AMPC

FINAL REPORT

Prototype development of machine to remove fat from beef striploins leaving a uniform thickness behind - Stage 2

FINAL REPORT

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1.0 EXECUTIVE SUMMARY

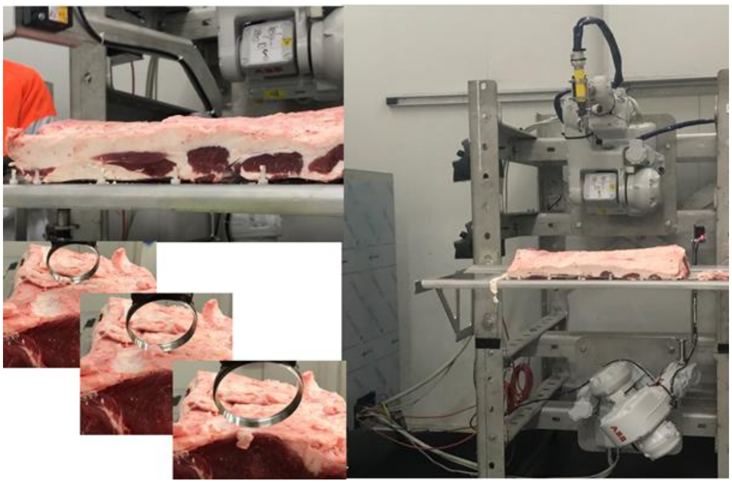
This project has achieved a first research capability solution for the automatic striploin fat trimming with the objective to leave a uniform layer of fat on beef striploin primal pieces.

During Stage 1 of the research feasibility, AMPC Project 2016-1032, the following was examined:

- Assessment of state-of-the-art solutions attempted by past R&D. Except for the ATTEC (now Frontmatec) Pork 3D fat trimmer, no successful previous work had been reported.
- The 3D port trimmer was tested during stage 1, revealing the design to be unsuitable for beef striploin primal pieces.
- Stage 1 investigated alternative options and presented a new approach to be researched under Stage 2.

Stage 2 has focused on a system solution to be implemented reaching a meat plant test, establishing the knowledge that allows a production prototype to be defined. The main task has been accommodating the variability in the striploin product and trimming process as well as customer specifications.

The value proposition has remained unchanged, except that the cost of labour has increased, and recruitment has become more difficult over the project period. A 100mm by 100mm fat of 1 mm thickness, weighs 8.3g. AU$ 260 is the estimated gain for 225,000 primal pieces, which is 60 carcasses per hour, 5 days per week 50 weeks per year on a single shift, with pricing of 15 AU$/Kg for beef striploin piece of 200mm wide and 470mm correctly trimmed saving 1 mm of fat on the primal. Over two shifts at 120 carcasses per hour, this estimate is over one million Australian Dollars/year.



The project has reached its objective to implement a first automatic solution for trimming striploin primal pieces using ultrasonic and laser measurement of meat thickness and fat integrated with robotics. The system has shown the pathway to a Stage 3 development to achieve a production prototype. A first trial in an Australian beef plant has revealed important findings in support of improvements and developments that overcome performance limitations of the first developed solution. The system as implemented may be used for extended trials to reach detailed specification improving on the definition for the production prototype derived from the R&D to date.

2.0 INTRODUCTION

Manual fat trimming is a labour intensive and an inaccurate process, especially when a uniform layer of fat is to be left to 1-millimetre tolerance on a piece of striploin beef, where the precise location of the fat-lean cannot be visually observed by an operator. There is significant skill applied (Figure 1), and the requirement for wearing safety gloved also reduces, if not making it impossible, to use human touch to gauge the fat-lean interface from the fat side as a way of applying a degree of control during the trimming actions, to leave a uniform fat layer behind on the lean meat. The R&D in this project has been targeting an automated solution as a first outcome for the industry establishing the approach and defining the components that may be integrated for automatic fat trimming to leaves a uniform layer of fat on beef striploin primal pieces.

The Stage 1 feasibility examined the variability of fat cover on beef striploins (Figure 2), taking example cuts from Australian meat plants. Current capability in performing such a task manually on a production line was also documented. Evaluation of fat cover sensing technology using ultrasonic, optical and mechanical devises with quantification of their limitations was reviewed and ultrasonic sensing was identified to meet the requirements in accuracy, speed and integration possibilities with different mechanical trimming arrangements. An important aim of the feasibility was the trimming methods for leaving a uniform layer behind leading to the definition of specification and approach for a validated concept for an automation solution that can achieve uniform fat trimming (UFT).

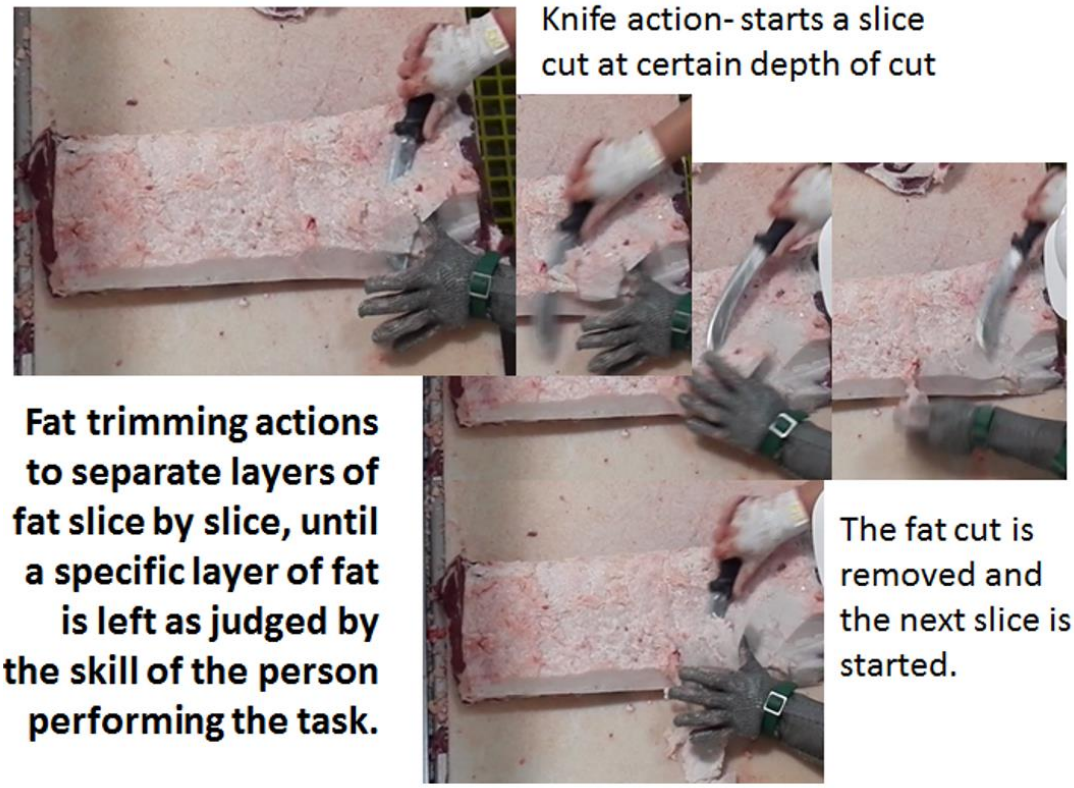


Figure 1: Manual trimming.

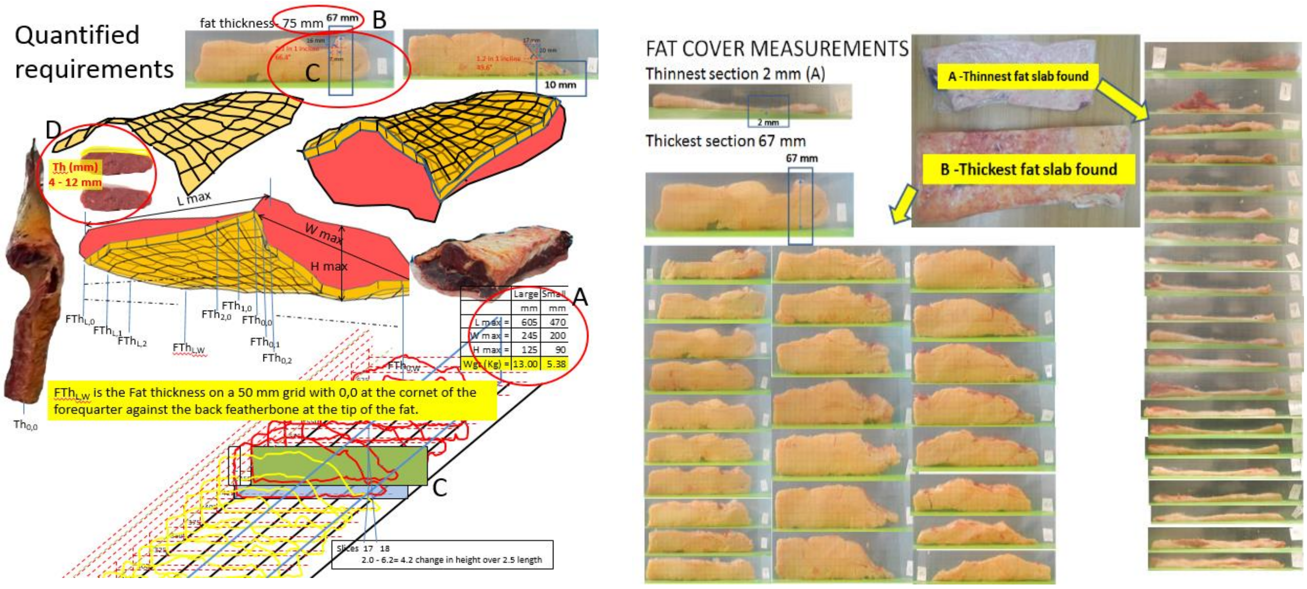


Figure 2: Fat cover variability on beef striploins in Australia.

Stage 2 has defined a robotic approach for uniform fat trimming(UFT) and Figure 3 shows the concept for a solution that may form the basis of a production machine.

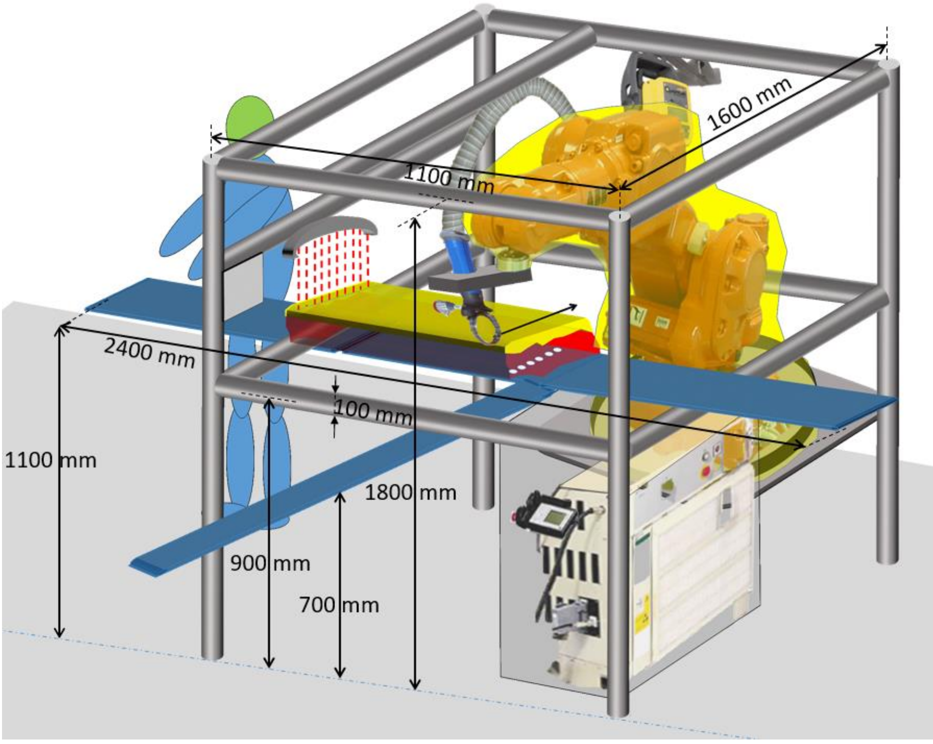


Figure 3: Overview of the UFT system for boneless beef striploin primal

The outcome of Stage 2 in reaching the basis for such a solution is presented in this final report.

