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Robotics in meat processing

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Chapter 8: Robotics in meat processing

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Abstract

Robotics find many applications in the meat industry ranging from meat handling to processing and packaging. There are several challenges which should be addressed prior to its implementation in the meat industry. Among several meat processing industries, the pork industries are advanced with a few examples of fully automated processing plants. This chapter outlines the potential benefits and application of robotics in the meat processing industries. Application of robots in various stages of animal processing are discussed along with a number of case studies.

Introduction

A robot is a programmable machine that is capable of carrying out complex actions automatically. Robotics is the branch of science which deals with the design, construction, operation and application of robots. In today's modern life, robotic technology has contributed in many ways to improving society. Robotic systems exploit artificial intelligence to replace many labour intensive operations in several industries. The automobile industry uses robots for the whole production process. In the electronics industry the use of robots to assemble circuit boards and computers is very common. These days in industrial fields like construction or ship building automatic climbing robots are increasingly being considered in situations where maintenance and inspection involves dangerous operations. Scientists are currently investigating micro robotics in the medical field with a potential to provide better medical technology in the near future. Other specialized field robots are being developed to work in many conditions such as in mines, under water or farm-fields (Prarthana et al., 2013).

When it comes to the food industry the use of robots has been traditionally limited to picking and palletisation. One of the earliest application of robots in the 1980s involved packaging of assorted chocolates into trays (Wallin et al., 1997). Today, however, robots are used in material handling and secondary or tertiary packing. Recent developments with faster computers and sophisticated sensors have made it possible to use robotics in the meat processing sectors, where their application has reduced processing costs, occupational injuries, improved efficiency and hygiene associated with meat products. Compared to other industries the working environment in the meat industry is not very conducive to robotics due to the noisy, damp and cold conditions. Slaughtering animals and cutting meat into pieces and disposing waste is an intensive physical demanding task. Due to these hostile conditions labourers are not readily available and the demand for automation has thus increased. Automation requires high financial investment and the payback can be expected only after a long time and when the volume of meat processed is very high. However, the advantages of automation are higher with few disadvantages, thus the need of automation cannot be ignored in the meat processing industry. The objective of this chapter is to review the application of robotics in the meat industry and the advancements that have been made up until now. The various advantages and disadvantages that come to mind when you think of automation of the meat industry are discussed. Case studies on automating a number of key processes have also been discussed.

8.1 Application of robotics in meat processing

The development of robotic technology for the meat industry has gained interest because of the decline in the labour force, unpleasant working environment and ever increasing hygiene requirements. The important challenge faced by scientists doing research around meat processing is to develop technology for safe, wholesome and convenient products that offer great value. In beef production the first reported use of robotic equipment was in splitting a complete carcass into carcass sides. A number of manufacturers produce such equipment which replaces this particular arduous manual process. Several manual operations have been mechanised, improving both process efficiency and hygiene in the meat processing industry.

For many years the meat industry has been industrialized in terms of organization and use of production lines. The meat industry is taking inspiration from other industries where robot assisted and computer controlled manufacturing systems are more common. Now, to maintain the increasing demand with globalisation, the meat industry is also ensuring the use of robots where it is justifiable. Traditionally plant modernization in the meat industry started by replacing a few arduous processes with machines rather than changing the whole production line. However, new plants dedicated to meat processing have fully robotized processing lines from animal handling to packaging. This helps in improving production, hygienic processing, consistency and accuracy.

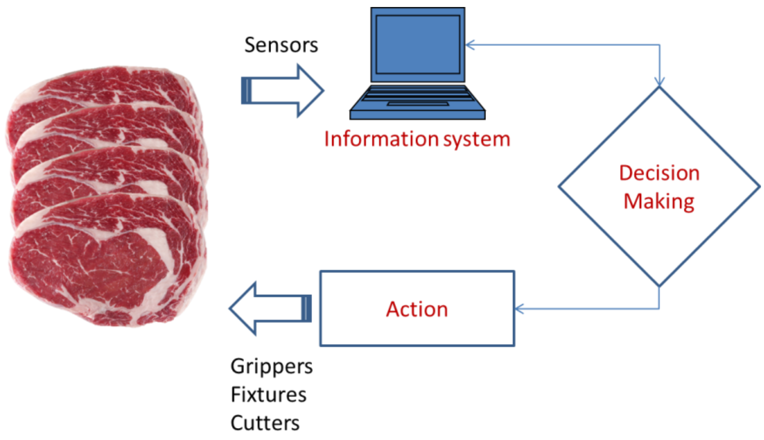

Figure 1. Schematics of robotic system in the meat industry (Adapted from Purnell, 1998)

