final report

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Final Report – Frontmatec BCC-3 beef classification system study and installation in Australia beef industry

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Executive summary

Frontmatec is renowned for developing carcass grading equipment for pig and cattle slaughterhouses and has recently launched a vision-based beef carcass grading system (BCC-3). This system is currently installed in one South American slaughterhouse and four European slaughterhouses. The BCC-3 system consists of 8 towers with 5 cameras in each tower resulting in image capture of a beef half carcass by 40 images in total. Based on those images 3D models of the half carcass are constructed through advanced image analysis software. The current project (P.PSH.0996) builds on the work already undertaken by Frontmatec by designing and building an algorithm that will suit the Australian Beef processing industry and if successful, should be followed by system installation in Australia.

In order to facilitate system installation in Australia four milestone criteria had to be met; 1) Improvement of processing time to keep up with Australian production line speeds, 2) Spatial calibration to improve the precision of the 3D model, 3) Develop methods to re-construct the occluded (hidden) area of the carcass, 4) Build an analysis tool that can identify carcass descriptors related to primal weights.

The processing time was increased by optimizing software and hardware, and introducing a topology supporting multiple analysis computers. Four approaches were used to increase throughput; 1) Software optimization (Source code and analysis steps), 2) Software parallelization (multiple cores), 3) Hardware optimization (Processors and chipsets) and 4) Hardware parallelization (multiple computers). A Dell R740 equipped with state-of-the-art Xeon Gold Processors was chosen. A total of three R740 analysis computers would be needed to fulfil the line speed requirements in Australia.

A new spatial calibration method was developed using a well-defined calibration target. This method has improved the determination of camera position by up to a factor of 60 and shows very high robustness against random effects of calibration target positioning.

A method for reconstructing sparsely represented or occluded areas in the carcass point cloud has been developed and tested. It is resilient against holes in the point cloud smaller than 200mm in diameter and reductions in the global point count by more than 50% and to data missing from one or more cameras.

The performance of the BCC-3 system with respect to prediction of primal and commercial cut weights is acceptable. Prediction of the weight of the pistol cut, inside, knuckle and rump from veal resulted in prediction errors of 0.910 kg, 0.280 kg, 0.191 kg and 0.162 kg, respectively.

In conclusion, image analysis processing speed was increased to suit Australian industry requirements (520 half carcasses/hour), spatial calibration is now part of the BCC-3 system providing a robust method of validating system performance against a standardised target. Methods were introduced and validated to mitigate occlusion issues foreseen in a high-speed production environment and an analysis tool has been developed for prediction of primal and commercial cut weight.

Frontmatec recommend that installation of BCC-3 systems will be facilitated.

Table of contents

1 Background

Frontmatec has designed and built a 360° 3D classification system for European grading system (EUROP Score) for beef, with the potential of estimating primal weights (Fig. 1).

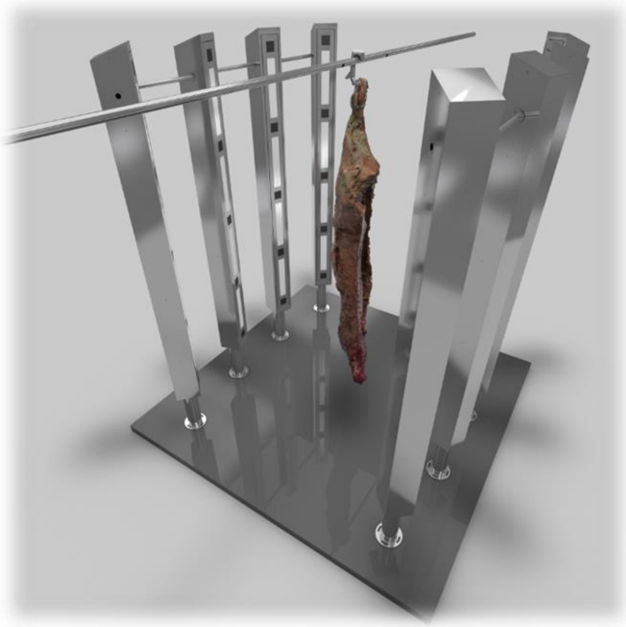

Fig. 1: Illustration of the beef carcass classification system developed by Frontmatec (BCC-3).

The current project builds on the work already undertaken by Frontmatec by designing and building an algorithm that will suit the Australian Beef processing industry and if successful, and will be followed by system installation in Australia.

