SENSORS ADAPTED FOR AUTOMATING TASKS IN BEEF AND SHEEP SLAUGHTER

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Abstract

Food Science Australia (FSA) has been developing sensing systems that are suitable for use in automating tasks commonly seen in Australian beef and sheep processing plants. This paper shows some of the imaging and profiling technologies and the issues encountered in implementing these systems in operating plants. Combining the sensing systems with tools or end effectors on robots that can assist in the sensing for some tasks is also discussed.

1 Introduction

There is a need in the Australian beef and sheep processing industries for the development of automated technologies that will enhance the profitability and contribute to the sustainability of production.

Two areas that have hindered automation have been the lack of developed sensing technologies and the variability in the product being measured.

Food Science Australia (CSIRO) has been developing nevel sensor and process control systems for beef and sheep slaughter tasks with an emphasis on automation to reduce costs and meet the challenges posed in sensing in this unstructured environment.

Industrial robots have been used to prove the sensing systems because of their dexterity and ability to be repeatedly modified with minimal financial outlay. The sensing systems developed as part of FSA research have ultimately been applied to adapt industrial robots to perform automated tasks on Australian processing floors.

1.1 Background

FSA investigated existing beef and sheep slaughter processing tasks and divided those tasks into three main categories based on the sensing required [Aust *et al*., 2005].

Category 1 tasks generally involve the sensing of external features with defined boundaries, and as such, can be automated with the use of the key technologies and consideration of materials handling and presentation.

Category 2 tasks generally require the detection of an internal feature or interpolation of an internal feature from reference features on the external surface.

Category 3 tasks fall into three main areas: discrimination of like tissue with undefined structure boundaries; real time tissue boundary discrimination; and contamination detection.

Category 1 & 2 tasks were initially targeted because relevant sensing systems could be based on commercially available equipment, making them more acceptable to industry partners. Category 3 tasks have not yet been addressed.

1.1.2 Production Environment

Sensing in the slaughter environment must contend with the issues of product variation, process floor restrictions and industry acceptance.

1.1.2.1 Product Variation

The Australian beef industry involves a wide variety of animals that are processed in a plant during any shift. Variations in breed, size, colour, sex and condition can, for example, give carcass lengths ranging from 1200mm to 3000mm and hundreds of kilograms differences in weight, making automation very difficult.

Variations in sheep are not as dramatic, and plants usually batch the product based on animal breed and/or age making automation in sheep a more desirable option. However, the condition of the sheep pelt can vary in condition (length, contamination, wet or dry) increasing the complexity of sensing and automation of the early tasks on the production line.

1.1.2.2 Process Floor Restrictions

The development of sensing systems required trialling under normal plant operating conditions. However, it was a requirement of testing at any specified processing plant not to interfere with production, alter existing lighting or interface with the production chain during those trials.

The developed sensing systems were installed and trialled with existing ambient lighting where possible. The systems also made provision for production personnel to move around the sensing equipment.

Due to existing infrastructure in the production environment, it was not always possible to get stereoscopic or orthogonal camera locations to provide the accurate location of a single feature in three dimensions. A combination of finding a feature in two dimensions using imaging and ranging to the surface of the feature using surface profiling was often used to determine the absolute position of a feature in space.

1.1.2.3 Industry Acceptance

To achieve industry acceptance of the research, it was intended that the sensing systems be designed such that it could be retrofitted and successfully demonstrated in existing production plants.

Sensing and analysis for any beef task had to be completed in less than 20 seconds, and sheep tasks needed to be completed in less than 6 seconds to meet current Australian production speeds.

Costs also had to be considered and the financial return of the total automated system had to be judged reasonable by industry.

2 Sensing Systems

Several advanced sensing systems were developed based on the restrictions of each task being considered.

2.1 Imaging Systems

In most slaughter environments, a single source or point of sensing is desired because of the location of existing infrastructure. Imaging from a single source does however restrict the analysed information to two dimensions. The third dimension required for final tool placement then has to be measured by either multiple cameras or other sensing methods.

One advantage of using cameras is that it is a non-contact sensing solution. This addresses one of the major issues in meat production: that of cross-contamination between carcasses by tool contact.

