final report

Project Code: PRTEC.032

Prepared by: Peter Aust ,Phillip Boyce ,Darryl Heidke, Kym MacRae
Jeff Owen & Peter Ring
Food Science Australia

Date published: February 2006

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

SENSORS FOR ADAPTATION TO THE MEAT INDUSTRY

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

CONTENTS

TABLE OF FIGURES

EXECUTIVE SUMMARY

This report details an evaluation of contrast agents for optical enhancement. Optical contrast marker agents are tags that mark a carcass to identify critical features or reference points which can be analysed using a sensing system either for a "manual assist sensing task" as identified in Milestones 1 and 2 of this project or as an intermediate step in a process task automation where the task or sensing component requires development in situation to be successful.

Various types of contrast tags are discussed including:

- colour carrier agents like dyes, paints and pastes;
- markers currently approved for use in industry such as adhesive paper tags, wax and crayons;
- surface object markers that can be developed for process compatibility (ie suitable to render);
- temperature markers;
- permanent markers such as branding;
- and reference or virtual markers which could take the form of a laser line which is placed on the carcass surface for only the period needed to capture data.

In order to be suitable for use in industry, consideration was also given to the approval process required to develop a new tag (documented in the report) and the effect of the tag on the final product presentation. Areas discussed include microbiological safety, visual appearance (if not removed during processing) and religious requirements (i.e. Kosher, Halal).

The final panel that was tested to define operational parameters and requirements was:

- Physical object agent
  - Pins
  - Tacks
- Reflective markers
- Paper markers
- Dyes
- Paints
- Active markers
  - Lasers
  - LEDs
- Temperature contrast – hot and cold
- Fluorescence – UV active substances

The testing criteria for the contrast agents were assessed against (1) consistency or application, (2) detectability for both colour and other alternatives (eg temperature), and (3) size. The following results were found.

Application

When applying dyes and paints to both hide and tissue surfaces it was very difficult to get a consistent finish and a controlled boundary shape. Some of these issues may be overcome by using alternate application technologies but the specific colour carrier also needs further development to minimise irregular raised tag finish surfaces or the concentration of tags ‘colour’ due to gravity. Both of these can be done when a specific task is chosen and environmental variables like moisture can be assessed. The results found that data inconsistencies caused reflection and saturation abnormalities, requiring more sophisticated image analysis while poor boundary control minimised the effectiveness of geometric filtering.

Object marker agents gave very accurate positional point location but damaged the attachment surface, meaning they are not suitable for all task applications.

Adhesive tags (paper and reflective) gave very good boundary profile control but were inclined to move (particularly on hide) as they did not attach uniformly to the test site area affecting both orientation of shape control and consistency of surface if shadow was created due to tag curvature away from surface. The later is a significant issue for reflective tags as the additional benefit of reflective properties is maximised when controlled lighting can be positioned with reference to the tag surface and data capture.

The need for a specialised lighting environment (minimal light or controlled frequency ie UV blacklight) as is required for UV activated tags and to maximise the robustness of laser virtual tags adds complexity for application of these markers on a commercial processing floor. Control of lighting does however make laser, UV activated and reflective contrast agents more robust than non-active counterparts, allowing more control of environmental variables which otherwise add complexity to image analysis.

Detectability

When contrast agents were assessed for detectability on the grounds of colour it was found that, in the carcass environment, green is a good tag agent choice. This is followed by blue, except on the fat covering of the brisket and muscle areas, then yellow. Red is the least preferred option.

Detection of laser and LED active markers is extremely robust when based on intensity analysis and thresholding. The higher the power or “brightness” rating of a marker and the greater this separation is from elements in the environment, the better the detection discrimination. When intensity analysis was used, results indicated that the colour and size of an LED tag had no significant influence on detectability.

The lighting conditions used to illuminate reflective tags significantly contribute to effective detectability. Reflective markers were most effective when illuminated perpendicular from the tag directly behind the image capture point.

Similarly the response level of UV activated markers is linked to the intensity of the illumination source. Results also indicated that tags should be greater than 5mm in diameter for data capture between 700mm and 1m of the target surface. Specialised broad scene illumination lighting, greater than 40W, needs to be used for robust detection.

Data showed that temperature markers with a temperature variation from the surrounding target surface of 15 °C were detectable in excess of 3 minutes, depending on application point. Results also indicated that when contrast temperature markers are created by heating or cooling the carcass tissue "hot" tags are maintained longest in muscle regions whereas "cold" markers are most effective on low muscle thickness areas like the belly cavity flank muscle where the tag gives a deeper chill thickness. Results showed that changes as small as 5°C for these carcass activated temperature tags were detectable for 30 sec when used as a hot marker and 15 sec when used as a cold marker. It was also found that as long as there is suitable temperature separation from the environment applied, physical object markers are robustly detectable with thermographic technology.

Size

To assess the size of marker tags most suitable for detection, a comparison investigation between actual and analysed tag feature properties was carried out. The comparison was based around the calculation of a "real world" perimeter from image analysis data with the actual "real world" perimeter – the "ideal" result is 1 which indicates accurate vision analysis. Variation from this value suggests the tag has been analysed as too large or too small. The averaged results were:

- Adhesive paper tags (stickers) – 1.045
- Dye – 1.123
- Paint – 1.095
- UV activated tags – 1.090
- Reflective markers – 1.012

The contrast agents with defined shape edge boundaries, which were reflective markers and paper tags, performed the most effectively for accuracy of size analysis.

The comparison analysis also showed that tags with a diameter or longest linear segment of less than 5mm, which was also those where the tag area compared to the total image analysis area were less than 0.02%, had the greatest variation from the ideal accuracy rating. The results indicate that tags should be greater than 5mm in size unless significant measures are taken to improve detectability in both the image analysis and the environment.

In summation, all of the contrast agents presented for consideration in this report need to be assessed for suitability for a particular slaughter application task, via consideration of its sensing requirements and physical constraints (like moisture), to select the most appropriate marker format. Once the task specification has been defined, with the assistance of information from this investigation, an effective tag marker can be developed.

PROJECT REPORT

PRTEC.032 - SENSORS FOR ADAPTION TO THE MEAT INDUSTRY

FOR Meat & Livestock Australia Ltd
Mr Sean Starling
Mr David Doral

1.0 INTRODUCTION

Milestones 1, 2 and 3 of this project investigated sensing technologies, which meet the criteria for approval by AQIS, required to automate beef and sheep slaughter tasks. One area investigated included 'manual assist sensing', where an operator can 'manually' input or assist sensing data to automate a given task. Examples of this are the marking of points on an image, or placing markers on a carcase to improve robustness of the detection algorithm for an optical system.

For the scope of this project optical contrast marker agents are tags that mark a carcass to identify critical features or reference points (for example marker dyes or physical target dots)

The objective of this milestone is to evaluate contrast agents for optical enhancement. Examples of agents can be considered to take the form of:

- Visual food grade dyes and marking inks.
- Active fluorescence
- Alternative markers in the form of:
  - Physical (paper dots, plastic buttons etc)
  - Active electrical signals eg LED
  - Corn starch (or food process removable/ treatable targets)
  - Temperature markers

Consideration is given to:

- Identifying and defining contrast agents
- Developing a specification for product including the requirements for AQIS approval and final presentation
- Defining test categories or regions
- Defining test protocols, format and apparatus
- Results, findings and conclusions

2.0 IDENTIFY / DEFINE CONTRAST AGENTS

The type of contrast agent selected for a marker will depend on the task, processing requirements, regulations and effect on the end product.

Physical markers generally consist of a contrast agent that is applied or attached to the carcase. A vision sensing system determines the position of the marker for subsequent processing.

A temperature based marker utilises a contrasting hot or cold temperature and thermal imaging system to identify reference points.

Reference or virtual contrast agents are markers that are applied temporarily to a carcase. A reference image is recorded and used for later processing.

2.1 Physical Markers

2.1.1 Food Grade Dye

Food grade dyes are already widely used for marking carcases, and should be readily accepted as a contrast agent. As a dye leaves a mark by either staining the substrate or by applying a thin film, the resulting marker may be inconsistent in colour, shape and coverage due to the nature and texture of the material it is applied to.

There are also UV fluorescing dyes available for medical purposes. Under suitable lighting conditions, these would fluoresce and provide a stronger contrast. Although acceptable for medical circumstances, gaining approval for these materials to be used on food may be challenging.

While the existing use of food grade dyes makes them an attractive option from a regulatory and religious view, it also restricts the range of colours available. The issue of customer acceptance of more indelible marks on product has to be addressed. Trimming or the development of a suitable removable water soluble dye may be required.

2.1.2 Paste or Paint

This type of marker is similar to dye, but has much greater viscosity, and would be applied by squirting or painting to produce a raised marker with a more consistent coverage, colour and shape.

It is unlikely that a paste/paint marker would have sufficient time to dry, and it would be necessary to consider any handling issues that may result in the marker being smeared. When applied to product, the marker would be required to be removable. A water soluble paste that can be washed off may be suitable as long as it conforms to food standards, regulatory and religious requirements.

2.1.3 Paper Tag

Paper markers should be readily accepted by processors as paper is already used for tags and for preventing contamination. The markers could also conveniently be removed by washing. They should also not present any problems if some of the markers end up in rendering.

The tag shape and colour can be used to convey information. For example, a larger marker could be utilised for easy identification, with a feature such as an arrow head or alternative colour identifying the exact reference point. Multiple colours or even a printed pattern can be used to achieve greater contrast.

A paper tag also has the advantage of being independent of the surface texture and colour, and provides a uniform consistent marker.

Fluorescent colours or a reflector could be used to improve the contrast of paper tags.

Paper markers can be secured by “wetting” them onto the carcase, mechanical attachment or an adhesive sticker as used in the fruit industry. Food regulations would need to be considered if an adhesive is used.

2.1.4 Wax

Suitable food approved coloured wax could also be used as a marker by melting it and applying it in a similar way to dyes and paste/paint. The advantage is that the wax would quickly solidify and result in a “dry” marker that would not smear like a paste or paint.

2.1.5 Crayon

Wax crayons are already used to mark carcases in some plants. Under some circumstances they may provide a suitable marker. Obtaining a consistent coverage and shape on surfaces such as fat may be difficult.

2.1.6 Object Markers

Object markers similar to a drawing pin would result in a marker that that is convenient to apply, raised and readily seen and can be easily removed once no longer required. Injection moulded plastic is the obvious material for these markers as they would be inexpensive to manufacture, and a wide range of colour and shape would be available.

An advantage of moulded plastic markers is that enhanced contrast can be achieved by including a reflector or fluorescent material in their construction.

However, plastics do present some issues with rendering and possible contamination of product. Plastic oesophagus clips are already causing problems for processors supplying the pet food industry, with pieces of the clips making it into cans of pet food.

Alternative materials could be investigated for manufacturing object markers.

Corn starch based bio-plastics are already being trialled for manufacturing oesophagus clips, and could provide a marker that has the properties of an injection moulded plastic marker, but will break down harmlessly in rendering and cooking. These bio-plastics are already being used for packaging, and when immersed in water, break down into a corn starch jelly. Bio-plastic manufacturers, and CSIRO researchers, have indicated that they are confident that a suitable formulation can be developed that will achieve an appropriate balance between durability and rapid break down in an abattoir environment. Suitable food grade materials such as wax or fat could also be used to coat bio-plastics that are affected by water. This may produce a marker that is durable during processing, but breaks down rapidly in the presence of water during rendering or cooking.

Other food based materials such as collagen or gelatine should be investigated to see if they can be used or adapted to produce an object marker.

2.2 Temperature Markers

For vision sensing to be effective, lighting and background have to be suitable. In an abattoir environment, markers could also be obscured by blood or fat, and not identified. Thermal imaging is less affected by these factors and, if thermal markers are used, may be more appropriate. With thermal imaging, lighting is not as critical providing heat from lights is not interfering with the image. Also, providing the background temperature is different to carcase temperature, the background will have little effect. However, it is possible for backgrounds to reflect thermal signals from other sources, and this needs to be considered when setting up a thermal imaging system.

Markers for thermal imaging can consist of hot or cold objects attached to the carcase. An example of this type of marker would be a piece of ice or dry ice attached to the carcase. An alternative form of marker would be to apply an object such as a hot or cold metal bar to the carcase and create an area of temperature difference that can be detected. Obviously this will only result in a temporary marker suited to tasks where an operator may mark up a carcase just before it enters an automated process. The issue of chain stoppages would need to be addressed for such an arrangement to be utilized.

2.3 Reference or Virtual Markers

Most forms of contrast agent require removal of the agent to be considered. The effects on product and rendering also have to be addressed. A virtual marker provides a reference without these issues.

An example of a virtual marker would be a digital image of a carcase with an operator holding a marker in place. The image would be later referenced for subsequent automated tasks. The marker could be in the form of a pointer with a distinctive identifiable end, or as the marker is not attached to the carcase, a light source such as a LED could be used to achieve a high contrast. An alternative form of marker could be produced by an operator pointing a laser at the carcase to produce a distinctive dot of light. This has the advantage of allowing the operator to be stationed remotely from the task. The image processing required with virtual markers is more complex as changes in carcase shape, orientation and lighting must be dealt with.

2.4 Permanent

A mark can be created by branding with either heat or extreme cold. This results in permanent damage that contrasts with the surrounding tissue. While traditional branding is achieved with a simple hot brand, laser technology is now being used to apply small shallow brands to fruit. The advantage of branding is that no material is applied to the carcase resulting in less regulatory and disposal issues. However, branding is unlikely to result in a high contrast marker, and removal can only be achieved by trimming.

3.0 PRODUCT SPECIFICATION

The effect of applying a contrast agent (marker) on the safety, quality and appearance of the finished product has to be taken into account. In particular, it is necessary to consider the effect of any residue that may be left behind if a marker is required to be removed.

The process and materials should also meet Good Manufactures Practices (GMP), and be acceptable to the final customer.

These requirements include:

- Microbiological safety
- Non-toxic
- No allergen risk
- Visual appearance if not removed during processing
- Staining of hide, meat or fat
- Easily rendered down if it is removed with trimmings during processing
- Religious requirements (i.e. Kosher, Halal)

Paint or paste type contrast agents could be developed using permitted food additives, such as starch or gums with a food colour or to make a compound using meat by-products such as collagen or gelatine with an added colour.

A high contrast marker can be made from materials such as paper or plastic. As these materials are already widely utilised in abattoirs, acceptance and approval should be readily achieved. Depending on the application, colouring such as ink on paper, and the method of attachment need to be considered and approved if necessary. An example of where such technologies are used is the Horticultural industry where paper stickers are applied directly onto apples and tomatoes, and the poultry industry where printing is applied directly onto the egg shell.

For a contrast agent to be successfully utilised as a marker, it must either already be approved by AQIS and Food Standards Australia New Zealand (FSANZ), or be able to be approved.

3.1 AQIS Approval

The Australian Quarantine and Inspection Service (AQIS) must approve all chemical compounds that are used in all areas of a registered establishment where their use may result in the chemical compound coming in contact with products, either directly or indirectly.

For any substance to be used as a stamping agent in Australian abattoirs, AQIS approval must be sought. Currently a wide range of colours can be used with the main solvent being ethanol. A list of available products and suppliers are available from AQIS. If the materials used to create the marker are not on the AQIS list, application can be made to have them added.

Information required by AQIS includes a detailed formulation of the compound including the name of all chemicals used, their chemical registry number and manufacturer. All dyes used must be identified by their colour index number and must be approved under the FSANZ regulations for food additives.

The AQIS charge for processing each chemical compound application including the issuing of an 'Instrument of Approval' is $AU200 and lasts for 5 years.

AQIS has already approved a number of stamping inks. This type of marker would also have to take into account the existing assignment of colours such as those used in Aus-Meat registered plants. For example, the colour blue may produce a suitable marker, but is already used to indicate condemned product.

Currently a number of different coloured inks are used on carcasses in the meat industry to identify the animal and its grading. In Australia Aus-Meat registered plants are required to stamp beef and sheep products as follows:

Beef

- Gold Brand
- Purple Brand
- Bronze Brand

Sheep meats

- Select Hogget – Brown Brand
- Lamb – Red / Pink Brand

The colours used for sheep and beef carcasses in other instances are as follows:

ξ Local & export branding -	Brown
ξ Local grading & company branding -	Red
ξ Branding for export to EU -	Methyl Violet
ξ Condemned -	Blue

3.2 Food Standards Australia New Zealand approval

There are a number of natural and artificial colours that can be used either in a meat product or on the outer meat surface. The materials used to produce a contrast agent cannot be classified at this time but will either be a Food Additive or a Processing Aid. Under some circumstances, a contrast agent may be classified as an Inspection Brand.

3.2.1 Food Additive

A food additive is any substance not normally consumed as a food, and not normally used as an ingredient of food, but which is intentionally added to a food to achieve one or more technological functions.

The additives are listed by name or number in the FSANZ code and as long as the use complies with any restrictions listed in the food code, may be added to a food or class of food to perform technological functions, provided that the proportion of the additive does not exceed the maximum level necessary to achieve the technological function (such as minimise micro growth) under conditions of Good Manufacturing Practice (GMP). FSANZ uses the Codex Alimentarius Commission Procedural Manual to set the relevant criteria for use in assessing compliance with Good Manufacturing Practice.

The additives of interest not only include colours but also possible carriers. These include vegetable gums, thickeners, emulsifiers, bleaching agents, mineral salts, anti-caking agents and propellants. They all have potential application in producing contrast agents but not necessarily for what they are normally used for in food processing.

3.2.2 Processing Aid

A processing aid is classified as a substance which is used in the processing of raw materials, foods or ingredients, to fulfil a technological purpose relating to treatment or processing, but does not perform a technological function in the final food. The substance used must be used at the lowest level necessary to achieve the function in the processing of that food. Unless expressly permitted in the FSANZ Standard, processing aids must not be added to food.

Processing aids that may be used in contact with the food include other foods, water, food additives and specified processing aids as out lined in the food code. Three permitted additives that maybe of interest include carriers, solvents and decolourants.

Examples of solvents permitted in edible inks include water; glycerol and its mono-, di-, and tri-acetic acid esters, propylene glycol; isopropyl alcohol; ethanol; and ethyl acetate.

3.2.3 Inspection Brands

If a marker placed on the carcass is not able to be removed, the shape used may be able to be classified as an inspection brand or as an identification mark if it is stamped onto the animal. This has definite advantages, the major one being that if the colour used is permitted under the FSANZ code it is not required to be declared on the label on the package containing the food.

3.2.4 Amending Food Standards Code

If the material used to create the marker does not meet FSANZ, application can be made to have the standards amended.

Food Standards Australia New Zealand is responsible for developing, varying and reviewing standards and for developing codes of conduct with industry for food available in Australia and New Zealand covering labelling, composition and contaminants. The process for amending the Australia New Zealand Food Standards Code is prescribed in the Food Standards Australia New Zealand Act 1991 (FSANZ Act).

Any individual or organisation, whether from within Australia, New Zealand or any other country may make an application to change the Australia New Zealand Food Standards. Before making an application to FSANZ, it should first be determined whether the food additive currently complies with the regulatory requirements.

The FSANZ regulatory role specifically relates to food for human consumption sold in, or prepared for sale in, or imported into Australia and New Zealand. The Act sets out FSANZ objectives (in descending priority order) in developing food regulatory measures and variations of food regulatory measures as:

(a) The protection of public health and safety; and

(b) The provision of adequate information relating to food to enable consumers to make informed choices; and

(c) The prevention of misleading or deceptive conduct.

In developing food regulatory measures and variations of food regulatory measures, FSANZ must also have regard to the following:

(a) The need for standards to be based on risk analysis using the best available scientific evidence;

(b) The promotion of consistency between domestic and international food standards;

(c) The desirability of an efficient and internationally competitive food industry;

(d) The promotion of fair trading in food;

(e) Any written policy guidelines formulated by the Council for the purposes of this paragraph and notified to FSANZ.

It is in the interest of applicants to clearly establish within their application how the sought change to the Code could further one or more of the above objectives.

Applications relating to food additives or processing aids should use the application document for food additives and a toxicological profile of the food additive or processing aid should be completed.

FSANZ will also require the food related material with an application (approximately 100g) so that analysis can be carried out on the material.

The FNASZ Act requires FSANZ to make its recommendations within 12 months to the Ministerial Council of the receipt of the application. This period may be extended if the applicant is required to provide additional information.

The initial application fee is $AU4000 where an initial assessment will be carried out and the application will be placed in 1 of 5 categories depending on its perceived difficulty. These Categories range from very simple to highly complex. The indicative cost to process the application ranges from $AU20, 570 to $AU170, 500.

If the new food additive/processing aid is accepted, this will only allow its use in Australia and New Zealand and for domestic use only. For every export market a separate application may be required for example USDA and also CODEX.

4.0 AGENT TRIALS – TEST PROTOCOLS AND APPARATUS

The contrast agent test panel selected for further investigation was as follows:

- Physical object agent
  - Pins
  - Tacks
- Reflective markers
- Paper markers
- Dyes
- Paints
- Active markers
  - Laser
  - LEDs
- Temperature contrast – hot and cold
- Fluorescence – UV active substances

4.1 Test Protocol

Trials were carried out for the purpose of being able to define the operational parameters and conditional requirements for a specified contrast agent. The protocol for the results was to capture assessment criteria for consistency, colour and size for each agent, independent of tag format, to enable comparative analysis. To do this consideration of the following was required:

- The effect on the results of the surrounding lab test environment;
- How the contrast agents could be applied and any tag type specific requirements;
- What trial equipment would be required to capture data; and
- That each contrast tag trial is controlled and repeatable.

Basic software processes were developed to allow comparative assessment of the colour and size criteria, and the effect of time on tag effectiveness for temperature based formats. Processes included functions such as colour plane extraction, pre-processing for brightness or contrast, manual thresholding, particle enhancement and extraction before property analysis of different tags in the same data set. Only fundamental image analysis tools were used so that comparisons of different trial results series was not affected by differing, more sophisticated software techniques for each contrast agent.

4.2 Apparatus

The following equipment was used during trialling.

Data Capture

- Colour Image Acquisition
  1. Allied Vision Technology Oscar – F-510C colour firewire camera. 5.1MP
  2. Canon G2 - Colour digital camera. 4 MP.

➢ Thermal Image Acquisition

SAT S160 Real Time Thermal Imaging Camera

Detector resolution 160 X 120, spectral range 8-14µm, temperature range -20 to 250°C. Accuracy +-2DEGC or +/-2%, imaging frame rate 50Hz.

Lighting and Environmental Control

Optical measurements were all recorded at test surface via the use of a lux light meter. The lighting was arranged in two formats – (1) the ambient florescent grid of the laboratory environment and the other (2) a controlled light pattern presented in Figure 4-1 and Figure 4-2. The controlled lighting pattern is a stereo system which allows the substitution of both white and blacklight (UV) fluorescent tubes and can incorporate halogen spotlights where required.

Figure 4-1 Lighting pattern - profile

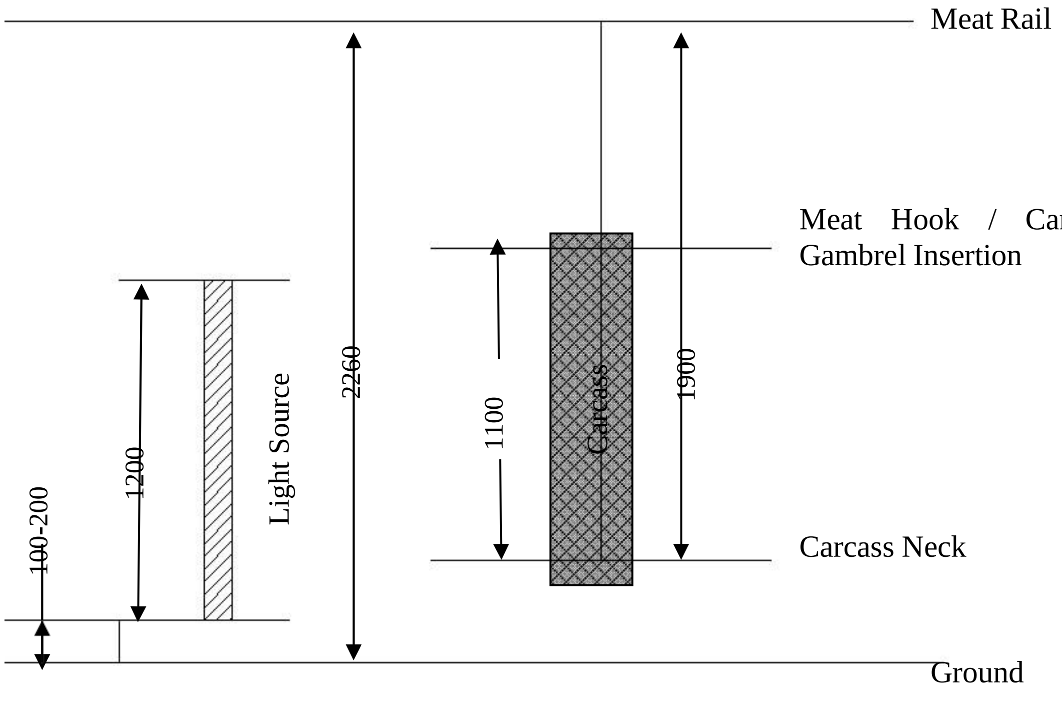
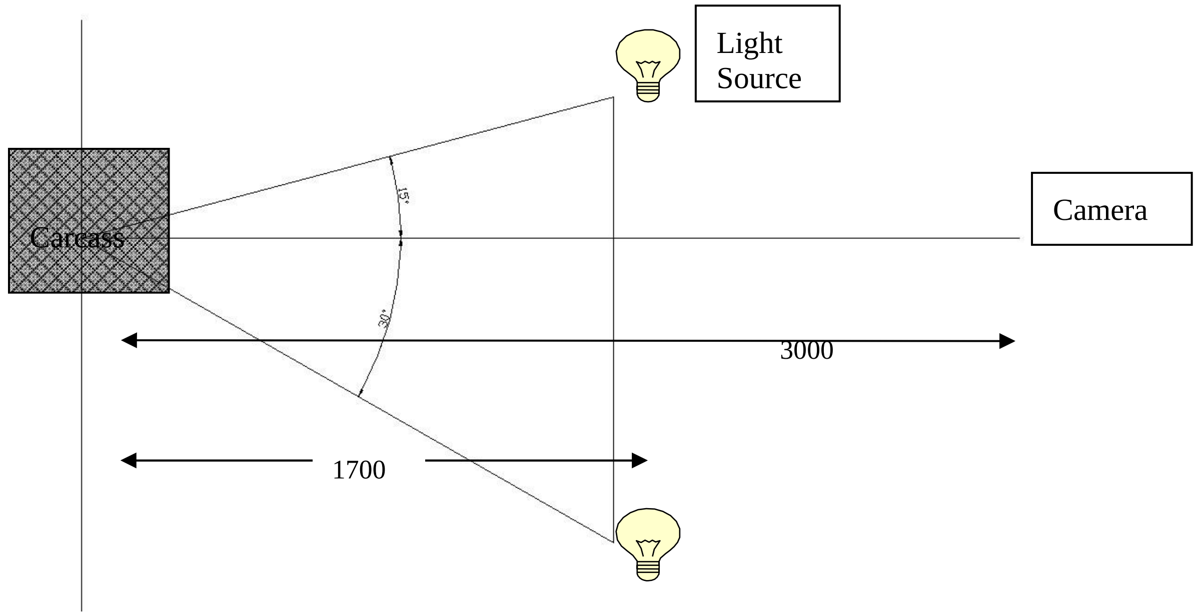


Figure 4-2 Lighting pattern - plan



Tag Application

Several stencils of varying sizes were developed to be able to control the application of the optical contrast tag agents to the surface. Additional marking devices were sourced or manufactured, including differing ice markers, and temperature (hot and cold) points, as shown in Figure 4-3 to simultaneously measure temperature tags on adjacent surface types. Electrical wands were also developed to test LEDs (Light Emitting Diodes) as virtual tag devices.

Figure 4-3 Temperature marking device and LED wand

4.3 Define Test Categories

The location of a marker, and the type of surface that it could be attached to will depend on the task required to be automated. Different surfaces such as muscle, fat (colour, texture and thickness) and shape due to location on the carcase may affect the performance of markers, and determine the type selected.

As a result of considering potential tasks, and the variety of surface types and shapes, the test regions shown in Figure 4-4 were chosen. Regions 1 and 3 consist of a thicker more curved or shaped musculature, while region 2 has a less severe curvature and thickness.

The sites shown within the regions were chosen to provide a representative variety of surface type, appearance and shape. The range of muscle thickness between the sites also allows for the investigation of the effects of thermal mass and surface area on hot and cold markers.

For the purpose of this project, it was not practical to investigate the variations between carcases and it was decided to carry out the trials on a representative sheep carcase. The sites were chosen to represent "typical" applications, and to provide indicative data.