To date, the BBC-3 has been proven on EUROP score (European grading system). This was tested on a Uruguayan processing system – INACUR (which is identical to the EUROP score)

The breeds that have been tested are Hereford, Angus and Crossbreeds of these two breeds.

Sample size of this test was 427 animals. And the results of the test revealed that 97% falls within +/-1 conformation class (on a 15 point scale) and 88% falls within +/-1 Fat cover class (on a 15 point scale).

Processors

This system enables the ability to estimate primal weights on either hot or cold side of the process.

Can potentially inform sorting (downstream) and payment (upstream) programs based on the actual volume of the primals.

May allow benchmarking of production for expected yields against actual yields.

Technology

Potential to combine the DEXA and BCC-3 technology's to improve the carcass cut-out.

May allow for the automatic breakdown on carcasses in the future such as robotics

This project has two major and somewhat separate components, those being firstly, the development of an algorithm to grade beef primal weights (this is in general and not specified to Australian conditions – Milestones 1 to 4) and secondly, the application of this technology in Australian production systems (milestones 5-7). As such this project could be split into two separate projects however to de-risk the project, and to ensure that there is a clear link to the Australian Industry, it was written as one project with a go/no go point between these components.

2 Project objectives

2.1 Objective cattle classification for Australia using the BCC-3 system

The objectives of the present project are diverse and includes:
Determine if the BCC-3 system can grade beef primal weights (European breeds also represented in Australia first).
Develop a Frontmatec BCC-3 algorithm applicable to the Australian Beef industry.
Develop and install a system that can grade beef primal weights in Australian production systems.
The first processing plant to have this system under a proposed 6-month period will then have the option to buy the system.
Support up to a 5-year period, the maintenance, service and general technical support of MLA and MLA's wider research groups.
Ascertain how such a system can benefit the Australian industry (whole of supply chain). Then develop a plan for commercial entry into the Australian market.

3 Methodology

3.1 Improvement of processing time to keep up with Australian production line speeds (Milestone Report 1)

Milestone Report 1 focused on demonstrating that the image analysis software version initially developed prior to the start up of this project could be optimised to keep up with the line speed on an Australian production line. The average time required for the image acquisition and analysis to produce a classification result had to be optimised as it was initially too time-consuming with approximately 213 seconds per carcass (17 half carcasses/hour). To keep up with the Australian required line speed a throughput of 520 half carcasses/hour would have to be achieved.

The time-consuming image analysis post processing steps; image undistortion, point cloud reconstruction, point cloud cleanup, conversion to mesh, 3D modelling and trait calculation as well as hardware optimization and parallelization was the focus of Milestone Report 1.

3.2 Spatial calibration to improve the precision of the 3D model (Milestone Report 2)

Spatial calibration must be conducted to determine the directions and origins of the camera orientation vectors.

The goal of spatial calibration is:

- To determine the positions and orientations (coordinates) of all cameras within the BCC-3.
- To embed the camera coordinates in a common (global) coordinate system.
- To ensure that the scale of the global coordinate system is the same as in the "real world".
- To ensure that the rotation of the global coordinate system is reproducible and corresponds to a well-defined rotation in the "real world".

Spatial calibration improves the precision of the 3D point cloud and subsequent model.

The spatial calibration method relies on acquiring images of a calibration target (Fig. 2). The functional part relevant for the spatial calibration is the chequered section (in the centre of Fig. 2). Its geometry is well defined as the size of the chequers and the thickness of the board is well defined. The board is light and ridged and can be suspended from the slaughterhouse conveyor (Fig. 3).

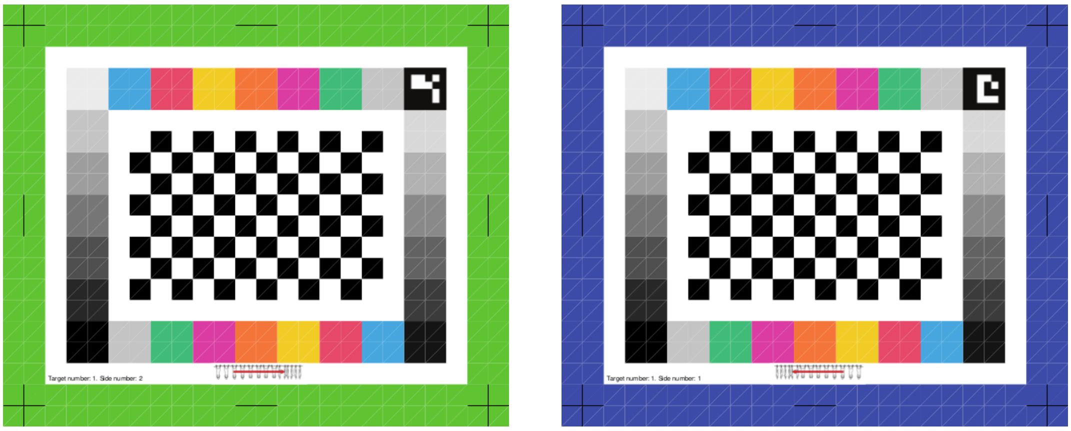

Fig. 2: The two sides of the calibration target.

