# final report

Project code: P.PSH.0776

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Date published: 9 July 2020

PUBLISHED BY
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# Automated MSA/AUS-MEAT hyperspectral handheld grading for beef

This is an MLA Donor Company funded project.

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

# Executive summary

The MLA funded project (P.PSH.0776) entitled "Automated MSA/AUS-MEAT hyperspectral handheld grading for beef" was initiated in 2016 and finishes at the end of 2019. The project has been conducted in collaboration with Murdoch University (Perth) and University of New England (Armidale) and has strong links to the Advanced Livestock Measurement Technologies (ALMTech) program.

The main objective of the project was to develop an automated handheld camera which grades the beef rib eye according to MSA/AUS-MEAT standards consistently and in accordance with visual grading conducted by highly trained graders. The overall project goal was to make available an instrument with prediction models that will enable all abattoirs in Australia to grade carcases in a uniform and consistent way and thereby creating high value for the Australian beef industry.

Vision-based systems for grading beef rib eye already exist on the market. However, the commercially available equipment does not appear suitable for all Australian beef grading. In the present project a lamb grading based handheld instrument has been further developed into one suitable for the beef industry which allows automated classification of physical attributes such as ribeye muscle area, marbling, subcutaneous fat depth and colour of fat and meat tissue. Traits which up until now are being visually graded by accredited AUS-MEAT and MSA graders according to AUS-MEAT's Chiller Assessment Language. Three handheld camera prototypes were built and used for testing by Murdoch University.

A total of 888 steers were included in the project and samples were collected under commercial slaughter conditions from steers belonging to the Northern and Angus Beef Information Nucleus (BIN) herds. Carcasses were quartered between the $12^{th}$ and $13^{th}$ rib and allowed to bloom for at least 30 minutes. Care was taken to ensure that bone dust and fat was removed from the surface of the ribeye area. Carcasses were then graded according to the AUS-MEAT Chiller Assessment Language by a Meat Standards Australia (MSA) grader between 8 – 24h after slaughter for all relevant carcass traits. The evaluated carcass traits being: ribeye area, subcutaneous rib fat thickness, MSA marbling score, AUS-MEAT marbling score, and meat and fat colour class. Subsequently, images were captured with the handheld camera equipment developed by Frontmatec Smoerum A/S. A sample was collected for NIR-based determination of the intramuscular fat content by Murdoch University.

In conclusion, algorithms for ribeye area, intramuscular fat content, marbling score against both MSA and AUS-MEAT classification and meat colour have been developed. Development of an algorithm for fat colour classification awaits a data set which covers a larger spread in colour classes with each class properly represented. Subcutaneous rib fat thickness cannot be determined by the camera solution. An alternative to subcutaneous rib fat would be total fat thickness. This trait is feasible but not part of the AUS-MEAT standard and reference data for this trait was not obtained in the project.

Based on the learnings from the current project Frontmatec intends to develop a commercial device after completion of P.PSH.0776.

# Table of contents

# 1 Background

Vision-based systems for grading beef rib eye already exist on the market. However, the commercial available equipment does not appear suitable for all Australian beef grading.

Recently, an article was published in Meatingplace.com under the heading “Technology is great, when it works”. This article describes a case in US where camera grading is used to classify beef rib eyes into USDA quality categories; Select, Choice and Prime. “Select” being the carcases with low marbling and hence lower eating quality. A software upgrade resulted in an uptick in the percentage of cattle graded “Choice” and a decrease in cattle graded “Select”. This misclassification benefits the farmers as they are paid more for lower quality carcasses but for the consumers it means that they purchase meat at a higher price but lower quality which is unacceptable for them.

Based on the above Frontmatec Smoerum A/S decided to participate in an MLA funded project to develop a handheld camera solution for beef rib eye grading and evaluate the ability to grade beef rib eye according to MSA/AUS-MEAT grading standards.

The present project (P.PSH.0776) will re-configure and further develop a lamb grading based handheld instrument into one suitable for the beef industry which allows automated classification of physical attributes such as rib eye muscle area, intramuscular fat (marbling), subcutaneous fat depth and colour of fat and meat tissue. Attributes which up until now are being visually graded by accredited AUS-MEAT and MSA graders according to AUS-MEAT's Chiller Assessment Language and MSA Grading attributes. The automated equipment will benefit the Australian beef industry and the goal is to make available an instrument with prediction models that will enable all abattoirs in Australia to grade carcases in a uniform and consistent way.

The main objective is to develop an automated handheld camera which grades the beef rib eye according to MSA/AUS-MEAT standards consistently and in accordance with visual grading conducted by trained operators.

This includes development of an image analysis system which can:

- Measure rib eye area
- Measure subcutaneous fat thickness
- Classify rib eye according to degree of marbling (both MSA and AUS-MEAT grades)
- Classify rib eye meat colour
- Classify rib eye fat colour

In addition, the ability of the handheld camera to predict the intramuscular fat content will also be explored.

# 2 Project objectives

## 2.1 Objective cattle classification

### 2.1.1 Using hyperspectral vision techniques to substitute manual grading per MSA/AUS-MEAT standards

This project will re-configure and further develop a lamb grading based instrument into one suitable for the beef industry to determine the relationships, and their respective correlations and prediction errors, to physical attributes such as ribeye muscle area, fat depths, marbling, intramuscular fat and fat and meat colour.
The hyperspectral based camera will, with modification, be used to measure beef carcasses for parameters that would quantify ribeye muscle area, meat colour, fat colour, marbling score, and fat depth profile according to MSA/AUS-MEAT standards.

