Final Report

First prototype automation for deboning lamb shoulder - Stage 3

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1.0 Executive Summary

In the butchery of lamb forequarter for deboned end products, the shoulder and the foreleg are removed from the primal ribcage. The manual process uses judgement and ability to manipulate both the primal and a knife to cut to achieve the deboning task.

This AMPC project at stage 3 has consolidated and extended the developments of Stages 1 and 2, reach a world first prototype robotic deboning process for ribcage separation from a forequarter lamb primal.

Practical trials in an Australian processing plant, place the performance to be equivalent to the manual process for the ribcage separation with respect to yield and separation speed.

Stage 3 has placed important focus on simplification and robustness of the subsystems as a prototype, whilst cost engineering the integration as a practical and transportable implementation.

The R&D has achieved a final solution after several iteration. The project has been technically challenged and hindered in its execution, whilst having reached important target outcomes. The impact of Covid19 has impacted timelines as well as stretched the resources. Post Covid period the project completed the integration with basic safety to allow testing to begin. Over a period of 9 months several test periods were scheduled and prior to the final testing planned for early 2024, it became necessary to upgrade the robot unit with a higher payload and longer reach to allow trials with the range of weights up to 8.5 Kg forequarter primals.

With the best efforts applied the integrated transportable cell was completed and tested early in 2024. Figure 1 shows the installation set up reached at location where the trials were performed.

<u>World first integrated robot unit for forequarter ribcage separation, deboning of lamb shoulders.</u>

The key technical achievements of the project as whole have been:

- Development of a handling solution for manual loading and unloading of a forequarter primal on to a robotic grasping unit incorporating sensing for initiating of a gripping action as a first step in the cycle.

- Definition of a handling process and the method for robotic deboning with the implementation of robot programs using soft servo methodology: the cartesian soft servo process, replacing the 3D force sensing, which revealed slow and ineffective in this application.

- Implementation and testing of appropriate rotary cutter blade, for use with a powered tool arrangement for meat separation.

- An integrated unit (Figure above) tested for performance in a lamb processing plant in Australia.

The project execution has required an upgrade of the robot arm, extending the capability to handle the weight of larger forequarter primal pieces. The upgraded system was used to separate ribcage of primals up to 8.5 Kg in weight. Benchmarking of the robot and manual process as figure below has focused on cycle times.

Manual and robot time cycles for ribcage separation

The speed performance of the robot separating the ribcage was benchmarked by video analysis at 22.45 seconds compares 22.18 seconds for the same in manual deboning.

Tests show the yield performance to be at 85% targeted at the start of the project.

The outcome and the findings of the project provide the basis and necessary information for future implementation of a robotic line applying the soft servo programming that has been applied by this project, demonstrating its practical use for the first time in a deboning application.

Forequarter lamb deboning is an intensive manual process, requiring judgment and skill of butchery under demanding work conditions. The task involves lifting and manipulation of primal pieces of 5 - 8.5 Kg weight with a time allocation of around 1 minute to perform the full task of deboning.

This project has concentrated on the separation of ribcage, achieving the same process cycle with comparable yield, reducing the exposure to heavy work by people who can perform the remaining steps in a full deboning of shoulders handling smaller weight pieces and less straining knife actions.

Stage 1 and 2 reached experimental solution for the task under earlier AMPC projects. The target to reach a transportable unit that may be used in trials in a meat processing environment has been the focus of Stage 3, now concluded as reported herein.

2.0 Project Objectives

The project objectives as originally set out in the proposal under Stage 3 were:

- Consolidate the development results and the tasks of team members under Stage 3 detailing the Lamb FQ Ribcage separation robot cell functions for prolonged testing of no less than 3 (up to 6) weeks in a meat processing operation.
- Implement enhancements in systems integration, safety, and speed of prototype solution for testing, including cutter tool, grasping-fixation and sensing for real-time adaptation accommodating size and shape of FQ primal pieces.
- Integrate and test the robot cell as a transportable solution.
- Perform functional testing to validate yield and speed capability prior to shipment.
- Arrange site testing and prepare location and plan for shipment.
- Ship, install and commission for site trials (including training).
- Perform site trials and document performance results.

Produce final report and plans for commercialisation.

3.0 Methodology

The project will follow the approach to reach the outcomes, achieving a successful prolonged testing of a world-first robot cell for lamb forequarters (FQ) ribcage separation, as a de-boning operation.

The robotic cell, which was reached under stage 2, will be recommissioned for testing at the start of the project. De-boning tests will examine each element of the system including the gripping fixation, cutter tool and blade profile, and sensing with enhanced improvements engineered in a step-by-step progression to reach the Stage 3 prototype. Testing at each stage will ensure performance as a robust solution.