The corners within the chess board are readily detected in each image. The locations of the corners in combination with the information of the true, physical geometry of the chess board allows the algorithm to detect the true position on an absolute spatial scale of the camera position. This allows all cameras to become embedded in the same global coordinate system.

The same target is used for calibrating colour and spatial information was chosen since the goal is to minimize the number of calibration targets used. The chess board used for spatial calibration furthermore allows for reliable identification of the locations of colour tiles within the calibration target.

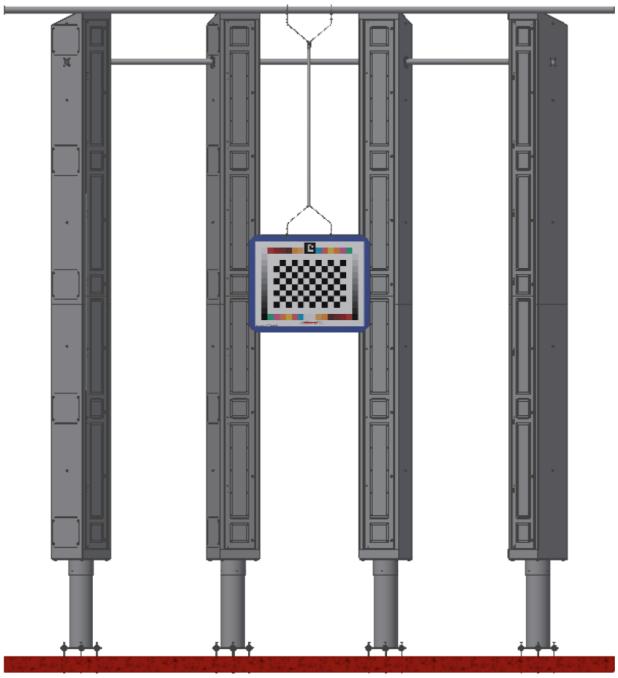

Fig. 3: Illustration of the calibration target suspended from the conveyor.

The intrinsics of all cameras are calibrated prior to installation and the calibration parameters are installed in the persistent memory of the server running the software backend. This is used for undistorting images.

During normal operation, it is required to perform a "morning test". The slaughterhouse validation target must be suspended at the centre of the BCC-3 and a set of images acquired. The calibration algorithm is executed, but instead of storing the output parameters, they are compared with the calibration parameters. If the comparison fails, warnings will be provided to the user and appropriate action needs to be taken.

3.3 Develop methods to re-construct the occluded (hidden) area of the carcass (Milestone Report 3)

A method to re-construct the occluded areas of the carcass was developed and tested. The method implemented to reconstruct sparse or occluded areas of a Point Cloud (PC) is based on the so-called Poisson reconstruction method. It is a commonly used tool within the field of computer graphics.

The task of filling in holes is in many ways similar to an extrapolation. It involves automatically filling in missing information and must therefore be subject to model dependence. The method implemented to reconstruct the missing areas of the carcass is very robust, and reliable. This is the case within the entire range of carcass geometries and it is very robust against a broad selection of imperfections in the reconstruction of the PC.

The evaluation of the success in meeting the milestone is based on computing the predicted volume on a PC that has artificially been made less than perfect (Fig.4).