The project constitutes 8 milestones with intermediate objectives:

1. Wavelength selection for multispectral camera solution
2. Construction of 3 camera prototypes
3. Initial data collection
4. Development of software version 1 and initial predictions of MSA grades
5. Repeatability test of 3 prototypes and validation using software version 1
6. Development of software version 2 and verification of camera reproducibility
7. Development of software version 3 and final camera prototype performance

# 3 Methodology

## 3.1 Building of 3 handheld camera prototypes

Three handheld multispectral vision-based camera prototypes for grading beef carcasses in Australia were developed and provided to Murdoch University for performance testing at commercial abattoirs. An illustration of the camera prototype is shown in Fig. 1.

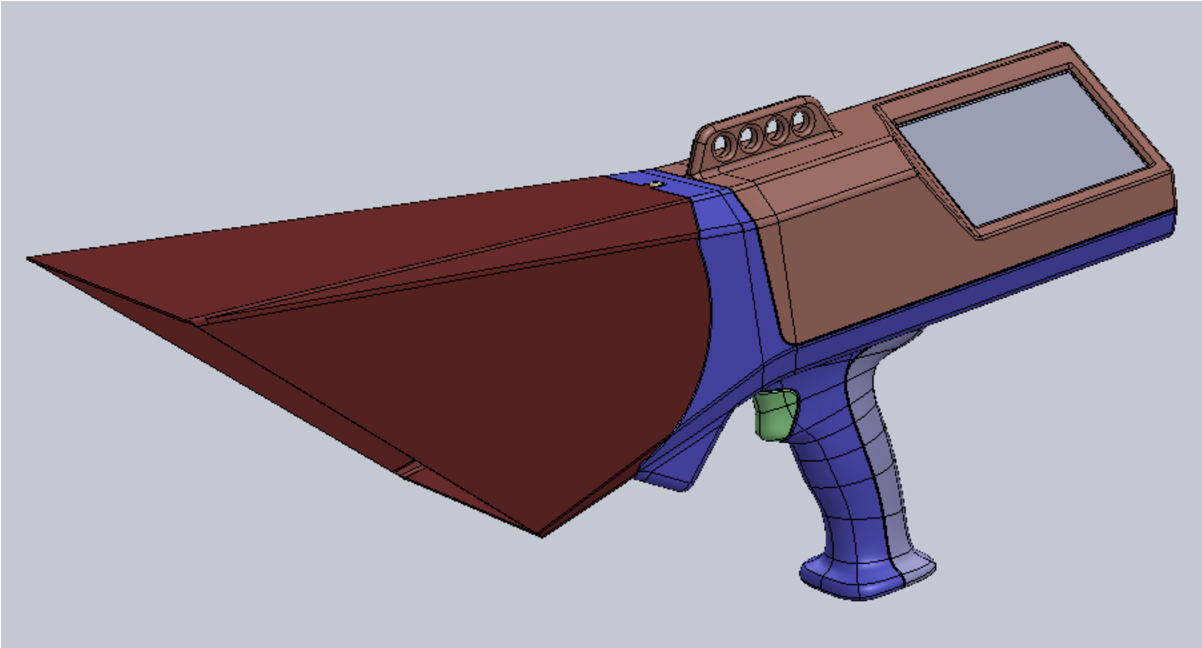

Fig. 1. Handheld vision-based camera for beef carcass grading according to AUS-MEAT/MSA standards

The handheld device constitutes two main components, a front-end shielding (shroud) and a camera housing (Fig. 1). The camera housing comprises the light source, camera setup, printed circuit board (PCB), touch display and an image capture trigger mounted in the handle. A flexible conduit cable is used for protection of electrical wires going from the handheld device to a computer.

The light source consists of a series of LEDs mounted on the PCB. The selection of LEDs was based on a test carried out in collaboration with the Danish Technological University, Lyngby, Denmark. They found that the MSA grading standard tiles as well as meat and fat colours could be differentiated using LEDs emitting light at five wavelengths in the visible range.

The shroud is produced in matte stainless steel which is a long-term stable material (no deterioration of coating material), it is easy to produce and clean, and it complies with the European regulation on Food Contact Materials (EC 1935/2004). The function of the shroud is both to avoid ambient light interfering with the reflected light originating from the light source and to act as a diffused reflector of light emitted from the light source and reflected by the meat surface.

## 3.2 Animal material

A total of 888 steers were included in the project and samples obtained over a two year period from 2017 to 2018. The steers belong to the Northern and Angus Beef Information Nucleus (BIN) herds. The tests were coordinated by Murdoch University and were conducted under commercial slaughter conditions.

Carcasses were quartered between the 12$^{th}$ and 13$^{th}$ rib and allowed to bloom for at least 30 minutes. Images were captured using the handheld camera prototype by Murdoch University. Care was taken to ensure that bone dust and fat was removed from the surface of the loin eye area. Carcasses were then graded by a Meat Standards Australia (MSA) grader between 8 – 24h after slaughter for all relevant carcass traits. The evaluated carcass traits being: rib eye area, subcutaneous rib fat thickness, MSA marbling score, AUS-MEAT marbling score, and meat and fat colour class. The procedures used by the graders for visual classification of beef rib eye is described in the AUS-MEAT Chiller Assessment Language document.

