Robotic and Automation in Meat Processing

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Abstract— The food sector generally has been slow to capitalize on the opportunities, particularly in the primary production operations before packing. Compared with other food industries the meat sector has been slow to jump on automation. In 2015 food engineers state of food manufacturing survey automation was identified as biggest trend affecting operations. It describes potential benefits and challenges, and robotic and automation equipment available and in development for beef, pork and lamb processing.

I. INTRODUCTION

In meat industry major works are performed manually than Robotics and automation. Butchery tasks are prime targets for the benefits of robotisation. They are unpleasant, physically arduous and cause high risk of work injury. But when combined with the biological variation of the raw material, poses substantial challenges. So replacing a skilled slaughter man or butcher is difficult. The tasks like putting lamb chops into packs, laying up sliced beef, handling ‘bundles’ of wafer ham, etc., is difficult by humans to handle. Though the technical aspects of these problems were analyzed by research projects, only commercially viable systems emerged. The ultimate aim of robotics and automation in meat industry is increased profitability. The use of robotics and automation in meat processing industry replacing human operatives has many potential benefits such as tangible, intangible, social or economic.

Drives for automation in meat production:
- Production quality
- Product consistency
- Worker safety
- Food safety
- Legislation
- Difficulties in recruiting staff

Production quality: The meat cuts just above the initial freezing point in range of 2-5°C. When temperature decreases, the cutting quality improves. Automation and robotics can be used for improve cutting quality and production rates.

Product consistency: In automated systems, irrespective of boredom, stress and tiredness perform task more consistently than humans. ‘Getting things right’ reduces waste and increases overall yield.

Worker safety: The meat processing industry has a poor safety for workers when compared to other manufacturing industry. In 2005–2008, the meat processing industry has mean annual injury of 1313 per 100,000 employees, which includes both experienced and trained staff.

Food safety: It includes risk of transfer of contaminating microorganisms from operators to food, so to reduce this risk human labour is replaced by machine. Removing staff from the production process can improve the microbial condition of processed meat.

Difficulties in recruiting staff: In meat industry, there is shortage of skilled labor. Because the work is repetitive, physically intensive and takes place in an unpleasant environment. So the employers find difficulties in recruiting and retaining.

Current status of meat processing Automation: The basic operations for conversion of animals to meat differ. For eg. In cattle & sheep-remove the entire skin, pigs-de-haired, pork & beef-carcasses are split. So all species have different cutting patterns to produce different meat products. Pork meat production is most widely automated. The majority of slaughter processing operation is currently performed manually with simple tooling. Hence, automation & robotics has much to offer meat processing industries.
II. MATERIALS AND METHODS

Automation of carcass production processes before primary chilling

- **Lairage**
- **Shining, sticking, killing**
- **Shackling**
- **Deharing, dehiding, defleecing**
- **Evisceration and dressing**
- **Splitting**

Automated Inspection and Grading

The transformation of the live animals to carcass is done in a very similar sequence in every slaughter house. During this process the unwanted parts are removed and then chilled to reduce spoilage. The meat is subdivided into 'primal' which are then processed to get retail joints and portions.

**Lair Age:**

Animals rest in the lair age after arrival. This allows them to recover from the stresses of transport and acts as a pre-slaughter process buffer. It is important to maintain low stress level since at stress, hormones are released into the blood stream that speed the breakdown of glycogen stored in the liver and muscles, creating by-products of lactic acid and water in the meat carcass. These can contribute to undesirable effects on the final quality of meat such as pale, soft, exudative (PSE) meat and dark, firm, dry (DFD) meat.

An automated pig lairage where the movements are performed gently and without human presence was developed. This equipment uses automated walls to gently herd pigs towards the slaughter raceway.

**Stunning, Sticking And Killing:**

The slaughter raceway leads animals from the lairage to the slaughter area. The activities of slaughter process are influenced by cultural, animal husbandry and occupational health and safety considerations. Errors have far reaching effects on animal welfare, meat quality and all downstream processes.

Two methods of killing are commonly in use: stun-and-bleed, or gas kill.

