AUSTRALIAN MEAT PROCESSOR CORPORATION

FINAL REPORT - Development of Primal Cut Recognition and Localisation Software for use in Robotic Pick and Pack Systems

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Executive Summary

Primal cut picking and packing is currently a labour intensive meat packing process which is completely manual. As a result of the technical complexities involved in this task, there is currently no automated solution capable of packing vacuum sealed primal cuts into cartons.

This project involved the design, development and implementation of an intelligent vision system and analysis software for the identification, geometric profiling and localisation of vacuum sealed primal cuts.

The primal cut recognition and localisation software utilises a 2D industrial HD camera and a 3D time of flight camera to capture the red meat primal cuts on an in-feed conveyor. The first camera detects and decodes a quick response code to identify the type of primal cut. The second camera produces a 3D geometric profile of the primal cut allowing the dimensions and position to be determined.

The geometric profiling component of the software is able to determine the centroid coordinates and calculate dimensions (length, width and height) of all cuts with a precision of ± 7mm. While the cut identification component reliably detects a range of QR-codes, with the recommended size of 20 x 20mm at a distance of 1.2 metres.

The vision system and analysis software was developed and tested by a series of in-house trials involving both ideal and realistic conditions. The final system was then trialled onsite at Oakey Beef Exports Pty Ltd in Oakey, Queensland.

Due to the high number of variables associated with primal picking and packing, meat processors have been reluctant to adopt an automated approach. The most widely used picking and packing process makes use of multiple operators (dependent on the stock produced, throughput, and plant size) to manually pick and pack primal cuts into cartons.

However, the introduction of an automated robotic solution may significantly reduce the number of operators required in the picking and packing operation, which would result in significant economic savings for meat processors.

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1 Introduction

Primal cut picking and packing is currently a labour intensive and completely manual step in the meat packing process. This step requires operators to transfer cuts of meat from the in-feed conveyor to the appropriate carton for storage or dispatch. Meat processing facilities incur significant labour costs with the manual picking and packing of primal cuts. This step 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.

As a result of the technical complexities involved in this task, there is currently no automation solution available that is capable of packing vacuum sealed primal cuts into cartons. The most practical and efficient method of placing primal cuts into cartons is through the use of manual labour. Due to the high amount of variables and hygienic practices associated with primal picking and packing, meat processors have been reluctant to adopt an automated approach. The most widely used pick and packing process makes use of multiple operators (dependent on the stock produced, throughput, and plant size) to manually pick and place primal cuts into cartons.

Previously in 2014 Strategic Engineering Pty Ltd completed a study titled "Concept Design and Feasibility Assessment for Picking and Packing Automation Solutions". This study concluded that the "implementation of an autonomous pick and pack system is feasible with existing technologies, although the development of such technologies is required for their adaptation into the red meat industry."[1] As recommended by the study, this current project involves the research and development of intelligent sensing hardware and software for use in robotic pick and pack systems.

The scope of this project was to develop and evaluate sensing hardware and software algorithms capable of rapidly identifying and locating red meat primal cuts on an in-feed conveyor. This task was performed with the use of an intelligent sensor network which captures and processes the three dimensional scene of the packing environment. Information such as primal cut type, position, and orientation is produced by the system in real time. The output of this project is a preliminary software suite capable of efficiently providing position and orientation information critical to the

[1] W. Trieu and M. Redding "Concept Design and Feasibility Assessment for Picking and Packing Automation Solutions", Project code: A.TEC.0107, Meat & Livestock Australia Limited, March, 2014.

autonomous picking and packing of primal cuts.

1.1 Project Objectives

The development of primal cut recognition and localisation software project objectives:

1. Develop a detailed design of the intelligent sensor network hardware and software architecture
2. Carry out hardware procurement and set up
3. Development of preliminary analysis software
4. Development of software
5. Trial of system in plant
6. Documented report including videos, images and results

1.2 Project Overview

The primal cut recognition and localisation software project produced a robust and reliable system to identify and geometrically profile primal cuts. The primal cuts are identified through the software decoding an attached Quick Response (QR) code, or alternatively a barcode, and geometrically profiled through the use of a Time of Flight camera and image processing software. The primal cut recognition and localisation software is intended to be interfaced to an industrial robot for a pick and pack system. Hardware components have been purchased in order to develop and test the primal cut recognition and localisation software.

The vision system consists of the following parts:

1. Scene capture
    - Time of flight camera, supplying digital real time measurements of ranges to objects in the vicinity.
    - Industrial HD camera, capturing real time frames.
2. Scene processing
    - Analysing captured scenes
    - Detecting presence of barcodes/QR-codes and objects
    - Geometrically profiling the objects

The current display element of the system is ancillary as it demonstrates the output that would be available to an interfaced industrial robot.

2 Methodology

The primal cut recognition and localisation software package was composed of two distinct components; the cut identification from scanning barcode/QR codes, and the 3D geometric profiling and localisation. Two different camera systems were required for each component, and their output images processed individually. The output from both cameras was processed separately in third party image processing software, extracting data from the individual camera frames. As each component was finalised, it was then exported into C++ and restructured to integrate to the standalone C++ software package for a real time feed.

For the component Cut Identification an industrial HD camera was used, as it is capable of providing high resolution images for reliable QR and barcode detection and decoding. For the component Geometric Profiling a 3D vision camera was used to map the scene and determine positions, orientations, heights, lengths and widths of objects in real-time.

2.1 System Hardware

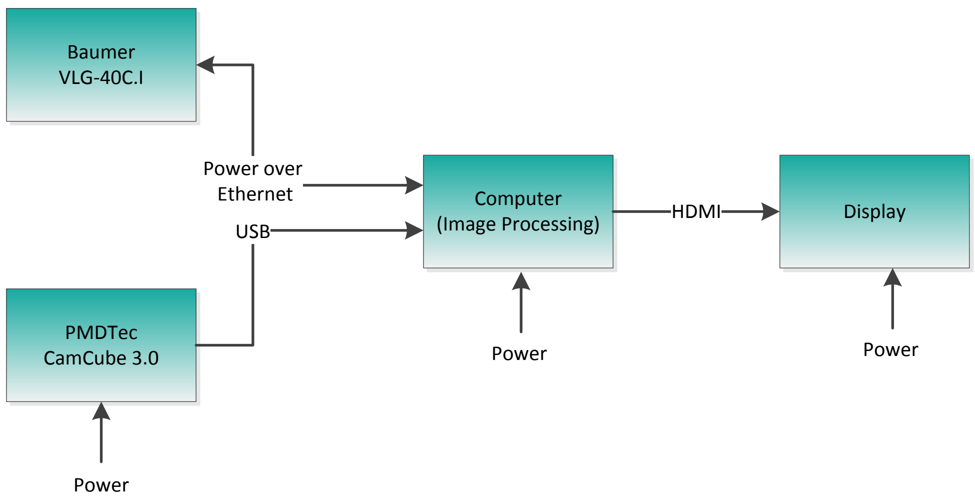

Figure 1: System Hardware Diagram

2.1.1 Time of Flight camera

A Time of Flight (ToF) camera has been selected as it best met the requirements of the project in order to carry out the task of supplying digital real time measurements of ranges to objects in the vicinity. There are similar systems available, such as Stereoscopic and LiDAR vision, which could similarly generate a 3D point cloud of the scene required for this project. However, the ToF camera is a reliable and capable hardware system that can capture an entire scene at once, without further processing to generate point clouds, and at a higher frame rate than other options. With the speed and accuracy of distance computation, as well as the inbuilt lens distortion correction, the data can be collected and processed fast enough to meet the speed and load density of typical conveyor belts found in meat processing plants.

The time of flight camera emits timed pulses of infra-red light to calculate the distance of objects within the scene. This is done through recording the time delay that occurs as the light reaches the surfaces of the objects and reflects back to the sensor panels located on the camera unit. Depending on the distance to the objects in the scene, this delay will vary accordingly. As the distances are internally calculated, no third party or external computation post-processing is required in order to interpret the data. This allows precise real-time tracking of meat segments with minimal delay. Figure 2 outlines the operation flow of the time of flight camera.