Image capture and analysis generally took much less than 300 milliseconds for each application, reducing the requirements of carcass stabilisation.

2.1.1 RGB Cameras

A colour or monochrome camera was used when surface features were able to be separated from the background.

A backboard (Figure 1) was used to eliminate any background images that may be in the field of view of the camera. However Figure 2 demonstrates that when the feature to be detected (e.g. the RFID tag on the ear) is of similar colour to the background and is difficult to separate, alternate sensing methods should be investigated.

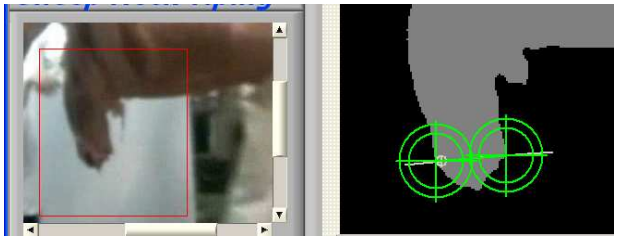


Figure 1: RGB camera used when isolating features from the backgound [Ring, 2006 b]

Figure 2: Detecting ear tags on beef with colour cameras [White *et al.* , 2007]

2.1.2 Thermal Cameras

Thermal cameras - while substantially more expensive than the same resolution RGB cameras - investigate a different spectrum and can provide a more robust solution for some production applications.

Figure 3 compares the detection of the beef hide separation line using colour images with a typical thermal image of the same area.

In the case of a dark hide (Figure 3a), a colour camera could be used to separate the external to internal hide surface (except where the hide was folded back to cover the external surface). Distinguishing the internal surface colour from the external surface of a light coloured hide (Figure 3b), while not impossible, becomes less robust in its application. Colour image processing also requires the added complexity of multiple algorithms to account for differing animal hide colours.

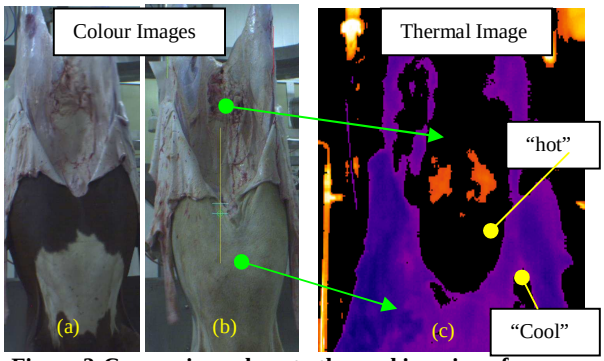


Figure 3:Comparing colour to thermal imaging of a carcass surface [Ring, 2006]

Using a thermal camera gives a clear separation between the internal and external surfaces of the carcass. The thermal image in Figure 3c took advantage of the insulating properties of the hide to separate the "hot"

internal surface from the “cooler” external hide surface. In this case, the flank folded back around the carcass soon lost the “hot” thermal signature as it cooled from being exposed to the open air. The abdominal surface retained the “hot” thermal signature due to the mass of the internal tissues and organs radiating heat for a longer period of time. The colour of the hide is irrelevant to the results of the thermal image.

Thermal cameras were also used to silhouette product on cooler backgrounds that may be contaminated by blood, dirt or other visual interference. Using a thermal camera reduces the problems of occlusions due to the condition of the carcass hide. Figure 4 shows a typical application of carcasses in front of a factory wall with considerable image contamination. The thermal images in Figure 5 demonstrates a robust separation of the carcass from the background irrelevant of the hide colour, or background contaminants.

Figure 4: RGB image showing white carcass against white background [Ring, Aplin, 2006]

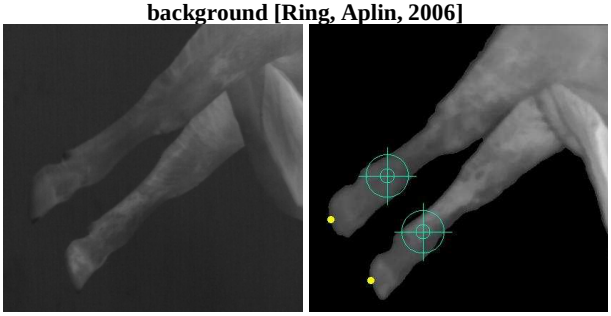


Figure 5:Using Thermal imaging to separate carcass from the background for analysis [Ring, Aplin, 2006]

2.2 Stereovision cameras

Stereo vision was investigated by FSA to determine the location of features on unrestrained animals in three dimensions. The advantage of using stereo vision was the image pair capture rate could be increased up to a possible 25 frames per second.