Some potential tasks require the markers to be applied to the external surface of the hide/pelt. While this presents fewer issues with contamination and product downgrading as a result of the marker, the hair/wool can affect the performance of the marker. In particular, dye or paint type markers may "run" resulting in lower resolution or shape definition. To eliminate the variable of carcase shape, a removed bovine hide was chosen for external marker evaluation. After inspecting sheep carcases, it was decided that the small number that could be trialled would not provide indicative results due to the variations in wool length, and conditions such as dirt and mud contamination.

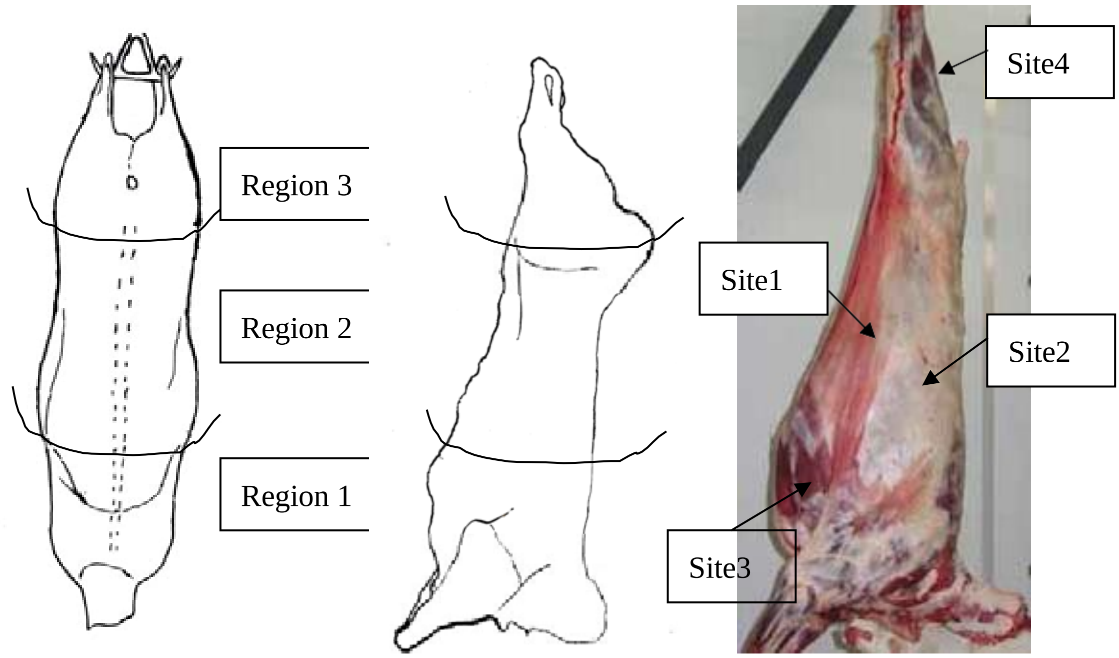


Figure 4-4 Carcase Regions and Trial Sites

5.0 RESULTS

To define operational parameters and conditions the contrast agents were assessed against the following testing criteria:

- Consistency Application
- Detectability – Colour and alternatives
- Size

5.1 Consistency / Application

To evaluate a tag contrasting agent both the ease of application and the consistency of the final "mark" needs to be considered. In order to assess the viability of contrast tags, trials were carried out on both fat and muscle surfaces as well as a beef hide as it was felt that this could give indicative results as to how successful a given agent could perform in terms of application. After consideration, a sheep pelt was not processed as with limited numbers a representative sample of wool sample conditions (ie length, dirt / mud contamination) is not practical.

Two environmental variables that affect the viability of a contrast tag agent are lighting effects and the variation of water or moisture on the carcase application surface as it progresses along the processing line. To simulate all possible combinations of these variables in the laboratory environment is beyond the scope of this project however if any of the investigated tag agents are implemented, in most cases carrier or formula modifications are available, or a lighting control scheme can be developed, to make an agent successful for a defined marking application.

- ***Dyes***

Figure 5-1 Dyes

Commercial dyes were applied to the carcase surface and hide using stencils to control the contrast tag size. The dye was either painted on the surface or applied using a "squirt" applicator (red dye results). The results are shown in Figure 5-1. Of the two application techniques "squirting" delivered more dye per tag and hence had a greater tendency to run on all surfaces however "painting" the tag still gave inconsistent coverage as a marker, concentrating (via gravity) at lower vertical points on fat and muscle areas. Dye tags on the hide surface did not give good results with the small sizes providing little or no discrimination and the large tags giving irregular coverage due to the hair fibres clumping together – other agents with greater surface consistency would be more effective for hide applications.

- ***Paints***

Figure 5-2 Paint

When using paints as a contrast agent the consistency of the paint is very important. It needs to be smooth enough to apply yet be able to maintain a regular raised surface profile tension for best results. Figure 5-2 shows some of the results from the trials, illustrating the irregular raised surface that occurred. Irregular raised surface paint tags can cause reflections or saturation abnormalities in image data which requires more filtering to close (tag) "blob" low coverage or high luminance areas lessening analysis robustness. During trialling the amount of paint for each tag during application was difficult to control giving both irregular surface profile as well as poor shape outline definition. This was an unexpected result as stencils were used.

All paint tags were clearly visible even in low light conditions (lowest tested average 250lux) including small markers on the hide as the paint sat on the surface and was not absorbed into the hair as occurred with the dye. Paint was also less prone to “bleeding” although this is dependent on the surface moisture present, water also causing a decrease in the evenness of the surface profile coverage consistency.

- ***Paper, Stickers and Reflective Tape***

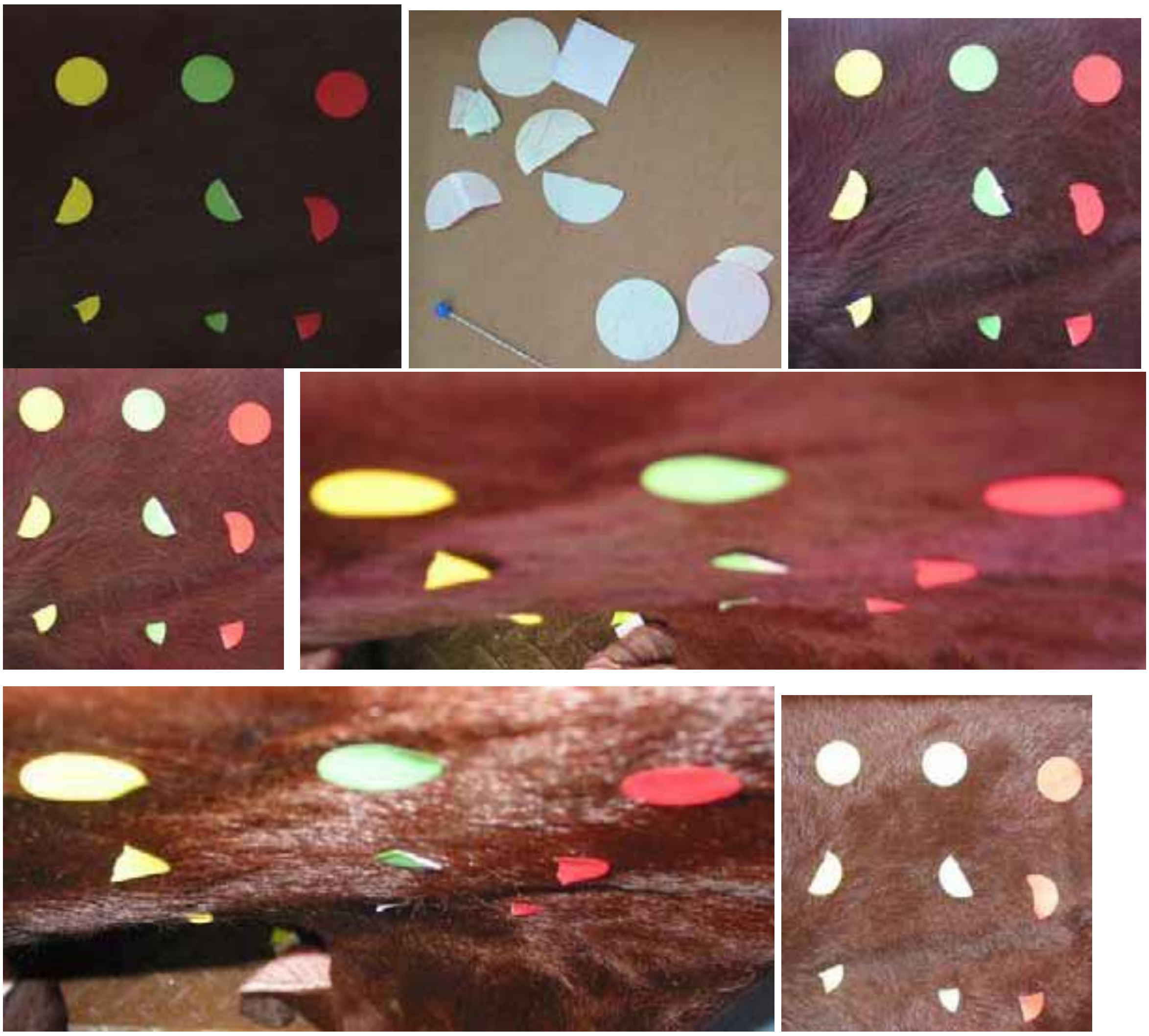


Figure 5-3 Paper Dots - Hide

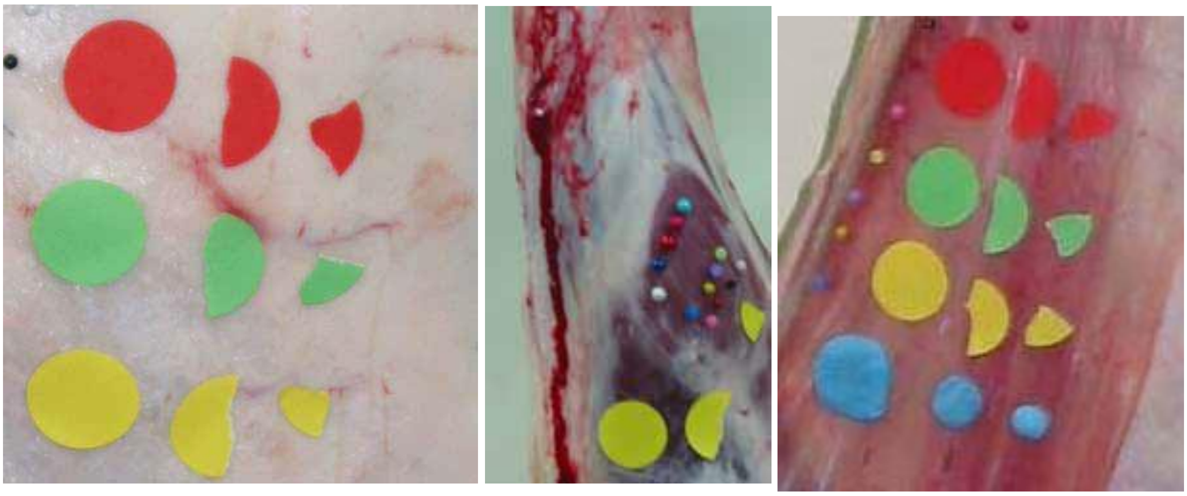


Figure 5-4 Paper Dots – Carcass Surface

Trials indicated that the use of paper dots and adhesive tapes as successful optical contrast markers will be very dependent on the point in the slaughter process for the required task and the position resolution required (ie how much the tag can be allowed to move). When used on hide the tags attached to the surface via only a few hairs, making tags difficult to position, allowing movement after application and the surface to not remain flush with the trial site - potentially causing size analysis accuracy degradation (see Figure 5-3 and Figure 5-4). Surface orientation at the attachment point also caused an issue with smaller tags difficult to apply in highly curved locations. This is also an issue with reflective adhesive tape markers (Figure 5-5) where robustness of image data is best when the tag surface is at a perpendicular orientation to a light source.

Fundamentally as the agents attach to the surface they have a more regular feature profile giving more control repeatability as an optical tag, requiring less consideration of process variables like surface moisture and viscosity, dependant on task feedback information required.

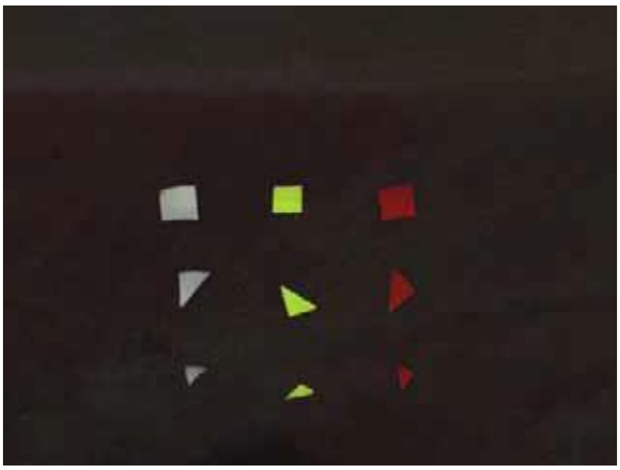


Figure 5-5 Reflective Ambient

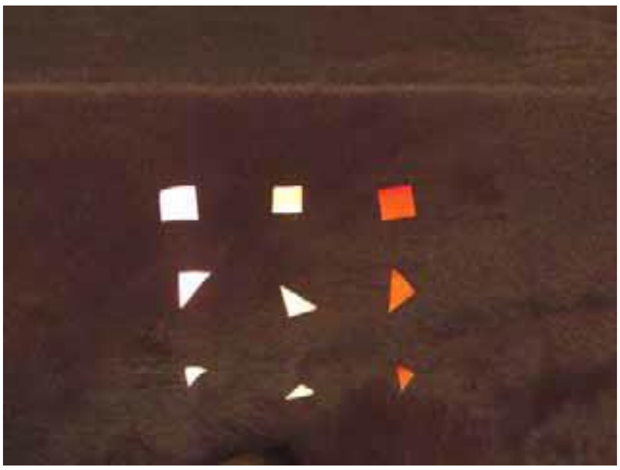


Figure 5-6 Reflective Single spot light

Figure 5-7 Pins

- ***Object markers - Pins and Tacks***

Pins give very accurate positional point locations however cause damage to the attachment surface. Pins, tacks and other object markers also give good dimensional profile repeatability (see Figure 5-7), which if data capture angle / tag orientation is controlled can give an alternative to the type of analysis available – ie tag profile can be the critical feature to analyse for. Consideration also has to be given to manufacture of the pin "point" attachment material so that it is robust enough to pierce the tag application surface, which can be relatively tough through the tissue layers found in the hide, and yet requires practical removal for further processing steps such as rendering.

- ***Laser and UV-Activated Gels / Dyes***

The consistency and ease of application of UV activated gels or dyes are similar to their conventional counterparts except that some are not visible without a UV blacklight (see Figure 5-9), potentially adding some complexity to implementation of these tags in a commercial abattoir environment. A similar issue occurs when using a laser line or point (see Figure 5-8) in that the 'virtual tag' is strongest in dark light conditions. Control of lighting makes Laser and UV light sensitive tags more robust than non active counterparts, allowing more control of environmental variables which can add complexity to image analysis for slaughter processing tasks. Lasers also have the advantage of providing a non-contact virtual marker, provided the laser marked tag point can be referenced to other reasonably detected carcass features. Dependant on the operation, a variety of laser strengths and colours can be considered.

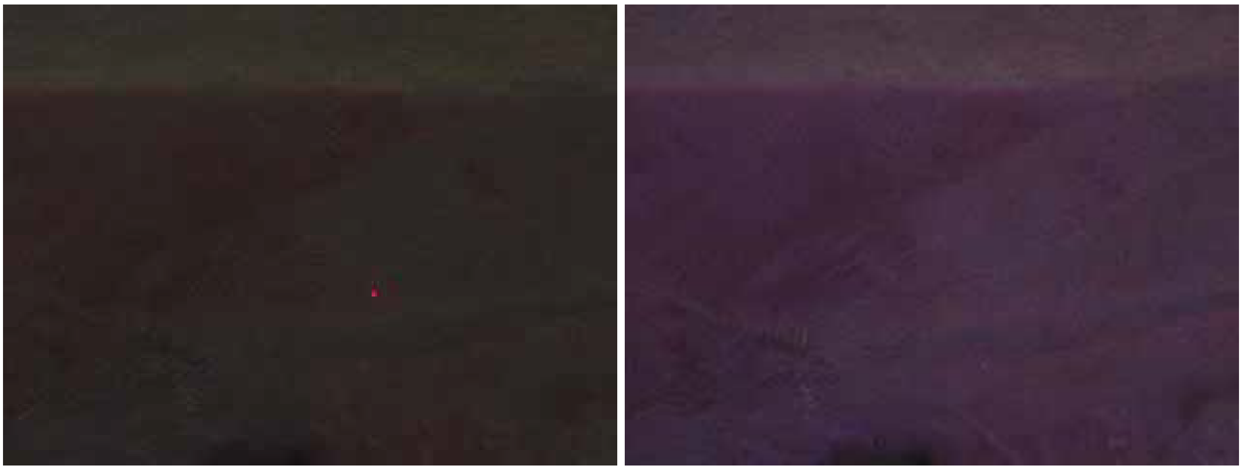


Figure 5-8 Laser (Left – no light; Right – ambient)

Figure 5-9 UV-activated Gel (Left – front view; Right – plan view)

5.2 Detectability- Colour

The tag agents that were examined included paint, dye, paper and pins that for the point of colour analysis have been grouped together as they are different methods of application with a uniform detection success criteria of colour.

Two types of colour analysis were conducted on the image data collected from the trial. The first utilises the Red, Green, Blue (RGB) component planes, the other examines data based on Hue, Saturation and Luminance (HSL) colour space. With RGB, colours are made by adding together components of the three primary colours and hence a single colour is represented graphically as a point within a cube (see Figure 5-10). HSL utilises a cylindrical system with hue referring to the colour, saturation to the amount of black or white that has been added to the colour (tint) and luminance to how bright or how much power the colour has (Figure 5-11).

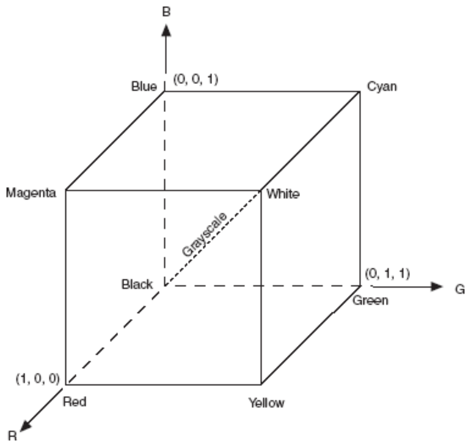
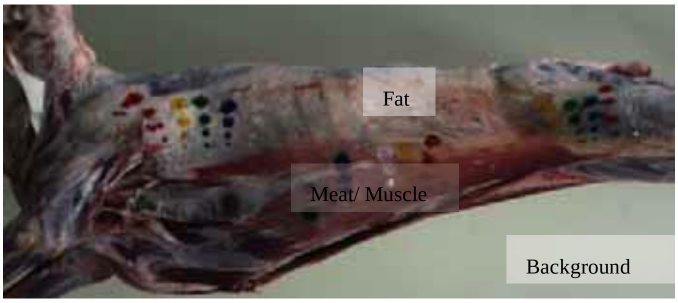


Figure 5-10 RGB Colour space (Graphic courtesy of National Instruments)

Figure 5-11 HSL Colour space (Graphic courtesy of National Instruments)

Before requirements of colour selection can be determined consideration should first be given to the carcass environment in which detection is taking place to better understand the data being examined. This has three main constituents from a colour analysis point of view – the background, fats and meat/muscle colours.



- Background

The background for the tag image analysis is a reasonably neutral colour that falls just within the green region. In a machine vision solution the selection of a background colour is determined by avoiding colours present in the detection environment.

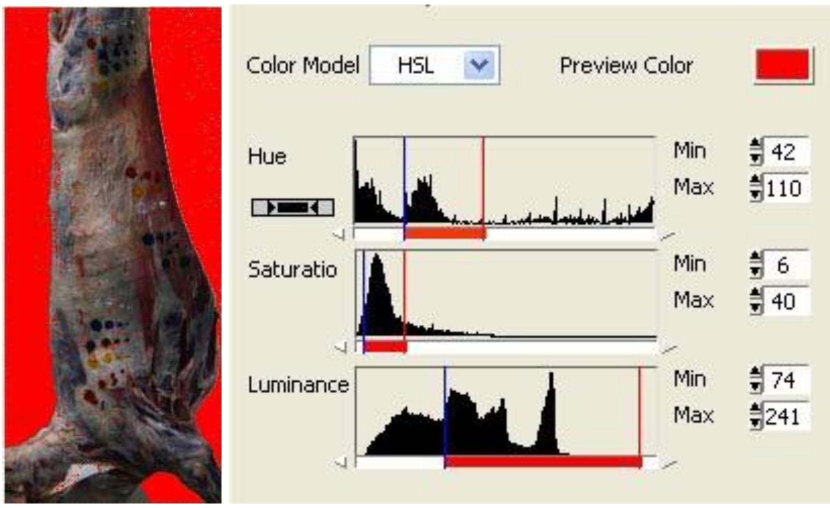


Figure 5-12 Background detection and HSL analysis

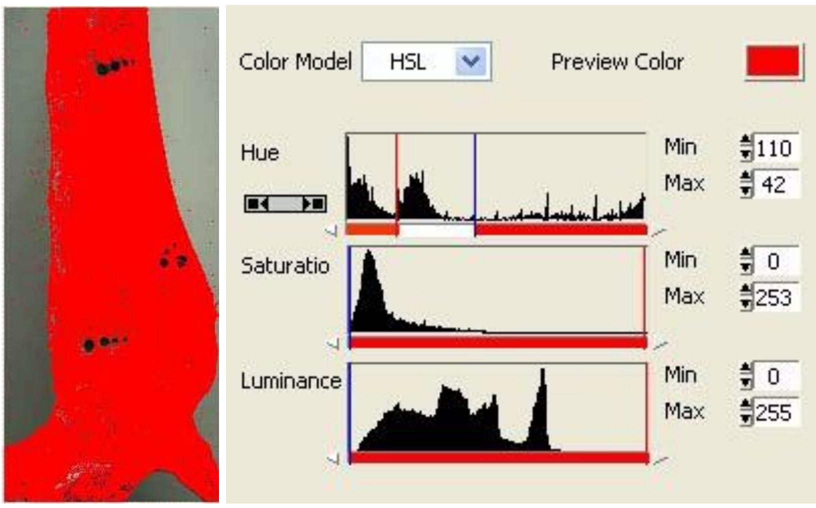


Figure 5-13 Negative of background HSL detection

By considering the negative of the background detection filters shown in Figure 5-12 it is shown quite clearly the area where the background falls in the colour spectrum. The HSL analysis also shows, when looking at the hue and luminance histograms, what a significant component of the image the background is. Figure 5-13 also shows the dark green dye marks on the carcass falls within the green hue region meaning that for discrimination of these from the background colour definition of saturation and luminance is required.

- Meat/ Muscle colour

Not surprisingly the muscle colour falls within the red region of the hue histogram. For comparison with the background colour and to assist in becoming familiar with the information shown in a HSL histogram analysis Figure 5-14 shows the analysis of a red bark area (shown by the green rectangle) relative the green hue region, illustrated by the detected green dye markers from Figure 5-13.

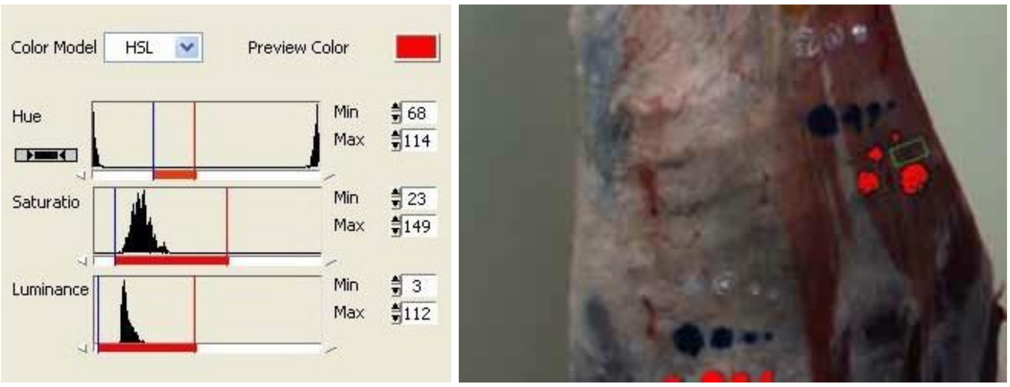


Figure 5-14 Muscle region in comparison to background

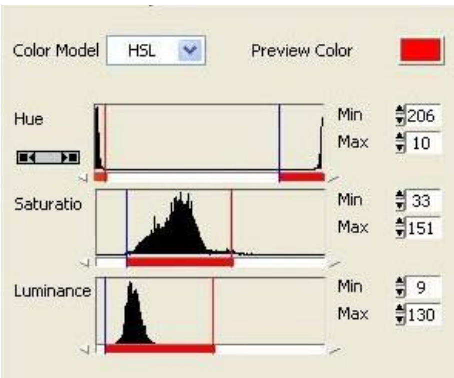


Figure 5-15 Muscle / meat HSL analysis

The red meat/ muscle HSL analysis region is shown in Figure 5-15. The hue histogram of the HSL analysis is between 206 and 10 (recall that HSL colour space is cylindrical). Figure 5-16 shows the results for HSL colour detection analysis in this region over a variety of image data. The primary area of this colour is found is in the “red bark” or “twitch muscle” of the carcase.

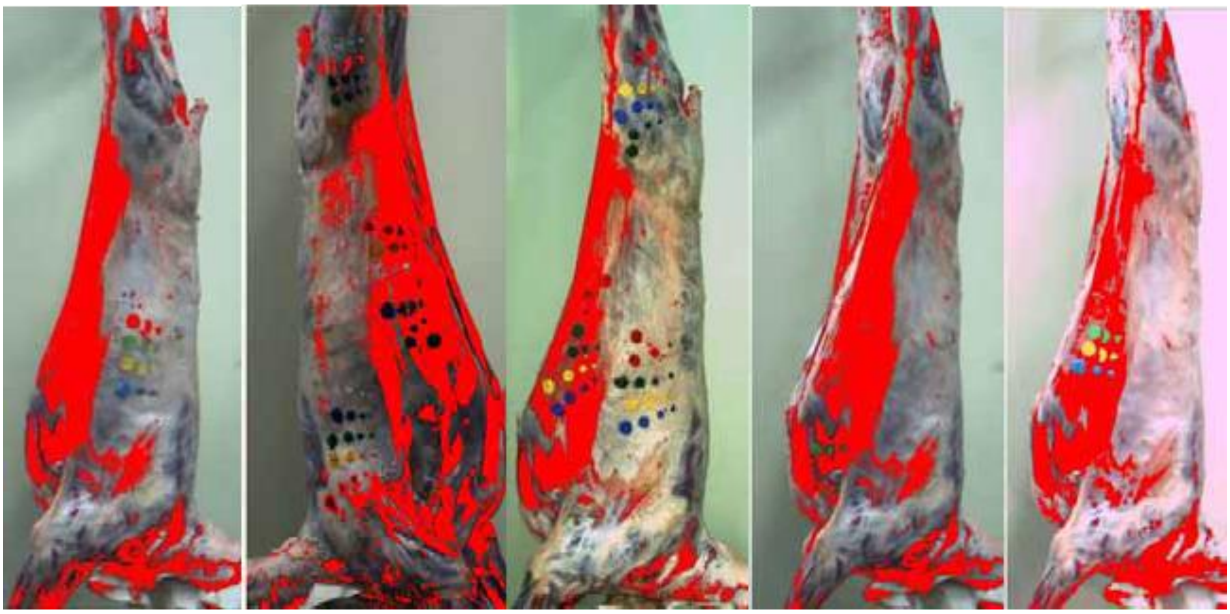


Figure 5-16 Results for muscle region detection analysis

- Fat colours

Analysis showed that there are two regions of fat colour – broadly descriptive as “back fat covering” and that found in the “brisket and muscle areas”.

