Final Report

AUSTRALIAN MEAT PROCESSOR CORPORATION

In plant trial of robotic picking and packing system

Strategic Engineering Pty Ltd

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1.0 Executive Summary

The task of picking and packing vacuum packed primal cuts of red meat is a labour intensive task which is currently undertaken as a manual process, resulting in significant labour costs and workplace health and safety risks. Through this project, an automated robotic system capable of replicating the pick and pack operations currently performed in meat processing plants was trialled on real product in an operating meat processing plant. The system developed and demonstrated during an in-house trial for a previous project (AMPC Project 2017-1065), was modified to suit the packaging area of JBS Brooklyn Plant.

The system consisted of a six-axis industrial robot, coupled with a vacuum pad foam gripper developed by Strategic Engineering. The gripper was used to physically grip and transport the primal cuts to destinations inside cartons from a moving conveyor. In conjunction, a high resolution three-dimensional computer vision system was developed and utilised in order to identify the primal cut to be packed, and determine the pick and pack parameters for accurate pickup and placement into the carton. A suitable outfeed carton fixture was manufactured to suit the restricted space available. Safety guarding and light curtains were used to provide adequate safety for the robot cell and the operators that were working nearby. Initial trials utilised an operator to manually identify each primal cut for the system to robotically pick and pack, and so a touch screen and HMI were developed for interfacing with the system.

Successful in-plant trials of the automated picking and packing system were performed in JBS Brooklyn plant. Packing was tested on a number of different primal cuts to find the optimal packaging strategy for the site. Initially, 4 different cuts were trialled, similar to the setup for the previous in-house trial. To maximise the efficiency of the robot cycle the system was trialled for two weeks packing just two type of primal cuts, the navel end brisket and the point end brisket, packing two cartons each per complete cycle. Following further discussion with AMPC and JBS, software modifications were made to automate the identification of one primal cut as a starting point to increasing the effectiveness of the system and ultimately fully automate the complete process.

Although only a subset of primal cuts have been picked and packed for the purpose of this in-plant trial, it is envisioned that a wider selection of primal cuts would be able to be handled by the system without major design modifications. The ultimate intent of this development pathway is to demonstrate the practicability and viability of autonomous picking and packing within the red meat industry using intelligent technologies.

2.0 Introduction

Primal cut picking and packing is currently a labour intensive and almost exclusively manual step in the meat packing process. Meat processing plants suffer significant labour costs and workplace health and safety risks associated with the manual picking and packing of primal cuts. This step requires operators to transfer cuts of meat from the in-feed conveyor to the appropriate carton for storage or dispatch, and can involve lifting primal cuts of up to 5kg or more, placing strain on the operator's body and leading to stress related injuries. The introduction of automated robotic solutions may significantly reduce the number of operators required in the picking and packing operation and present significant economic savings.

Despite the potential benefits, automating the packing of vacuum-sealed primal cuts into cartons has proven technically complex. The high number of variables and stringent hygiene standards in meat processing have made many meat processors hesitant to adopt automated approaches. As a result, manual labour continues to be the most widely used method for picking and placing primal cuts makes use of multiple operators (dependent on the stock produced, throughput, and plant size) to manually pick and place primal cuts into cartons.

A study conducted by Strategic Engineering Pty Ltd (MLA project A.TEC.0107) recognised the feasibility of implementing an autonomous pick and pack system with existing technologies. However, the study also highlighted the need for further technology development and adaptation to suit the unique requirements of the red meat industry. As recommended by the study, a series of follow-on projects lead to the development of a Primal Cut Recognition and Localization Software and then an Integrated Robotic Picking and Packing system that was demonstrated as part of an in-house trial.

The project "Development of Primal Cut Recognition and Localisation Software for use in Robotic Pick and Pack Systems" (AMPC Project 2014-1007) laid the ground work for a 3D vision system for primal cut identification and tracking. The project's main objective was to develop and assess sensing hardware and software algorithms capable of rapidly identifying and locating red meat primal cuts on an in-feed conveyor. This was achieved by employing an intelligent sensor network that captured and processed the three-dimensional scene of the packing environment in real-time. The system provided critical information in real-time, including the type of primal cut, its position, and orientation.

Following the identification software development, the project "Integrated Robotic Picking and Packing of Primal Cuts" (AMPC Project 2017-1065) lead to the development of a robotic system, complete with custom vacuum gripper and controlled by the 3D vision system software, which was capable of automatically picking and placing a subset of primal cuts. Primal cuts were identified, tracked and picked from an in-feed conveyor and efficiently packed into cartons. The 3D colour vision system, with its real-time data processing, was instrumental in identifying crucial information, such as the type of primal cut, its precise position, and orientation. The culmination of this project was the successful creation of an autonomous robotic cell, capable of efficiently picking and packing primal cuts without the need for manual intervention. This autonomous robotic cell was successfully trialled in-house as the outcome of the project.

The scope of this project is to take the Robotic Picking and Packing System as developed in the previous project (AMPC Project 2017-1065) and integrate, install and perform a successful trial of the system on real product in an operating meat processing plant. The host plant selected for the trial is JBS Australia – Brooklyn plant. Modifications to the system as it was during the previous in-house trial are required to allow operation and integration with the host plant. These included the addition of safety guarding and light curtains as well as design and manufacture of a new vision frame and outfeed area to meet the hygiene requirements of the plant.

The robotic system will work alongside human packers and be responsible for identifying and packing only a subset of primal cuts. The idea is that this will pave the way to more comprehensive automation of the picking and packing area. It’s envisaged that plants would be able to add modular robotic picking and packing cells one by one as the technology develops and processors become more confident in the technology. In the foreseeable future, plants will have the potential automate the picking and packing of around 70% of primal cuts using this system, leaving 30% to humans, achieving automation whilst maintaining a degree of flexibility.

3.0 Project Objectives

Objectives for the In Plant Trial of Robotic Picking and Packing System are outlined below:

- Determine if the Robotic Picking and Packing System as developed and tested in the workshop environment during AMPC Project 2017-1065 can be successfully installed and integrated into a meat processing plant.
- Determine if the Robotic Picking and Packing System can successfully share workload with human packers to pack a subset of the primal cuts (say 5 to 20% of products).
- Trial system in plant and report on its efficacy and suitability to the plant’s operations.

4.0 Methodology

4.1 Previous in house trial

As part of AMPC Project 2017-1065, Integrated Robotic Picking and Packing of Primal Cuts, an automated robotic system capable of replicating the pick and pack operations currently performed in meat processing plants was developed. This system was demonstrated during an in-house trail and served as the basis for demonstration of this project for an in-plant trial. The system was modified and redesigned to be integrated into an existing packing production area. After consultation with AMPC and member processors, JBS Brooklyn plant was selected as the host plant for the in-plant trial.

4.2 Hardware Procurement and Setup

Specifications of the plant setup and overall system are detailed below:

- The infeed conveyor selected is at a height of 1240mm from the floor with a belt width of 560mm, and a 50mm side wall.
- Other conveyors and nearby plant equipment informed the updated cell design to minimise interference with existing plant operations.
- The infeed conveyor belt is quite perforated which may pose a challenge to the calculation of the height of primal cuts. However, it is expected that this can be overcome.
- The infeed conveyor speed is approximately 18m/min.
- The conveyor will transport every primal cut type underneath the camera. An operator will manually verify each cut identified by the system for automatic picking and packing by the robot system.
- Primal cut height (maximum height off the conveyor bed) will be limited to 250mm.
- Full boxes will be manually removed by operators and replaced with empty boxes.
- Main cell footprint (enclosed by light curtains) is approximately 2 metres by 3 metres.

Figure 1: Position of proposed robotic cell.

Figure 2: Proposed robotic cell packing region.

4.2.1 Robot and Base

An ABB IRB4600 60-205 industrial robot, previously used during the in-house trial (AMPC Project 2017-1065), was used to perform the pick and pack operations. This robot has a 60kg payload capacity, 2 metres reach and a small overall footprint. Additionally, the conveyor tracking modules were added to the robotic controller to allow interfacing with an encoder on the conveyor and allow accurate tracking of the position of the primal cuts on the conveyor. Also, multitasking programs were used to handling data exchange between the robot controller and the vision application.

As the height of the infeed conveyor onsite has changed substantially, the base for the robot has been completely redesigned. The overall footprint for the base has been minimised to allow the robot to be located closer to the conveyor, as well as the outfeed packing area. The new base adds approximately 500 millimetres to the base of the robot, which increases the robots linear reach along the conveyor but requires the outfeed packaging area to also be raised up in order remain within the robots work envelope.

Figure 3: ABB robot installed in plant.

4.2.2 Vacuum Gripper

The vacuum gripper previously designed by Strategic Engineering for use during the in-house trial (AMPC Project 2017-1065) was utilised with the industrial robot to safely and securely pick up the vacuum sealed primal cuts. The gripper consists of two metal plates with a semi-closed cell foam pad. The overall dimensions are designed around the constraints of the cartons used to package the primal cuts. While the thickness of the foam was selected based on the size of the selected primal cuts to maximise the vacuum gripping force. The gripper is divided into separate modules, each of which can be independently controlled by the robot depending on the primal cut currently being picked.

Figure 4: Vacuum pad gripper.