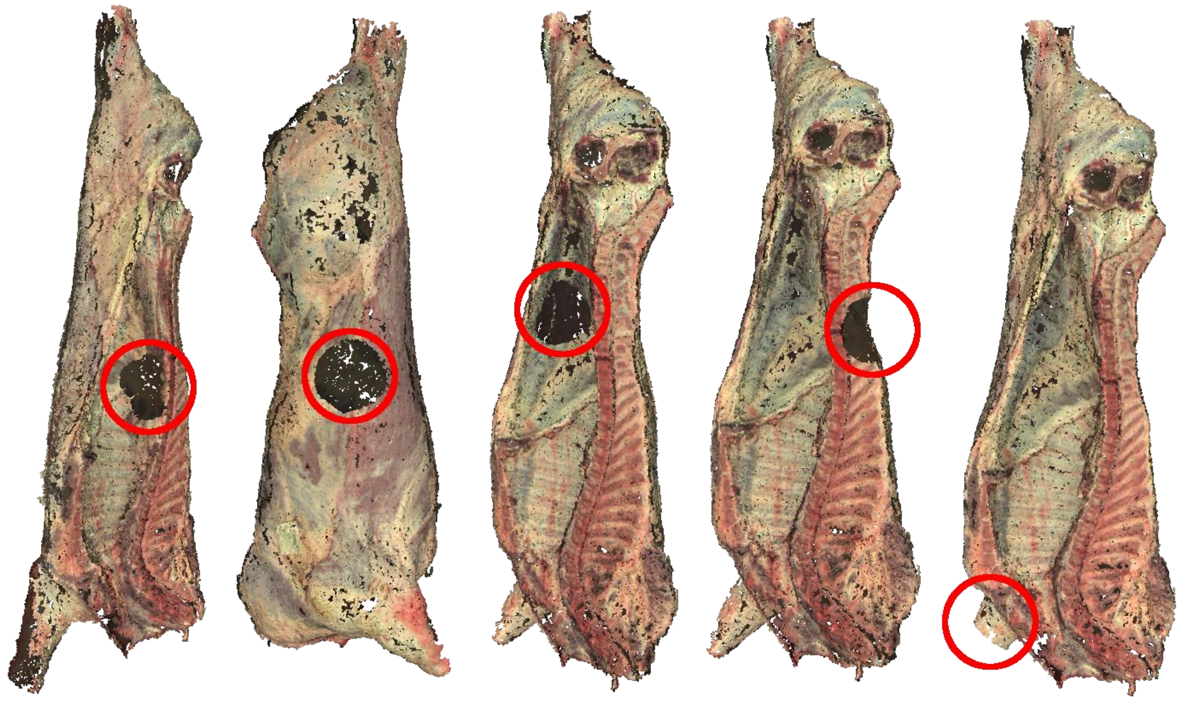

Fig. 4. Artificially introduced occluded zones. From left to right: zone1, zone2, zone3, zone4, far right shows a missing front leg

Another mode of failure is if one or more cameras are completely missing from the PC reconstruction input (Fig. 5). These situations are readily detectable in the control software of BCC-3 but excluding cameras from the reconstruction of the PC gives insight into what happens if one or several cameras are obstructed. For instance, this could be the result of very unclean camera optics or some object being directly in front of the cameras in question. Complete obstruction of a camera should not occur during normal operation, the test therefore simulates the worst-case scenario.