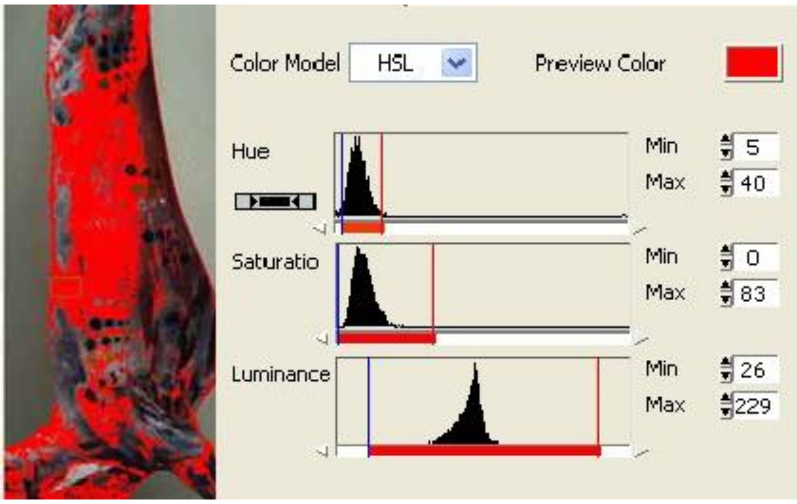


Figure 5-17 Fat 1 ("Back fat covering") HSL Analysis

“Fat 1”, which is the back fat covering region of the carcass has the HSL detection analysis shown in Figure 5-17. The hue histogram of the HSL analysis shows the Fat 1 colour is in the red to yellow hue region. From the earlier explanation of the HSL colour space it is recalled that “Saturation” is a measure of how much black or white has been added to a colour. The visually perceived white fat colour of Fat 1 is actually colours in the red hue region that as they saturate go to white.

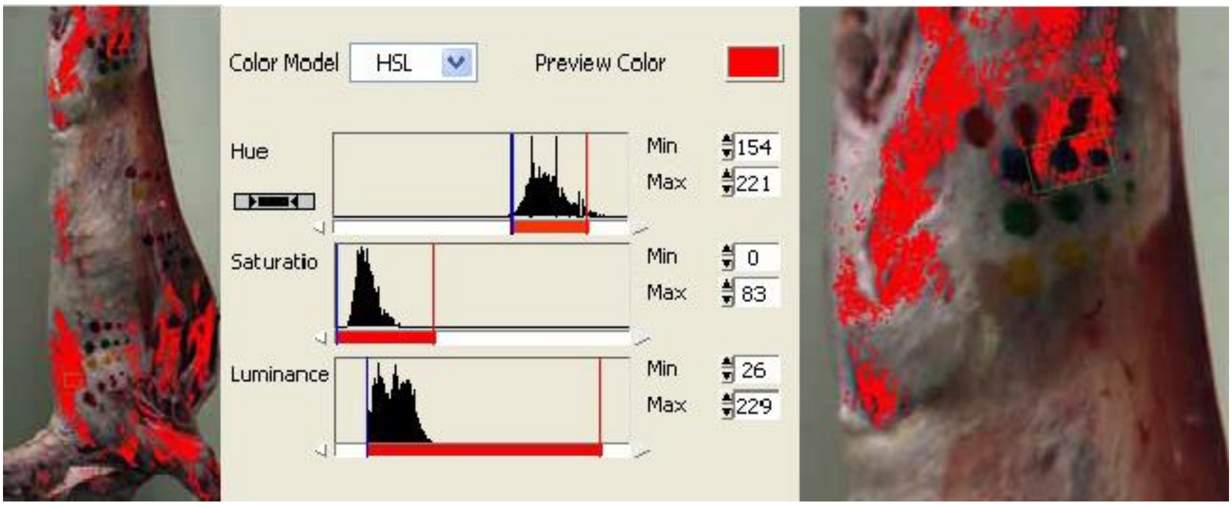


Figure 5-18 Fat 2 ("Brisket and muscle areas" fat) HSL Analysis

“Fat 2” is broadly designated as the fat covering on the brisket and over muscle areas (see Figure 5-18). The hue histogram of the HSL analysis shows the Fat 2 colour region as between 154 and 221 - which is in the blue hue region.

Combing HSL detection analysis for Fat 1 and Fat 2 gives the result shown in Figure 5-19, which has detected all the fats in the carcass environment separate from the muscle tissue regions and background colours.

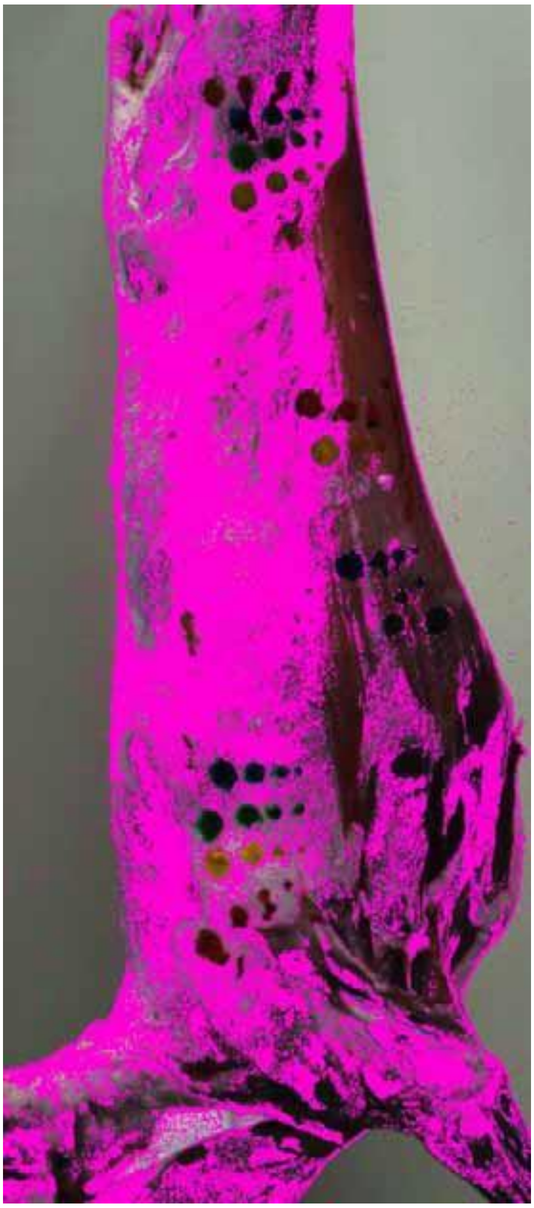


Figure 5-19 Combined Fat 1 and 2 HSL detection

Figure 5-20 Fat 1 (left) and Fat 2 (right) HSL detection

5.2.1 Green Markers

The HSL analysis data for the green paint, paper and dye tag contrast agents is shown in figures Figure 5-21 to Figure 5-24. Although a variety of green tag samples were tested under various lighting conditions (fluorescent and halogen, with average lux ratings from 250 to 670) the hue histogram of the HSL analysis falls within the same region of approximately 70 -110. This is further illustrated by the analysis of the overexposed high aperture paper sample in Figure 5-24. Filters for hue and saturation remain the same with only luminance needing to be altered to account for the increased brightness or higher amplitude/ power of the light.

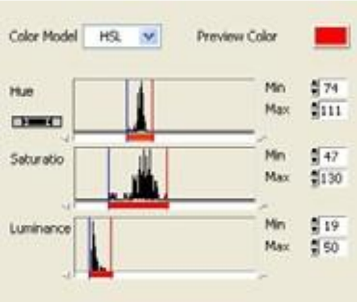


Figure 5-21 Paint Green Filter

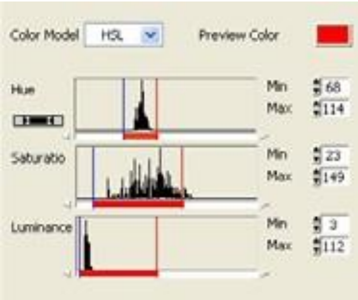
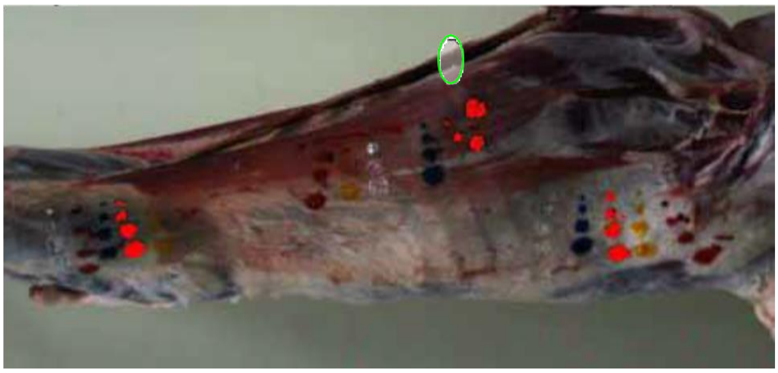


Figure 5-22 Dye Green Filter

It should also be noted that accounting for an increase in luminance does cause detection of element artefacts from the "green" background and "edge" interaction of the background with the object which can be controlled with different background selection as discussed earlier.



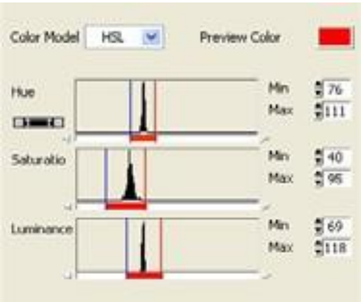


Figure 5-23 Paper Green Filter

The detection is reasonably robust with minor single-pixel response on the surface of the carcase at the belly opening shadow and some blue test sites (particularly dye contrast agents). Having specifically controlled lighting conditions and therefore narrow luminance filtering requirements eliminates this however even with a large luminance band geometric filtering would be sufficient dependent on what component detection is required.

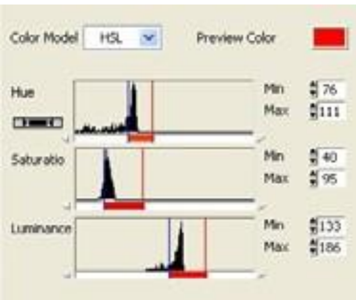


Figure 5-24 Paper Green Filter (High Aperture)

Following is the HSL analysis for green contrast tag agents on fat tissue (Fat 1 type – back fat covering) and muscle surfaces (both brisket and muscle areas).

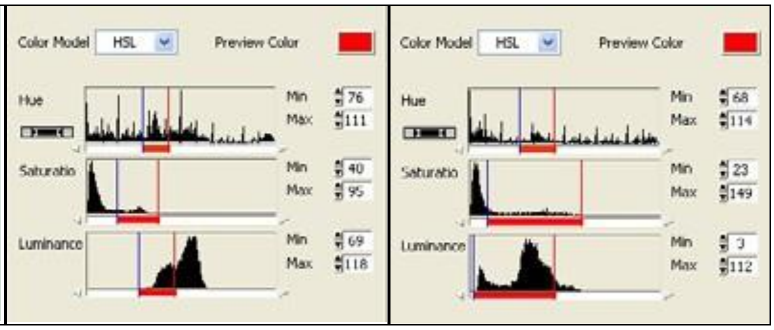



Figure 5-25 Green Tag on Fat Tissue **Figure 5-26 HSL Analysis Green Tag - Fat Tissue**

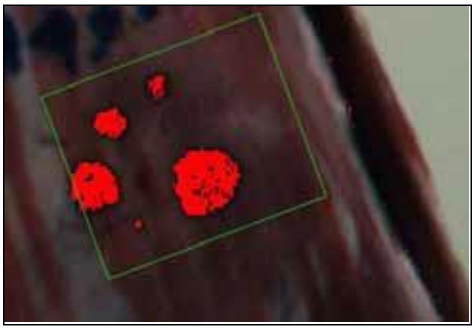
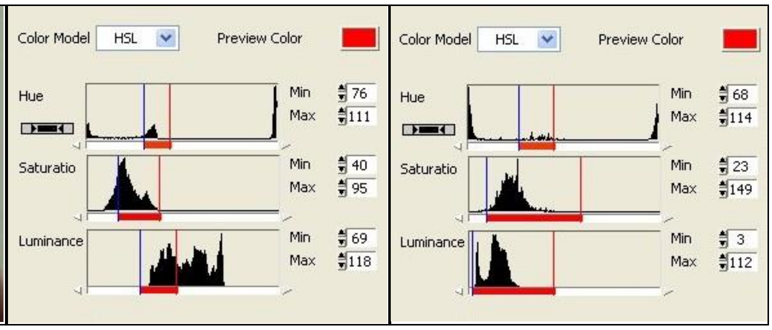



Figure 5-27 Green Tag on Muscle Tissue **Figure 5-28 HSL Analysis Green Tag - Muscle**

When green contrast agent tags are analysed on a fat tissue surface (see Figure 5-25) the hue histogram shows no competitive features in the green region. The “fat colours” show only as a significant saturation in the red region giving a distinct spacing from the green, making green coloured contrast agents good for observation on fat surfaces. A similar result is seen when green tags are used on the brisket “red bark” and other muscle surfaces. The “red muscle” region of the hue histogram shows significant separation from the analysed green tag region.

5.2.2 Blue Markers

As with the green coloured contrast tag agents the blue markers for paint, paper and dye all fall into a narrow colour region despite being visually quite different. This region is approximately 145 to 175 as shown in the hue histograms of figures Figure 5-29 to Figure 5-32.

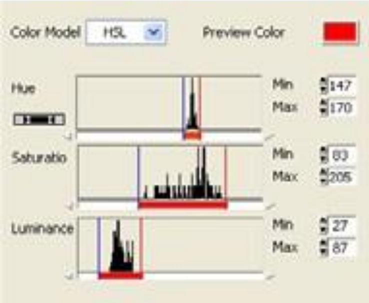


Figure 5-29 Paint Blue Filter

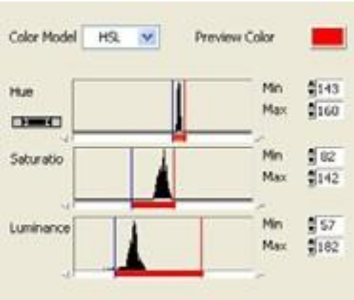


Figure 5-30 Paper Blue Filter

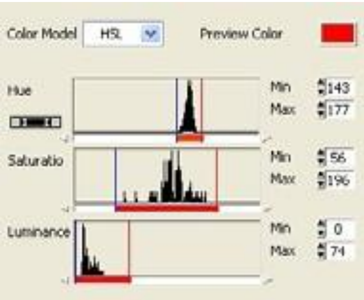


Figure 5-31 Dye Blue filter

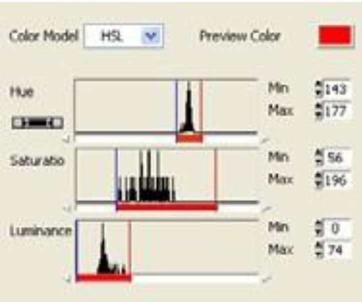


Figure 5-32 Dye Blue Filter (High Aperture)

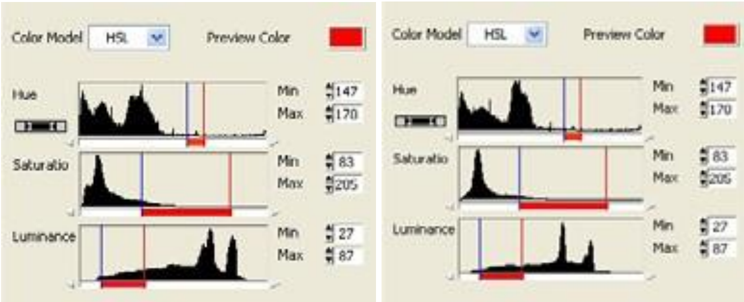


Figure 5-33 Paint tag agent – Image High & Low - Blue Filter

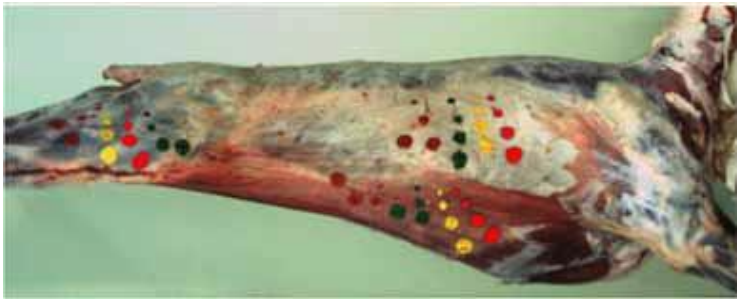
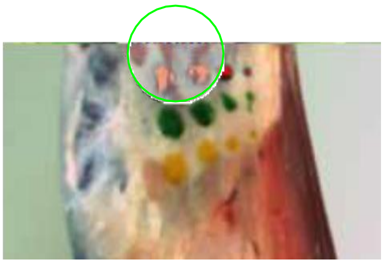


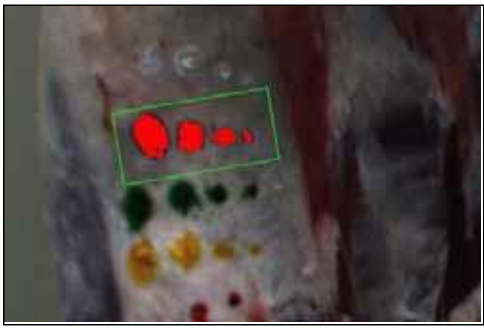
Figure 5-33 shows the histograms of two image examples for the paint tag contrast agents illustrating that the blue colour filter region is also observably different from any of the component regions found in the detection environment.



The blue HSL filtering was responsive enough to detect when a blue dye tag region became adulterated by red dye.

As the dribble no longer met the hue constraints it was not detected by the HSL filter and could be differentiated as such despite the fact the original blue dye would be a significant contribution to the final colour, demonstrating that blue HSL filters can be both robust and sensitive to small changes.

The figures following (Figure 5-34 and Figure 5-36) show the results for blue tag HSL detection analysis on red meat/ muscle and on Fat 1 (description earlier in section 5.2 with reference to carcass environment) “back fat covering” type tissue. The results show that, with control of lighting, the detection of blue contrast agents is robust as the markers are strongly differentiable from the surrounding tissue types in the red hue regions (recall Fat1 is also in the red hue region).



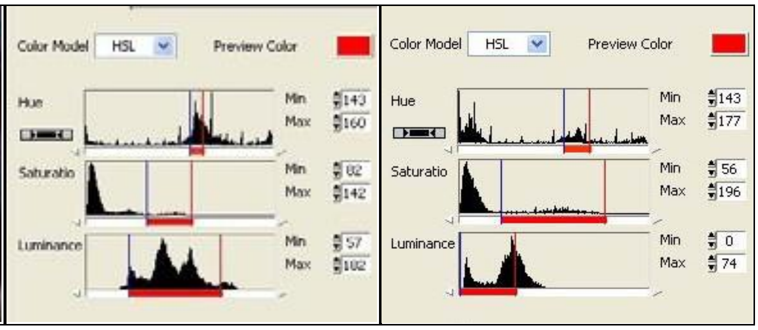
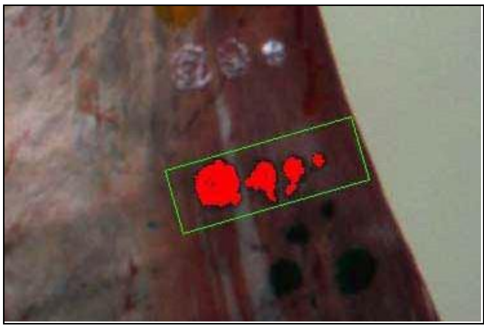


Figure 5-34 Blue Tag on Fat Tissue **Figure 5-35 HSL Analysis Blue Tag - Fat Tissue**



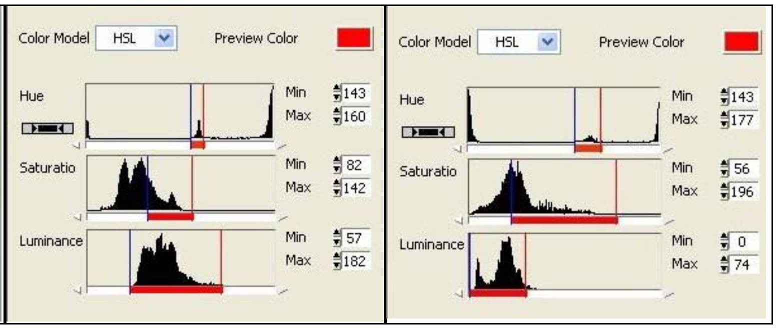
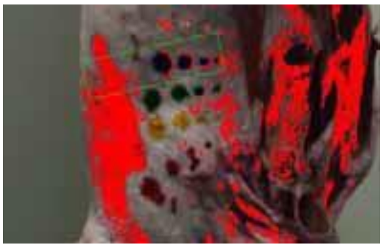
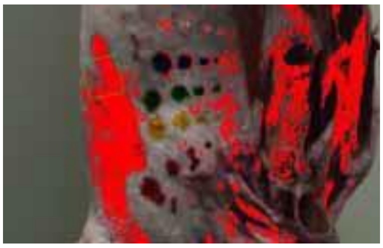
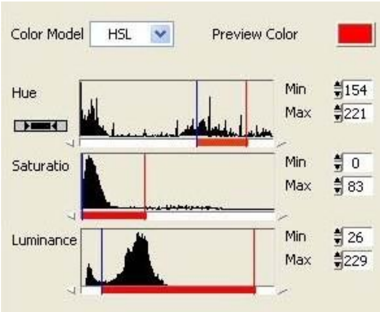
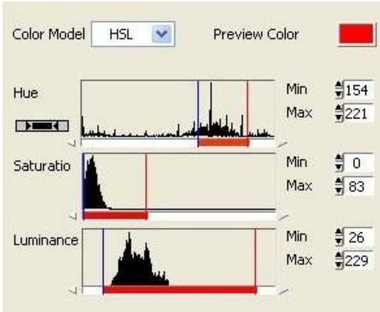
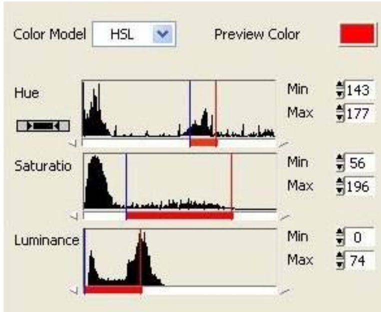


Figure 5-36 Blue Tag on Muscle Tissue **Figure 5-37 HSL Analysis Blue Tag - Muscle**

One area that does overlap the blue hue region is the “Fat 2 colour” that occurs from the fat around the brisket and muscle areas of the carcass. The data shown in Figure 5-39 and Figure 5-40 illustrates this with the hue histogram region of 143-177 for blue detection coinciding with the hue region of 154-221 for Fat 2 detection. To discriminate between the blue tag markers and the Fat 2 colour is not possible (Figure 5-38). The results indicate the blue optical contrast agents are not suitable for detection on fat covering on the brisket and muscle areas.

<table>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figure 5-38 Combine Fat 2 and Blue Tag HSL Histogram (Fat 2 detection)</td>
<td>Figure 5-39 Fat 2 HSL Histogram (Fat 2 detection)</td>
<td>Figure 5-40 Blue Tag HSL Histogram (Blue detection)</td>
</tr>
<tr>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
</table>

5.2.3 Yellow Markers

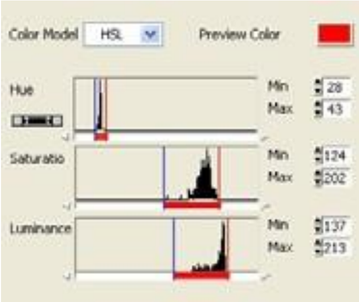


Figure 5-41 Paint Yellow Filter

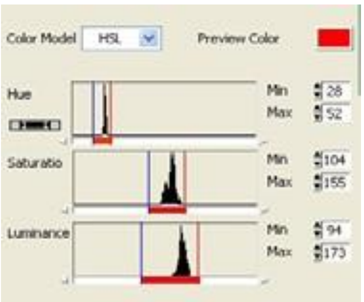


Figure 5-42 Paper Yellow Filter

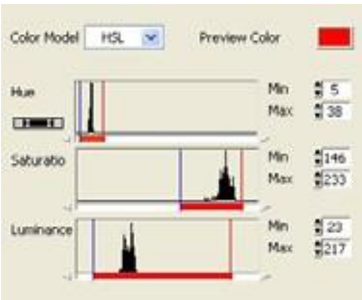


Figure 5-43 Dye Yellow Filter

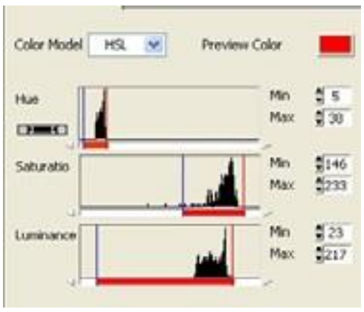


Figure 5-44 Dye Yellow Filter (High Aperture)

As is shown in Figure 5-41 to Figure 5-44 the yellow hue region is close to the "red" section of a HSL histogram with some crossover down to hue values like 5, but from the analysis lies generally between 25 to 50. Yellow tag samples also gave a higher more dense saturation region then blue and green sample tests suggesting a stronger pure colour in comparison to the carcase environment.

The results showed a fairly robust detection with even small contamination "smears" being detected of yellow paint tags during analysis. There was also strong detection of the dye markers; with only minor (<1%) on edge of red dye sites false positives. One dye tag on a muscle/ brisket test site was compromised by a red dye dribble and the analysis detected only the unadulterated parts of the tag (Figure 5-45).

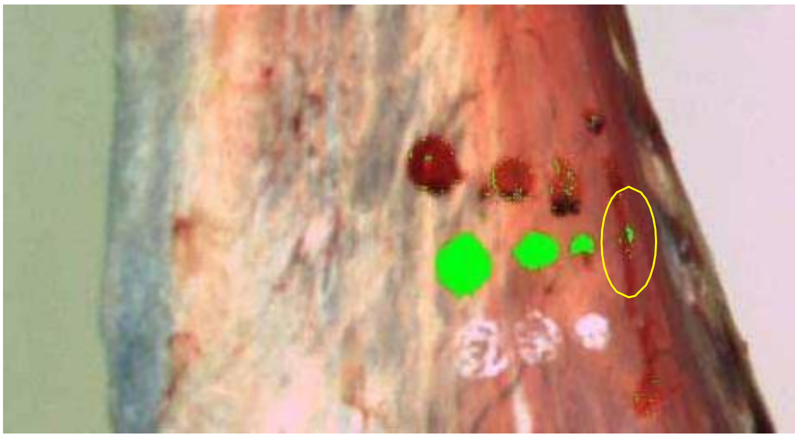
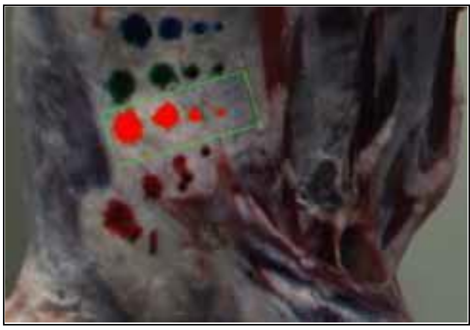


Figure 5-45 Yellow Tag Detection

The HSL analysis detected no environment or surrounding noise. The largest variation between tags is shown in the luminance settings with large luminance filter boundaries easily detecting tag regions on both standard and overexposed data. Altering the luminance settings can be used to affect control of the false positives otherwise minimal geometric / size filtering is sufficient to get reasonable results.



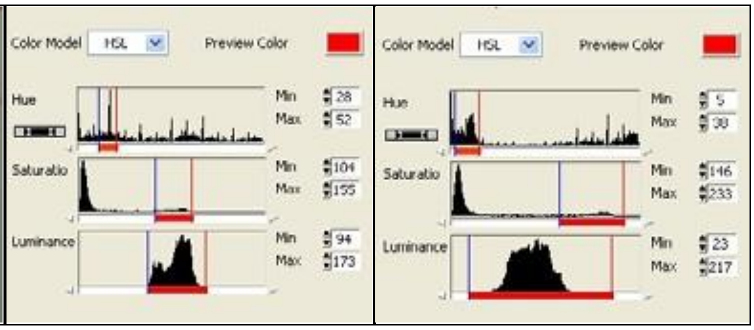
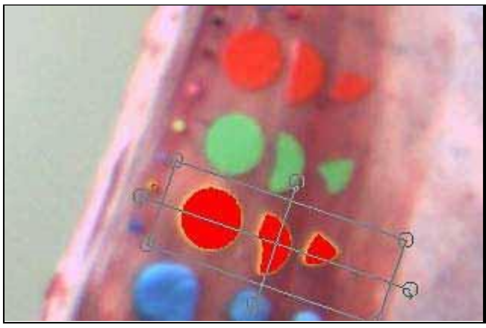


Figure 5-46 Yellow Tag on Fat Tissue **Figure 5-47 HSL Analysis Yellow Tag - Fat Tissue**



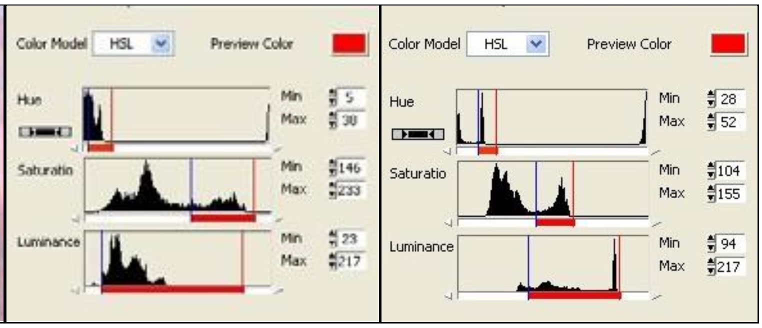


Figure 5-48 Yellow Tag on Muscle Tissue **Figure 5-49 HSL Analysis Yellow Tag - Muscle**

The yellow contrast agent tags were applied on fat (Figure 5-46) and muscle (Figure 5-48) tissue surfaces. The yellow region is identifiable on all the analysis HSL hue histograms although dependant on the data example the separation from the "red muscle" or saturated "pink fat" (visually going to white) is minor. With poor lighting control this is likely to result in an increase in detection of false positives from the red hue region (also seen in Figure 5-45 where detection robustness was illustrated).