To integrate the vacuum gripper with the robot, a suitable pneumatic valve control system was mounted on the upper arm of the robot. High flow rate inline vacuum ejectors were used to provide vacuum to the gripper. The attachment between the robot's roll face and the gripper was offset from the centroid of the gripper. This allowed the gripper pad to be inserted into a carton without interference between the carton and the robot arm.

4.2.3 Camera and Lights

A stereoscopic line scan camera, Chromasens allPIXAPro4096, and Corona II LED lights capable of capturing high resolution stereoscopic images was used to image the primal cuts on the infeed conveyor, similar to the camera setup used in the previous in-house trial (AMPC Project 2017-1065). Bright lighting is needed to illuminate the scene for the low sensitivity (low exposure) line scan camera. Two lights are utilised, forward and rear of the camera, to eliminate shadowing when the line scan is imaged.

From these images 3D positional data is generated to track the primal cut on the conveyor. Additional feature information of the primal cut in each image frame is also computed. This feature information is planned to be used to automate the identification of the primal cut. However, during the initial trial, an operator was still present to manually verify the type of primal cut.

Figure 5: Chromasens allPIXAPro (left) and Corona II LED lights (right).

4.2.4 Encoder and Trigger

The SICK DFS60B-S4PC10000 was the encoder that was selected primarily for its previous operation with similar line scan camera systems. This encoder is an IP67 rated, programmable, incremental encoder. As the site does not have an easily accessible conveyor shaft to couple the encoder to, an external roller wheel was used to track the conveyor motion. Due to the size of the encoder wheel, the pulse rate had to be programmed to a lower rate under the maximum input frequency of the robot conveyor tracking software. Initially the encoder was mounted temporarily to the conveyor frame with a clamp. This worked during production but was prone to movement following a wash down cleaning. A permanent mount was designed and installed to ensure the encoder wheel remains in contact with the conveyor belt.

Figure 6: SICK DFS60B-S4PC10000 Encoder and external measuring wheel with rubber O-ring.

For the trigger sensor, the same laser diffuse photoelectric sensor with background suppression was used during initial trials and was mounted on the camera and light frame. However, due to the presence of the side walls on the conveyor, the sensor had to be angled rather than positioned parallel to the conveyor belt. This allowed the possibility of not triggering accurately on the leading edge of a primal cut that was thin enough and positioned such that it could pass under the sensor beam. To prevent this a Balluff BOS01U8 through beam sensor was purchased and installed into the sidewall itself. The new sensor has a 3 millimetre spot size and is aligned to the conveyor belt creating a sensor line perpendicular across the width of the conveyor, ensuring accurate and consistent triggering of the primal cuts for image acquisition and robot object tracking.

Figure 7: Balluff BOS01U8 through beam sensor.

4.2.5 Camera and Light Frame

To hold the camera and lights in their correct positions above the conveyor, an appropriate frame which matched the specification was designed. All external components are manufactured from 316 Stainless Steel and utilise food grade, metal detectable gaskets and seals to provide IP protection to the internal components. The frame itself is composed of two main bodies (upper and lower half) which are able to be separated and transported into position prior to re-assembly. A cantilever design was utilised which allows the frame to be positioned on one side of the conveyor. The lights and camera are modular with respect to the frame, allowing them to be positioned and installed once the frame is in location.

The conveyor onsite has a significant slope as it travels to the current packaging area. After consultation with the camera manufacturer accommodations to be able to adjust the angle of the camera relative to the frame have been made to achieve the desired positional accuracy of the vision system. As the height deviation between the primal cuts is fairly large, the two LED lights were positioned to obtain a 200 mm depth of field image. This allowed the primal cuts to be correctly illuminated along their entire top surface contour.

Figure 8: Rendering of camera and lights frame design. Camera and light covers are transparent to show details of the camera and lights respectively.

4.2.6 Control Cabinet

The control cabinet will hold the Vision PC, LED light controllers, power supplies, control wiring and a touch screen human machine interface (HMI). The cabinet is made from 316 Stainless Steel, is IP66 rated and is mounted on machine feet to allow for the cables to enter through glands from underneath the cabinet. The cabinet is fitted with an intake and exhaust fan to protect the electrical components from overheating. Both fans are equipped with food grade, metal detectable gaskets and slopped covers, allowing the whole cabinet to be wash downed. However to protect the touch screen during the trial the whole cabinet is still being covered at the end of production each day.

4.2.7 Outfeed Carton Fixture

In order to hold the packaging boxes in place for packing a custom fixture was designed to suit the plant layout and requirements. The fixture is capable of holding four boxes at a time in three different orientations, as can be seen in Figure 9. The purpose of the differing orientations is due to the differing packing requirements of different cuts, similar to the packing options demonstrated during the in-house trial (AMPC Project 2017-1065). The two layered design minimises the overall footprint of the outfeed, as well as the cell overall, and is a more efficient layout with the additional height of the robot relative to the infeed conveyor. As handling of cartons is not within the scope of this research project, an operator will be responsible for manually placing empty cartons and removing the full cartons. This also allows the operator to verify the contents of the packed carton for quality control and identify any issues in the accuracy of the automated system. Any future development of this automatic picking and packing cell will include a more suitable carton handling operation.

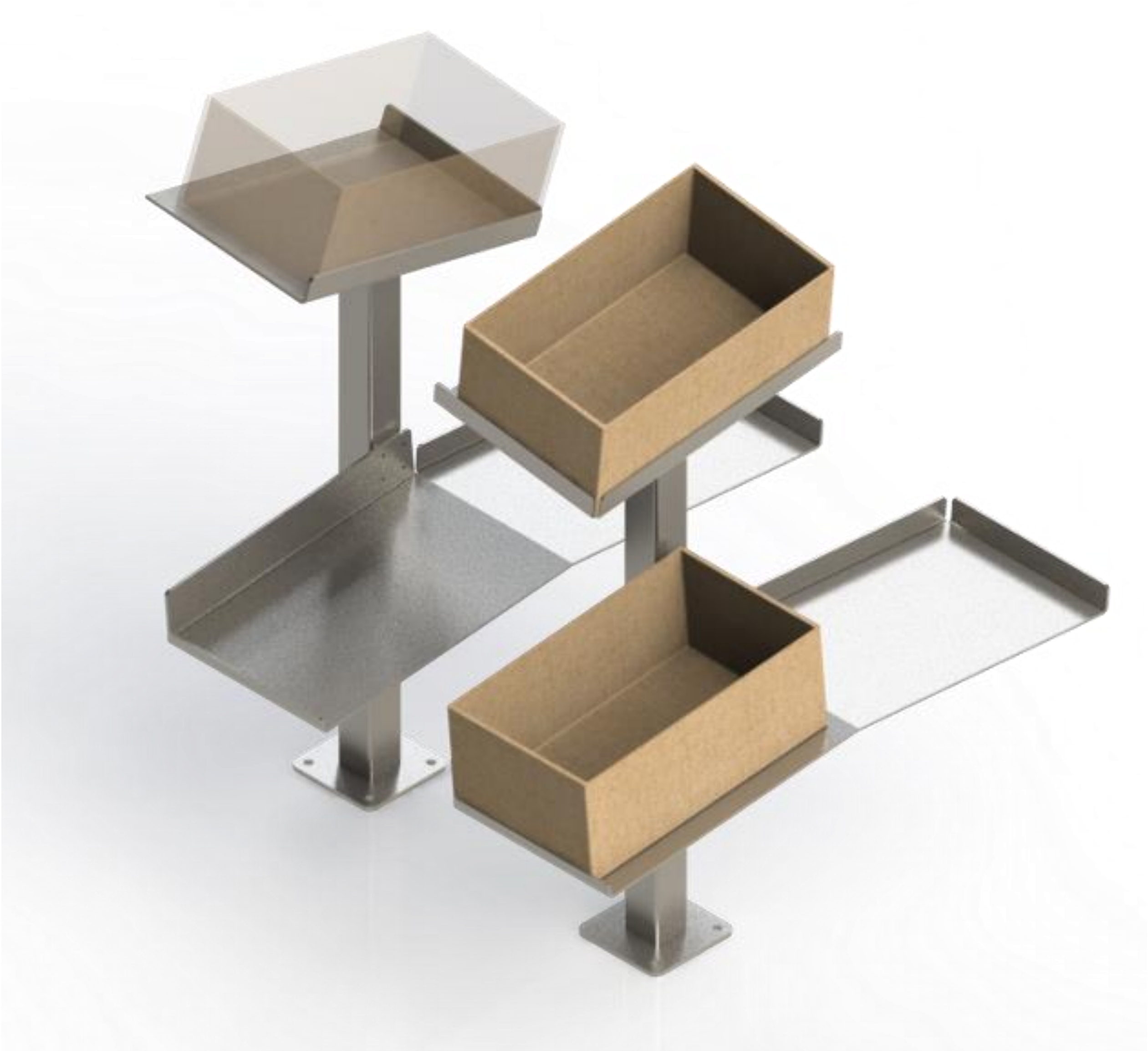

Figure 9: Packing carton outfeed fixture.

