31st May 2004

PROJECT CLOSE OUT SUMMARY DOCUMENT[1]
PRTEC.010 – Automated Scribing and Boning

Introduction to Project

Scribing tasks carried out in Australian abattoirs incur high costs in terms of labour usage, and availability, as well as significant Occupational Health and Safety risks. Thus it was chosen as one of the tasks to address for automation.

During the course of this Proof of Concept phase, it has been conceptually shown that a novel combination of a specifically adapted robot end effector, and appropriate image analysis software are able to control the robot to perform the required scribing tasks.

Further development of this technology requires the conceptual development of carcass stabilisation, robot arm controls, and selection of a suitable hydraulic saw to perform the scribe cuts in the appropriate position to produce brisket, spare ribs and quarter cuts.

During five months of investigation, three separate trials incorporating about 62 carcass samples were carried out in the meat processing facilities at Food Science Australia and also at Nippon Meats Oakey. The test outcomes have demonstrated that the IVP Ranger is an efficient system. The image laser scanning and processing of a 2.0 metre long carcass currently takes only 15 seconds.

However, to be commercially operational, the imaging will need to be done in less than 5 seconds which is considered to be achievable as part of any subsequent new project. The system does not have any significant environmental, engineering or safety constraints within the meat industry, such as light condition, temperature and electronic interference, etc, besides normal washdown protection.

Project Objectives

At the completion of the Project, the Food Science Australia aimed to complete the following to the satisfaction of MLA:

- Identification of carcass features on a digital image of a side of beef.
- Applied developed feature rules to determine and show the scribe saw cut positions for brisket, spare rib and carcass quarter cuts by lines drawn on the digital image of the beef side.
- Correlation of the image cut line data to the carcass morphology to determine the X, Y and Z co-ordinates of cut start and finish positions.
- Determination of the saw physical motion requirements for bone thickness & other carcass characteristics.
- Generation of the saw cut path trajectories.
- Demonstration of the control program using captured data to dry run the robot arm.

[1] Majority of text extracted from Project reports

Conclusions

At the conclusion of this Proof of Concept stage, following a series of trials with the currently developed scribing system, Food Science Australia concluded that the robotic scribing system detailed in the final report meets the major objectives of this project.

Results

This project has presented considerable challenges in terms of carcass variation not only in terms of size and profile, but including variations in fat depth, colour and presentation. As a result, there remains further software refining to locate more detailed markers to assist in the scribing process.

At this stage, Food Science Australia has been able to successful locate and identify the 5^{th} through to 12th ribs as well as spinal vertebrae, vertebrae joints, and featherbone, and the sternum joints.

As noted throughout the final report, further development work is required in the next project to achieve carcass stabilisation, as well as saw sterilising and bone dust removal regimes.

In order to design and develop the software and controls for this Scribing system, it was necessary to gain a complete understanding of the morphological characteristics of beef sides as well as other crucial issues in carcase profiling. The image analysis software has the ability to identify carcass features including some 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).

Since the image analysis software outputs information regarding carcass feature locations in combination with surface distances in relation to the camera, the integrated data is computed to direct the saw cuts in x, y, and z directions. It is realistic to expect that each scribe cut will be a smooth line, cut to a pre-set depth specification within +/- 1 mm.

The main recommendation of the final report, therefore, is to proceed with the further planned stages of this full project.

Where to from here?

Two actions have been instigated since the conclusion of this project.

Firstly, the AMPC Technology committee agreed to fund Food Science Australia to conduct stage 2 of this development work with the following objectives:

> *The current project objectives are to develop a prototype robotic scribe saw system using a commercial circular saw to carry out the following:*
>
> *Conventional scribe saw 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.*
> - *demonstrate the system in a laboratory environment, using the Food Science Australia Robot to keep project costs minimized.*

Secondly, an Australian Beef processor has been provided R&D project funding approval to fast track the R&D of this project to a commercial installation. As such stage 2 shall be completed by Food Science Australia and whilst this is being completed the following companies have been provided with a detail terms of reference to quote on delivering a commercial unit to the Australian Beef processor:

- Food Science Australia (Cannon Hill – Australia)
- Industrial Research Limited (New Zealand)
- Machinery and Robotics Automation (Sydney - Australia)
- QED (United Kingdom)
- Robotic Automation (Melbourne – Australia)

- Scott Automation (New Zealand)
- SFK (Melbourne - Australia)

It is anticipated that this third stage will commence in September 2004 and be completed by June 2005. Part of the MLA R&D proposal is that the Australian processor will hold an open day to demonstrate the final solution to the Australian industry. In addition the identified solution provider for this project are either companies that operate in a commercial sense (i.e. will be able to provide turn key solutions for the final product) or if they are not (such as Food Science Australia and Industrial Research Limited) and are successful will be "aligned" with a commercialiser prior to project commencement.

Sean Starling

Program Manager - Process and Systems Engineering
Meat and Livestock Australia
165 Walker Street
(Locked Bag 991)
North Sydney NSW 2059
Phone (02) 9463 9197
Fax (02) 9463 9182
Mobile 0419 89 1950
sstarling@mla.com.au
www.mla.com.au

Equipment and Automation Innovation Section

Automated Scribing and Boning Room Pre-work Proof of Concept

(Contract PRTEC.010 Project: 105689)

Report for:

Meat and Livestock Australia
Sean Starling

Prepared by:

Zeng Li
Toni Cannard

February 10, 2003

Food Science Australia
PO Box 3312,
Tingalpa DC Qld 4173

Tel: (07) 3214 2000 Fax: (07) 3214 2178
Email: Zeng.Li@csiro.au

Table of Contents

Table of Figures

EXECUTIVE SUMMARY

Scribing tasks carried out in Australian abattoirs incur high costs in terms of labour usage, and availability, as well as significant Occupational Health and Safety risks. Thus it was chosen as one of the tasks to address for automation.

During the course of this Proof of Concept phase, it has been conceptually shown that a novel combination of a specifically adapted robot end effector, and appropriate image analysis software are able to control the robot to perform the required scribing tasks.

Further development of this technology requires the conceptual development of carcass stabilisation, robot arm controls, and selection of a suitable hydraulic saw to perform the scribe cuts in the appropriate position to produce brisket, spare ribs and quarter cuts.

Of considerable note is the development of a transparent software structure, which comprises two image capture and analysis programs (IVP Ranger and CMIS), as well as LabView and a C interface program. The dual feedback between each of the software components provides real time analysis of both image densities as well as surface morphology. These combine to provide a real view of the carcass, locating ribs, spine, and featherbones, in addition to capturing information to build datum of carcase distances from the camera.

In order to design and develop the software and controls for this Scribing system, it was necessary to gain a complete understanding of the morphological characteristics of beef sides as well as other crucial issues in carcase profiling. The image analysis software has the ability to identify carcass features including some individual ribs (5^{th} through to 12^{th} 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).

Since the image analysis software outputs information regarding carcass feature locations in combination with surface distances in relation to the camera, the integrated data is computed to direct the saw cuts in x, y, and z directions. It is realistic to expect that each scribe cut will be a smooth line, cut to a pre-set depth specification within +/- 1 mm.

To prove the concept of the robotic scribing system two laboratory-testing units have been developed, a robotic control system and an IVP 3D Ranger system. The investigations carried out at Food Science Australia have concentrated on the objectives of this milestone of the project described herein. The investigation tasks included:

- set-up of a fast 3D image scanning system
- optimisation of the image operation interface
- the efficiency of image processing, and
- development of an industry oriented robust software system to handle the identification of the cutting lines.

During five months of investigation, three separate trials incorporating about 62 carcass samples were carried out in the meat processing facilities at Food Science Australia and also at Nippon Meats Oakey.

The test outcomes have demonstrated that the IVP Ranger is an efficient system. The image laser scanning and processing of a 2.0 metre long carcass currently takes only 15 seconds. However, to be commercially operational, the imaging will need to be done in less than 5 seconds which is considered to be achievable as part of any subsequent new project. The system does not have any significant environmental, engineering or safety constraints within the meat industry, such as light condition, temperature and electronic interference, etc, besides normal washdown protection. The in-house developed image processing algorithms using IVP Ranger (3D geometry) information compared with the conventional image processing techniques, which provide intensity information, has proven to be a most reliable and robust system to identify the morphology characteristics of the carcase and then generate the cutting lines.

However, the trials also identified the variation of the carcass geometry (i.e. sizes and cutting positions), which requires a high level of processing sophistication. More samples and the assistance of mathematical analysis models will be required for further development. In addition to this, a stable presentation of the carcass is required for both scanning and scribing.

In addition, during development, significant care has been taken to ensure that the control interface is very user friendly.

The recommendation of this report is to proceed with the further planned stages of this full project. However, it will be relevant at this point in time to review the costing for the full project to incorporate all considerations and recommendations of this report.

1. INTRODUCTION

1.1. *BACKGROUND*

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 our industry these boning practises are reasonably simple and repetitive. This lends each separate activity in the task to the simple 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 for different geographical demographics not withstanding):

- Maximise yield of edible product
- Maximise yield of high value cuts
- Maintain Aus-Meat and customer primal cut specification shapes
- Reduce labour requirement of the complete system
- Process compatible with the 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 objectives (this contract is only for the proof of concept stage) are to develop a robotic scribe saw system using a commercial circular saw to carry out the following:

Conventional scribe saw 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 contract is to carry out the proof of concept work as part of an eventual full project.

1.2. *OBJECTIVES*

The objectives of this proof of concept stage are to:

- Evaluate available image technologies to determine the most suitable vision systems.
- Investigate morphological characterises of beef sides to determine shape profile characteristics
- Manually identify suitable features for carcass profile measurement.
- Develop image analysis software to automatically identify carcass features.
- Develop a rule based cut position co-ordinate determination system
- Calibrate cut position co-ordinate for cut path, cut depth control system and saw profile shape.
- Trial, modify and demonstrate image and control systems.
- Prepare a cost benefit analysis of the developed process for the meat industry.

- Demonstrate software ability for characteristic determination, and graphically show cut path determination, represented by lines, on an image of the carcass side on a computer screen.

The deliverables of this proof of concept project stage will be a computer based software program that will carry out the following:

- Identify carcass features on a digital image of a side of beef.
- Apply developed feature rules to determine and show the scribe saw cut positions for brisket, spare rib and carcass quarter cuts by lines drawn on the digital image of the beef side.
- Correlate the image cut line data to the carcass morphology to determine the X, Y and Z co-ordinates of cut start and finish positions.
- Determine the saw physical motion requirements for bone thickness & other carcass characteristics.
- Generate the saw cut path trajectories
- Demonstrate the control program using captured data to dry run the robot arm.

1.3. *IMPLEMENTATION*

To implement the robotic scribing system, one of the proposed integrations is as shown in Figure 1.1. The operation requires the following major integrated function units to carry out several different processes.

1. Beef side handling mechanism
2. Fast 3D image processing unit
3. Real time operation interface
4. Robotic saw system

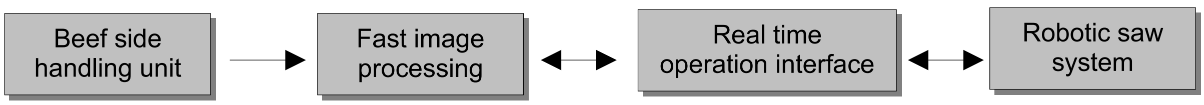


Figure 1.1 Robotic scribing system and interactions

In the above system, three units of the four, the beef side handling mechanism, real time operation interface and robotic saw system have already been investigated. For example, the auto-splitting system developed for the Japanese meat industry by Food Science Australia has successfully investigated the technical feasibility to automate the splitting operation, which is similar to the three functional units required above for the scribing process. At the commencement of this project, however, there was no suitable image processing unit in existence, which was capable of efficiently interpreting the morphology of the beef side and generating the information that could be utilised by the robot system to perform the scribing or similar task.

Therefore, it is believed that to prove the concept of a robotic scribing process, the critical step in the technical development, is to provide a fast image-processing unit. Within this initial milestone the objective given the highest priority is the provision of an image processing system with the task oriented generic algorithms that is able to enable quick determination of the cutting lines which can be used by the robot, this integration will occur during later development.

2. CURRENT PROCESS

The most common boning processes currently in use in Australia include:

- **Quarter boning**
  Sides of beef are separated into quarters by cutting between the 11th and 12th ribs. The beef quarters are transported, by overhanging rail, to the boning process operators who remove meat cuts in turn from the fore and hind quarters; To clarify the terms of bones which applied through the document, the Beef skeletal diagram provided by AusMeat is (1998) can be viewed in Figure 2.1.
- **Side boning**
  The complete beef side is presented to the boning room. Boning process operators remove the same meat cuts from each carcass side;
- **Table boning**
  Carcass sides are broken down to "bone in portions" by scribe saw and knife cuts, and transported to individual operators boning tables by a belt conveyor.

Most plants carry out some preparation work on the carcass using a circular saw to scribe through bones when required, however some side boning chains, producing only boneless beef do not use a saw to carry out pre-work cuts on the carcass.

The majority of meat processing facilities have at least 1 operator and up to 3 operators per shift carrying out these tasks depending upon throughput.

