image in about 75% of carcases when scanned by hand.

It is unlikely that the issue of the air bubbles will be resolved by further fine tuning of the existing process and the following options should be considered for this project:

1. Terminate the project at this point
2. Address the hide pull process to reduce or eliminate the air bubbles
3. Remove the bubbles prior to or during scanning
4. Refine the image processing software to enhance the images
5. Source or develop an alternative sensing technology

At this stage it is proposed to discuss these alternatives with the stake holders.

4.1 TERMINATION

In addressing unforseen issues, FSA has already funded a significant overrun in the cost of this project. Obviously, this situation cannot continue. It is unlikely that a simple solution will be found that can readily be applied to the existing process and termination of the project at this stage may be the most cost effective course of action.

It should be noted that while this project has not produced the preferred outcome at this point, the technology and knowledge generated may have significant application in other areas of slaughter and boning. It is also conceivable that new or developing forms of sensing could be applied to the process in the future.

4.2 HIDE REMOVAL

Trials at Cannon Hill and Ralph's Meats have shown that if the hide is manually cleared down the centre of the back of the carcase, a usable ultrasound image is generally obtained. It is unlikely that this could realistically be done at chain speed in a commercial abattoir. At best, it is likely that labour would just be shifted from the splitting operation to the hide removal operation, and it is unlikely that this would be commercially acceptable.

An alternative to the conventional downward and less common upward hide pullers is what is generally referred to as a "banana bar" hide puller. As part of a three step process, a curved bar is inserted under the hide in the neck region and peels the hide off as it is drawn upwards along the back. A similar process was developed by FSA engineers for an earlier project. The carcass was suspended by four legs and resting on a table arrangement. A flat blade was then forced along the table and between the hide and fat. It is likely that this sort of hide removal process would result in suitable ultrasound images. Efforts to locate such a system in Australia, for evaluation, have been unsuccessful.

It must be noted that even if this form of hide puller produced a suitable result, it is highly unlikely that processors would be prepared to invest in a robotic splitter and a new hide pull system.

4.3 BUBBLE REMOVAL

During trials at Ralph's Meats, water sprays were fitted to the ultrasound probe rocker assembly in an attempt to improve acoustic coupling with the carcase. The purpose of these sprays was to fill any gaps between the probe and carcase. It was observed that the water appears to fill some of the surface bubbles but would have no effect on the deeper bubbles below the fat.

In some cases, pushing the probe against the carcase with greater force may eliminate some of the bubbles. This would be of benefit in only some situations, as once the probe is being pushed against the end of the featherbone, no reasonable amount of force will have any effect on the soft tissue where the bubbles are located. To use more force would require some sort of support structure to brace the carcase, and this would require sterilising. It is also likely that the ultrasound probe rocker assembly and saw mounting assembly would require redesign for the greater loads. In particular, the probe housing would require revision to prevent the higher forces being transferred through to the probe and causing damage.

Electrical stimulation of the carcase while sensing has been suggested. It is unlikely that this would be successful as the muscles would contract but the fat would not, and this may actually make the problem worse. Stimulation will also distort the carcase.

4.4 IMAGE ENHANCEMENT

There are situations where computer software can be used to enhance poor quality video or images. Unfortunately, the fat to air interface around the bubbles has the effect of almost completely reflecting the ultrasound image. This results in no image being available to enhance.

4.5 ALTERNATIVE SENSING TECHNOLOGY

Rather than trying to eliminate the air bubbles, another option is to find a form of sensing that is not significantly affected by the bubbles. This approach is clearly outside the scope of the existing project, but alternative technologies should be considered. At this point, FSA project members have not been able to identify any form of "off the shelf" technology that could simply replace the ultrasound presently being used. Detailed below are some of the technologies considered.

5.5.1 X-RAY

From a sensing point of view, this is a mature technology that is readily available. Examination of medical x-ray images suggests that finding the cut line is feasible, and is likely to be significantly better than the existing ultrasound. At this time, it is unknown whether scanning can be carried out fast enough to meet a reasonable cycle time and would require further investigation and trialing.

Assuming that the x-ray technology is suitable for imaging, there are some significant obstacles to applying this technology. The existing robot was sized based on the mass of the end effector with the compact lightweight ultrasound probe. X-ray will add significantly more mass and the existing robot is unlikely to be suitable. X-rays also present a serious health risk. It is likely that the entire splitting process will have to be carried out in a lead lined enclosure which would have to include roof and doors. For these reasons, if x-ray sensing is pursued, it may be more appropriate to use a custom designed and built machine, incorporating the shielding, than an industrial robot. The x-ray source can either be a low power isotope that can not be turned off, or an x-ray tube that requires an extremely high voltage cable that cannot be continually flexed. While these technical restraints should be able to be addressed, the solutions will be expensive, as will be the x-ray equipment. There are some smaller, low powered and less expensive x-ray tube sources that do not require the extra high voltage cable. These units, if applied suitably, may provide an adequate solution at an acceptable cost.

It should be noted that while the cost of x-ray sensing may make it uneconomic for this project, it appears to be the most available technology for non contact sensing for automated slaughter and boning processes. For this reason, it may be appropriate to use this project to explore the application of this technology for other areas within the processing industry.

5.5.2 OPTICAL

Optical Coherence Tomography is a medical sensing technology that uses infrared light to obtain images from within tissue. This technology is appealing as it is non contact and compact. At present, this technology does not provide adequate depth of penetration for application in this project. Research and development is being carried out to increase the depth of sensing, but it is unlikely that this technology will be available in the near future.