The biggest challenge for using stereovision is achieving quality stereo pairs. In the meat processing environment it is difficult to enhance target objects sufficiently, to reliably derive corresponding matches of a quality suitable for stereo vision [MacRae *et al*, 2006].

Figure 6 [MacRae *et al*, 2006] shows different feature points were detected by each camera in the pair using the same lighting conditions.

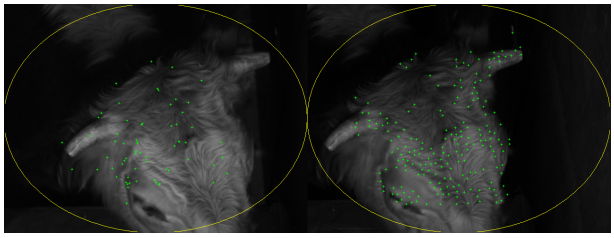


Figure 6: Stereo thermal images showing detected features

2.3 Surface Mapping

To locate features in three dimensions from a single sensing location FSA mapped the surface of the sheep and beef carcasses in different production plants using a SICK LMS400 laser profiling unit.

The SICK LMS400 operating at a scan rate ranging from 200 to 500 Hz [SICK, 2004] collected profiles in the vertical plane. Multiple profiles were collated across the horizontal plane to produce a three dimensional surface model.

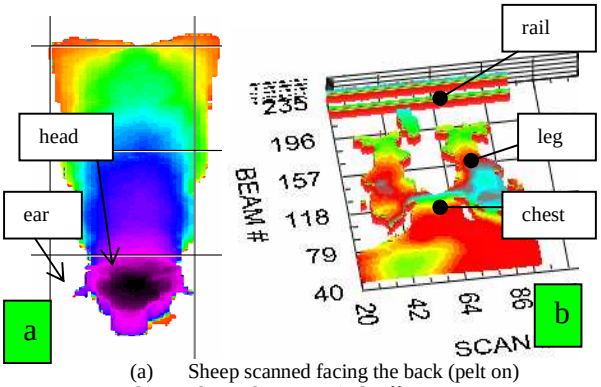
The vertical resolution along the profile was dependant on the distance from the product and the angular resolution of the individual measurements of the laser scan. For example, an angular resolution of 0.25 degrees, at a range of 1000mm, produces a vertical resolution of approximately 4.3mm between mapped points. Decreasing the range (limited from 700 to 3000mm) or increasing the angular resolution of the LMS400 (limited to 0.1 degrees) allows the vertical resolution to be increased.

The horizontal resolution of the surface map was determined by the rate of collection of vertical profiles.

2.2.1 Moving Carcass / Stationary Sensor

Taking advantage of the continuous production line - common in sheep processing plants - the LMS400 was kept stationary and the carcasses moved in front of the scanning location.

The resolution horizontally in this case is preferably resolved by measuring how far the production chain has travelled between recorded profiles (using an encoder). However, during trials - where interfacing to the production infrastructure was not permitted - a fixed time between profiles was used and a constant chain speed was assumed. The calculated horizontal resolution of the profile ranged from 1mm to 5mm, depending on the application.



(a) Sheep scanned facing the back (pelt on)
(b) Sheep chest scan (pelt off)

Figure 7:Laser profiled sheep carcass [Condie, 2007]

In the examples shown in Figure 7, the first laser profile allowed features such as the ear and horn location around the head of a sheep carcass (black patch) to be determined. The second profile was analysed to determine features such as leg and chest location, as well as leg thickness, allowing an industrial robot to deliver a vacuum unit for decontamination of the carcass surface.

2.2.2 Stationary Carcass / Moving Sensor

In some Australian beef plants the production line is "indexed" and can be stationary for 15 to 30 seconds between carcase movements, depending on production throughput.