Current Best Practice
The commonly accepted best practice boning is the side boning system, due to the following:

- The beef side is transported as a single unit;
- Product traceability is simplified as the same meat cut from each carcass is removed and processed in production order;
- Operators need only be trained to carry out a small number of tasks;
- System flexibility allowing meat cuts to be prepared that cross over quarter and table bone cut lines.

Yield of Strip loin and cube roll – The high value meat adjacent to the spine is separated from the bones in some plants by the use of hand tools and/or a cutting saw to maximise the product weight of these primal cuts.

The equipment to perform these tasks are:

- Dumbbell and wire, used to dislocate the cartilage from the end of the featherbone prior to the wire being pulled along the bone surface, separating the meat;
- Circular saw or bandsaw cut through the spine bone so that the featherbone and rib bones can be removed separately, increasing the meat yield from the position where these two bones meet.

Although these tasks are vital for increasing production returns the tasks are all simple and repetitive when compared to other boning room tasks, thus they are ideally suited for execution by robotics.

As such one of the first tasks identified in the boning room as a suitable first step for the introduction of robotic equipment is that of the scribe saw tasks – preparatory cuts using a circular saw immediately prior to the boning room.

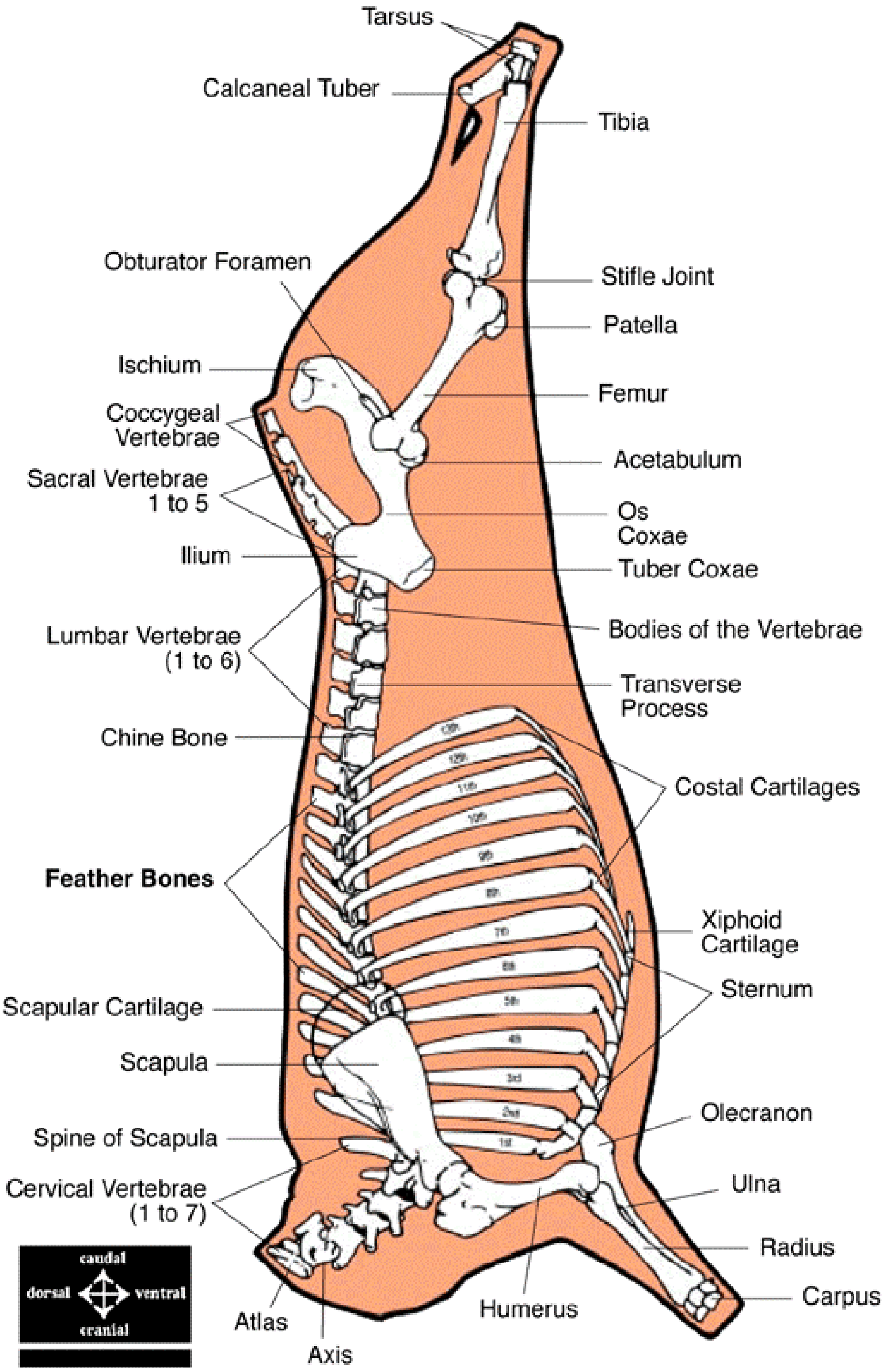


Figure 2.1 Beef Skeletal Diagram[i]

[i] AUS-MEAT Ltd, Handbook of Australian Meat 6th Edition CD-ROM, 1998

3. STANDARDS OF CUT LINES

Standard scribing cuts are described below, these are considered to be standard scribing cuts for meatworks for brisket removal; with b) and c) for preparation of bone-in cuts.

3.1. *DOWNWARD SCRIBES*

a) Brisket Cut – navel to point
b) Short Rib Cut – five rib from the 11th to the 7th rib (inclusive)
c) 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 ribs 4th to 1st rib – cut is marked out from where the 1st rib joins the spine and parallel of navel to point of brisket cut

3.2. *HORIZONTAL SCRIBES*

a) Quarter Cut – through the spine between the 11th and 12th rib to produce hindquarter and forequarter

OR alternatively,

b) Beefside Tri Cut – (US & Japanese standard practice) typically through the spine between the 6th and 7th rib combined with a cut through between the sacral bone and the 7th lumbar vertebrae (cuts a beef side in three pieces)
c) Neck Cut – through the spine between the 1st rib and cervical vertebrae to assist cold neck boning
d) Pistola Cut – through the spine between the 5th and 6th rib

[ii] AUS-MEAT Ltd, Handbook of Australian Meat 6th Edition CD-ROM, 1998

3.3. *BONE-IN CUT COMBINATIONS*

Noting that for each bone-in beef cuts there are many different arrays of cut combinations, i.e. Hindquarter may be produced as follows:

AusMEAT Specification Codes

Hindquarter	**Forequarter**	**Cut Placement**
1010 – 3-rib	1060 – 10-rib	through the spine between the 11th and 12th rib
1011 – 0-rib	1063 – 13-rib	through the spine between caudal to 13th rib
1012 – 1-rib	1062 – 12-rib	through the spine between the 12th and 13th rib
1013 – 2-rib	1061 – 11-rib	through the spine between the 11th and 12th rib
1014 – 7-rib	1064 – 6-rib	through the spine between the 6th and 7th rib
1015 – 8-rib	1065 – 5-rib	through the spine between the 5th and 6th rib

Four scribe cutting lines are pictured in Figure 3.3. The technology development described in the document is to arm the finding of the geometry characteristics and the automatic determination functions of the scribe lines.

Figure 3.3 Scribe cuts on a side of beef

4. SYSTEM OPERATION DEVELOPMENT

Prior to the commencement of this proof of concept stage, it was determined that to achieve a full works prototype robot project outcomes, the following issues must be addressed:

- Process design to separate mechanical work tasks from process operator work tasks
- Cutting (scribe) saw selection
- Beef side stabilisation
- Beef side measurement
- Cut position identification (conceptually in this stage)
- Cut depth control (conceptually in this stage)
- Bone dust & saw cleaning/sterilization (if required)
- Saw movement control (conceptually in this stage)
- Operator / machine interface and safety
- Environmental robustness of the system

Figure 4.1 Manual Operation

4.1. *PROCESS DESIGN*

The manual scribing operation is pictured in Figure 4.1 above. Basically, the scribing operation produces four cuts (see Figure 3.3) as specified by the meat industry standard unless special cuts are required by customers.

From the automation point view as discussed in Section 2, it has been demonstrated that the robot can easily deliver the cuts if the coordinates of the cutting lines are pre-determined. An IRB 4400/60 ABB robot shown in Figure 4.2 has a six degree-of-freedom motion to allow it to orient the end-effector (tool attachment) with 60 kg payload to any point and direction within its operational capacity (i.e. from the base centre the wrist joint can reach 2.14 m in the vertical direction and 1.955 m to the front). From the preliminary tests, it has clearly been shown that the robot's 60 kg payload and the capacity of the handling of circular saw torque are well within the robot's operating ability.

Apart from the coordinate information of the cutting trajectories, there are a few engineering issues as mentioned above, such as beef side stabilisation, beef side measurement and cut depth control that must be considered as well. While other issues, such as 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, and thus would be part of later stages of a full development project.

Figure 4.2 A robot scribing station prototype

4.2. *CARCASE STABILISATION*

Experience in the development of carcass stabilisation systems (during previous projects) has been applied to this task. For example, during the Autosplitter project, a pneumatic centralisation mechanism was designed to ensure carcases can be positioned evenly before the splitting operation.

SKF in Denmark and CEC BRITE-EURAM in UK and Germany have developed other similar stabilisation systems. The manufacturers of these systems claim that the performance of these mechanisms is satisfactory. The stabilisation system to be developed for the robot scribing process will have two operational tasks. One is to maintain a stable position for the carcass to be presented to the vision system; the other is to ensure that the carcass overcomes the force and torque generated by the circular saw.

When the trials were conducted in Oakey, it has found that the images produced by a laser camera system had significant noise. This was due to carcasses swinging. The stabilisation at the carcase scanning station and scribing position will be systematically considered in the next stage (if any) to ensure the scribing operation can be conducted efficiently and accurately.

It has been shown that after a carcass is positioned on 'stabilisation' board, the cut depth can be achieved by controlling the longitudinal movement of the saw carried by the robot. The robot has a repeatability of 0.07 mm. This means that the saw is able to repeat a cut within 0.07mm of the first cut. The 'stabilisation' board surface datum can be pre-programmed within the robot controller. After the saw cuts through the side to a certain distance from the board surface, the robot can automatically return or move along the cut trajectory accordingly.

Figure 4.3 Side of beef is restrained on a 'stabilisation' board

4.3. *PROCESS OVERVIEW*

The following operational flow chart highlights the integration of the robotic scribing operation structure and sequential tasks. It can be seen that there are three main operational streams to be implemented.

They are robot operation, carcass handling and stabilization, and scanning process. In summary, as the handling/stabilization and robot operation are commercial and/or generally proven, the technical development will be concentrated within the machine vision system to perform the scribing trajectory determination. A full description is provided in the next section and the technology and software development details will be presented later in this report.

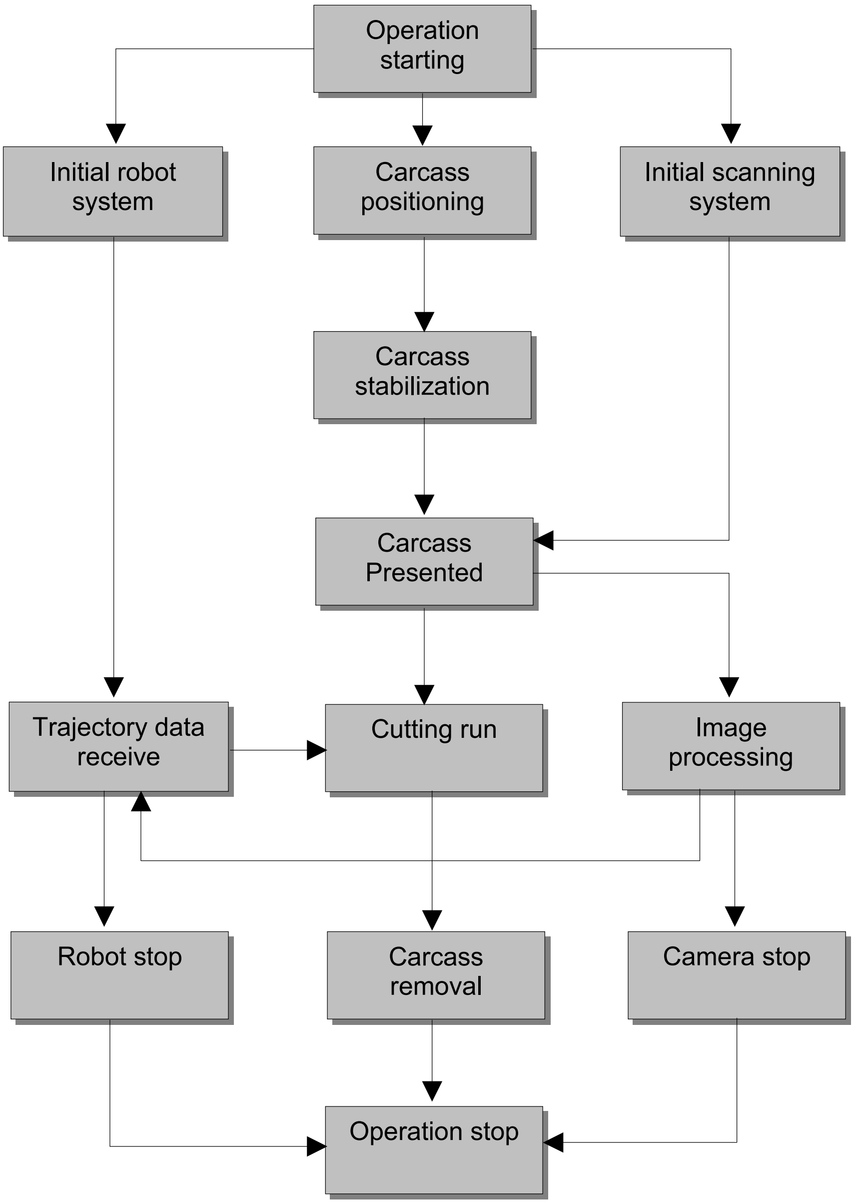


Figure 4.4 Robot scribing operation structure

5. SELECTION OF SAW/CUTTING DEVICE

A review of available saws and cutting devices (with preference given to devices that are currently in use in Australian abattoirs) was undertaken with the aim of selecting a device that will be suitable for adaptation to the robotic environment.