5.5.3 ACOUSTIC FEEDBACK

The acoustic attenuation of bone vs. soft tissue (muscle, fat) is a possible differentiating property which may be detected with sensors of low cost and ease of interfacing. Precise measures of attenuation are not available for the materials concerned at present. Propagation velocity which is (roughly) inversely proportional to attenuation reveals that tissue has a velocity propagation at 20 8C one half of that of bone (1980 m/sec vs. 4000 m/sec respectively (Kinsler, 1962)). An array of at least 2 acoustic sensors (hydrophones) could be tracked down the carcase and if located equidistant from a sound emitting vertebral column, would detect equal intensities. Any difference in the intensities would be due to asymmetry which could drive the saw appropriately.

An acoustic source injected into the vertebral column can be of a specific waveform if signal to noise is poor. An analogous solution is used for detecting abnormalities in bony structures of humans (Huang, 2000). Acoustic sources between 100 and 500 Hz were coupled to the sacrum and microphone signals coupled to each hip were analysed for coherence over the frequency range and a maximum deviation of 3 dB was found. An interesting economy of process may be to use the sound generated by the saw itself. At a constant drive speed a fundamental frequency will be present in the spectrum and sensors may be optimised for this.

It is envisioned that the hardware requirements for this form of sensing would be relatively compact, light weight, robust and inexpensive. Signal processing could be handled by existing computers further reducing implementation costs.

5.5.4 FORCE FEEDBACK

This proposed concept relies on measuring the lateral force on a guide plate or roller on each side of the feather bones. It is envisaged that the plates or rollers would be located in approximately the same location as the existing ultrasound probe. A force differential would be interpreted as the saw being off centre.

This concept is relatively simple and could readily be applied to the existing splitting saw and robot. It relies on the featherbones protruding, or at least able to be “felt” through the fat layer. It is unlikely that sensing would occur in the neck region and some form of stabilizing may be required.

This arrangement is also unlikely to be able to detect a gross error in positioning as the guides may both be on the one side of the centreline.

5.5.5 ROLLERS

Various attempts have been made to use rollers to force the carcase into alignment with splitting saws. One of the more successful arrangements was developed by FSA engineers on previous projects. The inverted carcase was suspended by four legs and the rollers pushed against the weight of the carcase. This had the effect of cradling and centring the carcase. This arrangement was reasonably effective, except when the carcase is well off line from hook placement, carcass shape and broken backs causing the centring effect to be lost.

An option for the robotic splitting saw would be to utilize internal and external rollers to centre the carcase. It is unknown if such an arrangement would be light enough to install on the existing robot.

5.5.6 NON-CONTACT ULTRASOUND

A non-contact ultrasound transducer has been developed, which is designed to receive data from a sample while correcting and compensating for the interference interface signals caused by not holding the probe in physical contact. While the ability of this form of ultrasound to function in air is encouraging, it is unknown if it will image through air pockets below the surface.

At present, this technology is being developed for burns victims and does not have enough penetration for the splitting saw application. If future development results in a greater sensing depth, this technology should be considered.

5.5.7 TELEROBOTICS/COBOTICS

Telerobotics is an area of automation where machinery or equipment is remotely controlled by an operator using a video link to monitor the activity. This technology is commonly used in the mining industry where underground machinery is remotely controlled using a combination of operator input and automation. Cobotics is similar, except the operator has force feedback control devices that allow him/her to feel what is happening at a remote operation. An example is a joystick that pushes back with an amount of force that is reduced but proportional to the force on an end effector of a robot.

These control technologies allow physically demanding, dangerous and unpleasant tasks to be carried out by people without the limitations of physical strength, age or sex. For example, older, injured or disabled workers could continue to work in an industry without physical limitation.

These two control concepts could be used separately or combined to allow an operator to remotely control the lateral movement of the splitting saw during the cut. The rest of the operation would be controlled by the existing automated system. As the operator is required for only part of the cycle, other appropriately timed tasks could also be undertaken.

6. CONCLUSION

This report concludes the design, manufacture, trialling, demonstration, installation and commissioning of the robotic Automatic Carcass Splitter commercial prototype.

A housing has been manufactured and fitted to an off-the-shelf medical ultrasound probe to allow it to function in an abattoir environment without loss of image quality. A protective cover for the robot has also been developed and installed on the robot. A steriliser design has been developed in conjunction with Ralph's Meat Company who was identified as a suitable site for installation of the prototype to conduct works trials.

The system was completed at Food Science Australia's Cannon Hill Facility and demonstrated to stakeholders from MLA and Ralph's, where it was agreed that the system was functioning to client satisfaction and that site installation should proceed. After investigation at Cannon Hill it was decided not to include a carcass stabilisation device in the commercial installation as the benefit the stabiliser provided could not justify the extra system complexity required to use it in the minimum space available at Ralph's.

During installation and commissioning at Ralph's it was found that severe ultrasound image degradation was occurring. This has been attributed to the upwards hide-puller causing the formation of subcutaneous bubbles between the carcass fat and muscle layers. Further investigation showed that this occurred with both upward and downward hide-pullers. To check system integrity hand-skinned animals similar to those at Cannon Hill were processed at Ralph's with comparable results.

A system cycle time of 35 seconds has not yet been achieved (currently 45 seconds) but areas have been identified to reduce time. This is dependent on agreed tool sterilisation procedures. Pseudo real-time communication with the ABB industrial robot has been achieved and all safety requirements for installation of a robotic control cell in an abattoir have been met. This has been verified by an external auditor.

Alternative sensing methods to provide saw position during cutting have been investigated and are presented as part of the recommendations. At this stage it is proposed to discuss these alternatives with the stakeholders.