ROBOTIC EQUIPMENT IN THE MEAT INDUSTRY

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ABSTRACT

Robotic technology is beginning to find uses in the meat processing industry. This paper attempts to describe the potential benefits and some of the problems in implementing robots for meat processing. An overview of some of the robotic equipment available and in development for beef, pork, lamb, poultry, fish and seafood processing is given. Standard industrial robots already perform meat industry tasks involving regular and uniform products and processes. Robotic automation is emerging for more skilled tasks but is not yet fully accepted or implemented in the meat industry.

INTRODUCTION

The word 'robot' can conjure up a wide variety of images; to a child it is a toy in the form of an angular human that moves on its own, to the factory worker it is the hideous machine that is out to steal his job, to the 'sci-fi' reader it is the android indistinguishable from the human. According to the Robot Institute of America, a robot is 'a re-programmable multi-functional manipulator designed to move material, parts, tools or specialised devices through variable programmed motions for the performance of a variety of tasks.'

This describes a commonly agreed description of a robot; a multi-jointed arm used for positioning components. Whilst this type of machine does have a few current applications within the meat industry, it is mainly in handling of standardised products such as boxes, pallets, and packages. The definition of robot needs to be broadened for the purposes of this study to include those items of skilled automation operating further back down the processing line and coping with the inherent variations of food products and production processes. These types of machines solve the problems of product variation in a number of ways, some use advanced sensing, some use stored knowledge of statistically likely variations, and others modify the process to utilise the strengths of robotics technology. In this study, the term robot will be broadened to include sensor guided automation that physically positions a tool or a product for processing. Systems with intelligence or decision making capability based on sensed information about the product can be included.

The prime problem in the meat sector is the natural variability of the raw product and much research is underway to develop systems flexible enough to process these products. This has key implications for sensors and elements in direct contact with the meat (see Figure 1). Sensors, grippers, fixturing and cutting tools all require the ability to cope with meat variations.

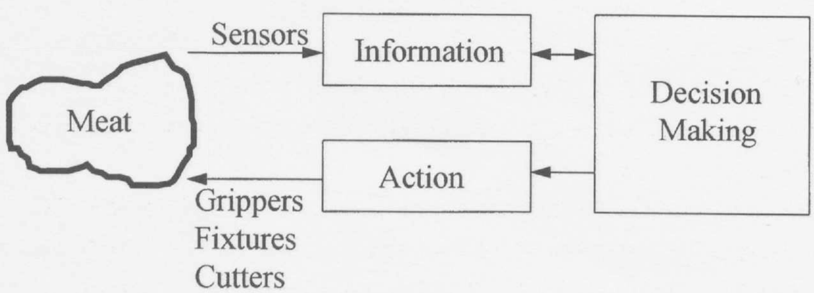

Figure 1. Robotic System Schematic

The food sector is five times the size of the automotive industry and grows by 3% every year (MacDonald, 1991). Despite the magnitude of the business, little robotic automation has been implemented when compared to other manufacturing industries.

POTENTIAL BENEFITS OF ROBOTS

The use of robots to perform meat processing in place of human operatives has many potential benefits, including tangible, intangible, social and economic. The hygiene and safety risks, coupled with high labour and social costs, limit the usefulness of human workers in the food sector, especially as food safety regulations are becoming more stringent. Employers are encountering increasing difficulty and cost in recruiting, training and retaining skilled butchery staff (Maunder, 1991). Cost calculations can only be made on an individual basis, but many generic drivers are quoted by the meat industry for the introduction of robots. These include:

- The need to increase in reliability and consistency of output. Robots do not become bored or forget things. Robots possess more accurate first time positioning than a human. The ability to get-things-right more of the time produces tangible yield benefits. Some robotic primal cutting systems claim to generate yield benefits to payback in under 2 years.
- A reduction in production costs. Not only are robot hourly rates below those of manual workers (Krutz, 1983) but some employers are having difficulty recruiting the appropriate skilled staff. Labour can account for as much as 45% of the total product cost (Clarke et al, 1986). Training costs for unskilled staff are significant. Advances in electronics and materials technologies continue to reduce robot costs yet staff based expenses continue to rise.
- A reduction in overhead costs. Automation can remove the need for operator facilities, lighting, heating, clothing, washing facilities, etc. with an associated cost saving.
- Replacing staff with automation can result in an improvement in worker safety. Butchery is among the most hazardous and unpleasant sectors of the food processing industry (North, 1991). It is the 7th worst in the UK for injuries requiring 3 or more days absence. Injury occurs to both experienced and trained staff, illustrating that it is the nature of the work rather than inexperience causing the danger. Cuts made with high force towards the body, bad knife design and cold fingers contribute to the poor safety record (North, 1991).
- The introduction of automation can result in a reduction in repetitive strain injury (RSI). RSI compensation is becoming an increasing concern of employers. Performing the same motion for prolonged periods of time in a chilled environment causes fatigue and damage to joints and muscles of butchery workers. There is an increasing number of cases where damages have been awarded to butchery staff for work induced RSI (Maunder, 1991). The incidence of RSI among workers in the butchery industry is worse than for the average manual worker. In some cases, the introduction of dedicated equipment exacerbates the RSI situation and increases worker stress. Operatives overseeing machines have to concentrate for long periods and then react rapidly to correct machine errors. The monotonous demand and output of machines force the human to keep up, inducing high stress levels (Jørgensen, 1989).
- Automation can result in improvement in food hygiene. The human operative is a factor in product contamination. The costs of preserving hygiene with the large numbers of staff present in a normal meat plant increase the overall production cost.
- It is accepted that temperatures in the range 0-5°C are preferred for improved cutting characteristics (Vickery et al, 1983) and inhibiting microbial growth. According to the UK Factories Act (1961), the minimum legal continuous working temperature for a standing, active labourer is 10°C. EEC directive 95/23/CE states that during cutting meat temperatures should not exceed 7°C and the processing rooms should be at a maximum of 12°C. Automation and robotics can work closer to the optimum temperatures than can be legally achieved with human operatives.
- Robots can possess abilities not present in the human. Infra-red detection, increased strength, X-ray vision, huge memory, etc. Robots do not require work-breaks or holidays, and can operate multiple shifts. Machines can be designed to operate under conditions where humans do not perform effectively. This would allow processing in environments beneficial to quality, eg. sustained low temperatures, aseptic atmospheres, etc. This can result in an increase in the overall production rate and product quality.

Justification of robotics for manufacturing is a complex process, mainly dependant on the production rate and flexibility required in the process. High production rates favour dedicated machinery that is inflexible. High flexibility can be achieved with human staff but lower throughputs and greater processing variance must be tolerated. Robotic manufacturing is suited to medium production rates.

In general, robotic technologies have advantages when compared to dedicated machinery.

• A robot is significantly more flexible and can be used on alternative specification products with no changeover time.

• The capital cost of a robot system is generally less than a purpose designed, few off, dedicated machine.

However, robots do have some limiting factors.

• Robots have a limited decision making ability. The human is excellent at evaluating situations and acting accordingly. The dedicated machine has a predestined function and correction of only the limited possible errors can often be incorporated into the design.

• Robots have a limited motion. Humans are exceptionally mobile and agile. Dedicated machinery can be built to suit the task. Standard robots are limited to a relatively small working envelope and generally to single armed operation. This poses constraints on positioning of other machines with which the robot must interact and requires suitable fixturing arrangements.

The limitations of dedicated machinery and human operatives make an ideal niche for introducing the flexible processing nature of robotics into the meat sector. However, there are still significant problems to be solved.

PROBLEMS

Almost 15 years ago, it was stated that 'Robots have not found their way into the meat industry because of the "wash-down" environment, cost, and the difficulty in applying existing technology to a highly variable object' (Horton and Grimson, 1985). Since then, research work has grown and robotic automation is beginning to be used for primary processing in the meat and food industry. The biggest problem is still that of coping with the natural variation in the product, but many systems are now in development or production. Each system tends to be specifically researched and developed for a particular task. Technology is still a long way from the general robot system capable of replacing people in most food operative situations as envisaged by Khodabandehloo and Clarke (1993).