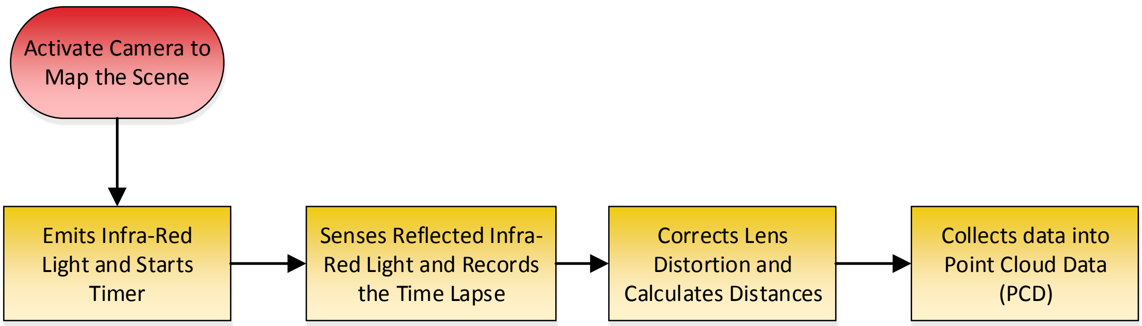

Figure 2: PMDTec CamCube 3.0 operation flow chart

The PMDTec CamCube 3.0 time of flight camera was selected as most suitable considering the requirements, having a sampling rate of 54Hz and a protection rating of IP67. Additionally, the CamCube 3.0 has a high resolution (200x200 pixels) and accuracy (<3mm at 1σ) at the intended ranges for this project.

Implementing the time of flight camera into the workplace is simple and unobtrusive to the work environment. A complete 3D scene is able to be generated with a single compact camera, unlike other systems which require multiple cameras in order to map a three dimensional scene. No external parts are required for the camera to operate; all sensors and lighting are provided within the camera unit. This reduces the operational difficulty of the system which minimises complexity and downtime.

A 12V external power source is required to power the CamCube 3.0 and optic expansion modules. A USB connection is required to establish a communication link between the CamCube 3.0 and the image processing hardware.

Figure 3: PMDTec CamCube 3.0 Time of Flight Camera

2.1.2 Industrial HD Camera

It was decided that the industrial HD camera, Baumer VLG-40C.I, provided the solution that best met the requirements of the recognition component. This camera has a large field of view, a high resolution of 2040x2044 pixels, a maximum frame rate of 29 frames per second and is deemed to be suitable for harsh environments as it has an IP67 protection rating and can operate in temperatures as low as +5°C.

A 24V external power over Ethernet source is required to power the Baumer VLG-40C.I. Ethernet cables are required to establish a communication link between the camera and the image processing hardware, and between the camera and the power source.

Figure 4: Baumer VLG-40C.I Industrial HD Camera

2.1.3 Image Processing Hardware

Image processing was conducted on a suitable high performance computer in order to process the data efficiently. This was important to ensure that the Point Cloud Data (PCD) received from the time of flight camera could be processed rapidly in real time. The image processing computer was run with a minimal number of programs and applications active to maximise the speed at which it could process the data. By dedicating the majority of the memory to the vision system while in operation, the implemented system is expected to run more efficiently.

The visualisation screen for the computer provided all the necessary User Interface (UI) requirements for the project. It displayed the incoming PCD data collected from the time of flight camera, the processed 3D image, captured frame from the industrial HD camera and all necessary extracted data (see **Figure 6** below). While the visualisation screen will be required in order to start and modify the vision system, sustained monitoring throughout the task by an operator is not required.

2.2 Analysis Software Functionality and Structure

The vision analysis system has been successfully developed and implemented in the programming language C++. The software has been packaged to be POSIX (Portable Operating System Interface) compliant as all test devices were configured to run in such environments. This will ensure that the developed software has the ability to be directly ported to functional units with minimal requirements for modifying the source code.

The software integrated with the two cameras allows for a three dimensional scene capture with the time of flight camera and a high resolution image capture with the industrial HD camera, which are subsequently processed. If the software detects an object on the conveyor, it decodes any detected barcode/QR-code and geometrically analyses the object. The outputted data, required to interface with an industrial robot, consists of the decoded information, centroid coordinates, object dimensions and orientation.

This vision system consists of several steps which are comparatively distinct from one another. The different steps and components of the standalone software will be discussed separately and in detail below. For some of these components well-established industry-standard algorithms and functions exist, however a significant amount of custom written C++ code was also developed.

2.2.1 Libraries and Image Processing Software

In addition to custom written C++ code and algorithms, the primal cut recognition and localisation software utilises MVTec HALCON, a powerful commercially available image processing software library; Visualisation Tool Kit (VTK), to provide required framework for visualisation of point cloud data and Point Cloud Library (PCL), an open source software library.

HALCON is utilised as it supplies visualisation algorithms and modelling techniques which allow for a rapid development of visual processing software. HALCON was used to create the Cut Identification software component and also some of the higher level functions that analyses the 3D image in the Geometric Profiling software component.

The VTK has also been utilised to assist with visualisation of the 3D captured point cloud data from the CamCube 3.0. The PCL supplies necessary data abstraction that allows the image to be segmented and processed, as well as enhancing the filtering process. By providing a framework for n-dimensional point clouds and 3D geometry processing, it provides a framework for the higher level functionality to be built upon.

2.2.2 Platform

All components of the primal cut recognition and localisation software were ported from the HALCON platform to meet the C++ POSIX (Portable Operating System Interface) standards. The POSIX platform was selected due to its low overhead, high custom ability and its familiarity. After the software components were exported from HALCON, restructuring of the C++ code was required to integrate the HALCON specific functions to operate in conjunction with the PCL and PMD-SDK. This also allowed for the Geometric Profiling and Cut Identification components to operate synchronously and share data. Transitioning the software from HALCON to POSIX compliant C++ allowed for development of the software in the environment that the final product will be implemented in.

3 Project Outcomes

This section describes the software architecture and structure used in the development of the primal cut recognition and localisation software. It details the design and development process for each image processing component and the standalone software structure. This project has successfully developed a software package capable of identifying the key characteristics of a primal cut that are required to incorporate a pick and pack system into a meat processing plant. With the implantation of two cameras, a ToF and an industrial HD camera, the software is able to read QR-codes located on the vacuum sealed meat and geometrically profile it.

Figure 5 outlines the operation flow of the software structure. The computer connects to the CamCube 3.0, using the PMD-SDK, captures an image and stores the measured distance data in a point cloud data array. The data array is further manipulated to invert the image to the correct orientation. The point cloud data is then inserted into a HALCON format data structure in order for it to be accessible for processing by the Geometric Profiling software component. Simultaneously, the Cut Identification software component grabs the current frame from the Baumer VLG-40C.I for analysis. The data from the system is correlated and visualised on the display.

The software and hardware have both been extensively tested in-house and on-site to verify the accuracy and capability of the proposed solution. QR-codes of 20x20mm at a distance of 1.2m are reliably read and located. Meat segment locations and orientation are accurately determined while the geometric dimensions are within a ±7 mm.

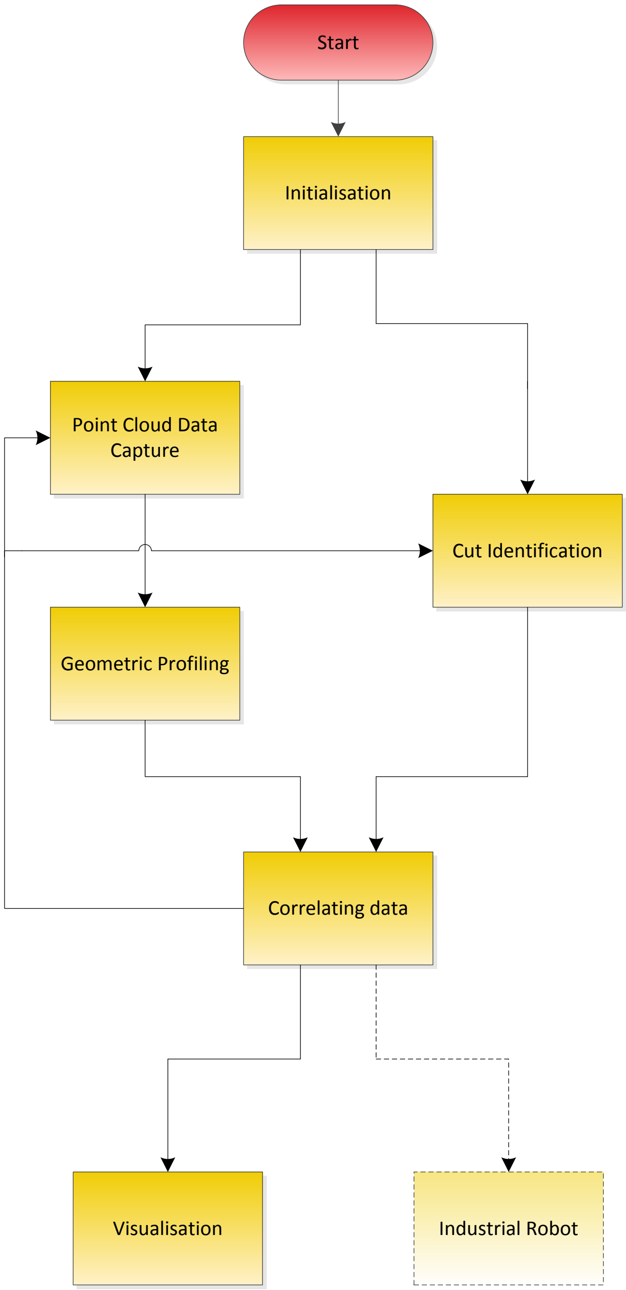

Figure 5: Primal cut recognition and localisation software flow chart

During the development and testing of the system, four windows are displayed on the visualisation screen to assist with debugging and to ensure outputs are valid. The output windows are shown in Figure 6. Window 1 visualises the current frame of the Baumer camera, with green squares contouring detected QR-codes, tracking the codes in real time. Window 2 displays extracted data from entire system that will be available for an industrial robot. Window 3 visualises the processed point cloud data, tracking the objects on the conveyor in real time. In window 4 the raw point cloud data captured from the CamCube 3.0 is displayed.