3.0 PROJECT OBJECTIVES

- To develop a full size first system for striploin fat trimming, leaving a uniform layer of fat behind, using the results from AMPC project 2016-1032.
- To trial the machine to validate the capability against specifications, requiring 6mm, 8mm, 12mm and 16mm fat thickness, uniformly over the striploin primal.
- To quantify benefits in yields and key economic drivers.
- To reach a machine design solution as a production prototype and report detailing results and the benefits

4.0 METHODOLOGY

The methodology of the project has evolved during the project based on the milestone results and the technology capabilities researched using lower cost implementation to ensure an affordable outcome.

The approach included the following:

- Establish capabilities in sensing for measuring fat thickness in manner that can be referenced in 3D space as input to an automated trimming system. Ultrasonic and laser measuring units have been used.
- A robotic approach using a modified trimming tool, adapted for use with an industrial robot.
- An arrangement that provides for robotic sensing and cutting as a two-arm and cost effective first solution.
- Based on the developments and trials of the project a production prototype may be defined with the anticipation of its implementation during a Stage 3 project, involving a broader team of organisations, providing also the process for commercialisation.

5.0 PROJECT OUTCOMES

Stage 2 has achieved the following:

- Evaluation of fat trimming tool based on the requirements of the project, defining a 55mm diameter rotary blade with a conic profile circular tip Bettcher trimmer for the purposes of first implementation. A larger diameter tool is envisaged for Stage 3, the specification of which has been discussed with Bettcher USA.
- Evaluation and capability assessment of an ultrasonic sensor of low cost for measuring meat thickness. The evaluations have used a robotic system and a purpose designed holding plate for the striploin meat to rest on, whilst the sensor performs measurements from below the meat. See Figure 4.
- A low-cost laser measurement unit has been defined, also integrated with the robot performing ultrasonic measurements, to determine the fat cover. The measurements are referenced to the base tray as in Figure 4.
- The system has been integrated in the first robotic set up for fat trimming as in Figure 5, in position for plant a first trial at an Australian plant marking the end of the project.

Figure 4: Ultrasonic and laser measurements arrangements.

Figure 5: Two-arm robot arrangement at USQ (left) and in plant trials (right).

Figure 6 defines the approach to implementation of a first production protype based on the Stage 3 developments.

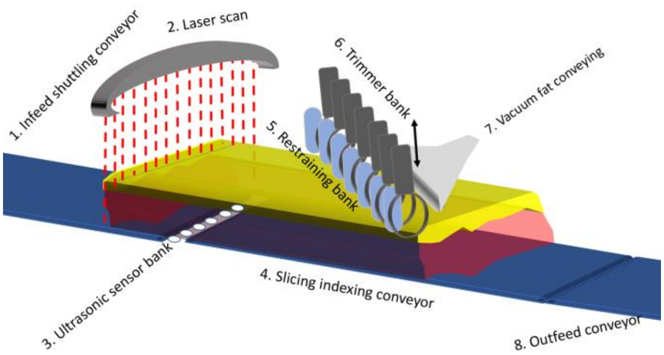


Figure 6: Production prototype approach.

The following provided a full account of the project progress and outcome.

5.1 Experimentation following Stage 1 outcomes in AMPC project 2016- 1032.

Trial were conducted with sensors, including mechanical probing, but the most promising is ultrasonic sensing for determining the position of fat and lean interface operating from the lean side. See Figure 7.

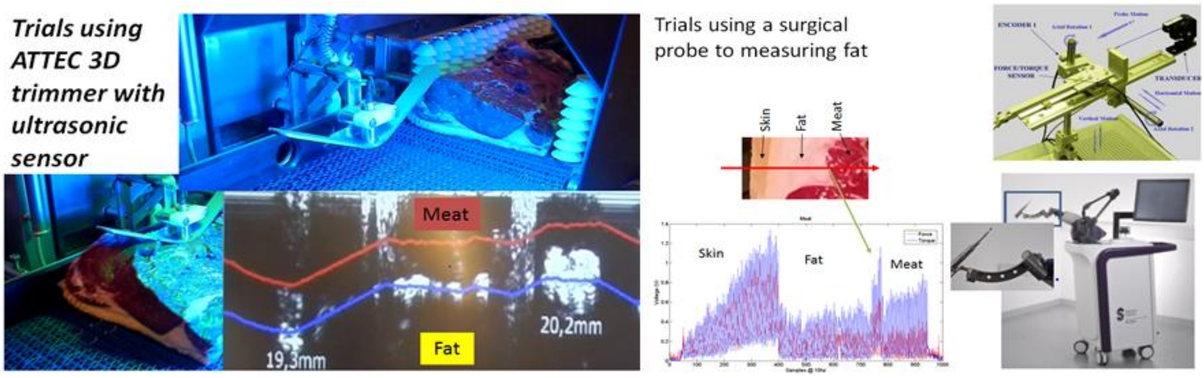


Figure 7: Sensing processes for fat-lean interface

Fat on beef striploins can, in some sections, be delaminate or have air gaps (bubbles) within their structure. The sensing approach measuring fat-lean profile from the lean side, as well as trimming the fat under cross sectional pressure minimizes or avoids complications related to delamination of air bubbles.

The work highlighted an important aspect of the sensing process, which is the requirement for a datum relative to the striploin primal piece in the 3D space. It is proposed to use computer vision or laser imaging to reference the cut paths to achieve trimming from ultrasonic information to the physical set up relating to specific striploin pieces being processed.

The process of fat separation may be achieved by a variety of tools. Reciprocating blades or pair of blades working in opposition to each other, where various forms of blade tips are also used have been seen in previous evaluations reported. Rotating blade can achieve separation also, commonly used in a variety of machine and powered hand tools.

Evaluations under considered trimming options, with practical fat trimming of Beef Striploin attempted in two specific cases, the wizard trimmer and the static "piano" type blades of the ATTEC 3D trimmer.

The wizard trimmer has capability to remove fat in thicknesses as low as 1 mm and as thick as 12 mm in a single pass at speeds higher than 0.3 m/s. The ATTEC 3D trimmer can achieve the same speed of trimming with static blades, however, trials suggest that the thinnest layer is 2.5 mm as a minimum, but the thickest is 20 mm, due to the machine design and construction constraints.

In stage 1, trimming capability in current machines or tools were also reviewed. These included the ATTEC 3D Fat Trimmer for pork loins and the wizard hand trimming tools available from companies such as Bettcher or Freund.

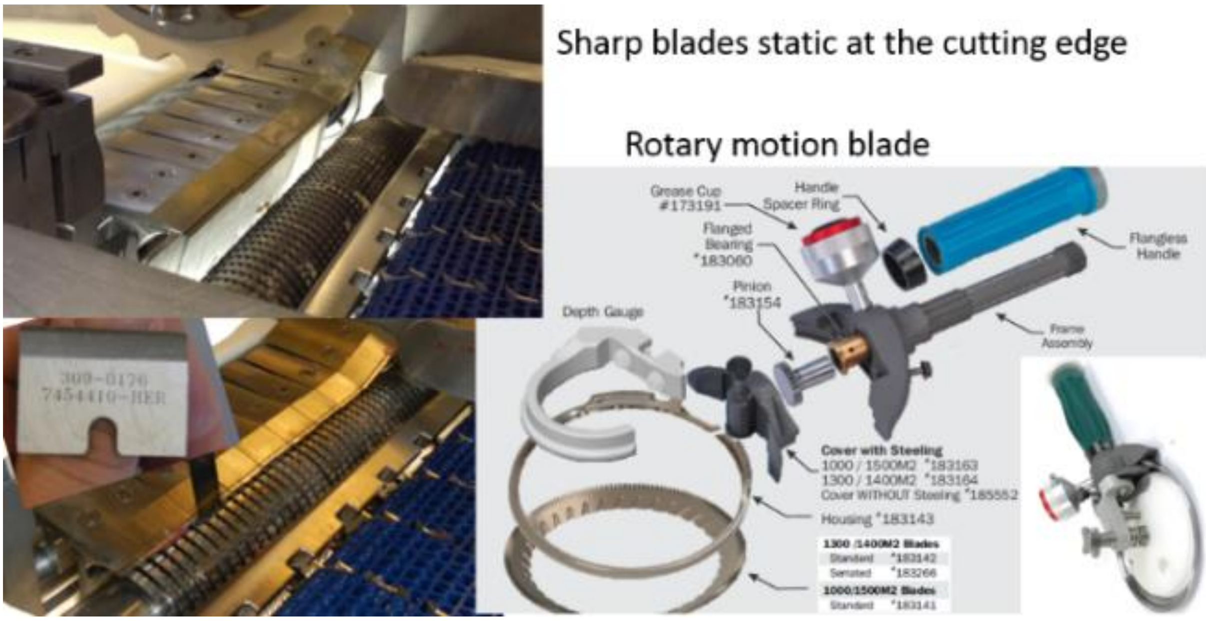


Figure 8: Current trimming capability.

Fat trimming leaving a uniform layer behind requires the change of cut thickness as the fat trimming process is being executed. The evaluation concluded that both methods (the wizard rotating cutter and the ATTEC static "piano" blades) may be used for trimming fat; however, further evaluations point to an open blade wizard rotating cutter can supports the necessary controllable process given that thicker than 20mm fat will need to be removed in certain cases. Additionally, there is a need to change the angle of line the cutting to achieve closer to a truly three-dimension contour of separation to meet the requirement, a feature that is limiting in the "piano" blade arrangement. It is thus concluded that the approach to reach a working solution requires 3D manipulation of the trimming tool.

A trimming used with a robotic or a 3D manipulation was to provide the basis for automation with the capability of removing fat in strips of 15-20 mm along the width of a striploin to a resolution of 1 mm at a speed of 20-25 mm/s, Figure 9. The Bettcher trimmer was established as the tool for the Stage 2.

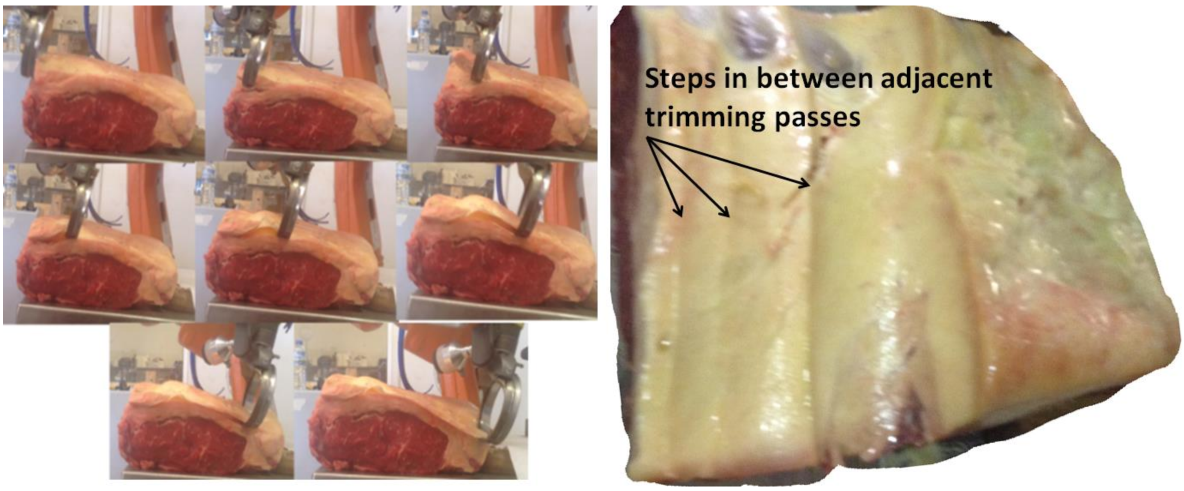


Figure 9: Steps in between trimming actions.

5.2 Ultrasonic subsystem

The sensing capability from the ATTEC 3D pork trimmer was adapted for beef and the capability tested using varying thickness beef striploin sections. Figure 10 shows the sensor system developed. principle of ultrasonic sensor operation implemented for this project.

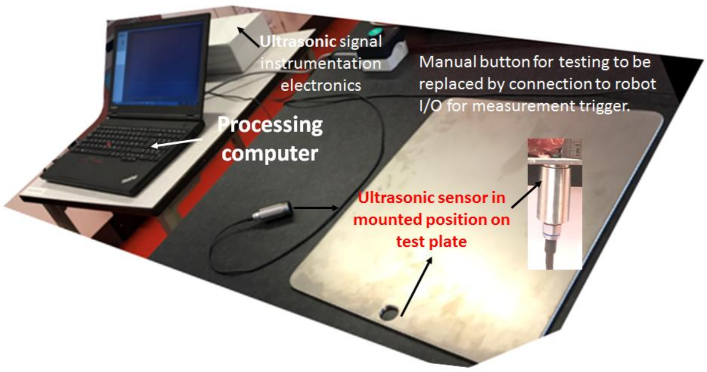


Figure 10: Ultrasonic sensing system for beef fat-lean interface measurements.