A benchmarking of yield based on manual deboning is to be made and used to verify capability as good as manual process. The testing at cycle target speed of 30 seconds per FQ is to validate the TRL5 status at the end of the project, supported by site trials.

Arrangements will be made to ship and install the cell as first near-production prototype for testing. A performance benchmark is to be established as part of the methodology. This will be a documentable measure of ribcage profiles after deboning, to be based on evaluation of separation paths achieved. The meat cover over the relevant regions of the ribcage area represents achieved yield. The depth of meat, in millimetres from the surface of the cut meat to the top of the rib bone, at several (more than 5) specific point of interest would define the deviation. As illustrated in Figure 1, the measurements would provide a quantifiable assessment to be established by the project as an addition to the visual assessment of ribcage profiles comparing the deboning results from the robot to the same from a manual processing. For a conforming FQ primal, the cut path over the separation areas away from the ribs, as shown, are to target a deviation not to exceed 3mm average for 85% of cuts and 5mm for all cuts. Separation areas of interest may be two regions of 40mm by 150 mm over the ribs in the middle of the rib cage and approximate 30 mm by 100 mm over the curvature of the back of the FQ, see Figure 1.

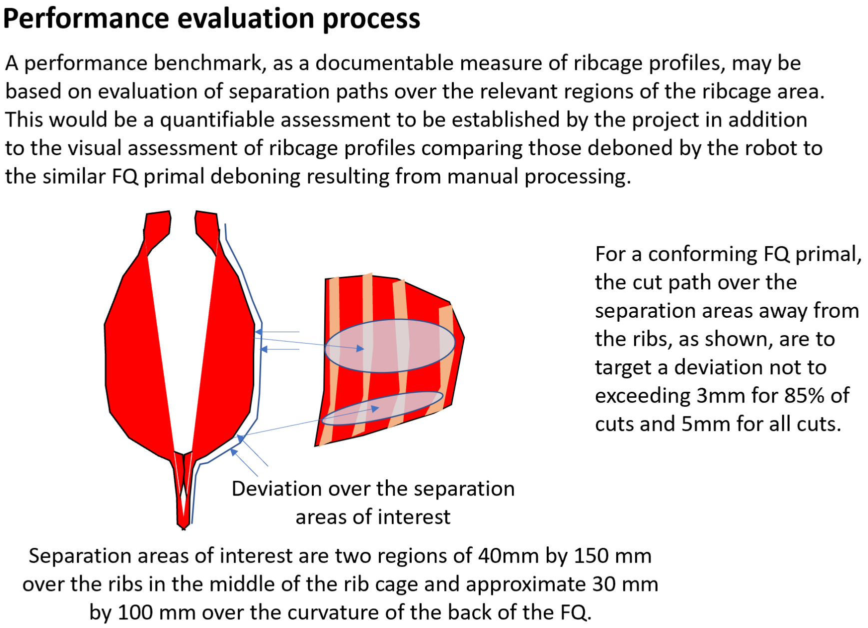


Figure 1: Benchmarking manual and robot ribcage deboning.

Validation of performance in a practical installation and assessment of cost-effective implementation will provide the supporting outcomes for future commercialisation post project end.

4.0 Project Outcomes

Stage 3 concept has modified the original two robot cell solution from Stage 2 Figure 2, simplifying and cost reducing the scope of the solution.

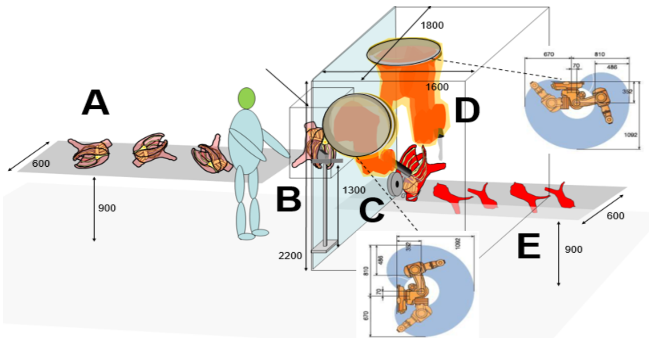


Figure 2: System overview.

4.1 Process and deboning steps.

The steps in the operation have been defined as follows:

- Operator loads a prepared Lamb FQ shoulder primal onto a gripping fixture held by the robot in the robot cell. The fixating gripper locates the shoulder primal attaching inside the spinal cord cavity and the under sider of the spine, within the FQ ribcage.
- A single rotary blade as in Figure 4 performing featherbone cuts prior to ribcage separation. The featherbone locating features of the gripper provide the reference for the start of each featherbone cut. The path is to follow the line of the spine along the axis of the FQ primal. The force data in the direction of the cut is to provide for the control necessary to prevent unacceptable blade penetration into the spine-bone, as it follows the profile of the spine to reach the end of the cut. Note the rotating blade is fixed and the robot carrying the FQ primal is motion.