8.1.2 Advantages and disadvantages of robotics for meat processing

Tasks in food manufacturing plants often require the handling and manipulation of individual products, which can be challenging given the variations in meat properties. The mechanization or robotisation of the meat sector is heterogeneous, depending on the animal species or breeds. The meat industry is one of the most hazardous and unpleasant industries in the food processing sector. The main reason for robotisation is to reduce the difficulty and danger in working environments (Matthieu et al., 2014). Using robots leads to lower production costs (Purnell, 1998). Automation can result in improved worker safety, it will also reduce repetitive strain injury. Performing the same motion work for prolonged periods in chilled environment causes fatigue and damage to joints and muscles of people. Automation can also result in improved food hygiene whereas human operation can lead to product contamination. Robots can be designed to work in harsh environmental conditions maintaining hygienic conditions which will increase the overall product quality (Tarrant, 1998). They are also made to withstand the effect of cleaning agents such as acids, cleaning enzymes, bleach etc.

There can be wide variations in size and shape of single product types; hence robots can be used in the meat industry to improve precision and hygiene requirements. Especially as the food safety regulations are becoming more stringent. Robots have limited decision making ability and cannot act accordingly. There is also problem of limited motion with robots as they are built to suit a specific task. Humans can take a decision extremely rapidly whereas robots have to be given a specific standard as criteria to accept/reject conditions. The components which are in direct contact with food are limited to be made out of specific material such as stainless steel or select plastics. Product surface can exhibit a very low coefficient of friction therefore handling tools design can be very challenging.

Table 1 Advantages and Disadvantages of automation in meat industry

Advantages	**Disadvantages**
Reduced floor space due to overhead mounting.	High initial investment.
Better quality end product and hygienic processing.	Not flexible like human.
Highly efficient and quick production.	Not completely reliable.
Suitable for working in all kind of harsh environment.	Complexity in handling biological material.
Reduced wastage.	Lacks quick decision makings capability.
Produces more uniform end product.	
Easy to clean and can withstand corrosion and acid wash.	
Light weight yet rigid construction.	

8.2 Robotics equipment

When automation started in the meat industry there were many companies which developed carcass splitting equipment. The performance of this equipment was not satisfactory in terms of accuracy of splitting and hygiene problems associated with deposition of dust on the carcass surface (Madsen and Nielsen, 2002). Beef and lamb carcass grading systems used in the past were based on visual assessment of fat cover however it suffered from lack of objectivity (Tarrant, 1998). Semi automated equipment for grading beef carcases were made using Vision Image Analysis (VIA) in Denmark, Germany Australia and Canada. Since then many new inventions have been made in terms of automation in the meat industry but only a few have been used successfully in commercial environments. The application of robotics in various meat processing stages is outlined below.

<u>Animal Reception</u>

Live animals are bought to the abattoir in trucks and unloaded. Here animals are rested for a day or two before slaughter. Animals should be handled considerately because stressed animals can affect the quality of final meat. Animals are cleaned properly before slaughtering to remove dirt from the skin. Abattoirs are specially designed to reduce the stress caused to animals as this maintains the meat quality. Proper bedding, water to drink, special lighting are a few of the special arrangements provided. In the case of poultry processing, the birds were picked up by hand and placed on moving conveyors but now mechanical harvesters in which moving rubber fingers collect and encourage the birds to move to the conveyor (Warriss, 2001).

Stunning and bleeding

Stunning is the process through which animals are rendered unconscious before decapitation to effect bleeding. The stunning process must render the animal immediately as it can affect the quality of meat. Stunning can be done by various methods which can be categorized as Mechanical stunning using bolt pistol, percussion stunner (free bullet), Electrical stunning by giving an electric shock (Figure 2) and chemical stunning by inducing anaesthetic gas such as carbon dioxide. As soon as the animal is rendered unconscious the animal must be killed by exsanguination this is done by cutting the blood vessels in the neck or the blood vessels entering the heart (sticking). In poultry electrical stunning is used to render birds unconscious long enough to allow automated neck cutting and reduce carcass damage.

There are many systems to convey animals to the stun station, most commonly used is a V shaped conveyor for pigs. Electrical stunning is carried out by human operator for animal welfare reasons due to complexity of placing accurately the stun electrodes on a moving animal. However, alternate stunning methods in which carbon dioxide is used to render unconsciousness has been fully automated. A company called Automated Control Concepts, Inc. made automated CO_2 stunning equipment consisting of a chamber below ground level. An elevator lowers the group of pigs into carbon dioxide atmosphere where stunning occurs. After appropriate dwell time the pigs are brought back up. The elevator tilts a bit allowing pigs to slide onto a conveyor belt where they proceed for exsanguination (Figure 3).

