AMPC

FINAL REPORT

First prototype automation for deboning lamb shoulder - Stage 2

Open report

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TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

The meat industry has a major requirement to automate its processes of slaughtering and meat preparation including primal cutting, sub-primal breakup and de-boning.

This project was proposed in 2016 as its Stage 1 feasibility of de-boning lamb shoulder primal pieces, following discussions and the declared need by several Australian meat processors. In particular, the separation of the rib cage has been evaluated and a solution for implementation as a first prototype reached under stage 2 in this AMPC funded R&D. The original approach considered similar steps to that applied by BMC (Koorosh Khodabandehloo) for a Shoulder Machine that produced bone-in square cut pieces. However, the approach for deboning has taken a different direction, because of the complexities in separation steps in lamb forequarter deboning complex manoeuvring or manipulation of both the cutter and the primal piece. New solutions have been examined and a first prototype integrated and trialled.

The specific milestones over the project to date have included the assessment of shoulder primal variability in relation to de-boning as intended for automation as well as examination of the manual process, and the automation possibilities, which have included significant practical trials.

A twin robot solution was considered to minimises the use of dedicated mechanisms and automation, whilst accommodating variability in deboning and primal shape and size. This approach has since been modified to a single robot cell with an integrated grasping and force sensing unit using a static powered cutter. The R&D, in its iterative stages, has reached a first world prototype for practical testing, which were concluded using shoulder primal pieces from a local butcher shop. The conditions of the trials have been identical to a typical meat room set up for the purposes of the testing using whole lamb forequarter pieces as if they were delivered to the cell from a production line.

2.0 INTRODUCTION

The meat sector is targeted to have significant labour shortages as the demand for food increases in the next few decades. Automation capable of accommodating the required processing throughput in an efficient and cost-effective manner will be a key factor in the sustainability of meat supply at the future volumes.

Reducing the reliance on people's time on the production lines, saving equivalent of 2 units of labour in the overall task at 300 pieces per hour is considered an important step.

Figure 1 shows the steps in the manual lamb forequarter process. The project has considered alternative, the requirements and method for separating the shoulder rib cage from the primal piece.

The robotic approaches and the scheme for separation have been based on similar techniques used by butchers, but structured and re-engineered for robotics. This has targeted the ribcage separation, which is difficult manual process (See Figure 1).

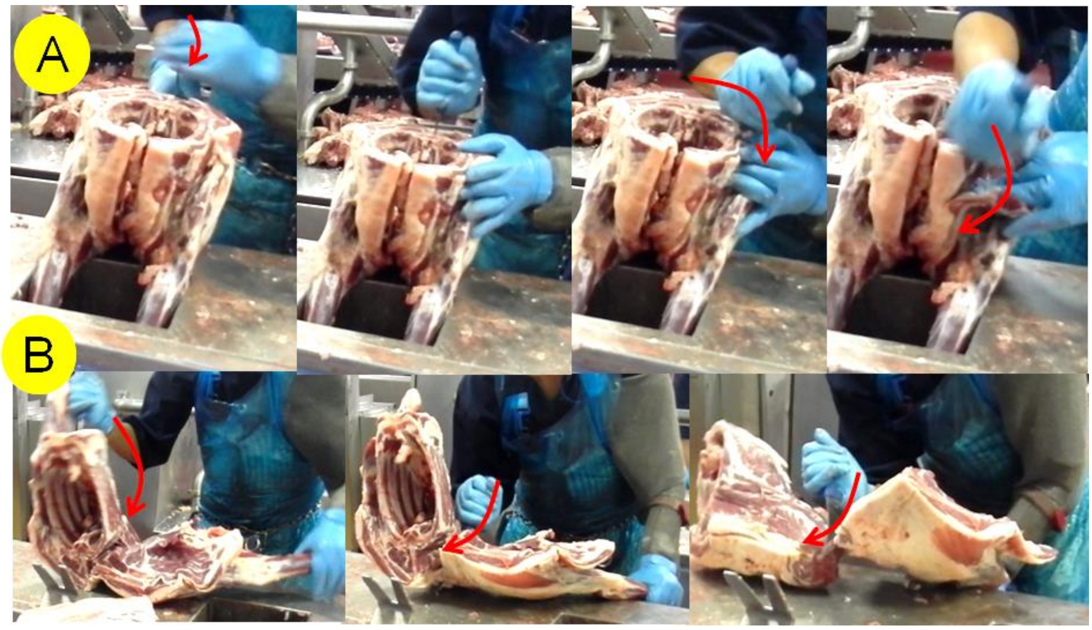


Figure 1: Pre-cutting of the eye muscles adjacent to the featherbones. Cuts along the 4th rib (A) are followed by separations as in (B)– recovering the 'banjo'.

