Final Report

BBFB – Stage 2

Robotic Removal of Button Bone and Flat Bone after Striploin Chine Bone Removal – Stage 2 First Integrated Cell

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1.0 Executive Summary

Deboning of flat bone and button bones after chine separation of a striploin primal is generally performed using a combination of a powered rotatory wizard cutter for button bones and a standard boning knife for flat bones. In some instances, use of a knife for button bone separation is observed.

This project is the world first to consider using a robotic method for performing button bone and flat bone separation attempting the integration of a robotic cell that may be used to assess automation possibility of the deboning process for the first time in a commercial setting at some point in the future.

The following has been achieved by the project:

- Definition and implementation of a holding or fixation method of the striploin for the purposes of robotic handling and presentation of the primal.
- Implementation of a sensory solution combining computer vision and laser measurement device (OD sensor).
- Implementation of a mounting solution for attachment of a standard trimming tool to a robot.
- Integration of the tool, fixation-handling arrangement, and sensory devices in a robot cell.
- Robot programming for button bone and flat bone separation supporting practical trials.
- Comparison of performance of robot in achieving deboning as comparable with manual boning.
- Evaluation of the results based on trials adjacent to the processing line.

The project has reached and revealed the following relevant and important in the pathway to the creation of automation for button bone and flat bone deboning:-

- A world-first implementation of a robotic cell for trials has been reached and tested.
- The Integration provides a low-cost approach, using proven devices including OD sensing and computer vision.
- A standard trimming tool has been used, the design of which has proved to have significant impact on yield. New approaches for developing more effective tools have been highlighted by the project.
- The robotic process as defined by the project provides a new method for using sensory information to guide cutting tools for deboning button bones and flat bones.
- Trials reveal the sensory process and the method, combined with novel robot programming to archive desired trajectory or robot path definitions for tool guidance.
- Trials also revealed that there is further R&D required to define more appropriate separation tools for deboning the flat bones and a deeper examination of the blade shape used for button bone separation. The current tool restricts the possibility to achieve the appropriate yield performance in deboning emphasising the need for further work in cutter tools for deboning flat bones and button bones.

An integrated robot cell has been implemented, which applies computer imaging and laser measurement to sense button bones and flat bone in a beef striploin, the programs that drive a rotary wizard cutter to remove each bone. Aspects of sensory and robot integration have been successfully reached.

2.0 Project Objectives

- Consolidate the development results and the equipment from Stage 1.
- Conceptual cell design with handling and positioning solution for presentation of the primal piece.
- Implement laser and imaging subsystems for determining cut start data and tool positioning for robotic operation.
- Develop tool guidance and control of bone movement during the separation process accommodating variability in bone piece shape and size.
- Integration as a first robotic process and first testing.
- Testing with benchmarking comparisons to current process (10-15 tests over the period) to compare capability to normal manual process.

3.0 Methodology

The methodology of the project will follow the learning from Stage 1.

The equipment used in Stage 1 practical feasibility provides the set up with enhancements that allow the implementation of the elements including handling, fixation, sensing, and tool setup for cutting.

The robotic cell integration provides for programming and testing. The cell uses a standard industrial robot with integrated ABB vision, SICK OD range sensing, end effector mounting and powered de-boning cutter. The operation is replicating a similar solution of comparable size and working speed to a manual worker, but as a robotic implementation.

The work, iteratively tested at each milestone of the project, has ensured functioning modules prior to experimental integration in the target robotic cell as a first world implementation, at TRL4.

The solution under Stage 2 involves validation for performance in a practical setup. Cost-effective implementation will provide the supporting outcomes towards commercialisation.

The programming has involved followed updated steps:

- The striploin placement in a fixture. The Laser from the OD sensor provides a guide for the placement of the striploin in the field of view of the camera on the robot within the work envelope of the robot. Note that with a long strip there is possibility of button bones being outside the reach of the robot with the current set up having a physical constraint.
- Image of the cut face of the bone provides the location of the centre of the bone in the vision frame of reference in 2D.
- The robot program calculates 2D offsets to place the laser position measuring and calculating the button bone location relative to the tool.
- The rotary wizard cutter blade movement by the robot separates the bone from the striploin meat. See Figure 1,