The system combined ultrasonic emitter – sensor with the corresponding instrumentation and signal communication, a laptop computer for signal processing, analyses and interpretation. A trigger switch is integrated for testing. The activation of the switch triggers a measurement that represents the meat thickened from the face of the sensor to the edge of the main back fat from below.

Figure 11 shows the functionality of the ultrasonic sensor. The emission of ultrasounds reflected through the meat by fat layers are processed using DMRI software that filters the measurement of interest.

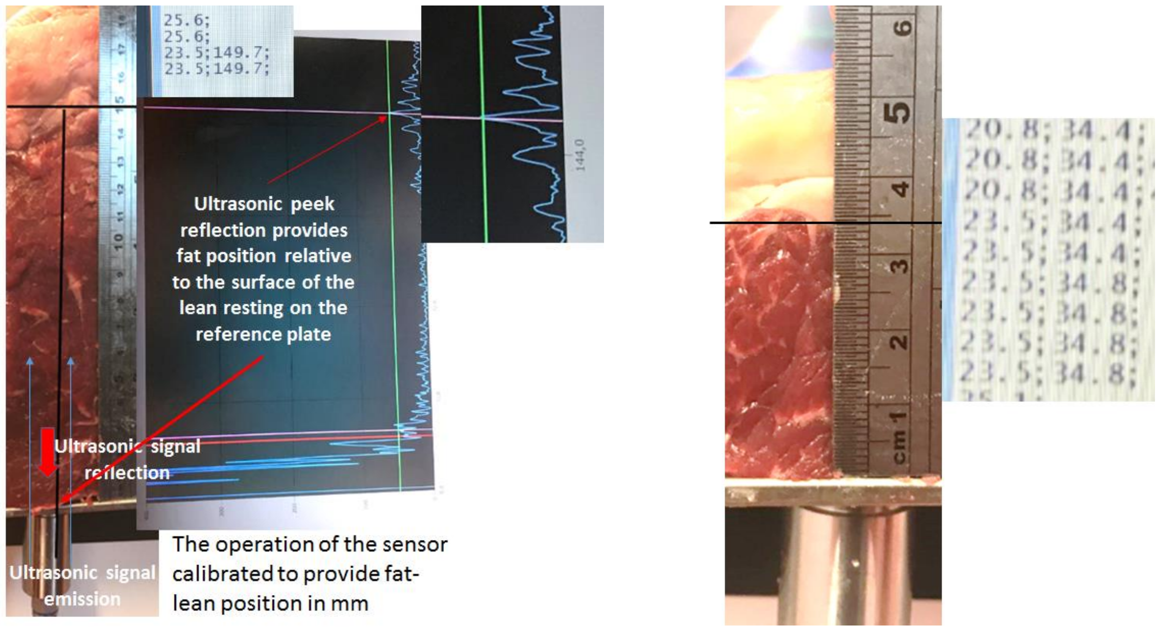


Figure 11: Ultrasonic sensing system for beef fat-lean interface measurements.

The system for measurement developed with DMRI was tested and Figure 10 shows the measurement a thickness of meat of 34.4 mm. The measurements were taken repeatedly by the system and the numbers showed consistency.

A physical check using a ruler also confirmed the measurement.

Figure 12 shows the test measurements for sections ranging from 30 mm to 150 mm. The results confirm that capability and the solution for measuring fat lean interface has been reached ready for integration.

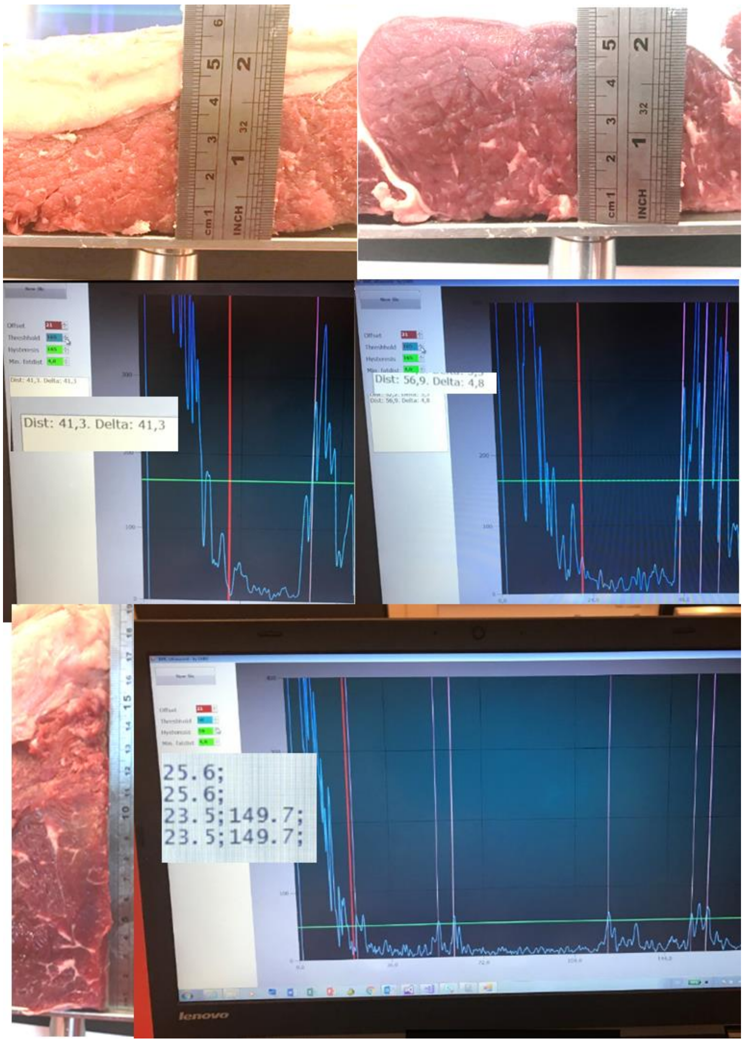


Figure 12: Ultrasonic sensing test results for the range of striploin thicknesses.

5.3 Trimming tool

A basic integrated set up implemented with ABB (Melbourne) tested the trimming capability with the ABB IRB 140 industrial robot Figure 13. This was to validate the core concept the cell in Figure 14.

Trials reached conclusion that the ABB IRB 140 may be implemented with enhancements to reach a first integrated cell.

The bracket has been manufactured to allow addition of guiding and restraining tools that would be required for fine trimming of striploin fat.

The tool mounting also allows for the attachment of additional mounting brackets for sensors such as the ultrasonic unit. For trials that support the integration process under milestone 7.

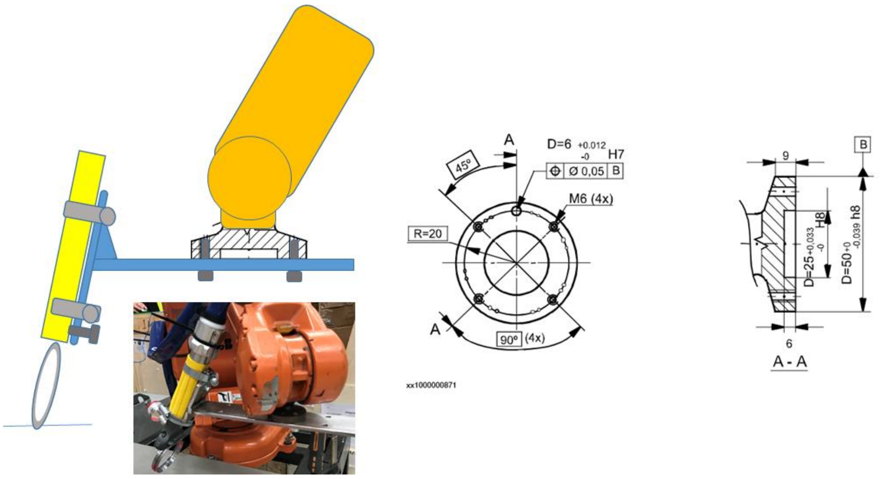


Figure 13: Bettcher tool mounting bracket as attached to the ABB IRB 140 robot.

The research at this stage established the process of trimming was defined in steps after scanning the whole primal and sensing the fat layer from the meat side.

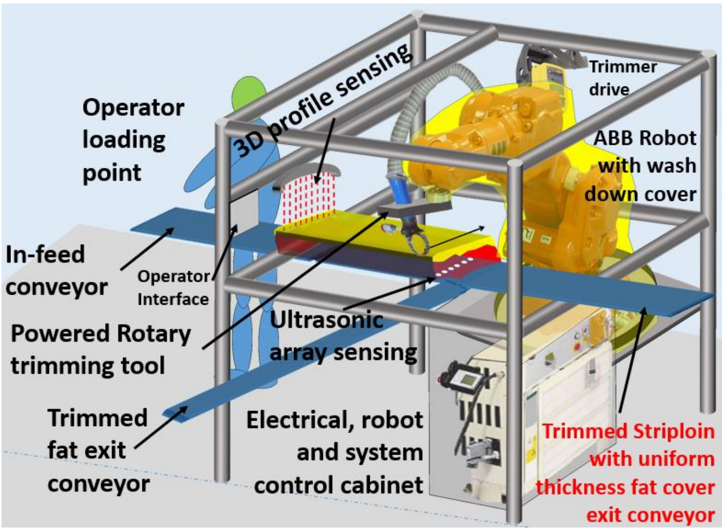


Figure 14: System over with including major modules.

The overall approach to the implementation of a Uniform Fat Trimming (UFT) solution was established, with reference to Figure 14, as follows:

- Operator loads the fully trimmed and de-boned striploin on the infeed-conveyor with the fat up.
- The infeed conveyor delivers the striploin through a 3D surface profile and measurement unit.
- The 3D profile is analysed for surface fat cover position referencing it to the conveyor belt surface carrying the striploin.
- An ultrasonic measuring unit integrated with the conveyor at the trimming point is to measure the thickness of the meat and the position of the fat lean interface from below, across the width of the striploin.
- The in-feed conveyor is to be in three separate and controllable sections: the section at the loading point, ending at the entry to the 3D scanner; the trimming section that ends at the point of robot trimming, and the exit section that is controlled with the trimming section allowing the exit of the strip loin once it is fully trimmed (Figure 14).
- The conveyor carrying the striploin to the trimming point, from the in-feed conveyor after the 3D profile scanner, is to be an indexing conveyor also with continuous motion function. The programmable indexing pitch capability allows the striploin fat to be moved across the width, whilst the next section in being scanned ultrasonically. The belt is to move the striploin in a continuous mode passed the 3D scanner at uniform speed, allowing the striploin measurement for 3D profiling as one mode, and indexing is steps (X mm in the range 10 mm to 20 mm: nominally 15 mm). X is to be programmed and fixed during trials.
- A trimming tool manipulated by an ABB 140 (or similar) is to be programmed to cut fat off the striploin from above, using the 3D profile and ultrasonic measurement information in strips of X.
- The trimming is to be across the width in incremented indexes that occur under robot program control. This plus the robot speed that is to be at 100mm/s, determine the throughput, estimated at 30 pieces per hour per robot cell.
- The intent is that the ultrasonic scan is performed as soon as the leading edge of the striploin arrives at the point above the ultrasonic sensor array, then the primal is indexed forward by the specified fixed distance (X) for the next measurement, whilst the trimming takes place on the section already measured. The process continues to the end of the trimming in steps of X.
- The trimmed fat is to exit on a separate conveyor as each fat strip is removed. It may be that the trimming of a given section of the striploin requires two or more passes depending on the thickness of the fat cover.
- No more than two passes would be envisaged, when the fat thickness is over 40 mm.

The basic robotic module was set up for further testing as in Figure 15.