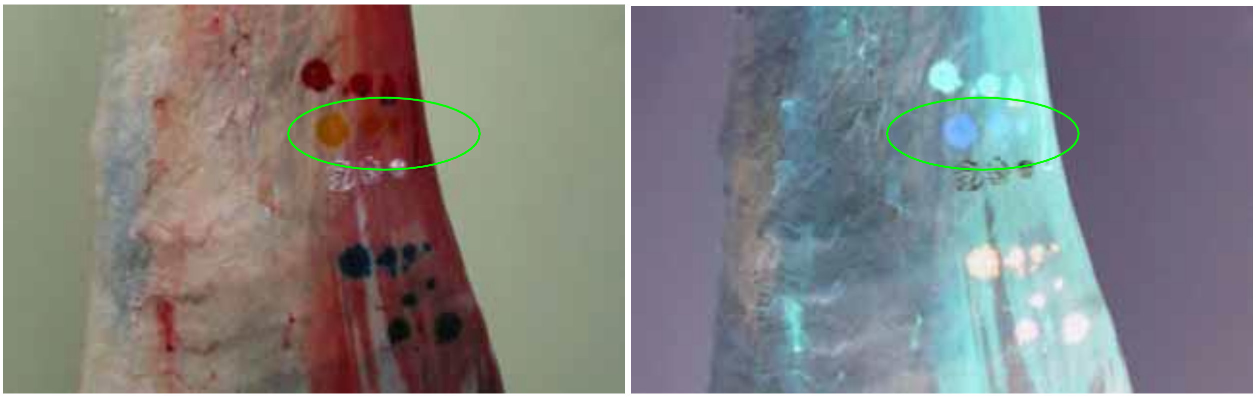


Figure 5-50 Left - Yellow contrast marker agent on red surface; Right - Data Image negative

One issue identified with yellow contrast tag markers is that, dependant on what colour carrier medium is used, they can be visually hard to see, particularly on red surfaces. An example of this is shown in Figure 5-50 [left]. Although in this case the yellow dye contrast agent is detectable with the HSL analysis (for illustration correlation the data negative image is shown in Figure 5-50 [right]) verification of placement by a human operator quickly is quite difficult adding complexity for application in the processing environment.

5.2.4 Red Markers

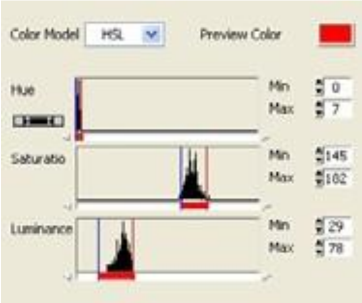


Figure 5-51 Paint Red filter

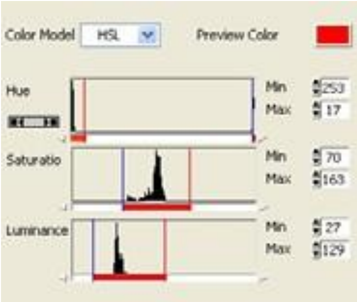


Figure 5-52 Paper Red Filter

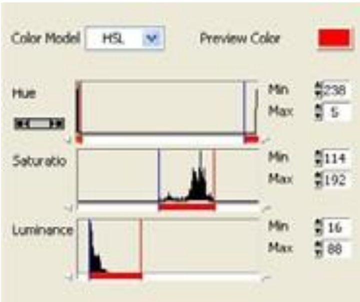


Figure 5-53 Dye Red Filter

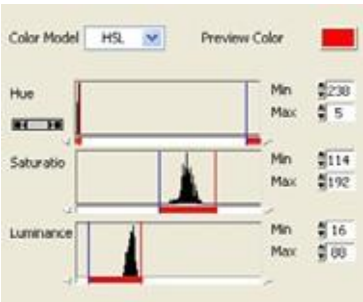


Figure 5-54 Dye Red Filter (High Aperture)

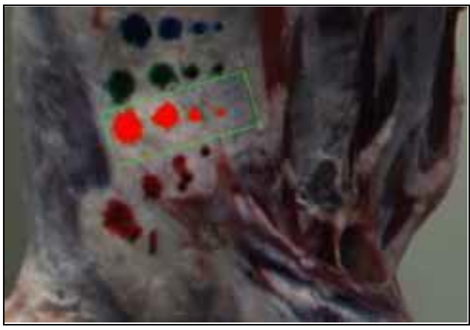
The “red” hue region of the analysed tags is between the 0-17 and 238 – 255 areas (see Figure 5-51 to Figure 5-54). From the earlier discussion about the analysis environment (start of section 5.2) it can be recalled that the red bark area and muscle “colours” also lie within this red region (Hue 206-10 see Figure 5-15). “Fat 1”, which is the back fat covering (shown in Figure 5-17), also has colour in the red to yellow hue region because as pink tones saturate the “colour” goes to white. This means that discriminating red tags from the carcass environment is very difficult.

Lighting variation made the analysis of red dyes very unreliable, with the red of the meat being analysed more often than the dye itself in the RGB colour scheme. HSL analysis also found it very difficult to differentiate “Red” contrast tags from the carcass environment “reds”. Using size filtering improves results yet this does not account for the correction of all false positives. Using analysis based on colour techniques like thresholding alone did not detect dye contrast agents as often the tag had the same hue as “redbark” muscle regions with a different saturation brightness (or luminance) range.

Paint tag had similar results with detection relying on object definition filtering (ie approximate size template). Again detection of the tags were sensitive to orientation and lighting changes and very difficult to discriminate due to similarities to carcase environment colours.

On fat tissue, the detection analysis of red paper marker agents could be tuned to an acceptable level, however once again, as lighting conditions alter slightly, false detection became more prevalent.

The lighting required to use red markers needs to be very controlled and consistent across the body to allow luminance or saturation to be the primary discriminator for detection, as hue is unlikely to be successful. Unfortunately, even with ideal conditions let alone the process environment, the likelihood of acceptable results is very low.



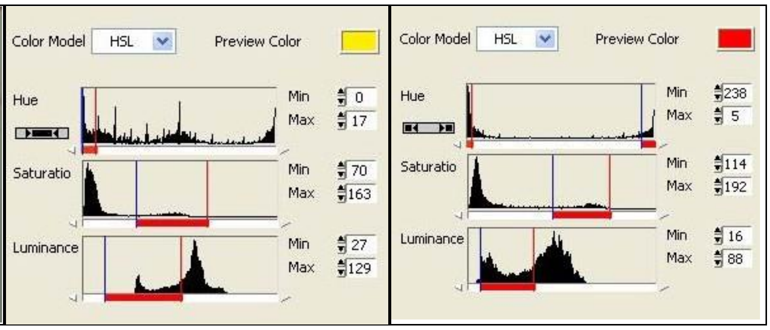
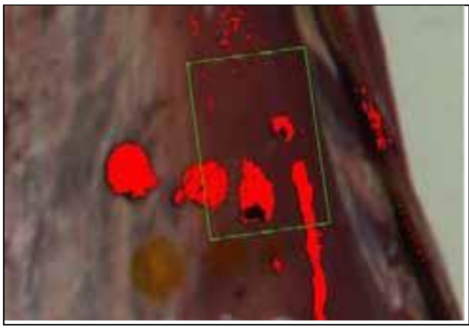


Figure 5-55 Red Tag on Fat Tissue

Figure 5-56 HSL Analysis Red Tag - Fat Tissue



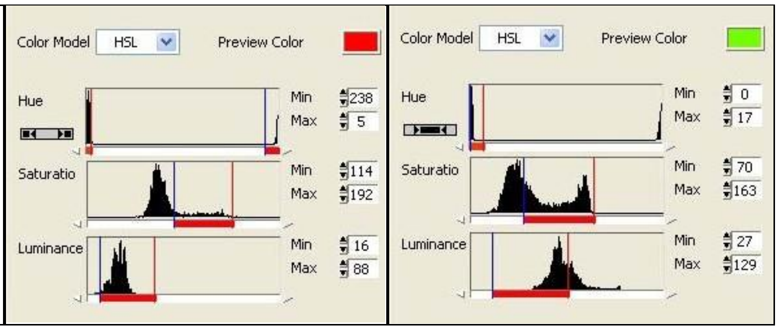
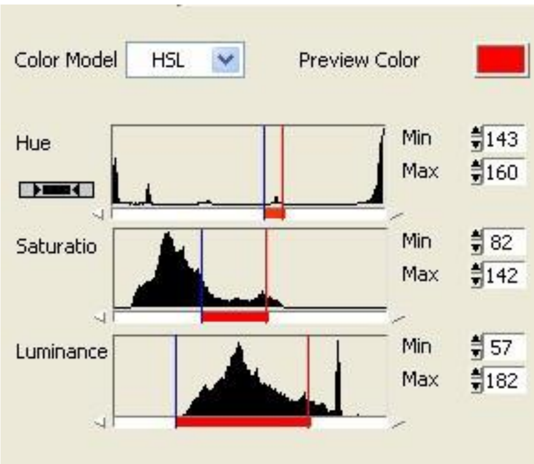


Figure 5-57 Red Tag on Muscle Tissue

Figure 5-58 HSL Analysis Red Tag - Muscle

Due to the coexistence of any red coloured contrast agents with the muscle / meat and fat colours found in the carcass environment, illustrated for fat in Figure 5-55 and muscle tissue in Figure 5-57 where the detection of the marker relative to the surrounding tissue surface is not observable in the associated HSL analyses, red optical contrast agents are not recommended. As the carcass and tags are widespread in the luminance and saturation ranges, for any accuracy in detection, heavy use of geometrical filtering is required.

5.2.5 Summation of colours



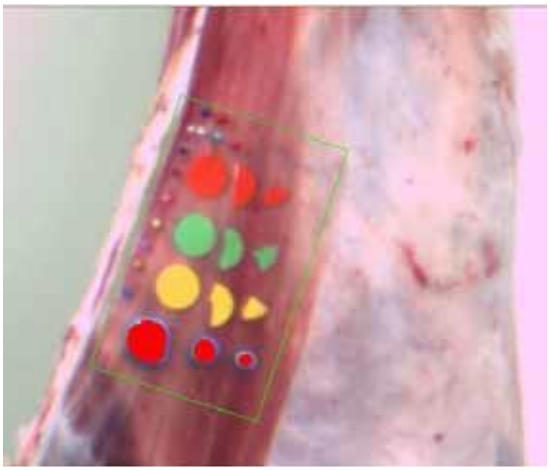


Figure 5-59 HSL Analysis Comparison (blue regions highlighted) Figure 5-60 Paper tags colour comparison

Figure 5-59 clearly shows from left to right where the red, yellow, green, blue and again red (hue ranges sit with relation to each other (recall HSL colour space illustration [Figure 5-11] from the start of section 5.2). When compared to the hue regions of components found in the detection environment like those of fat or muscle it illustrates that for the most robust detection green is a good tag agent choice, followed by blue (with careful lighting control consideration and not on "Type 2 - muscle fat" areas) then yellow. Red is the least preferred option.

5.3 Detectability - Alternative Marker Analysis

The detectability of contrast agents other than those related to colour analysis is presented in this section. These are:

- Lasers
- LED
- Reflective tape
- Temperature

5.3.1 Lasers

Laser tests were conducted at three basic aperture settings (high, medium and low) in combination with and without a red filter on the capture camera. Ambient fluorescent light was used in all cases. The image analysis for the laser contrast tag dot sites detection is based around intensity filtering, before feature extraction. The use of laser for the purpose of this tag test was to investigate the effect of intensity rather then colour tag information, which is examined via paint, dye and paper tag contrast agents.

- ***Laser – no filter – high, medium and low aperture***

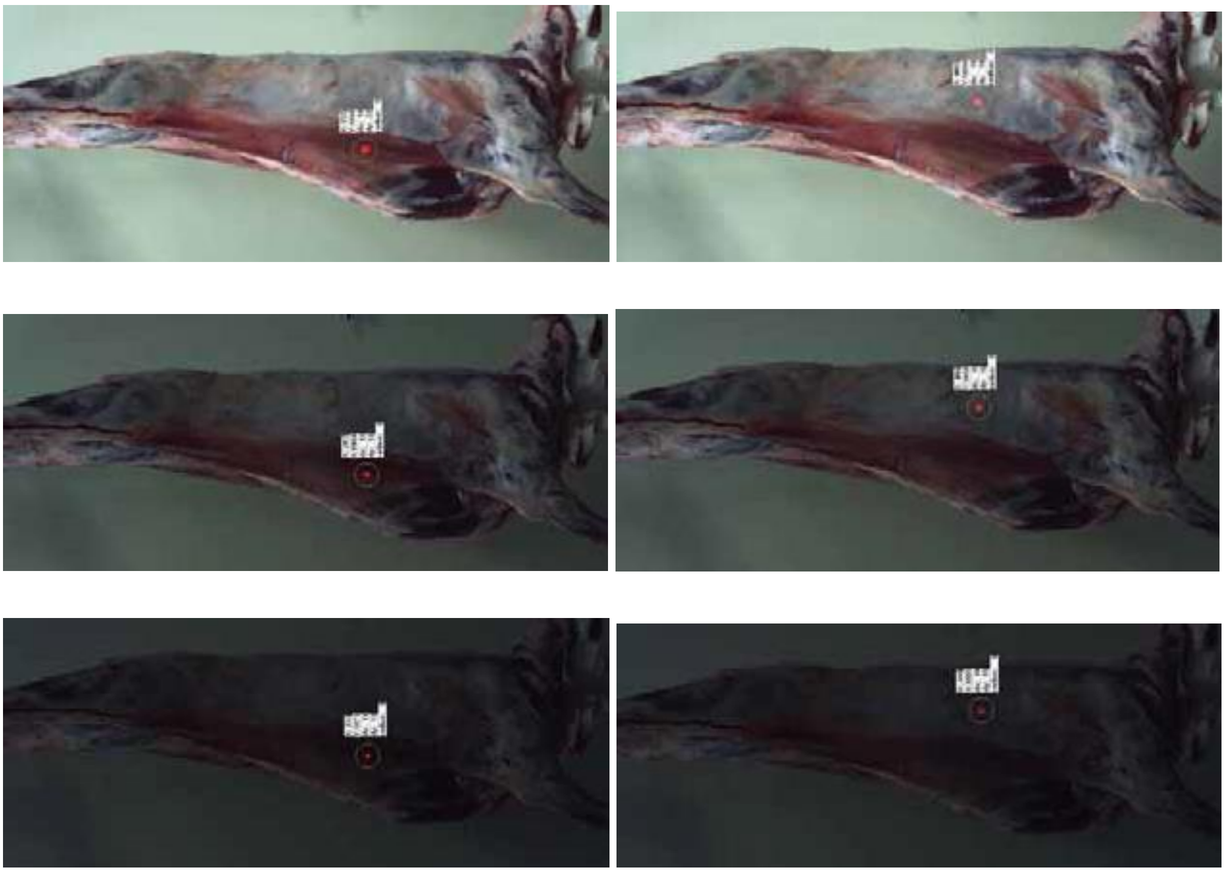


Figure 5-60 Laser data - No filter - High, medium & low aperture

When the data was captured using a high aperture setting and no hardware filter the "background" image was very clear. As the aperture setting is reduced the laser dot becomes more prominent until the "background" image is virtually eliminated. Reducing the aperture setting also minimises the effect of the laser dot to "bleed" into the image at the higher settings ie the dot appearing bigger in the image than what it actually is on the carcase. Although the intensity of the whole image is reduced, the high intensity laser dot still remains robust.

Using a red hardware filter to capture the image gives similar results. The red filter enhances the effect of reducing the aperture, assisting the laser dot to become the prominent feature of the image. For the same aperture setting the red filter only passes the red “light” response available in the image data.

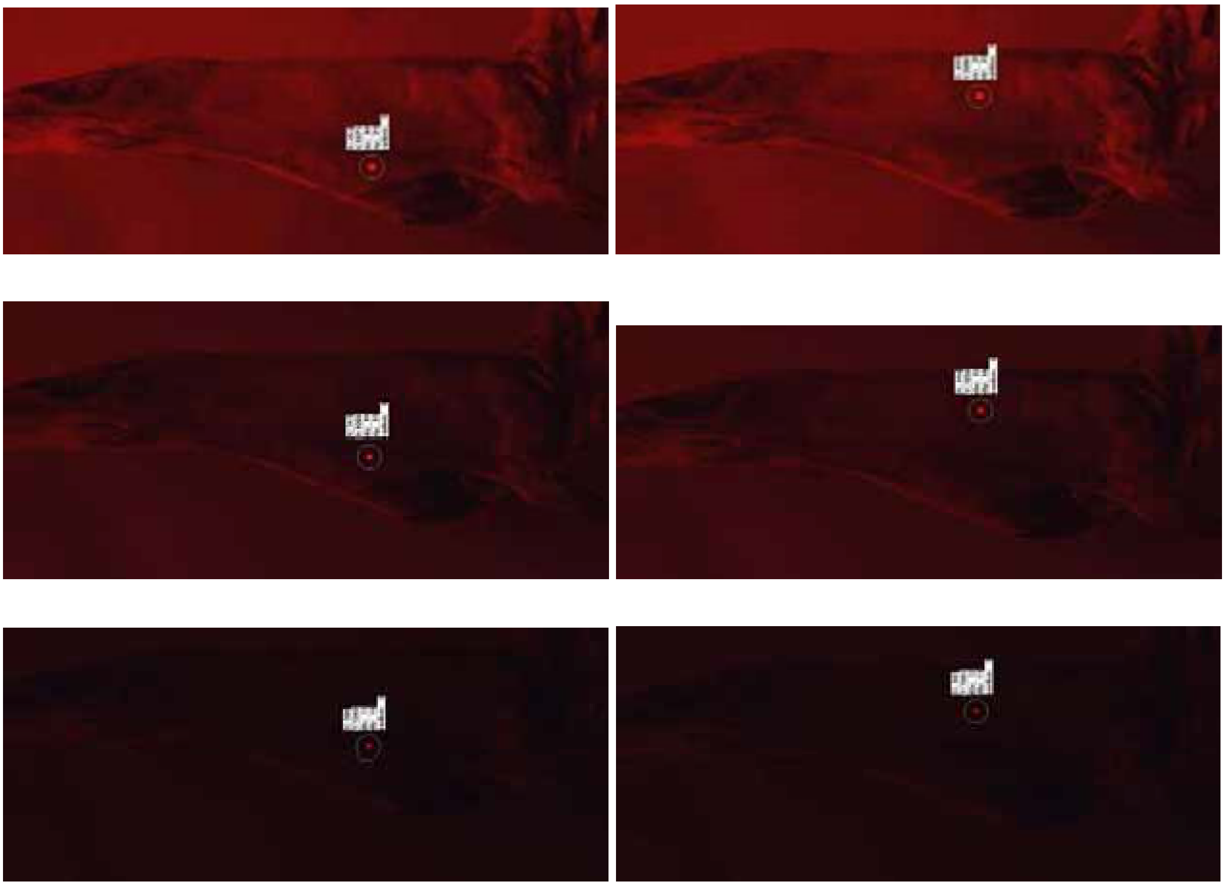


Figure 5-61 Laser data - Red filter - High, medium & low aperture

Using laser as a contrast tag agent in a virtual mark and capture situation, where a reference point relevant to the carcase is required and can be identified (and “marked” with the laser) by an operator for subsequent detection by machine vision, would be a viable intermediate option to developing robust automation solutions. An added advantage of using lasers is that the “marking” laser can also be used to provide distance data if calibrated with a 2D image capture.

An important consideration of lasers is the safety requirements needed if used in an environment where people may be exposed, particularly in the eyes. As laser is a coherent light source a significant amount of power can be transmitted to an object in a short amount of time, and they are classed as a source of non-ionizing radiation. When using the lower power classes of laser (2A and below) the blink reflex is a sufficient safety precaution however if using higher powered 3B restricted class lasers and above additional guarding with interlocks, covers and consideration of specular reflections (reflections from “smooth” surfaces) may be required. The power of the laser required is dependant on the application. For example detection of a laser point on a black and white hide will require more power because of black sections - recall from basic physics black is the total absorption of light by a substance and white is the total reflection hence more power is required to maximise any output from a “black” surface.

5.3.2 LEDS

Detection of LED position data was based on filtering of the RGB colour planes and intensity analysis. Yellow, blue, green, red and infrared LEDs of differing sizes were analysed via the use of purpose built wands to investigate the potential for LEDs to be used in a "virtual" tag marking application (test series specification shown in Table 5-1).

Table 5-1 Led Tag Test Series

Colour	Size	Rating Min – Max (mcd)		
Blue	3mm	12.5 - 40.0	20.0 - 90.0	
	5mm	20.0 - 60.0	40.0 - 150.0	
Green	3mm	8.0 – 32.0	40.0 – 60.0	100.0 – 300.0
	5mm	5.0 – 32.0	20.0 – 60.0	100.0 – 300.0
Orange	3mm	12.5 – 50.0	200.0 – 700.0	500.0 – 2000.0
	5mm	20.0 – 50.0	400.0 – 2500.0	
Red	3mm	12.5 – 50.0	400.0 – 600.0	1200.0 – 1400.0
	5mm	20.0 – 1000.0	700.0 – 1000.0	500.0 – 1000.0
Yellow	3mm	8.0 -32.0	100.0 – 400.0	200.0 – 1300.0
	5mm	5.0 – 32.0	100.0 – 500.0	
IR	3mm	11mW/sr	75mW/sr	

*mcd.: micro candela

Individual LED series results can be found in the Data Analysis sheets in the Appendix. It was found that the colour and size of the LED have little or no influence on the results of the tag detection – which was very robust – when intensity analysis is used. All of the LEDs were distinguishable, but the brighter or higher candela rating LEDs would be preferable as tag agents as the contrast to ambient light conditions is greater giving more robust discrimination. The duller LEDs, in particular the blue series and the low rated IR LED were less effective in comparison. When filters were added to the blue and infrared lasers the contrast again improved as the background was further reduced. The brightest LED from each series in shown in Figure 5-62.

It should be noted that the IR LED is invisible to the human eye and the images produced are those from a camera. As such the operator would not be able to tell if the LED is on or off meaning implementation as a tag agent requires verification by a secondary method. As a positive point an "invisible" tag would cause less disruption to surrounding operators.

With the aperture of the camera unchanged, the resulting analysed detection point ranged from 4 to 12 pixels in diameter which related to the 3 to 5mm lens of the LED.

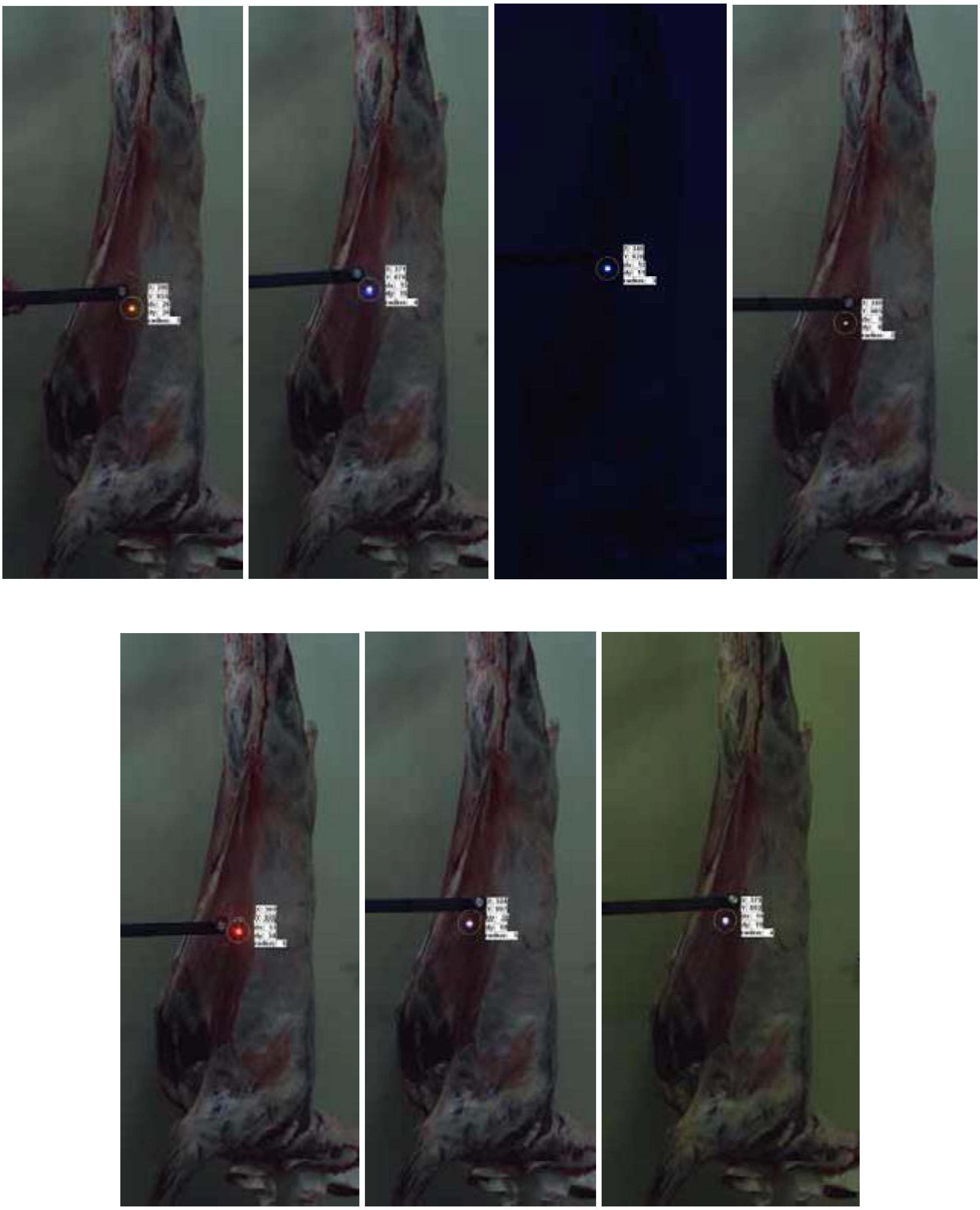


Figure 5-62 LED Results (a) Yellow series: 200-1300 mcd 3mm; (b) Blue series: 40 - 150 mcd 5mm; (c) b with blue filter; (d) Green series: 100 - 300 mcd 5mm; (e) Red series: 1200 - 1400 mcd 3mm; (f) IR series: 75mW/sr Kodeshi GaAs 3mm; (g) f with filter

5.3.3 Light Responsive Markers

Light responsive markers refer to those contrast agents that require consideration of lighting conditions in order to capture effective tag information. For the purpose of investigation reflective tape and UV inks and gels were trialled. The analysis software captured information in a particular plane (eg extracted the luminance plane in a HSL system), before filtering for brightness and thresholding for a particular tag condition (tag colour; minimum area, etc).

Reflective Tape

The effectiveness of reflective tape as an optical contrast marker is very dependent on the lighting conditions used for illumination. Two different reflective tapes were investigated in:

1. high ambient light condition
2. A controlled light environment which had the light source (2x500W spot lights) placed almost behind the camera (approximately on 5 degree angle around imaging sight line).

The second lighting method was very effective; however in the first setup (high ambient conditions) without the increased contrast lighting the reflective tags were very inaccurate. In ambient lighting, detection of the “white” reflective tags also generated false positives from reflections on the carcass surface (see Figure 5-63).

Figure 5-63 Reflective tape in ambient light

Figure 5-64 Reflective tape in controlled lighting

Figure 5-64 shows the results from the controlled lighting environment. The resultant background is more uniform and any carcass reflective surfaces fall below the tag specific thresholds. The orientation of the tags to the light source and capture device is significant. Using focused directional light means greater potential for occlusion shadows or spurious light from the surrounding process environment to interfere with target detection filter and threshold parameters and consequent results.

Reflective tags offer a useful added dimension to paper tags or stickers in that they do have reflective properties that with consideration of implementation can increase the robustness of tag detection. Natural reflectivity of the carcass surface needs to be controlled by specific lighting. Alternatively it can be masked by using tags outside the reflective features window ie as small markers have similar properties to the carcass artefacts only look for large tags.

UV Inks/ gels

Two different types of activated gels were fluoresced under 40W BLB fluorescent light tubes (wavelength approximately 365nm) – one a UV "invisible ink" pen, the other a "glow in the dark" gel. Food grade approved fluorescing agents are commercially available (as discussed in section 2.1.1 of this report) but as they tend to be a specialised item it was felt that the use of alternative "over-the-counter" products was suitable to test the principle of a UV activated contrast tag agent.