A meat sample was collected from the rib eye surface of the *M. Longissimus dorsi* and analysed for chemical intramuscular fat (IMF%) content by lab based Near Infrared (NIR) spectroscopy, calibrated by soxhlet extraction. Analysis of IMF% was performed at the University of New England, Meat Science Department (Armidale, New South Wales, Australia).

## 3.3 Image analysis software for rib eye camera

Image analysis software version 1 was finalized January 2018 and demonstrated proof of concept, however, it was clear that an updated analysis toolbox was required. Software version 2 was finalized in May 2019. Further optimization led to finalization of software version 3 in November 2019. This version is considered the final software outcome of project P.PSH.0776. The ability of this software version to correctly classify meat samples according to AUS-MEAT and MSA standards are presented in chapter 4.

# 4 Results

In the following sections the final results of the performance of the handheld ribeye camera prototype developed by Frontmatec are presented for the individual ribeye traits. Algorithms were developed on samples collected during 2017 and validated against a subset of samples collected during 2018 which was collected under standardised test setup conditions. The prototype performance is evaluated as the ability of the image analysis software version 3 to classify beef ribeye according to the industry standard requirements for approval of automated equipment. The new standard was very recently approved by the Language and Standard Committee.

## 4.1 Ribeye area

The automated camera solution showed high precision in determining the ribeye area with a squared correlation of 0.85 and a root mean square error (RMSE) of 5.1 $cm^2$ using visual ribeye grading as a reference.

The RMSE is the prediction error expressing the difference between the values estimated by the algorithm and the reference values obtained by an MSA grader. From a statistical perspective, 66% of the population lies within this prediction error, 29% of the population lies within 2xRMSE and 5% within 3xRMSE.

Fig. 2 shows the performance of the automated camera solution in relation to the Language and Standard Committee approval criteria for ribeye grading equipment. In order to fulfill the approval criteria for ribeye grading the blue bar representing the percent of carcasses within ± 4 $cm^2$ of the expert grader should exceed the dashed red line as the recommended accuracy standard states that 74% of the data should be within this range. The solid red lines represents the maximum allowed % of carcasses with deviations between the automated system and the expert grader with ribeye area deviations of more than 4.1 $cm^2$.

It is evident from Fig. 2 that the approval criteria for ribeye area are close to being fulfilled. There are a few samples with a ribeye area difference greater than 12 $cm^2$ between the automated solution and the expert grader. The reference results obtained in the present project is based on only one grader and it is therefore not possible to clarify if these samples deviates because of grader-to-grader differences. A re-evaluation of image quality did not reveal the cause of the deviation.

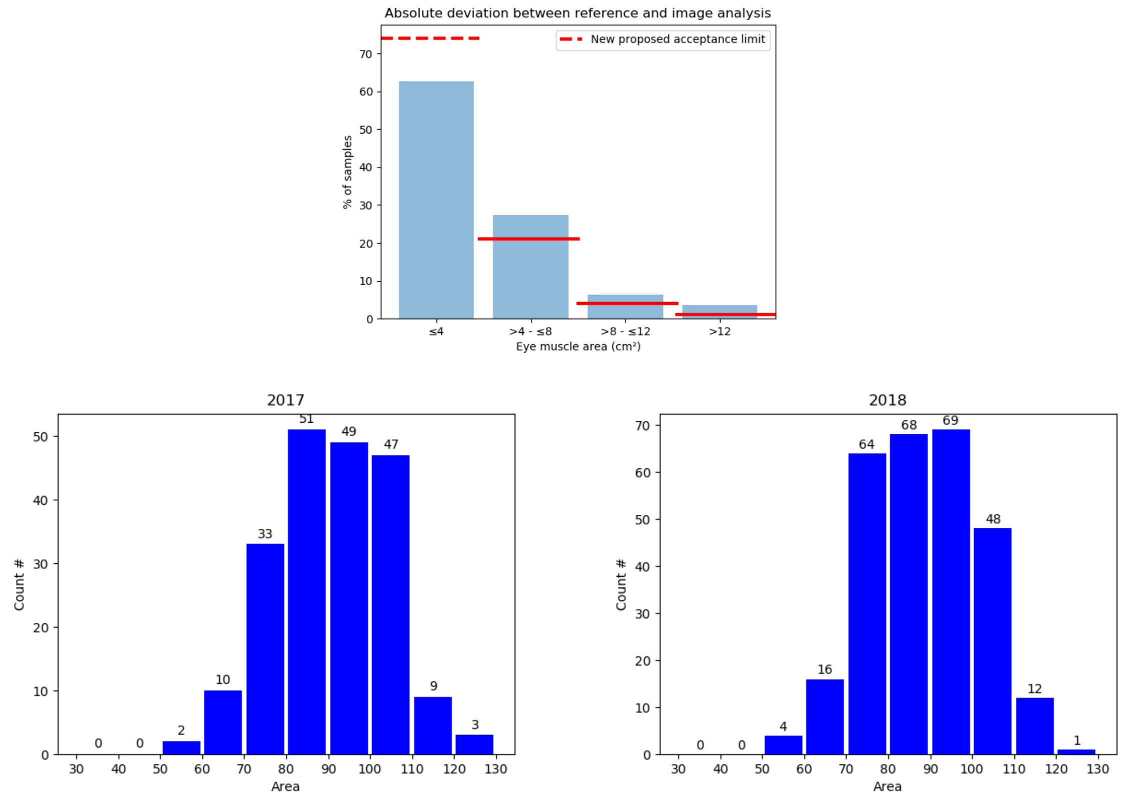


Fig. 2 Performance of the handheld cameras ability to grade ribeye area on the bias-slope corrected validation results according to the AUS-MEAT accreditation criteria (top) (N=282 carcasses). The histograms shows the distribution of ribeye area in the data sets used for calibration (2017) and validation (2018).