The Kentmaster Equipment (Aust) Pty Ltd Breaking Saw model: HKM-III (with anti-tie down option) was selected as the most appropriate saw/cutting device for use in the Automated Scribing and Boning Room Pre-work project.

Figure 5.1 below shows the Kentmaster Breaking Saw, while Figure 5.2 on the following page shows an assembly drawing of the saw.

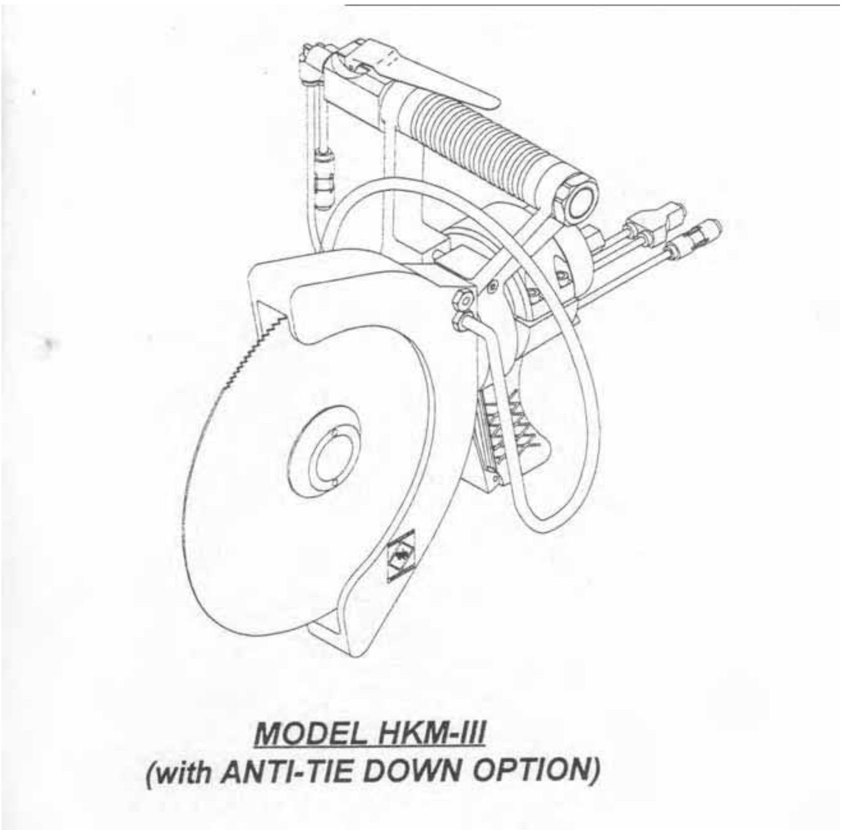
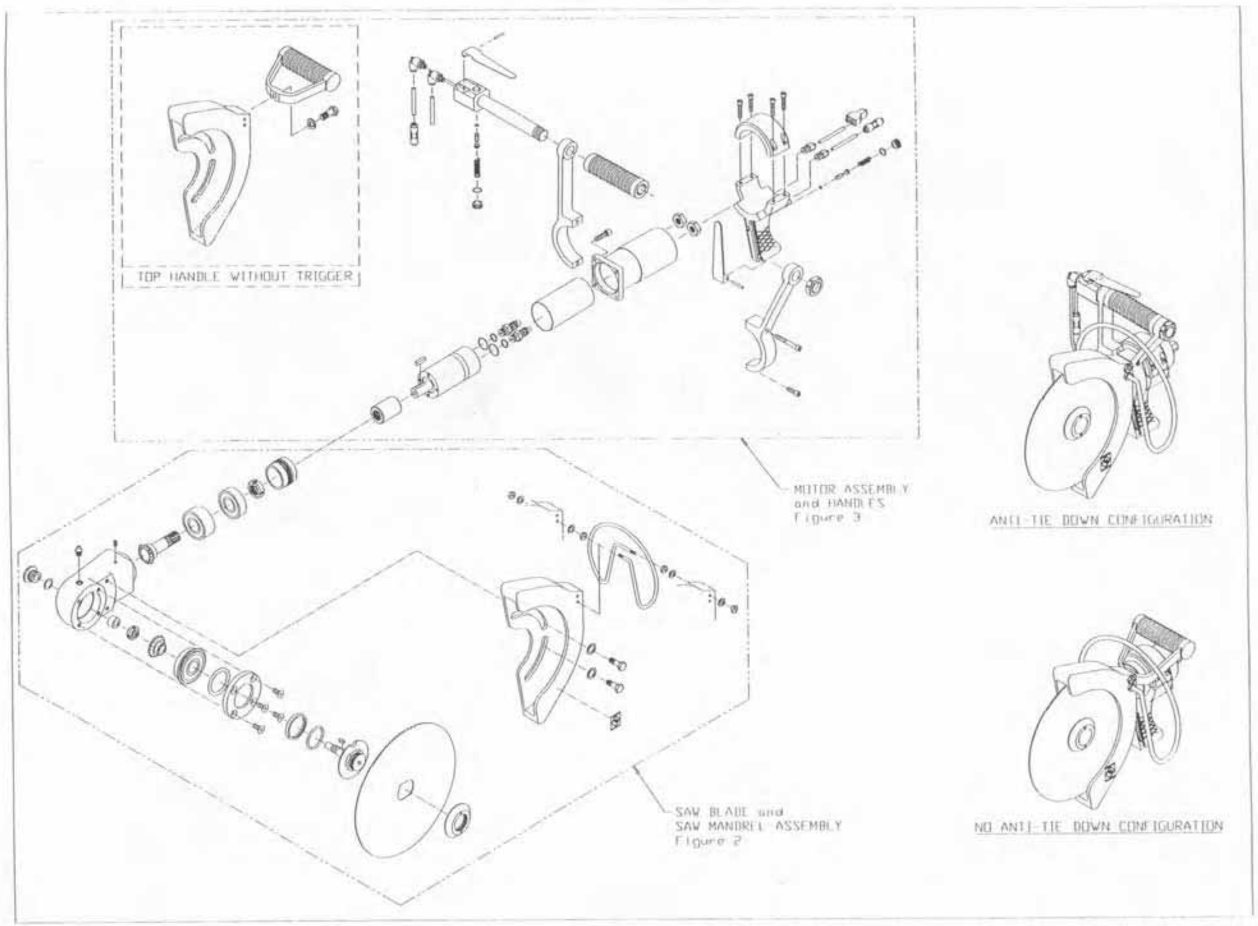


Figure 5.1 Kentmaster Breaking Saw

The main modification to the hydraulic breaking saw that will be required is the pneumatic controls will be altered to provide a hydraulic control system so it is able to operate with the substantial robot forces involved.



M-HKM-III-L & R-A 01-86

BREAKING SAW
MODELS HKM-III-L & R
Figure 1

PAGE 4 of 11

Figure 5.2 Kentmaster Breaking Saw Model HKM-III

6. SURFACE MORPHOLOGY DETERMINATION

6.1. *TECHNOLOGY VS MEASUREMENTS*

The cutting lines shown in Figure 3.3 have been marked with respects to the geometry of a full side of beef. From the cutting line definitions described in the Section 3, 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 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 starting and finish positions of the cuts.
- Determine whether left or right side is being processed (X axis) will determine 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 6.1 Scribe lines marked with respects to one full size of carcass

To determine the above features, a few different approaches were investigated. The intensity image processing method has been widely used in different industries in a repetitive, structured environment. For example, the inspection of an electronic board, with the uniform specifications of the colours and sizes of the electronic components, an industrial machine vision system with colour and pattern matching functions should easily handle the quality inspection processing operation. A carcass physical structure is shown in Figure 6.1.

6.2. *INTENSITY IMAGING*

In Figure 6.2 below, the left hand image is captured with a Canon digital camera, whereas the right hand image is the same but processed with colour extraction, threshold and border and small objects removal functions. The conventional machine vision system cannot provide a clear detection of the bone features and geometry with the colour and intensity information. It needs certain assistance inputs to complete the full extraction of above features.

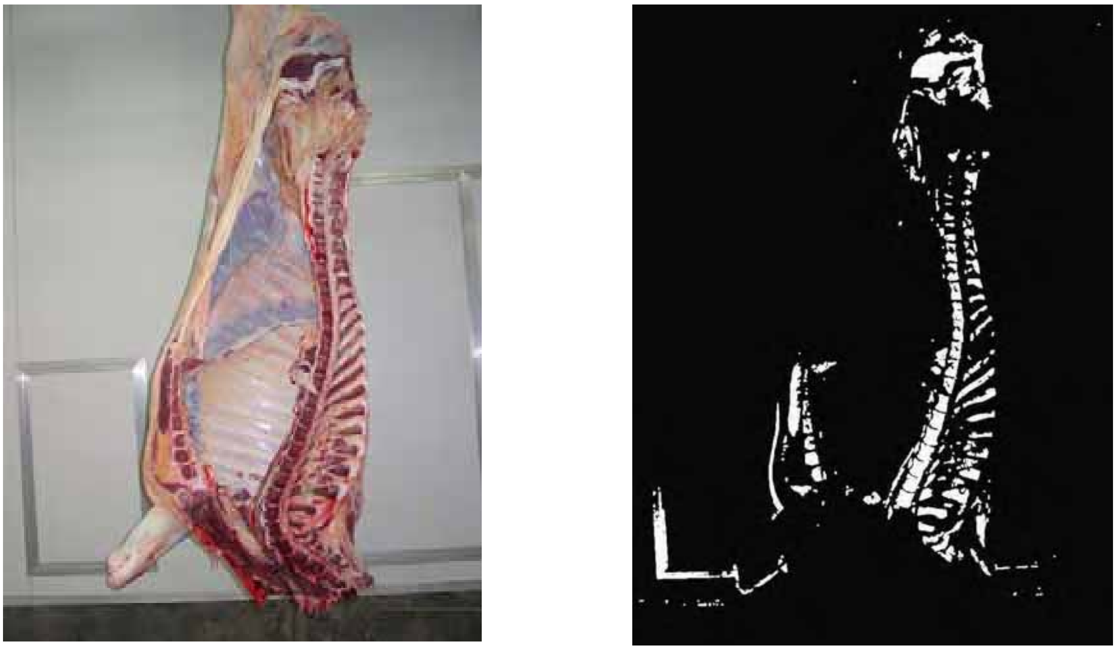


Figure 6.2 Presentation of a side beef (digital photographic image and a processed image)

6.3. *RADIANT IMAGING*

It is believed that the most effective technology that could be applied to determine the rib bone features would be an X-ray type sensing technology. One example is shown in Figure 6.3, an X-ray image (in false-colour) of a small aquarium goldfish by S.W. Wilkins, et al of CSIRO CMST (Nature, Vol. 384, No. 6607, 28 November 1996), including phase contrast, recorded using polychromatic radiation from a microfocus source, in which the details of bones are clearly displayed. The material characteristics (density) of bones can be directly detected by X-ray with the feature of short wavelengths and high frequencies.

However, the handling and implementation of X-ray sensing in the meat industry is difficult, and 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 technologies:

- ultrasound,
- magnetic resonance imaging (MRI)
- and other type technology (eg radar, etc.).