4.2.8 Safety

A combination of physical guarding and light curtains have been utilised to provide adequate safety for the robot cell. On the other side of the conveyor (opposite to where the robot is located), physical guarding will be erected to prevent operators being able to come in contact with the robot. Around the sides and behind the robot, a light curtain will be employed to prevent unwanted access to the Robot. If broken, this light curtain will E-stop the robot system, immediately applying the motor brakes and bringing the robot to a complete stop. Additional physical guards will close gaps between the light curtain mounting posts and the existing site equipment. Finally, operator procedures produced by the site will limit the number of workers nearby to the robot cell, and only trained personally are allowed to enter the safety enclosed robot area. These safety measures are also illustrated in the cell layout, Figure 11.

4.2.9 Wash down Covers

As this project is only a trial in plant, waterproof covers for the components that are not inherently waterproof have been designed and made. This primarily includes the robot and its controller. These covers will be placed over top of the respective equipment prior to wash down and will protect the equipment that is not rated for such rigorous cleaning. As an extra layer of protection for the HMI control cabinet, camera and lights during wash down procedures, waterproofing covers have also been organised to be placed over these components. This should ensure no intermittent issues caused by residue left on the optical windows of the stainless steel covers.

Figure 10: Washdown covers for camera and lights (left), control cabinet and robot (right)

4.2.10 Cell Layout

Figure 11 presents the proposed cell layout designed to fit within the tight spatial bounds of the allocated site area and resulting in minimal obstruction to existing operations. It should be noted that the depicted layout does not include the Robot cabinet.

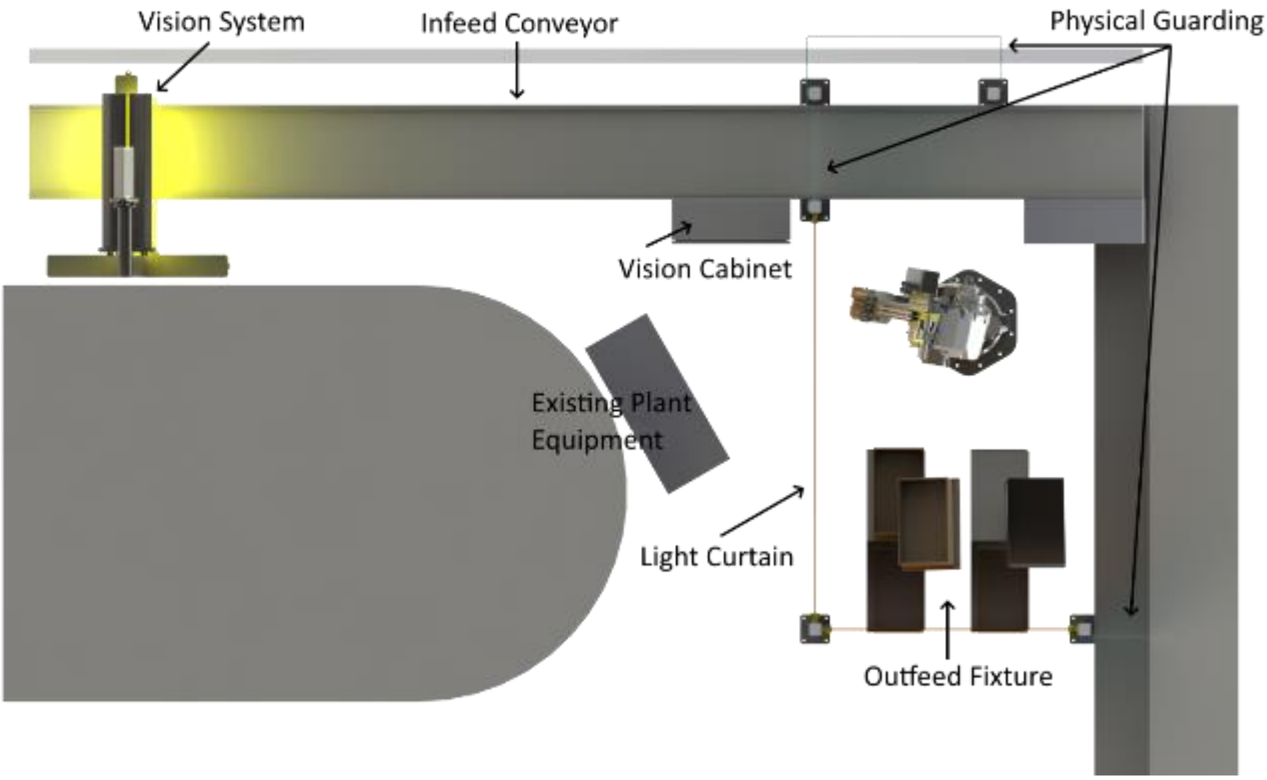

Figure 11: Cell Layout rendering, overhead view.

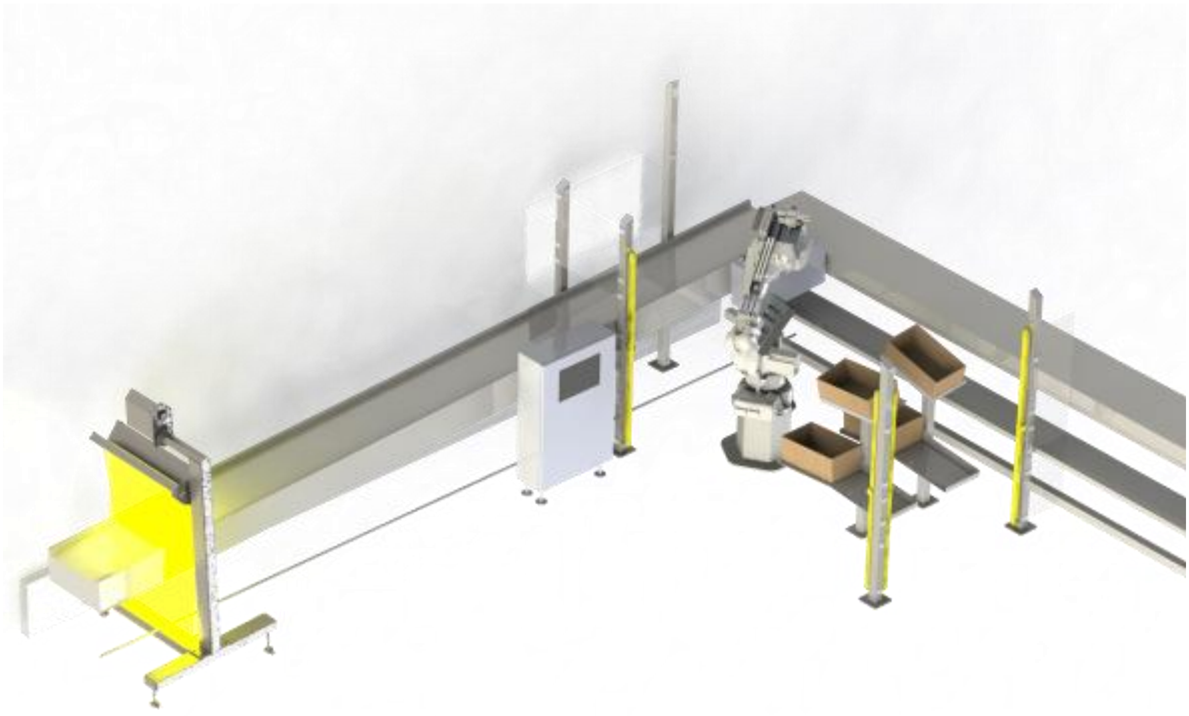

Figure 12: Cell Layout rendering top view.

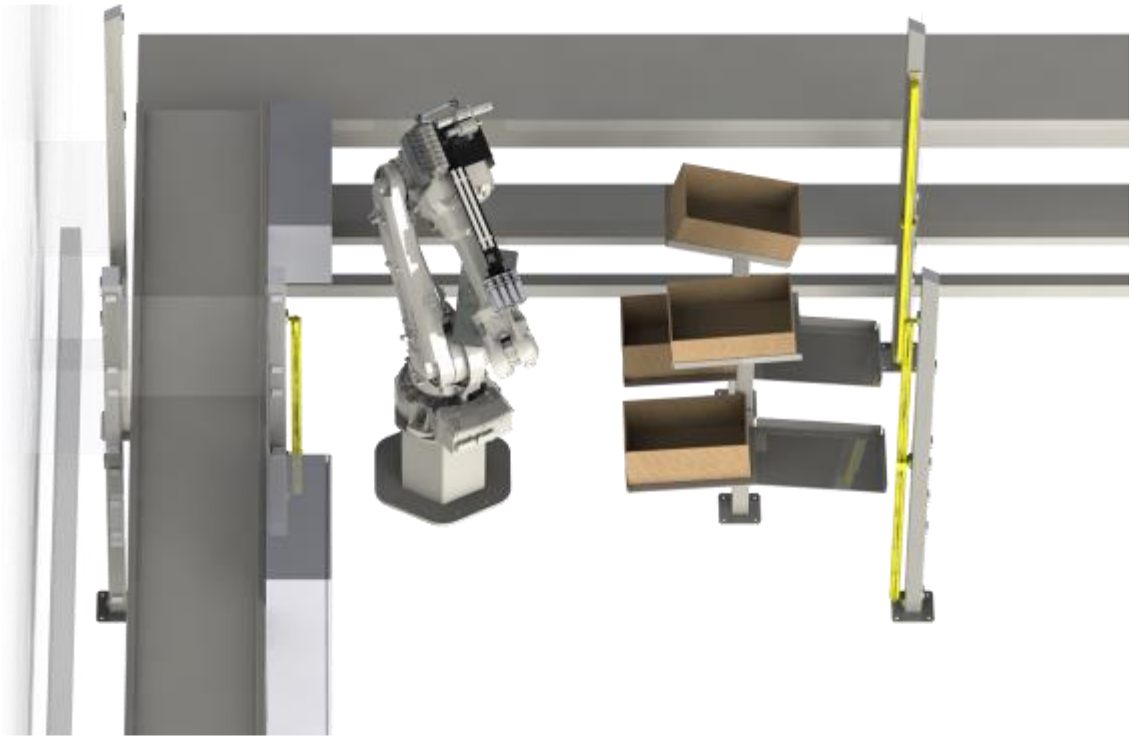

Figure 13: Cell Layout rendering side view.