The variability of size influences the process and the methods for automation need to accommodate the variations from primal to primal.

The main variability in dimensions influencing the deboning steps include:

- the overall width which varies by 40 mm about the main axis of the spine, with minimum width being 210 mm and maximum 290 mm,
- the overall length ranging 135 mm to 230 mm,
- Effective height excluding neck section ranging 265 mm to 335.

The method of deboning by hand has two options prior to the start of forequarter arriving at the boning station: with the neck removed by band-saw before deboning or the neck left on. The former is the adopted process as the separated neck gives a neck product in its own right (when sliced) and is wasted when attached to the rib cage, unless processed by mechanical meat recovery or rendered.

The process steps to separate the rib cage involves the following actions (Figure 2):

- Separation of shoulder muscle from the spine featherbone by performing two knife incisions one on each side of the featherbone along the back of the shoulder.
- Separation of the foreleg and shoulder muscle from one side of the rib cage and then the other side of the rib cage.

The approach to using automation would remove 30%-40% of the whole manual processing time, when focusing on the separation of the shoulder rib cage.

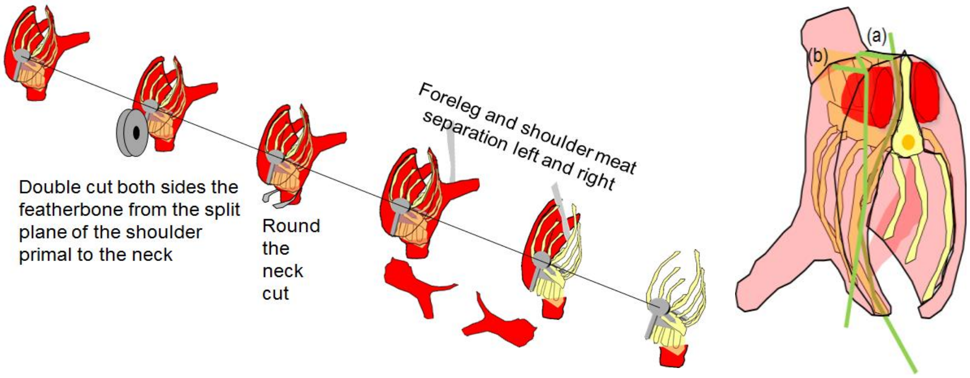


Figure 2: Early approach to automation.

Trials and observations of the processes have been conducted under the project milestones and a new approach for separation has been reached leading to a new concept in the early stages of the project as may be seen in the arrangements illustrated in 3.