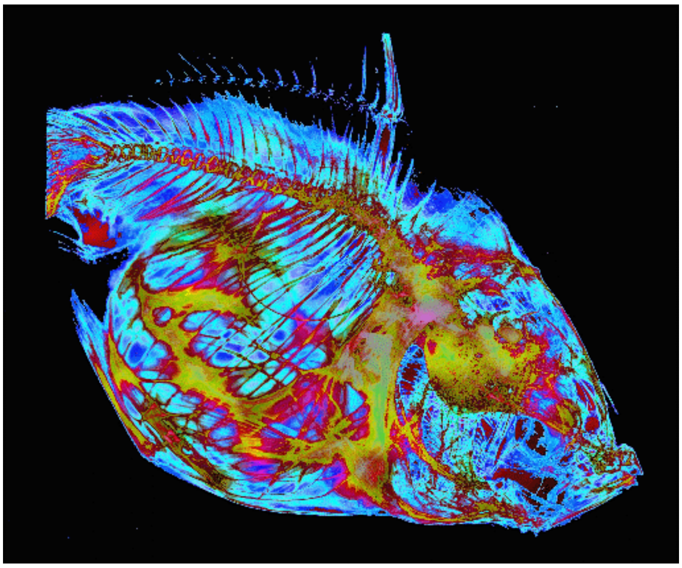


Figure 6.3 X-ray image of an aquarium goldfish

There are also a number of patents outlining the use of X-ray technology for finding bones in carcases prior to processing. However, all of these have gone no further than pure research interest.

Therefore, at this point, the project team decided to select another type of sensor that could be used in addition to the intensity image analysis. One technical motivation throughout this project has been use of geometrical feature findings eg, surface geometry to determine the carcass scribe cut locations.

6.4. *LINE IMAGING*

The IVP Ranger system provides surface geometrical information and was considered to be a suitable method for retrieving the desired physical feature locations. Before the confirmation of the application was made, the measurements and results generated from the IVP Ranger system were examined. The 3D surface scanning is plotted in Figure 6.4. The measurements can be generated from the scan image; two sections along vertical and horizontal sections are examined separately in Figures 6.5 and 6.6. The horizontal section and vertical section profiles have reflected the scanned surface ranges (heights) change, e.g. in vertical section the profile height difference is about 35 pixels, with around the same pixel difference is found in horizontal section.

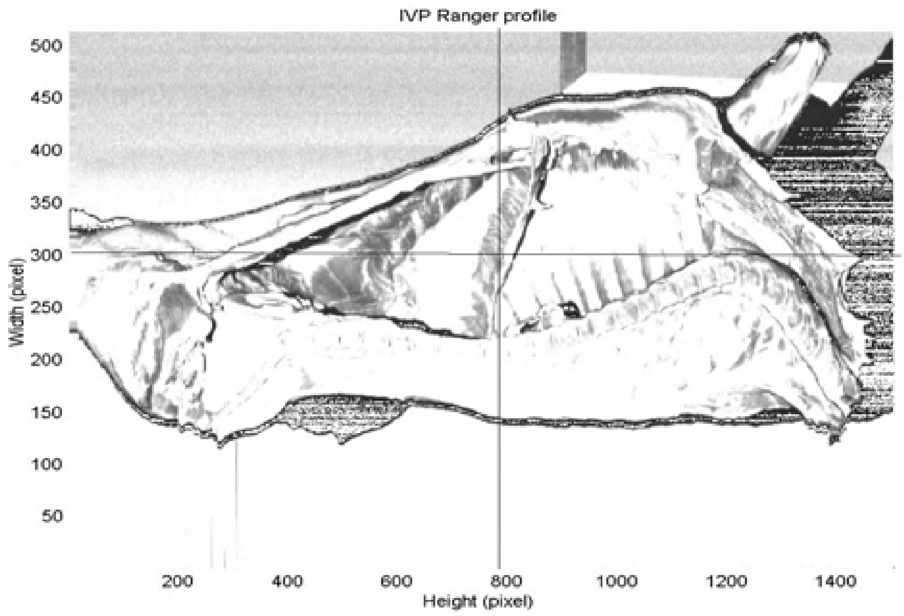


Figure 6.4 IVP Ranger scan image

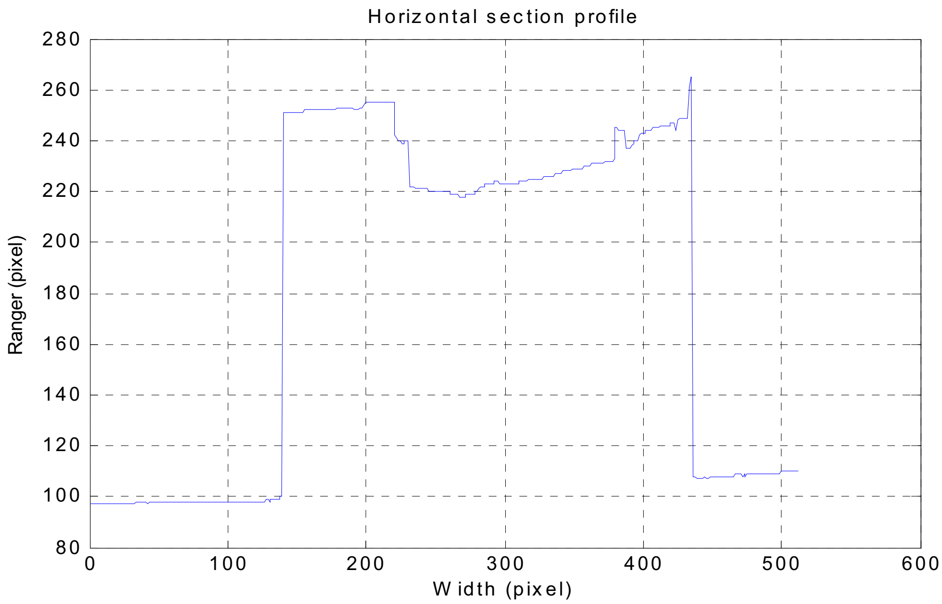


Figure 6.5 Horizontal section profile

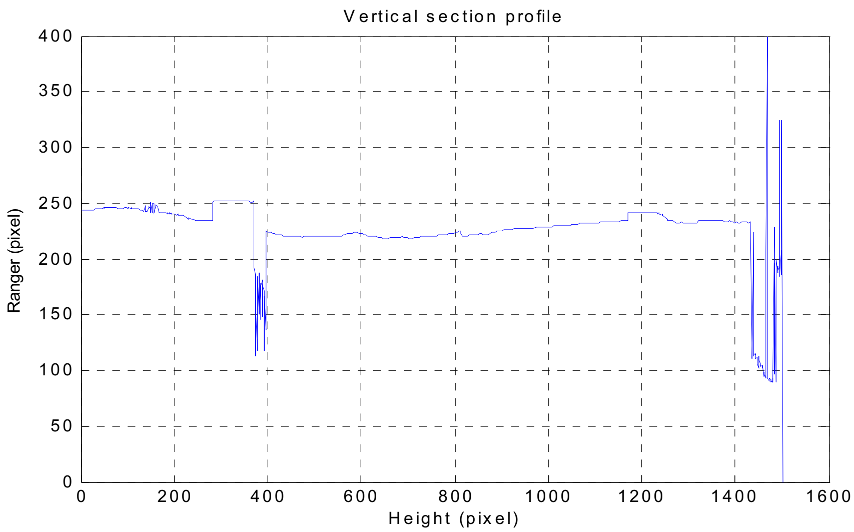


Figure 6.6 Vertical section profile

The carcass surface range variation detected by the IVP Ranger, one immediate program can be developed to find the chest cavity. The function here uses a common height as a reference, and then a contour with respect to the chest cavity was generated and plotted out as shown in Figure 6.7. The specific algorithm developed in Matlab outputs three coordinates of the contour directly. 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.

Therefore, with the 3D surface geometrical information, the chest cavity contour, leg profile and outline contour can be obtained. These are some of the key geometrical features required to determine scribe cuts.

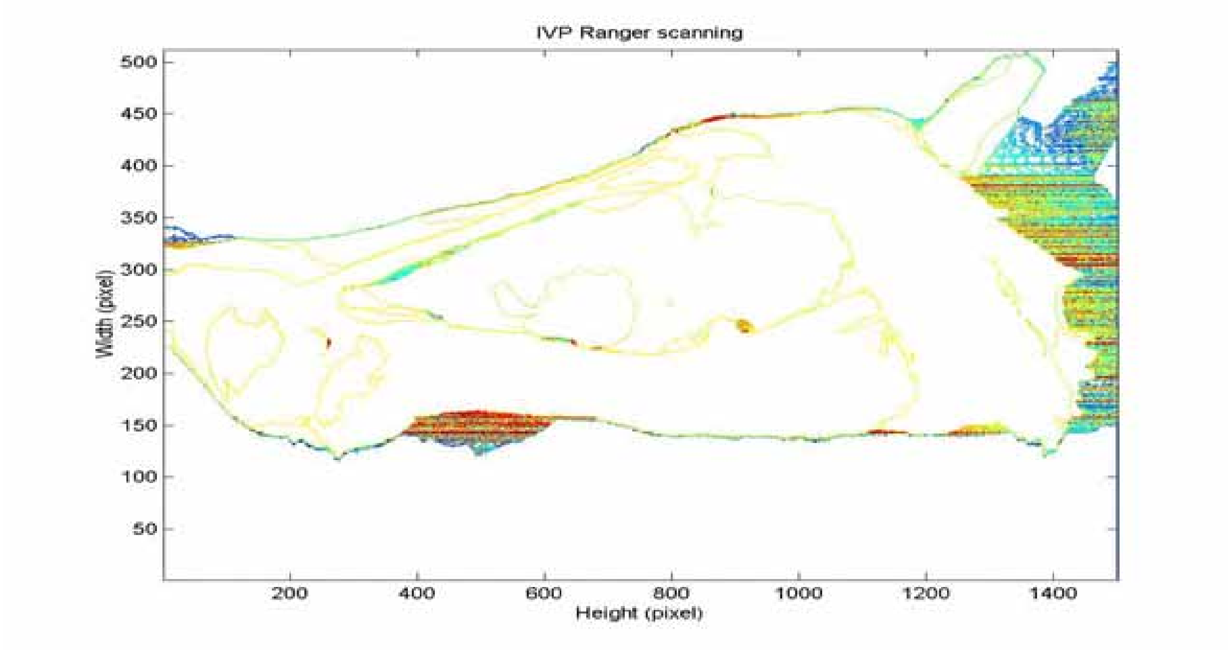


Figure 6.7 Contour function to find the chest cavity

7. RANGE IMAGING AND SYSTEM SET-UP

7.1. *RANGING IMAGING*

The development of the sensing technology to feasibly perform the determination of cutting lines involved the investigation an application of a 3 dimensional (3D) image system. Many machine vision users discover that traditional 2 dimensional (2D) vision systems simply cannot handle more advanced inspection tasks.

While 2D vision systems can solve many inspection applications, it cannot, as mentioned previously, handle low contrast conditions or measure an object's height. The IVP Ranger SAH5 is an off-shelf 3D image scanning system. It contains the MAPP 2500 Smart Vision Sensor (SVS) with an interface to the instruction port and a high-speed serial interface (HSSI).

The "Smart Vision Sensor" integrates a 512 x 512 pixel sensor, 512 A/D converters, and an image processor all on the same 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. The camera unit is supplied with 12 - 24 V and has a power consumption of 6 W. The IVP Ranger SAH5 is able to work stand-alone in an industrial process or in cooperation with other computers. The camera has three general inputs, three general outputs and one RS232 serial port. With the High-Speed Serial Interface the unit can send and receive data at high speed (maximum 260MBit/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.

The range profiles are acquired using laser triangulation, and the technique is known under a variety of names such as sheet-of-light range imaging, laser profiling and lightstripe ranging. Throughout this report it is referred to as sheet-of-light range imaging.

Figure 7.1 An intensity and a range image of a hand

Normally, the image from a camera depicts the intensity distribution of the viewed scene as in the left image above. A range camera, on the other hand, depicts the distance from the camera to the objects of the scene, see the right image in Figure 7.1. Dark areas are far away from the camera, and light areas are close to the camera.

Many active range imaging techniques use a scheme where the scene is illuminated from one direction and viewed from another. The illumination angle, the viewing angle, and the baseline between the illuminator and the viewer (sensor) are the triangulation parameters. The most common active triangulation methods include illumination with a single spot, a sheet of light or coded light. In single-spot range imaging, a single light ray is scanned over the scene and one range datum (rangel) is acquired for each sensor integration and position of the light.

Thus, in order to obtain an MxN image, MxN measurements and sensor integrations need to be made. In a coded light range camera the scene is illuminated with several coded patterns. The patterns can for instance be phase coded or gray coded. For instance, with the gray coded approach logR patterns are required to obtain a resolution of R levels. Therefore, integrations are needed to form one MxN image. Finally, in sheet-of-light range imaging a sheet (or stripe) of light is scanned over the scene and one row with 4 rangels is acquired at each light position and sensor integration, see Figure 5.2. In this case only N measurements and integrations are required to produce an MxN image.