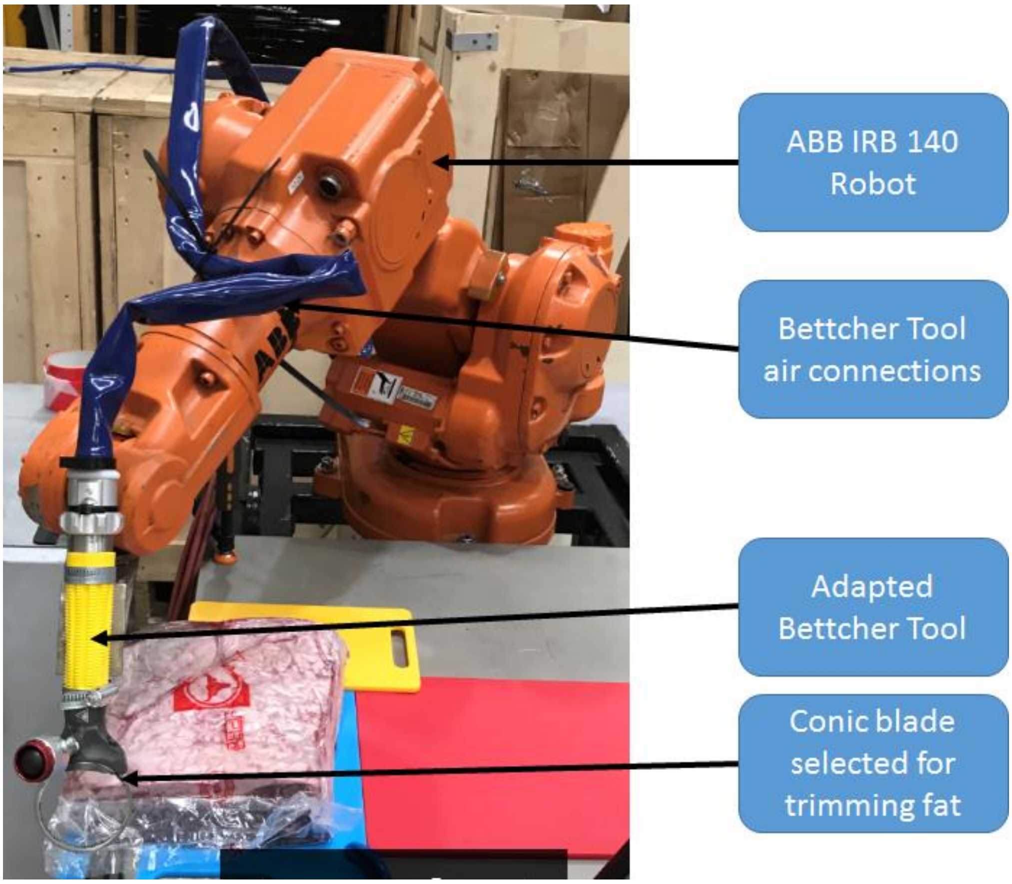


Figure 15: Set up for the coarse trimming trial with the ABB IRB 140 robot.

Specific checks were performed to ensure the suitability of the robot for the task including payload, speed of travel and reach. ABB Australia and FPE have provided useful input to the project, which is gratefully acknowledged.

With the cell set up as in Figure 16, trimming trials were conducted to show the capability in respect of the following:

- The Bettcher tool and the blade combined have the capability to cut through fat leaving the appropriate quality of finish. Trials suggest that a strip at intervals of 20 mm will result in an optimum surface finish without hindering cycle time. See Figure 4.

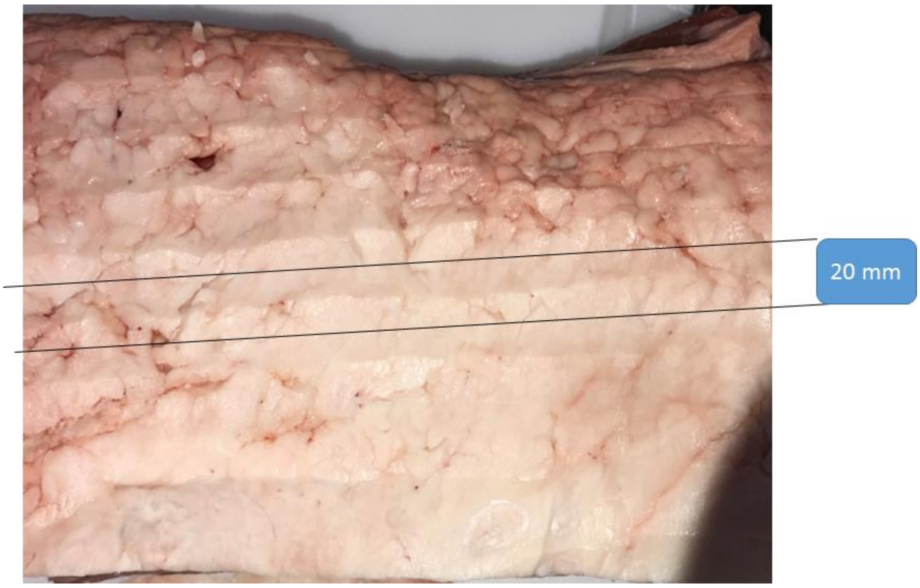


Figure 16: Coarse trimming results.

- The trimming pitch of 20 mm also leaves a profile that has minimal step change between slicing lines when viewed from the end, See Figure 17.

Figure 17: Slices after coarse trimming (no sensing) of the primal piece in Figure 4.

- Minimum thickness and maximum thickness using the blade profile are important capabilities and were tested during the trials. The capability of the physical trimming as desired with sensor integrated, supported by the basic robot cell arrangement in Figure 16 used for coarse trimming. Figure 18 shows the structured test results from trimming thin layers and a thick section of fat. The blade and the cell set up have been tested for the capability of 1-30 mm thick fat depth cutting.

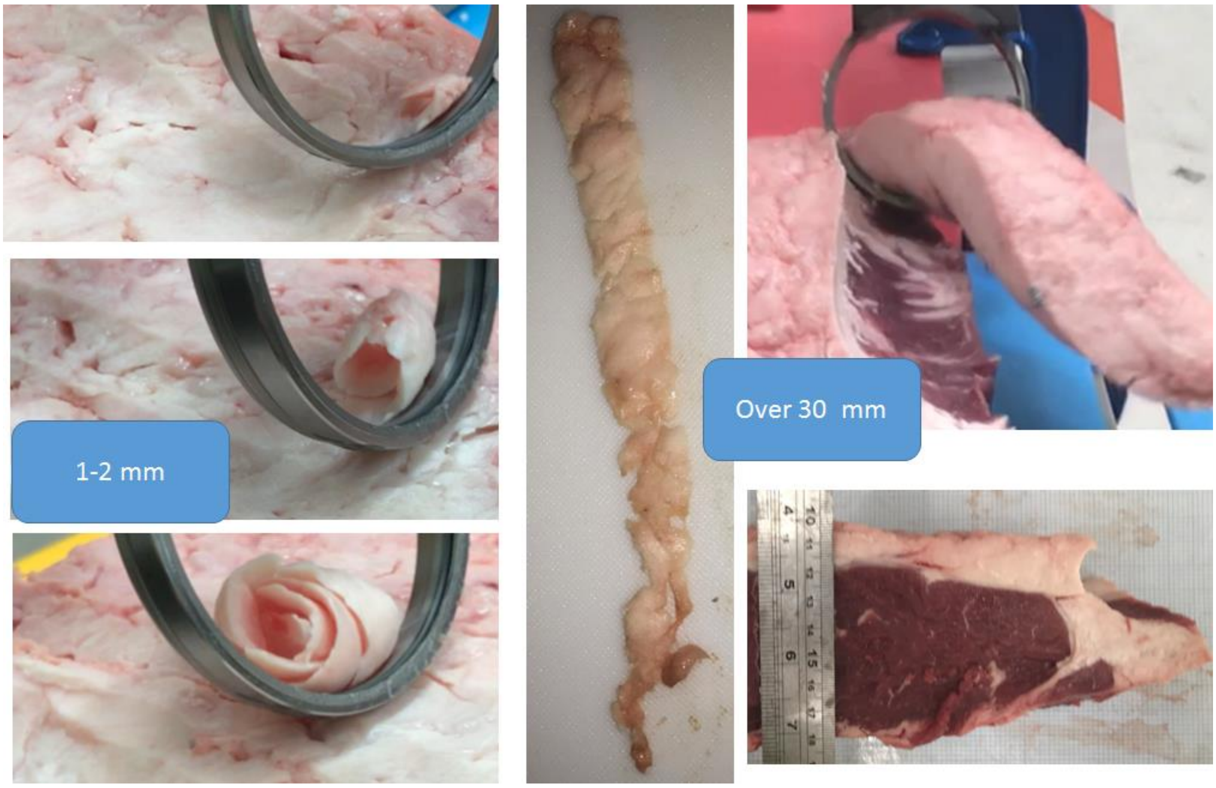


Figure 18: Trimming capability test reaching the range 1 mm – 30 mm.

The set up at ABB with the IRB 140 and the Bettcher tool provides for the Coarse cutting of fat successfully based on trials conducted.

5.4 Trimming and sensing process

The process of fat trimming of beef striploin to leave a uniform layer behind requires the following sensory inputs:

- Measurements of the fat surface profile
- Measurements of overall dimensions of the primal piece
- Measurements of the meat thickness as a means of generating the fat-meat interface profile measurements.

Evaluation of the sensing process for trimming accommodation the primal piece profile and ultrasonic sensing probe revealed the following:

- The fat surface profile measurement needs to match, at minimum, the trimming pitch of 20 mm, see Figure 19. The measurement of fat height (FH in mm) is needed above the surface on which the striploin is sitting.

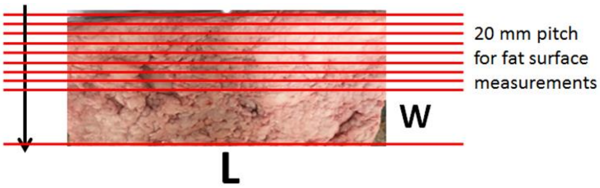


Figure 19: Fat measurement points at 20 mm pitch.

The measurement system for determining the fat height (FH) and the overall dimensions of the primal used the SICK 1000 laser system but was replaced by a much simpler and lower cost solution using the SICK OD range sensor. The set up with the SIC 1000 laser system evaluated had a resolution of better than 1 mm, which is the requirement for fine trimming. See Figure 20.

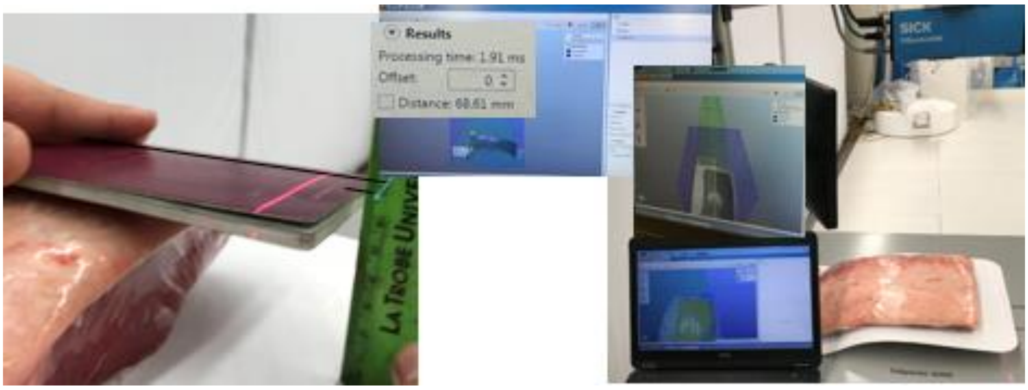


Figure 20: Fat measurement profile measurement set up using SICK TriSpector 1000 laser unit.

- Evaluation of the ultrasonic probe in the configuration of Figure 21 was made, using the IRB 140 in a similar set up to that illustrated. The consistency of the measurements confirmed the previously tested for a 1 mm accuracy measurement of the position of the fat-meat interface or the thickness of the meat (MT or MH – Meat Height).
- The sliding of sensor over the meat results in a build-up meat residue on the leading edge of the sensor in the arrangement of Figure 21. To avoid this, the robot needed to position the sensor using a plate carrier with features as shown from below. The probe to moved up and down to discrete measurement points, approaching the meat from below, touching the meat for each measurement and then separating away and indexing to the next measurement position.

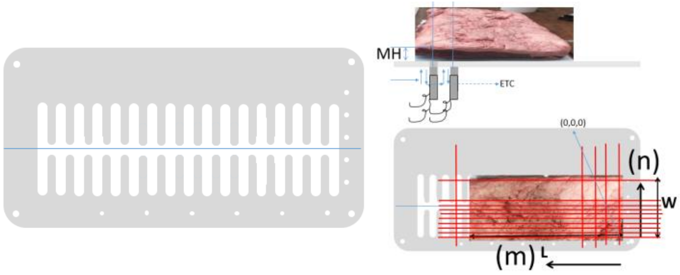


Figure 21: Striploin carrier plate with features for measurement of MT above the plate.

