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Robotisation and intelligent systems in abattoirs

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ABSTRACT

Background: Meat has been an important protein source for human nu-trition for thousands of years and will continue to be. According to the Organisation for Economic Cooperation and Development and Food and Agriculture Organisation's (OECD-FAO)outlook report 2018–2027, the meat consumption increased around 20% in the last ten years, and it is expected to grow another 15% for the next ten years. The harsh working environment in abattoirs and meat factories, such as cold and wet operating rooms and long difficult handling of heavy loads, contributing to the shortage of a skilled labour forces. This, coupled with a considerable increase in the meat consumption, paved the way for novel approaches in the meat industry to ad-dress this challenge, with robotisation and automation of the meat factories being a necessary change.

Scope and approach: In this work, we review the current state of robotisa-tion for the meat industry and its adaptability to a new production concept called the meat factory cell (MFC).

The reviewed systems are: (a) Frontmatec AiRA Robots for pork slaugh-terlines (b) Mayekawa Hamdas-RX for deboning pork ham; (c) SCOTT Au- tomated Boning Room for lamb slaughterlines; (d) SRDViand (*Systemes Robotis'es de D'ecoupe de Viande*) Z-cut robotic system to do the separation of the hindquarter and the forequarter; (e) SRDViand ham deboning system; (f) SRDViand ECHORD-DEXDEB, a robotic butcher left hand; (g) SINTEF GRIBBOT, a chicken fillet harvesting robot.

Key findings and conclusions: The slaughterhouse processes can be highly automated, with products available at the market, while the meat processing plants are mainly manual; deboning and fine cuts require a higher level of dexterity comparing to primary slaughter cuts, this leads to more researches of intelligent systems. In the other hand, a new way to process the slaughter products can lead to innovation and smarter systems on slaughterhouses, with the benefits to open new opportunities for smaller producers.

1. Introduction

Meat is an important protein source in human nutrition, with strong growth in meat consumption over the last ten years and with an expected increase of 15% over the next ten years (OECD/FAO, 2018). In 2018, more than 341 million tons of meat were produced worldwide (Roser & Max, 2019). Low volume producers, e.g., Norway, face different challenges compared to higher volume producers, e.g., Denmark and USA. An automatised produc-tion line is suitable in a high throughput plant, while the high starting and running costs of a highly automated or robotized line prohibit smaller produc-ers from accessing such technology (Mason, 2018). A traditional automatised slaughter line can process more than 1000 pigs/hour, where productivity is approximately ten times higher than the average production in Norwegian slaughter lines (Alvseike & Mason, 2018).

1.1. Hazard environment

A key problem for the traditional slaughterhouse line is the hazardous environment for the worker. It can be a cold, wet, slippery, and noisy en-vironment. In combination with the prevalence of sharp tools (knives and saws) and high-speed repetitive operations, this leads to many injuries and illnesses. According to the *National Employment Law Project* (Berkowitz, 2018), in the USA, pork packing workers have 2.4 times more injuries and 17 times more illness than other industries. According to UK statistics, there are three times more injuries in slaughterhouses than the average worker (Hansen, 2018). Moreover, Europe spent 2.1% of GDP on social benefits related to work incapacity; in Norway, absenteeism can reach 20% in debon-ing rooms due to illness or injuries. The most common types of injury are musculoskeletal, e.g., sprain/strain, dislocation, laceration, and amputation (Mansi &

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Academy, 2019). The environment and associated injury risks have led to global labor shortages in meat production, with the industry therefore looking to technology for a solution (Choi et al., 2013; Alric et al., 2014; Long et al., 2013; S R. K and Polson, 2017; Rohrbein et al., 2014; Misimi et al., 2016).

The Organisation for Economic Cooperation and Development (OECD) has the job quality index, a schema for measuring and assessing job quality, regarding earnings, security, and work environment. Automation can be used in slaughterhouses to improve all three areas of the job quality schema. This is an ongoing ethical debate; on one side some argue that automation causes unemployment, through robots or machines replacing factory floor workers. However, there is a counterargument which considers a longer-term perspective, namely in regard of the time and effort required to achieve automation in the first place. Furthermore, in the interim and long-term period, the sector will see an increase in more specialized jobs with better working conditions, higher levels of skills or education, and higher salaries.

1.2. Traceability

Another improvement that robotisation can bring to the meat industry is the traceability of meat, that is the ability to trace meat throughout the value chain. Today, this is not a trivial task as it can be rather complex (Demartini et al., 2018).

Traceability in the agri-food sector helps to identify potential risk in food, isolate the problem and to inform the public about contamination threats correctly. Pork meat traceability for EU is regulated by the Council of the European Union. Directive 2008/71/EC states that a pork part needs to be traced to a group of animals, not an individual one. According to "Study on mandatory origin labeling for pig, poultry and sheep & goat meat" report (Baltussen et al., 2013), *"The national databases for pigs do not contain information on all individual movements. This makes it more difficult to achieve the provision of full information on the origin of pig meat …"*.

The automation of a slaughter line does not yield to more traceability by itself, as the first concept is to merely do substitute an operator that does a repetitive job. Nonetheless, automation brings a set of tools, e.g., cameras, RF-ID's, control systems, and monitoring that can be used to improve trace-ability in the plant. In this manner, automated systems can keep track of the parts and pieces of a carcass in a line. However, much better traceability can be achieved if, besides the automation, a cell-factory concept is applied to the slaughter house, as proposed at Alvseike et al. (2017).