The natural biological variation of meat is at the root of the problem. Variable products require variable production strategies and thus flexible processing methods. This has implications for sensing systems and system elements in contact with the meat such as fixtures, grippers and cutting tools. Many meat products are relatively delicate and often damaged by inappropriate handling. These factors tend to exclude many standard robots and robotic sub-systems from tasks within the food industry.

'OFF-THE-SHELF' ROBOTS IN THE MEAT INDUSTRY

Robotics in manufacturing industry operate in a structured environment. These standard machines are also capable of structured tasks within the meat sector with only small modifications.

Near standard industrial machines have been used in meat packing applications for many years. Whatever is handled by 'off-the-shelf' standard robots tends to be uniform in size, shape and behaviour when gripped. This is also true of the majority of robotic tasks outside the food industry, thus it is reasonably foreseeable that these applications were among the first to be robotised in the meat sector.

Handling of heavy boxes and palletising in cold storage areas is a good example of using robots to remove humans from arduous tasks in unpleasant environments. People suffer from the continual lifting of heavy boxes in sub-zero temperatures. The robots used are relatively large cylindrical or cartesian machines performing the same lifting stacking task as would be seen in any other industry. The function and control of the robot is unchanged in that respect. However, the body of the machine has been modified to be of a stainless steel construction with sealed bellows covering all joints and the lubrication system has been modified to allow the use of food grade lubricants. (Anon, 1983; Anon, 1987).

Two more recent but very similar standard robots used in the meat industry are the 'washdown' versions of the GM Fanuc A510 and the Adept One robots. Both have a SCARA configuration with additional sealing bellows around the joints. They are used for packing reasonably regular products such as beef patties and direct handling of packaged products. These applications of basically standard machines are more advanced than palletising as food products have to be grasped from a conveyor. (Wallin, 1993)

A more sophisticated use of standard robots in the meat sector is the application of Bosch SCARA robots at the Waltner Fleischwarenfabrik meat manufacturing plant in Germany (Food Trade Review, 1997). Machine vision is used to recognise pork meat sections on a conveyor and one of 8 robots then grasps the pieces and places them correctly spaced onto an outfeed conveyor. A key requirement in this system was the need for precise synchronisation of robot and belt speeds. The most notable development in the application is the gripper technology to handle the flexible pork meat sections of varying size and shape. The grippers are apparently similar to gripper boxes as used on slicing machines to hold the free end of the log; a series of small spikes dig into the surface of the component thereby grasping it. This method of gripping is only suitable for products where some surface damage is acceptable, or meat that will be further processed.

Another "off the shelf" robot system available in the food industry is that developed by Industrial Research Ltd in New Zealand. Initially developed for the Y cutting aspect of the automated sheep fleece removal system this machine has gone on to be developed into a stand-alone product available to other robotic system integrators for the food industry. The configuration of the robot is suited to the Y cut application but modularity has been included in the design and several configuration options are available. The working envelope is similar to that of a cylindrical robot but turned to be horizontal rather than vertical.

Other standard automated system components are available. An increasing number of robot makers such as Staubli and Kawasaki now include IP65 rated machines in their ranges. Food grade grippers and end effectors are made by many manufacturers. Generic research on grippers is underway in Italy and USA (Rizzi, 1998; Georgia Tech, 1998). The latter is developing a multi use gripper integrated with machine vision to form a complete handling system. This is recreation of the basic abilities of a human, to see an object and then be able to grasp it appropriately.

GENERAL PURPOSE ROBOTIC SYSTEMS

Some robotic systems are equally applicable in a number of meat industries. Typically these are for products after they have been separated from the main skeletal structure and hence they exhibit very similar physical properties along with a relatively high value. The challenge for automation is in materials handling and maintaining yield with minimum wastage.

Among the types of machine that achieve this are vision guided water jet cutting systems such as those produced by Frigioscandia, Lumetec and Elrad. These systems take either a 2D or 3D image of the meat section and then portion it according to required shapes stored in the supervisory computer control of the system. Water jets make an ideal cutting tool for these profiling cuts as they are light weight, high power and can cut acute angles with little yield loss. Such cuts are made on chicken fish, beef steaks and to a certain extent for trimming fat from planar meat cuts. However, relatively high throughput rates are generally required to justify these expensive systems.