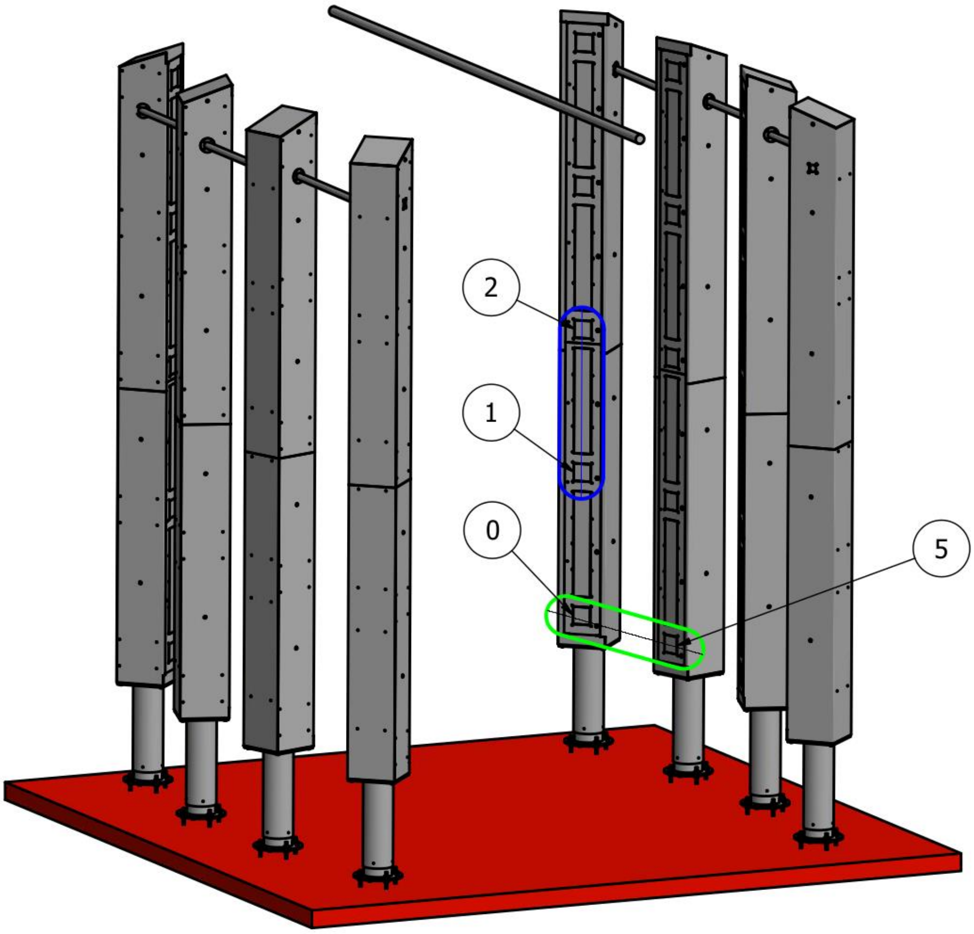

Fig. 5. View of the BCC-3 that shows the method for selecting cameras to exclude. The green outline encompasses a horizontal pair. In this case cameras [0] and [5]. The blue outline encompasses a vertical pair. In this case cameras [1] and [2].

3.4 Build an analysis tool that can identify carcass descriptors related to primal weights (Milestone Report 4)

Milestone Report 4 aimed at building a BCC-3 image analysis tool that can identify carcass descriptors which can be used to predict the weight of primal cuts.

The great advantage of the BCC-3 is the large amount of highly filtered measurement data available in the 3D models. A series of 1D, 2D and 3D generated image parameters such as carcass dimensions and surface texture parameters are derived from the image analysis software.

The origin of all image analysis parameters is the centre of mass of the model itself. This increases robustness and repeatability of the image analysis by making it independent of carcass suspension, such as conveyor and hook type.

Ultimately, primal and commercial cut weights are predicted from the carcass descriptors using multivariate data analysis.

A test was conducted over 2 working days in a Danish commercial beef slaughter house and 86 half carcasses were included in the trial. The slaughtering process were carried out according to national slaughter specifications. Images were acquired of both left and right sides. All half carcasses were then divided into two primal cuts; pistol (with 8 ribs) and forequarter. This process involves transfer of hooks from RF-ID hooks (half carcass) to Euro-hooks (pistol cut). The slaughter house has full traceability between the half carcass scanned by the BCC-3 (RF-ID) and the pistol cuts (Euro-hooks). The primal cuts were left overnight in the cooling room. On day 1 after slaughter the pistol cut was moved from the cooling room to the boning hall on the conveyor and the left sides were used for the primal test. The weight of the pistol cut was recorded by the slaughter house and collected from their database. The pistol cut was divided into round and full rib. The rounds were deboned by two butchers selected by the Boning hall Manager. The weight of the inside without cap, knuckle and full rump from each round were recorded.

In order to ensure a wide span of weight ranges for the deboned cuts the 86 half carcasses were selected according to conformation scores and hot carcass weight as these two traits were believed to create variation in the weight of the deboned cuts. The selected carcasses all had fat scores of either class 2 or 3 on a 15-point scale.

4 Results and Discussion

4.1 Improvement of processing time to keep up with Australian production line speeds (Milestone Report 1)

A line speed of 520 half carcasses/hour was achieved by optimizing software and hardware, and introducing a topology supporting multiple analysis computers.

The software speed improvement was gained through a number of methods. Filtering of the input images gave a large performance boost. Only processing relevant pixels in the 3D reconstruction gave an additional performance gain. Finally, large portions of the code was re-designed to run in parallel fashion.

Four approaches were used to increase throughput; 1) Software optimization (Source code and analysis steps), 2) Software parallelization (multiple cores), 3) Hardware optimization (Processors and chipsets) and 4) Hardware parallelization (multiple computers). The initial benchmarks were performed on a Dell R730 server platform. It became clear that the limited number of cores available would not support the massively parallelized structure needed to reduce processing time. Therefore, a Dell R740 equipped with state-of-the-art Xeon Gold Processors was chosen. The use of the R740 resulted in significant improvement of parallel processing, which reduced processing time substantially.

Table 1. Comparison of analysis time for the individual computation steps using the two server platforms Dell R730 and R740.