Figure 2 Manual stunning suitable for Halal   Figure 3 Automated pig stunning

Dressing, Evisceration, Cutting and boning

Dressing involves the separation of the head, feet, hide (in the case of sheep, goats and cattle), excess fat, viscera and offal (edible and inedible) from the bones and edible muscular tissue. After accessing all the parameters it was accessed that sensing will be required to automate the whole process. Image processing and 3D profiling is used as the method for sensing (Singh et al., 2012).

Industrial Research Ltd, New Zealand has marketed a robot called Envirobot used for critical Y-cuts in connection with dehiding and cutting of lamb carcasses and for sawing through the breastbone on the cattle carcasses. Envirobot is made to withstand the harsh corrosive and chilled environment in the slaughterhouse.

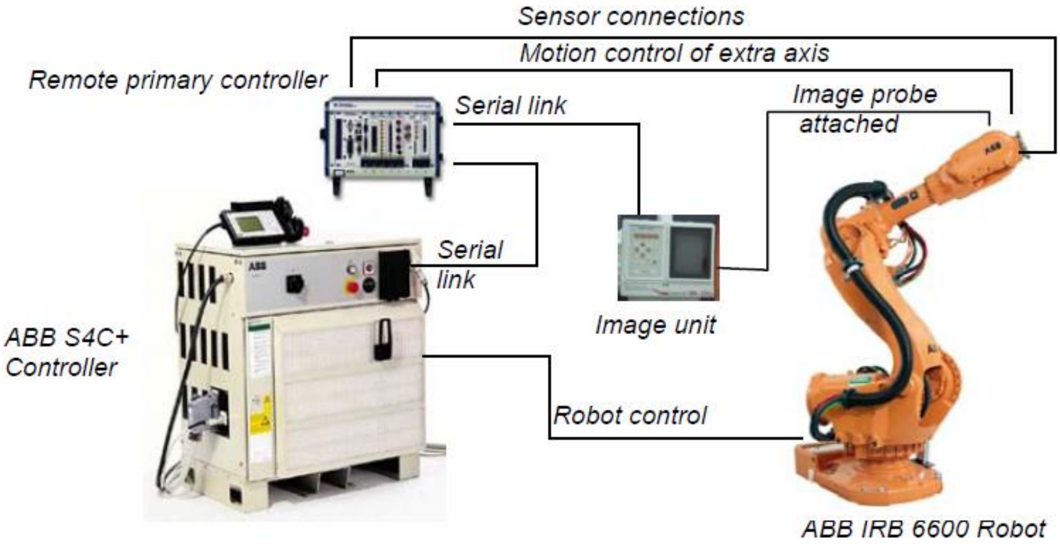

Figure 4. Robotic carcass splitting system (Adapted from Li et al., 2003)

Robotic carcass splitting system (figure 4) consists of a robotic system, and controller. The major work is done by ultrasound image processing unit along with remote primary control unit. Initially the position of backbone is detected *via* analysis of images using ultrasound unit (figure 5). The primary controller after processing data generates a traverse coordinate used to control horizontal positioning and rotary angle of the carcass splitting saw. While the robot arm is moving along the spine the saw position and rotation about its axis are automatically corrected with ultrasound feedback data. The image acquisition, communication and other control processes need to be fast enough to match splitting operation requirements.

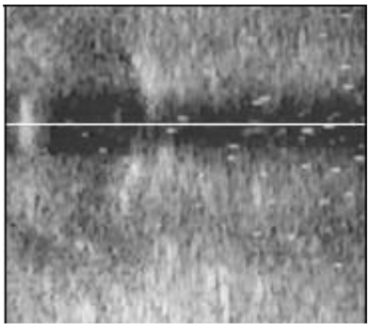

Figure 5. Spine position detected by ultrasound image (Adapted from Li et al., 2003)

Robotics in online quality analysis and control in the food industry is a major step which should be taken care of at every processing stage. Non destructive analysis of meat products can be done to identify the physical, mechanical, chemical analysis and abnormalities or deformities. It is a beneficial tool for online quality analysis of meat products. Thermal imaging uses the principle that every body emits infrared radiations. A thermal imaging system consists of a camera an optical system, detector, signal processing and image processing system. The TI detectors are heated by incoming infra-red radiation and temperature changes, which is measured by any temperature dependent mechanism such as thermoelectric voltage, resistance or pyroelectric voltage. The microbolometer is an IR sensitive detector which functions as a thin film transistor (TFT). The TI camera system converts radiation emitted from a sample in a specified waveband (e.g. 8-12 μm) into an electrical signal which is then processed into an image. The thermal image may be coupled with computer software for enhanced interpretation. The criteria of band selection are based on various factors including the operating distance, indoor-outdoor operation, temperature and emissivity of the bodies of interest. The thermograph obtained can be further analysed using a wide range of image processing techniques.