Fig. 2 also shows that the data used for development of the ribeye area algorithm was comparable to the ribeye sample distribution of the validation data set.

## 4.2 MSA and AUS-MEAT marbling

Ribeye marbling was assessed visually according to the MSA marbling system and the AUS-MEAT marbling system by a grader and the results were used as reference when developing the algorithm. The AUS-MEAT Marbling system provides an indication of the amount of marbling in beef ribeye. The MSA marbling system provides an additional indication of distribution and piece size.

The automated camera solution showed high precision in determining the MSA marbling score with a squared correlation of 0.75 and a RMSE of 65 marbling score points using the marbling score provided by the grader as reference.

Fig. 3 shows the performance of the automated camera solution in relation to the Australian Language and Standard Committee approval criteria for marbling classification.

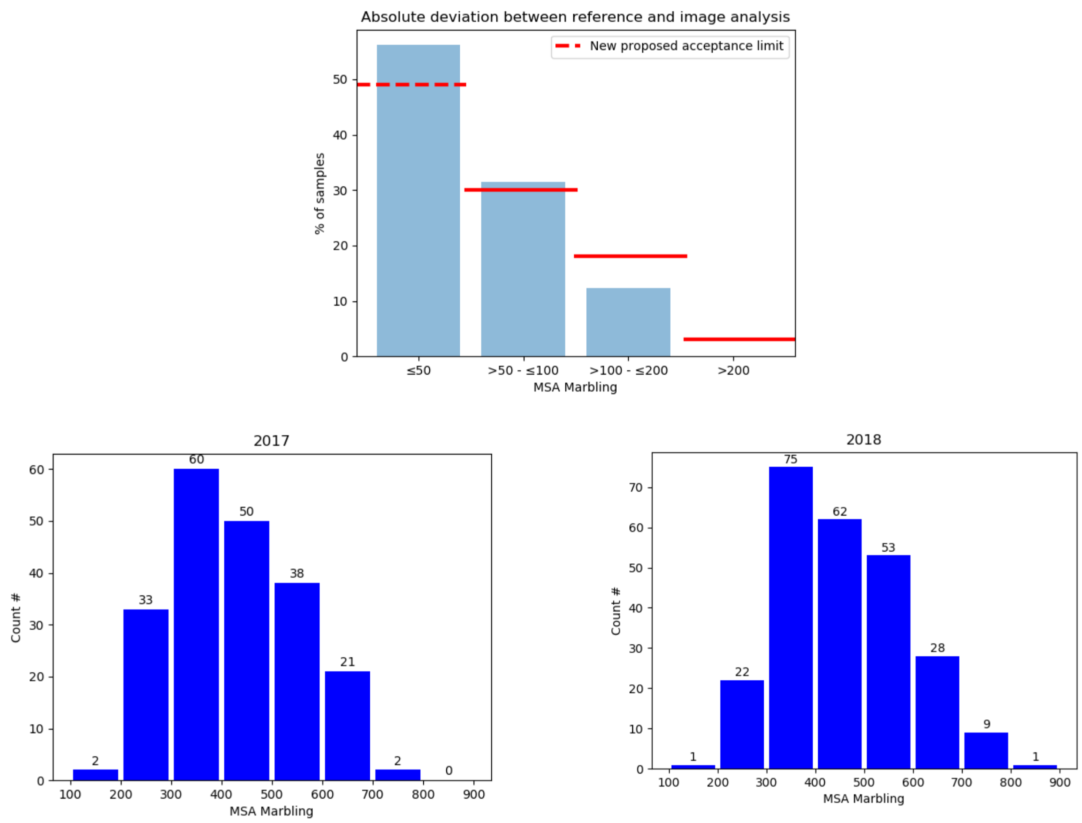


Fig. 3 Performance of the handheld cameras ability to grade MSA marbling score on the bias-slope corrected validation results according to the AUS-MEAT accreditation criteria (top). The histograms shows the distribution of MSA marbling scores in the data sets used for calibration (2017) and validation (2018).

The results obtained for MSA marble score obtained with the automated camera solution is very promising. The percentage of carcasses with less than 50 MSA marble score points from the expert grader exceeds 49% which are defined as the minimum requirement in order to fulfill the Language and Standard Committee approval criteria for ribeye grading (Fig. 3). Only a few samples exceeds the red solid line for samples deviating between 51 to 100 MSA marble score points from the expert grader and no samples exceeds the limit of the two remaining groups. No samples deviated more than 200 MSA marble score points from the expert grader. Fig. 3 also shows that the data used for development of the MSA marble score algorithm was comparable to the validation sample distribution.

The camera solutions ability to classify beef ribeye samples according to AUS-MEAT marble scores showed slightly poorer performance as the percent of carcasses deviating with ± 1 and above AUS-MEAT marble scores were too high compared to the approval requirement (Fig. 4). The algorithm must be further developed to be able to pass the accreditation criteria.