Stunning is carried out with an electrical shock across the head, or concussive pistol head blow, to halt brain function, and then a cut is made to the artery in the neck (sticking) to drain the blood. There are automated systems to convey animals to the stun station, most consisting of V-shaped conveyors to carry the animal to the stun operator. The current and voltage of the stunning shock is controlled, and varies for different animal sizes and species.

An alternative to stun-and-bleed is gas killing, whereby animals are immersed in a CO₂ environment that renders the animal unconscious before bleeding. This automated method is gaining popularity, particularly in pork production. The automated CO₂ stunning units operate like enclosed Ferris wheels, with multiple compartments rotating cyclically. Small batches of around six pigs are herded into each compartment. The compartment then descends into a deep well area filled with CO₂, emerging on the opposite side to pig entry where the compartment tilts, and the animals slide down a chute to the shackling line below. Residence time is typically around three minutes in 82% CO₂. Whilst gas stunning can produce higher quality meat, there are some concerns for animal welfare.

Beef stunning and sticking processes are ergonomically difficult to perform manually because of the size of the animal. Two bails captured the neck and applied an electrical current to stun the animal. The electrical pathway was then altered to effect a spinal inactivation. A pneumatically powered knife with oscillating blades was used to enter the thoracic cavity and sever the aorta.

**Shackling**

Once stunned, animals are manually shackled, usually with a chain loop around one hind leg, and hoisted to hang head down. A human operative then makes the 'sticking' cut to the artery in the throat to drain the blood. These shackling and cutting operations are complex and difficult to automate due to the complexity of the operations, the unstructured environment, the implications on downstream processes if performed incorrectly, and the need to maintain animal welfare if stunning fails.
Removal Of Hair Or Hide

Pork carcass production differs from beef and sheep carcass production in that typically hairs are removed from the skin, whereas beef and sheep plants remove the entire hide/fleece from the carcass. The removed hide has value as a base product for the leather industry. Whilst it is usual to remove only the hairs from pork and leave the skin on the carcass, some pork plants also perform de-hiding for pig leather, although this is not a common practice.

De-Hairing Pork

Once drained of blood, pork carcasses pass through a sequence of mechanized operations, typically consisting of first a hot water or steam scald to loosen hairs, and then through a de-hairing machine where rotating metal-tipped rubber fingers scrape and brush most of the hairs from the carcass surface. This is followed by a singeing operation, whereby the carcass passes through gas flames to burn off remaining fine hairs. Finally, carcasses pass through a second ‘polishing’ station, where burnt hair stubs are removed by rotating rubber flail fingers.

Fingers on flexible rubber mounts, gas flames and water jets can all act on the carcass without detailed knowledge of surface position. This approach allows simple mechanization to be used for these tasks.

De-Hiding Beef

The first task of beef de-hiding is to cut the hide along the belly from the crotch to the neck. This is a demanding task requiring a consistent cut typically 2 m or more in length, along the centre line of the carcass severing only the skin. The profile of the belly is detected with an infrared laser distance sensor, and this information is processed to form a smooth trajectory for the cutting tool. The purpose-designed tool consists of a guidance spike mounted tangentially to a rotating circular knife. The spike protects the underlying meat from cutting damage and serves as an anvil to improve the cutting efficiency. The tool is moved by robot to place the spike between the skin and meat and then follow the previously determined path to sever the hide along the belly.

Before this hide opening cut is made on feedlot cattle, there are often large deposits on the skin that must be removed. After the skin-opening cut is made, the hide is removed or ‘pulled’. Mechanical pulling arms supply the majority of the effort, but a human butcher is required to make specific preparatory cuts, attach the pulling mechanism and make assisting cuts during the pulling operation.

Evisceration And Dressing

Once the hairs or fleece/hide have been removed, all carcasses are eviscerated, whereby the internal organs are removed. The viscera generally separate into edible (heart, liver, kidneys, etc.) and inedible (intestines and bowel). There are substantial hygiene implications of error when removing the inedible organs as the contents contain feces and pathogenic organisms that can contaminate the carcass meat if spilt.

Although all processes follow the general sequence of rectum loosening, belly opening, and viscera removal, there are substantial detail differences for example, trimming, washing, additional cutting, other organ removal, other processing, etc., between species and plants.