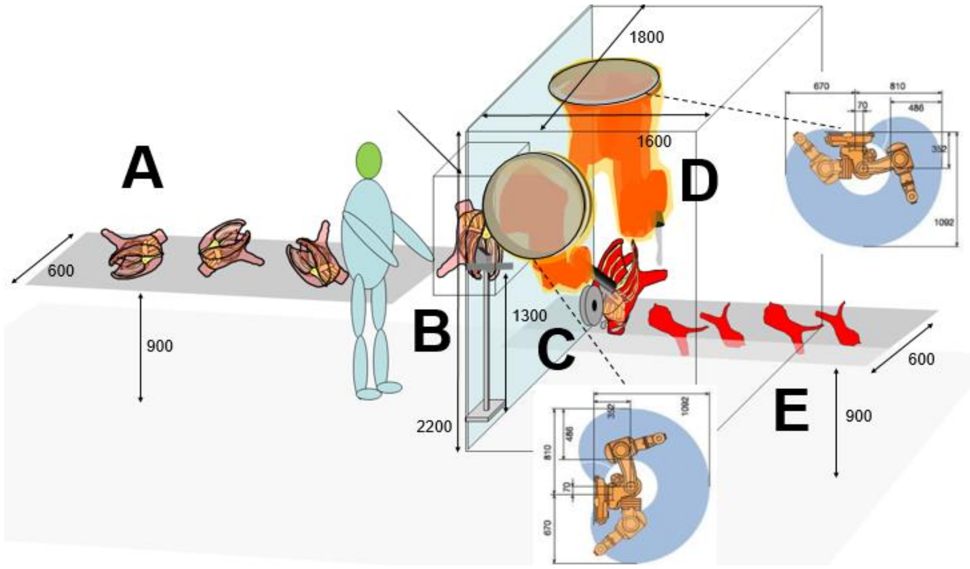


Figure 3: Early concept for an automated twin Robot Cell for lamb shoulder de-boning.

Figure 3 shows the overview of the early automated twin Robot Cell for lamb shoulder de-boning. A fixation solution was considered required for handling; however, this has been further refined into a grasping arrangement that holds the shoulder and allows its manipulation during complex deboning movements.

An important key development to date has been the solution to handling fixation. This has been tested by the project and Figure 4 presents the early implementation of the concept

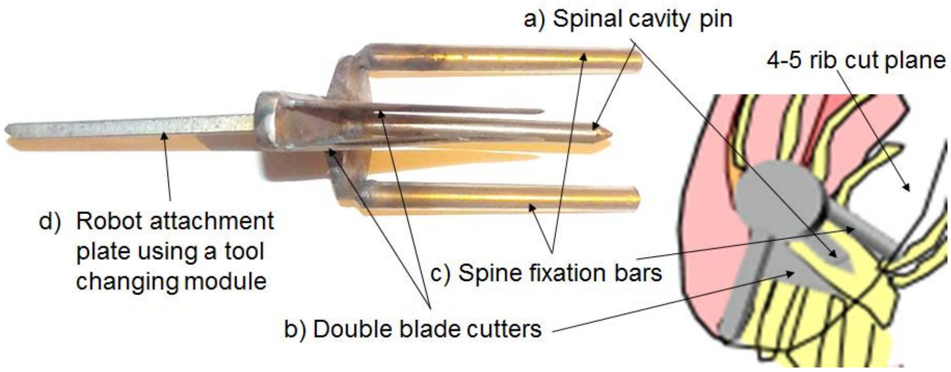


Figure 4: Stage 1 fixation unit.

A force-controlled rib profile following robot using a knife with a standard off-the shelf 6-axis load cell sensors available with an ABB robot, applying methodology from past research by Khodabandehloo has been the basis of Stage 2 for the projects to reach a first prototype, which has been reached and presented in this final report.

3.0 PROJECT OBJECTIVES

The overall objectives have been met with trials conducted in a close to production set up.

- To review the developments to date and document the requirements specification for an automated lamb shoulder deboning machine.
- To produce a functional specification for the automated system and plan its pilot implementation.
- To implement a first prototype machine in a workshop environment and test its capability using lamb shoulders of varying size.
- To improve on the design based on near production trials.
- To implement a final production prototype and test functionality prior testing.
- Structured testing with shoulder primal pieces and consideration of installation requirements for production.
- Documentation of test results, machine improvements and final report.

4.0 METHODOLOGY

The methodology for the project has been reviewed as the project has developed and described as follows.

- Assessment of process and variability.
- Review of the overall system specification.
- Definition of functional requirements of a fixation solution based on past solutions and experimentation.
- Definition of cutting solution based on research conducted by BMC in past robotic deboning projects.
- Evaluation of scope of sensing and definition of handling as well as separation requirements to reach a cost justifiable outcome with minimum requirement for subsystem development and maximum use of available proven modules where practical.
- Implementation of first experimental modules and testing.
- Implementation of first complete system for testing.
- Refinements and adaptation
- Final testing and integration for testing with forequarter primal pieces.

5.0 PROJECT OUTCOMES

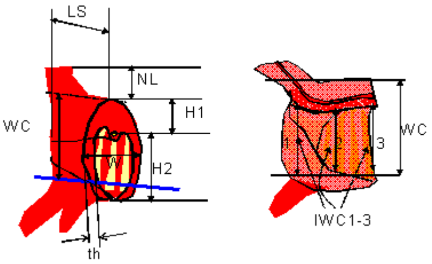
The following presents the considerations and project developments and outcomes.