- With the probe cross section being 20 mm and the meat requiring support the pitch for ultrasonic measurements is set at 40 mm. The measurement of meat height (MT) above the surface on which the meat is sitting may be measured on a pitch of 40 mm along the length of the primal and 20 mm steps along the width, Figure 22.

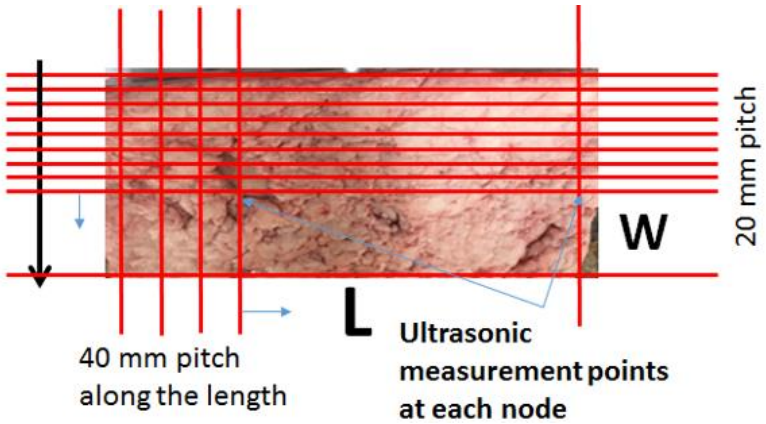


Figure 22: Ultrasonic measurement points at each node giving meat thickness or height MT

The sensing process has used the combined capabilities of the SICK sensor and the Ultrasonic Sensor, as developed for the project.

In summary, the measurements from the sensors define the profile of the primal piece as follows:

- MT(m,n) – the measurement of the meat height above the carrier plate at nodes 20 mm apart across the width of the primal and 40 mm intervals along the length, at each measurement node (m,n) by ultrasound (see Figures 21 and 22). The pitch of 40 mm has since been increased to 100 mm to eliminate irregular path following and increase the speed of measurement cycle.
- FH(m,n) – the measurement of the fat height above the carrier plate at nodes 20 mm apart across the width of the primal and 40 mm intervals along the length, at each measurement node (m,n) by SICK laser (see Figures 21 and 22).
- Measurements of Width (W) and Height (H) as well as the location of meat in the X, Y, Z space.

5.4.1 Two robot arrangement for integration of sensing and trimming

A twin robot cell was defined to perform the trimming, one robot dedicated to manipulation and positioning of the sensors and the other for trimming.

Figure 23 shows the approach as conceived, which also allows for complex angular positioning of the probe or the cutter if such is found to be necessary.

The striploin primal placed on the slotted carrier is scanned by the ultrasonic sensor and the OD sensor. The process would result in the measurement of fat profile at the specific nodes referenced to the zero point (Figure 23).

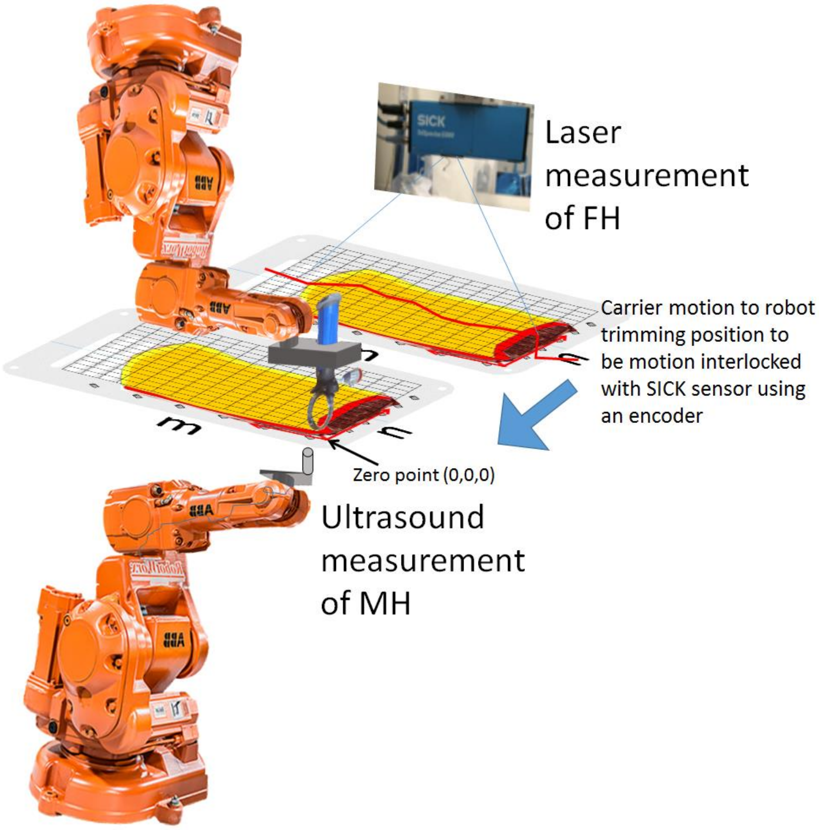


Figure 23: Set up for UFT trimming trial cell using two ABB IRB 140 robot.

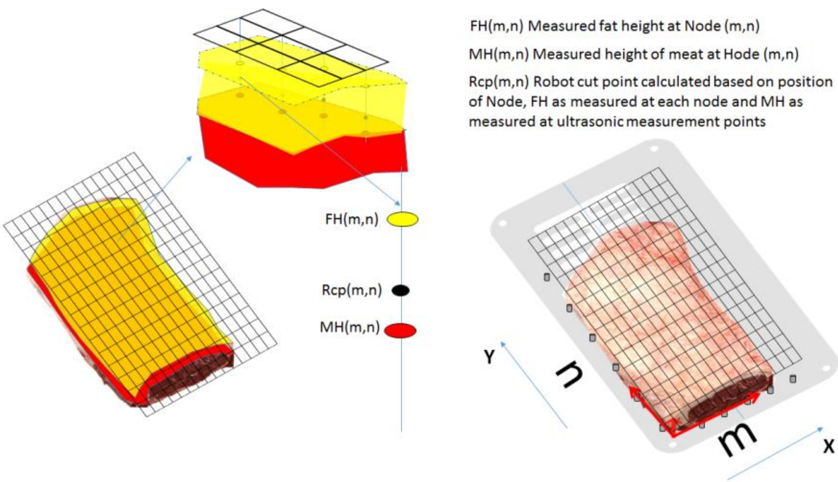


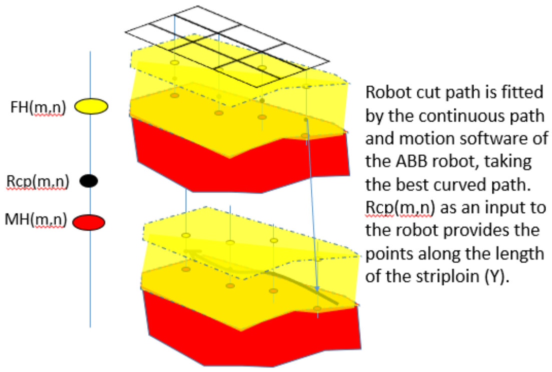
Figure 24: Determination of inputs for the robot cut paths.

Figure 24 presents the process for robot cut paths determination. At each node, two measurements referenced to the zero point are determined by the sensing subsystems mentioned earlier. The two measurements are FH and MT (or MH) at each node. The nodes being m and n, with M and N being the maximum number of nodes for the primal of width W and length L.

M is W/20+1 as an integer, 20 mm being the pitch at which trimming occurs. The extra single node allows for the trimming of the primal edge at the long edge at the last trimming pass.

N is L/40+2 as an integer, 40 mm being the pitch at which ultrasound measurements of MT are made at each node on the grid as illustrated. The extra 2 nodes for n=-1 and n=L/40 as an integer allow for the robot path to start from the edge of the primal at the start of the trimming action and to overshoot at the end of the fat cutting.

For each node along the Y axis, or along the length of the primal, Rcp (Figure 25) is calculated by adding 8, 12 or 16 mm to MH) depending on the desired fat thickness which is to be left behind.



<u>Figure 25: Determination of the robot cut paths for fine trimming.</u>

5.4.2 Next steps to reach integration of the robotic trimming of striploins

The understanding and the capability of sub-systems for trimming of beef striploin primal pieces was established. The trials with subsystems demonstrated the following capabilities, ready for integration and testing in a host plant:

- Ultrasonic capability for measuring fat meat interface.
- Laser sensing of primal dimensions
- Trimming capability using an ABB robot with the Bettcher powered rotary cutter.
- Method of robot path generation for Uniform fat trimming against fat cover specification.

Trials and measurement indicated that the following rules for Robot cut path points are the appropriate basis for implementation of the trimming scheme:

Note that MT(1,n) to MT(3,n) is not measured for all n due to indeterministic fat cover and the same for MT(M-3,n) to MT(M,n) for all n. In these case specific rules below determine Rcp for the corresponding grid points, Figure 26.

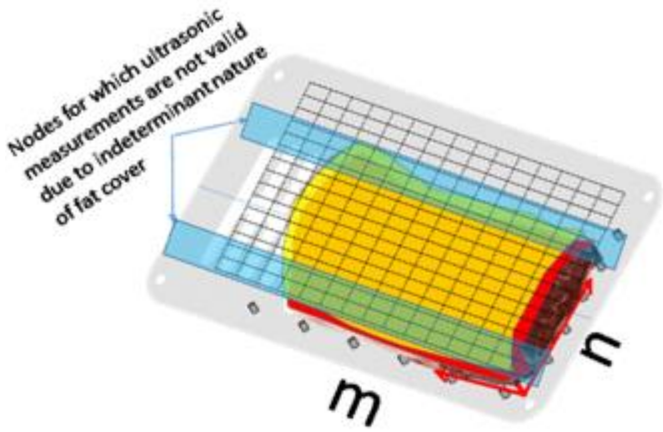


Figure 26: Blue zones show nodes for which MT (meat height is not measured).

a) Rcp(m,n) = FH – 5 mm for m=1 to 3 and for all n= 1 to N; the first trimming action at m=1 having the blade centred on the edge of the primal.

b) Rcp(m,n) = [MT(m,n) + dT], where dT is the desired fat cover thickness for m= 4 to (M-3) and all n= 1 to N.

c) Rcp(M-3,n) = [MT(M-4,n)]+[FH(M-3,n)/3] unless [FH(M-3,n)-MT(M-4,n)]/3 is greater than dT, in which case use Rcp= MT(M-4,n)+dT for all n.

d) Rcp(M-2,n) = [MT(M-4,n)]+[FH(M-2,n)/3] unless [FH(M-2,n)-MT(M-4,n)]/3 is greater than dT, in which case use Rcp= MT(M-4,n)+dT, for all n.

e) Rcp(M-1,n) = [MT(M-4,n)]+[FH(M-1,n)/3] unless [FH(M-1,n)-MT(M-4,n)]/3 is greater than dT, in which case use Rcp= MT(M-4,n)+dT, for all n.

f) Rcp(M,n) = Rcp(M-1,n) for all n.

The above have been the result of dissections and measurements of several primal pieces, which show the indeterminant nature of the fat cover long the long edges of the striploin pieces, representing a 50-mm wide strip section on both sides. To this end only the centre section of the primal is ultrasound measured.

In the event that fat thickness cover at some nodes, FT(m,n)=[FH(m,n) - MT(m,n)] are greater than (dT+30) mm, 30mm being the maximum fat removal capability of the trimming tool, then two or more passes will be made with dT set to a value of (30-dT, the desired final fat thickness cover) for the nodes where (FT(m,n)-(MT(m,n)-dT)>30 mm.

It is possible that ultrasonic measurements can be incorrect or out of range due to unpredictable anomalies in meat or sensor contact or ultrasound behaviour. In such cases Rcp(m,n) is to be cross referenced with adjacent note values to ensure safety in the process of path fitting. Such checks have been the subject for integration as part of implementation of safety protocols during robot motion task programming.

5.4.3 Integration of the robot with sensors and trimmer tool

The first integration process has involved the design and production of a multi-head end-effector that can carry the sensors and the cutting tool. The approach to this design ensures that the geometric referencing of the meat in the robot work envelope requires little co-ordinate transformation of the measurement data for generating the cut paths for trimming. There is also direct referencing of the Ultrasonic measurements of MT (or MH) and the OD Laser measurements FH. Figure 27 shows the physically integrated sensing units with the trimming tool all as one end-effector attached to the IRB 140 robot.

