A New Approach to Detect the Cutting Positions for a Robotic Beef Carcass Scribing System

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Abstract

Scribing (initial carcase side cuts) tasks carried out in Australian abattoirs incur high costs in terms of labour usage and availability, low accuracy and significant Occupational Health and Safety risks. Thus it was chosen as one of the tasks to address for possible automation. It has been shown that a novel combination of a specifically adapted robot end-effector and appropriate image analysis software is able to control a robot to perform the required scribing tasks.

The image analysis functions developed have shown the ability to identify carcass features including individual ribs (5th through to 12th at this point in time), vertebrae joints, sternum joints and featherbones. Once these features are identified, the cut path is determined and the robot control system can proceed to direct the circular saw along the cut trajectories and carry out each scribe cut one after the other (typically 4-6 cuts).

This document will describe the project investigation details. The experimental results are demonstrated. Finally, the technical considerations and recommendations for the further development of a full automated scribing system are outlined.

1 Introduction

The Australian Meat Processing Industry knows of the benefits of boning prime cuts of meats carefully to maximise the return on raw material. Fortunately for the industry, these boning practises are reasonably simple and repetitive. This lends each separate activity in the task to the adaptation of a manipulator arm (robot) with the appropriate end-effector and product information sensor. The industry believes that once robots are adapted to appropriate tasks, the following benefits will be realised in a relatively short time period (specific customer requirements not withstanding):

- Maximise yield of edible product
- Maximise yield of high value cuts
- Maintain Aus-Meat and customer primal cut specification shapes
- Reduce labour requirements of the complete system
- Process compatible with most current plants
- Improve overall plant productivity
- Maintain flexible processes to allow alternative product specifications, while maximising robotic utilisation
- Maintain the quality of existing boning room practices such as product traceability and hygiene.

The eventual full project objective (this project is only for the proof of concept stage) is to develop a robotic scribe saw system using a commercial circular saw to carry out the following tasks:

- Longitudinal cut – Brisket from navel to point;
- Longitudinal cut – Short Rib and other specialist oven ready cuts
- Transverse spine cuts – Carcass breakdown to alternative quarter specification.

The intent of this project (as part of an eventual full project) is to carry out the proof of concept work, which includes the following major objectives:

- Investigate morphological characteristics of beef sides to determine shape profiles.
- Develop image analysis software to automatically identify carcass features.
- Address the issue of product size variability inherent in the beef industry.

2 Definition of scribe cuts of beef meat

Four scribe cutting lines are pictured in Figure 1. The definition of these cuts are described as follows.

__Downwards Scribes__

Brisket Cut – navel to point (Refer to the skeletal diagram in Appendix. 1)
Short Rib Cut – five ribs from the 11th to the 7th (inclusive)
Various Spare Rib Cuts – to prepare rib meat bone-in for plate ready restaurant market

- Scribe cut through 11th to 7th rib between the short rib cut and the spine

- Scribe cut through 4th to 1st ribs – cut is marked out from where the 1st rib joins the spine and parallel to "navel to point" brisket cut.

Horizontal Scribes

Quarter Cut – through the spine between the 11th and 12th rib to produce hindquarter and forequarter
Or alternatively,
Beefside Tri Cut **–** (US & Japanese standard practice) typically through the spine between the 6th and 7th rib combined with a cut between the sacral bone and the 7th lumbar vertebrae (cuts a beef side in three pieces)
Neck Cut – through the spine between the 1st rib and cervical vertebrae to assist cold neck boning
Pistola Cut – through the spine between the 5th and 6th rib

Figure 1 Scribe cuts on a side of beef

Figure 2 Manual Operation

Most plants carry out some preparation work on the carcass using a circular saw to scribe through bones when required. The manual scribing operation is pictured in Figure 2. Basically, the scribing operation produces four cuts as specified by the meat industry standard unless special cuts are required by customers. The majority of meat processing facilities have at least one operator and up to three operators per shift carrying out these tasks, depending upon throughput.