Pork Evisceration

The equipment makes a few simple anatomical measurements that guide the process. These gross measurements allow for coarse positioning of the evisceration automation, and conformation of the flexible carcass or adaptive tooling is also used to reduce complexity and hence increase reliability of a relatively complex operation. A prepared carcass is automatically clamped open and an arm moves the viscera to expose the sternum, where a second set of arms loosens the leaf lard and severs the attachment of the diaphragm to the chest cavity wall.
A back cutter is then moved into the carcass to penetrate the diaphragm adjacent to the spine and sever the connective tissue between the organs and spine in the hind section of the carcass. A tenderloin tool then moves in opposition to the leaf fat arms to separate organs from the thoracic cavity. Activating these automation motions concurrently resolves forces in the system and removes the need for forceful carcass clamping and fixturing. The released organs are then pulled forward out of the carcass with a horizontal movement of the tenderloin tool, the clamps are released and the carcass is moved out of the supports. The automated system ensures tools are washed before the next carcass arrives. This automated evisceration system performs all these operations in 10 s giving a line speed of 360 carcasses per hour. Microbial analysis has shown that carcasses automatically eviscerated possess fewer pathogens (E. coli) and aerobes than conventionally eviscerated carcasses.

**Beef evisceration**

Once the cattle hide has been detached, the abdominal cavity is opened and the organs removed. Part of the opening process involves sawing the sternum bone to gain full access to the chest cavity.

Using the same robot and guidance system as the hide opening system, a reciprocating bone saw similar to, but more powerful than, a manually manipulated brisket saw, is moved down the centerline of the sternum. The automation was unable to cope with straightening the carcass and completing the cut in the 9 s cycle time available.

This mechanized approach relied heavily on compliance of the carcass and organs to a fixed trajectory.

**SPLITTING**

Pork and beef carcasses are generally split into right and left sides to ease handling and increase rates of chilling. Lamb and sheep carcasses are typically left unplugged.

Automatic carcass splitting equipment has been available for many years. These machines have a range of cutting actions and complexities. The basic systems use a simple downwards motion of a circular saw through the space where the carcass should be. A ‘Back fining’ is sometimes carried out as part of splitting for pork carcasses. This process reduces damage to the eye-muscle during the splitting operation by separating it from the dorsal spine ‘fins’ before splitting the carcass.

Automation for beef splitting was among the first examples of mechanization in the slaughterhouse, and many equipment manufacturers now include beef splitting machines in their product range. 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.

The equipment had vertebrae sensing system based on ultrasound and this experienced difficulties on some carcasses due to voids caused by the hide puller disrupting the consistent passage of the ultrasonic wave necessary for ultrasound sensing.

There is 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.

**III. AUTOMATED INSPECTION AND GRADING**

Farmers and animal growers are typically paid based on weight and conformation (muscularity) of carcasses. Impartial, accurate and reliable automated grading automation has been the subject of much development activity for all species.

Automated carcass weighing systems are common on most slaughter lines.
Automatic grading and classification systems typically compare image(s) of each carcass against standard reference carcass images for the various grades. This is impartial and removes variation due to individual graders. The captured image can be stored and used for traceability, production management or process quality audit. The laboratory development systems show the potential for rapid, economic, hygienic, consistent and objective assessment systems, there are still limitations in the industrial environment.

**Automated Chill Rooms**

Certain wavelengths of visible light can reduce shelf life and encourage rancidity of stored chilled meat. Automation to move carcasses in darkened chill rooms could improve product quality through reducing a contamination route from the human operative to the meat and reducing the spoilage organism growth rate.

**Automation of carcass separation processes after primary chilling:**

- **Primal Cutting**
- **Pork Primalisation**
- **Boning**
- **Slicing and Portioning**
- **Trimming**

All slaughterhouses undergo sequence of operations to transform the live animal into meat for consumption. After slaughter, inedible parts (skin, hair, intestines, etc.) are removed to produce a carcass, which is chilled and subdivided into smaller sections called “primals”.

