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Technical Report

Program and KPI: Program 3 KPI 2.30 - Pre-commercial prototype robotic sorting

Report Title: Summary report on livestock offal inspection and sortation with multi-sensor platforms in abattoirs [V.RDP.2000 Phase 1 Part 3]

Prepared by: Dean Gutzke [Meat & Livestock Australia]
Luciano González; Alessio Cotticelli; Cassius Coombs; Xiuying Wang; Yichao Hao; Jingwen Guan; Garth Tarr; Neil Horadagoda [The University of Sydney]
Brendan Allman [Rapiscan Systems]

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Ruberg, C., Morton, E. (2020) Summary Report on the development of prototype robotic sorting systems for offal or carcase down-grading or condemnation. An Advanced livestock measurement technologies for globally competitive Australian meat value chains project.

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Abstract

This program developed a multi-sensor platform combining multi-energy X-ray (MEXA) with visible and shortwave infra-red (SWIR) hyperspectral camera data and associated algorithms to automatically detect and sort cattle and sheep organs with defects in abattoirs.

The program was a collaboration between MLA, Rapiscan Systems and The University of Sydney. A multi-sensor platform, software and algorithms were developed as a proof-of-concept to detect defects in organs. The system developed was able to detect organs with defects with an average accuracy of greater than 90% in specific beef offals. The platform seems promising for the automatic detection of defects in organs.

In the next phase, an industry consultation working group comprising of processor representatives and technical experts, including Australian Meat Inspection Services technical representatives shall be consulted. A small consultative working group is scheduled at the conclusion of the extensive validation work at The University of Sydney, Camden pilot plant facility. A prototype demonstration and update of the validation findings will be presented to the industry consultative group to seek input in the potential applications of the developing technology. Other developing objective measurement technologies currently under concurrent review (including P&P Optica technology through project P.PSH.1350) will also be considered for pre-commercial considerations and recommendations for the next phase.

At the conclusion of the USyd pilot plant demonstration, willing processor participants (1 to 3 plants) will be invited to participate in a series of pre-commercial demonstrations at a beef processing pilot plant(s). It is proposed that more detailed feedback will be sought on potential applications of the pre-commercial prototype technology. These pre-commercial trials will be staged over period to collate the maximum amount of input from processors and technical industry experts on potential applications on offal disease detection methods using the Rapiscan pre-commercial solution.

Future work should use larger datasets to validate and strengthen the algorithms. The algorithms could also be improved using shape analysis in addition to spectral information and using both the spectral data with the X-ray data by the same algorithms.

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Executive Summary

This project developed and evaluated the pre-commercial multisensory platform and associated algorithms to process the data for the detection of defects in beef and sheep organs screening. The hyperspectral data provides detailed information on the surface whereas the X-ray penetrate tissues providing information inside the organs. The focus will be on the detection of defects in beef liver, lungs and kidneys with health issues (hydatids, abscesses and fluke). This program forms part of the overall ALMTech program 3 (project V.RDP.2000 Phase 1 Part 3) to deliver advanced measurement technologies for globally competitive Australian meat value chains. Specifically, this Part 3 evaluated the use of a multi-sensor imaging platform comprising dual-view multi-energy X-ray imaging (MEXA), visible (VIS) waveband hyperspectral camera imaging and short wave infra-red (SWIR) hyperspectral camera imaging at the USyd Camden pilot facilities on pre-commercial beef offal sortation solutions.

Normal and abnormal organs have been acquired from abattoirs, scanned by the multi-sensor system, and then histopathological inspection performed by expert veterinarians. Organs were considered abnormal (diseased or sick) first at veterinary inspection in the abattoir which are taken off the consumption chain and discarded, and then confirmed by histopathological inspection at the Veterinary teaching Hospital of The University of Sydney. Data collected was then used to develop various algorithms for the automatic detection of abnormal organs using various machine learning and deep learning algorithms, both supervised and unsupervised. Automatic identification of defects in both beef and sheep organs using hyperspectral imaging showed up to 92% accuracy. The algorithms developed can work automatically either 'flagging' organs with defects after classification, or showing an image with coloured regions where the anomaly is detected, which could assist indpectors for further inspection.