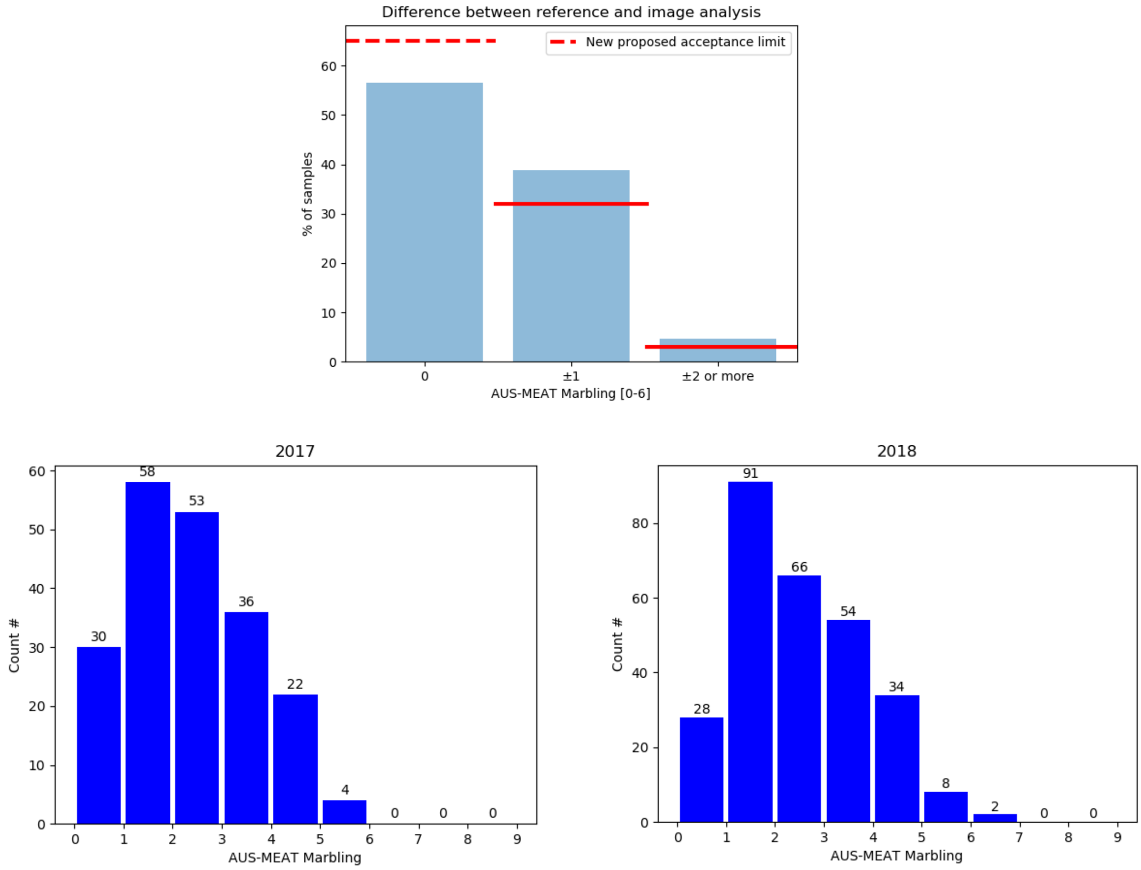


Fig. 4 Performance of the handheld cameras ability to grade according to AUS-MEAT marbling score on the validation results according to the AUS-MEAT accreditation criteria (top). The histograms shows the distribution of AUS-MEAT marbling scores in the data sets used for calibration (2017) and validation (2018).

Fig. 4 also shows that the two data populations used for development of the algorithm and as independent validation data set are comparable and therefore does not contribute to the observed differences between the determined AUS-MEAT marble score by the image analysis system and the grader.

## 4.3 Intramuscular fat (IMF)

Chemically analysed intramuscular fat content is not part of the approval criteria for automated ribeye grading equipment but in the current project (P.PSH.0776) the ability of a handheld camera solution to determine the intramuscular fat content has been a focus area.

The automated camera solution showed high precision in determining the intramuscular fat content with a squared correlation of 0.79 and an RMSE of 1.7 % using NIR analysis as a reference (Fig. 5). The lab-based NIR device was calibrated against a Soxhlet analysis.

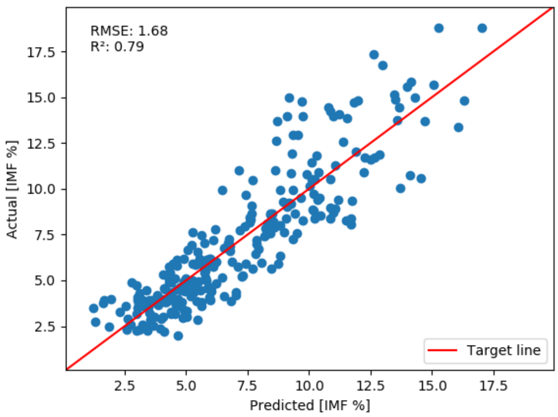


Fig. 5 Bias-slope corrected validation results of intramuscular fat (IMF) content determined by Image analysis software version 3 plotted against the IMF content determined by NIR spectroscopy (reference) (N = 267).

The intramuscular fat content of ribeye samples collected during 2018 ranged from 2-19% with an average IMF content of 7.1% and a standard deviation of 3.7%. The obtained prediction error should be evaluated in relation to the standard deviation of the data in order to decide if the performance is sufficient for the algorithm to be used for beef ribeye sorting in a practical setting.