In the case of an indexed chain the laser was traversed horizontally while the carcass remained stationary. The horizontal resolution between profiles using this method was measured as the distance the laser had traversed at the time of scanning.

Any analysed point in the map or the beef head (ears / horns / snout) shown in Figure 8 provides a location in three dimensions in space, allowing accurate positioning of the required tool. The map shown in Figure 8 trims all points that are farther away from the laser than the back of the head for clarity.

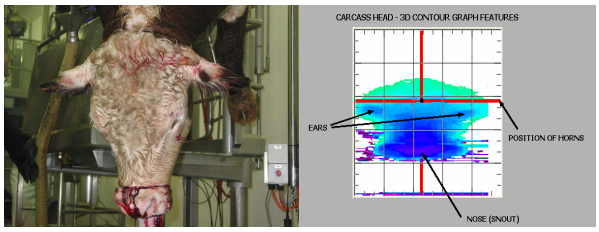


Figure 8: Laser scan for horn detection

2.3 Internal Feature Detection

Not all features required for automation can be determined by surface features alone. Some features – such as the ridge of the backbone – need to be measured using alternatives such as ultrasound or X-ray.

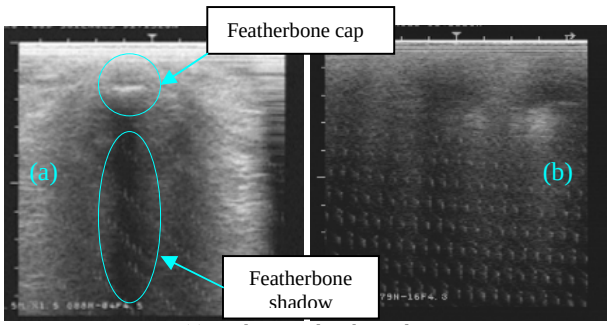
The tasks requiring this technology fall under the definition of a category 2 task [Aust *et al*., 2005].

2.3.1 Ultrasound

Ultrasound units provide a two dimensional "image" for analysis, with one dimension across the surface of the probe, and the other being the depth of the artefact from the probe.

Portable ultrasound units were investigated as a sensing technology for adaptation to slaughter tasks. Each ultrasound application requires the correct probe frequency selection and corresponding consideration of the surface and structure of the product being analysed. A lower the probe frequency produces greater the sensing depth.

The example shown in Figure 9 illustrates the detection of the featherbone along the spine of a beef carcass [Boyce *et al*., 2004] for splitting. A 3.5MHz linear probe was used giving a clear sensing depth of 60 to 100mm. The depth of the spinal channel varied from under 30mm around the lumbar to over 400mm around the shoulder. By sensing the spinous process near the surface, the projected centre coincided with the centre of the spinal cord or vertebral foramen when the carcass hung vertically. A cutting result of +/- 3mm was desirable, but +/- 1mm was regularly obtained [Beare, 2002] by analysing ultrasound images and tracking the spinous process at a rate of approximately 10 frames per second in real time during the cutting process of a controlled trial. The ultrasound probe required contact with the product, and – more importantly – no air gaps. The second image in Figure 9 shows an ultrasound of a carcass from the production environment with subcutaneous air pockets present in the carcass membranes. Air pockets prevented the transmission of the ultrasound signal and thus prevented the generation of an ultrasound image.



(a) Ultrasound with good contact
(b) Ultrasound with subcutaneous air)

Figure 9: Ultrasound images of beef featherbone

Some historical work that has been conducted by CSIRO [L&MAQ *et al*., 1992] developed a dual head probe ultrasound system to assess fat depth and eye muscle area non-invasively on live cattle. Figure 10 shows the results of an ultrasound scan, showing the characteristic beef eye muscle profile, which was achievable as good contact with the carcass surface was possible and the desired target data (eye muscle) was within a good area of the probe frequency scan region.