In the current work on beef offal disease detection (Phase 3), it can be concluded that, at this stage, multi-energy X-ray technology can be used to aid inspectors in the abattoir and infer the presence of potential lesions and their location within organs. However, the data collected at this preliminary phase was not useful for algorithm development required automatise the detection. This may require further refinement to the intensity of the X-ray bands and the distance between them.

In addition, X-ray can determine whether an organ of interest (i.e. by abnormal thickness upon palpation or discolouration) is too dense compared to healthy organs within the image library if this is expanded to have more organs, with appropriate thresholds for acceptance or rejection confirmed. In the future, disease processes could be identified by X-ray imaging once there is a significant amount of marked-up data with information from several lesions. A larger trial with more samples encompassing multiple disease processes would benefit the image library and the algorithms that can be developed for detection of diseases within organs. In contrast to X-ray data, the hyperspectral data from both VIS and SWIR regions showed a great potential for automated anomaly detection of both beef and sheep organs. This seems a more feasible solution in the short term if full automation is sought. It is hoped that when these diseases are identified and diagnosed, detailed health reports can be sent to producers in real time, and the risk of cross-contamination can be mitigated by the avoidance of invasive procedures to perform differential diagnoses of potential diseases.

Both trials showed promise for multi-energy X-ray sensors to be installed in commercial abattoirs to be an accompaniment to meat and offal inspectors, although replacement of the inspectors is

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not recommended at this stage. A collection of significantly more data from several species, organ types, and disease pathologies is warranted. In the time since the trials were conducted, the multi-sensory platform has undergone changes to improve offal throughput including optimising the rollers and protective lead shielding, and automation of image analysis to see a scanned organ in real-time and determine if a second scan is necessary, and allowing for longer projection times in order to scan more than one organ in succession.

From earlier phase 2 work (V.RDP.2018), visible and short-wave infrared hyperspectral imaging can be used to determine the disease status of sheep organs, with this pilot study proving that classification accuracy was adequate overall and was particularly successful for livers and hearts. However, it is worth noting that the diseases were often identified with the naked eye, palpation, or were presented as discoloured to abattoir inspectors. Future studies could use HS imaging, alone or in combination with other technologies such as multi-energy X-ray or CT, to identify specific pathologies within individual organs and their locations. However, they would need to use more samples, particularly those presenting similar lesions.

This could be very beneficial for the meat processing and veterinary medicine industries, particularly if HS is combined with deep learning algorithms. Hyperspectral imaging technologies are non-invasive and non-contact, with the potential to enable automatic sorting of livestock organs and disease detection in the abattoir, allowing animal health reports to be provided for producers.

From this research, it is concluded that the novel spectroscopic sensors evaluated are promising to classify organs by type and disease status. However, larger datasets and refinement of the methodology are required to validate these exploratory results, such as number of scans and ROI required for repeatability, and selection of specific regions with defects within an organ. This may provide greater accuracy, precision, sensitivity, and specificity metrics to support subsequent deployment of multi-sensory imaging platforms containing VIS and SWIR HS sensors in the meat industries.

Program 3 was successful in achieving its outcomes for 2.30 to develop and report on the pre-commercial algorithms for use in a prototype robotic sorting system in beef and lamb offals.

Further research should focus on developing an automated workflow for analysis, detection, and sortation of products. It is worth noting that installation of larger multi-sensory platforms would provide greater long-term benefits despite the upfront cost due to their ability to provide valuable information on the verification of feeding regime, health assessment, and organ identification without making contact with samples. Further testing of both X-ray and HS imaging within the multi-sensory platform on larger datasets can extend to predicting chemical composition such as fat and protein contents of meat samples. It is therefore concluded that the novel sensors explored in these appendices have enormous potential to automate the offal sortation and inspection processes that take place in the meat processing industry and afterwards such as retail.