Beef is aged at low temperatures for a long period of time during this period, sometimes microbial growth can occur. To overcome this problem the aging process and microbial growth should be monitored. Various chemical sensors can be used for this purpose. Electronic nose is being used as a quick quality sensing tool in online processing. It has great potential for use in other applications such as sensory quality, shelf life, spoilage, off favours and taints. With a few more advancements in this field the electronic nose could turn out be a most beneficial tool in automation (Ghasemi-Varnamkhasti et al., 2009).

In meat packing, online composition evaluation is an important step. Online fat/ lean ratio is an important parameter in pricing, procurement and also helps in improving the product overall quality. Using electronic probes for fat measurement and muscle depth is an easy and widely used method worldwide. However, this method is very strenuous and not widely accepted, therefore cost effective and suitable automation in the grading systems were done. This system has a sophisticated sensing system to find probing location. It consists of various sensors to measure the physical parameters like force required to probe into the flesh. There are various parameters which are synchronized to perform the operation with the required specification (Goldenberg and Lu, 1997)

Packaging

Beyond handling unwrapped products, robotic packaging systems have been successfully implemented in primary packaging, casing, stacking of cases into pallets and arranging the pallets into warehouse. Generally packaging in the meat industry involves packing sausages and processed meats. After primary processing, placing processed products into individual containers is the first step in packaging which uses picking robotic hands (Totosaus et al., 2007). More wide applications involve collation of cartons or boxes into bigger boxes and palletisation and wrapping of pallets with cling film for transportation.

Figure 6. Robot used for picking in the meat industry (Adapted from Anderson, 2004)

8.2.1 Case studies

Automation in Lamb processing

There has been significant automation in processing of lamb, mostly because the lamb carcass is relatively flexible when compared to others. Full automation has not been achieved yet, but combining human strength and automation at different levels has proved to be beneficial.

It was found that the first automated stunner for sheep and lamb evolved from pig stunning equipment which was developed in Europe (Longdell, 1996). Today the most prevalent method followed in EU for stunning is Electrical stunning (FCEC report, 2007).

The most notable automation processes developed are pelt removal and cuts assisting evisceration. This pelt removal technique was made in Ireland and New Zealand in 1990s, four main parts in the process are automated as follows:

Y – Cutting

It is a primary pelt removing task. The cut as shown in figure 7(a), marked by bold line, splits the pelt and separates it from flesh underneath. This is done by a human operator where they perform the delicate task of sensing and delicate positioning operations. The cutting tool developed uses an air powered reciprocating knife to both cut and clear the pelt.

Brisket cleaning

It is pelt removal task which occurs after Y cutting. The flap is lifted and pushed back as shown in figure 7(b). Full automation of this process would require a very complex sensing system. There should be precision in cutting. Semi automated with a cooperative robot or “cobot” is used for providing the brutal force and human operator doing complex sensing task. It is pneumatically activated where a human operator controls it with a joystick and performs the task of guiding.

Rip down and rear Y cut

The rip down and rear Y cut is for further pelt removal. A deep cut is made on the belly to help in removing the pelt.

Carcass opening cut

Carcass opening is the first step in the evisceration process where the complete pelt is removed and the carcass hangs by its rear legs. The cut involves slitting the belly wall (figure 7(c)) and then shearing through the brisket (Templer et al., 1999).