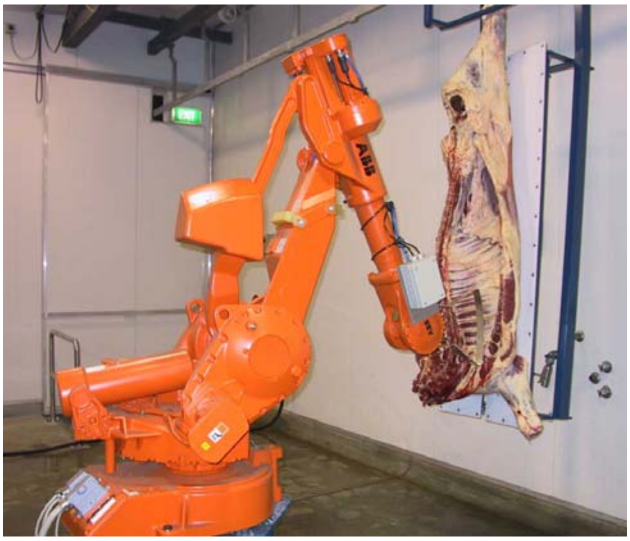

Figure 3 A robot scribing station prototype

From the automation point of view as discussed in Section 1, it has been suggested that the robot can easily deliver the required cuts if the coordinates of the cutting lines are pre-determined. An IRB 4400/60 ABB robot, shown in Figure 3, has six degrees-of-freedom to allow it to orient and position the end-effector (tool attachment) with 60kg payload within its operational volume (i.e. from the base centre the wrist joint can reach 2.140m in the vertical direction and 1.955m to the front). From the preliminary tests, it has clearly been shown that the robot's 60kg payload and the capacity of the handling of circular saw torque are well within the robot's operating ability.

Apart from the coordinate information for the cutting trajectories, there are a few engineering issues, such as beef size and weight validity, carcass stabilisation and measurement and cut depth control, that must be considered as well. Other issues, such as the presence of bone dust, saw cleaning/sterilization, saw movement control, operation interface and environmental robustness of the system can be classified as engineering integration issues for which technical solutions are known to be available. These issues would be part of a full development project. The primary technology development described in the document is aimed at finding of the geometry characteristics and the automatic determination functions of the scribe lines.

3 Surface morphology determination

3.1 Measurements vs cutting positions

The cutting lines shown in Figure 1 have been marked with respects to the geometry of a full side of beef. From the cutting line definitions described in the Section 2, the scribe cuts were separately correlated to the geometrical features along with vertical (Z-axis) and horizontal directions (X-axis). Fundamentally, if the identification of the following features that can be developed, then the determination of scribing lines should be feasible.

- Identification of the side outline (X and Z axes) that will be used to determine the start and finish positions of the cuts.
- Determination of side (left or right) being processed and thus indicate the cut starting position.
- Segment the chest cavity and locate critical features (brisket point X and Z axes), which could be applied to determine the brisket cut and short rib cut.
- Locate visible ribs (mainly Z-axis) to determine the horizontal cutting trajectories.
- Count vertebrae (mainly Z-axis), which is critical to determine the starting orientation and position of horizontal scribe cuts.

Figure 4 A side of beef carcass

To determine the above features, several different approaches were investigated. The computer vision method has been widely used in different industries