In the next phase, an industry consultation working group comprising of processor representatives and technical experts, including Australian Meat Inspection Services technical representatives shall be consulted to seek input in the potential applications of the developing technology.

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1 Introduction

The post-mortem inspection process of livestock viscera at abattoirs is expensive and laborious, but it is essential for the detection and condemnation of defective edible organs and carcases due to food safety issues. Lesions in hearts, kidneys, livers, lungs, and their associated lymph nodes are amongst the most common offal defects found in abattoirs.

The automation of the post-mortem meat and animal product inspection and processing in the abattoir has been sought for a long time. One such area of automation has been the sortation of offal based on fitness for human consumption via the detection of defects (including appearance), contamination, or infectious disease. In the abattoir, such examinations are carried out by meat inspectors under the supervision of a veterinarian. This inspection is of vital public health importance due to the removal of potential zoonotic diseases from the processing chain and thereby limiting human exposure. In addition, this inspection has economic benefits in surveillance of diseases and providing feedback to producers, which could be made quicker with automation. These findings highlight the economic benefits of automatic detection and rapid reporting of animal health to producers.

2 Objective

This project developed and evaluated the pre-commercial multisensory platform and associated algorithms to process the data for the detection of defects in beef and sheep organs screening.

3 Multi-sensory scanning system

The first part of the project consisted in developing the hardware and software required for the multisensory platform to collect the data required for the project. The functional requirements of a sensing system to drive robotic systems for sortation of offal for down-grading or condemnation as described below.

i) General Requirements:

- The sensing system shall be designed to operate in a hygienic abattoir environment.
- The sensing system shall be wash-down proof.
- The sensing system shall be designed to meet food safety standards.
- The sensing system shall be designed to meet ARPANSA radiation safety requirements.
- The sensing system shall have a 600mm (W) x 400mm (H) tunnel size.
- The sensing system shall have a conveyor speed of 200mm/s.

ii) Imaging Requirements:

- The system shall be designed with dual-view X-ray imaging. One view shall be directed upwards through the centre of the inspection area. One view shall be directed horizontally through the inspection area.
- The X-ray imaging views shall use 160kV X-ray beam quality with 1.0mA beam current

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- The X-ray imaging views shall use multi-energy X-ray (MEXA) sensors with 0.8mm pitch sensor elements. Each sensor element shall count photons into one of six energy bins with linear X-ray count rate capability up to 10^6 X-rays/mm^2/s.
- A visible wavelength hyperspectral imaging sensor shall operate in the range 400nm to 900nm with spectral resolution of at least 20nm over the full spectral region with pixel size not to exceed 2.0mm across the conveyor width.
- A short wave infra-red (SWIR) hyperspectral imaging sensor shall operate in the range 900nm to 1800nm with spectral resolution of at least 20nm over the full spectral range with pixel size not to exceed 2.0mm across the conveyor width.
- The X-ray, visible and SWIR camera systems shall be synchronised to an X-ray base frequency of 300Hz
- Data from each imaging source shall be transferred to a computer for subsequent real-time visualisation and algorithm analysis

iii) Software Requirements

- The scanning system user interface shall provide the system operator with pass/fail risk indication for all offal items
- The user interface shall include a scrolling image to show offal currently in the X-ray tunnel together with overlaid inspection results from automated health screening algorithms.
- When available, offal data shall be correlated with carcass ID using RFID, QR code, Bar Code or other similar ID technology by linking scanner and central abattoir databases
- Image review tools shall be provided for retrospective analysis of offal samples including both X-ray manipulation and hyperspectral data manipulation tools.
- The software shall meet relevant cyber security standards such as ISO 27001.