5.1 Lamb forequarter primal variability

The measurements defining the variability have been reviewed and the process steps defined using video recordings of current practices. Measurements on carcasses in the range 15Kg to 40Kg (Figure 5) have been reviewed.

Figure 5: Carcass range 15Kg-40Kg.

Figure 6 presents the feature in the shoulder primal pieces considered relevant and significant to the specification of the intended deboning process. The measurements of key carcass features provide the basic data for the specification of mechanisms and automated cutting program including sensory functions to guide achieve the process.



Kg	Weight of whole carcass from which the measured shoulder originated
L	Length of whole carcass from which the measured shoulder originated. Measured from the hook position to the bottom of the neck with carcass hanging from the hook.
WC	Width of cut measured from the back of the shoulder to the position of the cut separating shank and brisket
NL	Neck Length
H1	Distance between the back and the centre of spinal cavity
H2	Distance between the centre of the spinal cavity and the tip of the brisket
W	Widest width of the shoulder
Th	Thickness of the shoulder
IWC	Internal distance between the edge of the brisket and the position of cut as marked by WC. This is done in three positions 1, 2 and 3 to show the profile of the spine
LS	Length of shoulder measured from the rib cut position to the bottom of the neck

Figure 6: Measurements specification corresponding to features relevant.

The main variability in dimensions influencing the deboning steps include (See Table 1):

W - the overall width which varies by 40 mm about the main axis of the spine, with minimum width being 210 mm and maximum 290 mm,

LS - the overall length ranging 135 mm to 230 mm.

H - Effective height excluding neck section ranging 265 mm to 335.

Review of shoulder primal size variation									All in mm			
Item	Kg	L	WC	NL	H1	H2	H	W	th	IWC 1	IWC2	IWC3
1	16.7	1010	200	100	65	220	285	210	25	95	105	115
2	16.7	1040	200	120	65	215	280	230	110	105	110	135
3	17.2	1100	215	140	65	220	285	200	95	120	130	140
4	17.2	1100	215	135	65	220	285	220	95	120	130	140
5	18.7	1110	215	130	70	220	290	220	105	120	125	130
6	18.4	1050	200	110	70	235	305	230	100	105	115	125
7	19.1	1110	210	130	75	230	305	230	105	105	115	125
8	19.7	1110	220	120	76	235	311	260	110	105	116	125
9	20.7	1070	210	120	75	230	305	230	110	105	115	125
10	20.8	1190	230	110	65	200	265	215	100	130	140	150
11	21.2	1110	220	110	75	225	300	250	110	115	125	125
12	21.7	1120	220	100	65	230	295	220	95	105	120	135
13	22.4	1165	230	120	80	240	320	220	95	135	140	150
14	22.5	1180	230	120	80	235	315	225	100	125	135	150
15	22.8	1150	230	110	70	230	300	230	90	130	135	145
16	23.6	1130	210	110	80	230	310	260	95	115	125	135
17	24.2	1120	230	110	85	245	330	230	110	115	125	135
18	24.9	1110	210	110	75	230	305	270	105	110	120	130
19	25.9	1130	220	120	80	230	310	240	100	110	115	125
20	26.1	1110	220	100	80	225	305	240	100	110	115	125
21	26.6	1170	240	140	80	225	305	290	100	115	120	130
22	26.9	1180	235	110	80	245	325	270	100	130	135	140
23	27.3	1170	220	120	85	235	320	280	90	125	130	140
24	27.7	1150	240	110	85	240	325	250	90	125	135	140
25	27.3	1220	230	140	95	235	330	285	90	110	120	130
26	25.1	1200	230	120	90	240	330	285	100	110	120	130
27	28.6	1130	230	130	80	225	305	280	100	115	125	135
28	29.9	1140	230	120	95	225	320	240	110	130	130	135
29	30.2	1120	240	120	85	240	325	290	120	125	130	140
30	36.1	1240	240	115	90	230	320	270	120	130	140	150
31	36.8	1250	250	130	85	250	335	265	110	120	130	140