1.3. Production concept

For more than a century line-based approaches to production have been fundamental parts of the slaughterhouse and meat processing plants. The approach is conceptually simple, whereby materials or products move along a linear path, and they are processed at a series of inline stations, where typically short tasks are executed. A common set of tasks executed in a traditional pork abattoir can be seen in Fig. 1.

To challenge this paradigm, a cell concept, known as the meat factory cell (MFC), has been proposed in Alvseike et al. (2017) and Alvseike et al. (2018); the authors claim the cell to be more hygienic, efficient, and environmentally friend approach. The idea behind MFC is to have a multitasking system where the carcass is entirely processed in the same location, instead of having a line with many specialized stations performing short and repetitive cutting operations.

Nowadays the development of new automation systems takes for granted the traditional approach as the accepted paradigm for processing meat. There-fore, most of the automation systems developed to date have assumed some role within such production lines. These systems are difficult to adapt to complex concepts like the MFC, if not impossible, as the required functions require a higher level of situational awareness and adaptation.

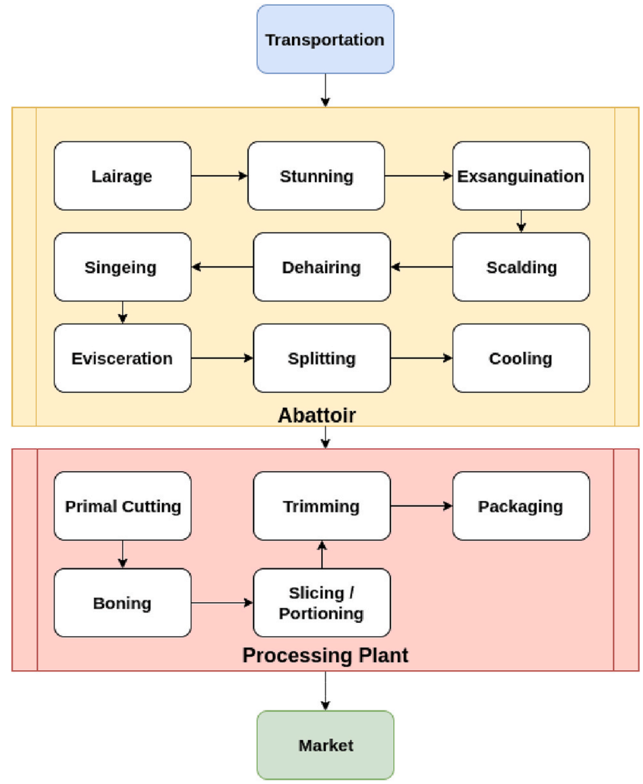

Fig. 1. Abattoir and meat processing plant tasks' diagram.

This work is organised into the following sections. Section 2 describes the abattoir environment, and makes a description of each phase of the plant as well as citing the current automation degree in each process. Section 3 gives an overview on how the systems were chosen and the evaluation points. Section 4 presents a review of the products and the research work on robotisation for the meat sector. Moreover, section 5 provides a summarized discussion on goals achieved by each system and section 6 conclude this work for the current robotisation degree.

2. The abattoir and automation

The meat transformation route starts with the transport of the live animal from the farm to the slaughterhouse, where the outcome is cooled halves carcasses that are, afterwards, transported to another facility for further processing, as cutting and deboning, and then packed to proceed to market. Fig. 1 gives a good overview of sub-processes inside the abattoir and post-processing of the meat.

Slaughterhouses' lines, primarily poultry and pork's are the most auto-mated sections of the referred process, considering intelligent and adaptable systems. Therefore, as a simplification factor to explain the current au-automation in the slaughterhouses, this paper will use Den-mark's pig slaughter industry as the reference model. The Danish Crown slaughterhouse [1] in Den-mark is a very export oriented and has one of the most advanced automated factories for meat processing in the world (Hinrichsen, 2010).

The slaughter process inside abattoirs condenses the moment the live animal arrives from transportation until cooling of the half carcass. Below, a brief description of the phases are presented.

1. **Transportation** is the delivery of livestock production from the farm to the abattoir. Probably the most straightforward process and the

[1] http://slaughterhouse.danishcrown.com/.

least prone to robotisation, not considering the development of autonomous trucks.

2. **Lairage**, after transportation, the pigs are put in lairage to rest. At Danish Crown, the pigs are laired for at least 1 h before slaugh-tering. According to Santé-Lhoutellier and Monin (2014) and Channon (2014) the time to minimize meat defects and stress due to transporta-tion is at least 2 h.
3. **Stunning** is the process to make the animal insensible to the killing.

The method has to be considered humane, i.e., making the animal unconscious and insensible to pain. There are several different methods, but the most commons are electric stunning, CO_2, and captive bolt. The stunning of pig and poultry are largely automated. CO_2 group stunning is used at Danish Crown slaughterhouses and is considered the most humane stunning method for pigs.