iv) Algorithm Requirements

- The system algorithms shall combine X-ray and hyperspectral image data to identify each type of offal as it passes through the scanning system. The target performance shall be 90% correct classification.
- The system algorithms shall provide a risk assessment for each offal item as it passes through the scanning system.
- The system algorithms shall combine image-derived information with other abattoir provided information, such as animal type, age, sex and farming data when available in order to maximise algorithm risk prediction accuracy.
- A total risk score shall be generated as an aggregate of all underlying algorithm risk score results. The total risk score shall be used to generate a pass/fail result.

v) Integration Requirements

- The system shall be capable of interfacing with abattoir database systems to recall information about a specific carcass and to store pass/fail information for each offal item for each carcass.
- The system shall be capable of mechanical integration with abattoir conveying systems to pass offal items through the scanner in a controlled manner.
- The system shall be capable of interfacing with subsequent robotic systems for automatic offal selection and rejection.

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Phase 1 of the project delivered the multisensory scanning platform encompassing hyperspectral (HS) technology and multi-energy X-ray attenuation (Rapiscan Inspection System AK198, Rapiscan Systems Pty Ltd., Torrance, CA) as described in Figure 1. The unit is now in continuous operation by the University of Sydney team.

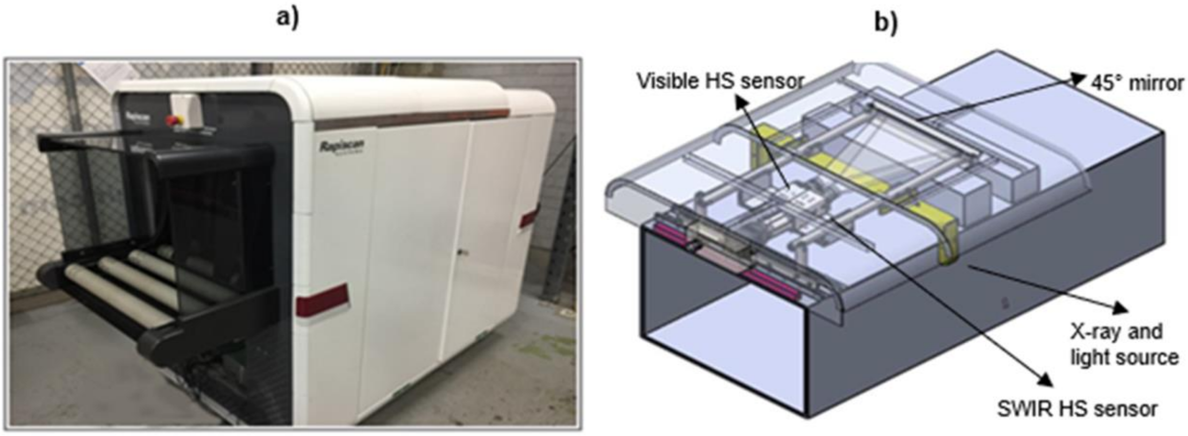

Figure 1. Rapiscan Systems multi-sensory imaging system used to scan beef cattle livers

The multisensory system included:

- a conveyor belt (~0.2 m/s),
- tunnel size = 1360mm L x 630mm W x 400mm H,
- two 160 keV generators (one up-shooter, one side-shooter),
- a cadmium telluride detector (CdTe: 0.8mm x 1.2mm x 2mm)
- 20 data acquisition boards (DABs) – 11 for up-shooter view and 9 for side-shooter view (112 pixels per board),
- acquisition rate 300Hz in six energy bands in the range 20-160 keV,
- Hyperspectral cameras
    - Visible/IR (450nm-900nm), in 300 wavelength bands,
    - SWIR (900nm-1700nm), in 512 wavelength bands,
    - Acquisition rate 30Hz – 150Hz depending on image resolution/size and to scale to X-ray image capture.
- run by an Ubuntu (Linux) Cube computer program, which controlled exposure time, image size, and acquisition rate.