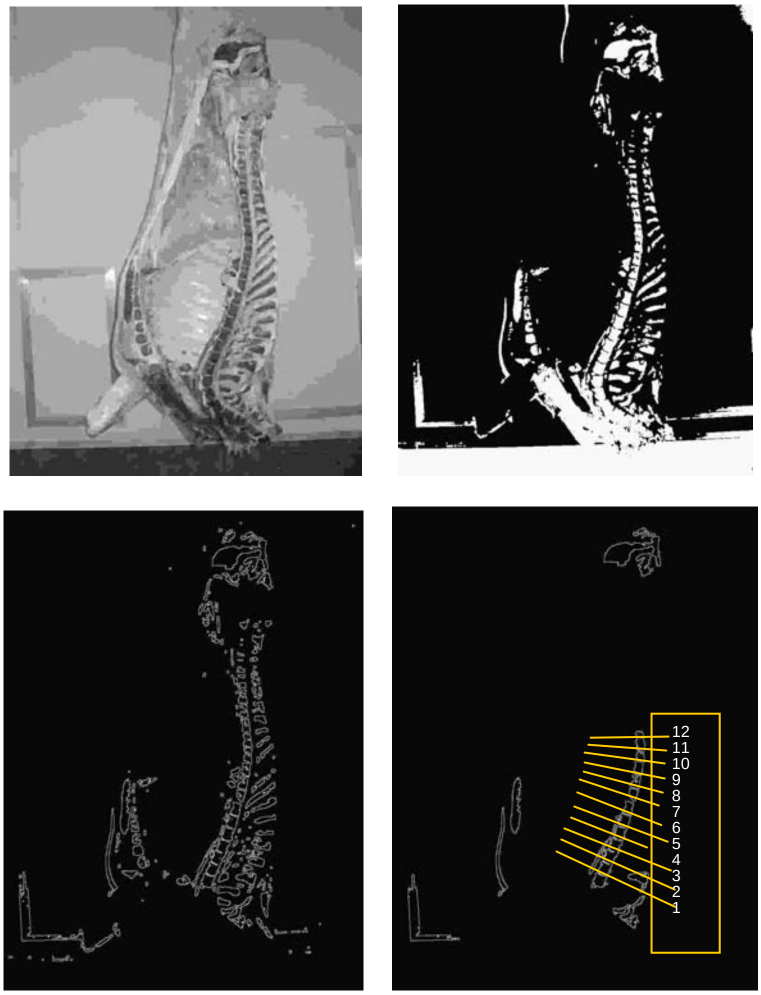

Figure 5 Processed images

where there is a repetitive, structured environment. An example is the inspection of an electronic board. With the uniform specifications of the colours and sizes of the electronic components, an industrial computer vision system with colour and pattern matching functions should easily handle the quality inspection processing operation.

3.2 Conventional image processing

Figure 4 shows an image captured with a digital camera, whereas the images shown Figure 5 are the same but processed with colour extraction, threshold, and border and objects removal functions. There are several features that can be identified, such as the position and direction of the vertebrae, the side of the carcass and even the number that relates to the ribs.

These features could determine the starting position of two horizontal (X-axis) cuts. However, the processed results derived from the original image cannot generate any geometric significance of the ribs that specifies the starting and finish position of the vertical (Z-axis) cuts. Based on the experiments, it has been found that the image processing result depends very much on the presentation of carcasses. The processing robustness varies if the settings of tests change, e.g. the lighting conditions. As examples, the application of computer vision systems in the meat industry can be found in [Fortin, 2003] and [Hatem, 2003], in which the same operational settings are maintained. In most applications of computer vision systems for meat processing, the details of bone structure are not required. For a computer vision system with the image information (colour and intensity), it is difficult to generate a reliable detection result of the rib bone features and geometry.

3.3 Radiant imaging

It is believed that the most effective technology that could be applied to determine the rib bone features would be X-ray sensing. The material characteristics (density) of bones can be directly detected by X-ray, with its inherent short wavelength and high frequency. There are also a number of patents outlining the use of X-ray technology for finding bones in carcasses prior to processing. The investigation and development can be found in [USPTO, 1 and 2]. However, all of these have gone no further than pure research interest with only laboratory scale experiments.

In reality, the handling and implementation of X-ray sensing in the meat industry is difficult, e.g. contained areas and other safety measures are needed. In the meantime, the acceptance of X-ray in food industry is unlikely as the radiation residual is always a significant consumer concern. From the experience gained through investigation of other sensing technologies, consideration was given to the following:

- Ultrasound, refer to [Davenel, 2000], [Beare, 2002] and [Simal, 2003]
- Magnetic resonance imaging (MRI) refer to [Davenel, 2000]
- and other type technology (eg radar, etc.), refer to the fat trimming project conducted in Food Science Australia, 2002.

Apart from the difficulties involved in handling and implementing these technologies, it is costly, even with the laboratory scale set-up of these methods. To adopt these technologies in a production environment, significant capital investment and commercial development would be required.

4 Range imaging

While 2D vision systems can be used in many inspection applications, it cannot, as discussed previously, detect the cutting features of a carcass. The focus has thus been turned to 3D imaging systems. One of the feasible techniques has been investigated is a “range imaging” system. Normally, the image from a camera depicts the intensity distribution of the viewed scene. A range camera, on the other hand, depicts the distance from the camera to the objects in the scene. The range profiles are acquired using laser triangulation, and the technique is referred to by a variety of names such as sheet-of-light range imaging, laser profiling and lightstripe ranging. To begin to demonstrate the range imaging principle, one image obtained is shown in Figure 6. The section profiles of the image are examined separately, and horizontal and vertical section profiles along the cross lines defined in Figure 6, are shown in Figures 7 and 8, respectively.