4.3 Vision System

The vision processing application system was used to capture images of the primal cuts which passed along the conveyor underneath the camera. Images were captured by the stereoscopic line scan camera and then processed to calculate picking and packing parameters which were used to guide the robot during the picking procedure.

4.3.1 Vision Processing

The HALCON development environment was used to create a module for the acquisition of images using inbuilt frame grabber functions. The images are transferred into the vision PC Application via the BitFlow frame grabber card. This frame grabber connects to the stereoscopic camera and receives the encoder pulse train as well as the external trigger signal from the through beam sensor. When a primal cut passes through the sensor beam the frame grabber triggers the camera to start capturing lines of pixels for a fixed distance of conveyor travel based on the settings for the encoder input. These lines are combined into an image that the frame grabber makes accessible to the application through the image acquisition module. As the camera is stereoscopic, both cameras capture an image simultaneously and each image is sent to the frame grabber.

Figure 14: Raw Master and Slave images.

The raw master and slave image data from the image acquisition module is passed to the Chromasens CS3D API for processing. This step outputs a rectified image by merging the master and slave colour images into one ‘centred’ image, and a single channel grayscale height map (disparity) image where each grey value pixel represents the vertical distance from the camera lenses to the height at that point of the image. The rectified and disparity images are passed to the image processing module.

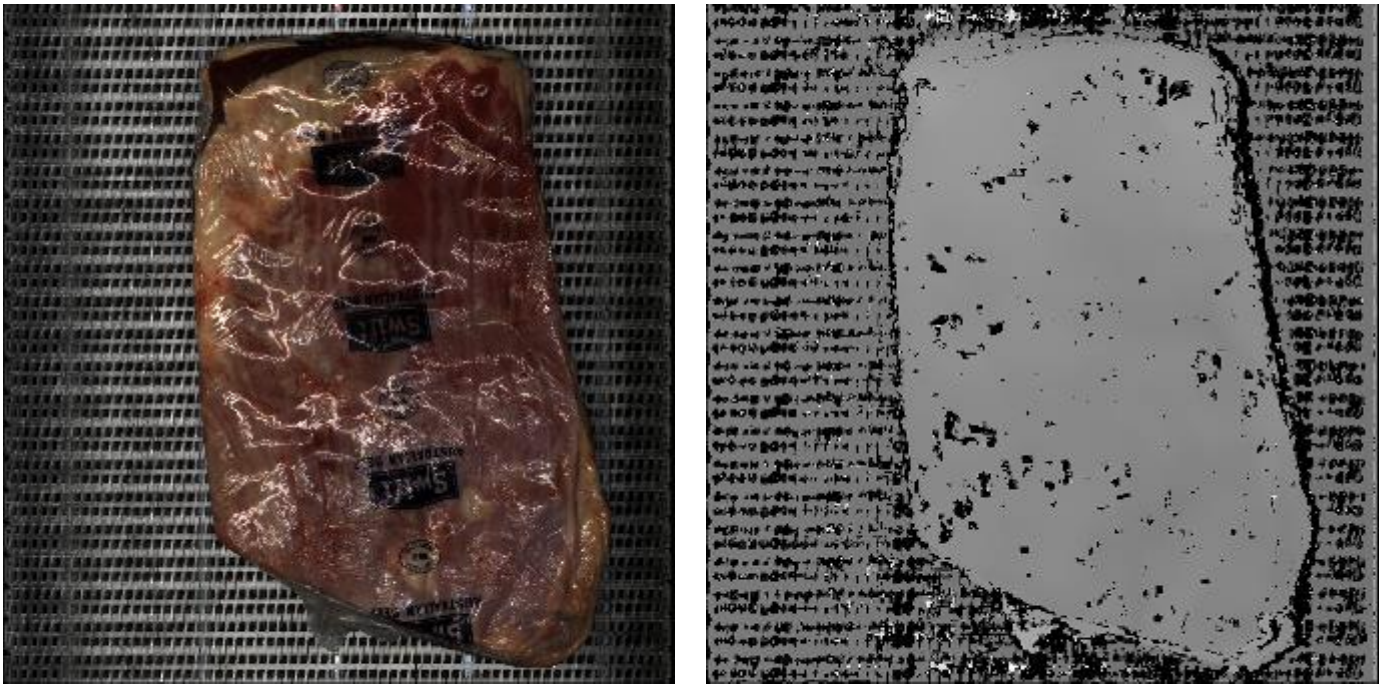

Figure 15: Processed Rectified and Height map images.

The image processing module receives the rectified and disparity images and, utilising HALCON library functions, determines the presence of a primal cut. The regions of interest identified by the system as a primal cut is displayed on the HMI screen for an operator to observe. If this region is actually of a primal cut that the system is currently packing, the operator will press the respective button on the HMI screen, informing the image processing module to proceed with this particular region and primal cut.

With this region positively identified, additional HALCON functions were used to determine measurements of the primal cut and its position on the conveyor belt. After some pre-processing of the primal cut region, a bounding box is used to determine the Length, Width, Centre Position and Yaw (Angle of rotation) of the primal cut.

Length and Width dimensions are taken straight from the length and width of the bounding box and are used for determining the pack location in the cartons. The Yaw angle of rotation of the meat on the conveyor can be found by measuring the angle of the box against the travel direction of the conveyor. The centre point of the bounding box and the yaw is used to provide the pickup position and rotation to the robot. Finally the height of the primal cut is computed by processing the disparity image to smooth out the ridges and remove any outliers from the region of interest, and then select the highest point on the primal cut.

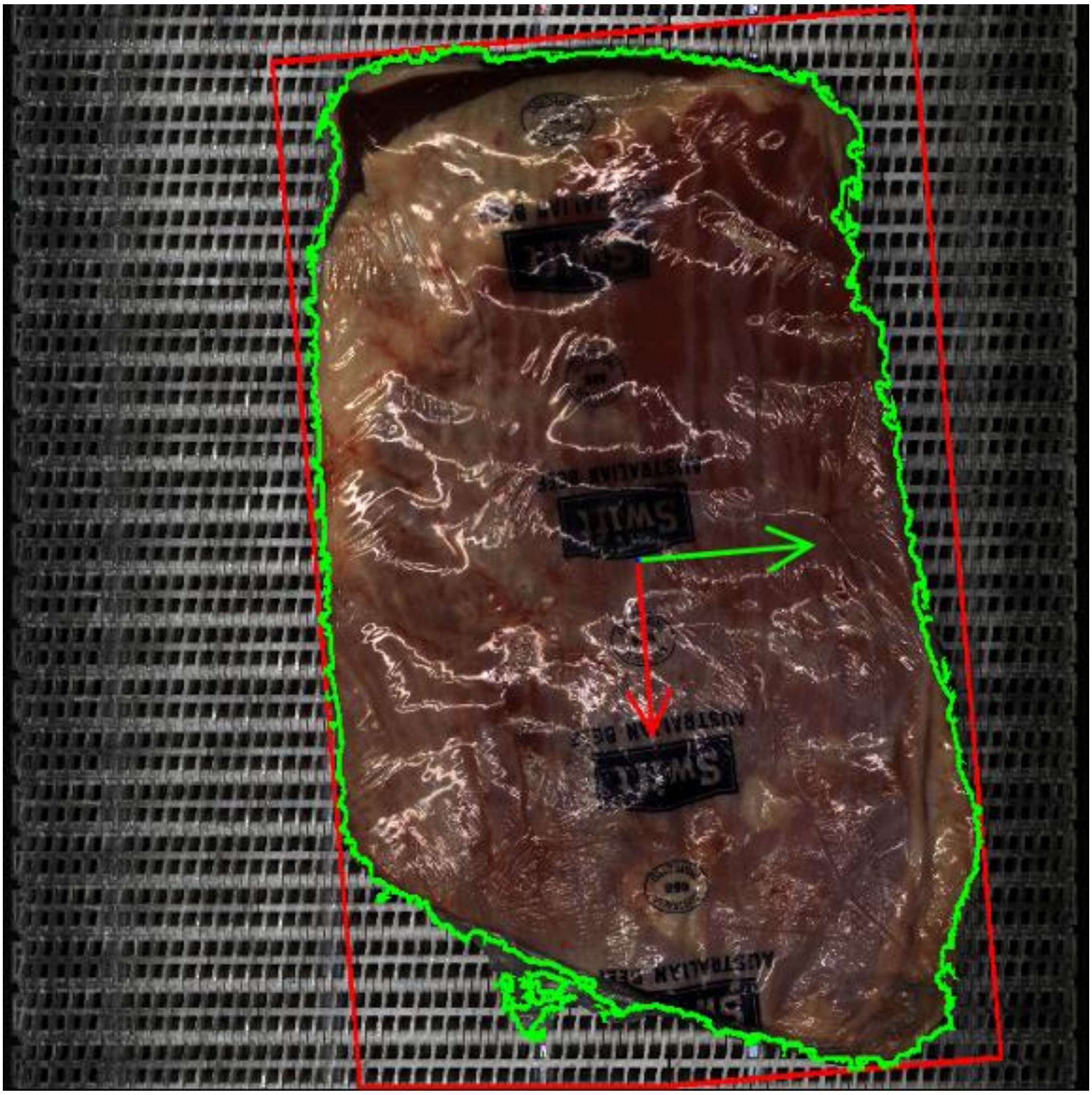

Figure 16: Processed Recitified image with region of the found primal cut (green outline), bounding box (red rectangle), pick position and rotation identified by coordinate arrows.