The multi-sensor system was commissioned at the University of Sydney Camden Campus in May 2020. The self-contained scanning system is not abattoir compatible and so currently needs to be used with samples in sealed trays to avoid the requirement for washdown.

Figure shows the system immediately after installation. Samples are loaded from the left, pass through the scanner and emerge from the right-hand side of the equipment. Figure 3 shows the complete installation in the laboratory at the University of Sydney.

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Figure 2. Photograph of the multi-sensor system once installed at the University of Sydney.

Figure 3. View of the installed system with the side-shooter X-ray view just visible to the left of the main system enclosure.

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4 Findings on dual sensing pre-commercial prototype

4.1 X-ray data

X-rays are a form of electromagnetic radiation (0.1-10 nm, 100 eV to 100 keV) characterized by higher energy than visible light (380-700 nm, 2 to 2.75 eV), meaning it can pass through most objects, including the body. Medical x-rays are used to generate images of tissues and structures inside the body. X-rays travel through the body and are absorbed in different amounts by different tissues, depending on the radiological density of the tissues they pass through. The image is formed by passing through the tissue and the remaining not absorbed by tissue being captured by a detector on the other side of the generator represented by the "shadows" formed by the objects inside of the body. Radiological density is determined by both the density and the atomic number of the material being imaged. The higher the atomic number of the tissue being imaged the higher the absorption of the rays and the higher is the contrast produced on the detector. For example, the bone structures will appear darker than other tissues. Conversely, less radiologically dense tissues such as fat, muscle, and air-filled cavities will ease the penetration of the X-rays and will be displayed in lighter shades of grey on a radiograph.

The aim of the present trial was to evaluate the potential of X-ray technology on the detection of the pathologies of foodborne concern. Among the fifty-two livers rejected for human consumptions scanned in Trial 1, we found 32 with various degrees of discolouration (focal and multifocal, located in the different lobes, extended and local), 7 abscesses, 5 ducts thickening, 4 fibrosis, 2 flukes and 2 cysts. Therefore, discoloration not accompanied by a change in tissue density is not expected to be captured by X-ray absorptiometry as it was the case in the present study. The X-ray data was expected to present a unique advantage to 'see' inside the organ and detect other lessions not visible in the surface. However, this did not seem to be consistent in the present study. There are several potential reasons for this, including the X-ray energy of the device used in the present trial being too strong or being too far apart from each other. However, it would be important to evaluate the images with meat inspectors and large number oforgans in a commercial setting because these images could provide value to them even without any further modification (e.g. helping t decide with further inspection and cutting the organ for confirmation).

Lesions such as abscesses and fluke lead to modifications of the hepatic tissue involving calcification and thickening processes that alter the physiological radiological density of the organ and could be detected through the X-ray images. Trial 2 showed that in lungs, a less dense tissue than livers, abscesses and CLA lesions were much more easily noticeable. Visual and X-ray intensity comparisons showed differences between livers, kidneys and lungs other than their size and shape.

Soft tissue abscesses are focal or localized collections of pus caused by bacteria or other pathogens surrounded by a peripheral rim or abscess membrane found within the soft tissues in any part of the body. Even if X-rays are generally of limited value for the evaluation of a soft tissue abscess, they might show soft tissue gas or foreign bodies, increasing suspicion for an infectious disease process or reveal other causes for underlying soft tissue swelling.

Fascioliasis or liver fluke is a food-borne hepatic trematode zoonosis, caused by Fasciola hepatica and Fasciola gigantica. F. hepatica is a flat, leaf-shaped hermaphroditic parasite. Radiological findings can often demonstrate characteristic changes, and thereby, assist in the diagnosis of

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fascioliasis. The early parenchymal phase of the disease may demonstrate subcapsular low attenuation regions in the liver.