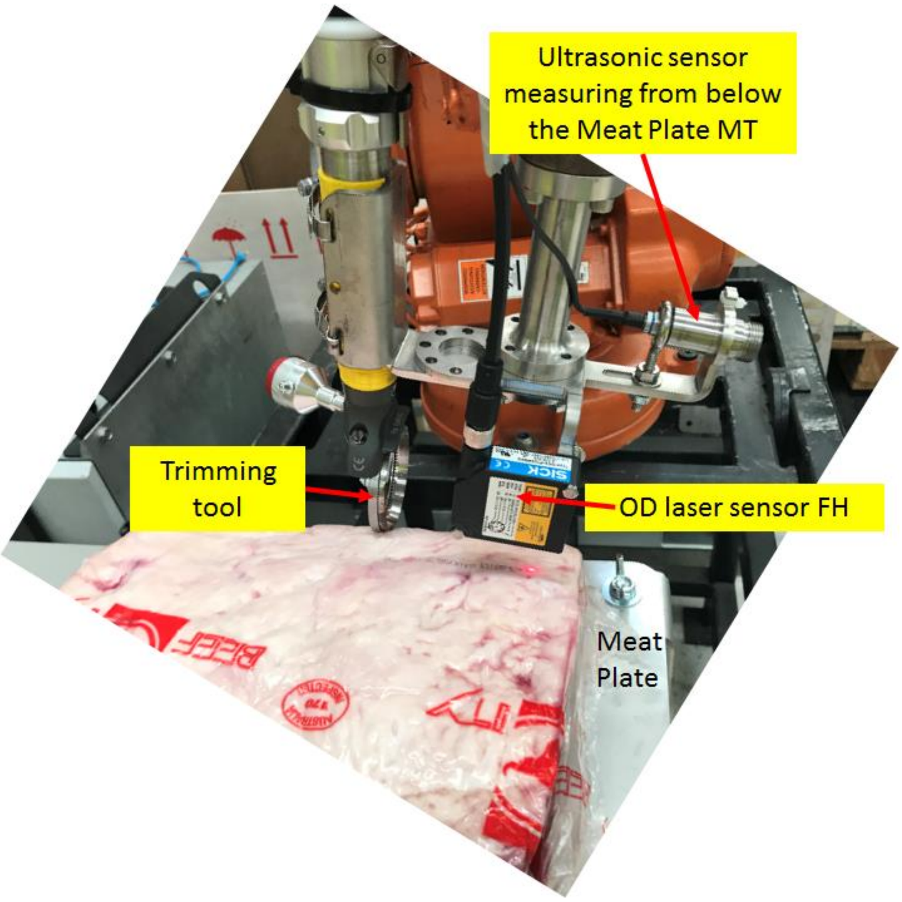


Figure 27: Physical integration of the end-effector.

Past trials demonstrated that ultrasonic sensing can only be reliable with a point contact at specific nodes (positions below the meat). The carrier plate was improved to the arrangement that allows the meat to be sensed for meat thickness or height along the length of the striploin. The carrier plate and the subsystems integrated with the robot are shown in Figure 28.

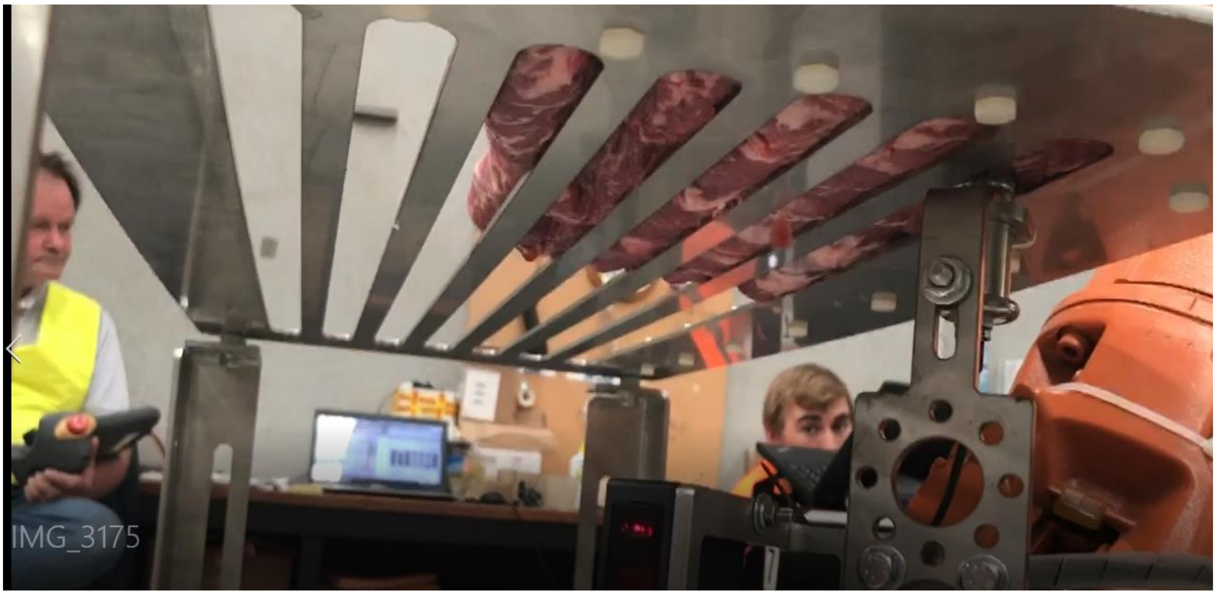


Figure 28: Measuring MT (Meat Thickness) with ultrasonic sensor from below.

The integrated tool head provides referencing of the positions measured directly to the robot thus avoiding complex co-ordinate transformation in the geometric 3D space.

The OD sensor is used by the robot to profile the fat height as in Figure 29.

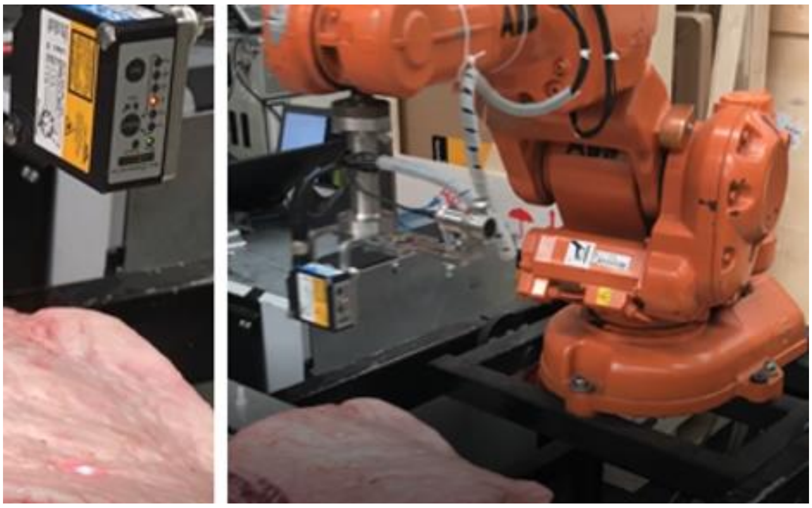


Figure 29: Measuring FH (Fat Height) with SICK OD sensor from above.

The OD sensor data and the Ultrasonic measurements were collected in one computer, and using the PC interface to the robot, the Data Integration provides Rcp (Robot cut point) at the node of interest. The nodes are on a 37 mm by 40 mm grid over the surface of the striploin referenced to placement co-ordinates of the meat on the plate. This reference point is shown in Figure 30 in red.

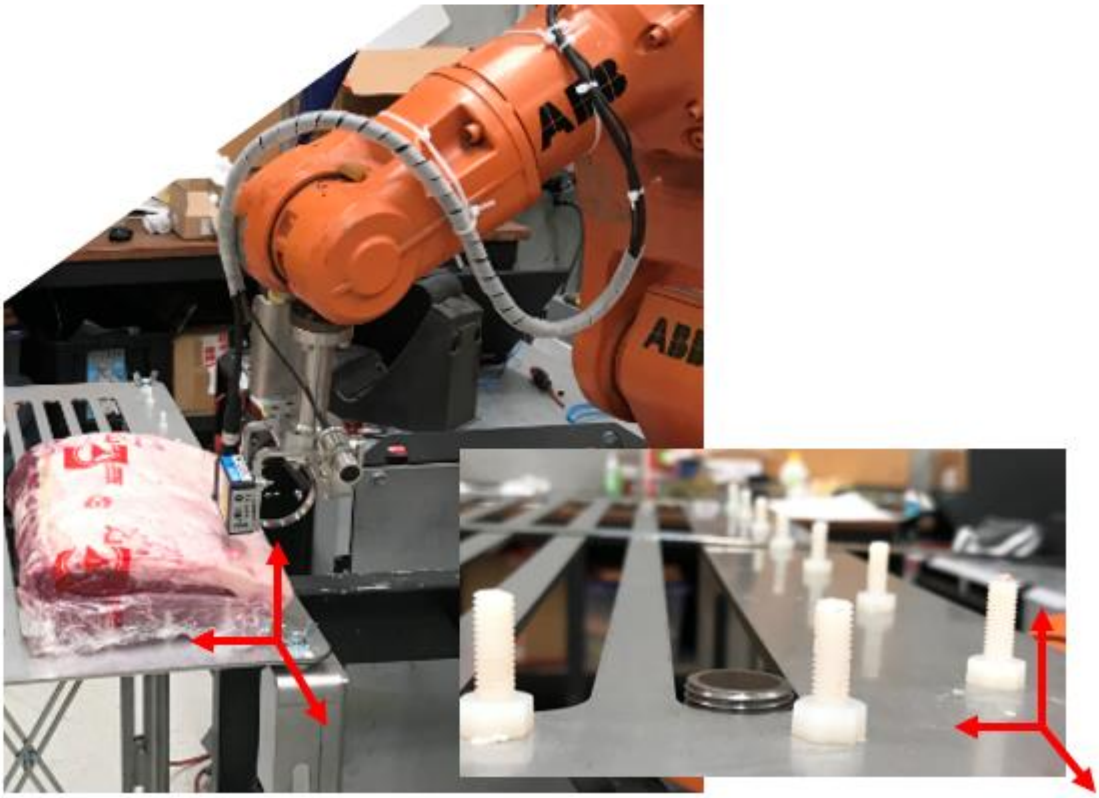


Figure 30: Integrated end-effector co-ordinate reference to meat plate.

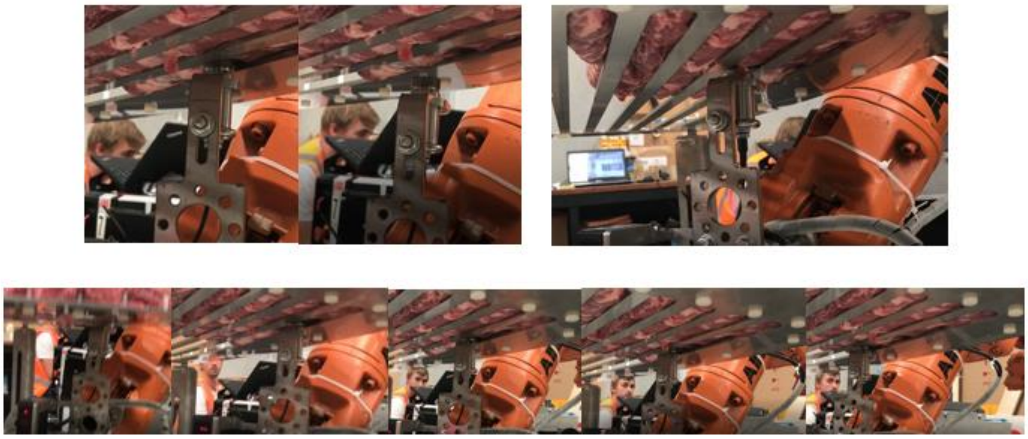
The calculation of the Rcp, based on the node measurements at the nodes over the striploin, uses the measurements MT and FH at the nodes.

The cutting pitch was in strips of 20 mm along the length and calculated using the Rpc values as interpolations of adjacent data on grid points along the length of the striploin. The cut path interpolations gave the tool tip paths for the robot to follow the striploin at a fixed distance above the Meat separating fat.

5.4.4 First trial using integrated tools and IRB 140 robot

The set up using the ABB 140 with integrated end effector was programmed to scan and trim a striploin primal piece as in Figure 31.

The data set for two passes were used and the table in Figure 32 references the ultrasonic and OD sensor data with the actual meat measurements performed on two longitudinal grids along the length of the striploin, 40 mm apart. The data has a match of better than 1 mm as an average, based on this single test. The meat cutting trial as a first attempt was performed and several points of improvement in the physical set up and programming as well as data transfer were revealed. The successful integration and first trial provided the basis for improvements to be implemented as an ongoing activity in the project.