4.3.2 Picking Algorithms

A modular picking algorithm was used to accommodate the various orientations and arrangements of individual primal cuts as they moved along the infeed conveyor. The cut type, size, volumetric profile, position and orientation with respect to the conveyor of the primal cut was passed to this picking module. In order to determine the pick position for the robotic gripper, three pick offsets were calculated from the robot's defined coordinate frame for the infeed conveyor. These included the distance from the edge of the conveyor to the centre pick point, the distance from the leading edge of the primal cut to the centre pick point, the maximum height of the cut above the surface of the conveyor belt.

Due to the infeed conveyor having solid side walls, the range of pickup locations were restricted compared to the previous in-house trial (AMPC Project 2017-1065). The robot program was prohibited from being able to pick up at a large offset from the centre of the conveyor to prevent a collision and potential damage to the robot and conveyor. As a result additional offsets were added to confine the robot to the space in which it was allowed to pick. In some cases this also affected how the robot was able to place the primal cut into the carton, carrying through the offsets generated for the packing algorithm.

As each primal cut required different packing conditions, the picking algorithm could also calculate different pick positions for the gripper depending on its group, picking style, and the number of primal cuts already packed in the carton. This allowed the gripper to pack each carton efficiently and to full capacity. However, as the packing arrangement for the same primal cut varied throughout production during the trial, this procedure was not fully implemented for all primal cuts and packing arrangements.

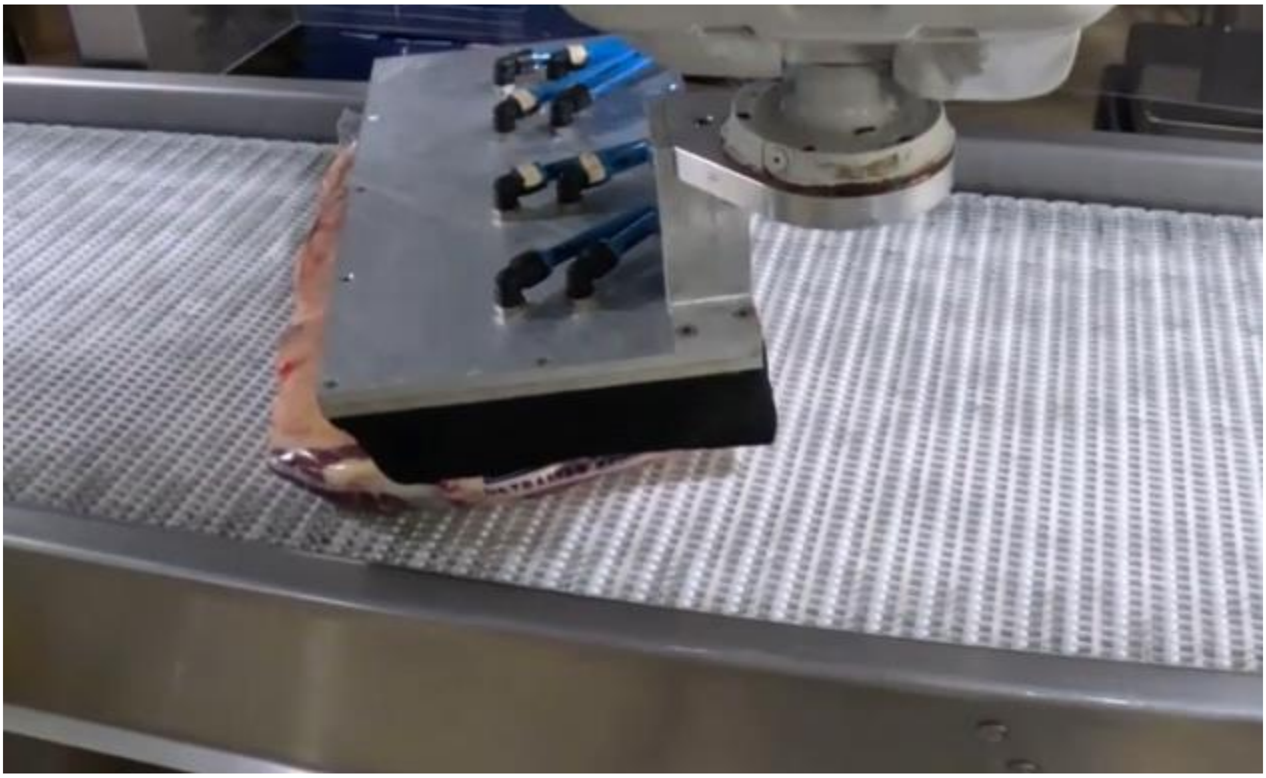

Figure 17a: Robot picking showing rotation based on primal cut angle relative to conveyor.

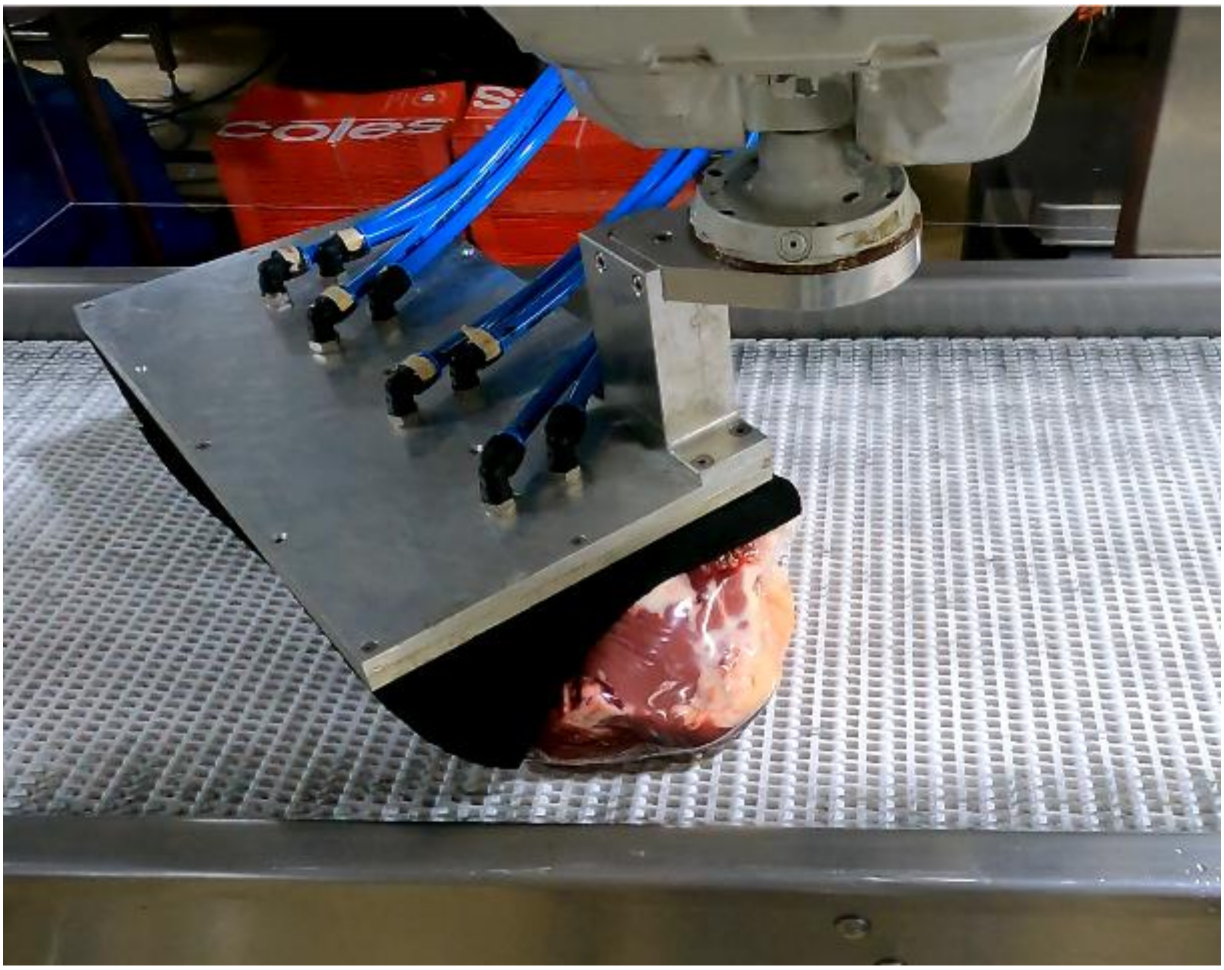

Figure 15b: Robot picking showing rotation based on primal cut angle relative to conveyor.