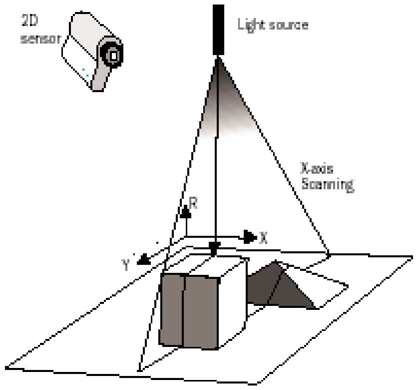


Figure 7.2 Sheet-of-light range imaging

In a sheet-of-light system the range data is acquired using triangulation. The offset position of the reflected light on the sensor plane depends on the distance (range) from the light source to the object, see Figure 7.3. Using trigonometry we can solve the equations for the range if we know the distance between the laser and the optical centre of the sensor (the base line) and the direction of the transmitted ray. The third triangulation parameter, the direction of the incoming light ray, is given by the sensor offset position. For each position of the sheet-of-light the depth variation of the scene creates a contour, which is projected onto the sensor plane. After extracting the position of the incoming light for each sensor row it obtains an offset data vector, or profile, that serves as input for the 3D computations. To make a sheet-of-light, the sharp laser spot-light passes through a lens, see. The lens spreads the light into a sheet in one dimension while it is unaffected in the other dimension.

As mentioned, two-dimensional range images can be obtained in at least three ways:

- by moving the apparatus over a static scene as designed here,
- by moving the scene along a conveyor belt, or
- by sweeping the sheet-of-light over a static 3D-scene using a mirror arrangement.

In any case, for each illumination position and sensor integration, in the first processing step, the output from the 2D image sensor should be reduced to a 1D array of offset values.

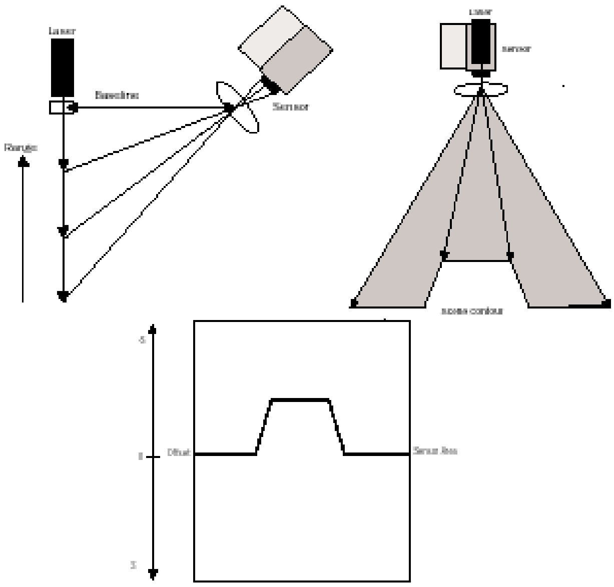


Figure 7.3 A range camera using sheet-of-light.

Figure 7.3 A, top left, shows the illumination with the sheet-of-light perpendicular, Figure 7.3 B, top right, parallel to the plane of the paper. Figure 7.3 C bottom, is a snapshot of the sensor area.

7.2. *SET-UP OF THE 3D RANGE IMAGING SYSTEM*

The system developed to drive the range imaging system is shown in Figure 7.4. The components assembled with the system are schematically illustrated in Figure 7.5.

Figure 7.4 Set-up of range scanning system at FSA Cannon Hill Lab

Basically, it is an electro-pneumatic system. After a carcass is positioned motionless at the scanning station, the linear pneumatic 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. While the displacement of the Z axis is generated by the drive. The scanning accuracy and resolution in 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, valve and quality of the Temposonics linear displacement sensor.

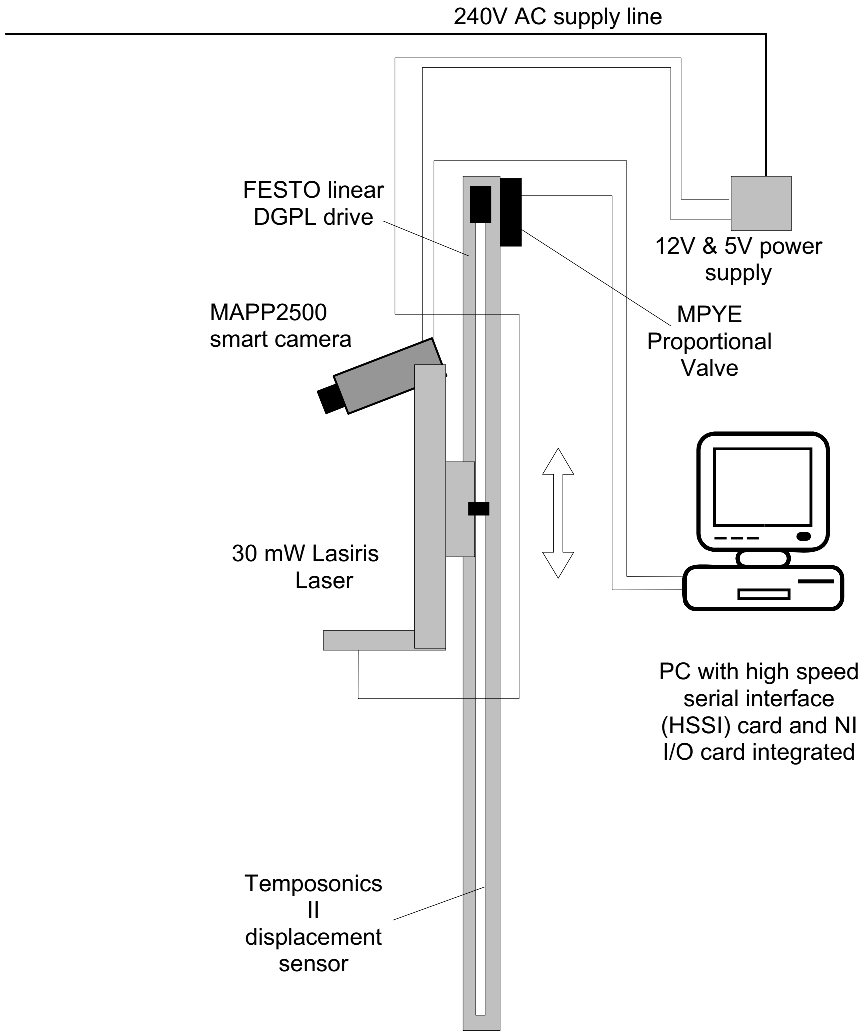


Figure 7.5 Schematic of Component Integration in Range Imaging System

A National Instruments I/O card installed on the computer governs the positioning for the initial position, velocity and stop position. The control interface for the motion of the system is shown in Figure 7.6.

From the software control panel it can be seen that the system has incorporated a PID control scheme to achieve speed and accuracy of the motion, and at the same time, the system has been developed with a position related triggering function. To ensure the scanned profile can be recorded with respect to the distance along the Z axis, the reading from the Temposonics sensor is acquired in real time and the increment is calculated accordingly. For example, with a 1 mm increment setting, the software will automatically output one pulse signal to a programmable function input (PFI) channel, when the scanning system is moved 1mm from the pre-triggered position along the Z axis by the linear actuator. Therefore, the displacement of the third axis is also precisely recorded.

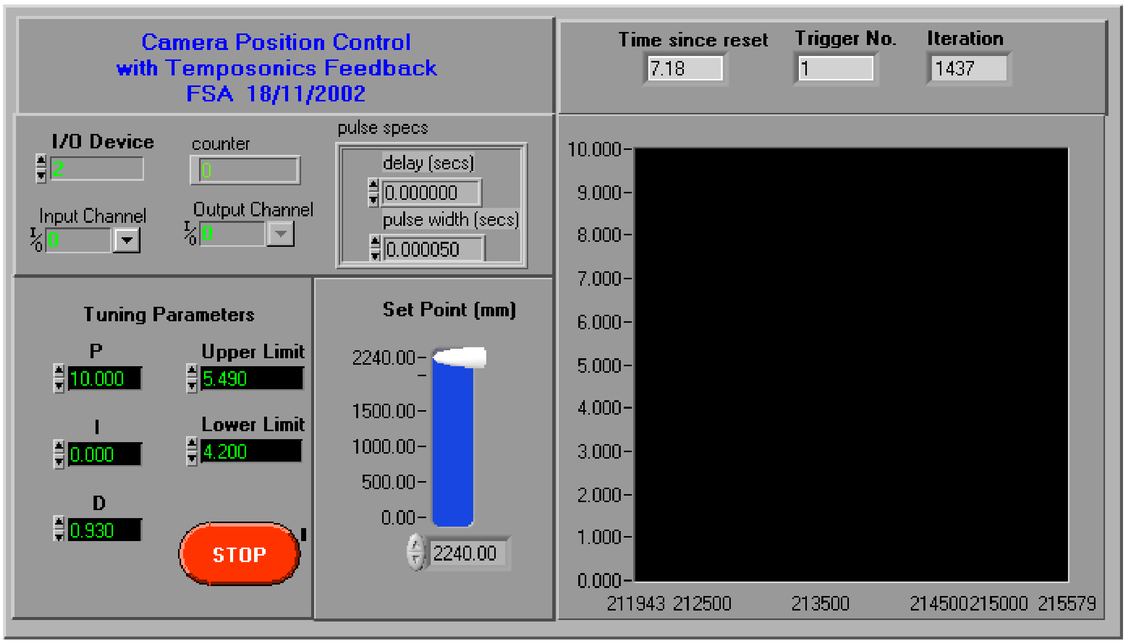


Figure 7.6 Control panel of IVP Range linear drive

8. DEVELOP CUT LINE IDENTIFICATION SOFTWARE

8.1. *IMAGE ACQUISITION*

To understand the image acquisition of IVP Ranger, two concepts within the system described in this section, they are the algorithms and data handling.

In IVP Ranger, the algorithms are implemented with the light-sheet projected horizontally or vertically on the sensor, see Figure 8.1. When the light sheet is vertical the PEs are used as one 256-bit processor to find the position of the sheet-of-light impact position of each row in a serial fashion. When the sheet-of-light is horizontal the PEs are used as 256 independent bit-serial processors, where all PEs find their own sheet-of-light impact position in their respective columns in parallel. Thus, with a vertical sheet-of light each sensor row processing gives one position value rangel whereas with a horizontal sheet-of-light each processor delivers one position value rangel, after all sensor rows has been processed. IVP Ranger contains both horizontal and vertical algorithms, and below some of the pros and cons of vertical and horizontal algorithms are discussed.

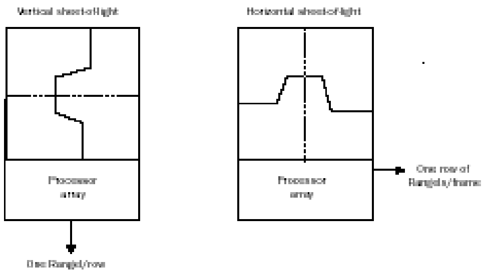


Figure 8.1 Vertical and horizontal sheet-of-light range imaging on MAPP2200.

8.1.1. VERTICAL ALGORITHMS

With a vertical sheet-of-light, range images with less than 256 samples per range image row are obtained by only utilizing a fraction of the sensor rows, see Figure 8.2. This does not change the rangel frequency, and thus the range profile frequency increases. For instance, if we generate profiles with 128 instead of 256 rangels the profile frequency can increase by a factor 2. In the vertical algorithms there is support for binning (analog summation) of 2 or 4 sensor rows, giving 128 and 64 rangels per profile. There is also support to select the first and last row to access, making it possible to choose the resolution arbitrary up to 256 (the number of rows). IVP Ranger also supports user specified row access, making it possible to have different sample density in different parts of the range profile.

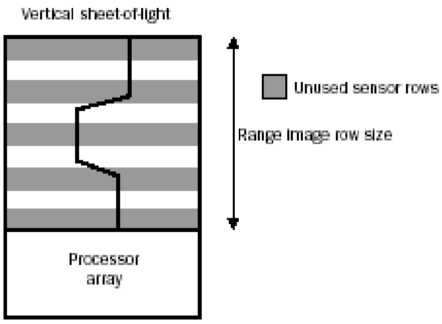


Figure 8.2 Increasing the range image speed by decreasing the image size

8.1.2. HORIZONTAL ALGORITHMS

With a horizontal sheet-of-light it is possible to increase the range pixel frequency by limiting the offset position resolution to a fraction of the sensor, see Figure 8.3. This can be done in two ways, either by using maximum accuracy over a smaller range interval, or by using lower accuracy over the maximum range interval. If we only process a fraction of consecutive rows we obtain maximum accuracy over a fraction of the range interval. This is supported in IVP Ranger.

It is also possible to address several sensor rows concurrently and read out the analogue sum of the rows to the A/D converters. If we process, say, the analogue sum of pairs of rows we obtain range images with half of the maximum range resolution over the whole range interval. This is currently not implemented in the Ranger package. IVP may be contacted for more information about the scheduling of this addition.

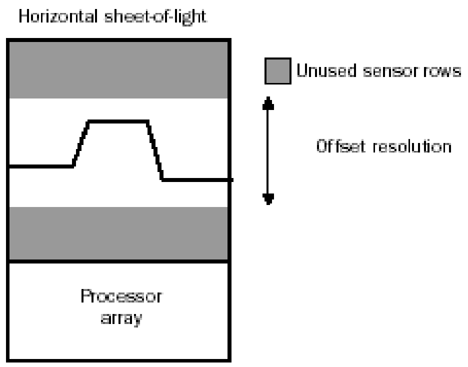


Figure 8.3 Increasing the range pixel speed by decreasing the range resolution

8.1.3. LOCALIZING THE IMPACT POSITION ON SENSOR

It is assumed that the scene contour is reflected vertically along the image array as in the left image in Figure 8.1. Along a row in the sensor, the sheet-of-light reflected from the 3D scene may produce a signal as in Figure 8.4. Various rules and algorithms may be formulated to derive a unique impact position (pos) from this 1D signal. The most natural procedure may be to find the position of the maximum intensity.