Table 1: Measurements presenting the variability in shoulder primal pieces from carcasses 15Kg - 40Kg in relation to features in Figure 6 relevant to de-boning

5.2 Forequarter deboning process

The processes of meat separation from a shoulder primal pieces have been examined using information and observations from plant visits. Figures 1 presented the main steps in the manual process. Figure 7 provides the schematic summary of the cuts in the early considerations for automation, where the featherbone cuts are made, separating the eye muscle to the back of the shoulder primal, followed by the cuts from below the foreleg and brisket direction, separating the banjo and the whole of the shoulder meat from the primal piece: leaving the ribcage carcass with neck attached. Note in both cases the operation is repeated for the left and right sides of the whole shoulder primal.

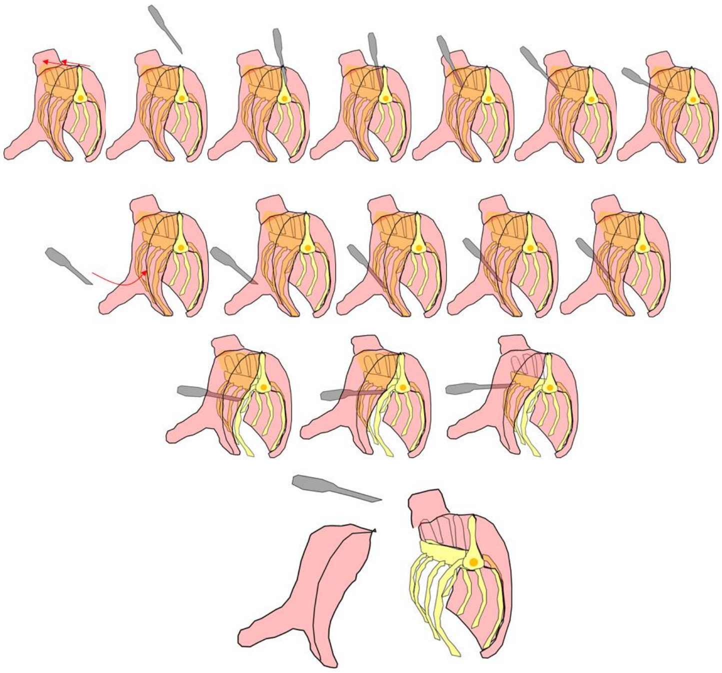


Figure 7: Start from top left and follow through left to right. Cutting scheme for full shoulder de-boning- note the pre-cutting along the seam of the 4th shoulder is not considered a necessity.

In the closing stages of the developments the process is re-arranged for the cutting tool to be static and the carcass to be driven against the cutter. This similar to ther Scott Technology, where the arrangement would allow the primal piece to be sensed and the robot guided to drive the shoulder primal against fixed blades, manipulating the shoulder in such a manner to achieve the desired separation for de-boning as in Figure 8 for square shoulder cutting of lamb forequarters.

Figure 8: Robot holds shoulder primal, driving it against fixed blades to perform. de-boning (Scott Technology solution).

An alternative is the to use a handling system that is loaded manually delivering the shoulder primal to the robot for de-boning, similar to the leg de-boning solution by Scott Technology (Figure 9).

Figure 9: Leg deboning by Scott Technology.

The approach for forequarter deboning is illustrated in Figure 10 supported by a test as in Figure 11.

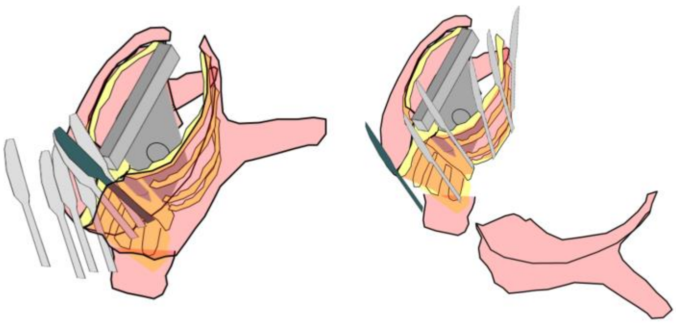


Figure 10: Scheme for robotic de-boning.