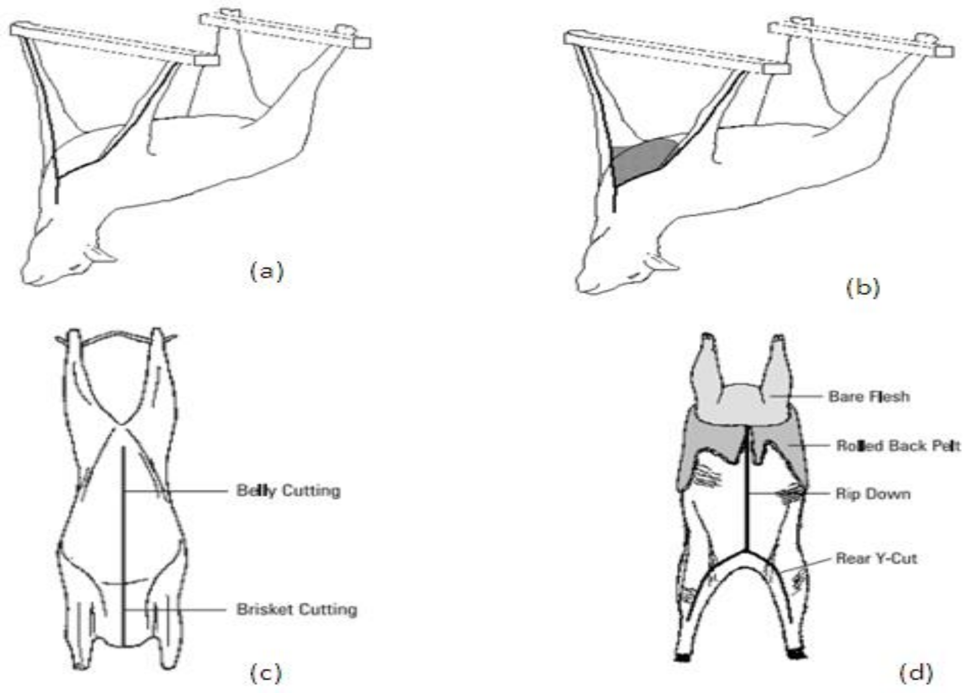

Figure 7. (a) Y cut – marked in bold black line (b) Brisket cut – flap lifted and shifted back. (c) Belly cut (d) Carcass opening cut – Rip down and rear Y cut followed by complete pelt removal.

Shoulder fleecing machine

The process of removal of shoulder meat is called as shoulder fleecing. It also includes removing the scapula and fore leg bones, from the neck and trunk vertebrae and the rib bones of a lamb carcass. There is a machine (figure 8) designed by MIRINZ for this which does this task in four steps. Initially a knife cuts the entire shoulder barrel, one on each side of the spine. In the next step the meat from neck bone is removed and this is done with the help of a pair of specially designed contour knives. Following this a third pair of knives removes the muscle from thoracic vertebrae and portion of ribs close to vertebrae. In the final fourth, a pair of knifes, specially designed and curved, is used to separate the meat from vertical portion of rib bones (Longdell, 1996).

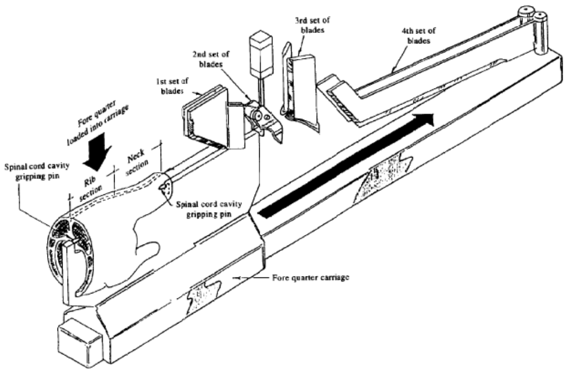

Figure 8. Layout of MIRINZ shoulder fleecing machine (Adapted from Longdell, 1996)