**Primal Cutting**

Automated and robotic systems play major importance in meat processing to produce primal. A simple automated cutting systems that separates half carcass into fore, middle and hind sections has been developed. The tenderloins, head and forefeet are manually removed. In the second stage each carcass side is moved towards a datum surface so that the length between the pubic bone and the foreleg can be measured. A second machine is used to separate the belly from the loin. In Sheep Primalisation, the lamb boning room was mainly of band saws and packaging machines. These drivers help to produce clean, square cuts and hygienic handling of primals.

**Boning**

This includes boning equipment for fore-ends and hind legs, and combined boning and trimming equipment for belly and loins. This technology has also been used to separate pork flank ribs from. This system has provided with a machine vision system which is used to assess the size and shape of the belly. Automated machine strips the meat from a beef rib set in 21 s. The technique made an initial 2D visual assessment of the beef joint, and sought to match that current meat section to a database of previous experience. If a match was found, the previous cut paths were replayed for the current meat section; if no match was found then force feedback from the boning blade was used to guide the robot along the bone and in doing so create another experience example to augment the database. However, these initial concepts would need to be extended substantially to produce a fully automated beef boning line for commercial use.

**Slicing And Portioning**

The development of slicers illustrates the importance of sensing for benefits of automation, particularly in slicing for multi-slice packs where control of individual slice weight is desired. Initially meat slicing was carried out by hand, as this was the only method possible, then mechanized fixed slice thickness machines with much higher throughput rates came to the fore. Further reductions in giveaway were gained with the first generation of automated slicing machines that changed thicknesses by scaling a slicing pattern from input meat section weight.
FIG. 13.4 (a) Cutting sub-system for beef foreleg deboning research equipment. (b) Beef foreleg deboning research system showing machine vision and lighting.

This gave advantages over fixed-increment mechanized slicing. However, because of the inherent variations in weight–length ratio of nearly all meat sections some giveaway losses were still apparent. The latest 3D scanning slicing machines make the next step with greater sensor data to improve performance further. A full 3D representation of input meat section is gained using a laser stripe or similar technique, which allows for better utilization and less giveaway.

However, the slice angle is often constant, limited by the mechanical arrangements of the equipment to maintain production rates.

**Trimming**

People are becoming increasingly health conscious and consequently there is a growing demand for lower fat products. In traditional manual trimming each individual operative makes the decision on how much fat to remove and then makes the cut using a standard butcher’s knife. This often results in straight cuts to trim fat from a curved surface and a high degree of variability between individual trimmers.

Many meat producers are too small to afford and benefit from this trimming technology. Additionally, there are specific problems with meat section geometry for some sections. Water-jet cutting is most commonly used on ‘planar’ food sections, such as beef steaks, pork chops, chicken breast fillets, pork bellies, etc., that are laid flat on the input feed conveyor and remain stable in this position through sensing and cutting. For some sections, such as lamb or pork chops, the narrow ‘tail’ of the chop can twist under its own weight to lie flat on the conveyor, thus preventing effective trimming.

Machine vision provided fat thickness profile along the length of each chop. The system then conformed the meat section to place the fat–lean interface at the desired fat thickness from a fixed cutting path.

**FIG. 13.5 Uniform fat trimming concept.**
After the cut is complete, the meat section is released and returns to its natural shape but with a uniform covering of fat over the fat–lean interface (Fig. 13.6).

IV. CONCLUSION

The development of automated meat processing systems has received substantial effort and investment, but uptake has been limited by technical and business issues. With improved technology and reducing production costs for automation, it has become increasingly possible to overcome these limitations. The potential advantages and rewards to the meat industry have resulted in a considerable number of process-specific applications and continue to drive R&D of more sophisticated systems. Despite the differing operations for beef, pork and sheep meat production, some general trends are common across a number of projects.

Some automation systems have been successful because they perform tasks currently not possible for a human operative. A human butcher could not perform the multi-armed cutting and handling operations achieved by evisceration automation. Even the strongest, most skilled butcher cannot match the consistency and high-force cut accuracy achieved with automated primal cutting. Automation of these types of tasks, unperformable by a human, is often the first to exhibit an acceptable cost–benefit ratio. Currently it is mostly uneconomic to replace a slaughterhouse operative with automation unless the automation yields additional benefits. Some successful projects have demonstrated an improvement over manual labor in terms of speed, consistency, accuracy and control.