## 4.4 Meat colour

Meat colour is the predominant colour of the ribeye muscle. Meat colour is visually assessed after blooming the rib eye muscle area and is scored against the AUS-MEAT meat colour reference standards ranging from class 1A – 6. Fig. 6 shows that the distribution of meat colour scores in the calibration (2017) and validation (2018) data sets are comparable, although the calibration data set showed more evenly distrubtion of meat colour class 2 and 3 compared to the validation data set. No class 1A samples were included in either of the two data sets and class 6 meat colour only contained a single sample in the validation dataset.

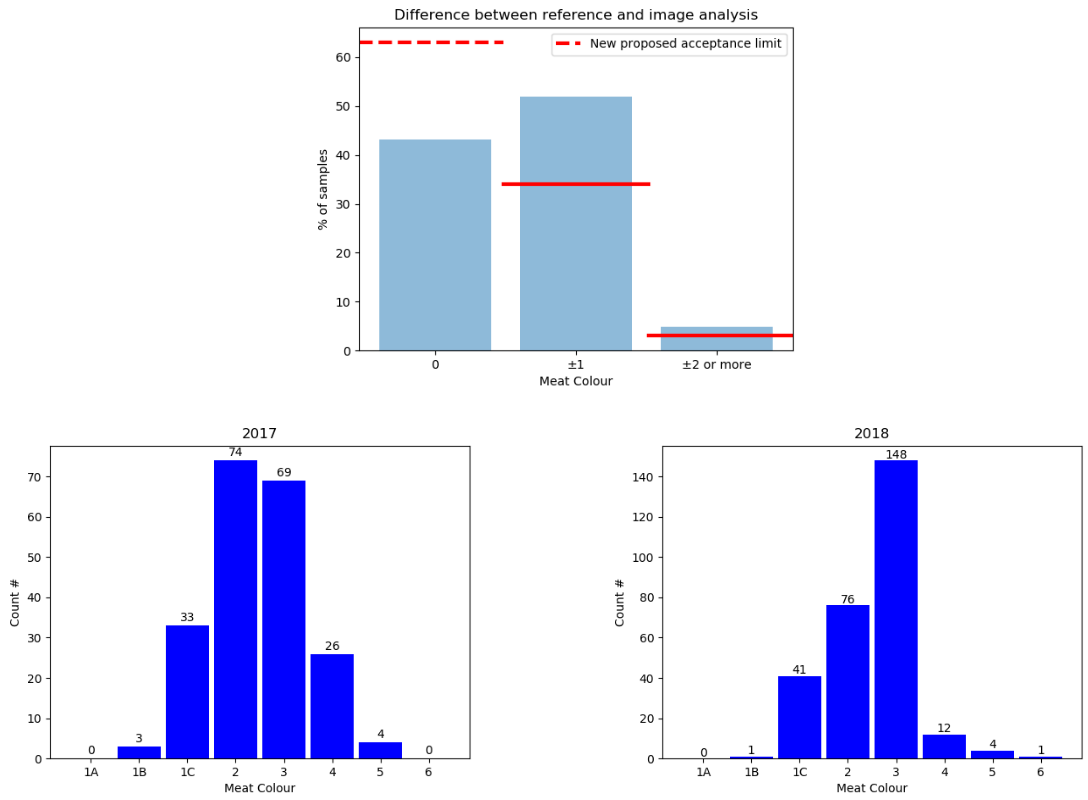


Fig. 6 Performance of the handheld cameras ability to grade according to Meat colour scores on the validation results according to the AUS-MEAT accreditation criteria (top). The histograms shows the distribution of Meat colour scores in the data sets used for calibration (2017) and validation (2018).

The camera solutions ability to classify beef ribeye samples according to meat colour class is not yet acceptable for proceeding to an approval trial and more work is needed before it will be ready to pass the AUS-MEAT approval criteria requirements for this trait. According to the approval criteria 63% or more of the samples must obtain the same meat colour class as the expert graders result. Fig. 6 shows that the currently implemented image analysis software is producing too many results which are deviating ± 1 colour class from the expert grader. However, only few samples are exceeding the limit for ± 2 colour classes or more from the expert grader.

## 4.5 Fat colour

Fat colour is determined at the intermuscular fat lateral to the rib eye muscle. It can be assessed on the chilled carcasses and visually scored against the AUS-MEAT fat colour reference standards ranging from class 0 (white) to class 8 (dark yellow). Fig. 7 shows the distribution of fat colour classes in the two reference datasets collected during 2017 and 2018. It can be seen that the selected carcasses did not represent any fat colour classes above class 4. In addition, the carcasses selected during 2017 which were used to develop the fat colour algorithm had a very narrow distribution and was not comparable to the distribution obtained during 2018.