4. **Exsanguination** means to drain the blood of the animal, causing its death. An incision is made to the jugular vein, carotid vein and tra-chea, or by just above the heart. EU regulation 1099/2009 state that the bleeding should happens as quick as possible and the Farm Ani-mal Welfare Council and the human slaughter Association consider the maximum time between stunning and the bleeding should not exceed 15 s. The incision is a manual process, even though there is automated support machinery for the operator.
5. **Scalding** is used to aid the removal of hair, respectively in pork and poultry, by submerging the carcass into hot water or spraying steam to the carcass. It is mostly automated in most production lines. The ideal temperature should not allow cross-contamination, avoiding bacterial proliferation but should also not cook the skin, i.e., generally between 58 and 62 °C (°C) for pigs and 50–58 °C for poultry.
6. **Dehairing** is the removal of the hair of the pig during the slaughter process, while defeathering is a similar part on poultry by removing the feathers. A friction process usually does the dehairing and defeath-ering using a rotary rubber blade or similar. This phase is currently automated.
7. **Singeing** is done after dehairing, and the carcass passes through a flame torch where the skin is dry, remaining hair is burned and bacteria killed.
8. **Skinning** is the act of removing the skin of some animals like cattle and sheep. Some automation exists, but still dependent on a human operator.
9. **Evisceration** is the removal of all interior organs. This process is still not automated, some of the tasks can be done by machines like lifting the organs, but the main task of removing the organs is still performed by a human operator.
10. **Splitting** is done along the vertebral column and should be as precise as possible to avoid damaging meat or leaving many bone fragments. The robotic arm can precisely split the carcass.
11. **Cooling** is done as the final step of the abattoir. Before sending the halves carcasses to the further processing, i.e., primal cuts, slicing, and packaging, they must be cooled by 24–48 h.

From the automation perspective and considering the traditional pro-duction lines, the slaughter process can be largely automated, but it is still dependent of human operators on several tasks. Large companies, as Marel or Scott Automation, have a broad line of a robotic system for different parts of the slaughter processing.

These companies claim to use 3D reconstruction system to adapt the system to individual carcass characteristics, but they do not publish in-depth material as this information is sensitive to the companies.

3. Methodology

The aim of this review is to identify the current state-of-the-art regard-ing intelligent systems for meat processing, and its adaptability for different scenarios. This review has been undertaken as part of research and develop-ment by the authors and others concerned with developing intelligent cutting systems using a cell-like approach as previously noted. In particular, the in-tended outcomes of this research are to address:

1. Production efficiency and robustness;
2. Worker's health;
3. Labour market shortages;
4. Hygiene standards and contamination risks;
5. Flexibility to accommodate production variation;
6. Scalability to suit all production volumes.

This paper provides an overview of the current relevant automation inside meat processing plants, particularly abattoirs, and cites robotic systems for specific tasks. To be included in this review, technologies (commercially available or in the research domain) had to: (1) have a perception system with smart sensing capabilities and autonomous operation and; (2) be capable of adapting to each carcass based on some live or pre-information. With these requirements, the systems can be classified as an intelligent system. Throughout this work the terms automation, robotisation and intelligent systems are used interchangeably. Table 1 shows the reviewed projects' stage, sensing technology and throughput when informed.

The points above were further expanded to the list below as the specifi-cations that were used to select the systems to be reviewed.

1. It has to be automation machinery for the meat sector;
2. It has to have a perception system to interact with the environment;
3. It has to operate autonomously;
4. And it has to adapt the cutting to each carcass characteristics to yield production.

The present work excludes from this review, automated machines that makes blind or straight cutting, as there are publications that review those systems (Barbut, 2014; Clarke et al., 2014; Purnell, 1998) and they are hardly adaptable to a different production environment.

Each system is reviewed as follows:

Table 1
Commercial and research intelligent systems for the meat sector comparison.

Product	Stage	Throughput	Vision
Frontmatec AiRA Robots[e]	Commercial	450-750 carcasses/hr	3D Detection[a]
Hamdas-RX[f]	Commercial	170-500 legs/hr	X-ray
SCOTT Automated Boning Room[g]	Commercial	600 carcasses/hr [b]	X-ray and Laser
SRDViand - Beef Carcass Separation (Alric et al., 2014; Guire et al., 2010, pp. 1–7)	Research	N/A [c]	RGB-D [d]
SRDViand - Pork Leg Deboning (Alric et al., 2014; Subrin et al., 2011)	Research	N/A [c]	RGB-D [d]
ECHORD-DEXDEB (Alric et al., 2014; Rohrbein et al., 2014)	Research	N/A [c]	RGB-D [d]
GRIBBOT (Misimi et al., 2016)	Research	4.75 s/breast	RGB-D [d]

[a] Probably 3D laser scanners.
[b] Scott uses precise numbers in some systems and a generic statement in other like *"Boning room throughput and operational efficiencies can increase by approximately 4%."*
[c] Not Available - As a research project the information has not been provided.
[d] RGB-D - Combination of RGB image with depth image.
[e] www.frontmatec.com/en/pork-solutions/clean-line-chill-room/aira-robots.
[f] www.mayekawa.ca/mayekawaproduct/food/robotics/hamdas-rx/.
[g] www.scottautomation.com/products/automated-boning-room.

- *Overview*: describe the authors motivation and a general view of the system;
- *Process*: makes a further description of the aproach and steps used on the system;
- *Critical review*: conclusion of the research as presented by the authors and evaluation of maturity, flexibility and adaptability of the system.