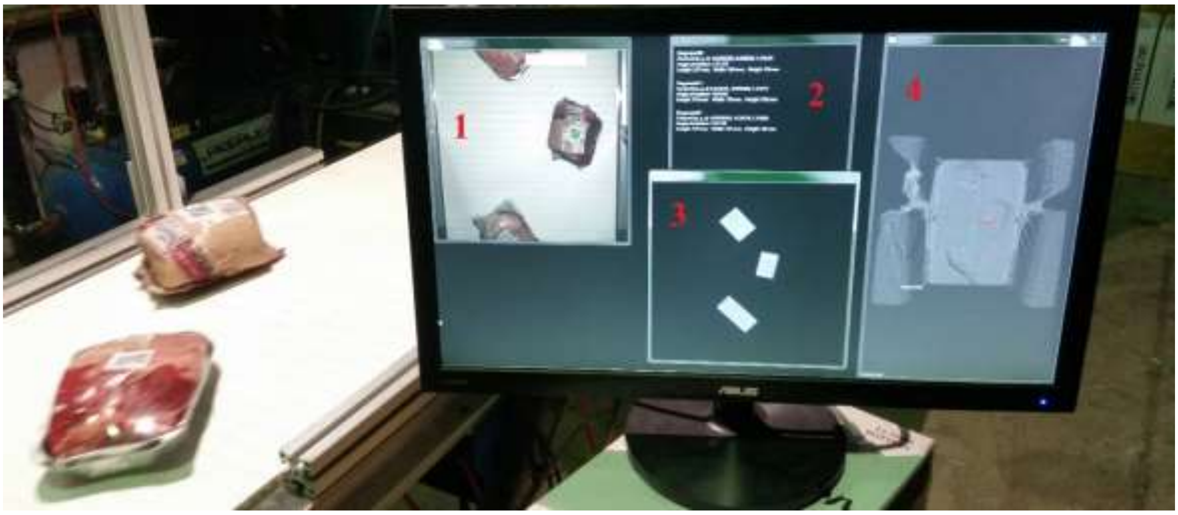

Figure 6: Primal cut recognition and localisation software visualisation

3.1 Point Cloud Data capture

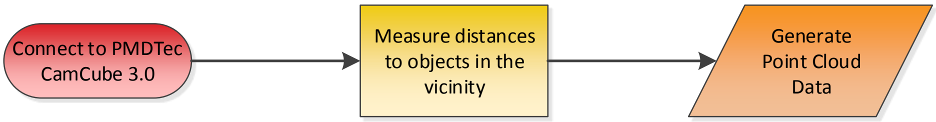

Figure 7: Point Cloud capture process flow

Figure 7 outlines the operation flow of the Point Cloud Data Capture software component. The Point Cloud Capture software component outputs three coordinate values, distance, intensity and amplitude, from which it can ascertain the data array into Cartesians coordinates (x, y, and z) by using the PMD-SDK function “pmdCalc3dCoordinates”.[2] These coordinates are then stored as point cloud data to be accessed by the Geometric Profiling software component.

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[2] “Beef Hock Location Vision System”, Project code: A.TEC.0078, Meat & Livestock Australia Limited, August, 2011.

3.2 Geometric Profiling

The Geometric Profiling component of this project obtains the information from the captured point cloud data and allows for up to five objects to be analysed within one frame.

In cases where multiple cuts of meat are present in one frame, the Geometric Profiling component segments each cut for further analysis. Features of interest of the cut are then determined, such as centroid position and overall dimensions – height, width, length.

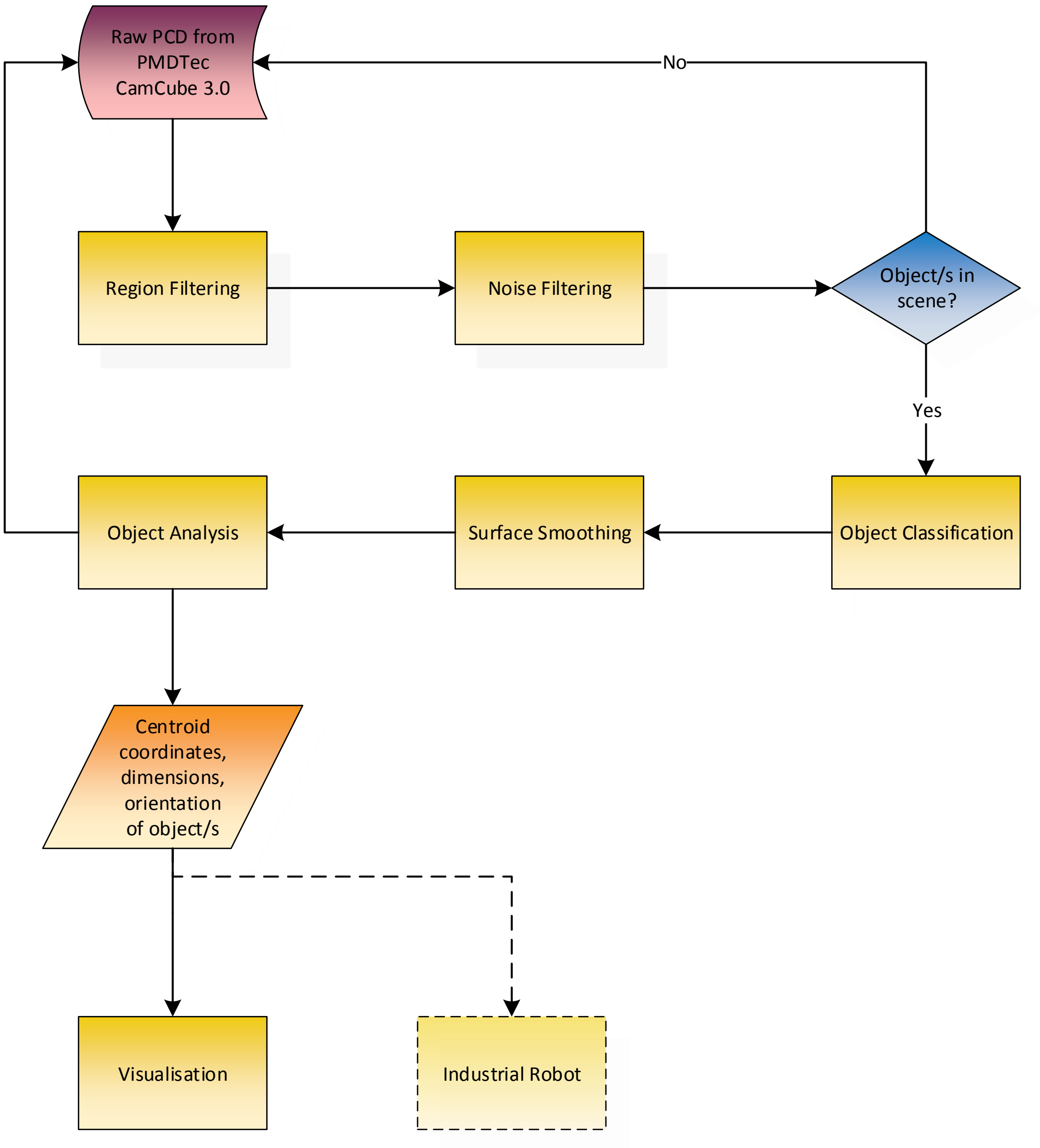

Figure 8: Geometric Profiling process flow chart

The development of the Geometric Profiling software component was carried out in HALCON.

Development of this component required a recursive approach. Each stage of the image processing was thoroughly tested with a wide range of static PCD files in order to debug and verify the robustness of the complete component. The software developed in HALCON with all its image processing stages was exported to a C++ file prior to integration with the Point Cloud Data Capture software component.

3.2.1 Access raw point cloud data

The Geometric Profiling component accesses the raw point cloud data captured from the Point Cloud Data Capture software component as shown in Figure 9.