Process	Dell R730	Dell R740

	Avg [s]	Max [s]	Min [s]	Avg [s]	Max [s]	Min [s]
Undistortion	0.5	0.6	0.5	0.2	0.3	0.2
Point cloud generation	18.2	24.5	14.2	11.0	13.5	7.6
Point cloud cleanup	0.5	0.7	0.3	0.4	0.5	0.3
Mesh generation	11.0	36.15	8.4	7.7	10.2	5.4
Housekeeping	0.1	0.2	0.1	0.4	0.5	0.3
Mesh analysis	12.2	48.0	5.1	0.9	1.8	0.5
All above processes combined	**42.5**	**81.3**	29.5	**20.7**	**25.7**	15.1

The cost of an R740 is approx. 40% higher than an R730 but performance is approx. 51% higher, making the R740 an obvious choice for this application.

The histogram shown in Fig. 6 is the result of the combined software and hardware improvements, when running the image analysis on a single R740 computer.

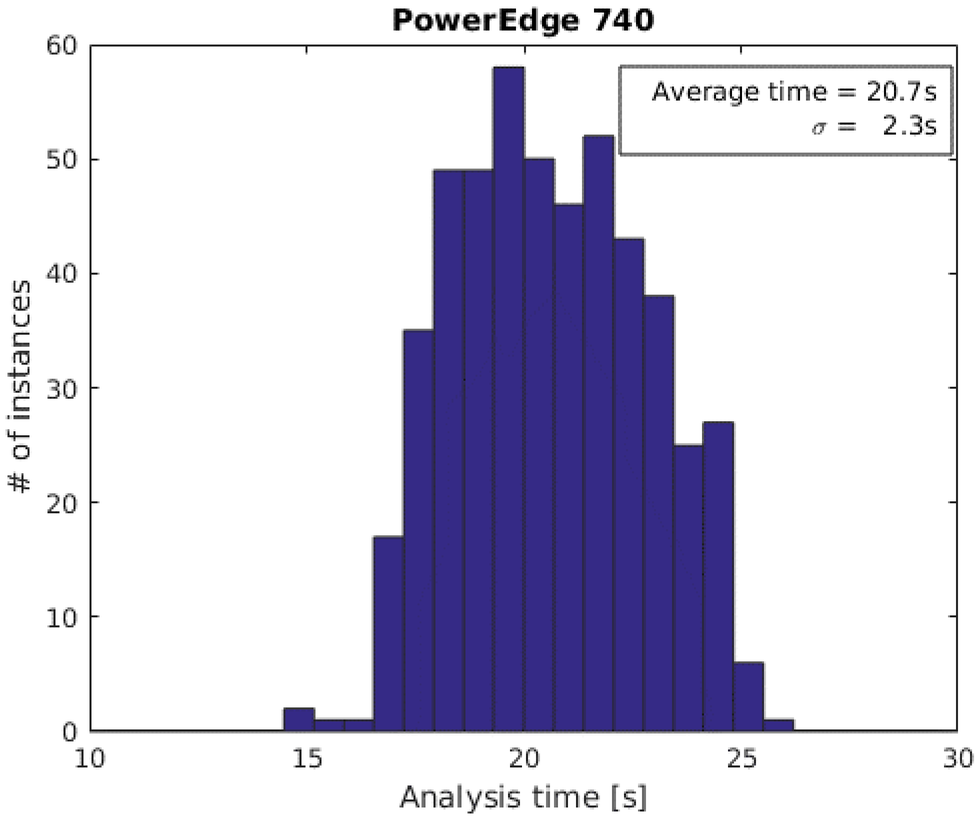

Fig. 6. Average analysis time per carcass achieved using a Dell R740 server platform

As seen in Fig. 6, the analysis time improved to 20.7 seconds on average, which means that a total of three R740 analysis computers are needed to fulfil the line speed requirements in Australia.

In case line speeds were to increase beyond the current maximum, more analysis computers could be added to support this.

4.2 Spatial calibration to improve the precision of the 3D model (Milestone Report 2)

A new calibration method was developed using a well-defined calibration target instead of feature detection on a randomized target. This method has improved the determination of camera position by up to a factor of 60 and shows very high robustness against random effects of calibration target positioning.

In conclusion, spatial calibration has been successfully implemented in the BCC-3 software package.

Table 2 below shows that calibration introduces a minor bias of up to 0.13 litre for all carcasses which translates to approx. 130 grams of carcass weight. More than 93% of all carcasses varies less than 1 litre.

