Time for Change: The Case of Robotic Food Processing

By Alex Mason, Tamas Haidegger, and Ole Alvseike

Research and development in food processing automation is not a topic one comes across every day in the robotics domain since it is historically a main target for special-purpose machinery. In the *agrifood* landscape, it is most certainly agritech—that is, technological development at the farm level—that has captured the attention of robotics researchers today. This includes a range of self-driving tractor vehicles or platforms for a range of agricultural needs—from sowing [1], fertilizing [2], handling pests [3] and mildew [4] through to harvesting [5]—well covered in the recent topical issue of the IEEE *RAM* [6]. One should also not forget milking robots, which have been available in use for several generations [7].

If we take a step back, however, and consider the agrifood value chain, there are other large segments where robot-based automation can be beneficial. Taking the case in Europe (specifically, the EU-27 [8]), the food sector employs about 16 million people, where 3.9 million are employed in the manufacture of food products (compared with about 7.4 million [9] in agriculture), including aquaculture and beverages. Food manufacturing has an annual production value of approximately €860 billion, compared with approximately €450 billion for agriculture [10]. This emphasizes one of the key drivers for agritech development, that is, the unfavorable ratio of employment versus production value (approximately €220,000 per worker in food manufacturing versus approximately €61,000 per worker in agriculture), which has opened a clear business case for robotics and custom machinery development.

While food manufacturing automation is an important part of business for many large companies, the actual product range addressed also features some specifically challenging domains, such as meat. To add some perspective, meat processing and production in Europe accounts for about 912,000 workers, almost €209 billion in production value, and more than 33,000 enterprises [8]. Arguably, they play a large role in the food value chain. In the absence of suitable alternatives, and with the forecast population growth from 8 billion in 2023 to almost 10 billion by 2050 [11], it is also likely to remain that way for the foreseeable future, maintaining the demand for more workers or better automation solutions. The food sector must support this growth in a sustainable way that includes waste reduction, more efficient use of raw materials, improved food security, and, perhaps, also evolving working environments. These are common characteristics that society demands from food production, and no less from meat processing. Therefore, if we should improve sustainability credentials, we must work with what we have, make it better, and significantly increase its availability across all volumes of production.

WHY AUTOMATE?

Automation technologies, including cognitive robotics and artificial intelligence (AI), have been a means for many sectors to improve their business in many ways. The recent pandemic has further accelerated the deployment of such technology [12], [13]. The International Federation of Robotics [14] has listed 10 common reasons for investing in automation and robotization that are highly relevant in the context of agrifood:

- Reduce labor costs per unit.
- Improve product quality and standardization.
- Improve the quality of a working day of employees.
- Increase production speed.
- Increase the flexibility of production.
- Reduce waste and increase production value.
- Comply with health and safety targets.
- Reduce employee turnover and become a more attractive recruiter.
- Reduce capital costs.
- Better utilization of production areas.

Red meat processing plants are often credited as the basis for the revolution brought by Henry Ford to the automotive sector [15]. At this point, it is important to make a distinction between red meat and poultry (particularly chicken) manufacturing. Highly automated chicken processing plants that handle upward of 10,000 birds/hour are not uncommon, and there have also been significant advances in cutting and deboning machines in recent years. Poultry processing therefore tends to be more time-critical, more automated, and less labor intensive than red meat processing, while agritech challenges are also present [39]. However, the pace of automation in red meat processing has not kept up with other sectors. That is evident if you visit a typical meat processing and production facility in the Western

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world, where you will find large numbers of workers performing a variety of highly repetitive tasks at remarkably high speeds. It comes into our minds immediately: *Why have these tasks not yet been robotized?* Apparently, the overall task complexity makes the complete automation uneconomical for most processors, and there are several parts of typical manufacturing that lack good solutions, thereby opening the door for ground-breaking research and innovation. This article considers recent advances in meat processing, the main challenges it faces, and discusses the possibilities in regard of a more robotic future.

MEAT PROCESSING AUTOMATION

To give an overview of midsize animal processing, an example from pork production is given in Figure 1. Naturally, for different species and facilities there can be deviations, but pork gives a good general overview and an impression of the typical process. The purpose of the process is to take in an animal, to disassemble (slaughtering in the abattoir), to prepare (tri-sectioning, cutting and deboning, further processing), and to ready it for the market (packing and palletizing). These are very clear and distinct physical areas within conventional meat processing and production plants.