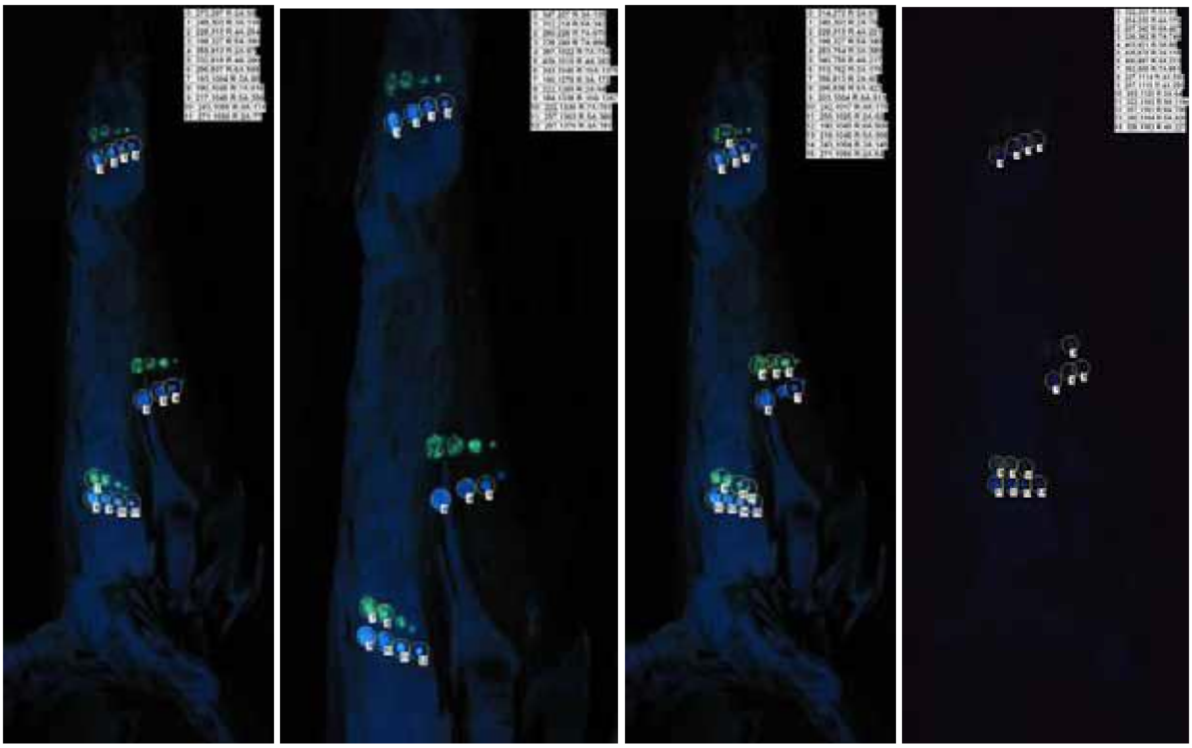


Figure 5-65 UV activated contrast agents: (a & b) "Invisible Ink" analysis [Canon camera]; (c) "Glow in the dark" analysis [Canon camera]; (d) Combined analysis [AVT Oscar camera at 1m]

The results of the UV contrast tags analysis is shown in Figure 5-65. The "Invisible Ink" analysis ("blue" colour in Figure 5-65 a and b) identified all markers excluding the small 5mm diameter tag on the curve of the carcass cavity (Region 2 Site 1). Although some of the "Glow in the Dark" gel tags were also identified (this is predictable when using intensity filtering as part of the analysis) no false positive readings from the carcase features were detected. Results for the “Glow in the Dark” (Figure 5-65 c) were less robust with tags in Region 3 Site 4 on the curve of the hind leg as well as those in Region 2 Site 1 not being identified.

The brightness or level of fluorescence is clearly linked with the intensity of “blacklight” to which the tag was exposed. This is supported by the reduction in the ability of the analysis to detect markers on curves away from the light and the cameras line of sight. To quantify this, better tag samples were illuminated at 700mm and 1m away from the two 40W light sources however the backlight intensity was still insufficient to quantify the improvement - although visually the closer the light the better the response available (see Figure 5-65 d).

From the results, unless carcase position (or alternatively the target zone in which machine vision would seek a tag) can be controlled, for a camera system between 700mm and 1m from the carcass, tags should be greater than 5mm diameter. If the whole carcase image is required for tag analysis a broad UV light source greater than 40W is required.

5.3.4 Temperature

An indicative core temperature of a beef animal is approximately 38°C. Variation occurs between animals due to factors like weight as well as through the body - between internal organs dependant on their function, or between the core temperature relative to skin or extremities as examples. Similarly, post stunning there are carcass temperature variations dependant on the part of the animal being monitored and what part of the slaughter process has occurred. For example the brisket or neck surface temperature pre-chill is around 23-24°C while the deep butt temperature increases to around 41-42°C one hour after stun (around 45°C if stimulation has been used). This means using temperature tags on a carcass will be very dependent on what sensing feedback is required and where the operation occurs in the slaughter process. Consideration also needs to be given to how plant variables such as equipment failures or meal breaks could affect monitoring.

For the purposes of this project cold and hot temperature change of the “existing” carcase surface as well as the addition of external tags was considered.

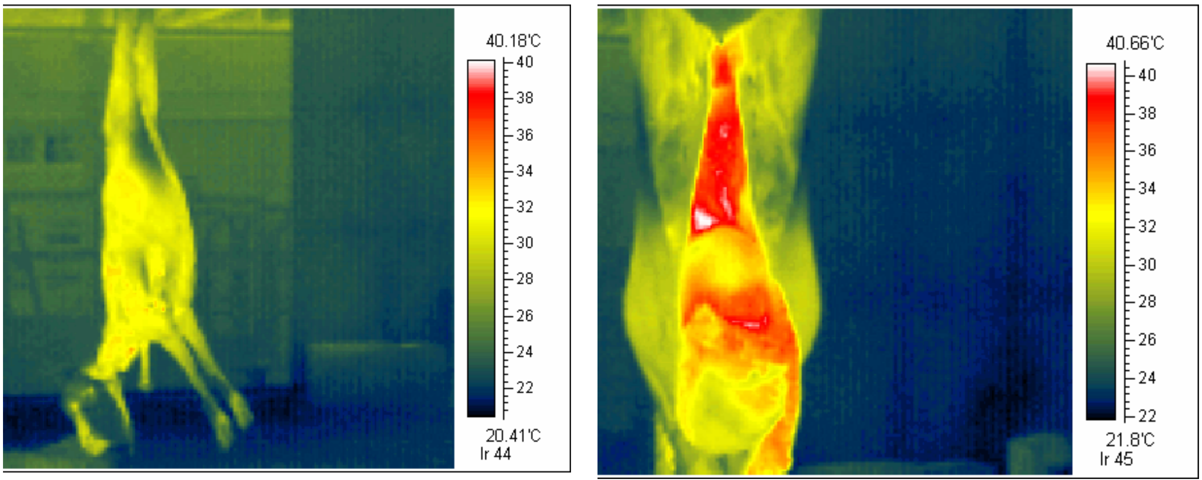


Figure 5-66 Sheep Carcass – Hide removed (left) and cavity open (right)

Cold temperature markers were applied by aerosol spray, using CO_2 ice stick like a pen and prepared ice cube pins. The spray did not apply as a uniform temperature tag, similarly with the CO_2, and while the ice cubes maintained temperature they “bled” as they melted.

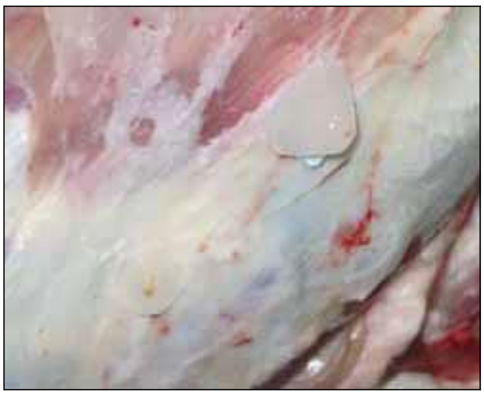


Figure 5-67 Ice-cube markers

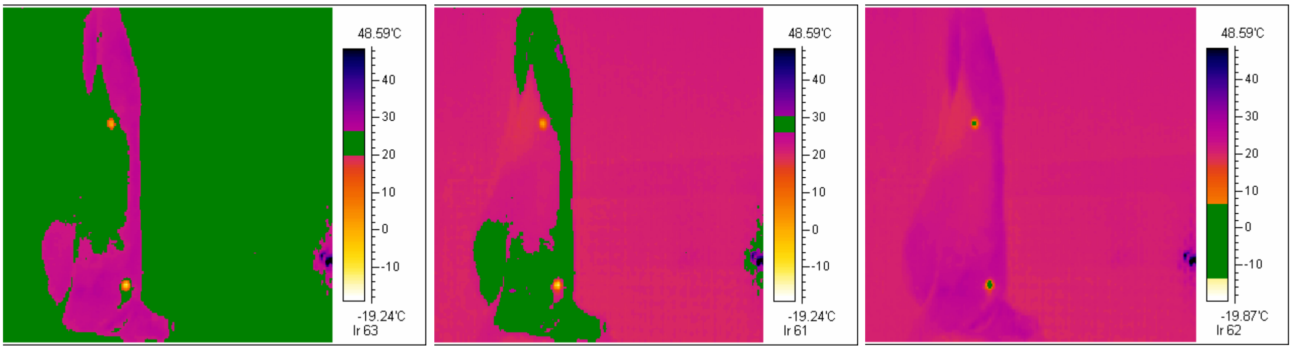


Figure 5-68 Thermal data regions

From Figure 5-68 it can be seen that at the time of testing the temperature of the carcass muscle region is between 26-30°C, the tissue around the empty carcass cavity and the surrounding background environment between 20-26°C and the marker samples in this example between -13.5 to 5 °C. As with colour discrimination the greater the difference of an object from its surrounding environment the easier detection analysis becomes. Temperature also has the added complexity of equalising to its local state so it deteriorates with time. In this case temperatures at least outside the 20 to 30° range are required, dependant on how quickly after application a measurement is taken and what feedback is required (ie a temperature measurement on the carcase cavity wall could still be useful in the 26-30° region).

Table 5-2 Temperature Data for Cold Spray Application Tags (°C)

Time	**Site 1** **5 Sec Appn***	**Site 2** **5 Sec Appn**	**Site 3** **5 Sec Appn**	**Site 4** **5 Sec Appn**	**Site 1** **3 Sec Appn**	**Site 2** **3 Sec Appn**
0sec					-9 - +10	-12.8 -+10
30 sec	6-18	19.59	21.98	14.4-18.4		
3min 30 sec	18-19.7	24.11	26.4	27.3 (27-28)	20.8-22	26.5-27.5
20°C Datum	++	45sec	30sec	45sec	2min 30sec	60sec

*Appn: Application; ++: beyond sample period

Table 5-2 shows an initial temperature measurement of 6 cold spray application markers, with additional data from the same site taken after 3 minutes 30 seconds also displayed. Figure 5-69 shows the thermal images related to this data. From this data only Site 1 of the five second application series is still below the 20°C carcass and environmental temperature threshold. Tag site 1 of the three second application series also maintained cooler temperature for a longer period. Of interest to note is both these sites were located on the flank muscle of the carcase belly cavity where (a) there is potential for a deeper chill thickness; and (b) the area is cooler and there is less muscle volume for the carcase body temperature to transfer through, unlike the other sites. Site 2 of the 3 second application, located on the shoulder region, illustrates this point quite clearly for although it has a lower initial temperature (-12.8°C) within 60 seconds of taking this measurement the temperature has normalised.

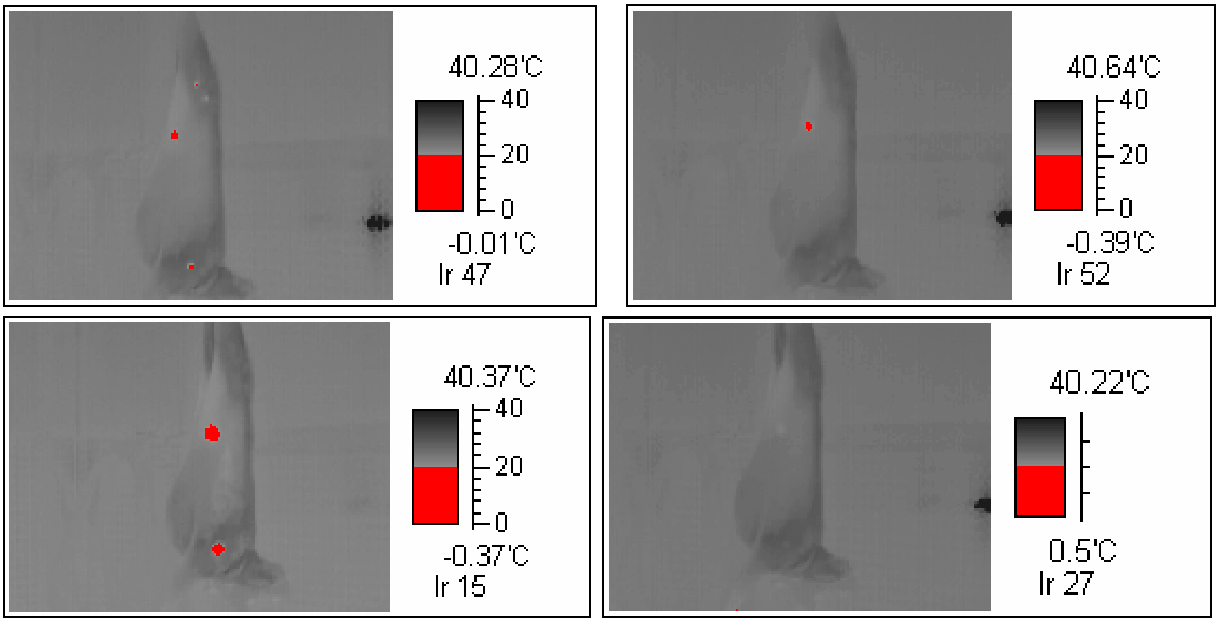


Figure 5-69 Thermal images for spray markers - Top 5 sec application, Bottom 3 sec

Hot temperature tags were created initially using both solid and hollow metal bars, and a large diameter electric heating iron. Later a two pronged solid bar tool was developed to investigate heated tags on different areas (ie fat and muscle) while minimising effects of actual application.

Table 5-3 Temperature Data for Hot Temperature Tags (°C)

Time	**Heating Iron Site1**	**Heating Iron Site2**	**Hot Rod (single site)**	**Hot Rod (multiple sites – spot)**	**Hot Rod (multiple sites – rod)**
0sec	35-50	35-50	30-40	27.5-42.5	27.5-42.5
2min			23.5-24.5	23-28	23-28
2min 30 sec	26.5-32.5	26.5-32.5			
30°C Datum	1min 15sec	++	30sec	45sec	1min 45sec

*++: beyond sample period

Results from hot temperature tags have similar findings as when cold temperature contrast tags are used (see Table 5-3). As expected the greater the temperature difference of the tag from the surrounding environment the more robust the discrimination of the marker. Similarly, as areas of greater muscle mass are warmer and have more volume to hold the heat energy, the transfer rate is faster for the cavity flank area test sites to return to the carcase local environment temperature (illustrated in Figure 5-70).

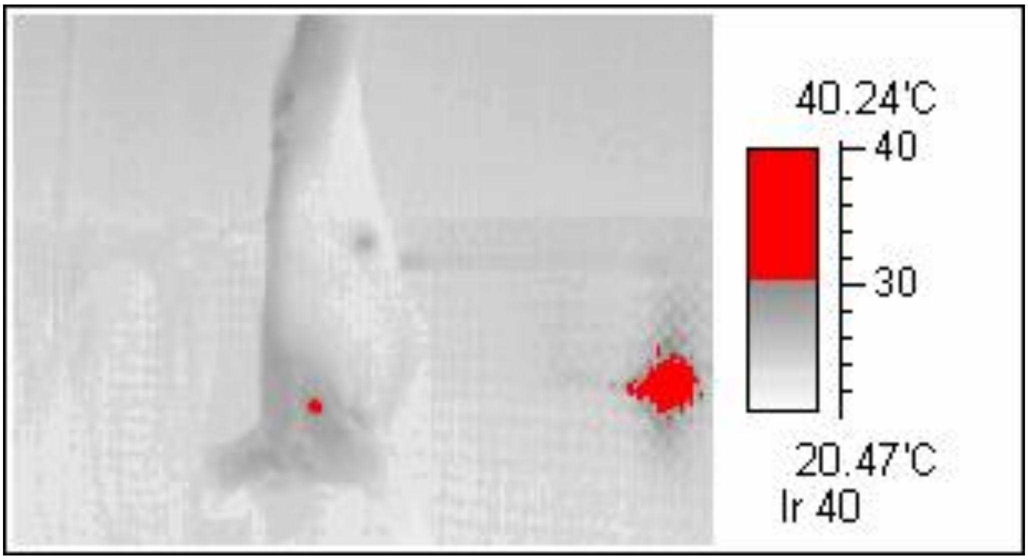


Figure 5-70 Heating Iron Application at 2minutes 30 seconds (site1 – top, site2 – bottom)

To consider surface effects on a micro level hot temperature marker tests were carried out using a specially developed two pronged tool on adjacent fat and muscle surfaces. Results indicated that muscle regions again hold higher temperature for a longer time period whereas fat gives larger initial values. In Figure 5-71 the contrast marker temperature range in the fat region is between 29.5 – 42.5 °C, in the muscle 29 – 38.5 °C. Two minutes later (Figure 5-72) the fat region markers are between 26 – 28 °C and the muscle markers 28.5-30.5°C). On the four different test locations, there was not enough data to draw any conclusions as to the effects of different muscle and fat types.

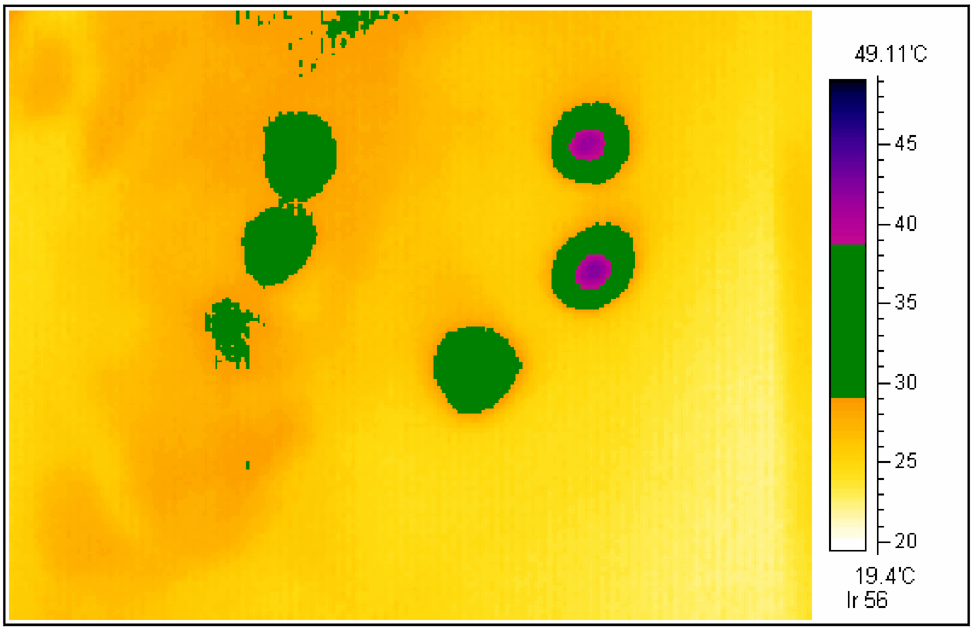


Figure 5-71 Heated bars at 0 sec (Fat - right, muscle - left)

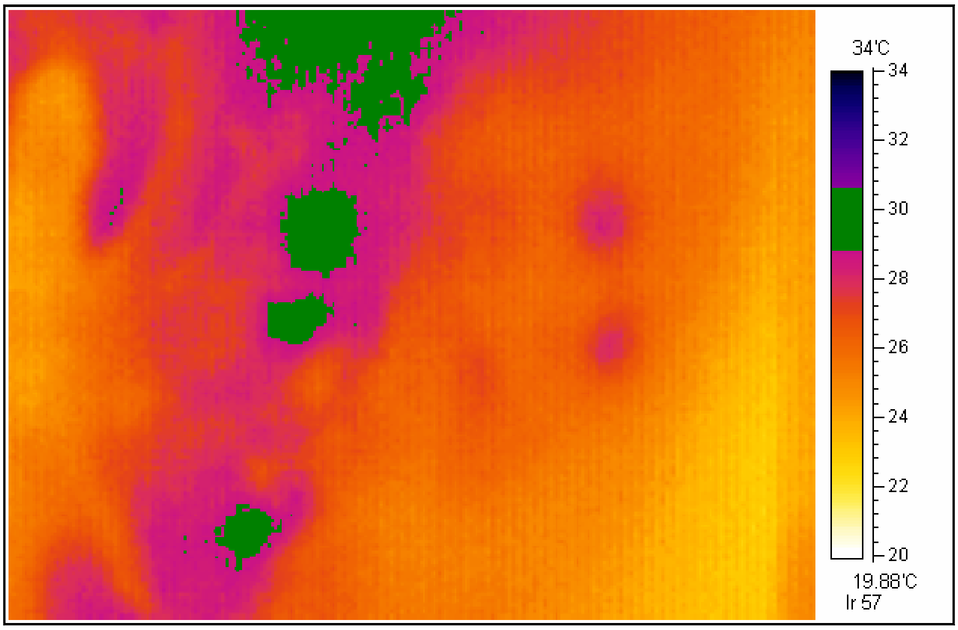


Figure 5-72 Heated bars at 2 min (Fat – right, muscle – left)

Adding external tags is another form of temperature based contrast agent. The images below (Figure 5-73) show a plastic pin tack quite clearly against the carcass surface. The pins were applied at ambient room temperature and as the plastic material of the pin is an effective insulator, heat is slow to transfer from the carcase to the pin. This type of marker is similar to object markers, but is discriminated by thermal rather than optical imaging.

The nature of the tag (ie shape and material) could be developed to increase differentiation from biological "natural" shapes and be process friendly for further operational steps such as rendering.

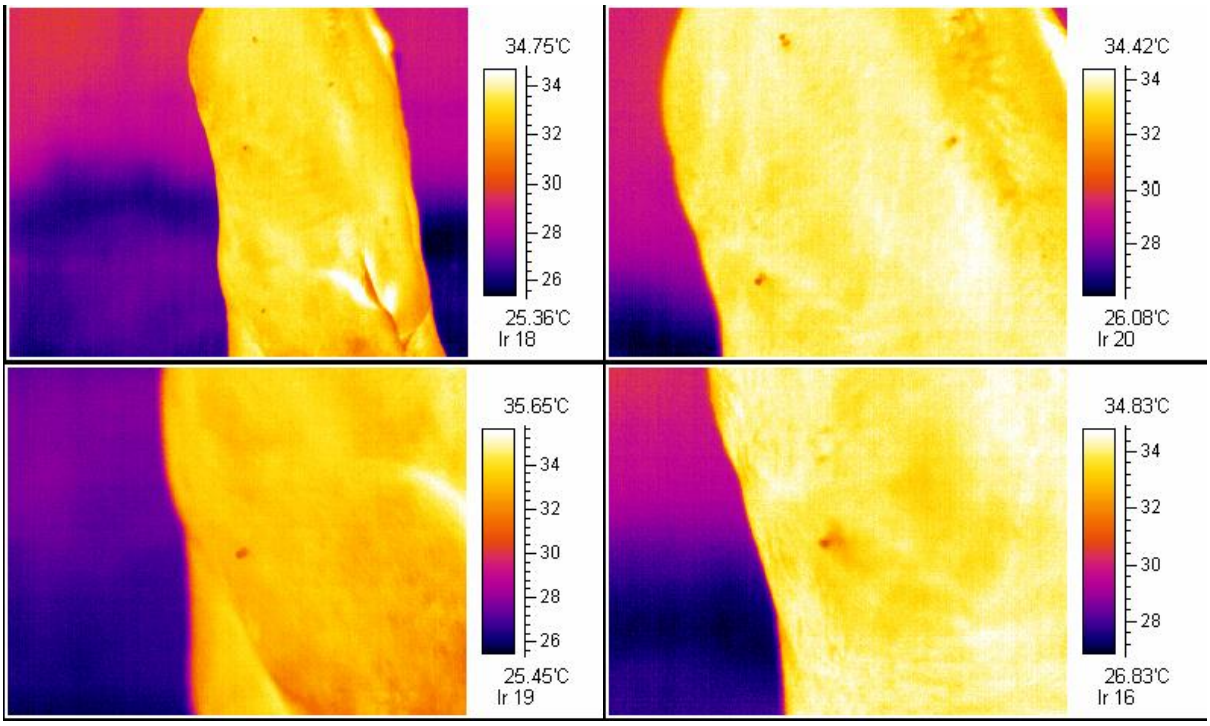


Figure 5-73 Pin Tacks on Beef Carcass (Hide on)

In summary depending on the area of application, the information requiring discrimination and the time before measurement occurs; small temperature variations can be detectable. Temperature change as small as 5°C on a carcase (temperature range 20-30°C in ambient environment) can be detected for 30 sec when used as a hot marker and 15 sec when used as a cold marker. As shown in the data a temperature variation between the carcass and cold tag of 15 °C can last in excess of 3 minutes depending on application point but the greater the temperature variation the more potential change in surface characteristics. The effectiveness of temperature markers as a contrast agent is very dependant on the time interval needed before measurement or data collection.

As an indication of the small temperature differences that can be discriminated by the thermal camera, the image below (Figure 5-74) shows the presence of ticks on the hide of a beef carcase.

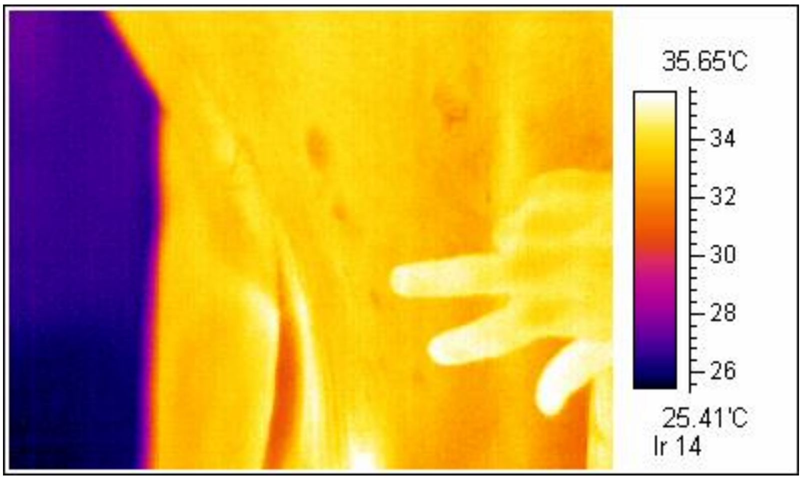


Figure 5-74 Thermal Image of Parasites on Hide Surface

5.4 Size

Quantifying the size required for an optical contrast agent or tag is difficult without consideration of –

(a) what carcase feature / data is required to perform a particular operation; and
(b) where the task operation occurs within the physical environment and therefore what space constraints, lighting, etc need to be considered.

Obviously a small circular tag will be easier to detect with an optical system concentrating on a particular region (possibly allowing a camera to be in close proximity to the carcase) where the tag is a significant portion of the captured image data, than trying to find the same tag from an image of the whole carcase. Identifying a small tag on a whole carcase rather than a focused region also increases the challenges of controlling things like lighting, carcass movement and positioning, or possible occlusions from persons or the environment. As noted elsewhere in this report, tags that clearly differentiate from the surrounding environment are more effective in regard to the potential for detection. This differentiation could be colour, shape, material or some other property like temperature or reflectance. For the purpose of discussion concerning the size criteria for a tag, the trial results are presented here. As much as possible a controlled, replicable data capture system as presented in Section 4.0, “AGENT TRIALS – TEST PROTOCOLS AND APPARATUS” was used for the purpose of comparison. However to evaluate an appropriate tag agent consideration of its use and operational environment was required.

In terms of detection of different tag sizes, despite the characteristic being used to discriminate a tag (i.e. colour hue or intensity) potentially being different between contrast agents, the detection image analysis has the general format of:

- Key criteria extraction e.g. luminance plane
- Possible secondary filter detection
- Conditional thresholding
- Object closing
- Area thresholding
- Analysis / quantification ⇨ Pixel area, perimeter and pixel shape diameter.

Reliability of detection (i.e. detectability) of a tag agent was covered in previous results sections and should be considered in conjunction with size results when selecting a contrast marker.