4.3.3 Packing Algorithms

The modular packing algorithm feeds directly from the picking algorithm, within the application they are essentially the same picking and packing module when compared to the other programming modules. To replicate packing configurations used in commercial processing plants, flat packing and sideways packing arrangements were developed. Primal cuts which were flat packed were picked from the centre and placed into the centre of the carton, stacking the cuts until the carton was full. For flat packing, simple offsets for the X, Y and Z coordinate axes were calculated relative to the robots coordinate frame for each carton location.

A combination of the six-axis range of motion of the robot and the offset attachment between the roll face of the robot and the gripper, made it possible to orientate the gripper to be able to side pack primal cuts into the carton. The carton was orientated on a fixed angle with respect to the horizontal which allowed the robot to place easily into the carton while assisting the primal cuts to stay stacked against the side of the carton once placed. Sideways packing had the option of packing along the long side of the carton or the short side of the carton. To achieve sideways packing, the offsets for the X, Y and Z coordinate axes were calculated as well as the rotation angles relative to either the short or long side of the carton.

Figure 18a: Robot flat packing to lower carton location.

Figure 16b: Robot flat packing to upper carton location.

4.3.4 System Process Flow

The vision processing application controlled the flow of data using four threads for image processing, three threads for communication and the main user interface (UI) thread. For image processing there is one thread for image acquisition, a pair of threads for loading and then unloading the CS3D API, and lastly one thread to perform the high level image processing, including displaying results and dissemination of data for picking and packing.

For communications, there is a thread for control of the lights and camera, and two threads for communication with the robot, one to handle the low level physical communication and one to handle the high level sequence handshaking and processing the picking/packing algorithms to generate the correct commands.

The main UI thread is required for all windows based applications that have a graphical user interface for a user; in this application the HMI for the operator. It handles updating the display as well as capturing and processing the input from the touch screen to control the application.

In the previous in-house trial (AMPC Project 2017-1065) the vision system relied on machine readable codes to be present on the primal cuts which was deem infeasible by the host plant, and so the system was modified to facilitate manual identification by an operator. This worked for proof of concept for the main automation aspect of the system as a whole, but is still unfavourable for the host plant as it results in lower productivity. In parallel with the in-plant trial, options were explored to try and automate the identification of the primal cuts. This led to the addition of another processing thread to analyse different features of the primal cut.

The system process flow of the system is outlined in the flowchart below in Figure 19.

1. Primal cuts vacuum sealed.
2. Primal cut heads downstream towards vision system and packing area.
3. Upskilled operator handles item and inspects quality of bag then places back on conveyor up stream of vision system.
4. Vision system captures meat, determines specifications and volume of cut of meat.
5. Operator confirms cuts of meat on Vision System.
6. Vision system checks dimensions and volume are within specified tolerances.
7. Vacuum sealed primal cut enters robot packing area, the following may occur:
    a. Vision system determines primal cut is pickable, robot picks and packs primal cut.
    b. Vision system determines primal cut as not pickable, robot skips picking primal cut, and primal cut continues onto manual picking and packing area.
8. Robot places primal cut into designated carton.
9. Operator inspects completed cartons.
10. Operator places completed cartons onto outfeed station.
11. Operator places empty cartons in packing station.
12. Cycle repeats.

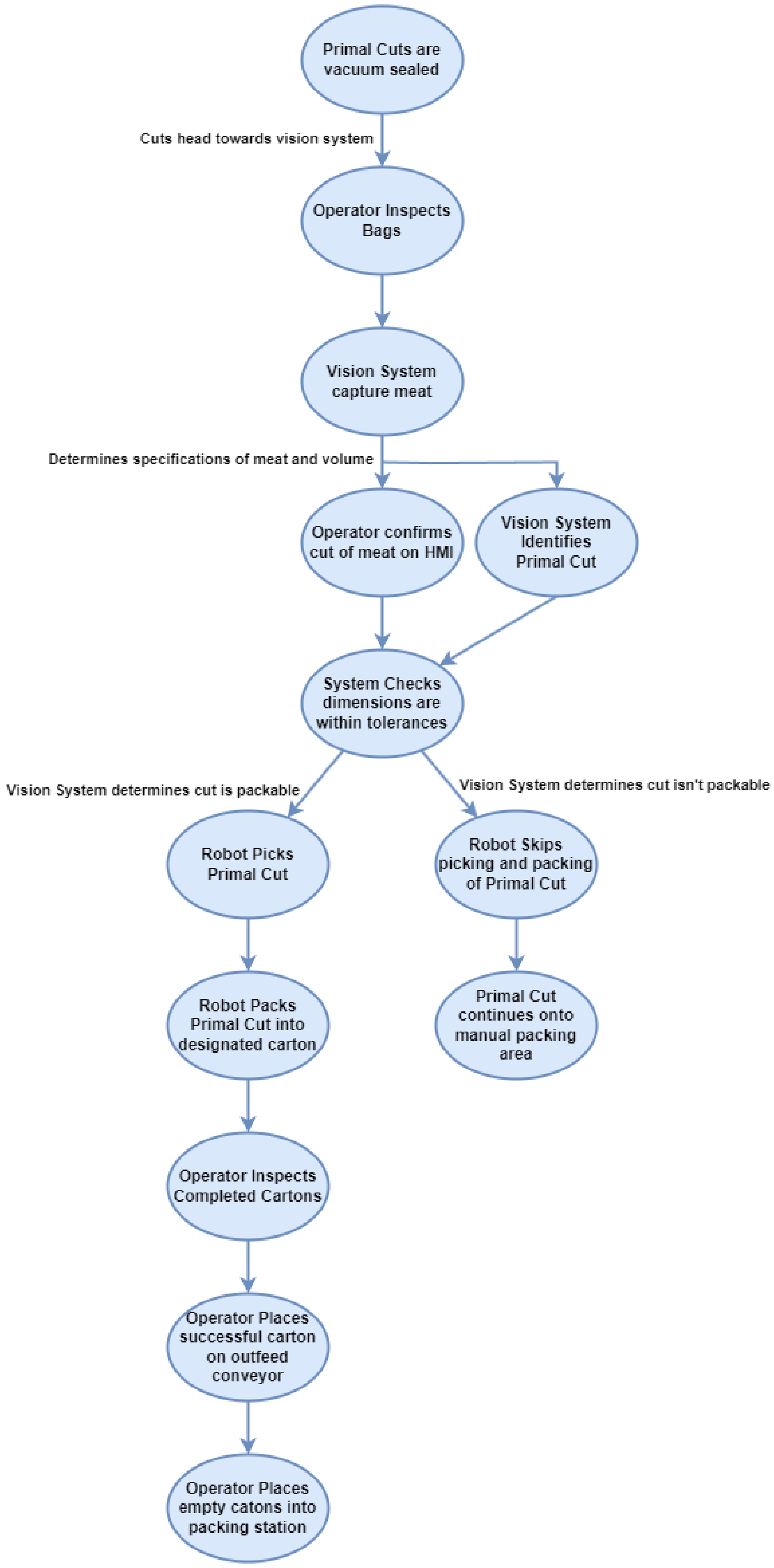

Figure 19: System process flow

4.4 Additional In-house Testing

The plant layout provided by JBS Brooklyn as well as onsite measurements were used to develop a 3D model of the relevant conveyor system and nearby plant equipment. This influenced the designs for the robot base, encoder, trigger, vision frame, control cabinet and outfeed carton fixture. Relevant designs and modifications were manufactured, assembled and tested in house prior to transporting all the equipment to site.

In-house testing included:

- Verifying the effect of tilting the linescan camera to match the elevation angle of the infeed conveyor, by elevating one end of the test conveyor to match the measurements made onsite. The relative error was determined to be non-zero but believed to be negligible for this application.
- The encoder mount, with external encoder wheel in contact with the conveyor belt, setup was tested on the test conveyor.
- The robot and vacuum gripper was tested and performed as expected with minor modifications since the previous in-house trial.
- The design for the outfeed carton fixture was developed with simulations for the reachability of the robot. The finalised design was manufactured and tested with the physical robot in the three distinct packaging orientations arrangements used in the previous in-house trial.
- The communication and integration between each individual component was tested for the current design. This included operation of the vision acquisition, 3D processing, conveyor tracking, and data exchange with robot. The safety operation of the light curtains and the robot was also verified.
- The requirements of the site did not allow attaching labels to the primal cuts as originally intended. As an alternative, the plant will provide an operator to manually verify the identification of the primal cuts by the vision system and determine what cuts for the robot to pick. The system will handle tracking, picking and packing the cuts into the outfeed boxes. To facilitate manual identification by an operator, the HMI touch screen has been added to the vision processing application. The basic functionality of this HMI was initially setup in-house for testing communication between the different system components, but did require refinement onsite during commissioning.