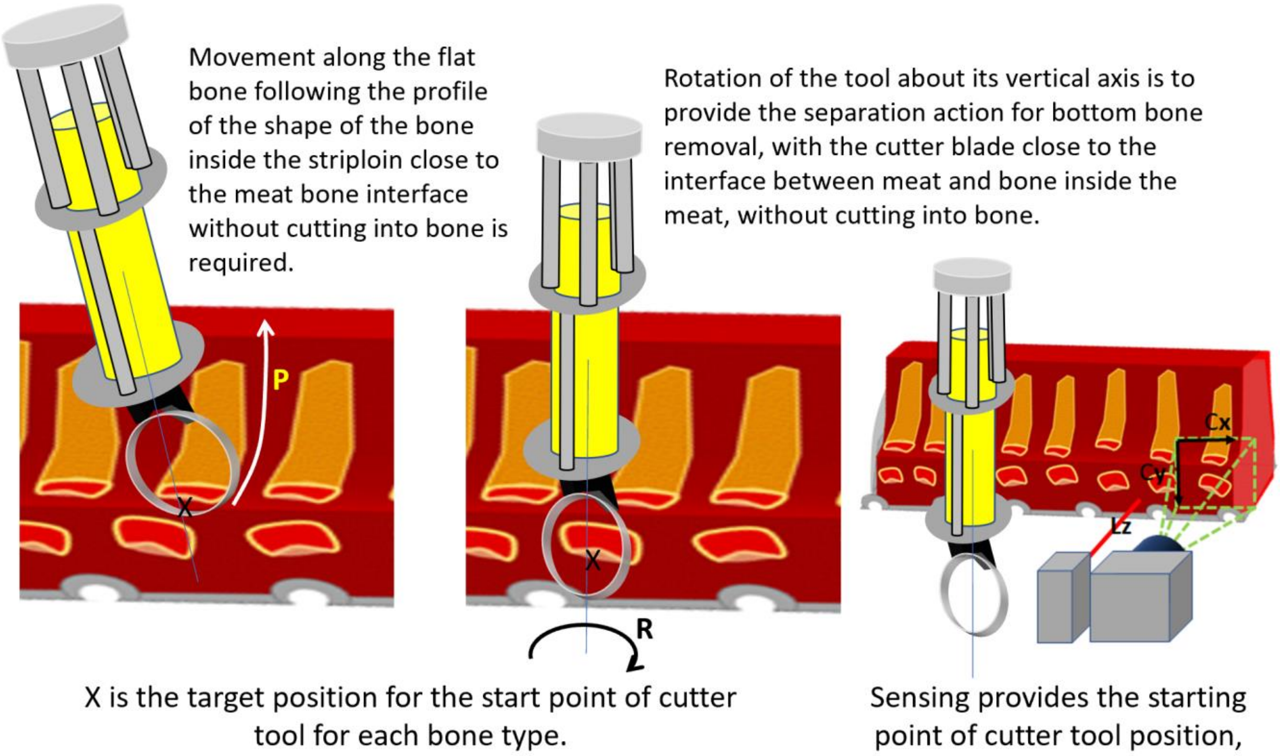


Figure 1: Approach to handling and robotic separation.

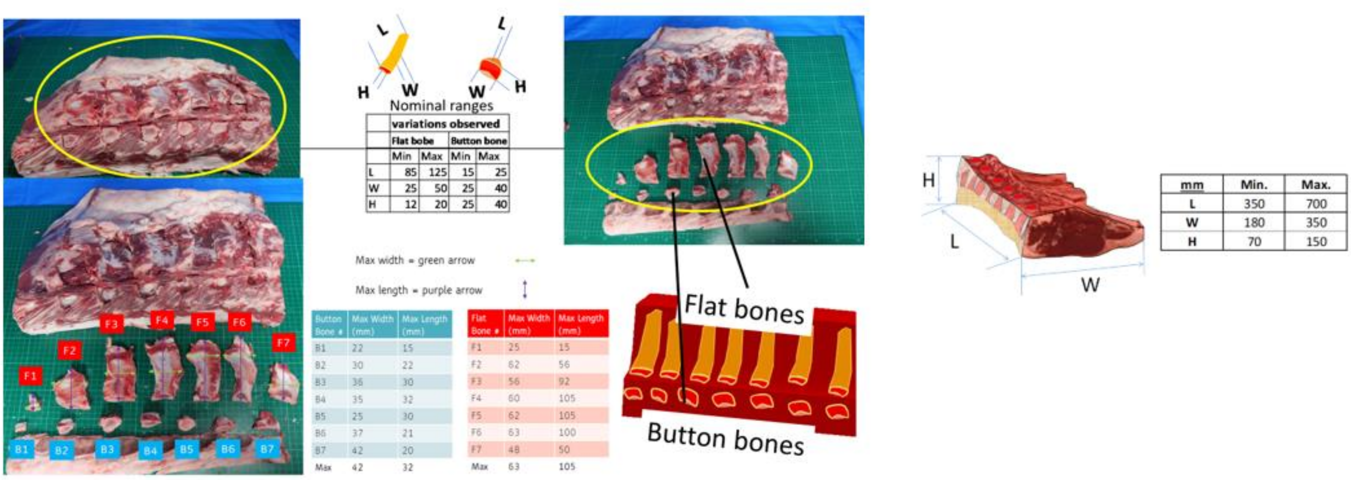
4.0 Project Outcomes

Figure 2 provides an overview of the task under consideration, as performed manually using a rotary trimming tool for the removal of the button bones and a normal butchers knife for the separation of the flat bones.

Figure 2: Current practice: removing button bones (left) and flat bones (right).

Variability

Consideration of variability has provided the necessary background to the processes of defining the solutions in this project in a systematic manner. Figure 3 right shows the variability in the overall dimensions of striploin beef primal pieces and the range of variability in button bones and flat bones. It is important to note that the button bone is approximately a half hemisphere with diameter of 35-40 mm in diameter as a maximum.

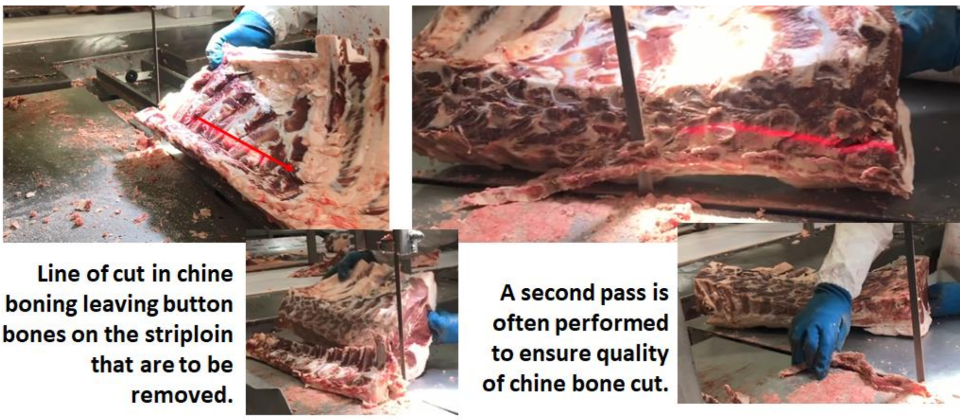


<u>Figure 3: Variability in striploin, button bone and flat bone dimensions.</u>

Based on assessments of variability and first practical set up of deboning using the tool developed and a robot, the width of each button bone and the same for the flat bone as provided from the imaging unit is important to the guidance of the cutter.