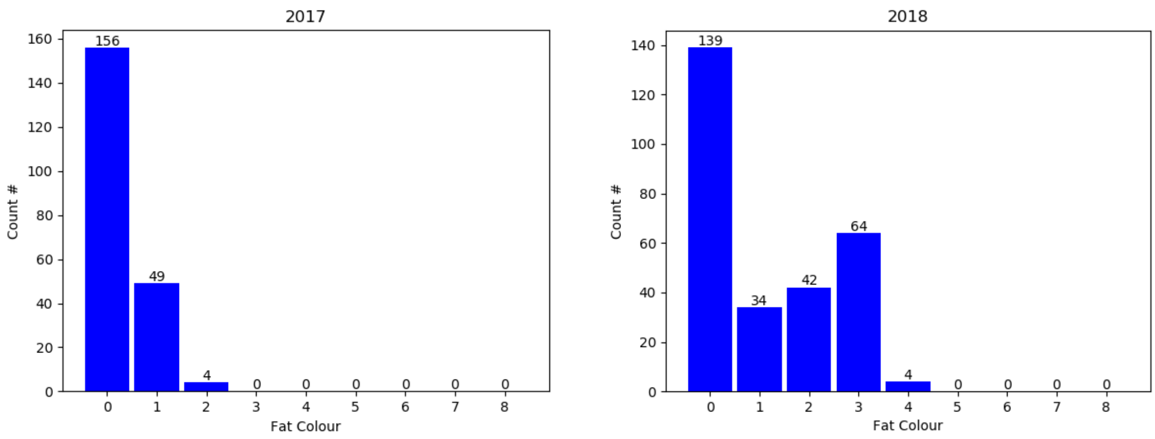


Fig. 7 The histograms shows the distribution of Fat colour classes in the data sets used for calibration (2017) and validation (2018).

Due to the severely skewed distribution towards low fat colour class score of 2017 calibration samples and the fact that fat colour class 0 and 1 alone contain sample counts suitable for modelling, development of a fat colour model useful for validation with 2018 image data covering additional colour classes was not possible.

# 5 Discussion

## 5.1 Handheld grading device

The beef ribeye images in the current project have been captured under commercial abattoir conditions using a handheld camera prototype. The commercial conditions have produced images of varying degrees in quality caused by inconsistent quality of carcass presentation and ribbing as well as operator handling challenges. It is clear from the project work that processing factors and operator factors play a critical role in the performance of the camera. Some of these factors are inaccurate camera positioning (Fig. 8, top left), uneven cut surface due to quartering (Fig. 8, top right), presence of residues on meat surface (including drip) (Fig. 8, bottom left), discolouration of meat surface due to water/drip (Fig. 8, bottom right). All of these factors will affect the image analysis software´s ability to correctly classify the individual ribeye traits.

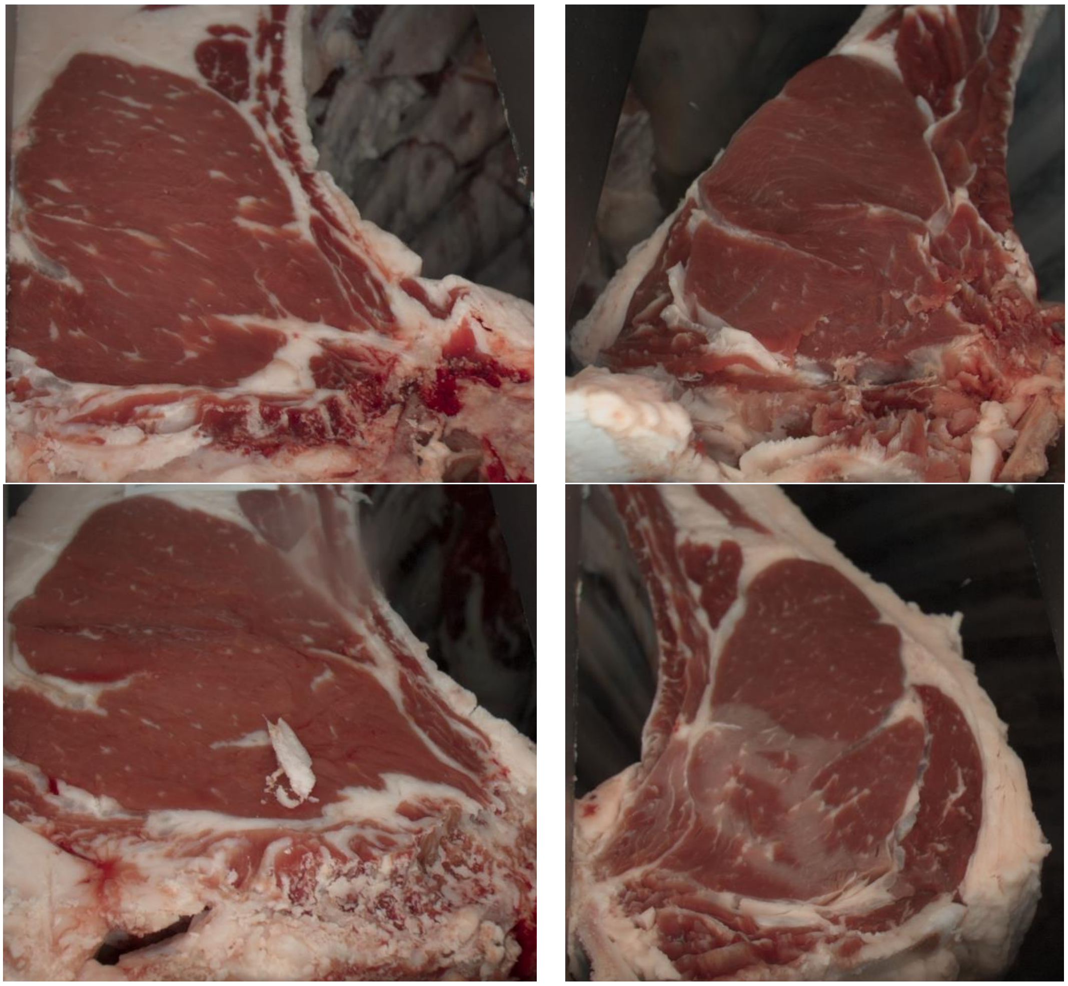

Fig. 8 Representative images resulting from inaccurate camera positioning (top left), uneven cut surface due to quartering (top right), presence of residues on meat surface (including drip) (bottom left), discolouration of meat surface due to water/drip (bottom right).