To quantify the different optical contrast marker agents, a comparison between the real perimeter of a tag and the calculated tag perimeter based on image analysis data was performed. A scale factor was generated based on the geometrical value of the longest line segment (e.g. diameter) of a tag in mm with relation to the longest analysed segment in pixels. The scale factor (in mm/pixel) was then multiplied to the analysed perimeter (in pixels) giving a calculated ‘real world’ perimeter. When this value was compared to the actual “real world” perimeter, a value of “1” (the ideal) would indicate that the calculated size of the marker is directly comparable to its actual size. Variation from 1 is an indication that the image analysis of a particular tag has inaccuracies i.e. analysed as too large or too small.

The following table shows the image analysis data and comparison analysis for each tag. The comparison value column has been highlighted.

Tag (mm)	Real Longest Line Segment (mm)	Real Perimeter (mm)	Maximum Feret Diameter (pixels)	Analysed Area (pixels)	Analysed Perimeter (pixels)	Comparison : Actual Perimeter Vs Calculated Perimeter	Percentage: Area / Image Area
Stickers - Green							
Circle dia 25	25	78.571	52.498	1705	151.516	1.089	0.123
1/2 circle dia 25	25	64.286	46.098	885	119.137	0.995	0.064
1/4 circle dia 25	17.68	44.643	32.696	427	95.422	0.865	0.031
Stickers - Blue							
Circle dia 30	30	94.286	51.923	1572	147.199	1.109	0.117
15	15	47.143	32.016	620	93.965	1.071	0.046
10	10	31.429	19.209	211	51.765	1.166	0.016
3	3	9.429		113			
Stickers - Yellow							
Circle dia 25	25	78.571	46.755	1509	139.610	1.053	0.099
1/2 circle dia 25	25	64.286	41.231	635	102.973	1.030	0.042
1/4 circle dia 25	17.68	44.643	26.926	265	65.344	1.041	0.017
Stickers - Red							
Circle dia 25	25	78.571	37.336	940	110.432	1.063	0.070
1/2 circle dia 25	25	64.286	35.355	362	82.488	1.102	0.027
1/4 circle dia 25	17.68	44.643	17.464	139	46.256	0.953	0.010

Dye - Blue (Ambient)							
Circle dia 20	20	62.857	36.401	691	105.024	1.089	0.072
15	15	47.143	24.207	341	67.586	1.126	0.036
10	10	31.429	10.440	64	30.361	1.081	0.007
5	5	15.714	5.657	15	14.723	1.208	0.002

Dye - Green (Ambient)							
20	20	62.857	33.242	557	90.457	1.155	0.058
15	15	47.143	23.770	334	66.989	1.115	0.035
10	10	31.429	13.928	114	39.620	1.105	0.012
5	5	15.714	9.220	33	22.120	1.310	0.003
Dye – Yellow (Ambient)							
20	20	62.857	34.205	616	121.000	0.888	0.064
15	15	47.143	26.173	374	75.880	1.084	0.039
10	10	31.429	13.928	105	37.620	1.164	0.011
5	5	15.714	7.211	27	18.723	1.210	0.003
Dye - Red (Ambient)							
20	20	62.857	44.654	684	130.733	1.074	0.071
15	15	47.143	23.707	205	69.414	1.073	0.021
20	20	62.857	33.734	651	102.052	1.039	0.068
15	15	47.143	25.000	364	78.654	0.999	0.038
10	10	31.429		unreliable	unreliable		
5	5	15.714		unreliable	unreliable		
Dye - Blue (Controlled)							
20	20	62.857	39.560	736	109.774	1.133	0.082
15	15	47.143	25.613	414	73.929	1.089	0.046
10	10	31.429	15.297	106	38.361	1.253	0.012
5	5	15.714	7.616	36	21.542	1.111	0.004
Dye – Green (Controlled)							
20	20	62.857	35.128	546	91.134	1.211	0.061
15	15	47.143	23.324	297	67.390	1.088	0.033
10	10	31.429	13.892	76	39.459	1.107	0.008
5	5	15.714	8.602	37	22.778	1.187	0.004
Dye - Yellow (Controlled)							
20	20	62.857	37.108	698	100.451	1.161	0.078
15	15	47.143	28.443	438	82.361	1.085	0.049
10	10	31.429	13.038	94	36.769	1.114	0.010

5	5	15.714	7.616	33	19.616	1.220	0.004
Dye - Red (Controlled)							
20	20	62.857	33.242	637	104.091	1.004	0.071
15	15	47.143	23.707	258	62.398	1.194	0.029
10	10	31.429		unreliable	unreliable		
5	5	15.714		unreliable	unreliable		

Paint - Blue							
20	20	62.857	46.228	1150	131.717	1.103	0.107
15	15	47.143	48.374	881	126.504	1.202	0.082
10	10	31.429	33.242	420	118.392	0.882	0.039
5	5	15.714	33.242	295	80.891	1.292	0.027
Paint - Green							
20	20	62.857	34.929	790	121.262	0.905	0.074
15	15	47.143	29.155	563	87.551	1.047	0.052
10	10	31.429	17.205	173	48.182	1.122	0.016
5	5	15.714	13.038	74	34.287	1.195	0.007
Paint – Yellow							
20	20	62.857	39.962	955	114.596	1.096	0.089
15	15	47.143	33.121	725	98.451	1.057	0.067
10	10	31.429	20.248	273	60.089	1.059	0.025
5	5	15.714	16.763	145	44.846	1.175	0.014

UV Gel - Green							
20	20	62.857	27.203	394	78.722	1.086	0.021
15	15	47.143	25.318	314	74.918	1.062	0.016
10	10	31.429	15.621	119	42.018	1.168	0.006
5	5	15.714	8.246	32	23.616	1.097	0.002
UV Gel - Blue							
20	20	62.857	43.417	1124	126.407	1.079	0.089
15	15	47.143	33.734	630	103.757	1.022	0.050
10	10	31.429	25.495	381	72.883	1.099	0.030
5	5	15.714	18.028	200	51.245	1.106	0.016

Ref tape: White - Ambient							
Square - 20 mm	28	80.0	38.91	834	109.37	1.016	0.066
Triangle 20X20X28	28	68.0	30.68	267	74.22	1.004	0.021
Triangle 14X14X20	20	48.0	11.66	46	28.04	0.998	0.004
Ref tape: Yellow - Ambient							
Square - 15 mm	21.2	60.0	36.62	710	102.01	1.016	0.056
Triangle 15X15X21.2	21.2	51.2	28.84	237	68.49	1.017	0.019
Triangle 10.6X10.6X15	15	36.2	18.36	92	42.37	1.046	0.007
Ref tape: White - Controlled							
Square - 20 mm	28	80.0	44.29	1062	124.69	1.015	0.084
Triangle 20X20X28	28	68.0	41.23	489	100.84	0.993	0.039
Triangle 14X14X20	20	48.0	22.47	188	56.40	0.956	0.015
Ref tape: Yellow - Controlled							
Square - 15 mm	21.2	60.0	40.61	849	111.68	1.029	0.067
Triangle 15X15X21.2	21.2	51.2	31.62	294	76.32	1.001	0.023
Triangle 10.6X10.6X15	15	36.2	19.70	97	44.96	1.057	0.008

Table 5-4 Contrast Markers Size Data and Analysis

The overall average of all “Comparison: Actual Perimeter Vs Calculated Perimeter” (Column 7) values is 1.084, with a standard deviation of 0.023. This suggests that the vision system is slightly underrating the size of the marker, by a factor of around 8%. As a breakdown, the average values for the individual marker types are:

- Stickers – 1.045
- Dye – 1.123
- Paint – 1.095
- UV Gel – 1.090
- Reflective tape – 1.012

Reflective tape with an average “Comparison” difference of around 1% would appear to be the best performing material of the group for detection on a carcase. Reasons for this include the reflective features of this material (minimises inter-marker property variation) as well as its clearly defined edge boundaries. This latter factor is also applicable to the stickers. They too give an average “Comparison” value close to the ideal.

The other materials used in the trials were in a liquid state, and thus there were practical difficulties in applying them to the surface of the animal. Although a plastic template was used, there were issues with getting an even consistency of carrier agent on the carcass substrate as well as controlling the edge boundary variations in the finished tag size. Overall, the Dye markers gave “Comparison” results which were significantly higher than the others.

The issue of size of marker did not appear to be overly critical, with little evidence of ‘trends’ when analysed with relation to a tag size category basis. Results indicated that there was little statistical difference in the “Comparison” values for the larger markers, e.g. 30, 20, 15 & 10 mm. However the smaller markers, with a major linear measure (e.g. diameter) of 5 mm or less, gave a value around 10 – 15% greater than the larger tags when compared for difference to the ideal. Correlating this difference with the “Percentage marker area / Image area” data in column 8 of the above table indicates that the size of the marker is only significant for the smaller tags with the ratio of tag size to image area below 0.02%.

5.4.1 Pins

Another area for consideration regarding the size of tags was the overall height from the surrounding tissue. To investigate the effect of this, pins of two different sized profiles were applied to the carcase for analysing. The results indicate geometry has little effect on the detection analysis; hence no indicative conclusions were able to be drawn. Profile geometry could be significant if protrusion from surface for image capture by an appropriately positioned camera was the discrimination technique applied to a particular sensing operation. This area requires further investigation. Figure shows the detection analysis for blue contrast agents (pin object markers) of two different profiles with comparison to the carcass surface.

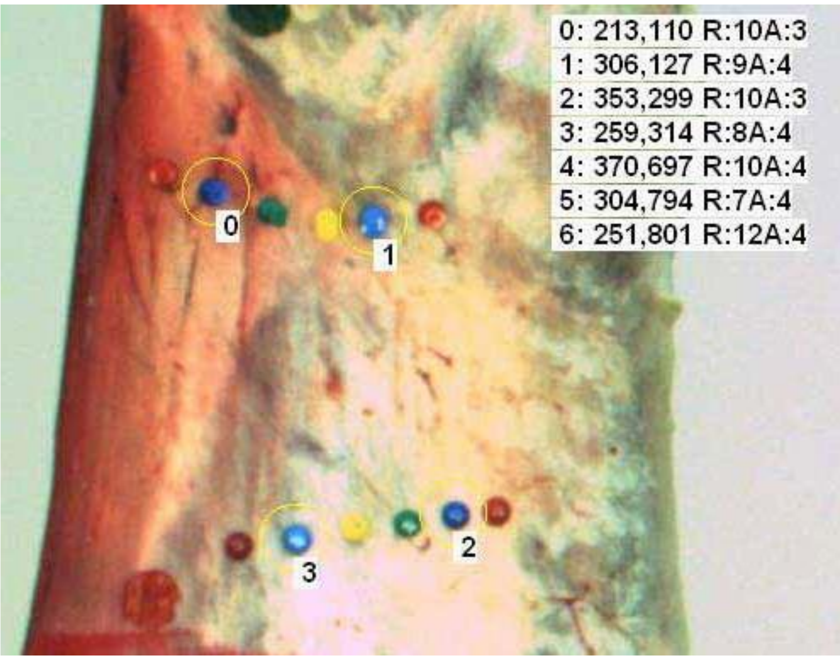


Figure 5-74 Blue detection analysis for pins (2 profile categories)

6.0 CONCLUSIONS

From the results it has been shown:

Application

Dye

Of the two application techniques “squirting” delivered more dye per tag and hence had a greater tendency to run on all surfaces however “painting” the tag still gave inconsistent coverage as a marker, concentrating (via gravity) at lower vertical points on fat and muscle areas. Dye tags on the hide surface did not give good results with the small sizes providing little or no discrimination and the large tags giving irregular coverage due to the hair fibres clumping together – other agent with greater surface consistency would be more effective for hide applications.

Paint

Irregular raised surface paint tags can cause reflections or saturation abnormalities in image data which requires more filtering to close (tag) “blob” low coverage or high luminance areas lessening analysis robustness. During trialling the amount of paint for each tag during application was difficult to control giving both irregular surface profile as well as poor shape outline definition which was unexpected as stencils were used. All paint tags were clearly visible even in low light conditions (lowest tested average 250lux) including small markers on hide as the paint sat on the surface and was not absorbed into the hair like the dye. Paint was also less prone to “bleeding” although this is dependent on the surface moisture present, water also causing a decrease in the evenness of the surface profile coverage consistency.

Paper sticker tags & reflective markers

Adhesive tags have issues that when used on hide they attach to the surface via only a few hairs, making tags difficult to position, allowing movement after application and the surface to not remain flush with the trial site - potentially causing size analysis accuracy degradation. Surface orientation at the attachment point also caused an issue with smaller tags difficult to apply in highly curved locations (skin on / skin off). Can be a significant issue with reflective adhesive tape markers where robustness of image data is best when the tag surface is at a perpendicular orientation to a light source. Fundamentally adhesive tags have a more regular feature profile giving greater control repeatability.

Object Markers – Pins and Tacks

Pins give very accurate positional point locations however damage the attachment surface. Pins, tacks and other object markers also give good dimensional profile repeatability which if data capture angle / tag orientation is controlled can give an alternative to the type of analysis available – ie tag profile can be the critical feature to analyse for.

Laser and UV-Activated Gels / Dyes

UV activated gels or dyes have similar consistency and application issues as conventional paints, dye or alternative carrier mediums except are not always visible without an activated light source complicating application in the abattoir environment. A similar issue occurs when using a laser line or point is used in that the ‘virtual tag’ is strongest in dark light conditions. Control of lighting makes Laser and UV light sensitive tags more robust then non active counterparts, allowing more control of environmental variables which can add complexity to image analysis for slaughter processing tasks.

Detectability

- Colour

When compared to the carcass detection environment which contains meat / muscle tissue in the red region, Type 1 fat colours in the red / yellow region and Type 2 fat colour in the blue region the results indicate that for the most robust detection green is a good tag agent choice, followed by blue with careful lighting control consideration and not on "Type 2 - muscle fat" areas, then yellow. Red is the least preferred option.

-Laser

When the data was captured using a high aperture setting and no hardware filter the "background" image was very clear. As the aperture setting is reduced the laser dot becomes more prominent until the "background" image is virtually eliminated. Reducing the aperture setting also minimises the effect of the laser dot to "bleed" into the image at the higher settings ie the dot appearing bigger in the image than what it actually is on the carcase. Although the intensity of the whole image is reduced the high intensity laser dot still remains robust.

-LEDs

It was found that the colour and size of the LED have little or no influence on the results of the tag detection – which was very robust – when intensity analysis is used. All of the LEDs were distinguishable, but the brighter or higher candela rating LEDs would be preferable as tag agent as the contrast to ambient light conditions is greater giving more robust discrimination.

-Light responsive markers: Reflective Tape

The effectiveness of reflective tape as an optical contrast marker is very dependent on the lighting conditions used for illumination. Best with controlled lighting directly behind image capture point. The orientation of the tags to the light source and capture device is significant as using focused directional light means greater potential for occlusion shadows or spurious light from the surrounding process environment to interfere with target detection filter and threshold parameters and consequent results.

-Light responsive markers: UV Gels

The brightness or level of fluorescence is clearly linked with the intensity of "blacklight" to which the tag was exposed. From the results unless carcase position (or alternatively the target zone in which machine vision would seek a tag) can be controlled for a camera system between 700mm and 1m from the carcass tags should be greater than 5mm diameter. If the whole carcase image is required for tag analysis a broad UV light source greater than 40W is required.

-Temperature

As with colour discrimination the greater the difference of an object from its surrounding environment the easier detection analysis becomes. Temperature also has the added complexity of equalising to its local state so it deteriorates with time. Temperature change as small as 5°C on a carcase (temperature range 20-30°C in ambient environment) can be detected for 30 sec when used as a hot marker and 15 sec when used as a cold marker. As shown in the data a temperature variation between the carcass and cold tag of 15 °C can last in excess of 3 minutes depending on application point but the greater the temperature variation the more potential change in surface characteristics.

Carcass activated temperature markers

Hot ⇨ indicated that muscle regions hold higher temperature for a longer time period whereas fat gives larger initial values.

Cold ⇨ Maintain cooler temperature for a longer period on where (a) there is potential for a deeper chill thickness; and (b) the area is cooler and there is less muscle volume for the carcase body temperature to transfer through. Like the flank muscle of the carcase belly cavity.

Object Marker ⇨ Physical tags generally applied at ambient room temperature, particularly when an effective insulator, are slow to transfer from the carcase to the object. Dependant on material and rate of carcase temperature change can be discriminated for significant periods of time.

Size

As a breakdown, the average values for the individual marker types are with 1 representing ideal accurate analysis:

- Stickers – 1.045
- Dye – 1.123
- Paint – 1.095
- UV Gel – 1.090
- Reflective tape – 1.012

Results indicate reflective tape to be the best performing. Attributable reasons are

- Clearly defined edge boundaries (also applicable to the paper sticker tags and supported as the next most reliable image analysis).
- Controlled lighting conditions which minimise variation in luminance and hue/saturation combinations.

The other marking agents were applied a liquid state and although a template was used, there was variation from designated tag shape (including “drips” or “running” which would affect the comparison analysis, as well as irregular consistency from application.

When the sizes of the different tag agent are grouped for comparison it was found based on comparison analysis averages that markers 5 mm or smaller had greater variation from the ideal accurate measurement category for image analysis. Hence the recommendation is to always use tags with a linear segment of greater than 5mm or greater than 0.02% of the tag area compared to the total image area.

FOOD SCIENCE AUSTRALIA
A JOINT VENTURE OF CSIRO AND AFISC

CSIRO

Afisc Australian Food Industry Science Centre

PROJECT REPORT

PRTEC.032
Investigation and Evaluation of Sensors for Adaptation to the Meat Industry

Milestone 1: Sensing Requirements for Beef and Sheep Slaughter Tasks
&
Milestone 2: Identify "Manual" Assist Sensing Techniques

Report for:
Meat and Livestock Australia
Sean Starling

Prepared by:
Peter Aust
Darryl Heidke
Kym MacRae
Ray White

July, 2005

EXECUTIVE SUMMARY

This report documents the outcomes of Milestones 1 and 2 of PRTEC.032 – Investigation and Evaluation of Sensors for Adaptation to the Meat Industry.

Two sheep and four beef plants were visited and the manual task data investigated and analysed. Each manual task was broken down to the sub task level and the sensing required to automate the operation optioned in 'data sheets'.
Each manual task was also considered in relation to its prospect of being automated – a category 1 task could be automated in the short term based around current knowledge; category 2 in the medium term as some research is required; and category 3 requires long term research investment. Issues affecting what sensing is required to automate the task, for example boundary discrimination required, detection of an internal or external feature and application of the technology, was considered to evaluate these categories.

The key technologies considered to be the most developed and applicable for automating slaughter tasks are optical, laser and mechanical sensing systems and as such are the discussed sensing option on most tasks data sheets. Other emerging technologies are also presented in this report for consideration in future automation applications.

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

BEEF TASKS	SHEEP TASKS
Stun	Stun
Remove Horns	Head Removal
Remove Forefeet	Spreader
Rear Hock Removal	YCut- Brisket open & strip
RFID Tag Removal & Data Entry	Bung / Evacuation
Hoist	Leg Reposition
Change Second Leg	Hock Cut Rear (Mechanical)
Stamp	Shoulder Puller Mechanical (Load)
Shanks	Pelt Removal (Mechanical)
Horn Second Cut	Gambrel Insert and Hang
Dentition	Neck Tip / Trim
Remove Head	Hind Hock Tip
Brisket saw	Front Hock Cut
Removal Tail	Vac San – Fixed Path Specification
Trim Skirts	Fat Removal – Fixed Path Specification
Weigh	Weigh
Wash	Branding / Marking
Chill	Record
	Chillers (loading)

Category 2 tasks generally require the detection of an internal feature or interpolation of an internal feature from the external surface. Alternatively they can require an extension of a sensing technology that identified a category 1 sensing solution to incorporate the need to track an identified feature. Category 2 tasks include:

BEEF TASKS	SHEEP TASKS
Stun	Stun
Plug	Sticking Halal (Unlikely to be automated due to religious significance).
Shackle, Hoist	Shackle

Bleed	Dentition
Bleed Halal – Transverse Incision	Ycut
Bleed Halal – Stick Bleed	Weasand – Clear Front of Neck
Cheek Hide Removal	Weasand – Open Neck/ Gullet; Expose Weasand
Pizzle Removal	Pelting (punching)
Skin Anus, Tail	Clear Pelt
Bagging	Open Abdominal Cavity
Dentition	Brisket Cut
Remove Head	Fat Removal – End Volume Discrimination
Brisket Saw	
Remove Tail	
Saw Carcass	
Kidney Fat et al Removal	

Category 3 tasks fall into three main areas: discrimination of like tissue with undefined structure boundaries; real time tissue boundary discrimination; and trim task contamination detection. Fundamental research to understand the nature of what is being sensed (ie the characteristics of a given type of contamination) is required to develop a task appropriate sensing methodology. Category 3 task include:

BEEF TASKS		SHEEP TASKS
Free and Rod Weasand	Rump	Free and Rod Weasand
Remove Muzzle	Flank	Udder / Pizzle Removal
Udder Removal	Hide Strip / Removal	Vac San – Contamination Detection
Skin First Leg	Evisceration	Gut
Skin Second Leg	Clear and Drop Rectum	Diaphragm and Pluck Removal
Contamination Trim Tasks including: • Forequarter Trim • Forequarter Revision Trim • Trim Tail • Brisket Trim • Hindquarter Trim • Revision Hindquarter Trim		Contamination Trim Tasks including: • AusMeat Trim • Neck Inspection and Trim • Channel and Inside Inspection • Retain Trimmer • Forequarter Trim • Tail Trim • Hind Leg and Rump Trim • Flank Trimmer • Checker

"Manual" assist sensing tasks, are those tasks where a human can "manually" input sensing to assist in automating a task, were analysed as:

BEEF TASKS	SHEEP TASKS	
Materials Handling	Materials Handling	Y cut
Stun	Stun	Weasand
Rectum	Halal Stick (Automation unlikely for religious reasons)	Gambrel Insertion
Bag	Shackle	Ring and Rake
	Head Removal	Gut

To assess the viability of a "manual" assist sensing application for a given manual task, consideration of the target plant's task break-up is required. "Manual" assist sensing will only be attractive where the redistribution of human labour from a partially automated process would lead to more efficient utilisation over the whole slaughter processing chain.

The results highlight that the further a manual process task can be broken down into its sub task components, the greater the opportunity of automating part or all of the given task – an increased chance of successful automation.

CONTENTS

1. INTRODUCTION

Intelligent sensing is critical for obtaining the most favourable measurement of characteristics, such as the spatial relationship of key structural features or the intensity of quality attributes, upon which artificial intelligence can be applied. Process automation in the unstructured and variable meat processing environment relies heavily on effective sensing.

The aim of Milestone 1 of this project is to evaluate all slaughter tasks for two beef and two sheep plants, detailing each task with respect to the possibility of automation and nominating what sensing identification / systems would be required. Information in this project has been normalised over two sheep and four beef plants.

Milestone 2 involves the recognition of those tasks that may possibly be automated if some of the sensing aspects of the process are carried out by humans.

Appendix A includes the beef and sheep slaughter task data sheets. Each work task data sheet has five main areas as outlined in the project objectives. These are:

1. ***Current task outline*** – Details the current manual task outline or work instructions.

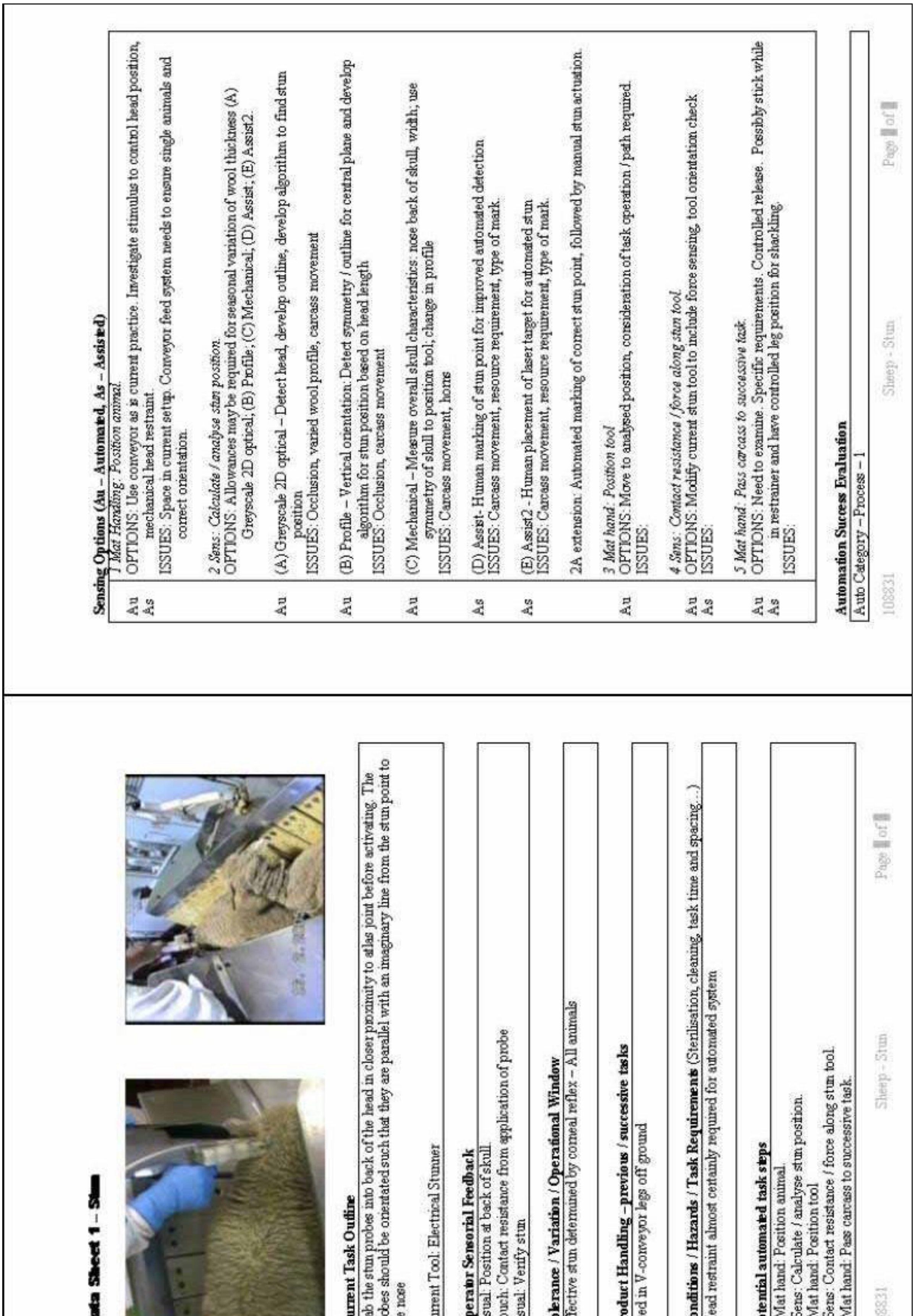
2. ***Operator sensorial feedback*** – What a human currently senses to perform the task (sensing inputs that would be required to automate the task; what the automatic system would have to find).

3. ***Potential automated task steps*** – Details the processing steps that would be required to successfully automate the current manual task.

4. ***Sensing options (automated and assisted)*** – Most appropriate sensing technologies to provide feedback for the detailed processing steps. Assisted sensing refers to human assistance to provide feedback to an automated system.

5. ***Automation success evaluation*** – An assessment of the likelihood of success to automate a given task. These success categories are discussed in more detail later in the report and this information captured from the data sheets is presented in matrix/ tabular form for ease of assimilation.

Figure 1-1 shows an example of slaughter task data sheet.



Data Sheet 1 – Stun

Current Task Outline

Stab the stun probes into back of the head in closer proximity to atlas joint before activating. The probes should be orientated such that they are parallel with an imaginary line from the stun point to the nose

Current Tool: Electrical Stunner

Operator Sensorial Feedback

Visual: Position at back of skull.
Touch: Contact resistance from application of probe
Visual: Verify stun

Tolerance / Variation / Operational Window

Effective stun determined by corneal reflex – All animals

Product Handling – previous / successive tasks

Feed in V-conveyor legs off ground

Conditions / Hazards / Task Requirements (Sterilisation, cleaning, task time and spacing…)

Head restraint almost certainly required for automated system

Potential automated task steps

1 Mat hand: Position animal.
2 Sens: Calculate / analyse stun position.
3 Mat hand: Position tool
4 Sens: Contact resistance / force along stun tool.
5 Mat hand: Pass carcass to successive task.