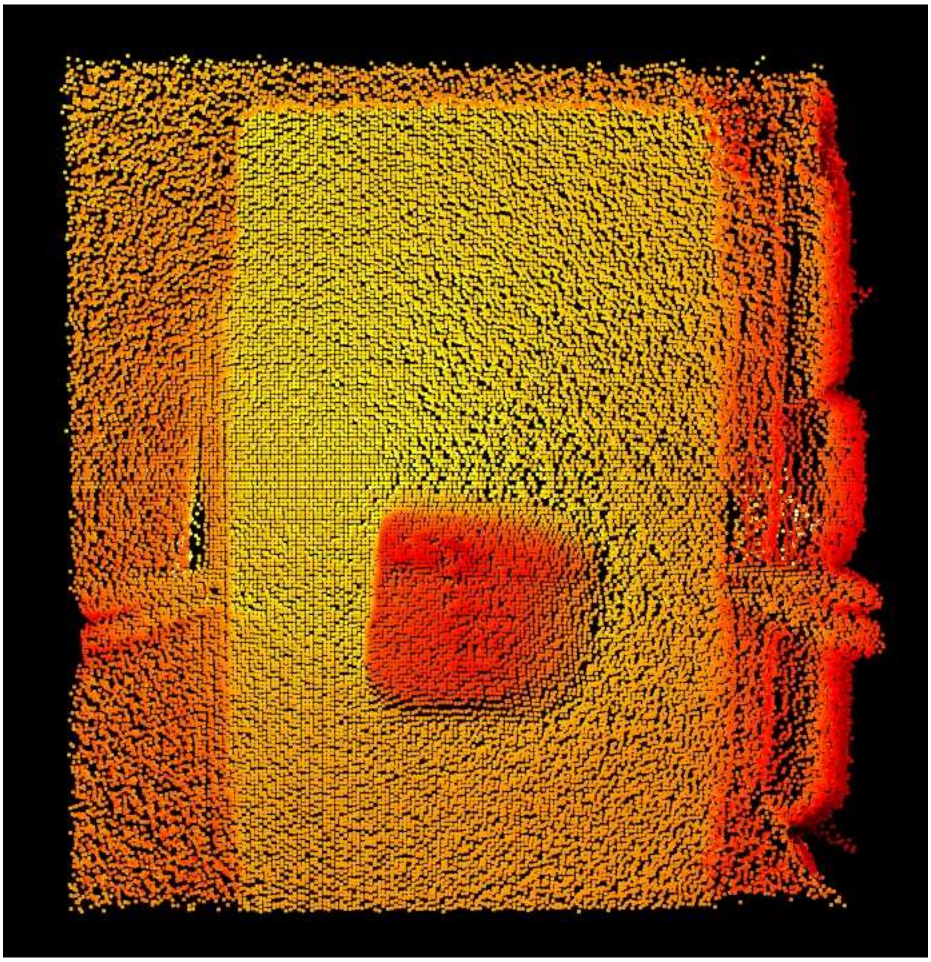

Figure 9: Raw Point Cloud data displayed using Point Cloud Library Visualisation Tool Kit

3.2.2 Region Filtering

The first major filtering process separates the point cloud data points that do not fall within the region or scene of interest. As the region of interest is the object(s) on the conveyor belt, a background subtraction is required to be performed to analyse the actual object(s) accurately.

A filtering process is then carried out prior to any further analysis to drastically reduce the amount of data that is analysed and aid in the reduction of processing time. There are three minor filtering steps within this stage; one filter for each of the x-, y-, and z-axes. For the z-axis, as the camera is fixed at a set height above the conveyor belt, any data points located below the conveyor belt surface are removed immediately.

Regions either side of the conveyor can be filtered out as the belt width is fixed. This assists in eliminating irrelevant objects, such as on-sight personnel or the camera supporting frame, from further analysis. The length of the belt in the field of view can also be restricted to optimise the region of interest.

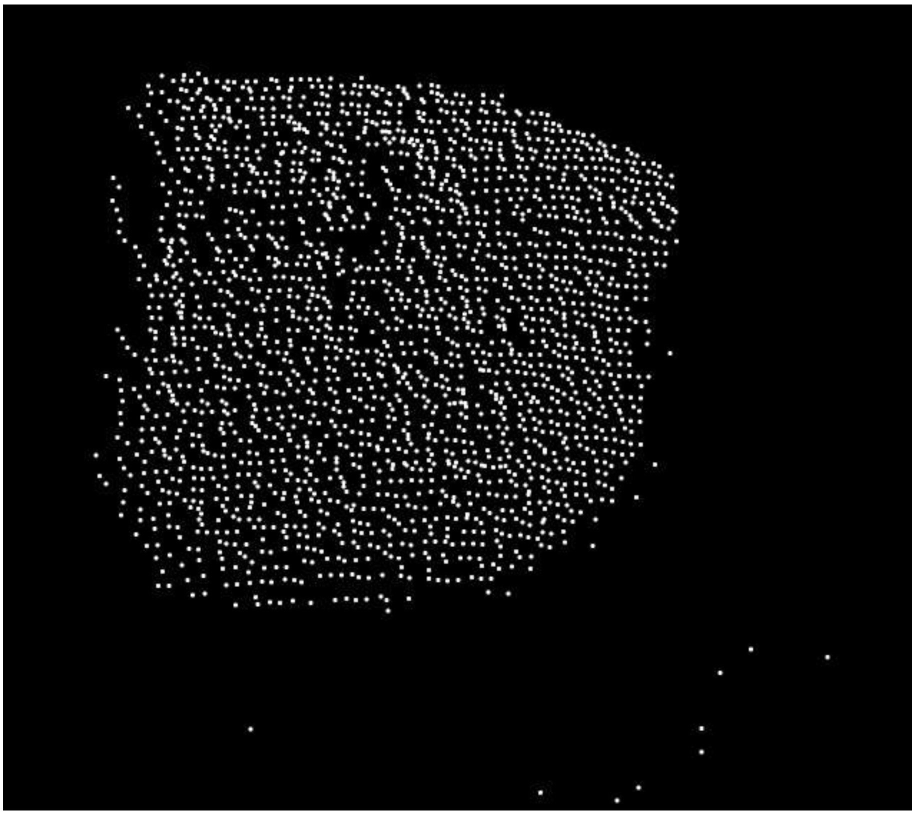

Figure 10: Region of interest isolated after region filtering

3.2.3 Noise Filtering

'Noise' is classified as outlying data points that are not directly correlated to a specific object within the scene. These outlying data points are primarily formed within the vision capture process of the camera due to interference between the emitted infra-red light and the environment; such interference can be caused by highly glossy or reflective surfaces.

The filtering is performed through comparing each data point with the remaining data set and determining its relevance depending on its deviation. Points with a large deviation are considered outliers, hence noise. Small clusters of noise which may form together to create tiny objects have also been filtered based on their relative size to the meat segments.

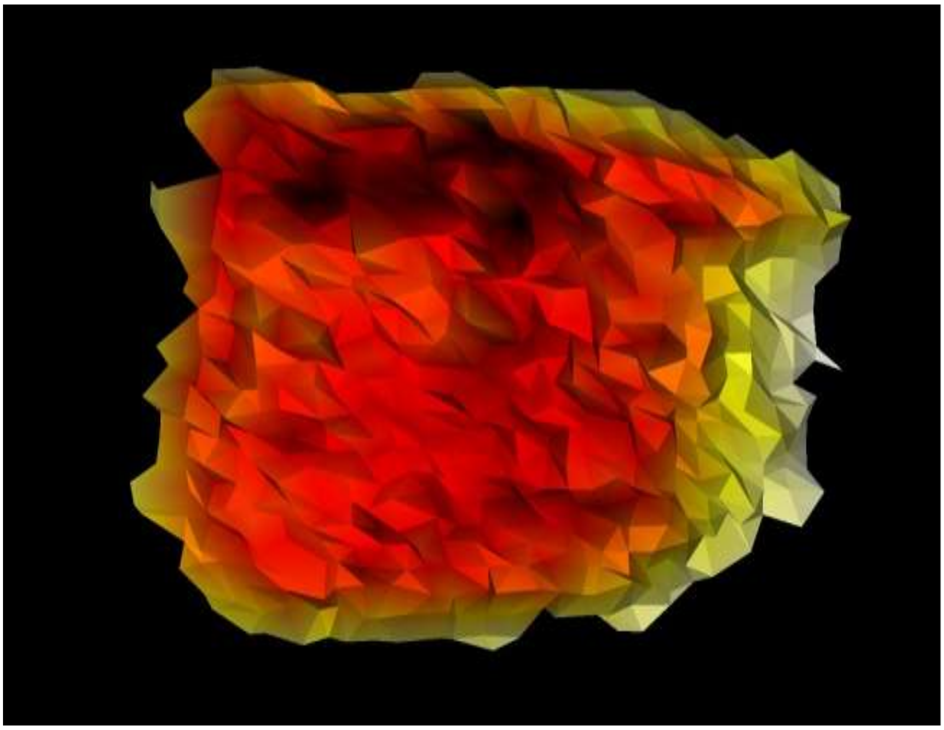

Figure 11: Noise filtering applied to the segmented point cloud

3.2.4 Object Classification

This step is closely related to the noise filtering process and involves categorising each range measurement within the given point cloud into structured clusters. Each point is described by its three-dimensional Cartesian co-ordinates (x, y and z) and is categorised based on how well it conforms to the neighbouring points. This allows for the effective subdivision of the input point cloud into manageable, more meaningful subsets that each represent a packaged piece of meat.