Figure 11: Trials in support of cutting scheme for robotic rib-cage separation.

5.3 Forequarter fixation and control for deboning automation and trials

Figure 3 shows the early a twin robot concept in which a robot would grasp and position the Lamb Forequarter for de-boning. The method of fixation for the shoulder primal of Figure 12 was implemented and tested. This arrangement locates the shoulder primal in a manner that allows an operator to load the fixture for robotic de-boning.

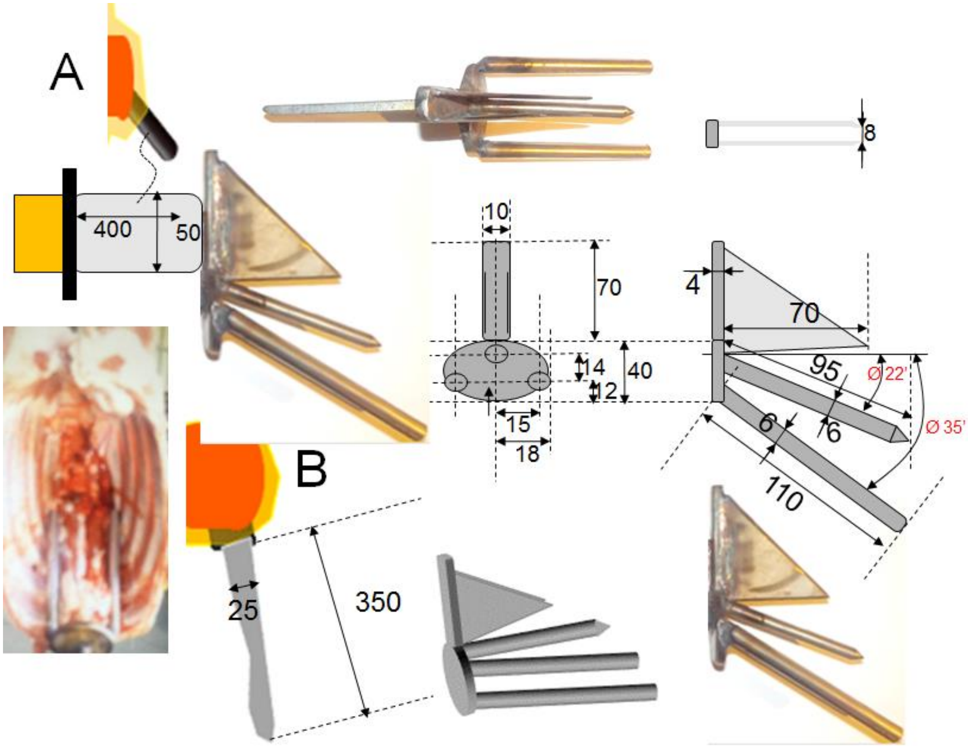


Figure 12: Fixation details, robotic tools and primal piece locating.

The fixation process was tested and used with an ABB robot equipped with a load cell to test the deboning process applying force control as illustrated in Figures 13, 14 and 15.

Figure 13: Force control using a 6-axis load cell on the robot tool flange.