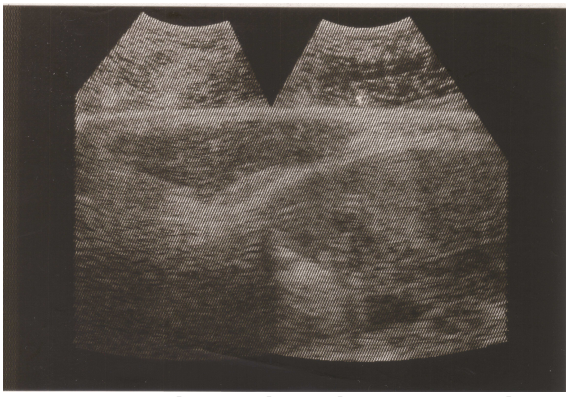


Figure 10 : Ultrasound scan showing eye muscle

2.3.2 X-ray

One of the more advanced sensing technologies for viewing beyond the surface is X-ray imaging.

Figure 11 is an X-ray image of a sheep hock showing clear bone structure. Image analysis of these X-rays can produce the location of a joint or other feature suitable for the processing task – cutting through the joint in this case.

Figure 11: Stationary X-ray of sheep leg joint

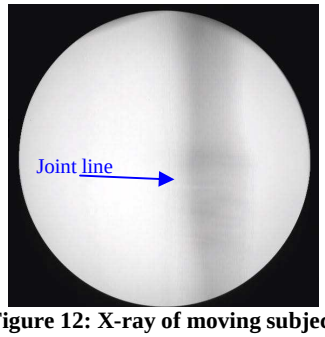


Figure 12: X-ray of moving subject

The image produced in Figure 11 was taken using a digital fluoroscopy unit and as such required the product to be stationary relative to the sensor for between 50 and 250 milliseconds.

The X-ray in Figure 12 was taken of a sheep hock joint moving at approximately 100mm/s (production speed) across the fluoroscopy unit. In this live X-ray the detail is obscured, and - although the image analysis algorithms become more complex – the main joint can still be located and used to reference the position of the cutting tool.

The use of X-ray technology must consider the safety of operators in the region of the X-ray unit. ARPANSA standards define the maximum desired radiation exposure be kept below 20mSv per year for an operator. All personnel working in the region of the radiation should be monitored. The cost of monitoring personnel, the enforcement and tracking of radiation exposure need to be considered in the running costs. However, with suitable containment of radiation and/or shielding, the use of X-ray equipment in the production environment can be made acceptable. This is easily demonstrated by the common use of X-ray equipment for airport security.

2.3.3 Subsurface Radar

One of the less developed sensing systems that FSA has investigated to analyse features beyond the surface of meat products is subsurface radar.

A subsurface radar unit developed by CSIRO with a 1.4GHz handheld probe was used to investigate the possible detection of bones inside carcasses. The subsurface radar system was used on a whole sheep carcass in a laboratory, and on bones buried inside processed meat. The subsurface radar detected abnormalities in a mostly homogeneous environment. A resulting scan of a large bone buried in meat can be seen in Figure 13 showing an artefact (the bone), but the results were too coarse to reliably detect features such as a joint.

Further development of this technology would be required, particularly in antenna development, before it would be suitable for application to automated meat slaughter tasks.

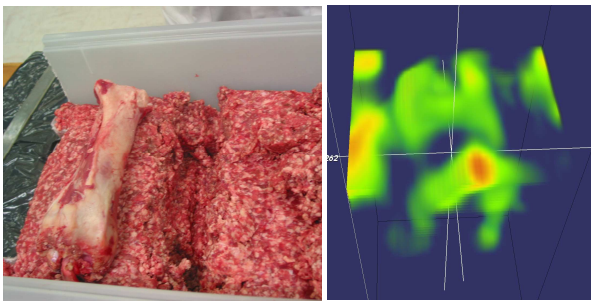


Figure 13: Bone in processed meat sensed using subsurface radar

3 Applying Sensing Technologies

The imaging techniques used by FSA require a very short period of time to capture and analyse a feature in two dimensions, but delivering a tool to that feature requires a third dimension in space.

This third dimension could be supplied by using multiple cameras or laser mapping techniques or sensing can be made less complex by considering the system as a whole, and how the tool or the materials handling around the process can be used to simplify the sensing.

3.1 Sensing Using the Production Environment

In some cases the control of the product does not require the third dimension to be measured.

In the case of the carcase in Figure 14, the legs of a sheep carcase are captured in gambrels on the production line. The process during this operation is to cut the legs no more than 200mm below the gambrel; therefore it can be assumed that the legs shall be located vertically below the gambrel.