Alternatively, we can threshold the signal and find the mid-position of the pixels above the threshold. Analogue devices such as position-sensitive devices measure the centre-of-gravity of the in coming light and this can also be computed with pixel-based sensors such as the MAPP.

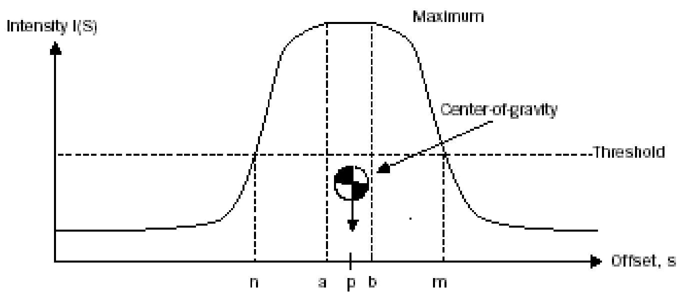


Figure 8.4 An illustration of three different ways to find the laser reflection.

As indicated in Figure 8.4, even if the signal is well-behaved, the localization of the maximum of a discrete and quantised signal might be ambiguous. Assuming that the signal maximum is flat in the interval a<=x<=b the position would naturally be chosen as

$$pos = \frac{(a+b)}{2} \quad (1)$$

An approximation may also be given by or &. Obviously, this simplification is allowed only if it is ensured that the interval b-a is small. If we use threshold the peak mid-position is given by

$$pos = \frac{(m+n)}{2} \quad (2)$$

where *n* and *m* are respectively the first and last positions with a pixel value above the threshold, see Figure 8.4. For signal peaks with a width of an even number of pixels equations (1) and (2) result in a position halfway between two pixel centres. This tells us that these formulas give answers with half-pixel resolution (sub-pixel resolution).

The centre-of-gravity position using the total signal is given by

$$pos = \frac{\sum_x XI(x)}{\Sigma I(x)} \quad (3)$$

where x is the pixel column position and I(x) the pixel intensity. The centre-of-gravity computation has a high resolution and may be in the order of 1/10 of a pixel. However, the accuracy of the result is often affected by noise and may be much less than that. Both the maximum and centre-of-gravity techniques can be combined with thresholding, so that only values above a threshold are considered in the computations. This makes the computations less sensitive to noise and background illumination.

Maximum-finding can also be combined with multiple thresholds to increase the position resolution. The IVP Ranger package contains maximum and threshold algorithms. The threshold and maximum algorithms are implemented both horizontally and vertically. This gives us 2 algorithm classes with 4 different implementations.

The vertical maximum-finding algorithm can also be combined with extra thresholds to give better resolution.

8.2. *DATA HANDLING*

All data that is transmitted over the HSSI is packaged in *message* according to a well defined protocol, see the IVP Ranger PC API section for details. Each message consists of one 256 B *block* of header information and 0-65535 blocks of data.

The camera unit contains a RAM area named VRAM, which is used for buffering of HSSI messages. In many IVP Ranger algorithms the data is never buffered in the VRAM as stated above, instead it is transmitted direct from the Dataport of the MAPP chip to the HSSI adapter board. In this case only the header information is stored in VRAM, and transmitted when required. The VRAM for IVP Ranger SAH5 camera, is 2063 Blocks long.

The HSSI adapter board contains a 2048 Block long Fifo memory. The NT device driver automatically transfers data, using DMA, from the HSSI ad-pater board into buffers in PC system memory. From this buffer data, it is moved into user accessible memory areas upon request. After each data request is satisfied, a user specified code (a callback) is called to notify the user that the transfer occurred, or notify of any error. The data transfers require little processing overheads, but it is worth to note that the longer each message is the fewer number of data transfers are required. Therefore it is better to send large messages than small. The size of the buffer in the PC system memory has to be at least twice the size of the largest incoming message. The buffer size is 6 MB per channel default, but can be changed using the IVP Driver Configuration tool.

8.3. *IVP RANGER PC APPLICATION INTERFACE*

IVP Ranger PC library contains functions for smart camera communication and system setup. It also contains functions for buffering and access of the data received on the HSSI channel via the SCadapter board. The software program listed in the follows which is an example of a generic implementation of profile acquisition with live mode and horizontal thresholding algorithm.

Program 1: A generic implementation of IVP Ranger profile acquisition

```
// ************************************************************************
//                    PCMain.cpp
//                    RANGER PC Consol application example
//                    a generic implementation of profile acquisation
//
// ************************************************************************

#include <stdio.h>
#include <math.h>
#include <conio.h>            // Console io functions
#include <stdlib.h>

          // Include files needed
#include "rangdef.h"          // Ranger type definitions
#include "r_prot.h"           // Ranger communication definitions
#include "rangerr.h"          // Ranger error list
#include "rangerAPI.h"        // RangerAPI on PC

//        Required error & string callback handlers
void StringCallback( char * pMsgBuff)
{
          printf(pMsgBuff);
}
void ErrCallback( WORD ErrNo)
{
          char *pString;
          RangerGetErrorString(ErrNo,&pString);   // Get the error text for the Error #
          printf(pString);
}

void main()
{

          WORD ret;   // Common return value
          WORD camID = 1; // My id of the used camera
          WORD board = 0; // Is always 0 if only 1 board in PC
          WORD channel = 0;  // the used channel, can be  0/1
          WORD comPort = 1;
          DWORD baudRate = 115200;  // Baud rate default 115200
          WORD parity = RS232noParity;  // Defined in rangerAPI
          WORD stopBits = (WORD) oneStopbit;
          BOOL ComPortPrms = FALSE; // Indicates if Com or Hssi is used as command channel
```

```
            // Initiate handling of string & error messages from
            // Camera & API
RangerInitStringErrorHandler( StringCallback,ErrCallback );
            // Set up communication with the camera
ret = RangerInitOneCamera( camID, board, channel,comPort,ComPortPrms,
            baudRate,parity,stopBits );
if (ret != RANGER_ERROR_OK)
{
                        char *pString;
            // Get the error text for the Error #
            RangerGetErrorString( ret, &pString);
            printf("Initialization error:");
            printf(pString);
            getch();
            exit(0);
}
printf("Initialization OK\n");
            // When camera is initialized, Load parameters from file
ret = RangerLoadCameraParameters( camID, "Rang.ini" );
if (ret != RANGER_ERROR_OK)
{
                        char *pString;
            // Get the error text for the Error #
            RangerGetErrorString( ret, &pString);
            printf("Parameter download error:");
            printf(pString);
            getch();
            exit(0);
}
printf("PRM download OK\n");
            // When parameters downloaded, start receiver
ret = RangerStartLive(camID);
if (ret != RANGER_ERROR_OK)
{
                        char *pString;
            // Get the error text for the Error #
            RangerGetErrorString( ret, &pString);
            printf("Start Live error:");
            printf(pString);
            getch();
            exit(0);
}
printf("Live started OK\n");
enum MessageContentEnum algorithm = RANGERHORTHR;
enum RunModeEnum mode = RANGERRUNCONT;

            // Start the algorithm in the camera
ret = RangerRunAlgorithm( camID,algorithm, mode);
if (ret != RANGER_ERROR_OK)
{
                        char *pString;
            // Get the error text for the Error #
            RangerGetErrorString( ret, &pString);
            printf("Run algorithm error:");
            printf(pString);
            getch();
            exit(0);
}
printf("Run algorithm ok\n");
printf("Hit a key to exit\n");

WORD tOut = 1000; // Receiver timeout in milliseconds
struct GenericHeaderStruct *pHead;
struct GenericDataStruct *pData;
struct ProfileMessageStruct *pHead2;
DWORD nrOfMissed;           // Possible missed data in receiver loop
BOOL cont = TRUE; // continue or stop
WORD profSize;
BYTE *pTmp;
DWORD Sum;
```

```
int i,j;
        // Run a receiver until kbhit or error
while ((!_kbhit()) && (cont == TRUE))
{
                // Get the next profile from the receiver
        ret = RangerGetLive( camID, tOut, &pHead,&pData, &nrOfMissed );
        if (ret != RANGER_ERROR_OK)
        {
                        char *pString;
                // Get the error text for the Error #
                RangerGetErrorString( ret, &pString);
                printf("Get Live error:");
                printf(pString);
                cont = FALSE;
        }
                // Check message type
        if (pHead->Message == RANGERMESSAGEPROFILES)
        {
                pHead2 = (struct ProfileMessageStruct *) pHead;  // Correct header
                        // Check message format
                if (pHead2->Format == RANGERBYTEPOINTS)
                {
                        // In BYTE points: 1 Byte/point.
                        profSize =  (WORD) ceil((float) pHead2->Points/ (float) BLOCKSIZE); // Number of Blocks for
the data
                }

                Sum = 0;  // Reset sum

                        // Go through data
                for (i=0;i<pHead2->Profs;i++)
                {
                        pTmp = (BYTE *) (pData +i*profSize); // Point to correct profile
                        for (j=0;j<pHead2->Points;j++)
                        {
                                Sum += *pTmp++; // Sum all data in profile
                        }
                }
                printf("\r Tag: %d Missed: %d Sum is %lu            ",pHead2->Tag,nrOfMissed,Sum);  // Print value
        }
        else
        {
                printf("\nGet Live error:\n");
                cont = FALSE;
        }


}
printf("\n");

// Stop the camera application
ret = RangerSendStop( camID);
if (ret != RANGER_ERROR_OK)
{
                char *pString;
        // Get the error text for the Error #
        RangerGetErrorString( ret, &pString);
        printf("Ranger stop error:");
        printf(pString);
}

// Stop the live receiver loop
ret = RangerStop(camID);
if (ret != RANGER_ERROR_OK)
{
                char *pString;
        // Get the error text for the Error #
        RangerGetErrorString( ret, &pString);
        printf("Ranger stop error:");
        printf(pString);
```

```
	}

	// Relase the serial & hssi resources
	ret = RangerReleaseAPI();
	if (ret != RANGER_ERROR_OK)
	{
				char *pString;
		// Get the error text for the Error #
		RangerGetErrorString( ret, &pString);
		printf("Ranger release API error:");
		printf(pString);
	}
	getch();
	printf("Hit a key to exit application\n");
	getch();
}
```

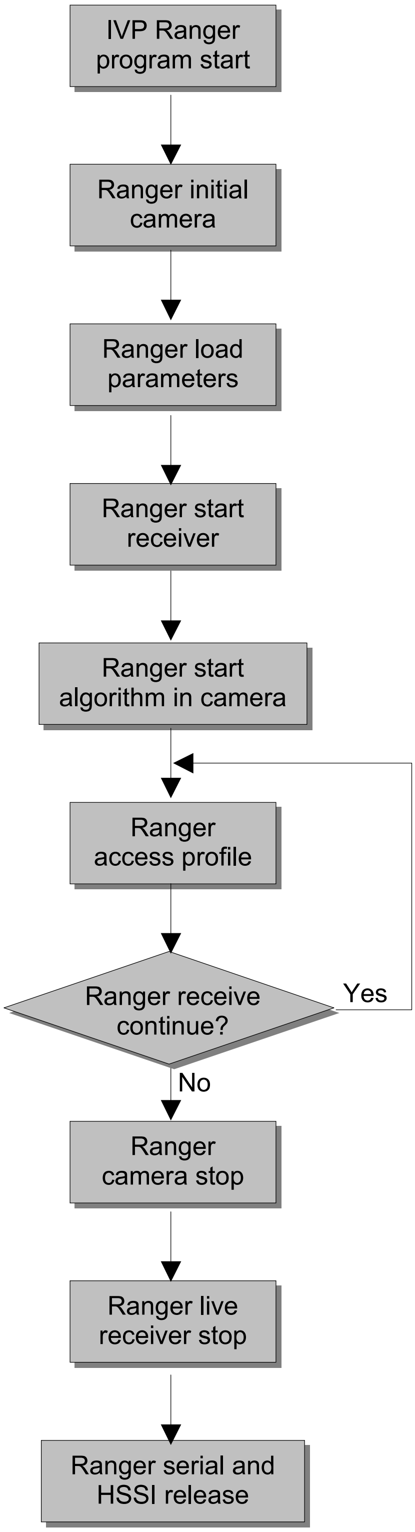


Figure 8.5 IVP Ranger application program structure

Basically, the program structure and operational flow is illustrated as Figure 8.5. The library functions wrapped as API DLL are available from IVP Ranger software. However, as the system has been integrated with the linear drive system with National Instruments (NI) I/O card, in order to keep the system interface simple, the program DLLs are all converted into NI library Vis (Vision Instrument blocks). Finally the new IVP Ranger application program is developed as shown in Figure 8.6. IVP Ranger and NI drive have been merged together as a uniform integration. Therefore, it provides much easier operation by implementing a single interface program. Having looked at the diagram behind the interface panel, it has been found that the program consists of several VIs (LabView vision instrument blocks). These VIs are becoming independent function components with error handling features.