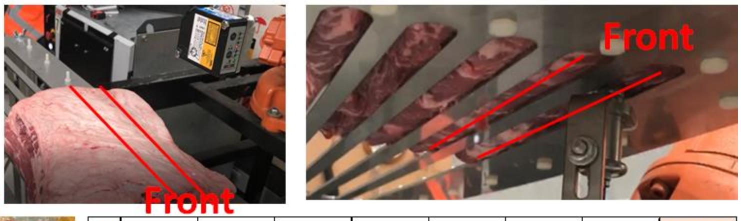
Ultrasonic scan phase giving MT

OD sensor scan giving FH

Figure 31: First test of the physically integrated end-effector with IRB 140.

First trial gives close match between measured data and actual meat fat and meat dimensions.

Measurements comparing Ultrasonic measurements of MT and OD Lase measurements of FT with the same measures manually from the cut meat along two measurement parallel lines as shown 37 mm apart at nodes 40 mm distance form the front of the striploin to the back.



NO								ERROR
1	NODE	1-1	1-2	1-3	1-4	1-5	1-6	MM
2	FH-OD	63.5	65.7	65.4	65.4	69.5	67.2	
3	MANUAL	61	67	68	65	67	66	
4	Diff.	2.5	-1.3	-2.6	0.4	2.5	1.2	0.45
5	MT-ULTS	30.3	35.9	38	38	46.5	47.5	
6	MANUAL	30	35	40	40	47	45	
7	Diff.	0.3	0.9	-2	-2	-0.5	2.5	-0.13
8	NODE	2-1	2-2	2-3	2-4	2-5	2-6	
9	FH-OD	84.5	80.3	75.3	74.3	74.9	74.4	
10	MANUAL	82	80	77	73	76	73	
11	Diff.	2.5	0.3	-1.7	1.3	-1.1	1.4	0.45
12	MT-ULTS	53.9	54.6	50.3	54.9	60.5	54.9	
13	MANUAL	60	55	50	53	57	53	
14	Diff.	-6.1	-0.4	0.3	1.9	3.5	1.9	0.18

Figure 32: First trial results gives close match between measured and actual FH and MT.

5.4.5 Improved system design and sensor communication

The project having reached an important milestone required a more robust set up and to this end a new integrated set up was established at University of Southern Queensland facilitating the developments.

A restriction in the previous integration, constraining the trials has been the method of communication between the sensors and the ABB robots.

A fresh review of the process resulted in a new approach that uses Analogue sensor outputs only, directly communication to the robot controller with the following advantages:

- Reduced time of measurement cycle.
- Simplicity in communication architecture
- Reduction in cost of the system for improved RIO.

Figure 33 shows the set-up, with simplified wiring as well as integration effort.

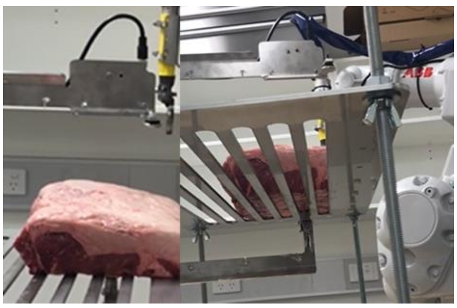


Figure 33: Measurements in Analogue form, used as input to Robot controller directly.

The system in a fully automatic mode, measuring and trimming was presented on 25th July 2018 at the University of Southern Queensland.

The following required steps to prepare the system for presentation at a meat plant were supported by the following:

- **i)** Design of a Robot Frame Assembly that provides for the appropriate mechanical integration to meet with the requirements of the plant. Figure 34 shows the basis of the is assembly.
- **ii)** Manufacture of new parts in support of (i) above. This required several iterations and was completed ready for flat pack transfer.
- **iii)** Improved software to allow optimum performance during the trails. Full program listing is available on request.

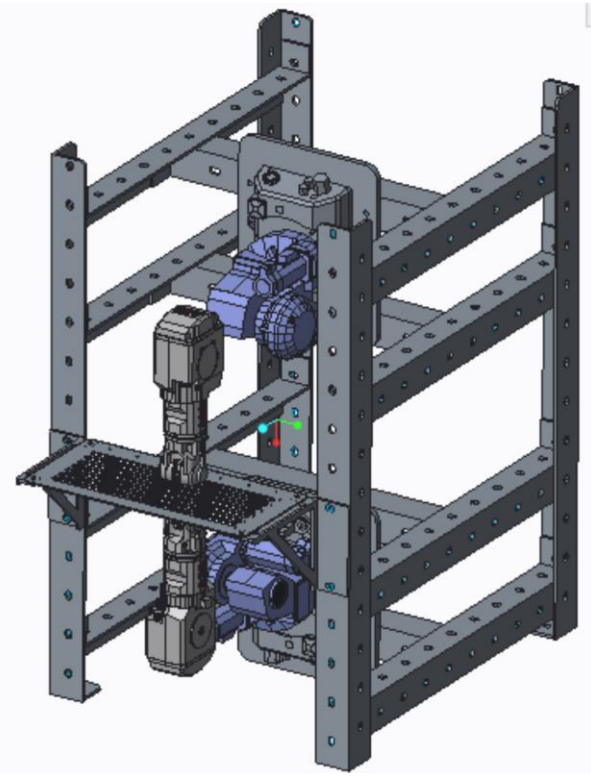


Figure 34: Improved set-up to be prepared and shipped to Plant for evaluation (full designs in AutoCAD are available on request).

5.5 Integration of improved system and testing

The two-robot system was integrated into a new frame for optimum operation during trials and transportability to plant for presentations and testing in support of the specification of a future production prototype.

On completion of the assembly the following was conducted:

- Theoretical review of the positioning of the robots relative to each other and the work place, with the largest striploin location in the trimming position fully within the work envelope of the two robots. This was evaluated with ABB using simulations under Robot Studio and has now been physically achieved.
- Calibration of the robots in the specifically designed stainless steel frame assembly, with the modification of the robot meat plate; positioning the plate to accommodate for the maximum reach of the robots and singularities.
- Rewiring and positioning the system in a half size sea container with easy connection of services.
- Reprogramming of the two robots under the new set up, one performing sensing and the other trimming (See Figure 34).

Figure 34: New set up.

- Performance checking prior to planning the transfer to a plant for further evaluation in relation to production system definition.

5.5.1 Performance evaluation

The updated set up at USQ has been reprogrammed and tests conducted for evaluation of the trimming process with a full-size striploin.

Figure 35 shows the new set up and the first attempted scheme for fat trimming along the paths 1, 2, 3, 4, etc. as shown along the length over the slots where ultrasonic measurements are acquired from below the striploin. The paths are 37 mm apart in line with the slots in the plate on which the meat rests (see Figure 2). Note that the rotary cutter that removes strips is normally cutting 15-20mm wide strips. With the cuts at 37 mm apart, rather than 18.5 mm apart, a scallop shape result is expected. However, this does not influence the evaluation and the trimming in between the slots positions is achievable by simple programming.

The focus of the evaluation, after the new assembly, has been to ensure that sensing data from the ultrasonic sensor as integrated with the controller, and the data from the OD sensor provide the necessary inputs for trimming to be evaluated, along the specific paths over the slots. The sensing pitch along the length of the piece was selected at 100 mm apart (blue lines in Figure 35).

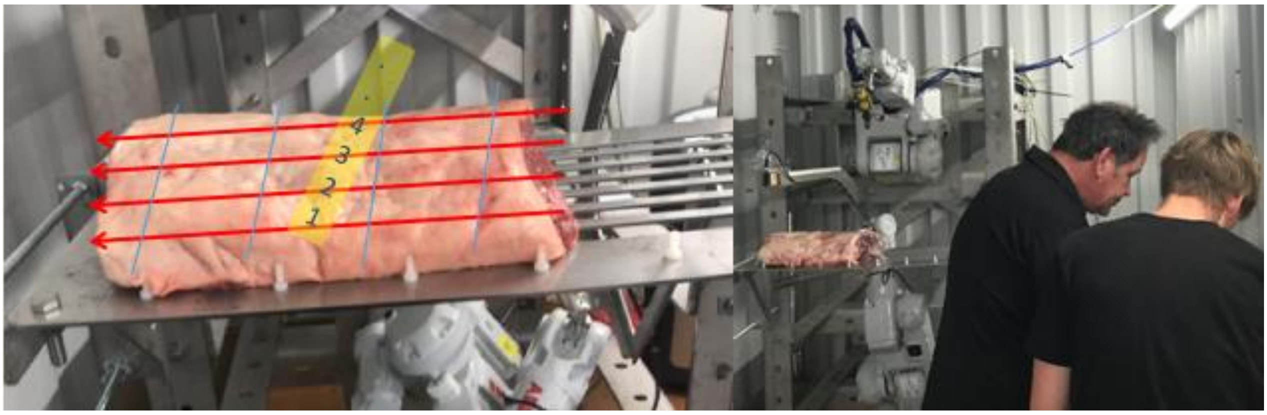


Figure 35: Trimming paths with coarse sensing positions 100mm apart.

Figure 36 shows the important results of the two cutting runs, with a 10 mm fat cover selected. A and B primal pieces, as shown in Figure 36, were dissected: the profiles show first evaluation of the outcome to be comparable to expectation.

Missing ultrasonic information, due to conditions of the meat and the geometry of the striploin have been the main causes of deviation over small regions trimmed. The evaluation of the cut profile along the length in the case of A, Figure 36, and (B) across the primal, provide the details for the required tuning of the system.

A

B

Figure 36: Coarse trimming: Performance assessment.

The following have been the main observations:

a) The ultrasonic information is taken at specific points along and across the bottom face of the primal. With size variations the measurements at the perimeter cannot be taken close to the perimeter edges. This was particularly important along one edge of the primal piece the volume of fat and absence of meat provides no ultrasonic data. The specific case may be observed for cut along the edge close to slot 1 (see Figure 35) and corresponding cut section along slot 1 in Figure 36. A new cutting scheme has been the consideration at this point.

b) The cut profile along the length deviates when the fat is too hard and too thick for the cutter to keep the blade at the required offset above the meat, cutting into the fat towards the end of the trimming process, revealing the meat. This causes the blade to divert into a path of least resistance, which is evident along paths 1 and 2 (see Figure 36, left of the image for case B).

c) The cutting is performed from right to left (see Figure 35), with the entry point of the blade using the data from the scanned sensing positions closest to the right-hand end of the primal. It is important at the blade entry is accurate relative to the edge of the primal end above the fat meat line. This requires the fat cover to be measured directly at the very edge of the cross section at both ends of the primal piece.

5.5.2 Scanning and trimming scheme refinements

Based on the performance testing, a new cutting scheme for programming the trimming process was implemented. The scheme allows for the fat cover to result in a desired presentation of the primal piece with the controlled layer of fat cover and thickness over the top surface and the end faces of the striploin as well as along the long edges.

With the meat placed on the trimming plate as in Figure 37, with the edges located against the reference studs, the OD (laser scan) sensing is to follow the lines in the sequence 1 to 8.

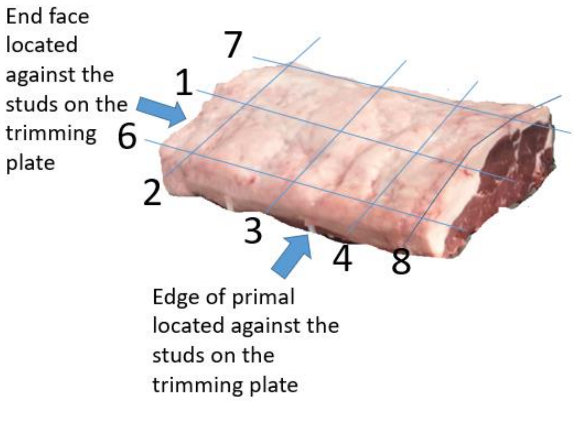


Figure 37: OD laser sensing scan.

The sequence (Figure 37) provided the dimensions that need to be used to determine the next scan line relative to the size of the primal piece as follows (note all measurements of height or thicknesses are measured relative to the trimming plate surface):

- Scan 1: along the third slot from a position 30 mm to the left of the primal as viewed in Figure 37, continuing to the right, parallel to the slot centre. (For details on the plate design and slot positions please refer to earlier Milestone reports.) The scan along path 1 ends once the laser sees the edge at the end face (to the right, Figure 37). The readings from the OD sensor provides the heights of the fat along the length of scan line 1 and the length of the primal along this line.