Equipment can be separated into two general categories; ***assistive*** and ***automatic***. Assistive technologies are those that help operators perform their role efficiently. Automatic systems, including robots and machines, cease the need for butchers to interact directly with the meat at all or (more likely) some stages. The typical arrangement of facilities is in a production line-based structure, where the output of one process provides the input to the next, and so on. This arrangement inspired Henry Ford, and it has advantages: *simplicity* and *high speed* among them. Further, the whole process is split into operations that can be rapidly learned and substituted.

It also imposes some challenges, mainly related to robustness (e.g., a line fault can cause large parts of the line to temporarily halt, reducing productivity), and the *scalability* of the system in terms of upfront cost. In addition, the benefits of rapid learning on manual lines comes at a cost: Each operator's task becomes repetitive, which can cause strain to muscles and joints. Psychologically, this can bore the operators; moreover, the work includes sharp tools, which presents further hazards.

> “THE FOOD SECTOR MUST SUPPORT THIS GROWTH IN A SUSTAINABLE WAY THAT INCLUDES WASTE REDUCTION, MORE EFFICIENT USE OF RAW MATERIALS, IMPROVED FOOD SECURITY, AND PERHAPS ALSO EVOLVING WORKING ENVIRONMENTS.”

It is not the intention of this article to formulate an exhaustive review of automation in the meat sector. Several comprehensive reviews already exist [16], [17], [18]. However, an outline of key examples available in the commercial and research domains are provided as points for discussion.

Assistive technologies**:** These most often include systems to move, hold, and present raw material to skilled operators. A simple example is shown in Figure 2, where a butcher is working on a slowly moving conveyor. Colleagues either side of them will perform some small tasks, until eventually the desired product is ready and boxed. Conveyors reduce the amount of movement the operators must perform, but they still must manipulate, cut, and lift. A more advanced system for cutting operations is shown in Figure 3, where the material is automatically presented to the operators and performance is monitored through built-in weighing systems. In Figure 4, a different type of conveyor, which transports turkey carcasses is shown. The presentation of the material to the operators increases their productivity, and reduces physical exertion. Analogous systems are available for most meat products, also including chicken and turkey.

Automatic technologies: Despite the automation gap that has developed, machines or robots are available for handling many processes. First-generation automation has been characterized by the implementation of single-task machines that utilize gravity and blunt forces, have little cognitive or sensing tools, and therefore depend to a large extent on standardization of animals. This type of machinery targets direct exchange with a manual operator. Examples from abattoirs include deskinning of sheep, dehiding of cattle, splitting saws for beef carcasses, scalding of pigs and poultry, dehairing of pork carcasses and defeathering of poultry, cutting of the abdomen,

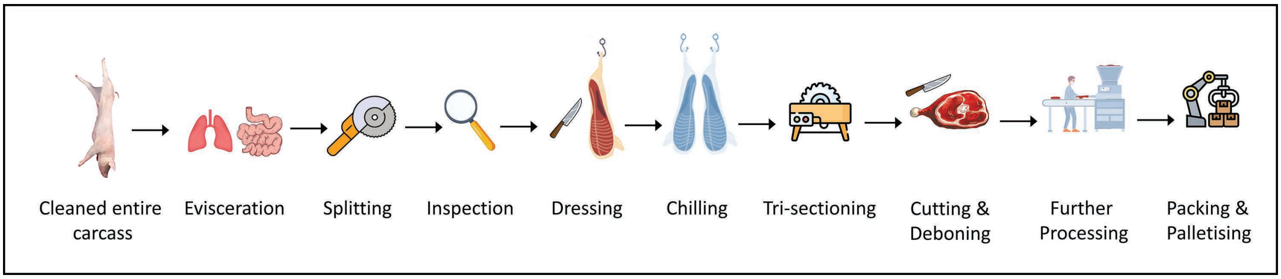

FIGURE 1. An illustrative overview of meat processing, using pork production as an example. Tasks up to chilling take place in the abattoir, while those after chilling are part of secondary processing (tri-sectioning, cutting, and deboning), further processing (e.g., cooking, marinading), and packing or palletizing for transport.

brisket cutting, and head and jowl cutting of pork carcasses while some organ handling tasks remains manual [17]. In secondary processing, more machines exist to handle very specific tasks, such as saws for tri-sectioning of half pork carcasses, rib removal machines, pork derinding machines. More generic equipment for weighting, sorting, slicing, and portioning is also available.