4. Current robotisation in meat processing

Contradistinguishing the slaughter line, further processing of the meat, e.g., cutting and deboning, is still mostly a manual process, relying on human operation, making it a robust area for research on the intelligent system. The reason behind this is that deboning and specific cuts are much harder to accomplish robotically due to the needed dexterity and sense during the process.

The need to understand the current level of applied intelligent systems on the meat industry leads to this review of the state-of-the-art on robotisation and intelligent systems; Therefore it includes published research material as well as commercially available products, as explained in section 3.

4.1. Challenges

When it comes to the meat sector, several challenges arise when designing robotic systems. Carcasses are soft, non-rigid material that has moving parts and tender surfaces that modifies its form if force or pressure is applied. Bodies with these characteristics are referred as "deformable materials". In the meat this is due to tissues elasticity as well as the joints the joints, and it can be easily observed by anyone who cuts meat; when pressure is applied, the meat tends to bow, creating a curvature between the knife edge and the meat (Long et al., 2013).

When being processed the carcass moves and rotates in addition to joints twisting, all of which contributes to a changing centre of gravity – this makes the carcass hard to grasp, manipulate and cut. Summing into this complexity, there are variations from individual to individual. Fig. 2 show in the detail, a deformation on the form of the carcass part after a cut had been made.

Moreover, the material is heterogeneous and composed of muscles, fat, tendons, bones and skin. Each one with its viscosity, density and deformation that can interfere with the cutting.

If a robotic system does not account for these facts with sensors, the final result would not be achieved. The meat would sag and consequently not cut, a bone can be hit and damage the tool, the piece or carcass can be dropped, and so on (Jørgensen et al., 2019; Long et al., 2014).

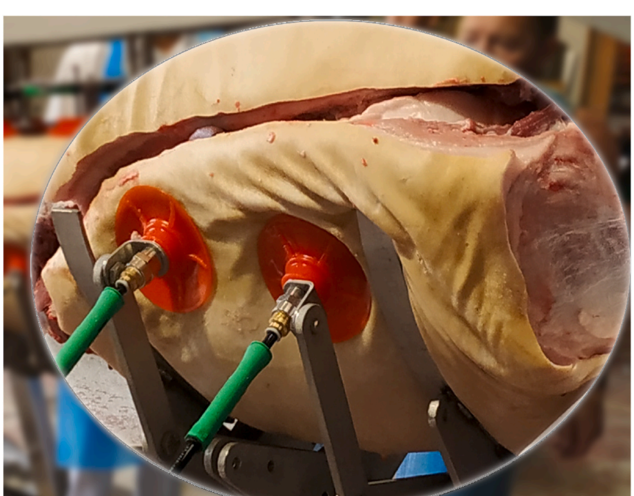

Fig. 2. Carcass as a soft deformable material detail.

4.2. Frontmatec AiRA robots

4.2.1. Overview

Frontmatec is one of the world leaders in automation when it comes to the meat industry. They have many automation system for slaughter and meat processing lines. Among them, the AiRA Robotics, a set of robotic system for the clean line of pork slaughterhouse.

According to their website,[2] AiRA is a complete program of dressing line robots. They are: the AiRA bung dropper, the AiRA Aitch Bone Cutter, the Aira Belly and Breast Opener, the AiRA Neck Clipper and the AiRA splitters. These system are reviewd together as they share some design con-cepts.

4.2.2. Process

The company states in their brochures that they use a "detec-tion unit (vision scanner)" to define the cutting trajectory and depth. Paying close attention to videos published by the company, it is noticeable the use of laser lines, leading to infer the use of a 3D laser scanning. The throughput of AiRA depends on the system and configuration deployed, ranging from 450 to 750 carcasses per hour.

AiRA RBD Bung Dropper identifies where the tail is and inserts a suction mechanism into the rectum to vacuum and dispose the bungs.

AiRA RHC Aitch Bone Cutter does a precise cutting to the aitch bone without damaging the intestines. It can be attached to the bung dropper or to the breast and belly opener to minimize the area used by the system at the plant.

AiRA RBO Breast and Belly Opener continues to cut from the aitch bone cutter opening the belly, breast and throat.

AiRA RNC Neck Clipper is capable of clipping the head just above the ears, without removing the entire piece.

AiRA Splitters splits the carcass into two part, by cutting along the spine. Frontmatec has different tools and configuration, it can use one robot and a saw (*AiRA RPS-S Splitter with Saw*), one robot and a knife (*AiRA RPS-H Splitter with Knives*) or two robotics arms for faster operation (*AiRA RPS-D Dual Arm Splitter with Saw*).

4.2.3. Critical review

Frontmatec has, to the extent of this work, the most advanced and robotized slaughter line for pork processing commercially avail-able. It uses advanced vision system to calculate the cutting trajectory, but it does not deal with complex cuts that demands dexterity of the robot.

It was designed for traditional slaughter lines with large throughput. As with most robotic system approved for food sector, it increases hygienic stan-dards as it washes the tools for every carcass and avoid human contamination. The systems can be somewhat flexible, but each of their system executes one or two specific tasks, elevating the costs to deploy the whole system and thus they are suitable for large producers.

4.3. Hamdas RX

4.3.1. Overview

According to Toyoshima et al., Hamdas-RX is a deboning robotic system for pork thigh capable of processing 500 thighs/hour. It removes the muscles from the femur and the tibia (shank bone) at the same rate and quality as a human. A pork thigh is a non-uniform soft object, i.e., deformable material as noted previously in 4.1.