It is important that the chine bone cutting influences are eliminated, requiring a visual assessment of the striploin using the imaging solution. It is expected that the integrated development cell to be reached will not attempt bone separation of a striploin that has not been correctly processed at the chine-bone bandsaw stage.

Figure 4 presents the observations, highlighting the potential for unpredictable outcomes that could occur, where button bones may not be fully separable from each other in the chine boning resulting in anomalies.



<u>Figure 4: Influence of chine bone cut on button bone and flat bone removal.</u>

The approach to the integration of the robot to reach trials stage in the is illustrated in Figure 5.

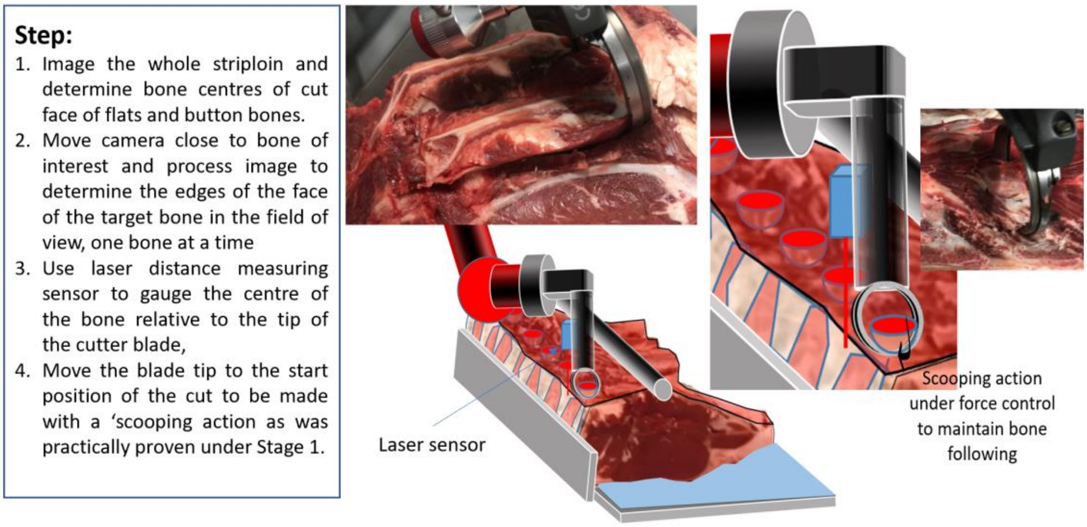


Figure 5: Button bone and flats separation.

As a concept, Figure 6 illustrates the cell configuration in a potential future application. The concept for the cell detailing its main sub-elements including:

- Robot arm and controller in a wash-down and mobile housing,
- End-effector comrising camera, cutter tool and required sensors for tool guidance,
- Safty enclosure frame,
- Striploin carrier for moving the striploin primal in and out of the cell and presentaion holding unit.