FIGURE 2. A conveyor system in a small processing plant, where butchers are cutting and trimming pork loins. For small processors, the workflow typically includes fewer automatic solutions, relying much more on manual labor.

FIGURE 3. A conveyor system combined with sorting stations (Marel, StreamLine) where performance of individual operators can be monitored, and tasks allocated automatically.

More intelligent machines, characterized by incorporation of sensors (e.g., cameras, proximity detection, X-ray) have enabled newer generations of equipment to be more responsive to biological variation. This has enabled, for example, a robot designed for beef carcass quartering and pork ham deboning [19], as well as a fully automatic line for lamb cutting and deboning [20]. Interestingly, it was noted that the deboning functionality of the latter system was removed, as its inclusion alongside a skilled workforce improved their efficiency to the extent that the robot could not keep pace. However, systems capable of automatic deboning have been produced by Mayekawa [21] for chicken (TORIDA and LEGDAS) and for pork (HAMDAS-RX and WANDAS-RX), for example.

Toward the end of the processing line, machines or robots for packing, boxing, and palletizing are becoming increasingly common (in, e.g., medium- and large-scale plants). In recent years there have even been developments in packaging of delicate and nonuniform products; chicken fillets, for example, which have required special grippers (see Figure 5), as well as machine vision for product identification, weight estimation, and positioning. In turn, all this has enabled robots to fill packets accurately and tirelessly with remarkable uniformity. Universal Robots has recently demonstrated a cooperative system for tray placement during the packing of sliced dry-cured meat products [22], enabling workers and robots to work together on the task. Once the product is packed, the task becomes much simpler due to reduced hygiene considerations, as well as to increased product rigidity and standardization. Manufacturing and logistics have used robots to handle packages, boxes, and pallets for decades, making adoption straightforward when compared to other plant operations. Combined with automated warehouse solutions, shop-specific pallets can be packed automatically due to vertical integration of business intelligence systems. Therefore, distribution can be optimized based on shop stocking levels and consumer demand.

Several innovative developments have taken place in the last decade, starting with modeling of two- or three-arm robot cells [23], [24], [25] for small, nonspecific, meat cutting tasks. Delgado et al. [26] reported a prototype dual-arm system with a holder for deboning hams that uses an X-ray sensor to accurately locate bone structures.

The Danish Technological Institute (DTI) recently reported a robot cell [27] that is analogous to tri-sectioning equipment by which a chilled half carcass is portioned into fore-, hind-, and midsection parts. While conventional equipment uses saw blades and therefore cuts in straight lines, the DTI system enables a curved cut; two 3D cameras enable prediction of a pathway, and a small robot with a customized pneumatic knife-tool performs the removal. This has the potential to improve yield and is well into the development stage. Romanov et al. [28] have also proposed the broader development of cooperative robots that can work alongside human operators to increase the capacity of existing cutting lines. Reconsidering the current structure of meat automation entirely has also been proposed, with a platform called Meat Factory Cell (MFC), which uses robots to perform more complex tasks in cells [29]. This system has recently been deployed in a small slaughterhouse in Germany; however, it is still in development (see the concept in Figure 6 and the physical platform in Figure 7). This platform seeks to perform a range of tasks within cells with a small footprint, potentially overcoming some of the challenges of conventional line-based approaches, namely, robustness, flexibility, and scalability.

FIGURE 4. An example of an assistive system used in Norway, which presents turkeys on a moving conveyor system for skilled operators to cut.

WHAT ARE THE MAIN CHALLENGES?

To answer that, one should consider several factors. Starting with the *raw material*, it is difficult to work with. Never underestimate biological variation. If you enjoy meat, perhaps even consider yourself in your kitchen at home: knife in one hand, the other trying to pin down a piece of pork loin, or a beef rump steak. It is slippery. It is wet. It is malleable. We haven't even

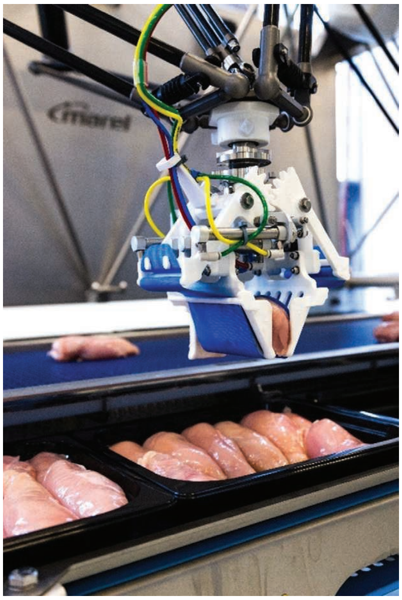

FIGURE 5. Special grippers are used for handling soft materials like chicken breasts both accurately and at high speed.