4.3.2. Process

The system uses an X-ray image to calculate the trajectory of the cutting tool for the robot. Even with the X-ray data, there are differences between planned trajectory and the real trajectory. To overcome this problem, the team designed a knife capable of dealing with the

[2] https://www.frontmatec.com/en/pork-solutions/clean-line-chill-room/aira-robots.

challenge of a deformable material. By mimicking the human wrist flexibility, the knife is able to handle the thigh's variations and twisted structure that could have occurred in the previous process.

Hamdas uses an X-ray system to recognise the position of the bone struc-ture and to identify between the left and right thigh. The X-ray image gives the information to predict the trajectory path for the cutting system. The robotic arm with the cutting tool attached receives the trajectory data and performs the "slitting", which is cutting the muscle along the bone. Parallel plates then separate the meat by pulling down on the bone, and tearing the meat apart. The final cut is made by rotary blades to finally separate the meat, ligaments and tendons from the bone end (Toyoshima et al.,).

4.3.3. Critical review

Hamdas-RX is a single purpose system to debone pork back legs. It was designed and developed as part of a traditional slaughter line, so it is not trivial to adapt it to the MFC concept.

The output of this robotic system is the ham meat separated from the bone. The system is currently commercially available, but it depends on an ample space to be deployed. The machine dimensions are approximately 3.5 m (width), 12.5 m (length) and 3 m (height), not counting the doors.

The use of an X-ray system increases the costs to acquire, maintain and operate the robotic system. It is specialized machinery for pork ham debon-ing, more attractive to larger producers due to its size and costs.

4.4. SCOTT automated Boning Room for lambs

4.4.1. Overview

SCOTT Atomation[3] has a lamb automated system that is able to process the whole carcass of a lamb. The system has a similar concept to the Frontmatec, as seen at section 4.2; it uses an X-ray system and 3D laser reconstruction to identify the bone structure and dimensions of the lamb and has six machines for cutting and deboning at a rate of 12 carcasses per minute.

The first step is to X-ray the carcass, identify the bone structure and send process information for the other systems. The cutting start by primal sys-tems, then the three resulting parts are delivered to the forequarter, middle and hindquarter systems, and afterwards the knuckle tipper system.

4.4.2. Process

X-Ray Grading is considered the heart of the system, where the carcasses are X-rayed and 3D scanned. The internal structure is calculated and sent to others systems to make the cutting.

X-Ray Primal system cuts the carcesses in three parts, the forequarter, middle and hindquarter. It uses the 3D image from the X-ray to improve the cut and angle on every carcass. A robotic arm grasps the forequarter while two large rotary blades cuts at the defined postion. Then, another arm holds the middle while two parallel straight blade with adjustable angles make the cut, the arm deliver the part to the midde system while the hindquarter continues hanged on the line and proceed to the hindquarter system.

The Forequarter system uses a robotic arm to grasp the forequarter delivered by the primal system, it then, uses a laser scanner to create a 3D image and define the exact cutting points on the piece. And finally, uses a bandsaw to make the cuts.

The Middle system can identify and remove the spinal cord, split the loin from the rack, and remove flaps. This system can have different configura-tions depending on the desired cut, improves yielding in an average of 60 g per carcass.

Hindquarter System has the hardest cutting task, that needs a high dex-terity to accomplish the job. The robot separates the legs from the aitchbone, which is the bone that connects the femur (leg bone) to the back bone. The hindquarter is the posterior part of the animal, comprising both legs and part of the spinal chord including the 12th rib.

The hindquarter is delivered to the support structure that has two grip-pers, one for each leg. Then a robotic arm with the knife proceed to do the cuts following on each side of the hindquarter, separating the muscles and ligaments from the aitchbone, using a torque sensor in the knife to adapt the cutting trajectory. After the robotic arm, both grippers that are holding the legs move farther away from the hindquarter, pulling the legs apart from the center aitchbone.

Knuckle tipper system removes the knuckle tip from the legs automatically, improving yield in 9 g per carcass.

4.4.3. Critical review

The SCOTT Automated Boning Room for Lambs is a complete intelligent system designed as modular systems that can be deployed seamlessly or independently. It uses 3D laser scanners and X-ray to predict the best cutting path for the parts and it was designed to be integrated in a traditional slaughter line. From a robotic perspective and for this review, the most interesting system is the hindquarter system, it is conceptually very similar to Hamdas-RX, but it was designed for separating the legs from the hindquarter of a lamb while Hamdas-RX was designed to debone pork's ham. They are already available on the market, and both uses an X-ray system to identify the bones and calculate the trajectory of the cutting tool, and both have a custom designed knife attached to a robotic arms' TCP (Tool Center Point).

4.5. SRDViand project - beef carcass separation

4.5.1. Overview

ADIV (*Association pour le Developpement de l'Institut de la Viande*) and Universit'e Blaise Pascal worked on different solutions for cutting and handling meat, i.e., a beef carcass separation, a pork leg deboning process, a pork leg deboning cobot operation, and a multi-arm autonomous system for muscle separation (Alric et al., 2014; Guire et al., 2010, pp. 1–7).