3.2.5 Surface Smoothing

A further 'smoothing' function is applied to the segments in order to limit the rate of change in the surface gradient. This normalises and minimises the effect that surface outliers have on the constructed mapped surface and creates a more accurate representation of meat segment surfaces.

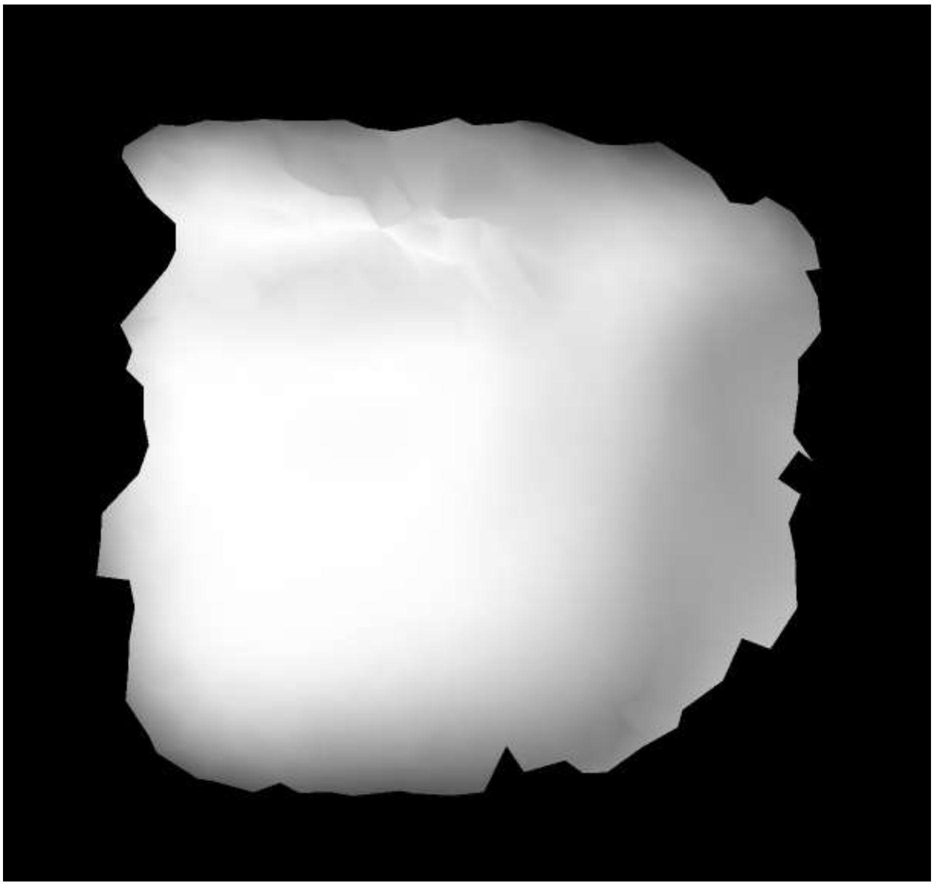

Figure 12: Smoothing function applied to segmented point cloud

3.2.6 Object Analysis

After the previous stages have been carried out the point cloud data can be used to analyse the segments of meat. Generated smallest bounding box models have been applied to each segment in order to obtain important characteristics for each piece of meat, including the dimensions (length, width and height), orientation and position. This information is extracted for further use in a potential robotic picking and packing system.

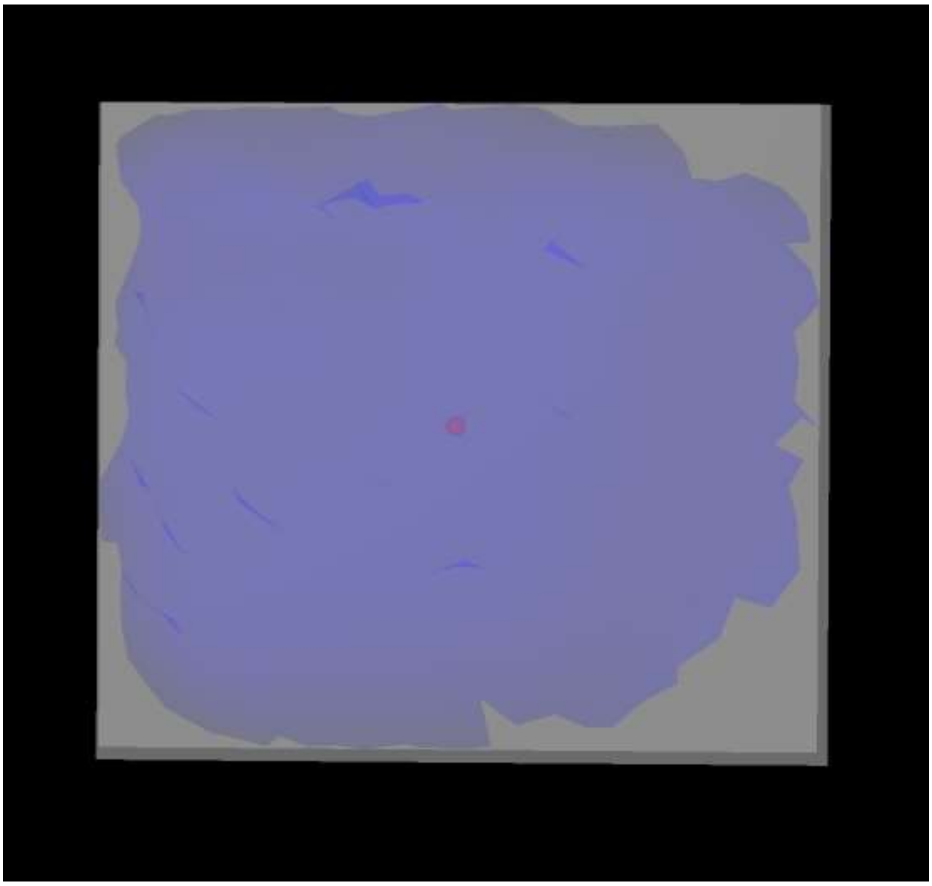

Figure 13: Orientated smallest bounding box shown around meat with centroid marked

3.3 Cut Identification

The Cut Identification component accesses the industrial HD camera, Baumer VLG-40C.I, and captures the current frame for analysing. This component currently supports detection and decoding of type 128 barcodes and QR codes.