4.5 Initial In-Plant Trials

Following the installation of the system components into the plant commissioning of the system was conducted. This involved testing and verifying all the individual components following power on, checking communication as well as integration of the components together, and ultimately testing of the complete system. There were a few challenges encountered during commissioning that caused some minor delays that required replacing of components, or modifications to the planned system as prepared prior to bringing onsite.

Initially a photoelectric trigger sensor was used for image acquisition by the camera system and conveyor tracking by the robot. This sensor failed while onsite during commissioning, and an alternate sensor that was available was put it its place. Although the replacement sensor did not have the background suppression that the original sensor had, it did function as required to continue commissioning of the system. When the system was starting to be used in production, post commissioning, it was identified that this trigger and in particular where it was positioned could be the cause for inconsistencies observed in the relative pick position that robot moved to over the primal cut. As such, the photoelectric trigger sensor was ultimately replaced by the through beam sensor identified previously in this report. This together with other refinements made significant improvements to the accuracy and repeatability of the robot picking.

The encoder used by the vision system for image acquisition and by the robot for conveyor tracking was intended to be mounted on top of the belt as there was no accessible drive shaft to attach it to directly. However, it was observed that some product could disturb the encoder wheel and even push it away from making contact with the belt, leaving it inactive and effectively stopping the whole system. As a compromise the encoder was mounted underneath the conveyor in contact with a non-powered roller immediately following the drive roller. This mounting position has proved successful and a more permanent mounting bracket was manufactured and used to secure the encoder.

The design change to the system to accept user input from an operator to manually identify the primal cuts changed the vision application system process flow. However as commissioning progressed it became evident that the operator could not going to be present 100% of the time for various reasons. As a result, the system needs to automatically handle the queue of images if there has been no user input for a certain timeout period. This in turn presented technical challenges with the planned communication to the robot and synchronising the objects the robot is tracking with the specific cut the operator has identified. Additional queues had to be implemented to the image processing as well as robot communication modules, and these modules had to implement countdown/timeout based functions to accept user input only when the primal cut is still within an area of the conveyor that the robot could still pick it.

Initial tests of the complete system in operation were conducted solely by Strategic Engineering staff. JBS operators and maintenance staff were then trained in the necessary operation of the system over a series of days, following which handover of the system was completed. The system was left with JBS personnel to conduct the in-plant trial. Overall these initial trials were successful, but had a lot of disadvantages for the host plant. Primarily, the requirement of a full time operator increased the total labour of the packaging area or took that personnel from their existing place in the packaging line. This coupled with the overall production efficiency of the robot cell being less than one operator manually packing, resulted in a reduced interest in running the cell.

Figure 20: Robotic Picking and Packing system operating during in-plant trial.

Figure 21: Outfeed Cartons during in-plant trial.

4.6 Extended In-Plant Trials

Following discussions with AMPC and JBS site, modifications to the control system were planned to increase the overall production efficiency for the site. This involved developing an automatic identification algorithm for one type of primal cut with sufficient accuracy to allow the system to operate automatically without an operator permanently at the screen. An operator would still be used to check the packaged cartons, unload the full and replace with empty cartons. However, in this system the operator would still be able to do other work for the majority of the time.

A catalogue of images were saved during production and analysed to identify key characteristics of the primal cuts that could be used for identification. Initial tests were conducted based on ratios of volumetric data, scaled to the approximate carcass weight currently in production. This was based on parameters used in the Naked Primal Cut Recognition Vision System (AMPC 2018-1048), substituting accurate weight data for approximate carcass weight. This method was informative but ultimately unsuccessful, only achieving around 50% positive identification of selected primal cuts.

Further development and analysis resulted in the following 9 characteristics being computed and used to identify the navel end brisket: Length, Width, Height, Volume, Length/Height ratio, Width/Height ratio, Compactness, Circularity, and Rectangularity. Within an experimentally defined range, these parameters were able to successfully identify navel end briskets with an accuracy of at least 95% and zero false positives, during initial tests. Preliminary examination of other primal cuts indicates that identification, of at least those present on this packing line should be possible.

Modifications to the robot program, vision application and communication between the two was made to facilitate the automatic identification of primal cuts. These changes were tested by Strategic Engineering staff and then handed over again to JBS operators. With this modified system, JBS are planning run an extended trial over approximately 2 months.

5.0 Project Outcomes

Successful in-plant trials of the automated picking and packing system were performed in JBS Brooklyn plant. Packing was tested on a number of different primal cuts to find the optimal packaging strategy for the site. Initially, 4 different cuts were trialled, similar to the setup for the previous in-house trial.

To maximise the efficiency of the robot cycle the system was trialled for two weeks packing just two type of primal cuts, the navel end brisket and the point end brisket, packing two cartons each per complete cycle. These two cuts were chosen because they were generally the largest and heaviest primal cuts on this particular conveyor line, as well as being easy for the operator to identify. The downside of picking these two primal cuts is that they both need to be flat packed, but this was mutually agreed as the best path forward for the current trial with both AMPC and JBS.

During the trial these primal cuts were successfully picked and packed into their respective cartons when correctly identified by the operator. The system was able to account for any primal cut orientation with respect to the conveyor by orientating the gripper during the pick sequence so it would align with the gripper ready to be packed into cartons. There was still concerns with the efficiency and labour intensity with using the system, as an operator was needed to identify the cuts but the resulting output from the system was generally less than the operator manually packing directly on the line.

Following further discussion with AMPC and JBS, software modifications were planned to attempt to automate the identification of one primal cut as a starting point to increasing the effectiveness of the system and ultimately fully automate the complete process. Following the implementation of these software changes and some refinement of the identification algorithm, successful identification of the navel end brisket was demonstrated with at least 90% accuracy with no false positives. Extended trials of the robotic picking and packing system with automatic primal cut identification are still ongoing, but the results so far have been very positive.

6.0 Discussion

6.1 Primal Cut and Gripper Selection Suitability

Successful in-plant trials of the automated picking and packing system were performed in JBS Brooklyn plant. Packing was tested on a number of different primal cuts to find the optimal packaging strategy for the site. Initially, 4 different cuts were trialled, similar to the setup for the previous in-house trial. However, variations in production for the site and the frequency of changing of carton arrangements and processing product became a significant delay and challenging to optimise for the trial.

As a rough example, production might start packaging tenderloins 8 to a carton with each in a single vacuum sealed bag, and then they would start bagging the tenderloins 2 to a bag still packing 8 (total) to a carton. Later in the day they would return to a single tenderloin per bag, but start packing 10 to a carton, before switching again for the end of production squeezing 4 tenderloins in a bag and packing 8 (total) to a box again.

This level of flexibility can be achieved with an automatic robotic system but was beyond the scope of this project trial. The current system was designed around one type of packing arrangement per type of primal cut. Although the logic behind the packaging algorithms can be expanded to allow selecting and switching between different arrangements, the currently implemented communication channels between the vision processing system and the robot controller would not allow for sufficient expansion to achieve this.

In addition to the changing packing arrangements, it was observed that primal cuts coming down the packing conveyor were more likely to be batched than distributed more randomly. This meant that there was often a lot of tenderloins grouped together and then potentially several minutes before another tenderloin would pass through the system. It was observed where the robot would pick a particular cut and then a number of that type of cut would pass through while it was packing this cut it picked it. And then the system would have to wait for the next bunch of that particular type of cut to arrive and eventually fill the carton.

6.2 Vision System and Tool Path Algorithms

The vision system was able to provide high resolution images and height maps. This allowed for the proper identification of the primal cut dimensions required for picking and packing the cuts into cartons efficiently. As the vision system relied mostly on the software implementation for packing, parameters could easily be altered during commissioning to suit the needs of the plant. It was observed that the vision system was able to handle the conveyor speed easily with no issues and without falling behind in processing.

The tool path was generated from the primal cut pick point to one of the four cartons. The robot traversed through intermediary points and rotations for the tooling required to approach the carton avoiding collision with the conveyor and any other obstacle, and then placed the primal cut in the empty carton position. This position was dynamic and changed depending on the number of primal cuts already in the carton. To return to the idle position above the conveyor for the next primal cut, the robot moves execute in reverse from the packing carton location.

6.3 Cycle Time Considerations

In the previous in-house trial (AMPC Project 2017-1065), a cycle time optimisation strategy was implemented In order to increase the throughput potential of the robotic system. As the grip strength of the vacuum pad gripper on each primal cut was highly dependent on its weight and topography, the maximum robot movement velocities and accelerations were designed to be varied based on these two factors. As the in-plant trial does not have immediate access to any weight values for the primal cuts that pass through the system, this methodology was modified to vary based solely on the available volumetric data.

As the system was primarily protected by light curtains rather than physically guarding on all sides, the overall speed of the robot movements were reduced. Although the light curtains do meet the necessary safety standards and could allow the robot to move at its maximum speed, the proximity to operators, especially requiring an operator to be right next to the light curtain at the HMI screen, and the likelihood of accidental trips of the light curtains that was observed, a reduction in overall speed of the robot was implemented for this trial.