The beef carcass separation is a robotic system capable of executing the Z shape cutting on a beef half-carcass, substituting a human operator. It was developed because of the identified problems the industry is facing like lack of skilled labour and elevated cases of accidents and illness factor (Guire et al., 2010, pp. 1–7).

4.5.2. Process

The robot has to cut from the 5th to the 13th rib, ten cen-timetres away from the spine and then, cut through the spinal column, as shown in Fig. 3. Separating the hindquarter and the forequarter of the beef carcass.

To identify the cutting trajectory, the system uses a 3D vision system with an accuracy of 1 mm. The system reconstructs the carcass, identifies the ribs, and uses force control to adapt the planned trajectory to the real trajectory using the bone as a guide for the knife.

4.5.3. Critical review

Guire et al. (2010) and Alric et al. (2014) claim the system is operational at the publication date. The vision system is capable of extracting the information necessary to identify the spine and to count the ribs. The system uses a robotic arm and vision system to perform the cut and it is a research product, that said, this platform can be used for other cuts and thus being adaptable to different production environments.

4.6. SRDViand project - pork leg deboning process

4.6.1. Overview

As part of the same framework as the Z-Cut carcass separa-tion, the researchers developed a ham deboning system, according to them, these are the main tasks the industry require robotisation.

[3] https://www.scottautomation.com/products/automated-boning-room/.

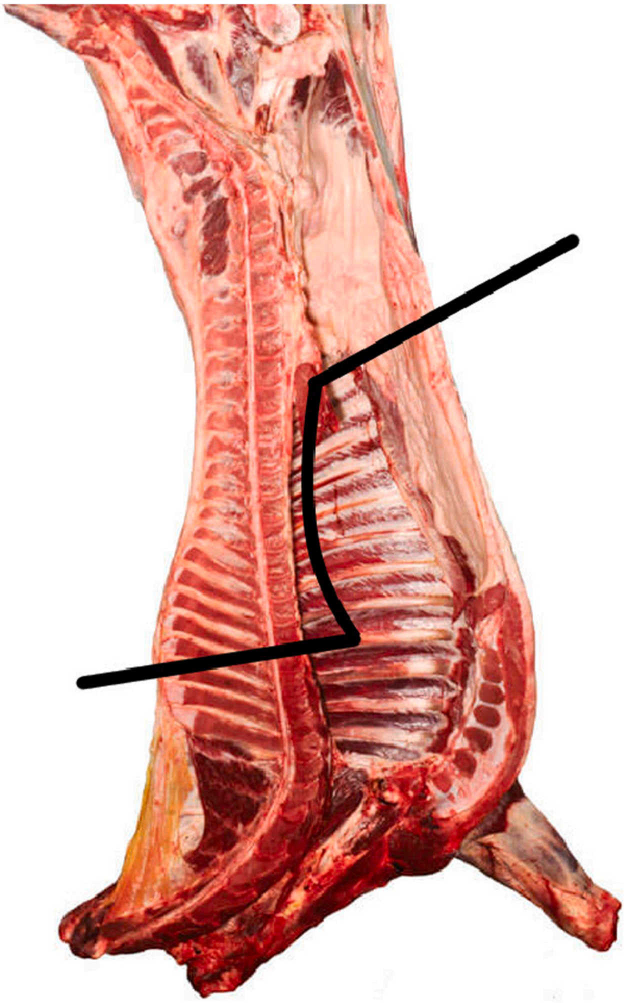

Fig. 3. Beef carcass Z-cut.

4.6.2. Process

According to Subrin et al. (2011), the first step was the ob-servation of the manual cutting done by an experient operator. They could identify that the operator marked the second fat vein and then followed the aponeurosis. Another observation was that the operator used the bone as a guide to the knife.

The observation phase concluded that the meat was deformable and het-erogeneous, and the joints could have moved, making the identification of the parts harder. During the cutting, the operator was always using the visual, tactile, and effort sensing to perform the operation.

The main objective of the study was to reduce the cutting forces and guarantee quality by avoiding bone chips and keeping the cut straight. Subrin et al. (2011) showed that if the cutting angle α is less than 30°, the cutting force is reduced by 30%. Thus to maintain the quality of the cut, is essential that the cutting angle α should be close to 30° or the normal speed V_n at knife speed V_f should be non-zero component vector combined with the V_f.

To accomplish the task of cutting through the pork's leg, following the bone trajectory as shown in Fig. 4 by the colors lines, the robotic arm is first programmed with a partially known trajectory, then force control helps the arm to adjust the trajectory according to the measured forces. The kinematics management uses a set of constraints to solve for a usable path (Subrin et al., 2011).

4.6.3. Critical review

The industrial results are promising as accounted by the authors, but further development should be carried to comply with in-dustries standards and required yielded production (Alric et al., 2014). One of the objectives of the researchers was to develop a system that was cheaper than Hamdas-RX 4.3, by using 3D images instead of X-ray and a more straightforward mechanical system. These same characteristics make the system more flexible and adaptable, but yet harder to develop.