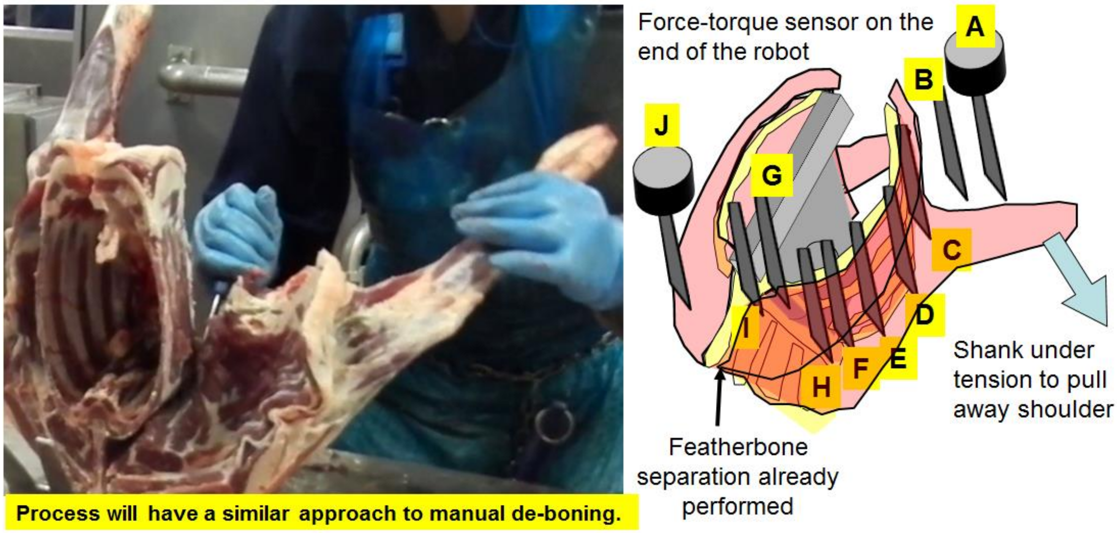


Figure 14: Separation requirement to free the ribcage.

The robotic actions in early trials followed the steps in Figure 14 as follows:

A) Point of approach at robot point fixed relative to the fixation allowing for carcass position, ensuring a clear distance.
B) Interim position to orientate the knife relative to the shoulder primal.
C) Drive into the meat until a line of contact is made with the ribcage (edge of the knife and not a point contact), aligning the knife parallel to the rib cage.
D-E and F) Cut with an oscillating action in the line of the knife whilst following the rib cage maintaining a force and torque on the knife to keep its edge. The shank to be under tension.
G) on reaching the line of the spine at the end of the ribcage, follow the line of the spine through to the base of the ribs to point G, followed by a secondary knife pass along the path H-I.
H-I) Run parallel with the spine as close to the seam between the featherbones and the spine, applying a controlled force to achieve meat separation.
J) Retract knife and clear the primal piece after shoulder and foreleg separation in one piece.

A dry run program for the actions in an experimental robot trials produced the outcome presented in Figure 15

Figure 15: Dry run with a robot.

Figure 16 shows the knife and bracket as attached to a second robot for controlled actions in de-boning tests.

Figure 16: The robot cutting knife.

The knife bracket is attached to the ABB force sensor (Figure 17) integrated in a working arrangement. The set up as illustrated used a twin robot arrangement for early trials and developments.

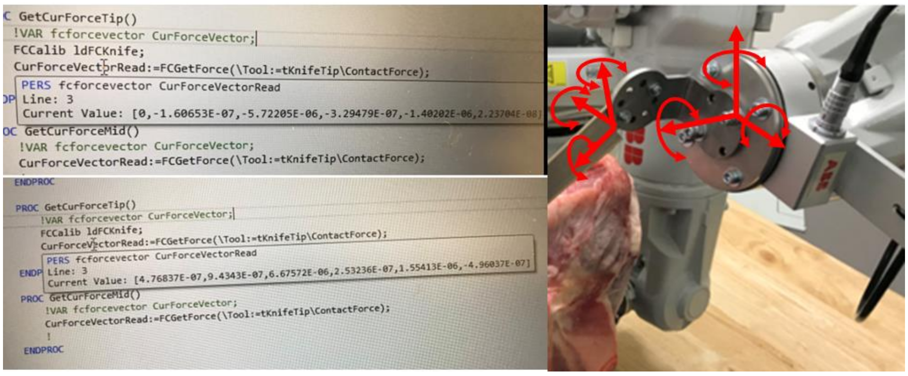


Figure 17: Force sensing module.

The force sensing subsystem was successfully integrated and tested. The values reflect forces and torques in Newtons and Newton-meters under the test condition where the knife is free floating and with the knife touching against the ribcage.

With the knife location in between the forelegs as in Figure 18, the direction of cutting is defined in the robot program. The fixation and positioning of the shoulder primal provided the consistent positioning of the shoulder and the forelegs for this start position.