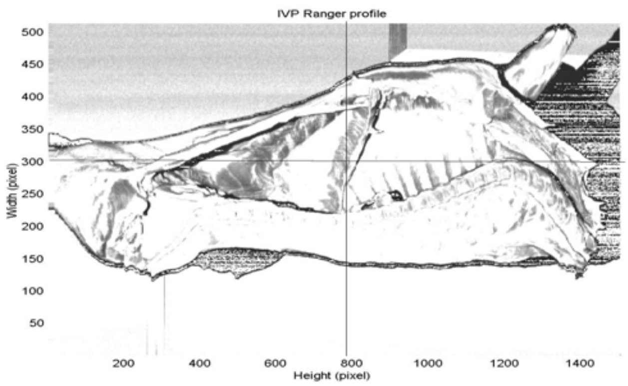

Figure 6 Ranger scan image

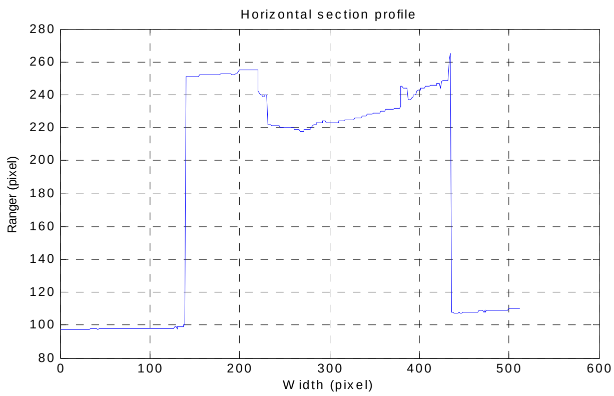

Figure 7 Horizontal section profile

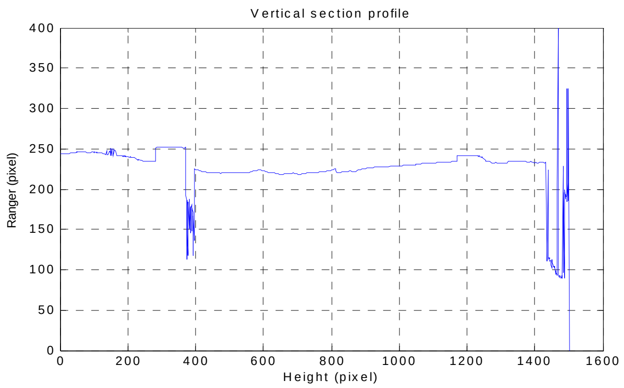

Figure 8 Vertical section profile

4.1 Set-up of a range imaging system

The IVP Ranger SAH5, 3D image scanning system contains a MAPP 2500 Smart Vision Sensor (SVS) with an interface to the instruction port and a high-speed serial interface (HSSI). The SVS integrates a 512 x 512 pixel sensor, 512 A/D converters, and an image processor all on the one chip. The image is processed on the sensor and only the result – and no other irrelevant information – is transferred to the PC via the high-speed serial connection. With the High-Speed Serial Interface the unit can send and receive data at high speed (maximum 260mb/s). The high-speed I/O port (data port) on the MAPP 2500 is available for high-speed data transfer to a host PC or to the built-in SDRAM memory.

After a carcass is positioned at the scanning position, the linear actuator controlled by a proportional valve drives the scanning unit from the top position downwards. Each scanning profile will record the ranger information i.e. the distance along Y axis, according to the column pixel, and the coordinates of X axis. The displacement of the Z axis is generated by the drive unit. The scanning accuracy and resolution in the horizontal plane is determined by the IVP Ranger image system. However, the quality of the Z axis measurement i.e. the vertical accuracy and resolution is dominated by the controllability of the actuator and valve and quality of the Temposonics™ linear displacement sensor.

4.2 Range image acquisition

The program structure and operational flow governs the camera initialisation, parameter loading, ranger receiver starting, camera algorithm starting and range profile accessing. When the range acquisition is completed, the camera stops, live receiver stops and HSSI release is implemented. The library functions wrapped as API DLL are available from IVP Ranger software. However, to adopt the system for particular usage and integration with the other functions e.g. the linear drive system, the program needs to be developed further using customer specifications. Finally, the new IVP Ranger application program interface for the carcass image scanning is developed as shown in Figure 10. With that interface, there are four sub window areas, i.e. the ranger parameters configuration, linear drive system control, single profile and intensity display, and 3D image display. Therefore, it provides much easier operation by implementing a single interface program (with system parameter setting and display). The functions behind these are all compiled into independent software components with error handling features. Thus application developments are simply an integration of these components.