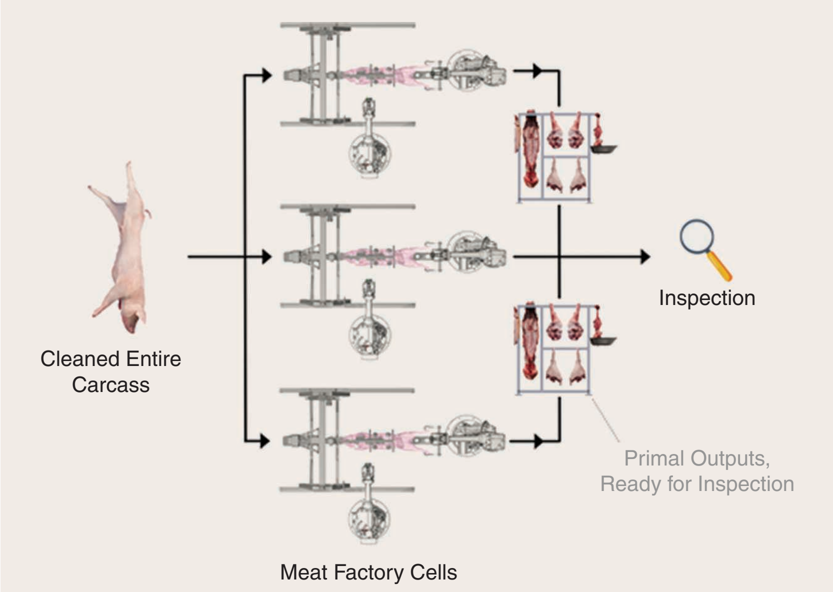

FIGURE 6. An overview of the MFC approach, where cells arranged in parallel process several carcasses simultaneously to produce primal cuts. While the cuts performed are not conventional [37], they are presented for inspection to align with today's practice.

gotten to the cutting yet! Which way shall we cut? Where shall we cut? Oh, where is the knife sharpener!? The task requires skill, dexterity, and experience, which are acquired through training and practice over a period of at least several months. Having robots perform these tasks has, therefore, historically been difficult. Automotive parts handled by robots are typically of a known size, in a defined position, dry, and largely rigid—meat rarely has any of those features.

> “IT IS IMPORTANT TO POINT OUT THAT WHILE SMALL PROCESSORS RELY HEAVILY ON LABOR, EVEN COMPANIES WITH A HIGH LEVEL OF AUTOMATION REQUIRE WORKERS.”

Legislation is another aspect to consider. Many legislative texts applied to meat processing do not consider functional requirements (“the outcome”); rather, they give normative formulations (“the process”), which can be restrictive for innovation [30]. Robotics regulations and standards also impose some challenges, namely, that they are rarely tailored to the needs of this sector [31], and they could be considered to follow innovation rather than helping to lead it. Robotics regulations do not prohibit implementation of most fully automatic systems, but they leave implementation of safety features as a responsibility of the manufacturer since “safety by design” is still the preferred principle.

Further, the meat sector can be described as *conservative*, and it must be. Supplying safe, quality products is important for consumer confidence, for example, and if you have a system that can do that, changes can still seem risky. Further, the sector generally prefers to purchase equipment from suppliers who are well known in the market, where there is a well-established support network that ensures good service and access to replacement parts. That can make it much more difficult for startups and innovators to enter the market with new solutions.