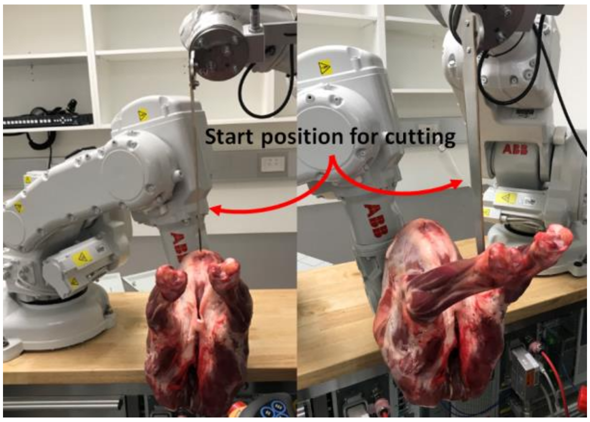


Figure 18: Start of the ribcage boning process.

The knife blade driven to the side of the breast bone with the angle that places the edge in between the upper part of the foreleg and the ribcage guides the sensing as the separation starts.

The oscillating forward and backward motion of the knife, whilst driving the knife edge into the shoulder achieved the separation until the knife blade reaches the ribcage. The path of the program is set to allow the cutting edge of the knife to avoid penetration into the bone, whilst the side edge of the knife is forced against the rib cage.

The first force control scheme is illustrated in Figure 19. The forces N1, N2 and N3 are required to be kept equal during the steps where the knife edge needs to follow the rib cage, whilst the side of the knife is forced by the robot against the ribs, keeping the sharp blade tip away from the bones.

Figure 19: Force control scheme.

Given that force control steps in the cutting actions need to be as fast as possible, the positioning of the carcass for single pass separation for each cutting action pass is important. Software modules provided for tests to reach fastest cutting actions under the current set up. Figure 20 shows the steps that are achieved by the program steps following the featherbone cuts.

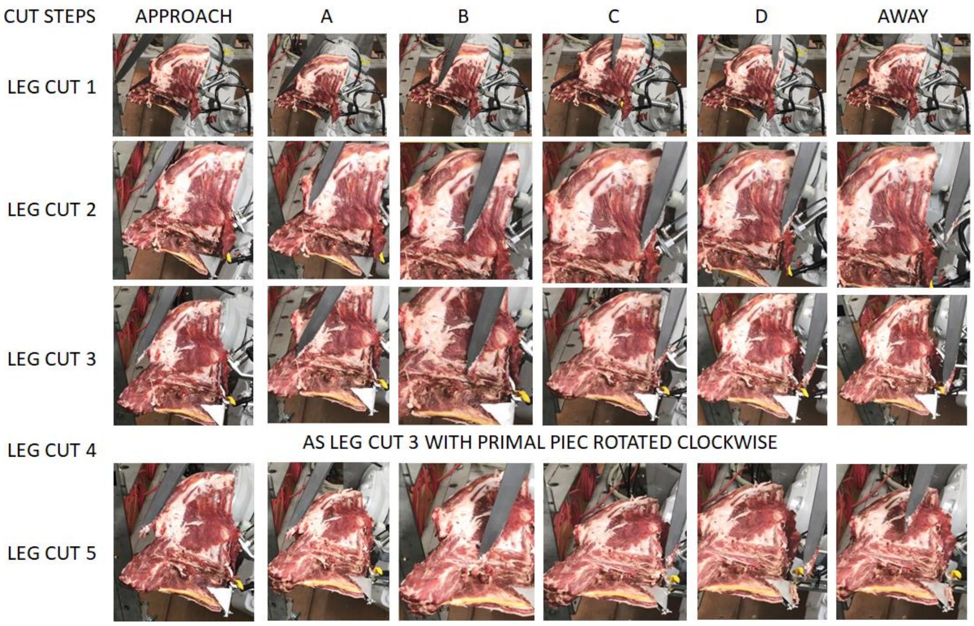


Figure 20: Primal piece positioning by the handling robot and synchronised cutting.

Tests have been conducted to demonstrate that the co-ordinated robot programming is as coded, with the program handshake giving optimum speed synchronised movements with the functions as in Figure 20 achieving the expected separations.

6.0 CONCLUSIONS

The project has met its objectives in the implementation of a first robotic de-boning capability as a prototype unit with the capability to perform deboning of the rib cage from a lamb forequarter.

The performance as assessed is comparable with what may be achieved manually, whilst the speed and consistency for operation in a plant are to be validated with large number of primal pieces.