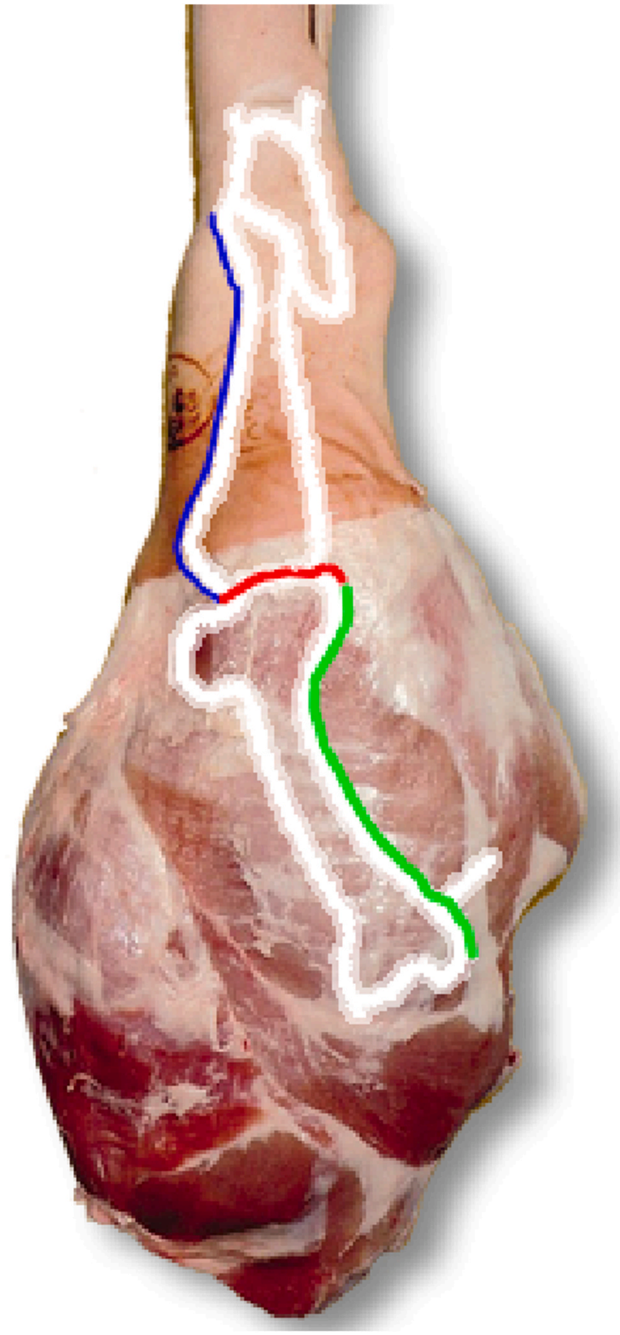

Fig. 4. Cutting path on a Pork's leg (Alric et al., 2014).

4.7. ECHORD-DEXDEB

4.7.1. Overview

Soft and deformable material grasping is yet to be solved as a robotic problem. Manipulators and grippers have to hold the object strong enough not to drop but, at the same time, gentle enough not to damage the material. The lack of sensibility on the tips of widely used grippers and real-time control systems able to deal with the complexity of this task makes it hard to handle delicate materials as meat (Alric et al.,

2014) (Rohrbein et al., 2014).

ECHORD-DEXDEB research this topic creating a dexterous robotic hand to collaborate with a human operator to perform a pork leg deboning. Most of the accidents during cutting happens on the left hand, considering a right-handed person that uses the knife on the right hand. To promote a safer environment, the authors developed a metamorphic four-fingered hand with reconfigurable palm to act as the left hand of the operator during the cutting (Rohrbein et al., 2014).

4.7.2. Process

The first step to develop the robotic hand was to measure the cutting force applied to the part using a Kistler's force sensor. Besides this, a knife with a force sensor was developed to measure the forces applied directly to its blade. During a deboning cutting action the maximum force on Z-axis was 170N.

Another important data for the project was the forces and movements of the butcher's left hand. It was used a commercial data glove adapted to mea-sure the forces at the butcher's fingertips as well as the fingers movements.

Based on these measurements, a set of assumptions were made in order to create the path planning algorithm for the robotic left hand. The assumptions were:

1. The movement direction should be away from the cut trajectory;
2. The total force applied should be limited;
3. The left hand should move;

With these data and measurements, the metamorphic four-finger hand was developed with a reconfigurable palm. They used a 5-bar linkage. The palm has two degrees of freedom (DOF), the thumb has 4 DOF and the remaining fingers 3 DOF. The learning strategy used for the reach of the hand was the teach-by-show, the butcher taught the robot how to reach the meat, the trajectory X_reach was defined, and during the robotic operation, the f_reach was the desired force resistance for the wrist sensor.

4.7.3. Critical review

Both hands, commercial Shadow and the metamorphic designed four-fingers hand, were tendon driven and both suffered the problem of not having enough friction between the fingertips and the meat during the grasping action of the part that was being cut by the butcher. The friction get worsen by the grease, besides the limited amount of force that both hands could apply to the meat.

Rohrbein et al. (2014) conclude that the experiment has promising capa-bilities to the meat industry, but further investigation has to be made on the grasping. The flexibility of a hand can be advantageous on a cell production system, where more different grasping and handling has to be done on the same environment.

4.8. GRIBBOT

4.8.1. Overview

Poultry is the most consumed meat in the world today and had the largest increase in consumption on the last decade. Poultry plants are the most automated among the poultry and meat industry; Marel [4] offers more than 200 products for poultry processing. Poultry carcasses has less variation than other larger animals as pig, sheep or cattle, yet the industry has an urgent need for more intelligent systems capable of coping with a high yield production with more raw material utilisation (Misimi et al., 2016).