This overall reduction in speed did help the vacuum gripper in securely gripping the primal cuts during the trials. However, compared to the in-house trial (AMPC Project 2017-1065), there was a much larger range in the size of the same type of cuts. Meaning that some cuts were significantly smaller due to the size of the carcass and some vacuum sealed cuts were actually packaged with two or more of the same cut. This large variation together with the lack of real time weight measurements made optimising the robot cycle time quite challenging. Some speed and acceleration improvements during robot pathing were reduced significantly in favour of maintaining hold of the primal cut rather than focusing on minimising cycle time as much as possible.

The initial trials relied on the operator to identify the primal cut for the robot to pick which had to be done within a time window where the information could still be transferred to the robot in time to be picked. Occasionally multiple primal cuts would be captured in the same image frame, either overlapping causing the system to combine the two cuts into a single region, or simply close enough together than two separate regions were identifiable. Alternatively, because of the way the camera images a frame, part of a primal cut could be cut off at the top or bottom edge. If the operator happened to still select that one of these cuts were pick-able, the system would try but in most cases would be lacking information to successfully pick. This would either result in a failure to pick, or worse, picking the wrong cut and placing it into the wrong carton.

6.4 Optimisation Strategies

In order to improve the cycle time and efficiency of the system several strategies could be implemented:

- The physical layout of the robot and cartons with respect to the conveyor could be optimised in order to reduce the total travel distance of the robot from the pick to the pack position. During the trials, the robot needed to rotate a full 180 degrees about its first axis to move from the pick to the pack position. By aligning the conveyor directly next to the cartons, the movement space of the robot would be significantly reduced. Additionally, if the robot were to be mounted overhead, although perhaps not feasible in every plant, this travel distance would be further reduced.
- Integration with a weigh scale or any other method for real time weight measurements of the primal cuts would allow further development of the cycle time optimisation system for each individual type of primal cut. Movement speeds for all primal cuts demonstrated in this trial could be significantly increased.
- Development of optimised grippers for particular primal cuts rather than generalising the gripper as much to function with as broad a range as possible. For smaller cuts, a smaller gripper with thinner foam could be developed which is fast in reach a holding vacuum and more manoeuvrable in and around the outfeed cartons. As another possible alternative, ‘V’ shaped or non-planer in general for defined irregular shaped cuts, such as anything with the ribs attached.

6.5 Multi-robotic picking and packing systems

A single robotic picking and packing system handling only a subset of the total primal cuts is never going to be economically efficient on its own. Every meat processing plant employs dozens of personnel in the packaging area, and while this system has the potential to remove aspects of the manual and physically demanding labour from the task, a single robot cell does not reduce the total labour cost required for the plant. An operator is still necessary, at least for now, to supervise the robot cell, and even adding additional cells as is takes up considerable space with the required safety guarding and other hardware.

However, this system trial does provide proof of concept and the next iteration move towards multiple picking and packing robots to handle a larger percentage of the total packaging production requirements. Such a system when picking from the same infeed conveyor would only require a single vision system for as many robots as there is space to reach the conveyor. It will also economise on the space required as the robots can share space and even effectively work together. With an integrated carton handling system and combined safety system around the whole multi-robot cell, a single operator could supervise and even manually package themselves what would otherwise require multiple operators.

7.0 Conclusions / Recommendations

This project successfully demonstrated the robotic picking and packing system through an in-plant trial. Continuing the work done in a number of previous projects, this outcome culminates in the research and development of the past 10 years to develop an automated system for packaging vacuum sealed primal cuts. There is still further work to be done to fully commercialise the system, but the results of this project should give confidence to the industry to continue this avenue of research in the future.

Although only a subset of primal cuts have been picked and packed for the purpose of this in-plant trial, it is envisioned that a wider selection of primal cuts would be able to be handled by the system without major design modifications. The limitations of and scope of this project being only a trial dictated the extent of what could be done and demonstrated. However, additional system tests on such primal cuts should be performed as further development of the core technology pushes towards a full commercial plant implementation.

The ultimate intent of this development pathway is to demonstrate the practicability and viability of autonomous picking and packing within the red meat industry using intelligent technologies. These technologies will initially be marketed towards medium to large scale red meat processors, however smaller processors may also see benefits in adopting this technology, as the system can be retrofitted into existing packing rooms.

7.1 Suggested Next Step Points of Action

- Design of an automated carton handling system for the current system to eliminate the manual handling of the empty and full cartons as done for the purpose of this project's in-plant trial. Including picking of empty cartons from a stack or infeed and automatic feeding of filled cartons to adjacent outfeed carton conveyor.
- Further development of the automatic identification of vacuum bagged primal cuts. Expand the range of cuts automatically identified as well as continued improvement in accuracy.
- Further development into the vacuum gripper technology to be able to handle a larger variety of packaging arrangements. Develop alternative grippers optimised for different cuts.
- Expansion of robotic picking and packing system using the results obtained through this research project to handle a greater range of primal cuts.
- Development of a multi-robot picking and packing system, capable of efficiently handling the majority of primal cuts on the same production line.
- Detection and handling of leaking primal cut bags.
- Automated process for bagging of primal cuts.

7.2 Project Flowchart

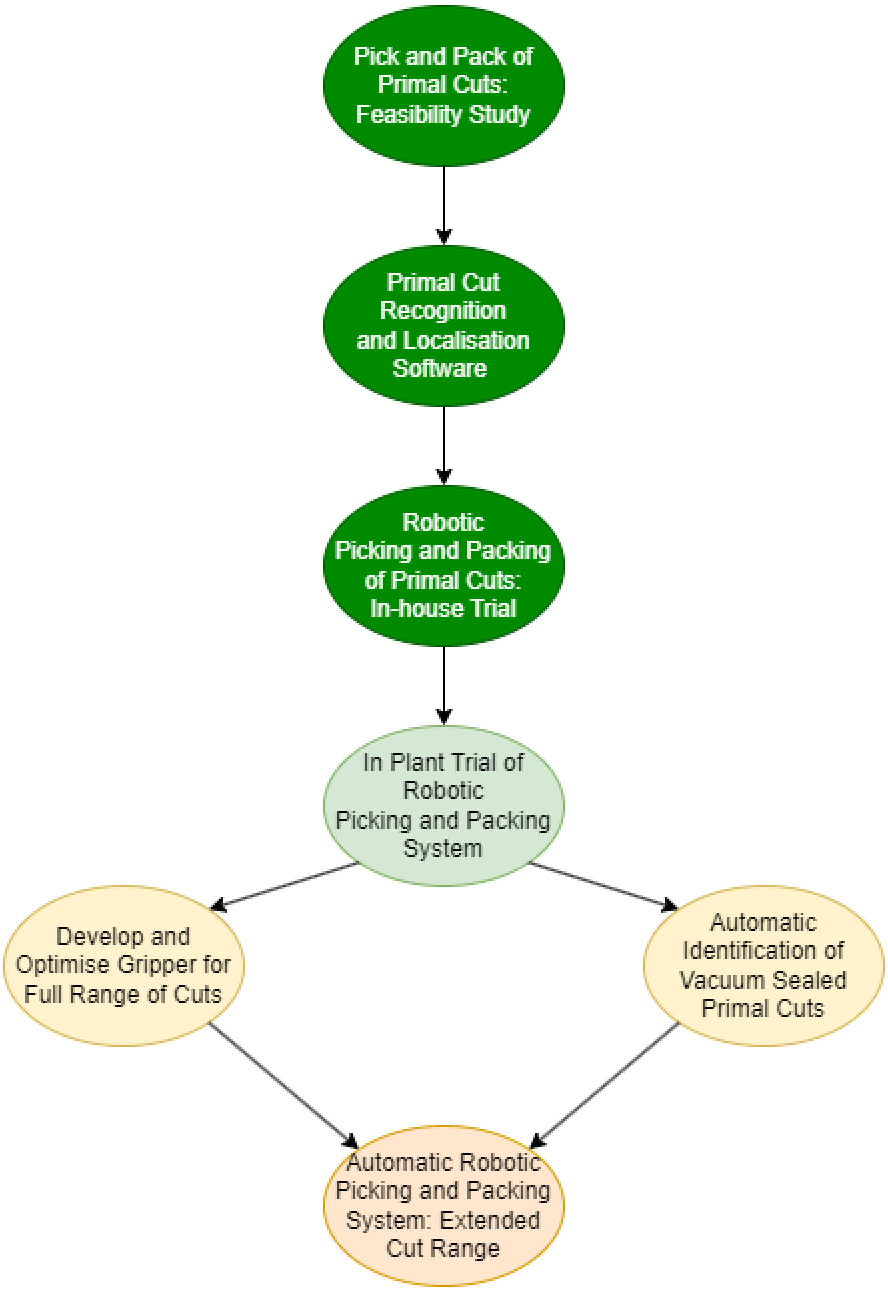

Figure 22: Current and Future Project Flowchart.

8.0 Appendices

8.1 In-plant Trial Video

A Video of the robotic picking and packing system operating in-plant is available at the link below:

https://www.dropbox.com/scl/fo/deb6pxn4xbjsh7oxf3l8v/h?rlkey=cdhx60xgcsi7a6arjqpvu8xak&dl=0