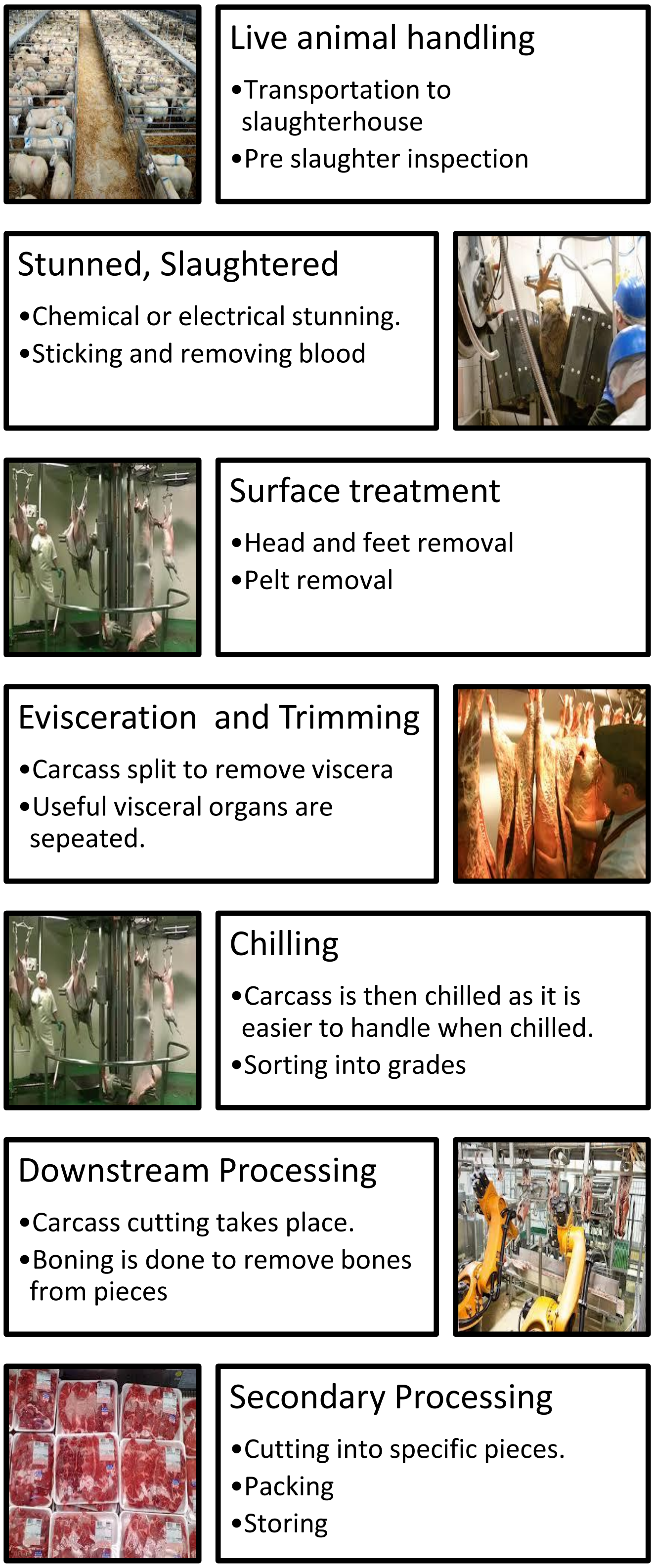

Figure 9. Process and sub process in lamb slaughtering

Robotic Technologies Ltd. (RTL) is a joint venture company, 50% owned by both Silver Fern Farms and Scott Technology Ltd. They developed a fully automated Lamb boning room and commercialized it in 2011. Initially X- ray scans, analyzes and provides accurate data for the cut point in the primal cutting system. The X- ray data is fed to Saddle and hindquarter machines of the boning room vision to deliver cut position accuracy. The components of this system include: Primal cutting, Forequarter processing, Middle processing, Hindquarter processing. Since 2003 MLA (Meat and Livestock Australia) has been supporting RTL for this project (Starling et al., 2011).