Sorting systems using machine vision and/or check weighers to group products is another task common to a number of meat industries. Several manufacturers make sorting and grading systems. The principle is identical in each. The position and shape or mass of each product item moving along a conveyor is determined. Computer algorithms are then used to select particular items based on the sensed information. Items are selected into groups of similar attributes by pushing or pulling the meat section from the conveyor.

Some systems in development go further, with a robot grasping the product and feeding it directly to the next process. Examples are:

- sorting and orientation of chicken pieces into packages of minimum overweight. (Khodabandehloo 1990).
- taking fish from a moving conveyor and feeding them to a deheading machine (Buckingham and Davey, 1995)

SENSING

Another aspect of proprietary equipment for robotisation in the meat industry are sensor systems. These need to resist the same environment as do the mechanical motion devices. Among the most common of these sensors is machine vision although other sensing devices are used to detect product and process variation. Many machine vision manufacturers have equipment that is suitable and used within the food sector. Image capture devices can be placed remotely from the operating site and thus removed from the rigorous cleansing regimes that have to be endured by equipment in close and direct contact with the meats. Vision is also very applicable to the complex data extraction required to enable processing of meat products intelligently. The subject of sensing with machine vision is a vast field and will not be considered further here.

ROBOTS IN THE MEAT INDUSTRY

As mentioned earlier there are few standard pieces of equipment in use in robotisation of the meat industry. The majority of systems both under production, in development or being researched adopt the use of specialised configuration manipulators and purpose built grippers and sensor systems to process the variable product. The following section describes robotic devices for use within the various meat sectors of pork, beef, lamb, fish and poultry covering the range of processes from when the live animal first arrives at the meat plant to packing (see Figure 2). Packing operations are already highly automated and a previous section of this document has described the use of robotics in this area.

	Pre-stun	Stunning to Standard Carcass	Cutting and Boning Room	Sorting and Packing
Beef		Automated splitting		Highly automated, some robotic devices
Pork	Automatic lairage	Most aspects automated, many robotic devices	Some robotic devices	Highly automated, some robotic devices
Lamb		Some mechanisation, Few robotic systems	Some automated equipment	Highly automated, some robotic devices
Poultry		Highly automated	Highly automated	Highly automated, some robotic devices
Fish		Some automation	Robotic systems emerging	Highly automated, some robotic devices
All meat types			Water jet portioning	Sorters and Graders

Figure 2. Robotic Equipment Summary Table

ROBOTS IN BEEF PROCESSING

Beef production is the least automated of the large carcass types. The first area where robotic equipment exists is that for splitting of a complete carcass into carcass sides. The equipment for this is produced by a number of manufacturers. Whilst this equipment removes the arduous manual process, many users of the equipment are still dissatisfied with its performance in terms of accuracy of splitting down the centre of the spinal column and the hygiene aspects associated with deposition of bone dust and other detritus on edible surfaces of the carcass.

An ambitious beef sectioning system is proposed by the Texas beef group in a patent issued in 1993 (O'Brien and Malloy, 1993). A chilled eviscerated carcass is mounted horizontally on an automatic guided vehicle and appraised using x-rays, 3 D machine vision and ultra sonic sensing. The results of the inspection are used to generate cutting paths to enable the carcass to be cut into optimal primal sections. A robot is used to effect this separation with high pressure water, abrasive and air jets. Flesh is cut with the water jet while the air jets keep the severed meat clear of the cutting area. The abrasive jet is invoked when cuts are to be made through bone. This is a particularly high-tech proposal in a patent and it is not known whether the ideas are being put into a commercial system.

Research into automation of beef boning has taken place in Australia (Clarke et al, 1988) and UK (Purnell et al, 1990, 1993). Both systems utilise force feed back systems to guide a reciprocating blades cutter along the surface of the bone. The UK system, developed at the University of Bristol, also involved machine vision and the play-back of experience to improve the cutting process. Although laboratory trials suggested the success of these techniques, cutting speeds were too low to be economic and no meat industry equipment was constructed.