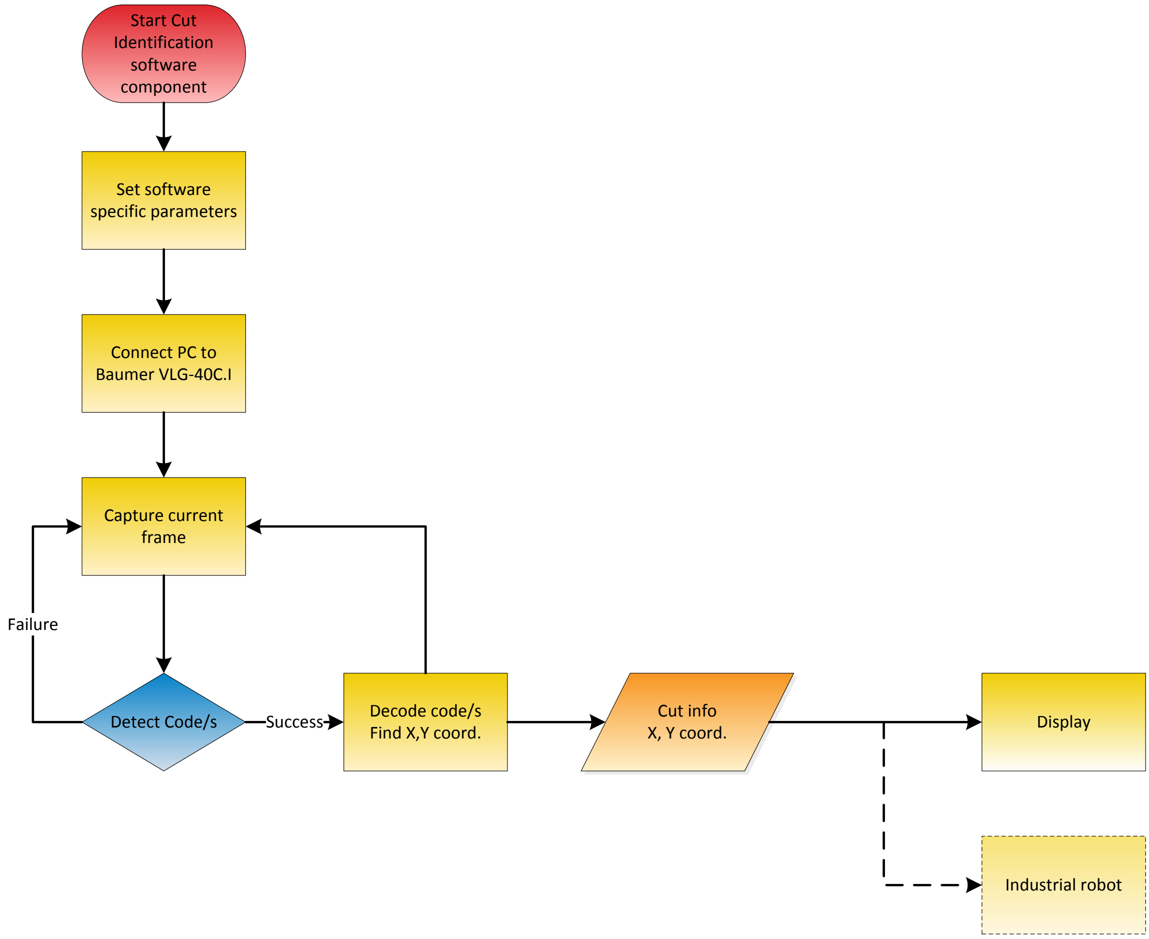

Figure 14: Cut Identification process flow chart

This component was developed in HALCON and further exported to a C++ file for integration with the other components of the primal cut recognition and localisation software. Each stage of the image processing was thoroughly tested with a wide range of static images containing various codes in order to debug and verify the robustness of the complete component.

3.3.1 Capture current frame

The resolution for the images captured by the industrial HD camera is 2040 x 2044 pixels. The captured frame is displayed on the visualisation screen. Parameters such as the pixel spacing and contrast were optimised through testing. This increased the success rate of detecting barcodes/QR-codes the so that the system could perform even in the instance of low contrast frames.

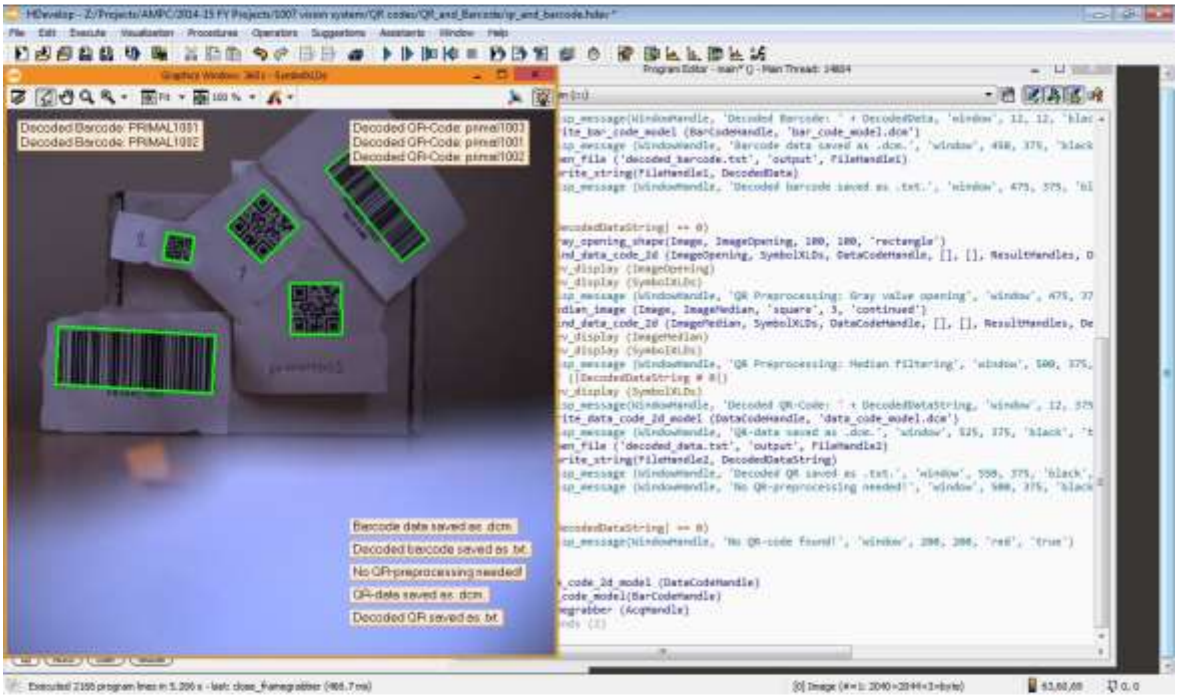

Figure 15: Screenshot taken during development of Cut Identification software in Halcon environment

3.3.2 Detect and decode barcode/QR-code

To visualise that the code has been detected, a green square/rectangle is drawn automatically around the detected code in the captured frame displayed on the screen. The software is currently able to successfully detect and decode up to 5 codes of each kind per frame, however a greater number can be accommodated if required. Detected codes are decoded instantaneously, and the software also identifies the centre coordinates of the code which will be of use for an industrial robot.

With assistance from HALCON's powerful image processing functions, the Cut Identification software component is able to detect:

- Codes in any orientation
- Codes travelling in any direction
- Slanted codes
- Somewhat damaged codes
  - QR-code
    - Minor occlusion – e.g. contamination
    - Corner occluded

        - Minor creases
        - Slight fading
    - Code 128
        - Horizontal parts occluded
        - Minor creases
        - Slight fading
- Multiple codes in one frame

3.3.3 Output and Display

The current frame, bounding boxes of detected code(s) and decoded string(s) are displayed in one window. The code centre coordinates and other decoded information are stored as this data will be of useful when interfacing with an industrial robot. As the software detects the codes in an arbitrary order, the decoded data is recorded and displayed in the direction of the conveyor, so that the cut that has travelled furthest along the conveyor is the first listed. The codes are then matched up with the pieces of meat by comparing their X, Y coordinates with the 3D bounding boxes fitted around each parcel of meat.

3.4 In-House System Trials

Prior to the final integration, the Cut Identification, Point Cloud Data Capture and Geometric Profiling software components were separately tested and optimised under various non-ideal conditions which may occur in a meat processing plant. The components each underwent three different tests to ensure reliability and robustness. When the full development of the primal cut recognition and localisation software was completed, the final test rig was used to verify the complete software capabilities.

Static testing and further testing under rough approximations of what the software would encounter, was conducted to identify weaknesses in the functionality of the software components as well as identifying steps to overcome them. The final test rig was utilised in a continuous running mode and the software components were fine-tuned under a variety of conditions. The final in-house testing rig consisted of an in-house built conveyor with a camera stand mounted 1.2m above the belt, which the two cameras were attached to on either side of the top bar, see Figure 16.

3.4.1 Cut Identification

The codes used for development and testing were QR-codes generated with arbitrary encoded strings and actual labels from the Oakey meat processing plant (Code 128).

3.4.1.1 Static testing

The Cut Identification software component was statically tested using printed codes from a close distance, <0.5m, in order to fully develop the identification program with all problem handling, such as slanted or occluded barcodes.

3.4.1.2 Rough approximations

To roughly approximate the intended use of the Cut Identification software component, a section of conveyor belt was placed on the floor. The camera was attached to a custom made stand with a height of 1.2m, which was placed above the conveyor belt. Various sized barcodes were placed on objects, with different dimensions and surface shapes, on various locations on the conveyor belt. This stage was significant in terms of determining the minimum code size and the settings for camera focus for the software to retain its ability to detect codes.