108831 Sheep - Stun Page of

Sensing Options (Au – Automated, As – Assisted)

	1 Mat Handling: Position animal.
Au As	OPTIONS: Use conveyor as is current practice. Investigate stimulus to control head position, mechanical head restraint. ISSUES: Space in current setup. Conveyor feed system needs to ensure single animals and correct orientation.
	2 Sens: Calculate / analyse stun position. OPTIONS: Allowances may be required for seasonal variation of wool thickness (A) Greyscale 2D optical; (B) Profile; (C) Mechanical; (D) Assist; (E) Assist2.
Au	(A) Greyscale 2D optical – Detect head, develop outline, develop algorithm to find stun position ISSUES: Occlusion, varied wool profile, carcass movement
Au	(B) Profile – Vertical orientation: Detect symmetry / outline for central plane and develop algorithm for stun position based on head length ISSUES: Occlusion, carcass movement
Au	(C) Mechanical – Measure overall skull characteristics: nose back of skull, width; use symmetry of skull to position tool; change in profile ISSUES: Carcass movement, horns
As	(D) Assist- Human marking of stun point for improved automated detection ISSUES: Carcass movement, resource requirement, type of mark.
As	(E) Assist2 - Human placement of laser target for automated stun ISSUES: Carcass movement, resource requirement, type of mark.
	2A extension: Automated marking of correct stun point, followed by manual stun actuation.
Au	*3 Mat hand: Position tool* OPTIONS: Move to analysed position, consideration of task operation / path required. ISSUES:
Au As	*4 Sens: Contact resistance / force along stun tool.* OPTIONS: Modify current stun tool to include force sensing, tool orientation check ISSUES:
Au As	*5 Mat hand: Pass carcass to successive task.* OPTIONS: Need to examine. Specific requirements. Controlled release. Possibly stick while in restrainer and have controlled leg position for shackling. ISSUES:

Automation Success Evaluation

Auto Category – Process – 1

108831 Sheep - Stun Page of

Figure 1-1 Data Sheet Example

2. KEY SENSING TECHNOLOGIES

Automation on meat slaughter floors will assist in reducing the costs associated with processing through increased efficiencies, improved quality, better labour utilisation and reduced OH&S outlay. However technology on a slaughter floor also needs to be robust and reliable as well as being able to be supported, hence for the purposes of this project only those technologies that are considered mature and nearing commercial support have been considered as sensing options and detailed in the data sheets. This requirement is reflected in the project contract, which outlines as a project objective - the recommendation of a technology only if it is considered 'fool proof'. Section 6 of this report presents some emerging technologies and their potential for use in slaughter task automation applications for discussion but in the task data sheets only the more conventional sensing modes have been considered. This section (section 2) presents an overview of the most 'common' of these: optical; laser profiling and mechanical.

2.1 OPTICAL

Optical sensing technology refers to the use of a 2D optical CCD (Charge Coupled Device) camera to capture an image in combination with developed application-specific software to identify a feature or some other information from the image. As hardware becomes cheaper and the processing algorithms more sophisticated, the use of optical vision sensing to control automated processes is becoming more prevalent. In the food industry alone there are many instances of vision use for product analysis (via surface characteristics), sorting and defect detection.

Although vision systems are not capable of viewing the internal structure of a carcase as x-ray and ultrasound systems can, the distinctive external properties of certain sections of the carcase provide adequate characteristic information for recognition at a useable degree of accuracy. Extracting this information consistently is the major challenge for developers. An important issue that must be considered for optical technology is the presentation of the object to the camera including lighting, background and external conditions, as the more complicated an image is the greater complexity required in the algorithm to reliably detect features for sensing feedback. Complicated images also lead to an increase in analysis time.

Dependant on the analysis required, the current technology is capable of very short processing times, in the order of milliseconds, which is an important factor in food processing with its' associated high production speeds. Vision systems can also be set up so they do not require any extra contact or even close proximity with the article being processed. Optical systems also do not need extra considerations for operator safety and are a relatively low cost technology to implement.

2.2 LASER PROFILING

Laser scanning is a technique that can be used as a means of determining the profile of a surface, discriminating any features or characteristics at extremely high resolution (sub mm). Laser profiling equipment generally consists of a standard optical laser and a commercially available camera, with the intelligence of the system built into software to allow the collection of surface profiling information with very high accuracy. However, this technology is not suitable for detecting sub-surface features.

Food Science Australia engineers have used this technique as a means of obtaining high-resolution scans of beef carcases. Figure 2-1 shows a typical scan of beef side. It may be possible to detect certain surface features this way, but not those at any depth under the outer surface layer. Laser-scanning methods would be applicable for a number of feature recognition tasks.

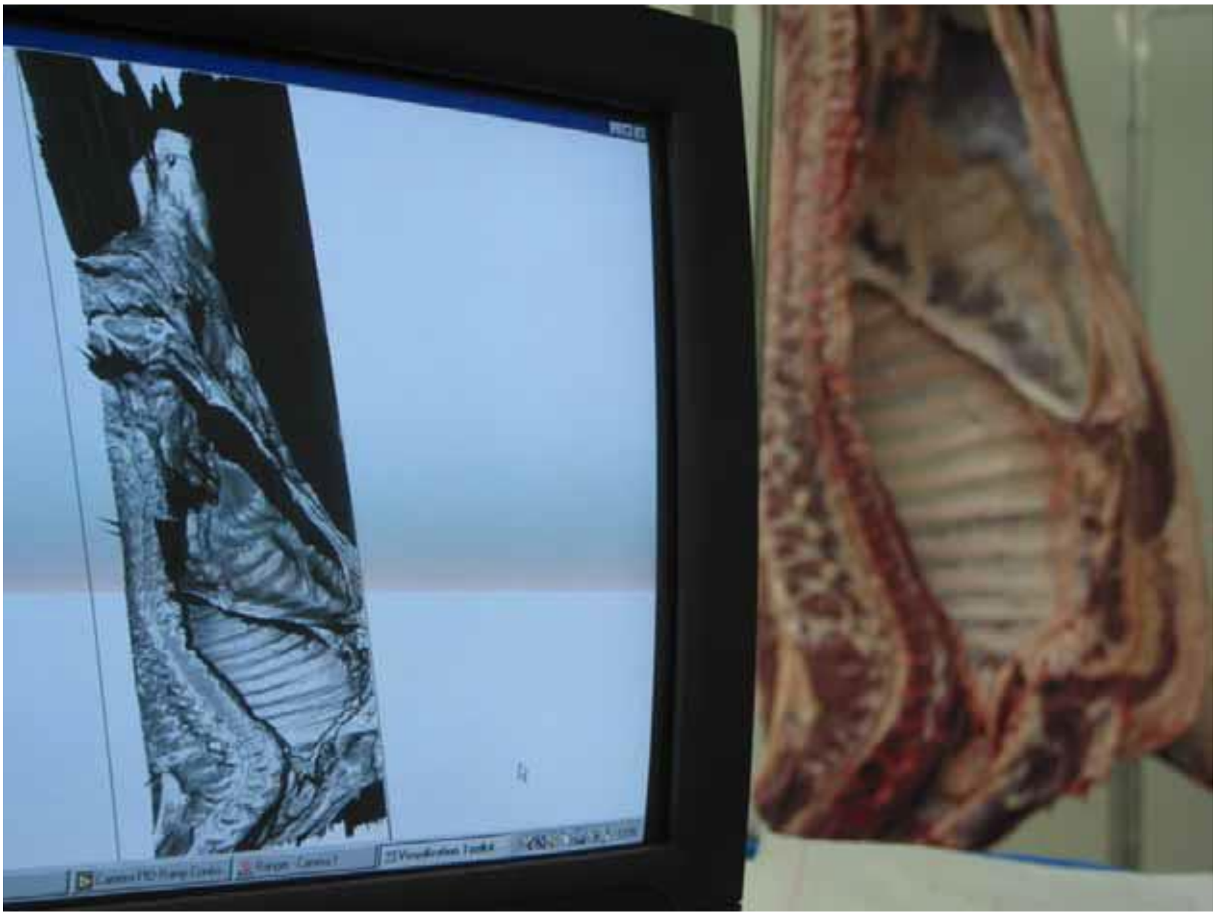


Figure 2-1 – Laser Surface Profile Scan, Carcase in Background (Unpublished photo, 2004, copyright Food Science Australia)

Laser technology can be implemented in a form that can generate a profile of an object (continuous update of a point) or map an object surface area (continuous update of a line). Another version of laser mapping utilises the ‘time of flight’ method where an optical image is analysed to record information about a moving laser line.

2.3 MECHANICAL

Purpose built application specific mechanical sensing systems include touch plates, rollers and mechanical guides combined with electrical actuators in the form of proximity and photoelectric sensors, mechanical limit switches and temposonic / resistive measurement sensors.

3. SUMMARY OF TASKS

The level of task breakdown dramatically affects the compatibility of a given process operation with sensing and automation. For example, the removal of the neck pelt an unspecified distance along the back of a sheep carcass is much more achievable than the development of a pelt removal system for the entire pelt of a carcass with no pre work (removal of hide around legs and 'pit areas'). Materials handling throughout the task and/ or slightly modified prework to remove the entire pelt in a single step without hide damage might be possible but is outside the scope of this project which is concerned with automating current manual tasks.

This section presents a summary of the data captured in the manual task data sheets previously introduced in section 1 of this report. Flowcharts are presented below showing normalised lists of beef and sheep manual slaughter tasks along with summaries of the automation success evaluation categories from the data sheets of these detailed tasks. The task are loosely organised around processing flow however tasks with like sensing requirements, for example contamination detection, or tasks requiring several sub operations to achieve a process function, for example leg slit then gambrel insertion, have been grouped together when in practice the sub task are usually distributed across the processing chain to achieve the most efficient use of manual work effort. A list of the 'assisted' sensing sub tasks, which is those sub tasks where human input can be used to give sensing feedback to an automated process, is also included.

The automation success evaluation category areas are an evaluation based on the sensing requirements as to the likelihood of success of automating a given task and can be broadly classified as the following:

Category 1 - Automation of the task is achievable with adaptation/ application of available technologies
Category 2 - Automation of the task requires some research but should be achievable
Category 3 - Blue sky research, technology development required to automate the task, long term investment may be needed for a result.

It should be noted from reading through the task data sheets in the appendix, and the flowcharts and category summaries included in this section, that there are many similarities between beef and sheep slaughter processes due to task functionality of processing a carcase – the carcase must be eviscerated, the outside hide and extremities must be removed in a hygienic fashion and a carcass must be inspected at critical points throughout the process for biological diseases and contamination. The main difference between the two species is that of size of scale and the associated force required to manipulate tissues like bone, cartilage and muscle.

The scope (and contract) of this project required two sheep industry plant site visits for task investigation and evaluation. Although this has been carried out there was some consideration that both plants visited use the 'inverted' dressing method, hence no evaluation of a 'traditional' dressing method plant has occurred. After deliberation it was decided that the task functionality of the 'traditional' dressing method is captured by the 'inverted' dressing method with relation to evaluation of sensing requirements.

Domestic and export plants were represented in both the beef and sheep industry participants survey sample.

3.1 BEEF

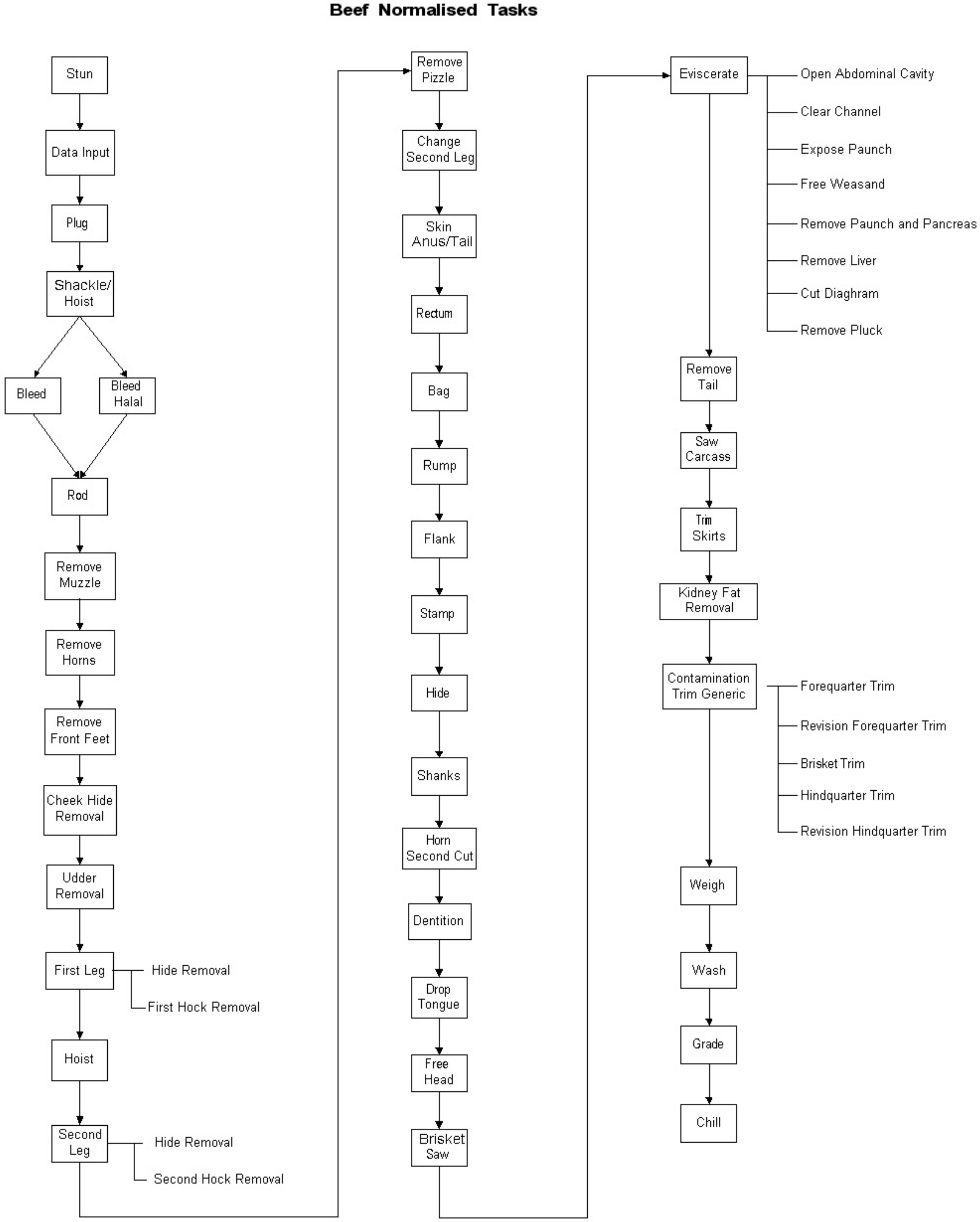


Figure 3-1 Beef Tasks Overview Flowchart

3.1.1 MATRIX

Automation success evaluation category 1 tasks for beef include:

TASK	Discussion of Issues
Stun	The stun process involves delivering an impact tool / charge to a specific location to cause the animal to become 'stunned'. This is considered a category 1 task if the head can be restrained.
Remove Horns	External feature. Reasonable discrimination.
Remove Forefeet	External feature. Reasonable discrimination.
Rear Hock Removal	External feature. Reasonable discrimination.
RFID Tag Removal & Data Entry	External feature. Reasonable discrimination. Commercial automatic options available for read.
Hoist	Reasonable discrimination. Known positions.
Change Second Leg	Reasonable discrimination. Known positions.
Stamp	External features. Big tolerances.
Shanks	External feature. Reasonable discrimination.
Horn Second Cut	External feature. Reasonable tolerance.
Dentition	To create category 1 classification need to use X-ray. Internal structure/ materials handling presentation issues.
Remove Head	If plant does not require removal at joint, cutter finish, external feature guide, big tolerance.
Brisket saw	Dependant on tool access and positional information required (eg carcass orientation, abdominal cavity open, etc) else Category 2.
Removal Tail	Category 1 if tail removal is not required at specific joint location and can be referenced from external features.
Trim Skirts	External feature. Reasonable tolerance.
Weigh	NA – automated options available commercially.
Wash	NA – automated options available commercially.
Chill	NA – automated options available commercially.

Automation success evaluation category 2 tasks for beef include:

TASK	Discussion of Issues
Stun	The stun process involves delivering an impact tool / charge to a specific location to cause the animal to become 'stunned'. This is considered a category 2 task if head can not be restrained and target is required to be tracked.
Plug	Internal application of plug in weasand.
Shackle, Hoist	Moving target, unstructured.
Bleed	Internal structure referenced from external, tight tolerance (cut arteries not weasand / adjacent tissue damage)
Bleed Halal – Transverse Incision	NOTE: Automation unlikely due to religious reasons. Internal structure referenced from external, tight tolerance (cut arteries not weasand)
Bleed Halal – Stick Bleed	Internal structure referenced from external. Reasonable tolerance.
Cheek Hide Removal	Internal structure referenced from external.
Pizzle Removal	Internal structure referenced from external. Possibly need discrimination between pizzle and surrounding tissue (non – surface).
Skin Anus, Tail	External features. Materials handling complexity.

Bagging	Presented internal feature hence external sensing of similar tissues. Important materials handling issues.
Dentition	Materials handling presentation and discrimination challenges
Remove Head	This is a category two task if sensing automation system needs to replicate current human work task knife separating along joint of the atlas and occipital bones. Has material handling challenges and referencing internal structure from external features.
Brisket Saw	Referencing internal structure from external features. Tight tolerances (paunch damage contamination).
Remove Tail	Internal structure referenced from external features. Specific tolerance.
Saw Carcass	Tissue morphology challenges. Reasonable tolerances.
Kidney Fat et al Removal	Boundary discrimination challenges. Dependant on tolerances/ specification.

Automation success evaluation category 3 tasks for beef include:

TASK	Discussion of Issues
Free and Rod Weasand	Internal structure sensing and update required. Like tissue discrimination. Specialised automation feedback/ mechanism development required.
Remove Muzzle	Discrimination of like tissue. Undefined structure boundaries.
Udder Removal	Discrimination of like tissue. Undefined structure boundaries.
Skin First Leg	Real time tissue boundary discrimination required
Shin Second Leg	Real time tissue boundary discrimination required
Clear and Drop Rectum	Discrimination of like tissue. Undefined structure boundaries. Materials handling challenges.
Rump	Real time tissue boundary discrimination required
Flank	Real time tissue boundary discrimination required
Hide Strip / Removal	Real time tissue boundary discrimination required
Evisceration	Tissue discrimination, materials handling challenges, tight tolerance on structure boundaries and connective points. Requires research and further investigation; automation concept verification and greater task breakdown may lead to simplification of evisceration task in favour of automation but require further offal separation and presentation.
Contamination Trim Tasks including: • Forequarter Trim • Forequarter Revision Trim • Trim Tail • Brisket Trim • Hindquarter Trim • Revision Hindquarter Trim	CANNOT be done automatically unless trying to detect particular type of contamination with a given characteristic.

3.2 SHEEP

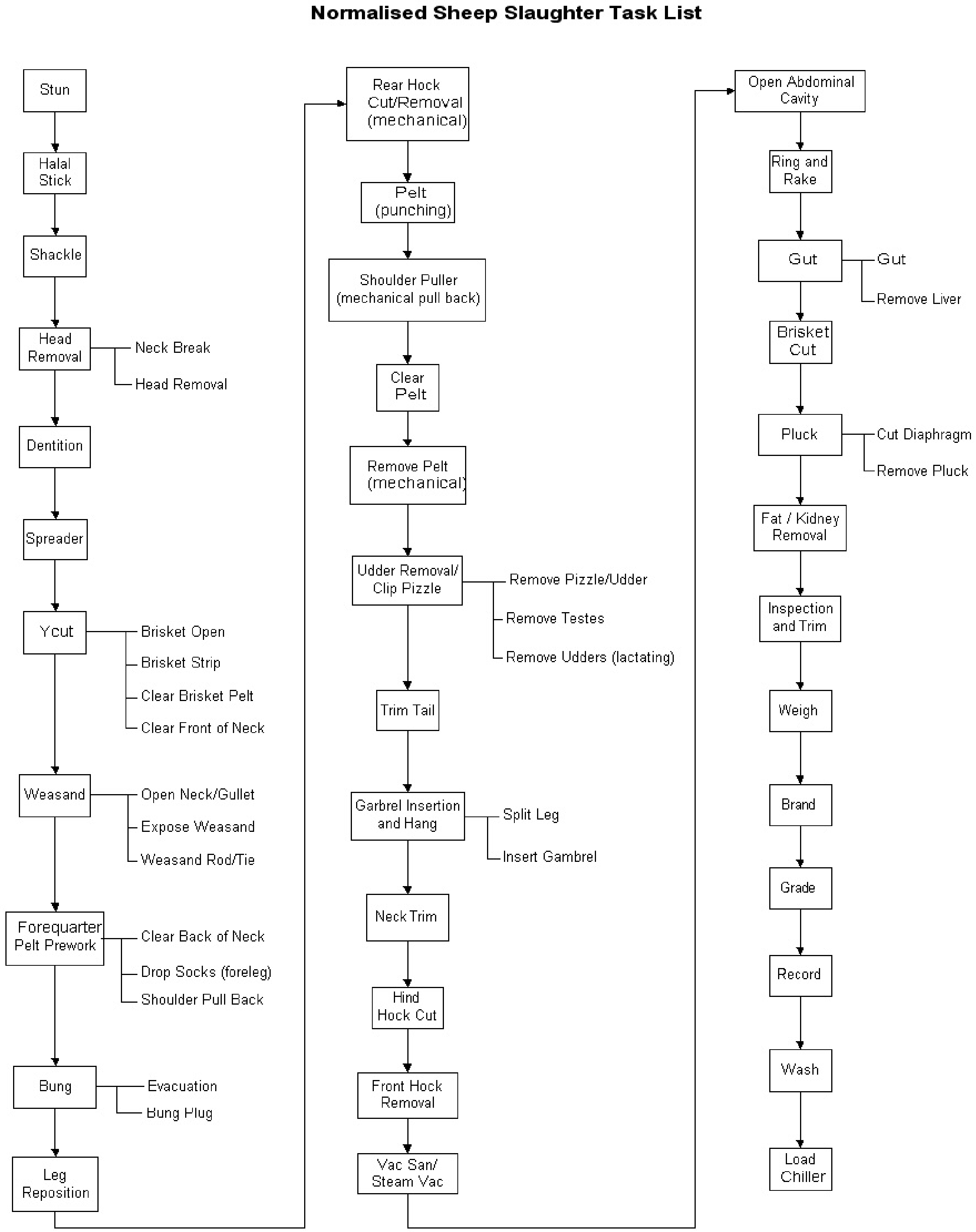


Figure 3-2 Sheep Tasks Overview Flowchart

3.2.1 MATRIX

Automation success evaluation category 1 tasks for sheep include:

TASK	Discussion of Issues
Stun	The stun process involves delivering an impact tool to a specific location to cause the animal to become 'stunned'. This is considered a category 1 task if the head can be restrained.
Head Removal	'Cut' referenced to external feature, big tolerance (if knife separation at joint specified requires research and higher Automation Success Evaluation Category).
Spreader	External features. Good discrimination.
YCut- Brisket open & strip	External features. Large tolerances.
Bung / Evacuation	External features. Good discrimination.
Leg Reposition	External features. Known positions.
Hock Cut Rear (Mechanical)	Automated options currently available. External features. Large tolerances.
Shoulder Puller Mechanical (Load)	Automated options currently available. External features. Large tolerances. Known positions.
Pelt Removal (Mechanical)	Automated options currently available. External features. Large tolerances. Known positions.
Gambrel Insert and Hang	External features. Reasonable discrimination. Known positions.
Neck Tip / Trim	External features. Reasonable discrimination.
Hind Hock Tip	External features. Good discrimination.
Front Hock Cut	External features. Good discrimination. Dependant on task specification known positions.
Vac San – Fixed Path Specification	External features. Reasonable discrimination. Big tolerances.
Fat Removal – Fixed Path Specification	Referenced to key external features. Big tolerance.
Weigh	Commercial automatic options currently available.
Branding / Marking	Plant specific specification. External features. Big tolerances.
Record	Commercial automatic options currently available.
Chillers (loading)	Commercial automatic options currently available.

Automation success evaluation category 2 tasks for sheep include:

TASK	Discussion of Issues
Stun	This is considered a category 2 task if the head cannot be restrained, hence tracking of target features is required.
Sticking Halal	Internal structure referenced to external features. Tight tolerances (no weasand damage).
Shackle	External features. Reasonable discrimination. Big tolerances. Dependent on materials handling, require target tracking. Unknown operational window and known position. Smart end effector.
Dentition	Internal structure/ materials handling presentation issues. Boundary discrimination challenges.
YCut	External features. Strip tool orientation/ materials handling challenges.
Weasand – Clear Front of Neck	Specialised end effector tool (else category 3 task if hide interface required). Materials handling challenges.

Weasand – Open Neck/ Gullet; Expose Weasand	Referencing internal structure from external features. Tight tolerances (no damage). Multiple structure boundaries. Materials handling challenges.
Pelting (punching)	Referencing internal structure from external features. Specialised end effector tool.
Clear Pelt	Cat 2 if can generate standard path relative to carcass physiology for broad tool. Discrimination of tissue boundaries. Specialised end effector tool. External features. Reasonable tolerances.
Open Abdominal Cavity	Internal structure referenced from external. Specialised end effector tool. Tight tolerance (no damage to paunch).
Brisket Cut	Internal structure referenced from external. Tight tolerance (no damage internal organs).
Fat Removal – End Volume Discrimination	Boundary discrimination challenges. Dependant on tolerances/ specification.

Automation success evaluation category 3 tasks for sheep include:

TASK	Discussion of Issues
Free and Rod Weasand	Internal structure sensing and update required. Like tissue discrimination. Specialised automation feedback/ mechanism development required.
Udder / Pizzle Removal	Discrimination of like tissue. Undefined boundary discrimination challenges. Materials handling / end effector challenges. Tight tolerances (zero milk/ urine).
Vac San – Contamination Detection	See Generic Trim Data Sheet
Gut	Tissue discrimination, materials handling challenges, tight tolerance on structure boundaries and connective points.
Diaphragm and Pluck Removal	Tissue discrimination, materials handling challenges, tight tolerance on structure boundaries and connective points.
Contamination Trim Tasks including: • AusMeat Trim • Neck Inspection and Trim • Channel and Inside Inspection • Retain Trimmer • Forequarter Trim • Tail Trim • Hind Leg and Rump Trim • Flank Trimmer • Checker	Cannot be done automatically unless trying to detect a particular type of contamination with a given signature characteristic.

3.3 ASSISTED TASKS

Tasks that were identified as assisted tasks were:

3.3.1 BEEF

1. *Materials Handling*
   Task: Control position from previous steps either automatically or manually so mechanical manipulation can be used to bring the carcass into position.

2. *Stun*
   Task: Identify head and eyes (calculate/ analyse stun position). Operator could mark the stun point via laser position or marker dot.

3. *Rectum*
   Task: The rectum ringing process changes from category 3 to category 2 if an operator performs ringing task once anus has been gripped and presented. Bagging system could also incorporate into anus grip tool.
   ISSUES: Improved hygiene (remove human from dirty contact surface), improved OH&S (remove operator hand from cut zone).

4. *Bag*
   Task: Human verification of the proper placement of the elastomer ring and bag on the bagged rectum – could also verify 'zero tolerance' conformance.
   ISSUES: Hygiene – zero tolerance

3.3.2 SHEEP

1. *Materials Handling*
   Task: Control position from previous steps either automatically or manually so mechanical manipulation can be used to bring the carcass into position.

2. *Stun*
   Task: Calculate and analyse stun position. Human marking of stun point could be utilised for improved automated detection. This could either be performed with a physical marker or through the placement of a laser pointer. An extension of this would be the automated marking of the correct stun point, followed by manual correction / manual stun actuation.
   ISSUES: Animal movement, resource requirement, type of mark.

3. *Halal Stick*
   Task: Sense cut start and end.
   a. Operator marking of the cut position could be made for subsequent automated detection.
   b. Operator identification could be used for when the animal is in position for decapitation - Head removal could be activated manually. This option would require investigation for halal approval.

   ISSUES: Carcass movement, resource requirement, type of mark.

4. *Shackle*
   Task: Locate joint in leg. An operator could utilise a marking device, such as a laser, on the leg to indicate correct shackle position. Alternatively operator could mark an image from an optical system.

5. *Head Removal*
   Task: Detect cut position. Operator marking of the cut position could be made prior to automated detection. Operator identification that animal is in position for decapitation could be utilised, possibly followed by manual activation of head removal.
   ISSUES: Carcass movement, type of mark.

6. *Y-Cut*
   Task: Identify grip positions from manual cut markings or manually locate grip positions. Manually indicate cut start and end positions, as a physical mark and analyse OR laser target positions OR click points on an optical image.
   ISSUES: Time, carcass movement, occlusions, hide covering, sensitivity, orientation.

7. *Weasand*
   Task: Weasand could be cut manually and presented to auto rodding and clipping device.

8. *Gambrel Insert*
   Task: Legs could be controlled and positioned manually; following on from previous step, also could use mechanical manipulation to bring the carcass into position.
   (Possibly load both legs onto gambrel at the same time.)