Figure 8.6 IVP range acquisition interface

The system being trialed is placed approximately 3000mm from the carcass being scanned. The camera and laser are moved vertically using a pneumatic slide with a travel of 2250mm. The slide is equipped with a position encoder that is used to trigger the IVP Ranger system so that range profiles are captured at regular spatial intervals.

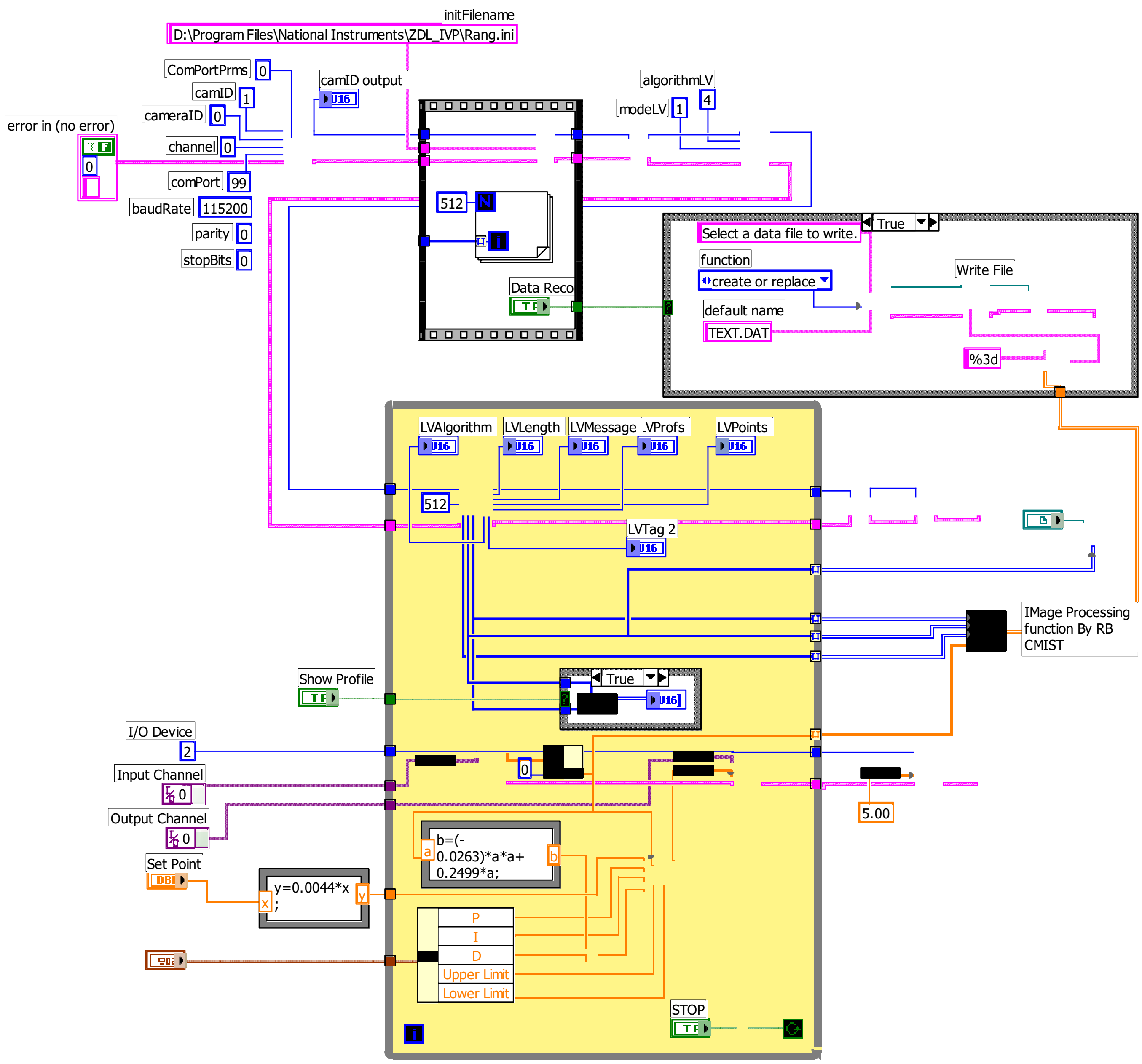


Figure 8.7 Diagram of the operation interface with customised VIs developed

8.4. *IMAGE ANALYSIS*

8.4.4. STEPS

The image analysis of organic material can be a complex task. The main issue, in this case, is to identify 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.

The steps required are as follows:

1) Identification of side outline.

2) Determine whether the left or right side is being processed.

3) Segment the chest cavity and locate critical features (brisket point).

4) Locate visible ribs.

5) Count vertebrae.

Steps 3, 4 and 5 are the most difficult. It is not yet clear whether it is possible to extract this information from the range image. Step 5 is the most likely to be difficult to achieve using range information.

The diversity of beef sides requires a high level of robustness from the image analysis algorithms. The most robust approach is likely to combine some high level anatomical knowledge with morphological filtering and segmentation. 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, which will help locate regions within the carcass side which requires more complex processing.

8.4.5. PROTOTYPE CODE

The prototype version 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 only the most 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 brisket point.

4) It is also possible to begin looking for much more subtle features, such as the ribs. The ribs are very slightly raised relative to their surroundings, but the difference is very slight and not always detectable using the IVP system. 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. This provides an estimate of rib base positions and inter rib spacing. Future work may enable segmentation of all the ribs which will make it possible to select cuts very flexibly.

5) It is not yet clear whether locating individual vertebrae using the range data is feasible, and if the rib segmentation is successful it won't be necessary. It is likely that the intensity image will be more useful because the cartilage between vertebrae is quite visible.

Figure 8.8 Processed image

Apart from the surface morphology determination of IVP Ranger unique scanning functionality, and the IVP system also has a live image acquisition function. If the image taken by IVP Ranger can be analyzed during the scanning process, the extra information can help improve the accuracy of the determination of the scribe cuts significantly. With the functions provided by VisionBuild package from NI, a generic image processing program has been developed which can be incorporated into the IVP operation interface as well. The processed images are shown in Figure 8.9 on the next page. The functions applied are:

- Color extraction
- Gray morphology
- Remove small object
- Remove large object
- Edge detection
- Particle filter

The spine bone and joints are clearly detected and the horizontal scribe cuts directions and position can be determined by the image analysis too. This extra analysis information can either improve the IVP Ranger detection accuracy or simplify the IVP scan processing (i.e. reduce the number of profiles and resolution, or increase the scanning speed).

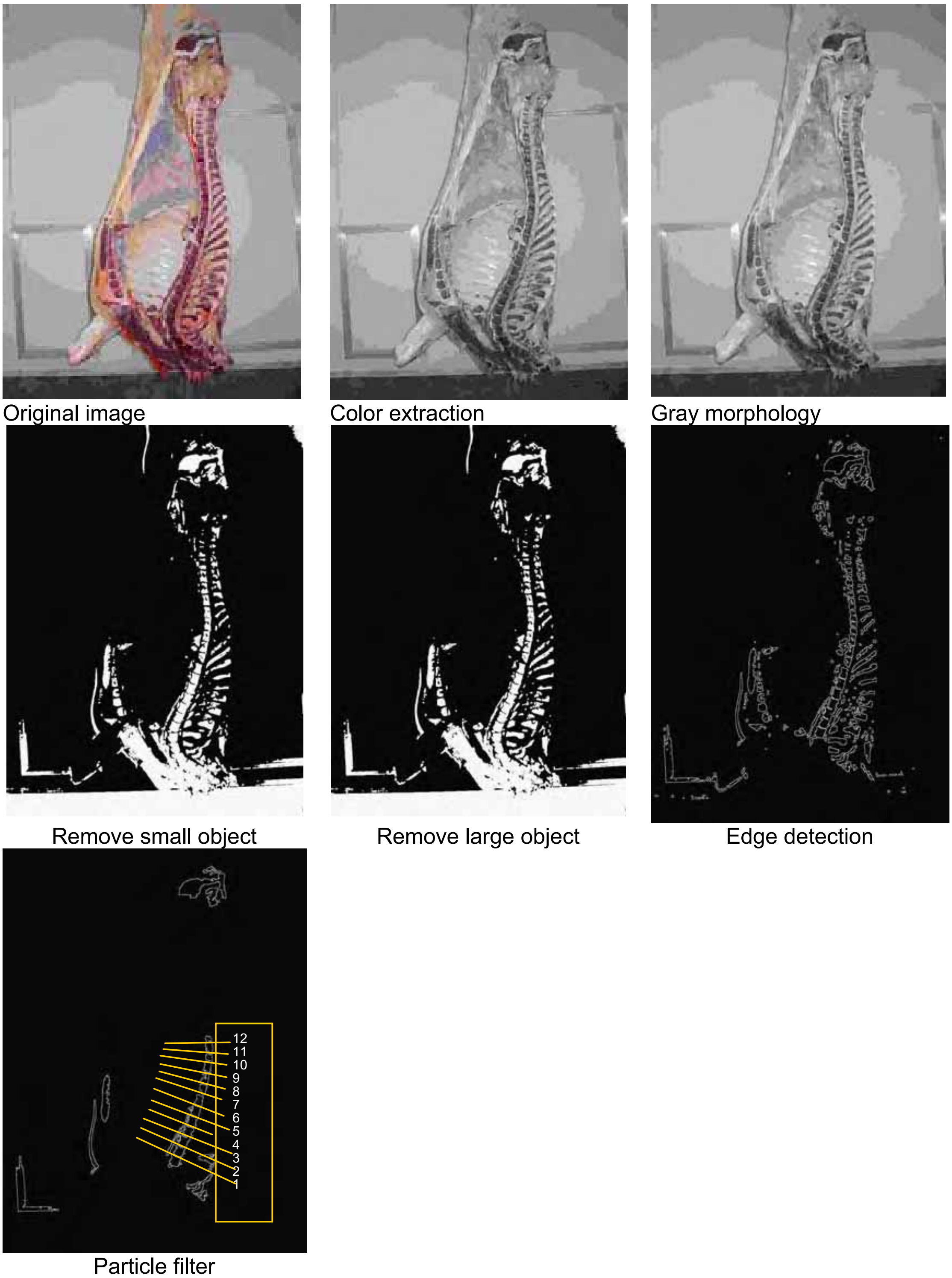
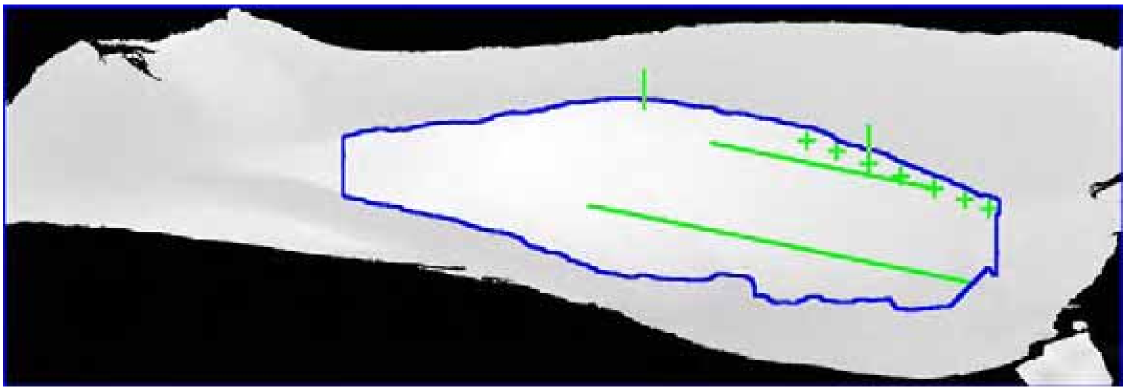


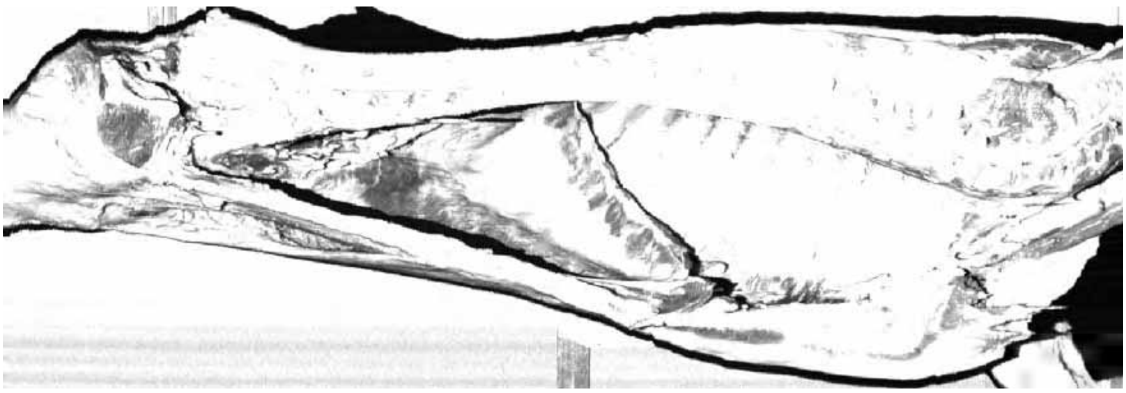
Figure 8.9 IVP Ranger processed images with different functions