- Scan 2 is to be across the primal over the left positions of the slots on the plate parallel to the left-hand face edge of the primal. The scan provides the height of the fat across the primal along this scan line and the width of the primal at this position. The width of the primal may be determined from this scan.
- Scan 3 and 4 are 150 mm to the right of the scan line 2 in the direction shown, to gauge the edge profile. The number of scans may be increased for a longer primal piece, as scan 5 (not shown at 150 mm to the right of Scan line 4). The robot programming is to accommodate this. Note that with primal length maximum around 600 mm 2 to 5 150 mm steps would cover the number of scans to determine overall dimensions.
- Scan 6 and 7 are defined using the edge information from scans 2, 3, 4 (and 5). The fat heights along the scan lines provides the information for guiding the trimmer.
- Scan 8 is to follow the top surface of the primal to measure the fat height as close to the edge of the right end face of the primal piece. Scan 2 gives the same for the left-hand end.

The next step in the process was to scan the meat height along the slots at specific intervals, if not done already, and the edges of the primal piece close to the bottom edge of the meat at the right face of the primal (as the view in Figure 37).

With the OD and Ultrasonic information, the trimming paths would follow the scheme as in Figure 38.

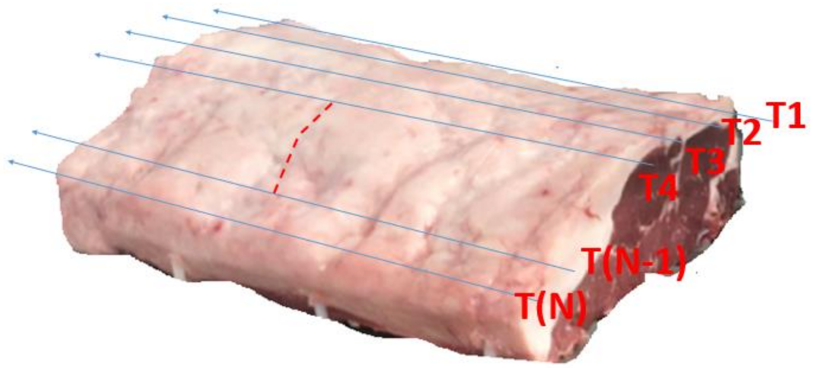


Figure 38: Trimming scheme.

Based on the trimming trials during the evaluation, the trim lines with a rotary blade removing 15-20 mm widths of fat. The program tuning to accommodate the scheme for trimming has been reviewed and improvements tested using an imaging system of the end views of the primal piece. The scan lines need may thus follow the paths as below with corrections using imaging data:

A) Trim path T1 would follow the edge of the primal along the length of the edge removing a 10 mm wide strip of fat with a depth of fat that is 1 mm below the height of the fat as measured by the OD sensor. The measured meat height by the Ultrasonic sensor (US) defines the fat trim thickness along the slots close to the long edges of the primal. With US data measuring the fat cover to be greater than the target fat thickness target to be achieved, the path along the edge of the primal would need to be adjusted to trim the necessary depth of thickness for the specified fat thickness to be left behind. The US data would come from scan along the nearest adjacent slot. If the adjacent is greater than 18.5 mm away from the edge, then T2 would need to be placed half way between the line along the edge (T1) and T3. The same process is to be followed for the other long edge corresponding to T(N) and T(N-1).

B) The entry and exit point of the blade along all the trim paths T1 to T(N), must be placed in a manner that leaves the two end faces of the primal having a uniform presentation fat cover as seen from the ends where the eye muscle is clearly visible. If the fat cover at the two faces is smaller than the thickness of the specified fat thickness to be left on, then the blade entry needs to shave a less than 0.5mm fat below the OD sensor height measurement for a best quality finish.

C) Once The first trim along the length has been performed over the first slot closest to the edge, where T1 was performed, the scheme needs to continue following the process as in A, until the trimming over the slot closest to the TN at the other edge of the primal is reached. It is observed during the performance evaluation that fat close to the reference edge should only be slightly trimmed as the striploin eye muscle effectively ends approximately 50 mm from the edge at T(N-1) path or the last trim line over the slot.

It is important to emphasise that the trimming at the edges along the length must remove as little fat as possible, tapering the profile of the fat removal in a manner that leaves a quality finish. The specification of a production prototype would need to accommodate this process with the input from an imaging system, evaluated with ABB.

5.6 Plant presentation, trial and production prototype definition

Figure 39 presents the original approach for a solution as a fat trimming system, which has reached a first implementation using a two robot system doe trials.

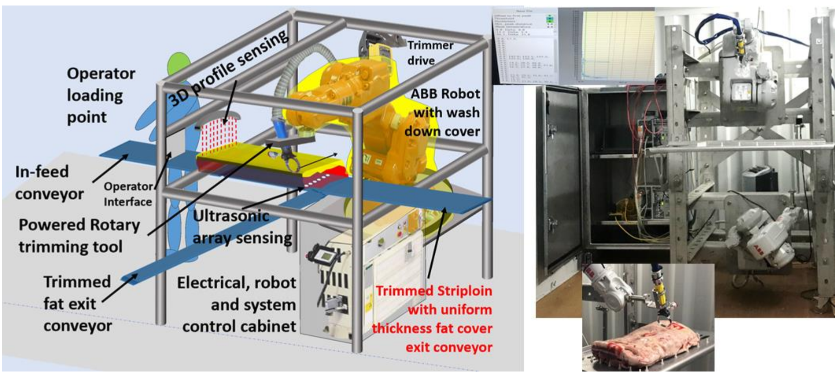


Figure 39: Integrated UFT system achieved.

Figure 40 shows images of the trial session at an Australian to present and evaluate the system against production requirements as a practical step to Stage 3 of the project to reach production prototype solution for industrial testing, integrated within a production facility as a first pilot implementation.

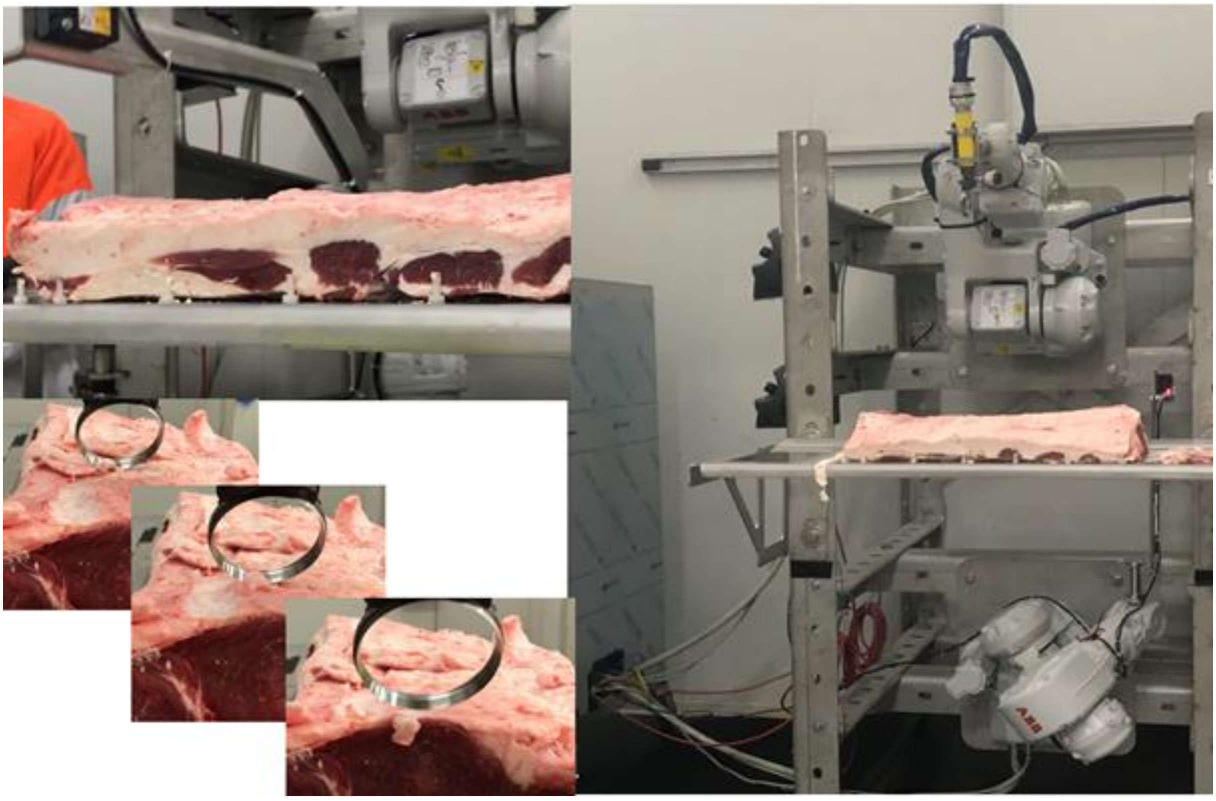


Figure 40: Trials in a plant in Australia.

The trial marks the end of Stage 2 with the following observations providing the main implementation considerations for a production prototype under a follow up Stage 3 project:

a) The ultrasonic sensor requires a drive system that allows forced contact with the meat. The mechanism needs to be position sensed to ensure that the point of contact in the vertical direction registers correctly the Meat Thickness measurement(s).

b) The blade requires a guard that could auto adjust relative to the blade tip, with the gap between the guard and the tip of the blade corresponding to the thickness of the fat being removed. This has wide spread use in a similar process that would trim fat from a whole carcass in a controlled manner.

c) The fat may be removed with a simple vacuum conveying tube integrated with the trimming tool.

d) An infeed system may be implemented, with capability of measuring the primal piece using laser scan solution already tested and proven by the project as well as an ultrasonic array of up to 7 sensor heads integrated with an indexing conveyor. This subsystem would provide the cut data for the robotic trimming system. The system architecture would use the robot controller to drive the process and acquire the data direct to a robot controller as is the case in the current system to keep integration costs low and utilise the capability already achieved under the Stage 2 project.

e) Figure 41 presents a higher speed version, which would require engineering 7 trimming units with single axis vertical drive units positioning the trimming blades independently up and down. A restraining bracket, also having a controlled vertical position maintaining a pressure on the primal piece close to the point of trimming, would hold the fat down as the primal is conveyed in a synchronised motion with the sensing positions past the trimmer.

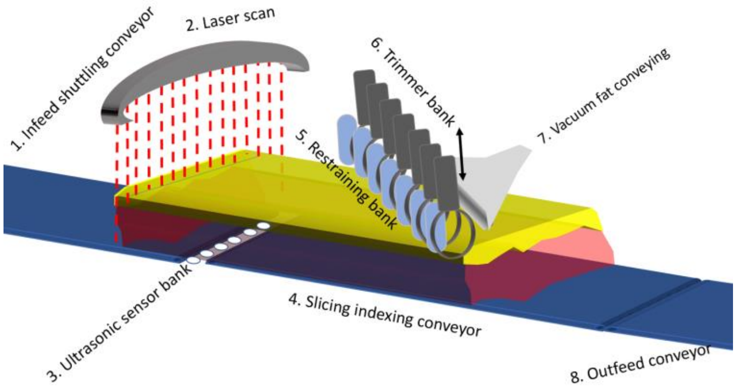


Figure 41: Definition of a high throughput system.

f) Trials indicate that the speed of trimming has a safe maximum speed of 100 mm per second and with seven trimming actions along the length of the striploin of 600 mm length maximum, the trimming cycle is approximately 60 seconds with the robotic option of Figure 39. The time cycle projections with 7 trimmers is limited by the scanning process which is estimated to require 30 seconds per primal piece with the ultrasonic sensor. A high throughput system (Figure 41) would operate at 120 striploins per hour, whilst the cost would be about 3 times the robotic system of Figure 39. It is important to note that the Stage 2 project has proved the performance of a high throughput solution; however, additional development is anticipated with respect to integration to achieve the configuration in this definition.

6.0 CONCLUSIONS/RECOMMENDATIONS

The project has reached its objective to implement a first operational robotic solution for trimming striploin primal pieces using ultrasonic measurement of meat height and fat thickness. The system has shown the pathway to a Stage 3 development to achieve a production prototype and first trials in an Australian beef plant have revealed important findings in support of improvements and developments that overcome performance limitations of the first developed solution under Stage 3. The system as implemented may be used for extended trials to reach detailed specification improving on the definition for the production prototype derived from Stage 2 R&D.

7.0 ACKNOWLEDGEMENTS

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