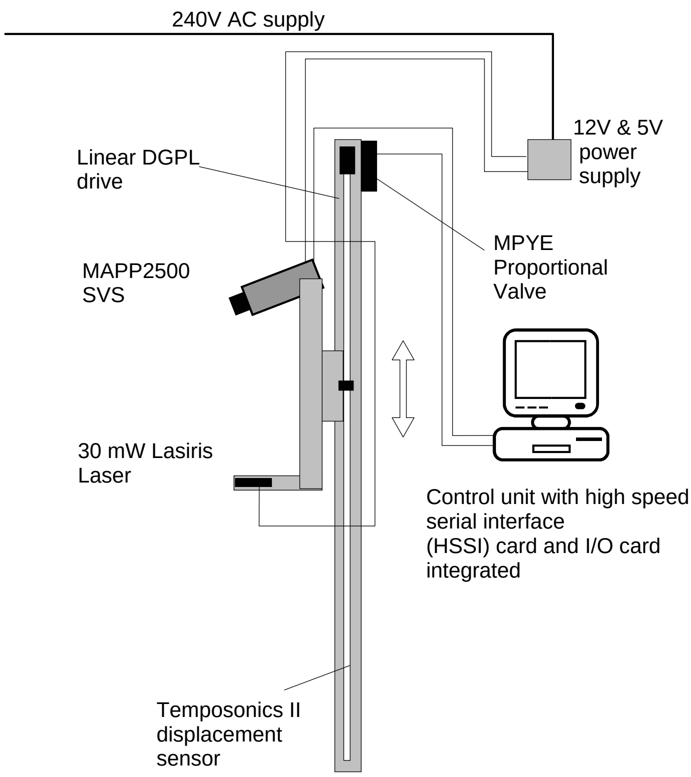

Figure 9 Set-up of a range imaging system

The scanning system being trialed is placed approximately 3m from a carcass. The camera and laser are moved vertically using a linear drive, with a travel of 2250mm. The drive is equipped with a position sensor that is used to trigger the IVP Ranger system so that range profiles are captured at regular spatial intervals.

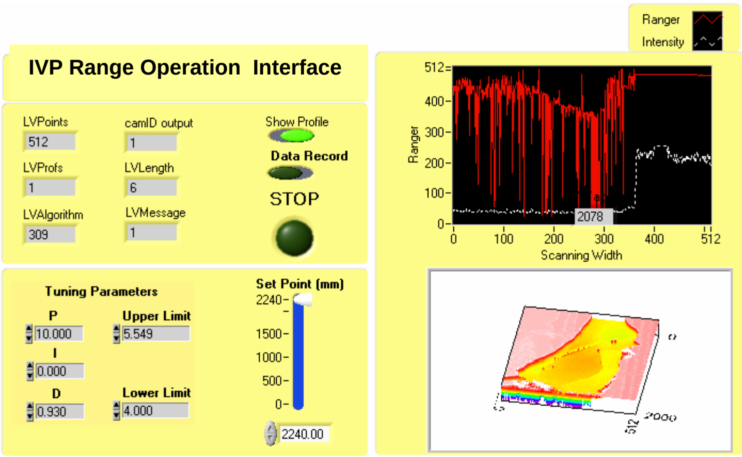

Figure 10 IVP Ranger Operation Interface

5 Image analysis

The main issue in this case, is the identification of the start and end positions for scribing cuts in a side of beef. It is hoped that enough information can be obtained from the range image so that the scanning time will be reduced.

With the 3D information of the range image, an algorithm was developed using Matlab functions to identify the outline and segment of the chest cavity to determine whether the left or right side is being processed.