8.4.6. SAMPLE IMAGES

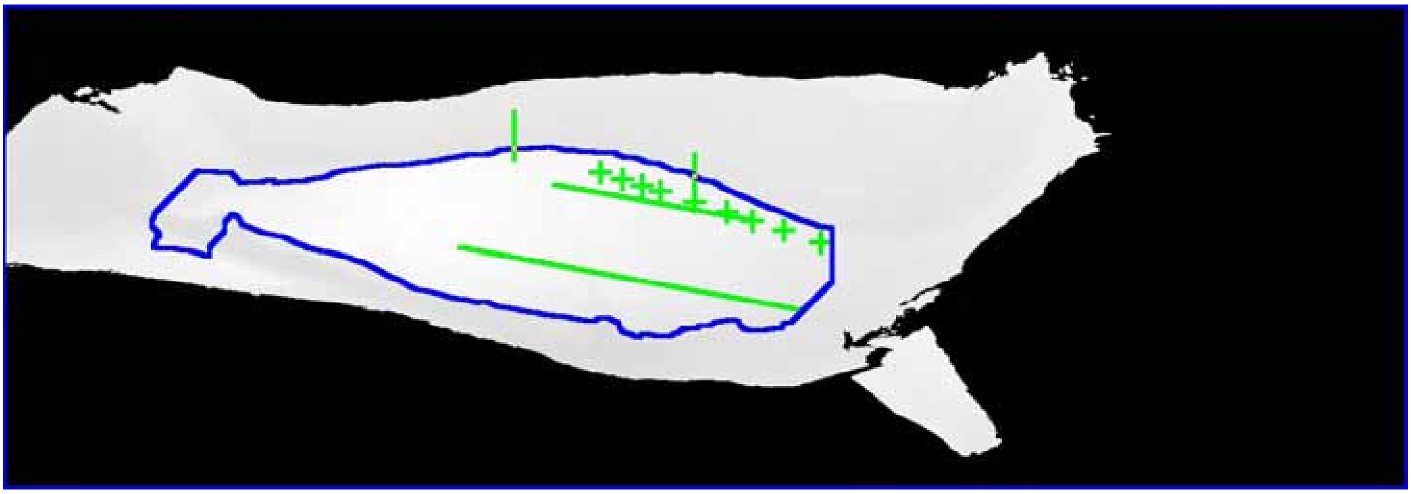
The following images illustrate the image capture and subsequent generated and analysed images. The first image is the Canon Digital photograph, the second image is the Cut line determination and, the third image is the surface profile generated from IVP Ranger.

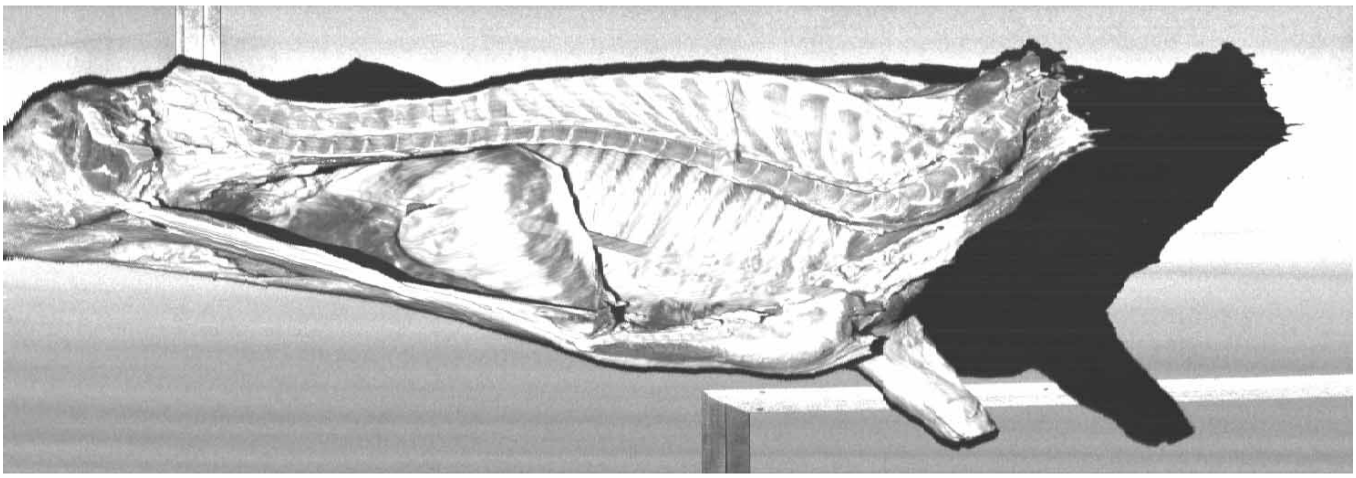
Animal 1 processed on 24/1/03



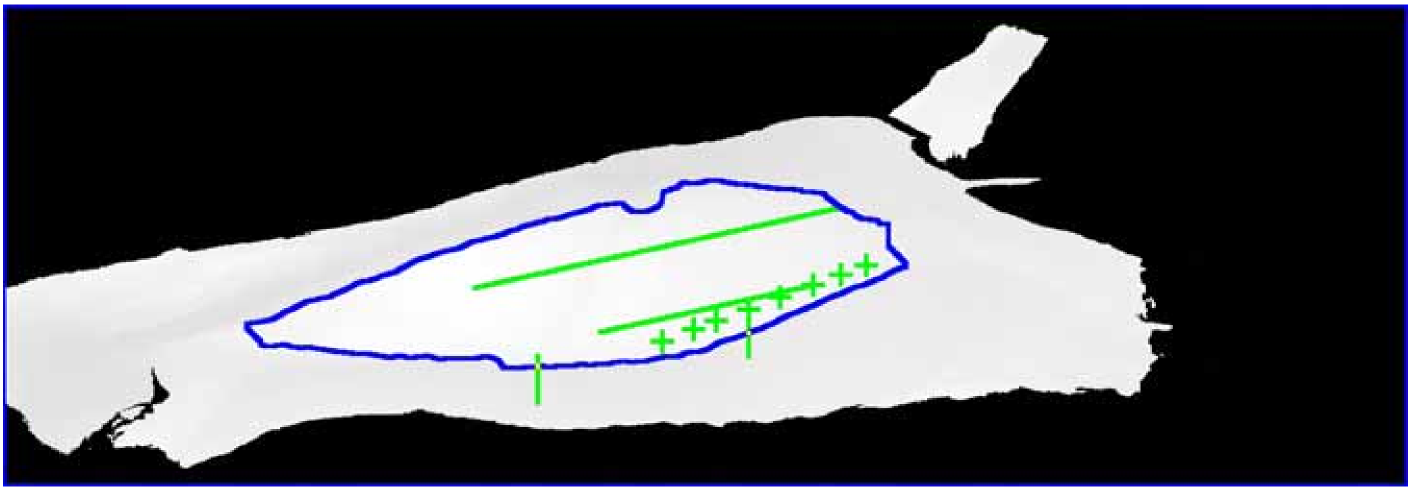


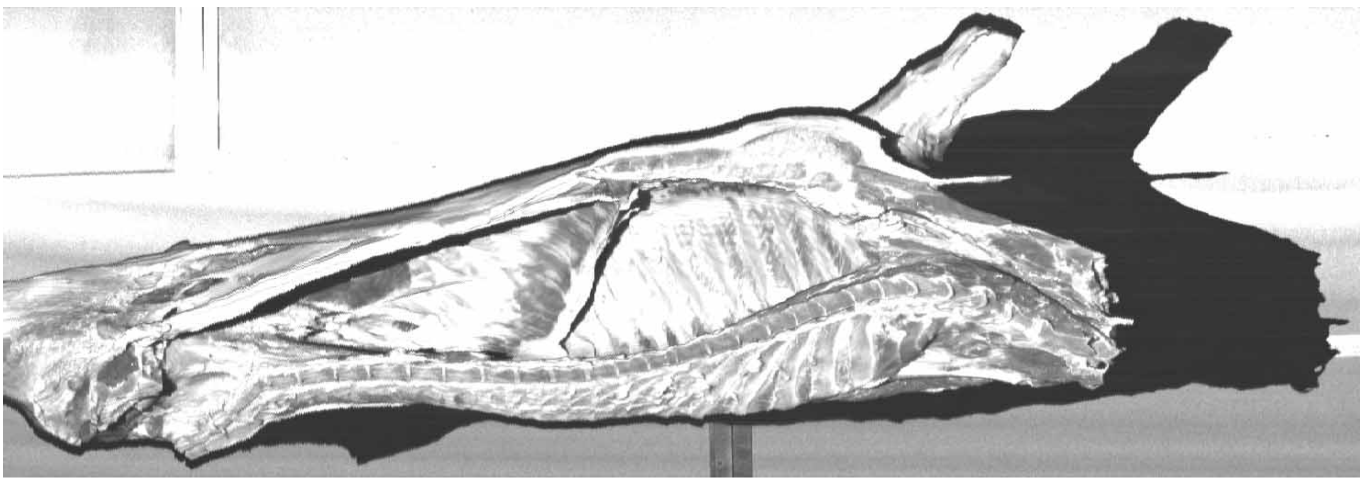
Animal 2 processed on 24/1/03





Animal 1 processed on 23/1/03





9. COST/BENEFIT ANALYSIS OF THE DEVELOPED PROCESS FOR THE MEAT INDUSTRY

Food Science Australia has prepared the following cost/benefit analysis of the developed Auto Scribing process for the meat industry, in accordance with the objectives of this stage of the project.

When considering this analysis it is vital to consider the following factors that cannot be quantified:

- **Occupational Health & Safety costs** – significant people and other costs are incurred when OH&S accidents happen.
- **Pneumatic Saw** use issues (stall/restart) – stalled saws are released by the operator. The person must hold the carcase with one hand and holds the saw with the other hand while trying to release the saw from the carcass. All this occurs while the power is still on to the saw. As the saw comes out of the carcass it commences rotating immediately and may run straight across the surface of the carcase, in which case, it may contact the operator's free hand causing major injury to the hand/forearm.
- **Inaccuracy** of traditional methods – when operator is scribing, they are making cuts as fast as possible, however with the objectivity and control of a robot it is possible to more accurately position the cut for financial benefit, that is, maximising particularly the high value cuts.
- **Quality of cut** – robot cutting methods are proven to increase the quality of cut resulting in an increase in product yield and product consistency, see comparative photos below in Figure 9.1.

Figure 9.1 Mechanical Arm and Manual Saw Cuts

- **24 hour processing** – robotic scribing would be able to process carcases ready for next boning room shift (after 12 hours in the chiller) with an option for 24 hour automated scribing.

9.1. *PAYBACK PERIOD CALCULATION*

Estimated Overall Commercial Prototype Project Cost $900K

Retail Cost of Scribing Unit from a future manufacturer ~$220K
(incl Robot, Sensors, Carcass Stabilising, Sterilising – approximate manufacture cost $170K)

Labour cost (1-4 staff, either one or two shifts) $70-80K per annum, per labour unit, per shift, including all on costs (Superannuation, Workcover, Training, Protective equipment, holiday and sick leave)

Floor area required ~3m x 4m

Based upon an expected retail cost of a fully developed unit of $220,000 installed (excluding site pre-work)

Purchase Price	$220,000	AUD				
Depreciation Period	5	years				
Discounted Interest Rate	5.56	%				
Number of Labour units reallocated (shift independent)	1	2	3	4	5	6
NPV	$114,685	$437,782	$760,880	$1,083,980	$1,407,074	$1,730,171
IRR	24%	67%	106%	144%	181%	218%
Payback (Years)	2.75	1.39	0.89	0.69	0.59	0.46

However from a commercial sense, a meat processing Operations Manger would probably be more prudent to enter into a maintenance lease arrangement with the manufacturers, for example, $80K per year for 5 years.

10. RECOMMENDATIONS

At the conclusion of this Proof of Concept stage, following a series of trials with the currently developed scribing system, we conclude that the robotic scribing system detailed in this report meets the major objectives of this project.

This project has presented considerable challenges in terms of carcass variation not only in terms of size and profile, but including variations in fat depth, colour and presentation. As a result, there remains further software refining to locate more detailed markers to assist in the scribing process. At this stage, Food Science Australia has been able to successful locate and identify the 5th through to 12th ribs as well as spinal vertebrae, vertebrae joints, and featherbone, and the sternum joints.

As noted throughout this report, further development work will also be required in the next project to achieve carcass stabilization, as well as saw sterilizing and bone dust removal regimes.

The main recommendation of this report, therefore, is to proceed with the further planned stages of this full project. However, it will be relevant at this point in time (given the significant challenges to date) to review the costing for the full project to incorporate all considerations and recommendations of this report.