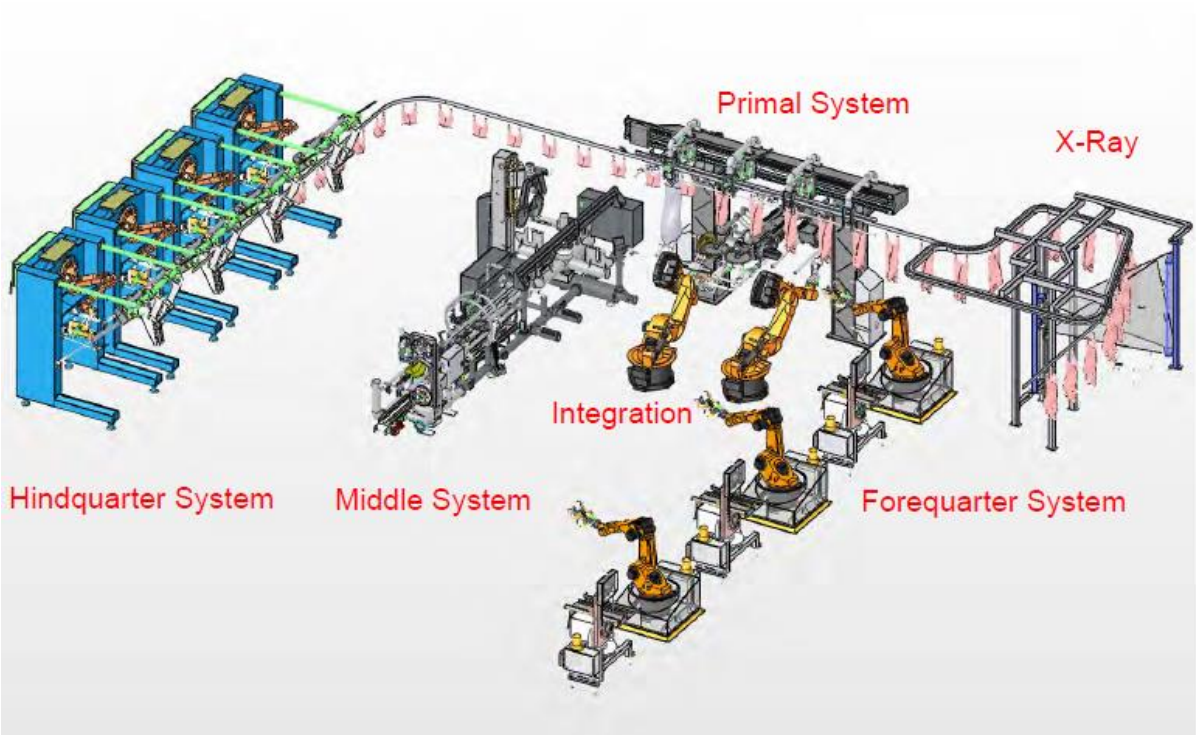

Figure 10. Fully automated Lamb boning room – RTL Vision (Adapted from Starling, 2011)

Automation in Pig Processing

Pig carcasses are the most uniform large carcass and pork has a high demand worldwide, which has resulted in this industry being more automated than any other. Also pig slaughtering, cutting and boning are hard and labour intensive work. The figure 12 shows the various processes involved in the processing of pigs. The pre slaughter handling of pigs is important for ensuring good meat quality.

For pigs stunning can be carried out by electric shock or anaesthesia with carbon dioxide (60-70%). Stunning with a bolt pistol is not done because of the problem with skull penetration. Sticking is done by cutting the cervical vein and one of the arteries (Barbut, 2001).

Scalding is an important process to obtain good results in dehairing. It is done by raising the temperature of skin to loosen the root hair so that it comes out easily. Scalding can be done by three main methods

- Immersion in hot water
- Sprinkling hot water
- Steam scalding

The temperature (60^0 – 65^0 C) is an important aspect in this method, as too high a temperature can lead to bad meat quality, whereas a low temperature will result in problems in dehairing. Scalding using steam is the most preferred method as it is more hygienic. The problems associated with contamination with water are also avoided.

Figure 11. Pig scalding using steam (Adapted from http://www.mps-group.nl/en/)

Figure 12. Process and sub processes involved in pig slaughtering

Dehairing

This Automated dehairing machine by Meat processing systems, Netherlands is ideal for dehairing around 250 pigs per hour. It consists of stable, special cast iron frame and U bars and the heavy scraper rollers. Continuous flow of water ensures automatic removal of hair and nails. A perforated mesh is provided at the bottom of machine to eliminate hair and nails.

Figure 13. Dehairing machine

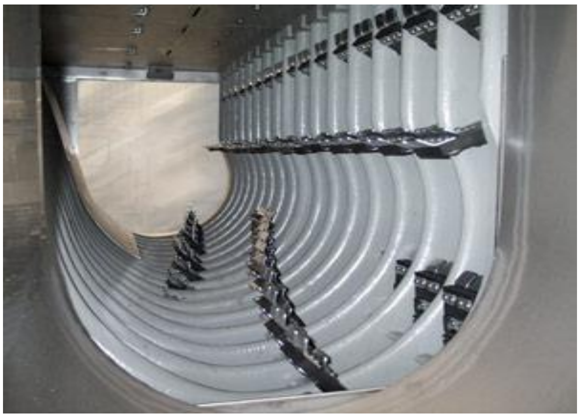

Figure 14. Interior of Dehairing machine

(Adapted from http://www.mps-group.nl/en/)

Cutting

An automated line was developed by the Danish Meat Research Institute (DMRI) and consisted of 8 automatic machines. The Danish pig slaughter program started in 1998 and the complete slaughter line was made available by 2006. In the beginning of the automated line a series of machines will cut the throat, loosen the fat end, divide the hind legs, open the carcass and perform evisceration. The Evisceration equipment developed by DMRI cuts the diaphragm, tears off flare fat and loosens the intestinal tract such that the entire intestines and organs are removed from the carcass prior to separation. As the separation is conducted outside carcass the chances of contamination are less and product is safer (Nielsen et al., 2005). A measuring station is present so that robots can adapt themselves to the variations in carcass size. An automated carcass cutting machine was also developed by Danish Meat Research Institute. This machine helps in cutting the half carcass into fore end, middle and hind leg (Hinrichsen, 2009).