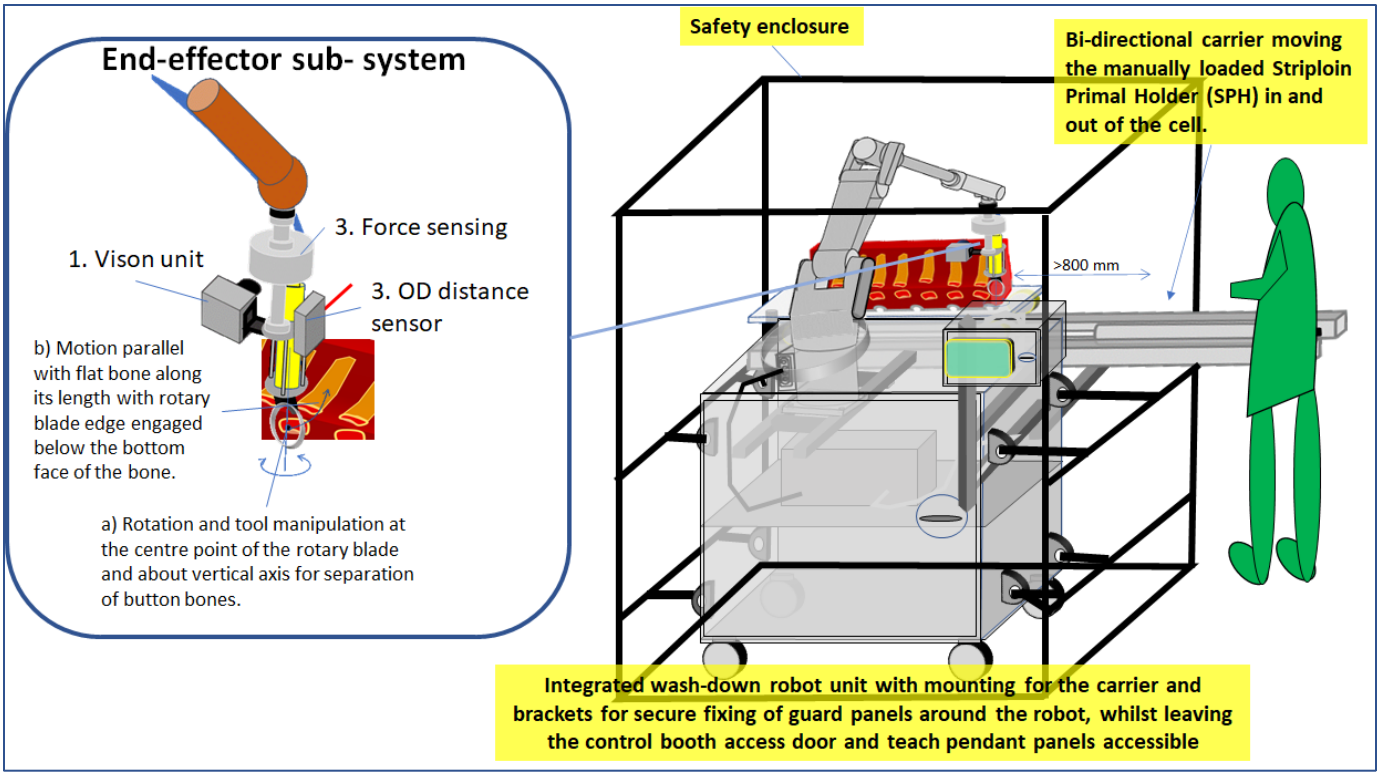


Figure 6: Concept of the Robotic cell for Button Bone and Flat Bone separation.

The overall process would be as follows (with reference to Figure 6):

(i) Operator loads the Striploin Primal Holder (SPH) – This may be a task that is performed by the band-saw operator performing chine boning or the operator removing residues of the featherbones and trimming prior to button bone and flat bone removal.

(ii) Once the SPH is loaded, (details of SPH is provided below), the carrier moves the primal piece into the robot cell through a gap in the guarding panel with the appropriate proximity to prevent a person reaching the cutter or moving elements of the robot unit trough the gap.

(iii) With the striploin positioned the robot is to process an image to ensure the position and orientation of the primal piece is correct and determines from the image the cut faces of each button bone and flat bones facing the camera.

(iv) Once the features and the approximate position of each cut face is determined, a close-up image of each bone face is processed for accuracy and its distance is gauged using an OD sensor adding depth information to the 2D image processed from the close-up image (See image in Figure 1 bottom right). The image provides the circumferential profile with 3D geometric co-ordinates of the edges of the cut face profile in the robot frame of refence thus allowing the cutting edge of the blade to be positioned at the start of the cut point for each deboning action.

(v) In the case of the button bone the separation would require the rotating cutter blade to be revolved about its vertical axis (a) as shown in Figure 6 (left inset) and for the flat bones the motion will be along a path parallel to the long axis of the flat bone as shown (b).

(vi) It is intended that a mechanism to be detailed as part of the end effector would restrain the separated bones and there will also be provision for the bones to be collected in hopper below the SPH.

(vii) The striploin primal is carried back to the loading position in this concept for unloading and reloading of the next primal. The carrier would also provide for the exit of the bone pieces in the hopper for automatic release outside the cell.

The design of SPH has been a key aspect of the development in Stage 2 and undergone a further revision after trials before this final report, and a final additional test.

The solution is of:

a. Simple in design and low cost for manufacture and integration, whilst provide the capability for holding and restraining the primal piece.

b. Easy to integrate and use including easy washing.

c. Have simplicity for loading and ergonomic placement and removal.

d. Provide for the secure holding during separation to the limit that allows successful execution of deboning by a robot.

Figure 7 right shows the latest SPH which may be integrated in such an arrangement that also allows indexing for the execution of the deboning process as illustrated.