ROBOTS IN PORK PROCESSING

Pork carcasses are the most uniform large carcass, and this, combined with the large amount of pork meat eaten world-wide has resulted in this industry being more automated than beef. The majority of equipment manufacturers are located in Europe, primarily from Denmark, Germany and Holland. Collaboration between research centres and machine manufacturers in these areas have resulted in some highly automated pork production lines using robotic technology.

An automated lairage system has been developed at DMRI and now is produced by SFK in Denmark. The walls of the automated lairage slowly move towards the stunner shepherding the pigs gently and without stress towards the killing area.

Automatic electric stunning is available from several manufacturers utilising either a V-belt or breast support conveyor to take the weight of a walking pig and convey them to the stunning zone. Automatic electric stunning is common although there are automated stunner systems using CO_2. An automated sticking device has been developed in Holland that locates the breast bone in the animal and locates the sticking knife accordingly. Stunners that use breast support rather than V-belts do not cause the legs to cross and automatic gambreling is possible (Paardekooper et al, 1994). Such machinery is currently in development in Holland. Dehairing and flaying processes do not require robotic automation as current mechanised systems are effective. After dehairing, the belly of the carcass is opened prior to evisceration. Automeat of Holland produce an automatic carcass opener. A pair of shearing blades similar to scissors enter the carcass at the sticking wound and slice through the sternum opening the carcass to between the hind legs. This piece of equipment is synchronised to the line and uses restraint rollers to hold the carcass against the cutting mechanism. After carcass opening and before evisceration the leaf lard may be pulled by robotic automation.

Back finning is sometimes carried out before splitting. This process reduces damage to the eye-muscle during the splitting operation by separating it from the dorsal spine 'fins' before splitting the carcass. A robotic device using a relatively complex arrangement of rotary knives, plain blades and active rollers has been developed in Denmark for this task in the Danish pork industry.

Carcass splitting and opening has given rise to a large number of automated systems. Systems are available from suppliers such as Stork, SFK, Danfotech, Durand, Automeat and from Best & Donovan in the United States. The splitting operation follows evisceration. First the rectum is loosened by an annular knife guided by a central spigot locating in the rectum and cuts out the entire anus without contamination to the outside of the meat. The tool can be manually or automatically deployed. Spine splitting cutter blades then run from this incision along the centre of the spine to the head. Various methods for guiding these cutters are used, the most common being shaped rollers locally locating the vertebrae to the correct position relative to the cutters.

Although most producers claim an increased accuracy of automatic carcass opening and splitting the experience of some users is that there is still deviation from the precise centre line of the carcass. This can cause problems for carcass inspection and subsequent automated systems using the spine as a reference or datum position.

Automated cutting systems for pork exist that separate a half carcass into fore, middle and hind sections. The process was developed in conjunction with DMRI and the equipment is produced by Attec in Denmark and Itec in Germany (Folkman, 1995). Carcasses hanging on a standard gambrel are pulled across a conveyer belt and the hind feet cut off. This releases them from the gambrel onto the conveyor. At a second station each carcass side is moved against datum surfaces and the length between the pubic bone and the fore leg is measured. This measurement is used to position circular saws further down the line to anatomically derived cut positions for that carcass side.

European funded projects have looked at improving pork primal cutting using more standard industrial robotic techniques. This work encompasses the fore and hind cuts as well as the longitudinal loin-belly cut (BE4420, 1992). It is this type of cut separating high and low value meat that is critical for overall plant profit. The potential consistency of robotics is of high value to the producer. This work is continuing with the construction of an industrial demonstrator system

Fully automatic systems for collecting and grading information and carcass stamping have been developed in Denmark and in Holland. Since 1989 all Danish export pork carcasses have been classified with the fully automatic Pig Carcass Classification Centre developed at the DMRI. Work on pork evisceration by robot has been carried out in the mid-80's under a European Union funded programme (BE1452, 1991). This work has been continued by the DMRI and industrial companies working towards an automated pork evisceration production system.