Based on manual inspection of the images captured in 2018, positioning of the camera by the operator clearly poses a problem. Of the images captured for 556 carcasses a total of 28% showed imperfect positioning to an extent that impacts one or more of the grading traits. The errors can be divided into three main categories:

- Smaller or larger areas of the ribeye muscle being outside the imaging area, leading to incorrect estimation of the ribeye area and possibly impacting marbling scores as well.
- Too little or no fat visible above the ribeye muscle area for fat colour estimation according to the specified standard.
- Parts of the rib fat being outside the imaging area, making it impossible to estimate either total or subcutaneous rib fat thickness.

On a final note, both fat and meat colours may also be impacted by inconsistent illumination caused by imperfect positioning.

Uneven ribeye and rib cut surface impacts illumination of the surface and affects the precision of the classification.

When inspecting the obtained colour data for the 2017 images included in fat colour class 0 and 1, the within-class colour variation exceeds the between-class colour variation and consequently the two fat colour classes cannot be separated. Several factors may lead to this result, among which inconsistent illumination most likely play a significant role and the reduced size of the area selected for determination of fat colour between image analysis version 2 and 3 may also impact the colour. Varying illumination relates to the remaining inconsistency in positioning of the camera, and the reduced area for fat colour determination is the result of an attempt to more closely mimic what the graders are doing.

Fig. 9 No presence of fat in the image due to incorrect positioning of the shroud during image capture.

Fig. 9 shows the influence of incorrect positioning of the shroud. It leads to complete absence of the intermuscular fat area in which fat colour is evaluated. Therefore, the fat colour class cannot be correctly evaluated.

## 5.2 Approval trial

In the present project two expert graders have been assessing the beef ribeye samples. Visual evaluation by trained graders are known to be exposed to inaccuracies caused by grader-to-grader variation and within grader variation (drift over a day). However, the graders evaluations were not compared on the same samples. It is therefore not possible to evaluate the graders contribution to the reported prediction errors. It is likely that reference values obtained using objective measurements would have decreased the prediction errors. However, currently AUS-MEAT approval criteria are based on visual grading.

During an AUS-MEAT approval trial the requirements would be that at least three graders would independently grade the carcasses.

Furthermore, images should be captured on the same samples with three cameras and multiple images should be captured with the same camera to allow for reproducibility and repeatability checks. In the current project reproducibility and repeatability tests were also conducted and some variation between the camera prototypes did appear.

New approval criteria for automated ribeye grading equipment has been approved by the Language and Standards Committee. The criteria describe for each ribeye trait the minimum percentage of carcasses which must be similar to the expert grader and only deviating with a small margin. It also states the maximum acceptable percentage of carcasses with a larger deviation between the camera result and the expert grader result.

## 5.3 Challenges discovered in relation to beef ribeye grading

Table 1 lists the challenges experienced during the project (P.PSH.0776) and establish possible solutions to those challenges.

Table 1. Overview of challenges discovered in relation to beef ribeye grading by a handheld camera device and suggestion for possible solutions.

| Challenge | Possible solution |
|---|---|
| Positioning of camera | Training of operators in correct handling and positioning of the camera during image capture.<br>Ensure that the cut is sufficiently deep.<br>Raise a flag in the software when captured images will not allow calculation of all traits. |
| Uneven cut surface | Training and instructing the operators regarding cut quality for image capturing may alleviate the problem. |
| AUS-MEAT standards<br>• Subcutaneous rib fat thickness<br>• Fat colour | <br>Measure only total fat thickness and not subcutaneous rib fat thickness<br>If the fat area above the ribeye used for measuring fat colour is too small the fat colour evaluation can be based on the exterior fat tissue along the cut rib surface. |
| Hide puller damage | Software flag for hide puller damage – no result is given for total fat thickness. |

# 6 Conclusions/recommendations

In conclusion Image analysis software version 3 has shown that algorithms for ribeye area, intramuscular fat content, marbling score against both MSA and AUS-MEAT classification and meat colour can be developed. Development of an algorithm for fat colour classification awaits a data set which covers a larger spread in colour classes with each class properly represented. Subcutaneous rib fat thickness cannot be determined by the camera solution. An alternative to subcutaneous rib fat would be total fat thickness. This trait is feasible but not part of the AUS-MEAT standard and reference for this trait was not obtained in the project.

Based on the learnings from the current project Frontmatec intends to develop a commercial device after completion of P.PSH.0776.

# 7 Key messages

- The handheld rib eye camera developed by Frontmatec determines ribeye area, marbling score and chemical intramuscular fat with high precision
- Subcutaneous rib fat thickness will not be included in the image analysis software
- A data set covering a larger spread in fat colour classes is needed to develop algorithms for fat colour classification
- The new AUS-MEAT accreditation standards for camera devices are critical for the success of automated ribeye grading
- Ensure consistent rib eye grading results and eliminate any potential subjective influence on payment to farmers through development of automated grading equipment