The cutting location (centre of the leg bulge) only needs to be measured in the remaining two dimensions: height below gambrel and horizontal offset of each leg.

This can reduce the complexity and cost of both the sensing and the cutting tool, and ultimately the cost of the equipment.

Figure 14: Carcase captured by fixed gambrels

3.2 Reducing Complexity by Using Simple Sensing

Tool design can be used to reduce the complexity of the sensing required for a process.

In the case of Figure 15 the vertical and horizontal location of the beef leg was established using analysis of a thermal image of the carcass silhouetted against a cool wall taken with a camera behind the cutter (keeping it away from the harsh environment).

A cutter fitted to an industrial robot was then delivered along the viewing axis of the camera to an approximate cutting position and final reach of the robot was determined as the leg was detected by the proximity sensor inside the cutting tool.

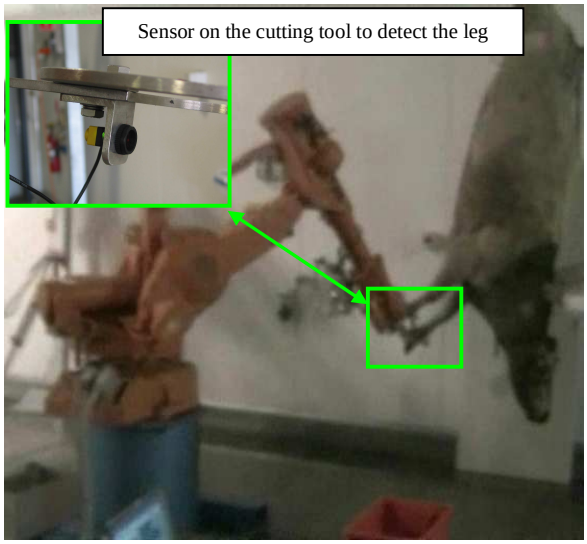


Figure 15: Using a sensor on the tool to provide final tool placement [Ring, Aplin, 2006]

3.3 Using the Tool to Reduce the Sensing

The use and design of the tool can influence how the much sensing is required for automation.

In the case of a beef splitting saw, the ultra sound unit was located approximately 100mm below the cutting blade (Figure 16). The action of cutting the beef carcass demands that the sidewards movement of the saw be a fluid motion so that the blade is not jammed into the bones as it moves down the carcass. The lag between measuring the centre of the backbone and the time taken for the saw blade to arrive at that measured point allowed the positional update to be extended from the desired 10 updates per second to as low as 3 updates per second, while still producing an acceptable split of the carcass. The roller guides at the base of the saw followed the spinous process preventing gross movement of the carcase, such that a corrective movement of less than 70mm was then required for saw blade to align to the backbone centre, and hence 70mm required for an ultrasound probe.

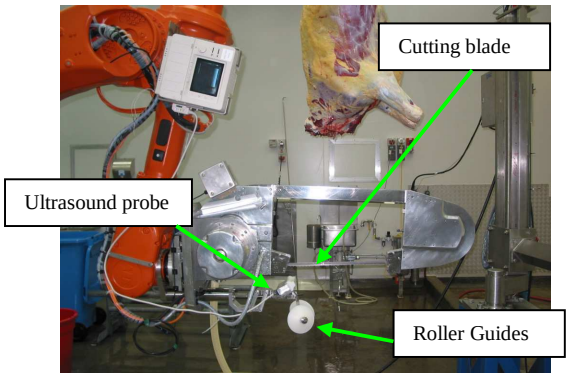


Figure 16: Beef splitting saw arrangement [Boyce *et al.*, 2004]

Conclusions

There is a large range of commercially available sensors that can be applied to automation of beef and sheep slaughter tasks. Each task needs to be considered separately and the appropriate sensor chosen, not only for the task, but also for the environment it is being used in.

Cameras can capture data quickly when the lighting and background of the image is suitable, but may not always be useful for colour analysis on beef or sheep carcasses. Thermal imaging – although more expensive - can produce a more robust solution, especially when imaging carcasses with the hide or pelt still on the animal.