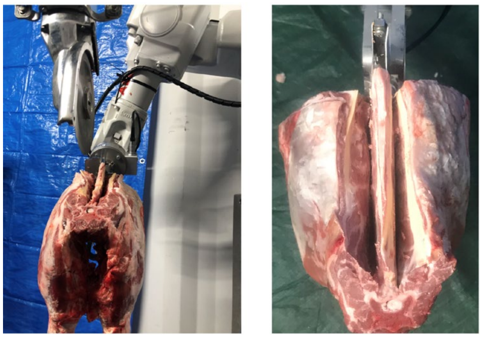


Figure 3: Featherbone cuts.

- The motion program for deboning, orientates the FQ primal to perform the separation of the forelegs on the right and left of the ribcage (Figure 5), using the same static rotary blade, using force date to control the process. The motion program, with the force module achieves path following for each specific move.

Figure 5: Shoulder separation from the ribcage (right side shown).

- Once both left and right shoulders are separated from the ribcage, the robot returns to the loading position for the FQ to be removed, before a the next FQ is loaded.

Figure 6 illustrates the processes as designed and implemented.

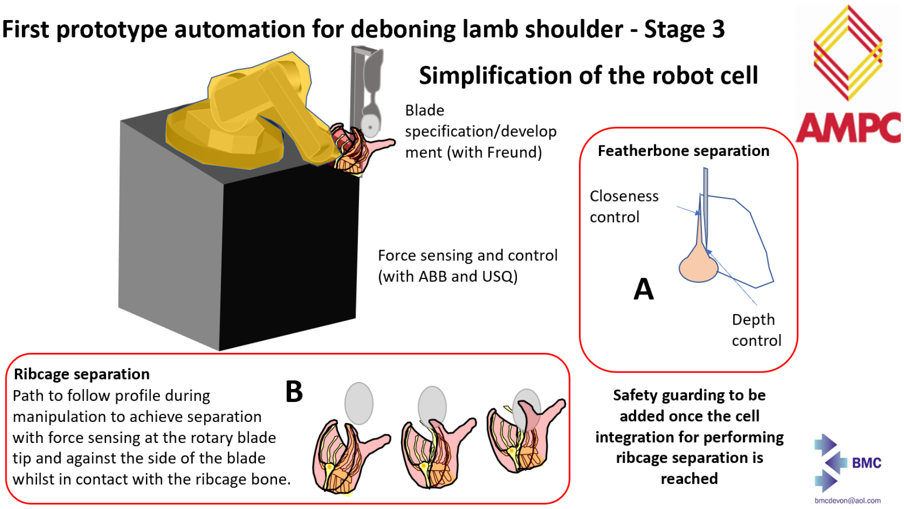


Figure 6: Set-up to support developments for featherbone (A) and ribcage separation (B).

4.2 Integration with IRB 140

Figure 7 show the integration of the robot set up for testing the blade using the IRB 140. Tests and robot programming were performed using remote connection during Australian and international lockdown period. The expected powered cutter and blade performance tests were conducted, as illustrated.

The cartesian soft servo a new additional feature of the ABB robot replacing the 3D force sensing was pursued, given the deboning speed target of the project.

A transportable arrangement was defined and integrated (Figure 7) to avoid calibration and lengthy set up when the system is installed at plant for testing.

A Soft Servo approach was implemented replacing the complicated six-axis force control methods, also reducing the cost of final solution to an end-user.

Figure 7: First robot set up.

The implementation of the robot as Figure 7 above, provided the hardware and software set up for the application Soft Servo methodology, applied and tested for functionality. This has been made possible with the specific procurement of the cartesian version of the software package as a recent release (2022-08-23 Skribenta version 5.5.019 – SoftMove Application RobotWare 6.14). SoftMove provides a Cartesian Soft Servo, which lowers the stiffness of the robot in a predefined direction in a dynamic manner, keeping the original behaviour of the motion in all other directions. When using SoftMove the behaviour of the robot modifies the path being followed during the movement allowing the path to deviate in a manner that avoids the blade to penetrated bone, whilst the profile of the ribcage is followed by the robot motion. It is important to highlight that the outcome reached has required several structured steps and tests to ensure that the SoftMotion process is correctly applied. The end solution considered feasible for the undertaking of Stage 3, has used SoftMotion in relation to the work object being the rotary blade, as the carcass orientation is changed during the desired deboning manipulation of the forequarter. The program follows the general profile of the ribcage, adapting the path for a soft movement when the FQ ribcage is in contact with the blade separating meat along the direction of the move along the ribs as illustrated in Figure 3.