Although originally there were several research groups working on separate fully automatic pork lines, the research and development in Europe is now becoming complementary with some groups each focusing on different aspects of the pork line rather than directly competing. A project assisting this is the EU funded Meat Automation Concerted Action (MACA) that stimulates discussions between users, equipment makers and researchers to further enhance rapid and effective development of the European meat and meat processing equipment industries.

ROBOTICS FOR LAMB PROCESSING

The majority of the work on sheep and lamb automation is taking place in Australia and New Zealand. In particular the Meat Industry Research Institute of New Zealand (MIRINZ) are active in the area of automation for the lamb industry. An advantage when dealing with lamb carcasses is that the carcass structure is relatively flexible and can be used to conform to the shape of the processing equipment rather than having to adapt the path or the equipment to suit the carcass shape as is required in pork and beef processing. Although much work has been done, no fully automatic robotic devices for any aspect of the lamb industry have been found. However, several systems combining the individual strengths of both man and machine have been devised. Most notably an inverted dressing system that takes the sheep from stunning through pelt removal to an intact carcass has been developed. This process involves both people and machines working together, the humans make crucial preparatory cuts and then feeding machines to do the arduous work. The advantage of mechanisation is that the carcass hang configuration can be varied throughout the line to ease individual operations for the humans. This leads to an improved product line in terms of efficiency and hygiene. The full line is anticipated to reduce staffing levels by over 40% (Longdill and Loeffen, 1991). The structure of the process presents the distinct tasks to be robotised at a later date if economic.

MIRINZ have also done work for lamb boning that utilises x-rays to determine bone position before subsequent cutting by machine.

ROBOTICS IN THE POULTRY INDUSTRY

High speed dedicated automation for the processing of poultry has been available for many years. This type of equipment assumes that each bird is of a constant size and shape and processes it as such. Poultry is perhaps the most uniform of the major carcass types and this is not an erroneous assumption. However, in recent years researchers in the UK and USA have been attempting to improve poultry cut up processes further by the use of sensor driven robotic techniques. These systems are still in the R&D stages and are not near the market as yet. The anticipated benefits of this is the more precise separation of body parts at the joints and an improvement in the hygiene of the operation as it is anticipated that much meat could be trimmed from the carcass without the need to eviscerate. Studies at the University of Arkansas continue into robotic chicken dissection. Earlier research work in the UK (Khodabandehloo et al, 1990) has looked into the appraisal and grasping of individual chicken portions coming down a conveyor line. Each piece is oriented correctly and placed in one of a number of trays so as to minimise overweight on each pack. Although this has been demonstrated at a laboratory scale the work has not proceeded further.

ROBOTICS IN FISH AND SEAFOOD INDUSTRY

Research and developments in the area of automatic fish processing equipment are beginning now to emerge. Marel of Iceland produce intelligent portioning machines with vision control for fixed weight slicing of fish sections. The system takes a 3 dimensional representation of the fish and adjusts the cut position to give constant weight portions. Up to 5 portioning cuts per second can be achieved.

A European Union funded project 'Robofish' involving robotic handling of the slippery and flexible fish to feed them into a deheading machine (Buckingham and Davey, 1995). Accurate deheading is important to maximise yield. A special purpose robot was constructed by Oxim, a British Company that utilises a continually rotating motion rather than the normal back and forth action used in other robotic machine loading applications.

Development of integrated grippers with tactile and visual feedback specifically for the fish industry is under way in Canada. It is aimed that this work will connect the appropriate sensors to cutting devices such as water jets and artificial intelligence to replicate the yields that can be achieved by skilled manual fish cutting methods.

CONCLUSIONS

Robots have been performing simple tasks such as palletising in the meat sector for over 15 years. In the last decade robotic technology has advanced to a stage where automatic performance of skilled meat processing tasks can now be countenanced. Much research and development has been carried out around the world and is on-going. The fruits of these efforts are beginning to manifest themselves as technically and economically feasible commercial systems. The pork industry is the most advanced with fully automated processing possible within 5 years.

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