A company (ATTEC) based in Denmark has made automatic and semi automatic lines for primal pork cutting. In the semi-automatic version all cuts are performed by circular knifes resulting in clean cuts and no bone fragments from sawing, optimum yield without product loss. In fully automatic cutting lines for pork the carcass is cut into four parts: hind feet, leg, middle and shoulder. The automatic measuring system measures each half carcass ensuring optimum registration, maximum yield and labour saving. This processing line is based on servo electric and mechanical principle (http://www.attec.dk/).

ATTEC together with DMRI has made equipment for cutting of the rib tops and dividing the loin and belly automatically. The conveyor is equipped with a grasping device, which pulls the rib tops out to their full length. This straightens out the backbone, simplifying the subsequent sawing off of the rib tops. After fixing in the conveyor, the middle passes through measuring stations, which measures the length and any inaccuracy in the earlier carcass splitting. Based on these measurements, the saws are adjusted to cut off the belly from the loin and subsequently cut off the loin from the rib tops (Madsen and Nielsen, 2002).

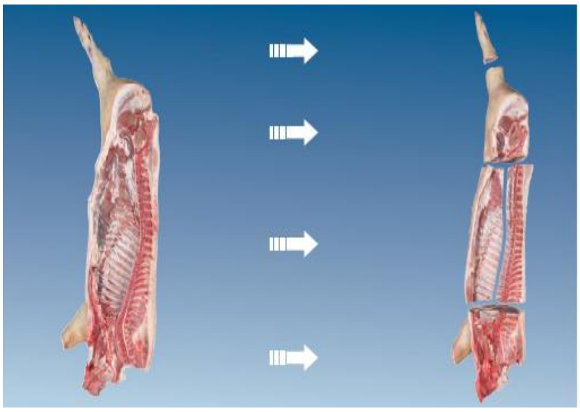

Figure 15. Fully automated cutting line   Figure 16. Cuts made on half pig carcass

Boning

The machine for removing surface bones – neck bone and riblet – was developed in cooperation with the Dutch division of the American company of Townsend Engineering. After this operation 2-3 operators are required to carry out final trimming of the boned fore ends. For removing the interior bones – shank bones, humerus and shoulder bone another machine is used.

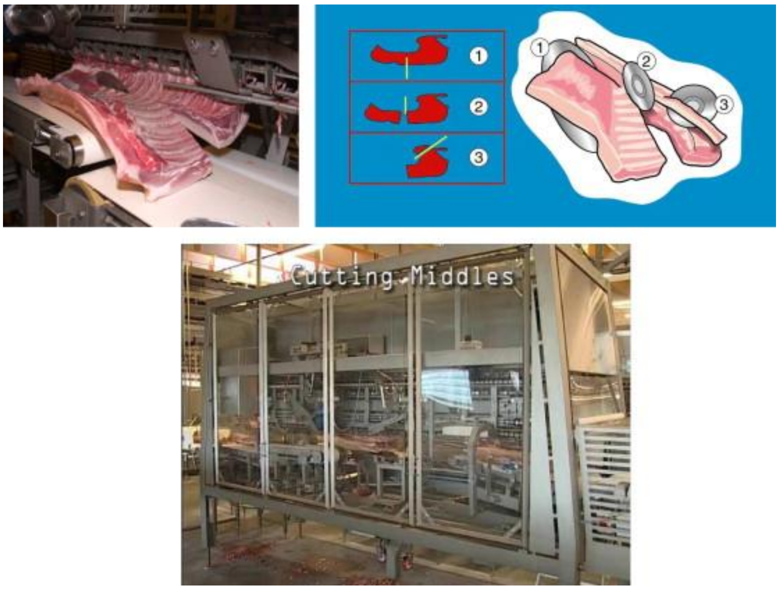

Figure 17. Middle cutting machine. The machine cuts off rib tops and separates the loin and belly automatically

8.3 Future role for robotics in the processing of meat and meat products

When thinking about ways that industrial robot arms are used, the meat industry may not spring to mind. Most likely, people think first of the automobile or electronics manufacturing industry. Automation can be found right along the production line in the meat processing factory - from slaughter through to the final packaging and despatch. The meat industry is currently using industrial robotic arms, and is planning to integrate even more automation in the near future. The plan for the industry is to make these kinds of robotic industrial arms more available to smaller markets, and make them more universal for meat processing. While this process is highly automated already, the meat industry would like to further automate their system, and is currently devising leaner, more efficient ways to break down and debone various animal carcasses.

Robotics hold the promise of reducing the processing cost by helping speed up processing lines, making production more efficient and reducing labour requirement. The time is not far away when all the processes in meat processing, starting from the primary processing, secondary processing , packing and despatch, will be fully automated.

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