Ultrasound is successful for subsurface sensing when good contact with the product can be achieved, but any air gaps in the product makes ultrasound unreliable. X-ray sensing can provide clear subsurface detail, but the requirements and cost of safety must be considered for any installation.

Stereo or orthogonal vision applications can be used to capture three dimensional features of carcasses, but placement of cameras or recognition of features may be limited in the production environment. Laser profiling can provide a three dimensional map of carcass features from a single scanning point but an extended period of time is required to gather the profile information, and the carcass must be stable during profiling.

Combining information from multiple sensing technologies can provide suitable sensing techniques to give sufficient data for tool automation in beef and sheep slaughter tasks. Mechanical sensing or incorporation of sensing with tool design can also minimise the sensing requirements in some applications.

5 Acknowledgements

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6 References

[Aust *et al*., 2005] Peter Aust, Darryl Heidke, Kym MacRae, Ray White *Investigation and Evaluation of Sensors for Adaptation to the Meat Industry,* MLA Report - PRTEC.032, 2005

[Beare, 2002] Richard Beare, *An Ultrasound Imaging System for Control of an Automated Carcass Splitting* Proceedings of the 12th Scandinavian Conference on Image Analysis, pages: 375-381, 2001

[Boyce *et al*., 2004], Phillip Boyce, Kym Macrae, Jeff Owen, Peter Ring, *AUTOMATIC BEEF CARCASE SPLITTER-STAGE 2: Investigating Hide Puller Alteration,* MLA Report - PRTEC.029, 2004

[Boyce *et al*., 2004], Phillip Boyce, Kym Macrae, Jeff Owen, Peter Ring, *AUTOMATIC CARCASE SPLITTER, Trial and Optimisaion of Commercial/Works Prototype: Final Report,* MLA Report - PRTEC.007, 2004

[Condie, 2007] Peter Condie, *Stage 2 OF THE Vision and Laser Sensing Systems Suitable for Beef and Sheep Slaughter Tasks, Milestone 6 Report: Sensing System Development First Sheep Task Sheep Head Removal*, MLA Report - A.TEC.0051, 2007

[Garner *et al*., 2007] Dr Stephen J Garner, Ray White, Peter Condie, *Stage 2 OF THE Vision and Laser Sensing Systems Suitable for Beef and Sheep Slaughter, Milestone 3 Report: Sensing System* , MLA Report - A.TEC.0051, 2007

[L&MAQ *et al*., 1992] Livestock & Meat Authority of Queensland & CSIRO Meat Research Laboratory, *Project LMAQ9 Joint ultrasound project: Efficacy*, Livestock & Meat Authority of Queensland, 1992.

[Ring, 2006 a] Peter A Ring, *Development of Vision & Laser Sensing Systems Suitable for Beef and Sheep Slaughter Task, Milestone 1 Report (Part A): Beef – Abdominal-thoracic Hide Open,* MLA Report - PRTEC.042, 2006

[Ring, 2006 b] Peter A Ring, *Development of Vision & Laser Sensing Systems Suitable for Beef and Sheep Slaughter Tasks, Milestone 5 Sheep: Neck Tipping,* MLA Report - PRTEC.042, 2006

[Ring, Aplin, 2006] Peter A Ring, Richard Aplin *Development of Vision & Laser Sensing Systems Suitable for Beef and Sheep Slaughter Task, Milestone 3 Report: Beef Front Hoof Removal*, MLA Report - PRTEC.042, 2006

[SICK, 2004] *LMS400-0000 Laser Measurement System – Operating Instructions*, SICK AG – Division Auto Ident – Germany, P/N: 8 010 421/ 0684/ 22-06-04, 2004

[White *et al*., 2007] Ray White, Jeff Owen, Peter Aust, *Stage 2 OF THE Vision and Laser Sensing Systems Suitable for Beef and Sheep Slaughter, Milestone 2 Report: Data Gathering 1st Beef Task – RFID Tag Location for Removal,* MLA Report - A.TEC.0051, 2007

[MacRae *et al*, 2006], Kym Macrae, Darryl Heidke, Jeff Owen, *Enhanced Current Hand Tools Using Telerobotics*, MLA Report – PRTEC.041, 2006