Table 2. Effect on volume of a large sample of beef carcasses, when using 5 repeated worst-case calibrations

Calibration run	Bias [litre]	Percent within +/-1 liter [%]
1	0.131	93.9
2	-0.087	95.7
3	-0.017	96.7
4	0.054	96.3
5	0.027	95.7

4.3 Develop methods to re-construct the occluded (hidden) area of the carcass (Milestone Report 3)

By computing a watertight triangular mesh, a variety of global measures become computationally available. Quantities like the volume, surface area, volumetric centre of mass, or inertial axes become well-defined quantities.

The volume is an excellent figure-of-merit because it relates in a very direct way to the weight - and hence to the value - of the carcass. Furthermore, it is necessary to predict the global volume accurately when computing more complicated measures such as the volumes/weights of primal cuts. Hence, accurate prediction of the carcass volume must be a hallmark of a good method for closing holes in the PC.

A method for reconstructing sparsely represented or occluded areas in the carcass PC has been developed and tested. It is robust and reliable and preserves the determined volume of the carcass when even major imperfections are artificially introduced. It is resilient against holes in the PC smaller than 200mm in diameter and reductions in the global point count by more than 50% (Fig. 7).

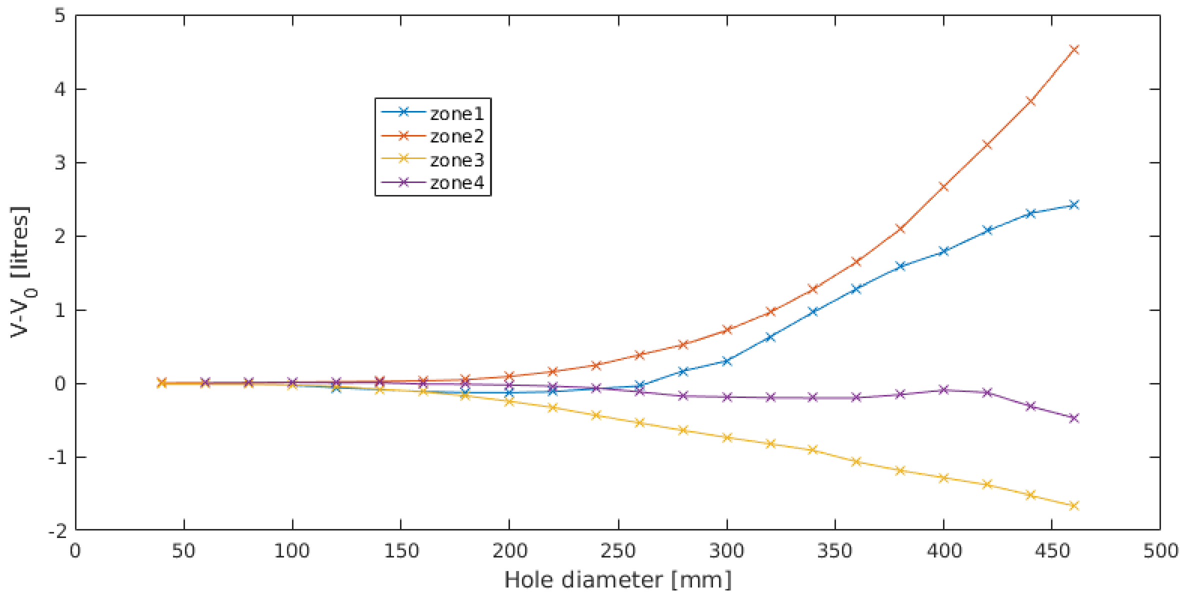

Fig. 7. The influence of hole diameter on the computed volume of an imperfect PC subtracted by the volume of the standard carcass. The four zones represent PC holes in different parts of the carcass as shown on Fig. 2.

The reconstruction method is resilient to data missing from one or more cameras as shown in Fig. 8.