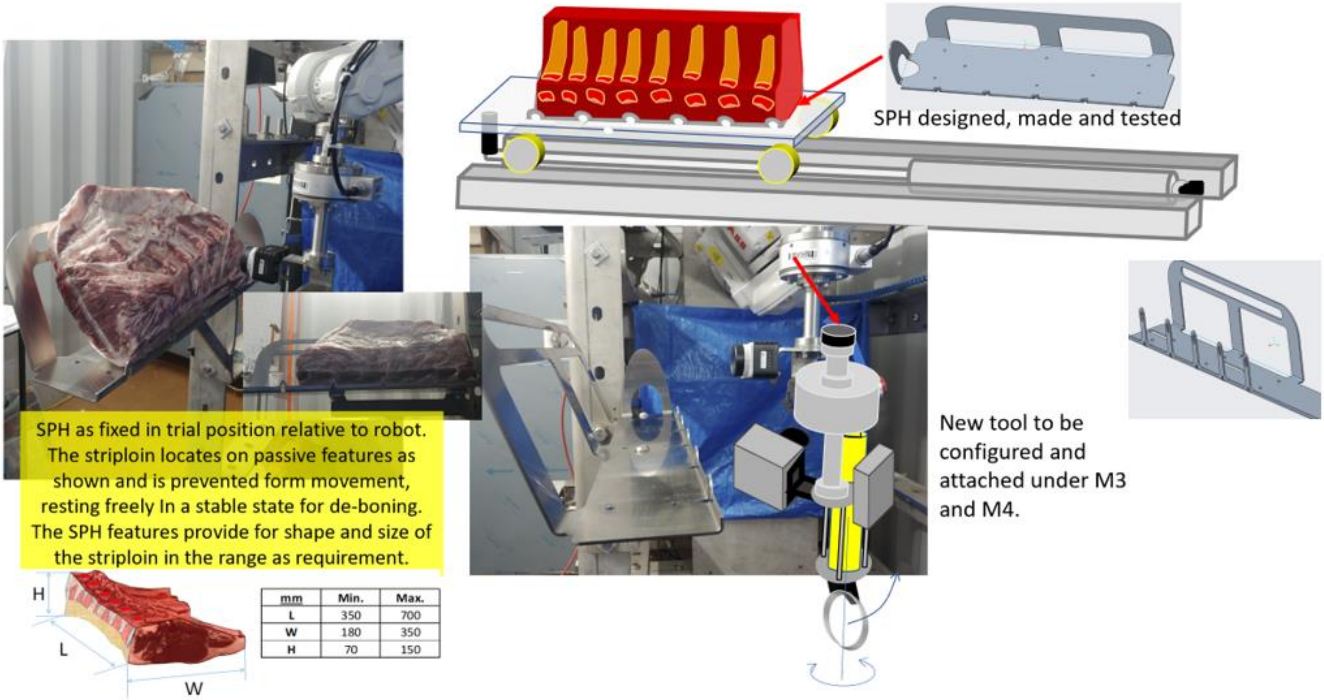


Figure 7: SPH (Striploin Primal Holder) designed, fabricated and tested.

The steps for deboning (with reference to Figure 8) were programmed as follows:

i. The robot positions the camera at a point where the lens is within 130 mm - 150 mm from the face of the bones).

ii. The OD sensor laser range gives the correct position of the cut face of the bone (chine boned/trimmed face from the previous steps)

iii. Image is processed to determine the points of interest in 2D using the ABB integrated camera, with the most key features extracted: these being the centres of the faces of each button-bone and each flat bone in the field of view. Note the set-up is such arranges that only one whole button bone face and one whole flat bone face is in the camera field of view, whilst accommodating the range of size variations. The image processing uses a ‘one-off’ calibration data and the actual position of the bone centre, derived from the unscaled 2D image (Cx and Cy) and the OD distance measurement Lz). The Lz value is accurate to better than 0.2 mm, which is used for scaling and corrections for the determination of the cut start position needed for robot cutter tool to be positioned.

iv. OD sensor provides the distance Lz in the robot frame of reference, allowing the determination of tool position in Rx, Ry and Rz (Figure 6) for each button bone and flat bone.

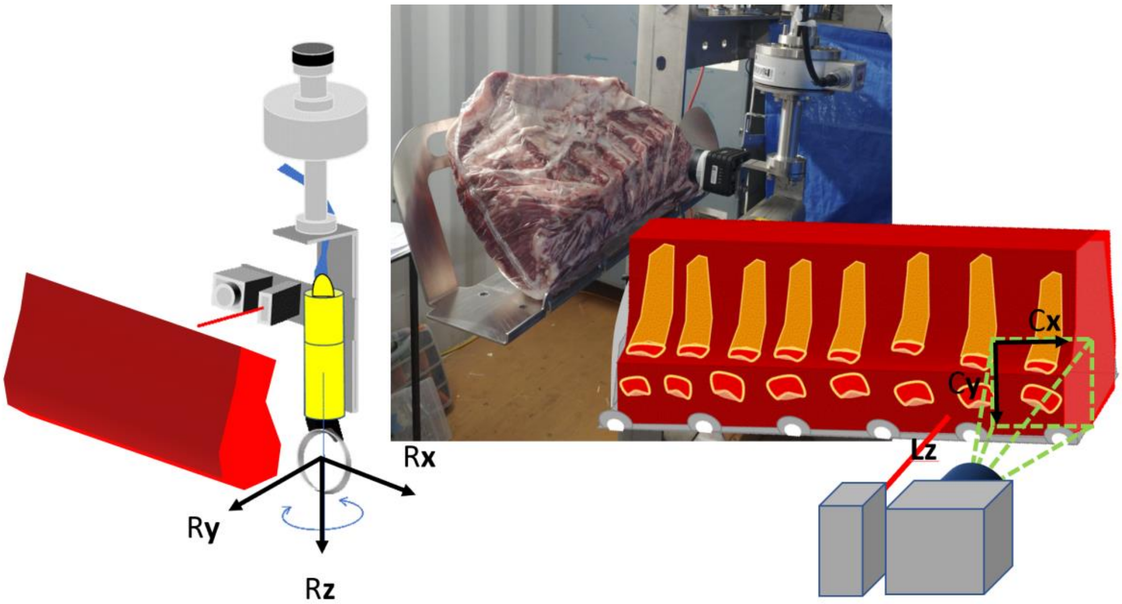


Figure 8: Measuring bone position with OD and camera sensors.

The calculated points FB_n and BB_n (Figure 9) for each button bone allow the cutter to be located at the start of each.

The separation action after the start position would involve a blade rotation (180 degrees) about the vertical axis of the cutter (Rz) for the button bone; and over the rear profile of the flat bone until separation is complete.