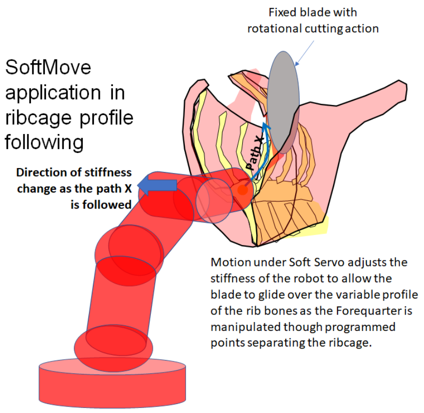


Figure 8: SoftMove process for adaptation of separation path to ribcage profile.

Functionality was tested using the arrangement shown in Figure 12 and the SoftMove process of Figure 8. The successful pioneering enhancement of the sensory based control using Soft Servo provides the outcome important to the integration of the complete cell, with behaviour of the robot adapting the separation path for variable size and shape forequarters. Figure 9 presents the images of the trials conducted.

Motion (left to right) with ribcage in contact with blade, the robot, adjusting position perpendicular to the blade,

Figure 9: SoftMove process for adaptation of separation path to ribcage profile.

4.3 First integration of prototype and first site trials (speed-Yield)

Figure 10 presents the booth specifically designed and manufactured with the enhancements that make integration and transportation easy for the execution of the transportation and trials.

The system as a transportable unit was successfully moved and tested for functional. Figure 17 presents images of testing after transportation of the robot unit with all major subsystems assembled.

Figure 10: Integrated and testing.

Figure 11 shows images of the video clips that have been used to compare manual and robot speeds for the separation of ribcage from a Forequarter Lamb. See confidential video accompanying this report.

The cycle of 22.45 seconds for robot separation of the ribcage deboning is comparable with the same manual operation time of 22.18 seconds.

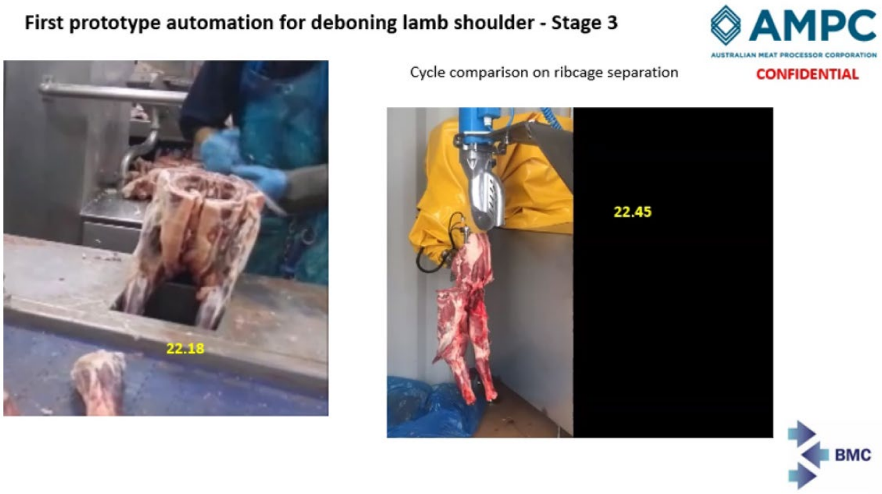
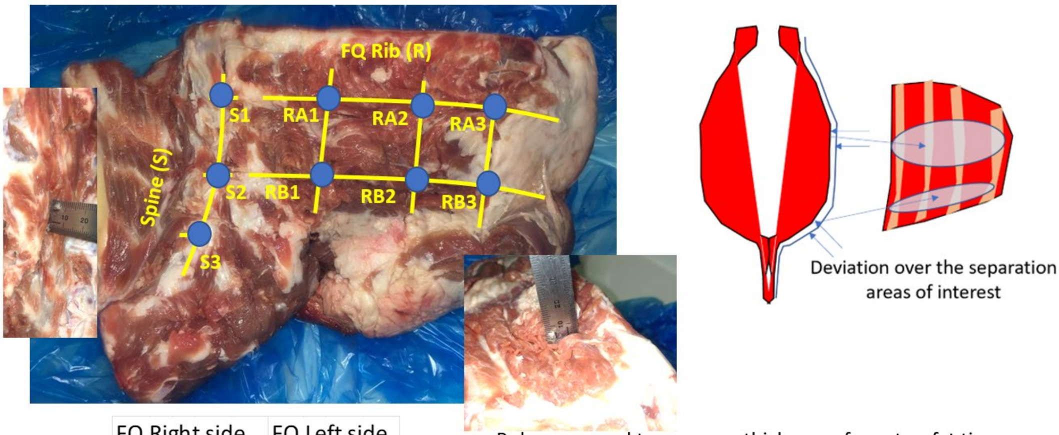


Figure 11: Robot and manual ribcage separation cycle comparison.