Figure 16: In-house final testing rig

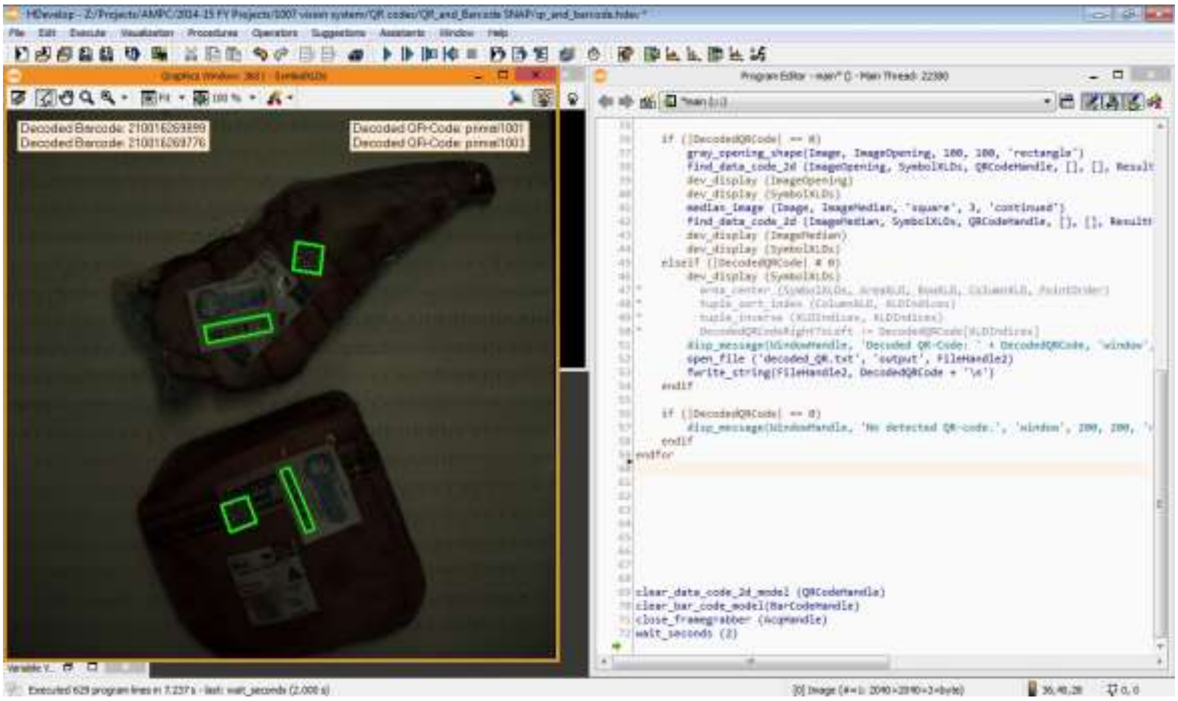

Figure 17: Cut Identification software under rough approximations

3.4.1.3 Test rig

To finalise the Cut Identification software component, the camera was attached to the in-house test rig. QR-codes and barcodes of different sizes were attached to pieces of vacuum sealed meat and run past the test rig on the in-house conveyor. The software was operated in continuous mode to verify that it could detect and decode the codes attached to moving cuts.

3.4.2 Point Cloud Data Capture

3.4.2.1 Static testing

To detect calibration issues and correct for lens distortion and noise, the Point Cloud Data Capture software component was statically tested on various objects on an assorted range of light coloured backgrounds. During this stage it was determined that the most suitable distance between the CamCube 3.0 and the object of interest would be 1.2m.

3.4.2.2 Rough approximations

To roughly approximate the capturing of point cloud data the test rig was used, however with only stationary objects. This stage of the testing was essential as the optimum integration time was selected (850µs) and the final filtering processes were modified to suit the environment.

3.4.2.3 Test rig

Utilising the in-house built test rig in continuous running mode, the Point Cloud Data Capture software component was tested and optimised to efficiently capture the point clouds of objects of interest moving through the frame.

3.4.3 Geometric Profiling

The point clouds captured were analysed in the Geometric Profiling software component in HALCON, where features of interest were identified. When the image processing was tested as below and finalised, it was ported to C++ code.

3.4.3.1 Static testing

The Geometric Profiling software component was statically tested using the point cloud data captured from a 1.2m high custom made stand to which the time of flight camera was attached.

3.4.3.2 Rough approximations

To roughly approximate the intended use of the software a piece of a conveyor belt was used as a background to the point cloud data being captured with the time of flight camera. A range of various objects were placed on the belt and the data collected from the Point Cloud Data Capture software component was processed in the Geometric Profiling software component. The physical dimensions were compared to the dimensions measured by the software to detect inconsistencies requiring modification of camera or software settings.

3.4.3.3 Test rig

To fine-tune this component, point cloud data of vacuum sealed meats was captured using the final test rig. The Point Cloud Data Capture software component was used to capture frames which then were tested in the Geometric Profiling software component. Features of interest of moving cuts were analysed and areas for improvement within the Geometric Profiling software component identified and addressed.

3.4.4 Primal cut recognition and localisation software

To test the complete primal cut recognition and localisation software the in-house test rig was used. For initial testing, the conveyor was stationary to ensure software components operated synchronously and to ensure the geometric profiling of the objects were accurate. Following the initial testing, the complete software was tested with the conveyor running continuously. For this test the cameras had to acquire images synchronously while continuously detecting/decoding all codes and geometrically profiling all pieces of meat. Figure 18 illustrates the continuous run test of the standalone software. The software was able to pick up the QR code and provides dimensions and positioning of the vacuum sealed cut.

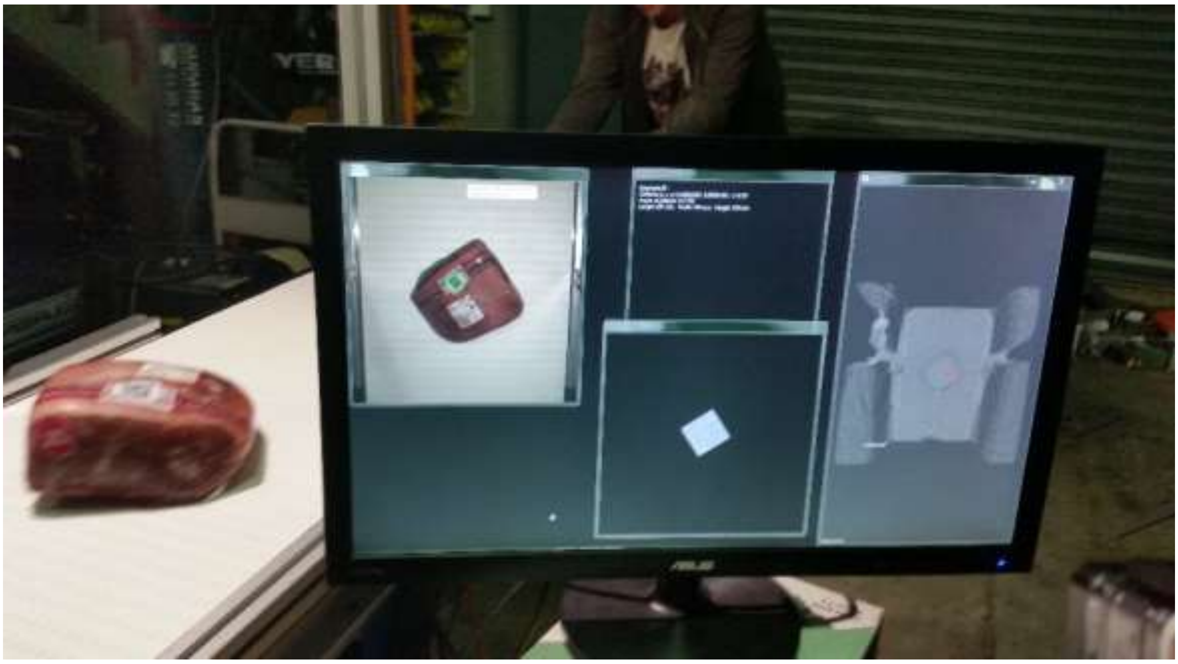

Figure 18: The display for the in-house testing

3.4.5 Analysis

During the initial testing, a sample consisting of 100 primal cuts of various recorded dimensions and orientation were separately placed in the field of view of the cameras. The test was deemed successful if the software was able to geometrically profile all objects within reasonable precision. After analysing the recorded dimensions it was determined that the primal cut recognition and localisation software is able to geometrically profile primal cuts of vacuum sealed meat on a conveyor with an accuracy of ± 7mm.

The same sample of 100 primal cuts was used for the continuously running test, with QR-codes randomly located on their surfaces. This test aimed to calculate a pass/fail ratio of the software being able to detect, geometrically profile the cuts and detect and decode the QR-codes when cuts were located on a running conveyor. The test was deemed successful if the software was able to detect, geometrically profile the cuts and detect and decode the QR-codes. After analysing the recorded results it was determined that the primal cut recognition and localisation software is able to geometrically profile the cuts and decode QR-codes with a 100% pass ratio during optimal conditions, e.g. correct camera focus, spacing on primal cuts, reasonable lighting, etc.

3.5 On Site System Trials

The final stage of development was conducted on site at Oakey Beef Exports Pty Ltd on the 21st of May 2015 to ensure the equipment and packaged vision software was fully functional and operating during expected conditions.

Figure 19 to **Figure 21** illustrates the setup of the on-site trial and displays the data calculations obtained from the vision software.