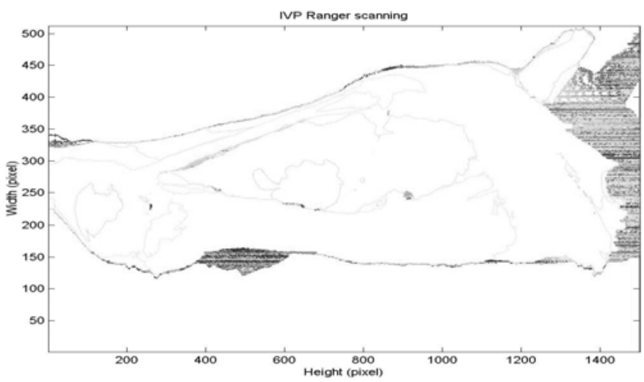

Figure 11 contour function to find the chest cavity

After the carcass surface range variation has been detected by the IVP Ranger, one function was developed to find the chest cavity, which uses a common height as a reference. A contour with respect to the chest cavity is generated and plotted out as shown in Figure 11. This feature could be used to determine the trajectories of the two vertical (Z-axis) cuts (but not starting and end points) and starting point of horizontal (X-axis) cuts. The specific algorithm developed directly gives the three coordinates of the contour as an output. Apart from the cavity contour, the leg profile is clearly shown on the plot, which can be used to determine the side of the carcass as well. The shading area on the bottom side can be eliminated by using a height threshold. The outline of the side of beef can be presented neatly without any surrounding objects.

An alternative approach: a prototype code developed based on CMIS library functions [Li, 2003] to process the range image, operates as follows.

1) Threshold based on range information does a reasonable job of separating the side from the background, although regions of missing data caused by occlusion are common. Range based thresholding is robust if the background (the rear wall in this case) is at a consistent and known distance from the carcass.

Finding the background (bgMask) also provides a mask describing the shape of the side (sideMask).

2) The side being processed may be determined simply using a projection of the sideMask onto its short side. Thresholding the projection at two levels, and comparing the centres of the resulting object, provides a robust indicator of which side is being processed.

3) The chest cavity is a complex shape that cannot be segmented using simple threshold techniques. The watershed transform is a powerful tool that is capable of segmenting complex objects if suitable markers can be found. A marker for the chest cavity can be based on a line drawn relative to the widest part of the sideMask. This line can be reliably drawn inside the chest cavity using basic anatomical assumptions. The second marker is a dilated version of bgMask. A watershed transform applied to the gradient of the range image using these two markers segments the chest cavity appropriately.

After locating the chest cavity it is possible to use the shape of the cavity outline to approximately locate the critical features, such as the point of the brisket.

4) It is also possible to begin looking for much more subtle features, such as the ribs. The ribs are very slightly raised (max 3mm) relative to their surroundings, and this difference is not always detectable using the range measurements. Some preliminary experiments have shown the feasibility of locating ribs near the spine. This was done using projections along a narrow window near the spine,

which provides an estimate of rib base positions and inter-rib spacing. Three carcasses with range image processed are shown in Figures 12 through 14.

Figure 12.a Carcass 1 digital image

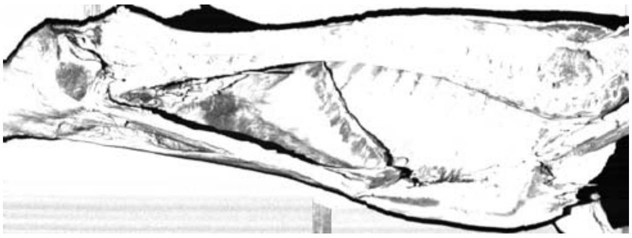

Figure 12.b Range image

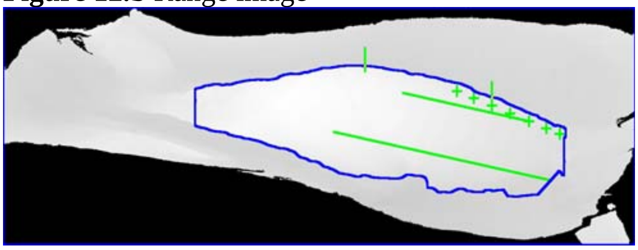

Figure 12.c Determination of cutting points

6 Discussions

Using two image processing approaches, the ability to find the carcass outline, chest cavity and side has been demonstrated. It has been shown that with 3D range data the vertical cutting trajectories are identified with reasonable accuracy, although the determination of the starting and end points needs to improve further. The ribs are very slightly raised (max 3mm) relative to their surroundings. Thus the IVP has not provided enough information to locate individual rib and vertebrae. The result is that the location of horizontal cuts is not feasible with IVP range system.