In Trial 1, the X-ray technology did not seem to recognize the shape of the lesions, though the images described various degrees of modifications of the hepatic pattern depending on the lesions found. For each liver scanned, an area of interest was marked based on the macroscopical aspect of the organ and the mark-up was then confirmed during the post-mortem inspection. By the lesion marked, the six radiographs displayed lighter shades of grey when compared to the healthy tissue. The hepatic lesions caused by the pathologies observed (i.e., duct thickening, calcification, etc.) weren't accurately recognized by the radiographs, the technology was only capable of showing unusual shades of grey by the marked-up areas.

The purpose of this report was to show the potential for multi-energy X-ray to differentiate organs in a simulated abattoir setting and to present X-ray images compared with whole and dissected photographic images of the same organs, with markings and notes to inform the data science team who will develop the algorithms to differentiate the lesions upon the X-ray images compared with the corresponding region of interest upon healthy organs.

The livers from cattle significantly larger than sheep, and with several presenting noticeable lesions indicative of disease processes. The images within Trial 2 were of mixed species (mostly sheep) and organ type, with lamb pluck X-rays showing differences in density for different types of organs, while the bovine livers were shown to be significantly denser than ovine livers, and a Wagyu liver was shown to be denser than a non-Wagyu liver. Therefore, the size of the tissue or organ being scanned may influence the ability of the X-ray sensor to detect differences of abnormal tissues. It is possible that the region and distance between the X-ray images has to be tailored for different animal species.

Trial 2 showed that when a lesion is visible to the naked eye, or tissue abnormalities are felt via palpation, prior to sectioning, an X-ray image can discern its shape and further information without requiring sectioning. However, when an organ is simply discoloured or there is some subliminal evidence of disease process due to an overly thick surface such as liver fluke deep within a large bovine liver or capsular fibrosis, the X-ray images cannot be marked and therefore intensity histograms from a given ROI would be the optimal method to determine whether an organ can be passed as fit for human consumption or not.

4.2 Hyperspectral data

Hyperspectral (HS) imaging, in the form of two sensors within the multi-sensory platform, is a non-contact technology encompassing the visible spectrum (400-900 nm) and short-wave infrared spectrum (900-1700 nm). The HS images generated from frame-by-frame slices of a hypercube within a region of interest (ROI) are surface-based and can detect differences in spectral signatures within different products such as organs, meat, and agro-food products.

These spectral signatures are extracted from given ROI across each sample, and can be compared and contrasted with one another using machine learning modelling techniques such as partial least squares discriminant analysis, random forest and artificial neural networks. As a non-contact, non-destructive classification tool, HS has shown tremendous promise in classifying organs by organ type, and determining whether an organ of a particular type is diseased (see Appendices A-C; Chapters 9-11 in the primary report). Various algorithms were developed in the

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present project with the potential to be integrated with the multisensory platform meaninglessly. The high accuracy achieved for both beef and sheep suggest that further evaluation and refinement of the algorithms with larger datasets could aid to finalise a prototype system for commercial deployment. However, the scanner should also be modified to be able to withstand the wet conditions of an abattoir.

5 Conclusion and recommendations

5.1 Conclusion

The program was a collaboration between MLA, Rapiscan Systems and The University of Sydney. A multi-sensor platform, software and algorithms were developed as a proof-of-concept to detect defects in organs. The system developed was able to detect organs with defects with an average accuracy of greater than 90% in specific beef offals. The platform seems promising for the automatic detection of defects in organs.

It can be concluded that, at this stage, multi-energy X-ray technology can be used to aid inspectors in the abattoir and infer the presence of potential lesions and their location within organs. However, the data collected this far was not useful for algorithm development required automatise the detection. This may require further refinement to the intensity of the X-ray bands and the distance between them. In addition, X-ray can determine whether an organ of interest (i.e., by abnormal thickness upon palpation or discolouration) is too dense compared to healthy organs within the image library if this is expanded to have more organs, with appropriate thresholds for acceptance or rejection confirmed. In the future, disease processes could be identified by X-ray imaging once there is a significant amount of marked-up data with information from several lesions.