Figure 19: On-site trial equipment setup

Figure 20: Screen during on-site trial

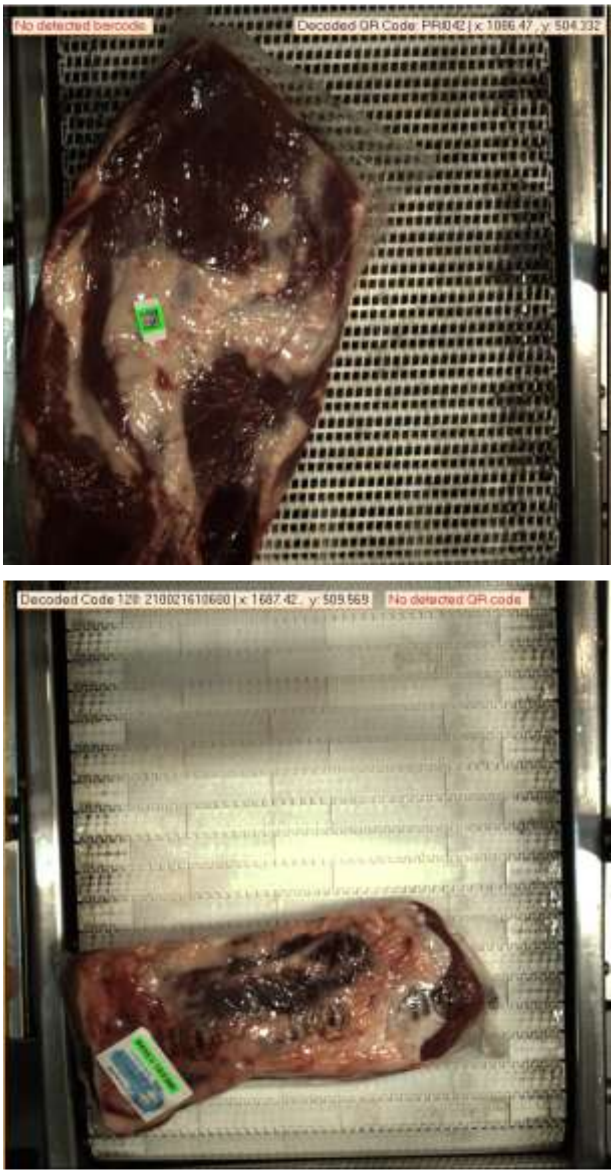

Figure 22 Screenshots of visualisation window

Figure 21 Test equipment setup during on-site trial

3.5.1 Analysis

During on-site testing, a QR-code was manually placed on the passing vacuum sealed primal cuts prior to entering the conveyor where the vision system was mounted. The primal cuts passed under the vision system and the collected data was recorded. The data collected included processed images from both cameras of the vision system, as well as the successful identification and profiling of the primal cuts as manually determined by observations of the visualisation screen.

The actual dimensions of each primal cut could not feasibly be measured during testing as this would halt production. Therefore, the recorded dimensions could not be directly compared to determine the accuracy of the geometric profiling. The recorded dimensions were compared to an average dimensions based on the type of cut, which agreed with the accuracy determined during in-house trials of ±7mm.

A sample consisting of 100 primal cuts of various dimensions and orientation were affixed with a QR-code to determine a pass/fail ratio. The test was deemed successful if the software was able to detect, geometrically profile the cuts and detect and decode the QR-codes. In the chosen sample, the vision system was able to detect and decode all QR-codes.

4 Discussion

The testing of the vision system on the in-house test rig was close to but limited in its ability to replicate the working environment at the meat processing site. Such limitations need to be taken into consideration.

- The availability of the meat samples were limited to the cuts in local butcher stores and supermarkets. This limited the variation in size and shape of actual primal cuts observed in processing facilities.
- The maximum feed rate during in-house testing was 0.22m/s while the feed rate on-site was fixed at 0.25m/s.
- The in-house camera setup had a clear view of the conveyor whereas the on-site workspace had limitations as an overhanging carton conveyor was blocking a portion of the camera view.

The implementation of the vision system in the on-site environment was susceptible to issues beyond the current scope of the project. It would be recommended that the following issues be addressed before commercialisation of the project to ensure the capabilities and accuracy of the project are not impeded.

- The unenclosed setup of the conveyor belt within the project environment of the cameras is susceptible to external interference by moving foreign objects. Such objects or personnel that obstruct camera vision will invalidate the data analyses and forward incorrect information to a robotic pick and pack system. External objects that remain static can be removed from the point cloud during processing but may still affect the performance of the system. It would be recommended that the vision capture area be enclosed to help prevent such occurrences.
- The placement of meat upon the conveyor can drastically change the filtering capabilities of the geometric profiling system. Primal cuts that are situated on the conveyor where a portion of the meat is outside the region or scene of interest, predominantly overhanging on the sides of the conveyor belt, will be inaccurately analysed for dimensions and centroid coordinates.
- If two or more segments of meat pass beneath the PMDTec CamCube 3.0 that are in close proximity to one another, almost touching or overlapping, the filtering process will not differentiate between the separate meat. The two cuts will be analysed as a single larger

segment which will invalidate all data obtained from the capture for those segments. A valid solution for this would be to pass the primal cuts from a slower moving conveyor to a faster moving conveyor before the vision system, allowing the pieces to separate more. Additionally a comb on the conveyor to stop primal cuts from resting on top of other cuts and bring them all to one level could be utilised.

- The Cut Identification process requires the barcode/QR-code to be facing towards the Baumer camera. Therefore it is highly recommended to prevent situations along the conveyor between the code placement and the vision system setup that may result in the meat drastically changing orientation, particularly inversion of the primal cut.

It is expected that in an automated pick and pack system utilising this vision system technology, additional rejection handling measures need to be introduced. This will combat rare instances where the system does not correctly identify or profile the primal cut. An appropriately designed rejection system could handle many of the issues identified above, allowing the vision system to run more efficiently.

The overall project has overcome many challenges to produce a highly robust and accurate software package. The results obtained from the in-house testing have performed better than first predicted. These findings have successfully been replicated on-site with little to no issues. The results gathered for the primal cut geometric profiling over a series of sample tests has shown the software is capable of pinpointing the positioning, dimensions and orientations of the primal cut sample within a ±7mm accuracy. For the scope of the project these results exceed the required accuracy for the proposed pick and pack robotic system.

Moreover the primal cut recognition software has proven to successfully identify a range of 20x20mm QR codes at 1.2m camera distance. Due to the vast variations in primal cut heights, QR codes smaller than 20x20mm can experience unpredictable performance as the focal range becomes more sensitive when reading an image of fewer pixels.

The performance of the software is optimised for the testing purpose with a refresh rate of 3Hz. It is expected the software could be capable of handling faster conveyor feed rates by removing the unnecessary visualisation components of the software even whilst cooperating with a robotic pick and pack system.

5 Conclusion

This project managed the successful design, development and implementation of a primal cut recognition and localisation software utilising modern sensing technologies, algorithms and image processing. The developed system utilises two synchronised cameras; a PMDTec Camcube 3.0 ToF camera to capture point cloud data and a Baumer VLG-40C industrial HD camera to capture high resolution digital images. The captured scenes are analysed and the Primal Cut Recognition and Localisation Software is able to detect and identify cuts and geometrically profile them in real time.

The requirement for the completed primal cut recognition and localisation software to produce predictable and repeatable results over an extended period of time is vital to ensure reliability and commercial viability. The primal cut recognition and localisation software developed for this project consists of point cloud processing and visualisation algorithms to aid in data analysis and representation. The ability to visualise each step of the development assisted in determining the feasibility of such a system in an industrial setting.

The software package is capable of processing and analysing images from the CamCube 3.0 and VLG-40C.I cameras at a rate of 3Hz. The Geometric Profiling component of the software is able to determine the centroid coordinates and calculate dimensions (length, width and height) of all cuts with a precision of ± 7mm. While the Cut Identification component reliably detects a range of QR-codes, with the recommended size of 20x20mm at a distance of 1.2m.

5.1 Recommendation/Future Direction

The primal cut recognition and localisation software requires a barcode/QR code to be affixed to each primal cut for identification by the system. From the results gathered during the on-site trial and in-house tests, it is recommended to utilise QR-codes rather than standard barcodes. This is due to the QR-code's built in error correction and reliable format even when placed on irregular surfaces or being partly occluded or faded.

In most red meat processing plants, affixing an identifiable code onto every primal cut for an automated picking and packing system will involve an additional unit of manual labour. It is still feasible that the economic savings of an automated picking and packing solution offsets this, but it would be advantageous to automatically identify and attach the required code.

The continual development and advancement that has been made in camera sensor and three dimensional perception technologies in recent years have made solutions such as those stated in this report more viable in the red meat processing industry. Time of Flight cameras have become an affordable and robust technological approach to three dimensional vision and optimisation of automated machinery integration.

In the development of primal cut recognition and localisation software a time of flight camera was successfully implemented to track and geometrically profile primal cuts of meat on a conveyor in real time. This technology can also be used as a stepping stone for development of a naked primal cuts recognition software system. Such a system would allow primal cuts to be identified, placed in the appropriate sized bag, sealed and affixed with a QR code automatically. This research would further the development of a completely automatic picking and packing system.

6 Bibliography

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