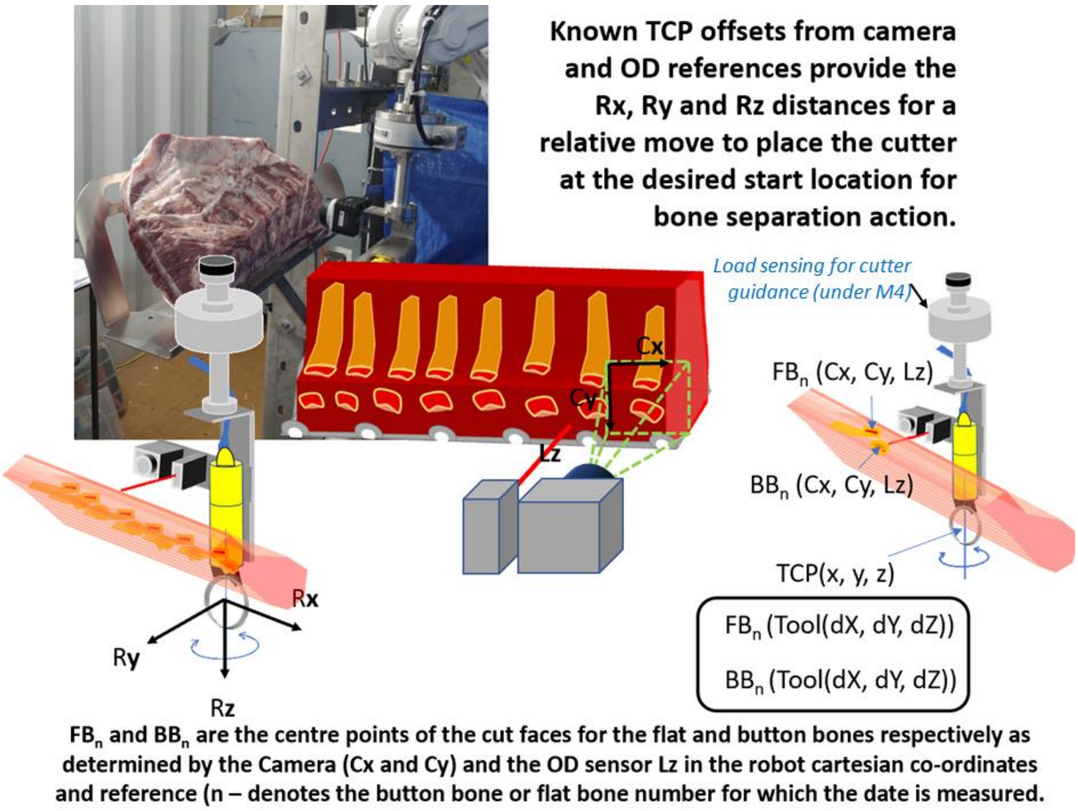


Figure 9: Extracting bone positions in robot tool co-ordinate system.

Figure 10 presents the results. The camera image (top left) and the transformation using calibration and OD sensor data give the tool positions for the button bone face and the flat bone face, respectively.

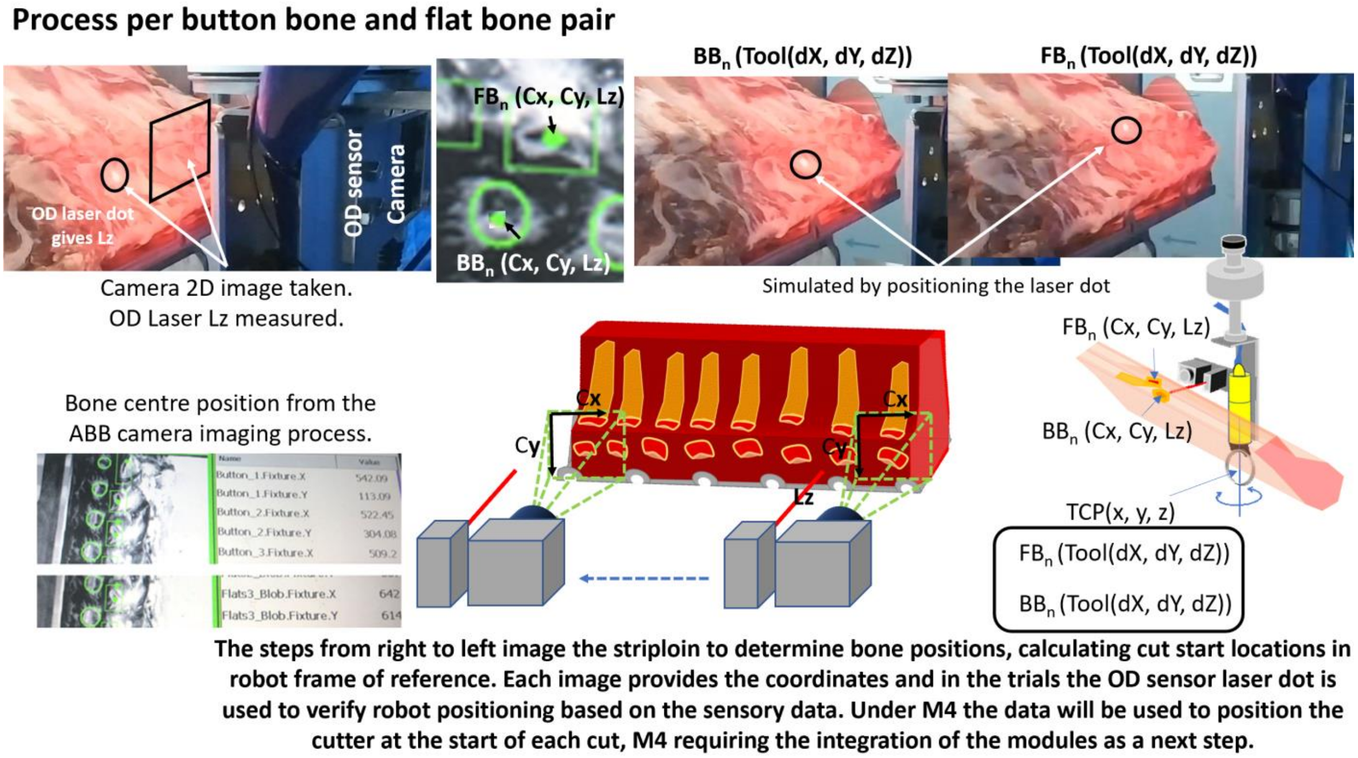


Figure 10: Positioning the tool relative to the bones using the laser dot.