A larger trial with more samples encompassing multiple disease processes would benefit the image library and the algorithms that can be developed for detection of diseases within organs. In contrast to X-ray data, the hyperspectral data from both VIS and SWIR regions showed a great potential for automated anomaly detection of both beef and sheep organs This seems a more feasible solution in the short term if full automation is sought. It is hoped that when these diseases are identified and diagnosed, detailed health reports can be sent to producers in real time, and the risk of cross-contamination can be mitigated by the avoidance of invasive procedures to perform differential diagnoses of potential diseases.

Both trials showed promise for multi-energy X-ray sensors to be installed in commercial abattoirs to be an accompaniment to meat and offal inspectors, although replacement of the inspectors is not recommended at this stage. A collection of significantly more data from several species, organ types, and disease pathologies is warranted. In the time since the trials were conducted, the multi-sensory platform has undergone changes to improve offal throughput including optimising the rollers and protective lead shielding, and automation of image analysis to see a scanned organ in real-time and determine if a second scan is necessary, and allowing for longer projection times in order to scan more than one organ in succession.

From earlier phase 2 work (V.RDP.2018), visible and short-wave infrared hyperspectral imaging can be used to determine the disease status of sheep organs, with this pilot study proving that classification accuracy was adequate overall and was particularly successful for livers and hearts.

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However, it is worth noting that the diseases were often identified with the naked eye, palpation, or were presented as discoloured to abattoir inspectors. Future studies could use HS imaging, alone or in combination with other technologies such as multi-energy X-ray or CT, to identify specific pathologies within individual organs and their locations. However, they would need to use more samples, particularly those presenting similar lesions.

From this research, it is concluded that the novel spectroscopic sensors evaluated are promising to classify organs by type and disease status. However, larger datasets and refinement of the methodology are required to validate these exploratory results, such as number of scans and ROI required for repeatability, and selection of specific regions with defects within an organ. This may provide greater accuracy, precision, sensitivity, and specificity metrics to support subsequent deployment of multi-sensory imaging platforms containing VIS and SWIR HS sensors in the meat industries.

This could be very beneficial for the meat processing and veterinary medicine industries, particularly if HS is combined with deep learning algorithms. Hyperspectral imaging technologies are non-invasive and non-contact, with the potential to enable automatic sorting of livestock organs and disease detection in the abattoir, allowing animal health reports to be provided for producers.

Program 3 was successful in achieving its outcomes for 2.30 to develop and report on the pre-commercial algorithms for use in a prototype robotic sorting system in beef and lamb offals.

5.2 Recommendations and next steps

In the next phase, an industry consultation working group comprising of processor representatives and technical experts, including Australian Meat Inspection Services technical representatives shall be consulted. A small consultative working group is scheduled at the conclusion of the extensive validation work at The University of Sydney, Camden pilot plant facility. A prototype demonstration and update of the validation findings will be presented to the industry consultative group to seek input in the potential applications of the developing technology.

A detailed economic feasibility was developed and shared with an industry consultation group at the conclusion of Phase 2 (project V.RPD.2018). This will be re-visited as part of the overall consultation process to ensure the assumptions on the value propositions and potential applications are continuously being evaluated.

Other developing objective measurement technologies currently under concurrent review (including P&P Optica technology through project P.PSH.1350) will also be considered for pre-commercial considerations and recommendations for the next phase. At the conclusion of the USyd pilot plant demonstration, willing processor participants (1 to 3 plants) will be invited to participate in a series of pre-commercial demonstrations at a beef processing pilot plant(s). It is proposed that more detailed feedback will be sought on potential applications of the pre-commercial prototype technology. These pre-commercial trials will be staged over period to collate the maximum amount of input from processors and technical industry experts on potential applications on offal disease detection methods using the Rapiscan pre-commercial solution.

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