Figure 12 shows the measurements on a test ribcage as deboned by the robot at trial location. The maximum measured depth of tissue (meat/fat) over the ribcage at 5 mm was recorded.



	FQ Right side			FQ Left side		
	S	RA	RB	S	RA	RB
1	3	5	3	0	3	1
2	4	2	2	1	2	2
3	2	1	1	1	1	2

Ruler was used to measure thickness of meat or fat tissue remaining on ribcage as deviation over the separation area of interest (above right illustration) at the node positions shown in blue (above left image,.

Figure 12. Yield performance from first trail at processing plant.

The planning of a second trials included upgrading the robot with the IRB 1300 for higher payload and reach.

Measurements using a ruler at test regions (Figure 13 right) and observation of the deboned faces place the performance, as a first attempt withing 3 mm against the deviation profile of Figure 3 (top right). It may be noted that the robot motion, as guided under SoftMove controls the forces between the FQ and the cutter blade, especially during the separation of the 4th rib bone (Figure 20 right) fully exposing the rib face almost in every case. The tests that follow document the results.

The final report will provide further elaborations, highlighting the important aspects of blade design, cutter tool housing and positioning relative to the robot, and the cutting tip shape in relation to the contours being separated.

Spine rib region 3 mm

Shoulder rib region 3 mm

Figure 13: Testing and measurements.

Figure 14 shows the robot unit in the trial position.

Figure 14: Robot unit is position at trials site.

The summary of the trial outcome is presented in Table 1.

5 March 2024 FQ lamb ribcage trial				
Test	Spine score	Shoulder score		
1	3	3		
2	4	3		
3	3	1		
4	3	3		
5	3	2		
6	2.5	2		
7	5	3		
8	3	1		
9	2	2		
10	2	1	Overall %	Target %
1-3 Score	8	10	90	85%
>3 score	2	0	10	15%

Table 1 Trial summary.

Overall, the results have shown the viability of the process based on the structured testing. It is noted that an 8.7 Kg lamb forequarter would be the upper limit for the robot unit payload.

5.0 Discussion

The performances based on the work that has been completed support the capability of deboning by soft servo and the solution at TRL 5 as targeted. The speed performance of the robot at 22-23 second for ribcage separation compares with the same in a manual process. The yield performance as quantified is compatible with manual operations based on observations, which may be quantified in follow up projects implementing a future production pilot using the results from Stage 3.

The test results for the 10 runs using primal pieces in the range up to 8.7 Kg was concluded.

6.0 Conclusions / Recommendations

This AMPC project at stage 3 has consolidated and extended the developments of Stages 1 and 2, reach a world first prototype robotic deboning process for ribcage separation from a forequarter lamb primal.

Practical trials in an Australian processing plant, place the performance to be equivalent to the manual process for the ribcage separation with respect to yield and separation speed.

Stage 3 has placed important focus on simplification and robustness of the subsystems as a prototype, whilst cost engineering the integration as a practical and transportable implementation.

The trials demonstrate the SoftMove function is an Important and useful feature for application of robots in deboning. Observations highlight new findings related to the approach taken in implementing a robotic cell manipulating the meat piece against a cutter blade in a deboning application, and more specifically deboning Lamb Forequarter, separating the forequarter ribcage,

The ribcage separation testing demonstrated the capability of the SoftMove in a unique manner as a World first in de-boning. The yield and speed performance as documented highlight the same capability as achievable in manual ribcage separation. A throughput of one forequarter per 60 seconds will be achieved with the addition of separate featherbone knives, allowing time for loading, and unloading, and the ribcage deboning cycle of 22.45 seconds being close to 22.18 seconds manual cycle.

The work to date provides a pioneering implementation towards future implementation and considerations of new handling and line integration aspects. Extending the solution to a prototype demonstrator based on a carrier solution for the forequarter primal, applying the deboning solution of Stage 3 is recommended.

7.0 Acknowledgement

The support of AMPC, the kind input of the host plant tremendous efforts of Fraser Border and the team at ABB Australia are gratefully acknowledged.

KK 30th March 2024