The process of robotic de-boning is achievable for button bones (based on initial robot test observations).

Cutting tool integration – implementation of end-effector

To establish the approaches for guidance and robot movements to achieve separation the wizard power tool was integrated with the sensory devices in a physical arrangement as shown in Figure 11 (left).

Figure 11: Cutter end-effector separation trial with button and flat bones.

The end-effector was used in robot trial for the practical evaluations resulting in the groundwork for the development of guidance and control for the robotic separation of button bones and flat bones. The cutter unit was integrated in a movable cell suitable for a meat environment combined with the sensory and guidance methods developed.

Figure 12 presents the assembled cell and the test images from first testing.

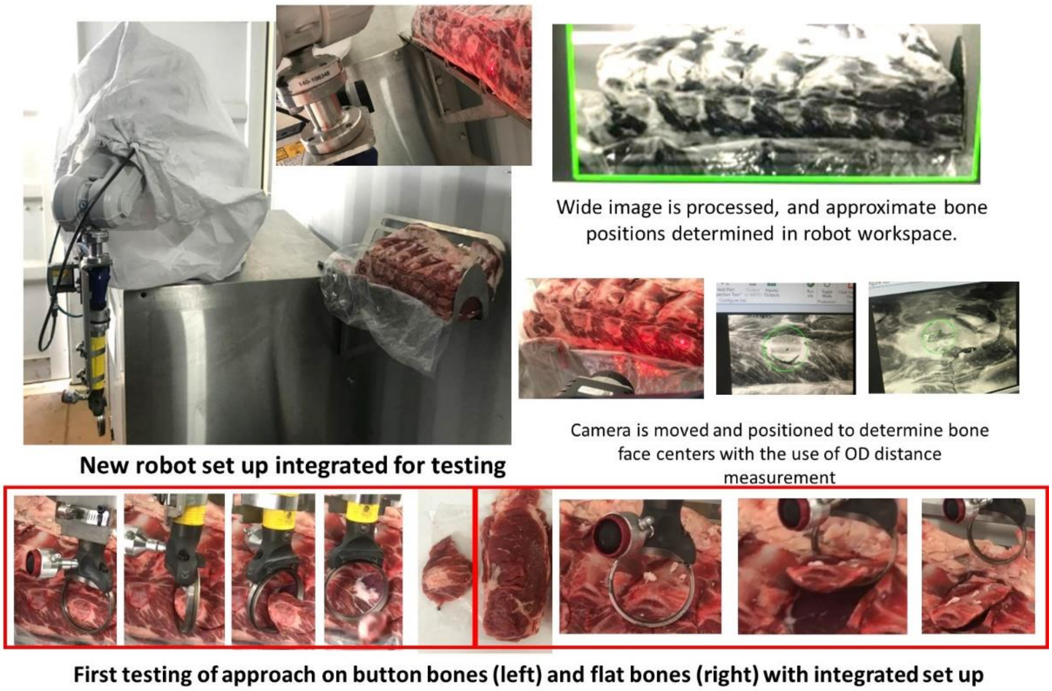


Figure 12: Integrated set up and first testing.

Further testing has provided comparisons between the manual and robot processes.

Falt bone separation

Figure 13 shows the flat bone separation outcome as performed manually, comparing with the robot. Given the circular shape of the blade yield is compromised as illustrated.

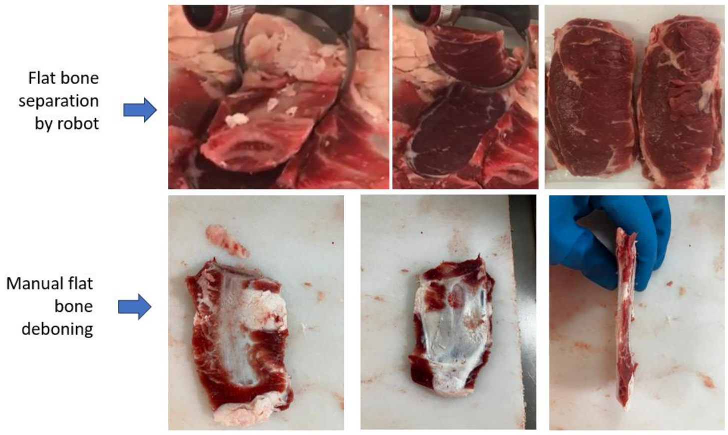


Figure 13: Approach to handling and robotic separation.

As may be noted the shape of the blade does not allow separation directly below the flat bone and alternative separation is needed. The processes of sensing and robotic cutting however have been reached and may be used at a later stage in this development with a new cutting tool.

Button bone separation

Trials adjacent to the line were performed after customising the cell for tests to compare the separation of button bones by the robot with manual process. Fifteen cases of separation runs are presented in Figure 14.