GRIBBOT is chicken fillet-harvesting robot with 3D vision, a custom-designed gripper, and a transport system to present the breasts to the robotic arm. The system has been developed by SINTEF in research to develop a novel concept on fillet harvesting that would increase the utilisation of raw material at an early stage of the processing and would have a more substantial throughput capability compared to the current automated systems.

4.8.2. Process

The researches first studied in detail the manual process of chicken fillet, as it is the most common method applied as it has a bet-ter production speed and has better use of raw material compared to the automated process. In a manual process line for fillet harvesting, the first step is feeding the line with the breasts, then an automated machine makes the initial incision and then the operator grasp and pulls the fillets with both hands in a downward/backward movement, tearing the meat from the breast's bone.

The GRIBBOT system is composed of the following modules:

1. **Transport System** is responsible for presenting the chicken breast to the GRIBBOT harvesting gripper, and it was built as a rotary table made of stainless steel and with a cone elements where the breasts are fixed.
2. **Robot vision** is the visual perception system, it makes uses of the Kinect for Windows v2 RGB-D camera; a depth camera that uses time-of-flight of infra-red light projection to calculate the depth of the objects in each pixel. The 'hand-eye calibration' technique was used to calculate the transformation of the camera in relation to the robotic arm's base to use the camera as the vision system of the robot, and this process is well detailed in (Misimi et al., 2016).
3. **Gripper** is a critical tool for food handling, as a soft and deformable material, as such a special design had to be made to specifically grasp and pull the fillet without damaging the piece, besides the team had two principles; mimic the human hand, and scrape function to maximise raw material utilisation. The GRIBBOT gripper has a curvature and textured surface to better hold the meat while it pulls the fillets from the bone.

4.8.3. Critical review

The authors conclude that the development of the system as a proof-of-concept was a success. They were capable of harvest-ing a full fillet, including the tenderloins, in 4.75s, with improvements and optimisation the time can decrease.

The system was developed as a research project and had commercial po-tential. It was thought as a product to execute a specific task of a traditional line, making it harder to use on a different concept.

5. Current status and future needs

The automation systems described in the previous section, were concep-tually designed to be integrated in a traditional production line, whether in a slaughterhouse or in a processing plant. That is a natural choice, given it is how the industry works nowadays.

That said, this section compares the systems making the assumption that if a system is still in the research stage it is easier to adapt them to different approaches with regards to the production concepts. On the other hand, requirements like efficiency, robustness and maturity have a much higher score on systems that have been productized by companies and have been deployed on costumers.

Regarding the requirements: worker's health, labour shortage and hy-giene, the systems will not be discussed separately, given that robotic system are *"de facto"* built to solve these problems, thus being intrinsic to all of them.

The Table 2 summarises the relation between each system with each re-quirements.

As seen, the slaughter lines, from stunning to splitting, can be almost fully automatized. Large automation companies offer a variety of products that solves specific tasks of the process. That is true due to easier cuts done in the slaughterhouses. But that is not the reality in the

[4] https://marel.com/search.

Table 2
Automation and robotized systems comparison table.

System	Efficiency/Robustness	Maturity	Flexibility	Scalability
Frontmatec AiRA Robots	High	High	Low	Low
Hamdas-RX	High	High	Low	Medium
SCOTT Automated Boning Room	High	High	Low	Low
SRDViand - Beef Carcass Separation	Low	Low	High	Unknown
SRDViand - Pork Leg Deboning	Low	Low	High	Unknown
ECHORD-DEXDEB	Low	Low	Medium	Unknown
GRIBBOT	Medium	Medium	Low	Medium

process plants, where deboning and fine cuts have to deal with bones, ligaments and connecting tissues.

Furthermore, this work have presented a products that are being devel-oped or are already in a commercial state that has some intelligent system ca-pable of perceiving the environment and adapt the operation accordingly, for the meat industry, they are: (a) Hamdas-RX by Maye-Kawa, (b) Hindquarter System by SCOTT, (c) Beef Carcass Separation on the SRDViand frame-work by ADIV/Pascal Institute, (d) Pork Leg Deboning on the SRDViand framework by ADIV/Pascal Institute, (e) ECHORD-DEXDEB by ADIV, and (f) GRIBBOT System by SINTEF.

The work makes an approach to a new paradigm of factory cell in the meat industry and identifies systems that are adaptable to this new production methodology. Today, development is still aiming traditional lines, but the growth of artificial intelligence and robotics are broad-ening the possibilities of production procedures.

During this investigation, we concluded that is still a broad area to re-search on intelligent systems for the meat industry as well as the exploration of new paradigms in production environment and methodology.

Researches have the possibility to focus on different methodology as the meat factory cell. Instead of assigning a specific task to a robotic arm, this could perform different operations on the carcass. The development of such systems could be attractive to smaller producers, that cannot invest a large amount of money on automation but could also be scalable to larger producers when deployed in parallel.

6. Conclusion

This review presented an overview of the current meat industry automa-tion. It reviewed existing relevant products and research from pork, poultry and cattle production. A more in-depth view of the pig slaughter process was detailed, and the Danish-Crown automation was presented as a current state-of-the-art of commercial products for slaughter lines, making the reservation that are differences between lines of different animals.

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