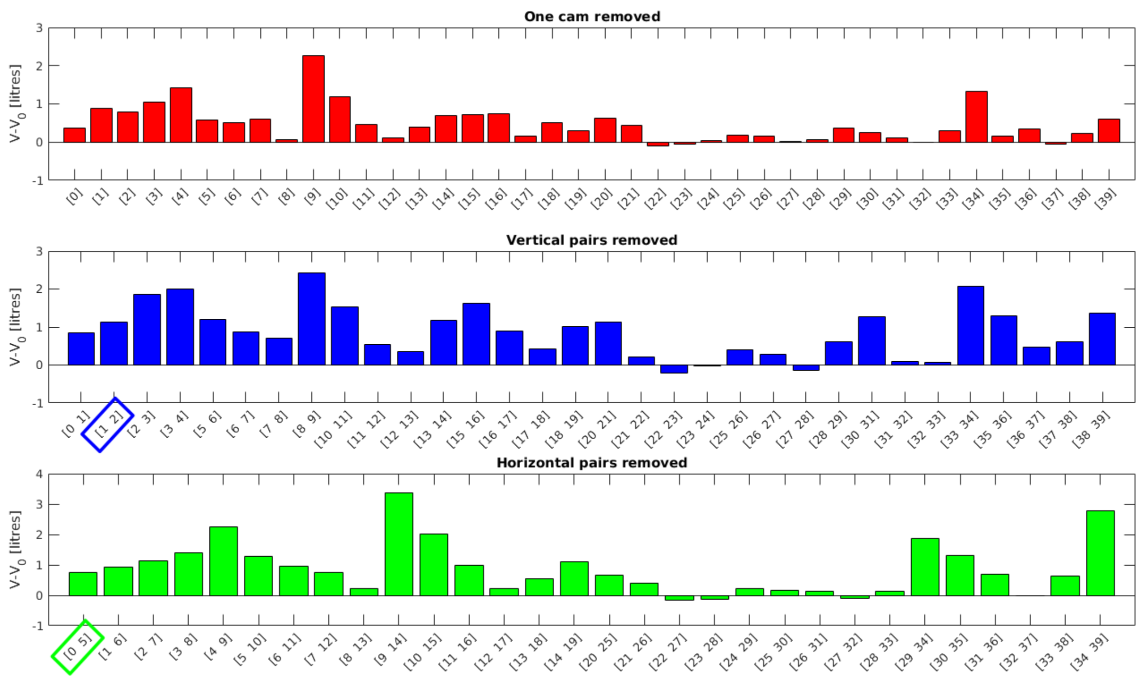

Fig. 8. The difference in computed volume of an imperfect PC to the standard carcass when excluding one or more cameras from the PC reconstruction process. Excluding single cameras (Top), pairs of

vertically adjacent cameras (Middle bar) or pairs of horizontally adjacent cameras (Bottom). The examples shown in Fig. 5 are marked with boxes of similar colours in this figure.

4.4 Build an analysis tool that can identify carcass descriptors related to primal weights (Milestone Report 4)

The performance of the BCC-3 system with respect to being able to predict the pistol cut weight as well as three deboned cuts from the round (inside without cap, knuckle and rump) is evaluated in Milestone Report 4.

The achievement criteria of milestone 4 was successfully met as the criteria was to build a BCC-3 image analysis tool that can identify carcass descriptors which can be used to predict the weight of primal cuts.

The prediction accuracy and prediction error (Table 3) of the developed prediction models for the pistol cut, and 3 specific cuts in the round did not significantly improve by including the HCW in combination with the BCC-3 carcass descriptors. This indicate that the BCC-3 system successfully predicts the primal weight without external input.

Table 3. BCC-3 model performance for prediction of beef primal weight and commercial cuts

	Model			Reference	
	#PC	R2cv	RMSECV (kg)	Average (kg)	Std.dev (kg)
Pistol cut	3	0.967	0.910	53.51	4.59
Inside	2	0.775	0.280	4.80	0.582
Knuckle	1	0.852	0.191	2.79	0.332
Rump	2	0.805	0.162	4.18	0.468

Table 3 shows slightly improved results compared what was reported in Milestone Report 4 as the image analysis is continuesly being improved.

5 Conclusions/recommendations

5.1 Conclusions

The project has unfortunately been terminated by MLA due to delayes in obtaining reference data for use in Milestone Report 4.

The main conclusions are:

- Image analysis processing speed was increased to suit Australian industry requirements (520 half carcasses/hour)
- Spatial calibration is now part of the BCC-3 system providing a robust method of validating system performance against a standardised target
- Methods were introduced and validated to mitigate occlusion issues foreseen in a high-speed production environment
- An analysis tool has been developed for prediction of primal and commercial cut weight

5.2 Recommendations

Since the termination of this project, five BCC-3 systems has been installed in South American and European beef slaughterhouses indicating that the predictors produced by BCC-3 has a global commercial potential.

Frontmatec therefore highly recommend that the work described in Milestones 5-8 will be re-initiated in a separate project.

6 Key messages

The key messages are:

- BCC-3 provides the option of grading according to EUROP score thereby enabling benchmarking against European beef slaughterhouses
- BCC-3 provides the foundation for developing predictors to support sorting and yield benchmarking in the Australian beef industry
- The BCC-3 hardware and software platform is no longer an R&D project but a mature beef grading system ready for implementation