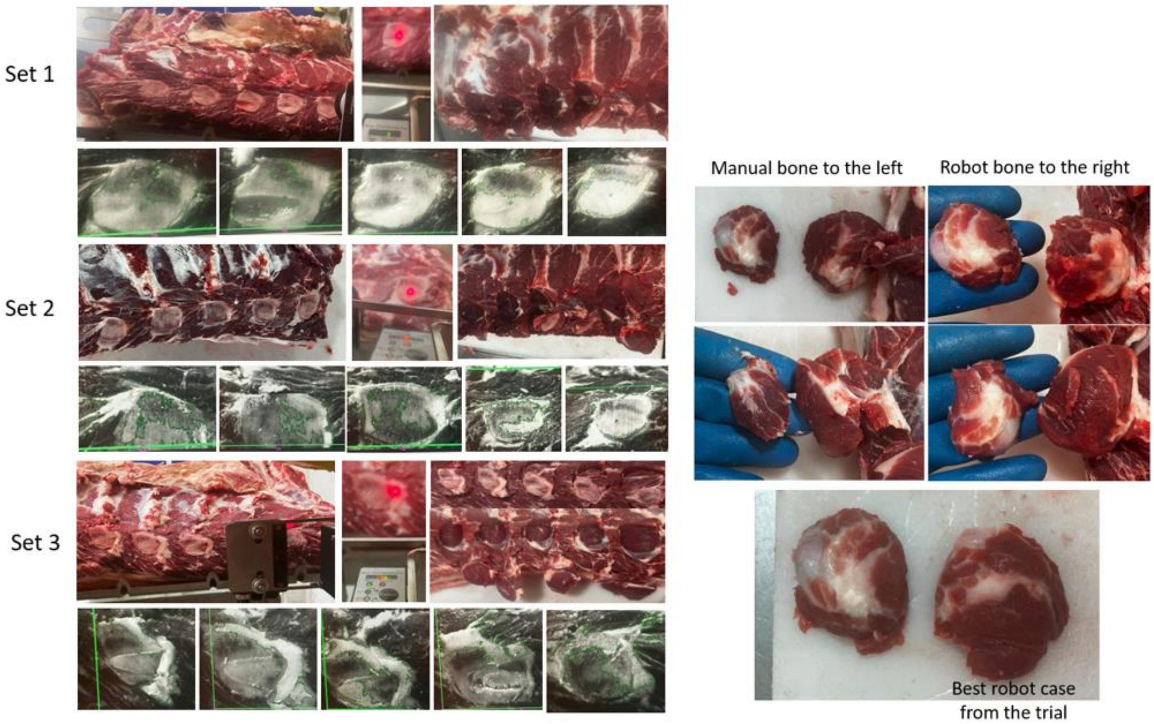


Figure 14: Trial results in three sets.

Tuning of the robot programmes has been necessary between each set and the comparison with the manual process shows the extent of yield damage in set 1 improving to set 3, where the best case is shown: Figure 14 bottom right. The button bones separated by the robot compared with the profile from the manual deboning as photo to the left of each button bone of Figure 14 right, were considered 'too meaty', giving poor yield. No further tests, beyond the three set (Figures 14) were possible, whilst the results have revealed all that may be important as outcomes under stage 2.

The following may be summarised based on observations during the trials and assessment of videos that were possible to record:

- The manual process uses a smaller diameter blade, and the boning action involves complex handling of the tool.

- By reducing the diameter of the blade of robot tool a more accurate separation path may be achieved; however, this may require more dexterous manipulation of the tool.

- The dominant errors resulting in yields loss being compromised, revealed by the trial, relate to the lighting conditions, influencing image processing, determining the button bone centres. This may be improved by a new set up that encloses the camara mounting arrangement keeping the ambient lighting out.

- The programme calculates the path of the blade for a single 180-degree rotary motion with a movement that needs to account for the width of the button bone in relation to the diameter of the blade. A button bone diameter of 35 mm has been used in the determination of the blade tip needing to be located on the edge of the button bone at the start of the cut, relative to the button bone centre. The determination of the button bone width by image processing has been impractical because of the sensitivity to lighting. Dynamic thresholding combined with an enclosure of the camera under structured lighting is necessary. Improvements require a study of the possibilities to reduce impact of lighting and enhancements in the vision programming to provide button bone dimension information.

- The orientation of the striploin has an impact, where the plane of the button bone relative to the face of the blade needs to be parallel. This may be improved, introducing a fixation scheme that holds the striploins button bone face more parallel to the blade.

5.0 Conclusions / Recommendations

The project has the following:-

- A world-first implementation of a robotic cell for trials has been reached and tested.
- The Integration provides a low-cost approach, using proven devices including OD sensing and computer vision.
- A standard trimming tool has been used, the design of which has proved to have significant impact on yield. New approaches for developing more effective tools have been highlighted by the project.
- The robotic process as defined by the project provides a new method for using sensory information to guide cutting tools for deboning button bones and flat bones.
- Trials reveal the sensory process and the method, combined with novel robot programming to archive desired trajectory or robot path definitions for tool guidance.
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An integrated robot cell has been implemented, which applies computer imaging and laser measurement to sense button bones and flat bone in a beef striploin, with the programs that drive a rotary wizard cutter to remove each bone.

6.0 Acknowledgements

Special thanks are due to AMPC for funding this project and the input and support for JBS Beef City. The efforts of Fraser Border (RAMS Australia), working with BMC is very much appreciated and duly acknowledged.