The IVP system is commercially available. However, its application results depend very much on the laser-camera geometry settings (angle and distance), lighting conditions, and resolutions used (horizontal and vertical). To detect small size variations (e.g. 3 mm) with an object like a beef carcase, probably a better SVS is needed. This is currently available from the same supplier.

Figure 13.a Carcass 2 digital image

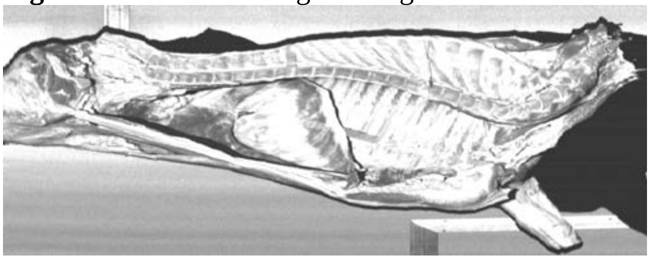

Figure 13.b Range image

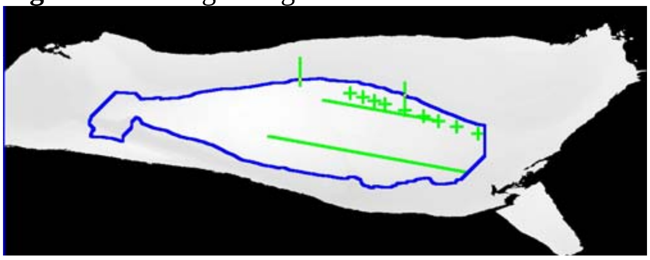

Figure 13.c Determination of cutting points

Figure 14.a Carcass 3 digital image

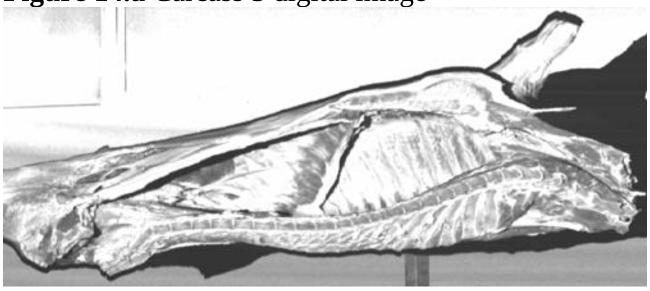

Figure 14.b Range image

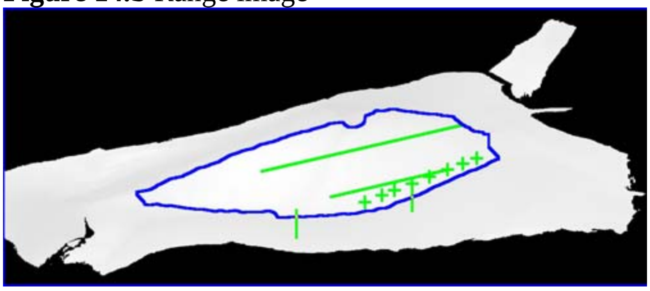

Figure 14.c Determination of cutting points

To improve the detection of the cutting positions, it has been proposed that a further investigation to use two imaging types, i.e. intensity and range. IVP range system acquires two types of information i.e. range and intensity, simultaneously as shown in Figure 10. With a snapshot, an intensity image of the carcase can be obtained at the beginning of the process. Similarly, it is likely that the intensity image (see Figure 5) will be more useful as the cartilage between vertebrae is quite visible.

7 Conclusions

This project has presented considerable challenges in terms of carcass variations not only in terms of size and profile, but also in fat depth, colour and presentation. The diversity of beef sides requires a high level of robustness from the image analysis algorithms. The most robust approach is likely to combine a high level anatomical knowledge system with morphological filtering and segmentation, associated with the process of intensity and range images. The carcass outline is something that is likely to be easy to extract robustly providing knowledge about relative size and position of different parts of the side - eg foreleg, brisket width etc. This will help locate regions within the carcass side which requires more complex processing.

Acknowledgments

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[USPTO, 2] Us Patent 5,314,375, Method and apparatus for automatically segmenting animal carcasses

Appendix 1. Beef Skeletal Diagram [Aus-Meat 1998]