9. *Ring & Rake*
   Task: Operator could perform ringing task once anus has been gripped and presented automatically.
   ISSUES: Improved hygiene (remove human from dirty contact surface), and improved OH&S (remove operator hand from cut zone).

10. *Gut*
    Task: Operator could assess belly rip position, both start and finish. Mechanical – contact sensor manipulated across carcase perpendicular to cut.
    ISSUES: Occlusion, carcass movement, carcass surface, paunch protrusion from cavity as result of earlier process steps.

4. SENSOR RESULTS

Following are examples of task process applications where a conventional sensing technology is considered to be the most appropriate. The majority of category 1 and some category 2 tasks would utilise these technologies.

4.1 OPTICAL SYSTEMS:

For the purposes of this survey optical sensing has been optioned on several tasks as a method for finding data information about edge profile 'shapes' for joint detection or to detect task specific features like the cavity opening points for brisket cutting and evisceration. This information would be relayed to task-specific developed equipment or to an articulated robot combined with innovative tool end effectors. In an 'assisted' sensing application, like marking the stun position, optical sensing is used to allow an operator to give feedback to an automated system.

Applications that could use optical systems included:

- Joint detection for cutting or shackling positions
- Edge profile of skull to calculate stun position
- External carcass features like eyes, skin folds, abdominal cavity openings
- Features related to colour change like the 'red bark line', liver detection or the separation between the thick and thin skirt.

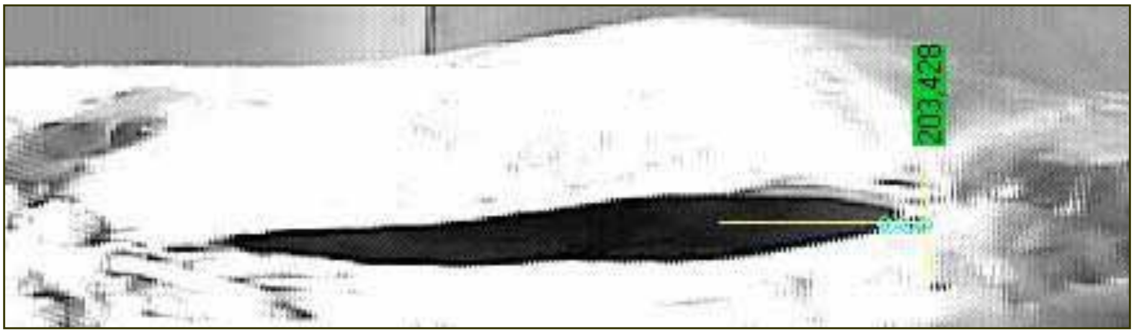


Figure 4-1Optical analysis of sheep brisket point abdominal cavity opening (Food Science Australia report, 2003)

4.2 LASER SYSTEMS:

Laser technology is appropriate for tasks where the automation system requires sensing of external surface features. Positional information (including orientation) can be collected from the surface of an object on which a decision can be made (example: verify clearing end position is greater then specified target) or automation can be moved to (example: position blade cut point to positionX, positionY, positionZ). Also as laser systems have a fast update rate technology is good for movement detection.

Applications that could use laser included:

- Profiling the skull surface to detect base, snout and overall width as key features for analysis of stun position.
- Carcass features like length, width.
- Surface profile changes like natural muscle seams or the weasand neck opening cut.

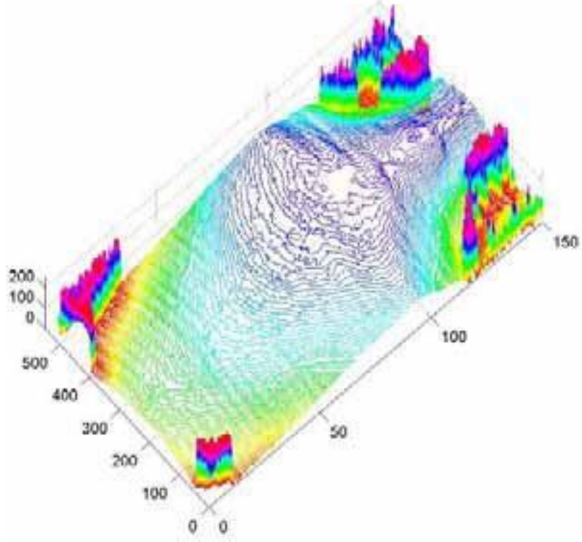


Figure 4-2 Laser Scan of Beef Carcass Surface (Unpublished image, 2004, copyright Food Science Australia)

4.3 MECHANICAL SYSTEMS:

Mechanical systems can be useful where significant surface change is detectable and / or gross materials handling and positioning can be controlled. A mechanical systems could, for example, be used for stunning if the head was positioned such that a touch plate could measure the head length, from which an approximate stun position could be extrapolated – the system is not however going to be able to compensate easily for horns and head orientation, and the stun tool itself would need to incorporate depth correction. Advantages of mechanical systems are that they tend to be robust and can handle harsh environments. The brisket point end of the abdominal cavity opening could be located via a 'sensitive' finger with a preset start position that catches along the skin flap and provides some carcass centring and stabilisation before position clamps are activated. Mechanical 'rollers' could also detect a joint change in a leg or the junction of the base of the head with the neck.

4.4 OTHER: XRAY, NMR, MRI

Examples of other technologies that are nearing maturity in other industries, and thus included as data sheet options, focus on the sensing need to collect information about internal structure. Examples of this is the use of X-rays for precise joint detection for tail removal and teeth feature boundary detection for dentition; and possibly MRI or NMR for the discrimination of feature boundaries between like tissues. Tasks that require these kinds of technologies tend to be Category 2 or 3.

5. DISCUSSION OF TASKS

Automation success evaluation category 1 tasks tend to be those that require sensing of external features with defined boundaries. They utilise key sensing technologies like laser and optical imaging systems and as such the 'secret' or technique to reliable feedback detection is to control the materials handling and presentation of the item to the technology.

Category 2 tasks generally require the detection of an internal feature or interpolation of an internal feature from the external surface. Alternatively tasks can involve specialised tool automation development either to control materials handling better or to "dumb down" the task sensing requirement. Another task area is the extension of features discriminated in a category 1 task to include the added challenge of tracking the identified feature.

Category 3 tasks fall into three main areas:

- Discrimination of like tissue with undefined structure boundaries.
- Real time tissue boundary discrimination.
- Trim task contamination detection.

Tasks from category 3 require some fundamental proof of concept research to develop viable sensing methodologies. This means that to be able to develop a sensor based system for contamination identification, first the contamination itself needs to be investigated to find out what fundamental characteristic it possesses around which a technology could be formed. An example of this is using ultraviolet to fluoresce the chlorophyll in faecal/ ingesta contamination. If the discrimination of like tissue boundaries was possible, then developing a method to do this in real-time for automation control could be achievable.

Manual sensing 'assist' subtasks require the efficient distribution of human labour to be viable. To further investigate this, the analysis of all the parts of tasks that occur on a specific plant slaughter processing line would be needed to evaluate the benefits of progressing with an 'assisted' automated system processing task development. There may also be some benefit to progressing along this development path for a given task as an intermediary step to final full task automation as sensing technologies progress.

The survey does highlight that the smaller the subtasks can be broken down for single manual processing step, an increased success of automation is achievable. Redistribution of labour to more efficient task areas by automating small parts of many manual tasks may also be desirable.

6. EMERGING TECHNOLOGIES

A number of emerging technologies may have future application in automating meat slaughter processes. A selection of these sensing mediums has been presented in this section with some discussion as to their suitability in determining the feature characteristics of carcasses and possible application areas.

The technology groups presented are:

a) Diaphanography
b) Spectroscopy (including NIR)
c) Thermography
d) Ultrasound (including non-contact)
e) Microwave / Radar
f) T-rays
g) X-rays
h) NMR and MRI

6.1 DIAPHANOGRAPHY (OPTICAL IMAGING)

Diaphanography - also known as transillumination imaging and optical mammography (due to its prevalent application to breast cancer detection), involves shining a light source through an object and viewing the "shadow" caused by the propagation of light through the various tissue types. It has been used as a tool in medical diagnosis for imaging the fluid in the newborn skull, in the breast and in the scrotum, and for assessing the state of sinuses utilising visible light (Wells 1984). Current areas of development for diaphanography include "Time-resolved" optical imaging, which utilises pulsed rather than constant light sources, and time gated detectors in an effort to minimise the blurring effects of light scattering in tissue. Because NIR passes through tissue with less scattering of light, other work is based around the use of near-infrared (NIR) wavelengths for illumination.

As research continues diaphanography optical imaging could potentially be suitable for future meat product application where there is some homogeneity to the tissue structure and the depth of the sample under investigation is suitable for illumination.

6.2 SPECTROSCOPY

Spectroscopy provides a non-destructive means of measuring certain parameters of organic materials such as meat and fat. The main application would be in the detection of contaminants on the outside surfaces of carcases. There are two main types of Spectroscopy: Absorption and Emission. The former is generally applied to fluids and isolated solid samples for the detection of for example metal ions. The later includes fluorescence spectroscopy, which uses the principle of detecting the photon emission from a substance, utilising the electromagnetic spectra. High energy photons are used to excite the sample, which will subsequently emit lower energy photons. In other words, the absorbed energy is radiated as a light source. With the development of better cameras and spectrophotometers, this technique is becoming more of a practical solution for the identification of certain properties or characteristics of food and the like.

A feature of biological tissues is that it contains fluorophores that can emit certain wavelengths through the process of autofluorescence. These wavelengths can be detected and analysed to ascertain information about a sample. In some applications, the technique of fluorescence imaging can be enhanced through the use of contrast dyes. This is known as spectral fluorescence difference imaging (SFDI). The difference between the fluorescence spectra emitted from the dye and the tissue in the NIR region can be measured and used to select a pair of specific wavelengths for imaging. The SFDI offers a significant improvement over the conventional single wavelength imaging approach. However, the issues associated with the application of dyes may preclude the use of this method on a slaughter floor.

6.3 NEAR-INFRARED (NIR) SPECTROSCOPY

In the infrared and NIR spectrum the spectral components of individual compounds can be detected. Called chromophores, these compounds have absorption spectrums (absorption level at given wavelengths) which contribute to the overall measurability of a sample.

Examples of chromophores found in meat tissue are haemoglobin and water. Analysing the reflected and scattered light from a sample exposed to NIR light enables some assumptions about the chemical composition and physical structure of the sample to be made.

NIR spectroscopy has been used in food to detect fruit ripeness (brix), measure meat toughness, detect the mix of hamburger ingredients and to measure the protein and moisture content of grains.

An Australian technology developed by Stewart Baud with the Victorian DPI uses a NIR sensor to correctly classify sheep carcasses as lamb or mutton and hogget and is achieving 99% accuracy (Department of Primary Industries (Victoria), 2005).

NIR is compatible with real time process measurement, can be used at intensities that will not harm biological substances so it is non-invasive and can be used for reflectance and transmission measurement - opening up a wide variety of potential future applications with increased understanding of the nature of meat product characteristics.

6.4 THERMOGRAPHY

A thermographic image shows the heat distribution of an object as it radiates energy in the infrared range. The resultant thermogram maps the surface temperature without the need for contact with the object being measured, and allows inferences to be made about the condition of its internal structure.

Possible applications for the use of thermography in the automation of slaughter tasks include:

- The detection of bruising, abscess and other tissue abnormalities which would cause a disruption in the blood flow and associated heat distribution
- Detecting key features for evisceration – differentiating between paunch and internal wall cavity OR diaphragm and surrounding cavity boundaries
- Detection of the hide - tissue interface seam to enable a tool to “fleece” the hide off the carcase minimising hide damage. Seam would be detected via variation in temperature of removed hide compared to meat tissue.

One of the main issues against using thermography is being able to detect a significant difference in the heat content of a desired feature in comparison to its surroundings. Unfortunately various temperature changes will occur in post-slaughter animals from many different causes leading to possibly unreliable or non-robust feedback sensing. However as thermographic technology is both non contact and real time, it may have relevance for use in specific tasks with refinement.

6.5 ULTRASOUND

Sound which has a frequency of greater than 20 KHz is regarded as ultrasound. In a conventional system an ultrasound probe or transducer contains an array of piezoelectric elements which generate sound waves into a sample of interest and receive back a signal which can be processed (generally presented in a graphical form for medical and veterinary applications) to detect 'interfaces' that exist within the sample. Interfaces occur between tissue of differing acoustic densities causing the signal to change as it reflects or transmits through the interface at an altered frequency. In this way an ultrasound scan image shows a tissue profile of all the samples interfaces and elements.

When considering what applications ultrasound may be suitable for in terms of sensing for a slaughter task consideration is required of whether resolution or depth is the critical controlling factor for successful determination of a sample feature. Increasing the frequency of an ultrasound signal also increases its attenuation (Swatland, 1995) meaning that at higher frequency there is poor penetration of the meat tissue sample, whilst at lower frequencies there is poor resolution of the components within the sample.

Examples where research has been conducted into meat applications that use ultrasound include:

- Quantify tissue thicknesses and cross-sectional areas via the energy reflected from the tissue boundaries to measure livestock characteristics (Fischer, 1997).
- Detection of Onchocerca nodules (Food Science Australia report, 2003).
- Control of an automatic beef carcass splitting saw through detection of spine features (Food Science Australia report, 2000).
- The "Efficacy" project that developed an ultrasound system to assess fat depth and eye muscle area non-invasively on live cattle (CSIRO report, 1991).

Figure 6-1Ultrasound scan showing eye muscle from Efficacy project

One issue with the application of conventional Ultrasound technology is that to get the best result the entire active face of the probe should be in contact with the sample as the equipment cannot overcome the reflection it receives from the air/ tissue interface. This poses an interesting challenge for maintaining hygiene in the slaughter environment. While only in the early stages technology known as "non contact ultrasound" has been developed in the medical field for applications such as the assessment of skin capillary action to assess burn victim damage which as it matures may also have applications in meat automation. Whilst this technology is only in the application specific development phase, and is only suitable for shallow sample detection depths, improvement in transducer technology may allow suitable application in the meat industry for future feature detection.

6.6 MICROWAVES/ RADAR

Microwaves are part of the radio spectrum and are electromagnetic waves longer than infrared and shorter than radio broadcast frequencies. RADAR (RAdio [Angle] Detection And Ranging) detects distances to objects by analysing the microwave/ radio waves reflected from an object's surface. By consideration of the pulse "echoes", elapsed time from transmission of signal and frequencies shifts of the response information about distance, velocity and the nature of a detected object can be derived.

Frequency specific transmitters control the response of an application. By tuning the system to the desired interface then detecting and interpreting secondary responses (artefacts) further information can be extrapolated about the structure of an object. For the same power long wavelengths give high penetration, short wavelengths give shallow penetration: traditionally radar has been used to measure large distances in military applications but the technology can facilitate sensing of objects down to the centimetre range. Interface detection of multiple interfaces is achieved by interpreting the change of signal response as it passes between different mediums.

CSIRO has been working on a sub-surface radar system which transmits high frequency electromagnetic pulses into the area being investigated and can be used to detect echoes reflected from the interface between different layers. Designed to pickup metallic and non-metallic objects with probe distances from <1cm to several meters this technology may have possible application for sensing feedback in slaughter automation.

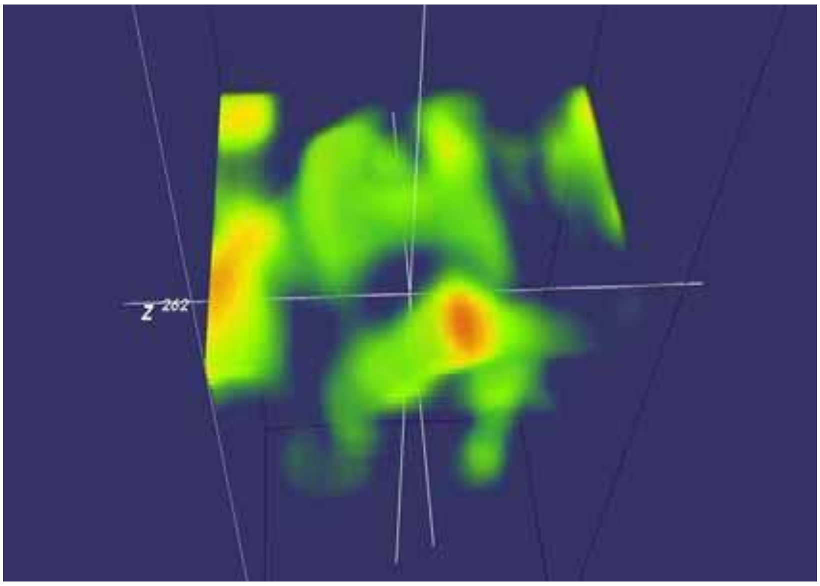


Figure 6-2 Sub-surface radar scan of femur bone (Unpublished image, 2005, copyright Food Science Australia)

6.7 T-RAYS

"T-rays" are generated via an optoelectronic system that uses laser pulses to generate, detect and measure electromagnetic pulses in the terahertz (10^{12} Hz) frequency band. Sometimes termed the quasi-optics region this frequency lies between that of microwaves and infrared radiation in the electromagnetic spectrum. The system measures the amount of distortion (absorption, dispersion and reflection) that occurs when T-rays interact with an object.

Terahertz waves are unique because they can pass easily through some solid materials, yet they can also be focused to create images of objects behind the obscuring material. One method is to translate the signal data into an image format, with each pixel representing the characteristics of the material sample at a specific condition.

Terahertz radiation does not travel through metal or water making this a good technology to identify weapons in an airport screening application or checking connections in semiconductors but unsuitable for the detection of abnormalities at any significant depth within biological tissue. Current research has also been conducted into the use of T-rays for inspection of items that may contain potentially harmful terrorist chemical agents as many biological compounds are sensitive to the terahertz region. It should also be noted that terahertz radiation is non-ionizing.

Two example applications that T-rays may be used for in automation of slaughter tasks could be:

- Surface contamination
- Hide meat interface and surface detection for opening cuts / hide removal

6.8 X-RAYS

Conventional X-ray imaging involves directing ionising radiation through a sample and recording on a medium, e.g. photographic film. Ionizing radiation is radiation in which an individual particle (for example, a photon, electron, or helium nucleus) carries enough energy to ionize an atom or molecule (that is, to completely remove an electron from its orbit). X-rays have short wavelengths with high frequencies that pass relatively unchecked through tissue such as skin and muscle and are absorbed in varying degrees in bones. Due to the transmissive properties of X-rays, significant shielding (often lead) is required to minimize or eliminate unwanted exposure.

X-ray can provide good measures of the body in terms of bone mass and area density, but does not supply particularly good discrimination of soft tissue composition. For example, results of trials undertaken by Food Science Australia on Prune Pit detection indicated that there was a lack of suitable contrast between prune flesh and pits, materials which are quite different. This ruled it out as an inspection technique for detecting pit fragments in pitted prunes. Given this, using Xray in the conventional form, it is unlikely that the contrast exhibited between different layers of muscle would be discernible.

One of the primary issues against using X-ray for carcase scanning is the perceived and real threat of exposure to the ionising radiation from the source. There is the potential for meat workers to suffer adverse health consequences if they were to be inadvertently and/or over exposed. The result can be burns, cancers and genetic mutations. X-ray machines currently used in the meat industry for detection of bone and metal in meat cartons are of a similar scale to those used for airport baggage scanning. Adapting current technology to scan sides of beef would still require shielded enclosures, infrastructure which would be difficult to allow space for on conventional slaughter floors.

This technology could be developed and modified to improve the performance in the area of discrimination of soft tissue features, such as cartilage and connective tissue. However, it could not be used as a hand-held device because of shielding requirements, with even digital X-ray presenting correlation problems for real-time marking of certain sites for later processing.

6.9 MAGNETIC RESONANCE IMAGING (MRI), NUCLEAR MAGNETIC RESONANCE (NMR)

Magnetic resonance imaging (also known as magnetic resonance topography) is a further development of the field of nuclear magnetic resonance, and is a widely used form of medical imaging. Note that in the world of medicine, the word “nuclear” has been dropped from the name to avoid association with nuclear energy and the concept of radiation exposure.

Magnetic resonance imaging (MRI) is a non-destructive and non-invasive method of determining the internal characteristics of a body such as an animal carcase. MRI is a three-dimensional technique allowing a free choice of slice orientation in the sample. In the field of meat science, MRI research applications have been published showing the intramuscular fat distribution, as well as intramuscular connective tissue concentration (Bonny 2000). Applications outside the meat biological field include determining quality characterisation of timber and produce.

Most medical MRI relies on the relaxation properties of excited hydrogen nuclei in water. When placed in a strong uniform magnetic field, the spins of some atomic nuclei within the tissue all align either parallel or anti-parallel to the magnetic field. In this state, the protons and neutrons have the ability to emit a small radio frequency (RF) pulse following the transmission of a large RF pulse. This is known as Nuclear Magnetic Resonance (NMR).

The rate of reemission of the radio waves is different from nucleus to nucleus, depending on local environment, and this effect can be utilised to differentiate the protons in one tissue from those in others. The resolution of an MRI system is a function of the strength and homogeneity of the magnetic field, and the accuracy with which the NMR frequencies can be selected and measured.

While Computed Tomography (CT) provides superior spatial resolution (the ability to distinguish two structures an arbitrarily small distance from each other as separate), MRI provides far better contrast resolution (the ability to distinguish the differences between two arbitrarily similar but not identical tissues). The basis of this ability is the complex library of pulse sequences that the modern medical MRI scanner includes, each of which is optimized to provide image contrast based on a particular property of the subject.

The costs and complexity of MR equipment has generally limited its use to that of a research tool. The high costs are in both the initial equipment purchase as well as the costs of running and maintaining the required superconducting magnet. Also, processing an image is relatively time consuming. There is a safety issue in that the magnet has the ability to impart motion on ferrous items in the vicinity of the device. This has previously resulted in injuries and deaths. Despite this, some research has already been undertaken in the use of MRI for the meat and livestock production industry, primarily for carcase grading systems and stock enhancement selection.

In general, MRI and NMR methods are technically suitable to detect internal carcase features. Overlooking the limitations of the system such as high costs, it appears that the discrimination of features in the output images could make the method suitable for use in a slaughter situation in some instances.

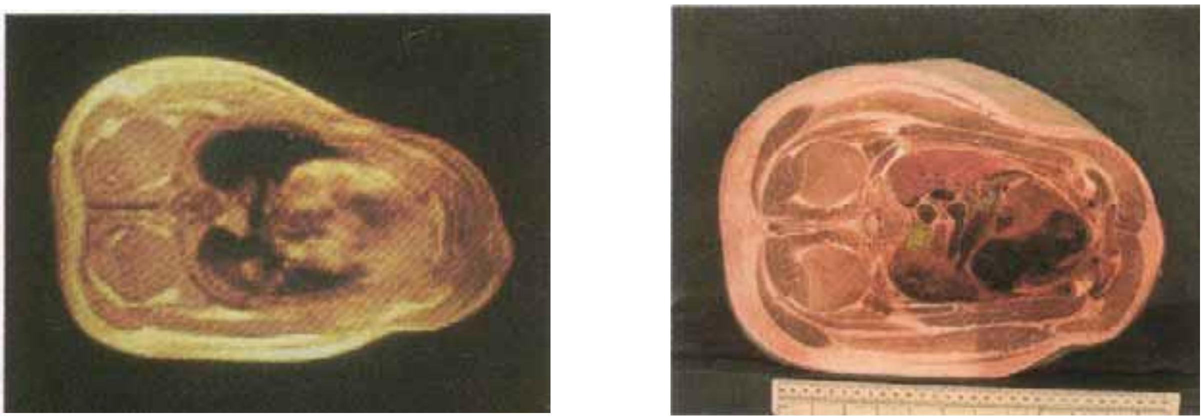


Figure 6-3 – NMR density image and corresponding cross section colour image of a pig (Fuller et al. 1984)

7. CONCLUSION

This report documents beef and sheep slaughter tasks with respect to the types of sensors that could be used to automate manual process tasks; and an evaluation of the potential for automating each task.

Tasks that were identified as being “Automation success evaluation category 1’ with automation possible in the immediate future though the application, adaptation and integration of known technologies included:

BEEF TASKS	SHEEP TASKS
Stun	Stun
Remove Horns	Head Removal
Remove Forefeet	Spreader
Rear Hock Removal	YCut- Brisket open & strip
RFID Tag Removal & Data Entry	Bung / Evacuation
Hoist	Leg Reposition
Change Second Leg	Hock Cut Rear (Mechanical)
Stamp	Shoulder Puller Mechanical (Load)
Shanks	Pelt Removal (Mechanical)
Horn Second Cut	Gambrel Insert and Hang
Dentition	Neck Tip / Trim
Remove Head	Hind Hock Tip
Brisket saw	Front Hock Cut
Removal Tail	Vac San – Fixed Path Specification
Trim Skirts	Fat Removal – Fixed Path Specification
Weigh	Weigh
Wash	Branding / Marking
Chill	Record
	Chillers (loading)

Tasks that were identified as being “Automation success evaluation category 2’ with automation possible in the short term through research development of sensing technologies included:

BEEF TASKS	SHEEP TASKS
Stun	Stun
Plug	Sticking Halal
Shackle, Hoist	Shackle
Bleed	Dentition
Bleed Halal – Transverse Incision	Ycut
Bleed Halal – Stick Bleed	Weasand – Clear Front of Neck
Cheek Hide Removal	Weasand – Open Neck/ Gullet; Expose Weasand
Pizzle Removal	Pelting (punching)
Skin Anus, Tail	Clear Pelt
Bagging	Open Abdominal Cavity
Dentition	Brisket Cut
Remove Head	Fat Removal – End Volume Discrimination
Brisket Saw	
Remove Tail	
Saw Carcass	
Kidney Fat et al Removal	

Tasks that were identified as being “Automation success evaluation category 3’ requiring long term research included:

BEEF TASKS		SHEEP TASKS
Free and Rod Weasand	Rump	Free and Rod Weasand
Remove Muzzle	Flank	Udder / Pizzle Removal
Udder Removal	Hide Strip / Removal	Vac San – Contamination Detection
Skin First Leg	Evisceration	Gut
Shin Second Leg	Clear and Drop Rectum	Diaphragm and Pluck Removal
Contamination Trim Tasks including: • Forequarter Trim • Forequarter Revision Trim • Trim Tail • Brisket Trim • Hindquarter Trim • Revision Hindquarter Trim		Contamination Trim Tasks including: • AusMeat Trim • Neck Inspection and Trim • Channel and Inside Inspection • Retain Trimmer • Forequarter Trim • Tail Trim • Hind Leg and Rump Trim • Flank Trimmer • Checker

Tasks that may be automated using assisted “manual” sensing include:

BEEF TASKS	SHEEP TASKS	
Materials Handling	Materials Handling	Y cut
Stun	Stun	Weasand
Rectum	Halal Stick	Gambrel Insertion
Bag	Shackle	Ring and Rake
	Head Removal	Gut

REFERENCES - BIBLIOGRAPHY

AT&T, (1995) Media release: Bell Labs scientists create 'T-rays' to see inside objects, http://www.att.com/news/0595/950525.bla.html, accessed 3/9/02.

Bonny, J., Laurent, W., Labas, R., Taylor, R., Berge, P., & Renou, J. (2000), Magnetic Resonance Imaging of Connective Tissue: a Non-destructive Method for Characterising Muscle Structure, *Journal of the Science of Food and Agriculture,* Vol 81, pp. 337-341.

Department of Primary Industries (Victoria), (2005) Science, Research & Development: Animal Production Sciences Projects, http://www.dpi.vic.gov.au/DPI/nrensr.nsf/childdocs/-BA211CA6E23454E6CA256ECC0022E283-5931264674E94402CA256ECC0005620C-F47F09019F6D6A3ACA256F620003ADBF?open, accessed 02/2005

Fisher, A.V. (1997), A review of the technique of estimating the composition of livestock using the velocity of ultrasound, *Journal of Computers and Electronics in Agriculture*, Vol 17, 217-231.

Fuller, M.F., Foster, M.A. & Hutchinson, J.M.S (1984), 'Nuclear Magnetic Resonance of Pigs', in Lister (ed), *InVivo Measurement of Body Composition in Meat Animals*, Elsevier Applied Science Publishers, England, pp. 123-133.

Skjervold, P.O., Taylor, R.G., Wold, J.P., Berge, P., Abouelkaram, S., Culioli, & J., Dufour, E. (2003), Development of Intrinsic Fluorescent Multispectral Imagery Specific for Fat, Connective Tissue, and Myofibers in Meat, *Journal of Food Science,* Vol 68, No 4, pp. 1161-1168

Swatland, H.J. (1995), *On-Line Evaluation of Meat*, Technomic Publishing Company, Inc, USA.

Wells, P.N.T. (1984), 'Introduction to Imaging Technology', in Lister (ed), *InVivo Measurement of Body Composition in Meat Animals*, Elsevier Applied Science Publishers, England, pp. 25-35.