Much of the sector operates at low profit margins and, therefore, investing in new equipment must have a high or secure return on investment to be attractive. Khodabandehloo [32] states that commercial systems need to target a return on investment of 18–24 months for users to be motivated to invest. However, and perhaps this is one of the more considerable challenges for automation, investments in automation are typically large—building a new processing line is not a decision taken easily. That has led to a rule of thumb in pork production, for example, where one must process 600–700 carcasses/hour, or in the region of 25,000 per week, before automation can be considered economically viable. (Let us not discuss the challenges that means to local production and supply chains [40], [41].) The farther below that level the production is, the lower the likelihood of automatic or even advanced assistive technologies being implemented. This creates significant divisions in meat processing: the “haves” and “have-nots” of automation. Robotics-driven innovation and automation are considered important tools for accelerating sustainability [33]. Therefore, the inability of a large part of the sector—many thousands of enterprises in Europe alone—to economically access automation solutions can only reduce the ability of the sector to meet societal expectations in regard to sustainability.

The inability to access robotics and automation also exacerbates another ticking time-bomb in Europe, that is, availability of labor. It has been no secret that the meat sector, like many other parts of the agrifood sector, has relied on migrant workers. However, recent factors like Covid-19 [34] and Brexit [35], along with longer-term factors, such as an aging population and a gradual decline in numbers of employees in the sector, the overall effect is a small labor pool. It is important to point out that while small processors rely heavily on labor, even companies with a high level of automation require workers.

On the other hand, robots and machines require maintenance, and there are some parts of production that cannot be automated at present; those include special products with detailed cutting, organ handling, supervision of packing machines, hygienic

FIGURE 7. The physical MFC platform, built in Norway as part of the European Commission–funded research and innovation project Horizon 2020 “RoBUTCHER” [38].

inspections, and loading of machines at the interfaces between processes.

Finally, it is notable that the meat sector is fixated on performance metrics like speed and volume. Khodabandehloo [32] reinforces these, stating that if robots would be accepted, at the very least, their performance needs to match the capacities of skilled operators or butchers. However, one has to consider the real necessity of that: Is high-speed production in a low-volume plant necessary? No, of course not, because the raw material will be rapidly depleted and the duty cycle of equipment will be low. For a low-volume producer, solutions which relieve pressure to find workers, improve robustness, and enable flexibility may well be as relevant, if not more. Achieving these characteristics will require better, faster, more agile (yet safe) collaborative robots.

TIME FOR A ROBOTIC CHANGE… BUT HOW?

Change is hard. Slowly, yet gradually, it is happening all around us, and therefore it is important to consider what can be done to encourage change for the manufacturers in the meat sector, and perhaps beyond.

TECHNOLOGY SOLUTIONS

Clearly, meat and food present challenges for traditional automation due to their biological nature. It is clear, therefore, that further development of hard- and soft- solutions are necessary. Physically, interacting with those materials can be tricky; therefore, we need more dexterous tools to manipulate, as well as tools or sensors than can provide feedback. Vision systems have also been improving. Nevertheless, improved robustness for industrial environments, as well as depth accuracy, resolution, and noise rejection can only improve the accuracy with which robots can perform. New AI models will also be necessary to provide better generalized perception, so that training robots for each individual product (which number in the thousands) will not be as laborious as it is today. Such AI models may also be used for providing safety assurance in, for example, a collaborative environment. Of course, this article addresses more on robotics and automation, but if that should truly be successful, then holistic consideration of digital transformation must also be considered. Using sensors, data, and value chain information will improve processes and outcomes.

LEGISLATION EVOLUTION

Today, legislation can be difficult to navigate. From a food safety perspective, prescribing processes rather than objective outcomes stifles innovation and the ability to consider radical (rather than incremental) development. If disruptive innovations can lead to sustainability, then it follows that the bigger the innovation, the larger the contribution to sustainability goals. From a robotics perspective, work has already started regarding providing better, more accessible information relating to robot legislation and best practice; the COVR tool kit [36] is a good example of that. Yet, robotics, technology, and our excitement to use it to our advantage moves at such a pace that it is important for standards to keep up. We can, for example, establish more specific best practices for collaborative food automation environments, which will lead to both attention and improvement of technology to enhance capability.

GOOD SUPPLIER NETWORKS AND COLLABORATION

It is unlikely that we can make the meat or food sector less conservative. Instead, we need better solutions for collaboration between innovators and established supply networks. In the meat sector, these two can coexist without competing since they can cater to different target markets (i.e., small versus large). In this way, perhaps we can bring innovation to the market but maintain the assurance of service that the sector needs and is accustomed to.

INCREASED EMPHASIS ON SCALABILITY

The challenge noted today is the large investment required to establish a processing line, particularly one that incorporates some level of automation. A focus on robotic solutions which better suit the needs of small- and medium-scale processors will improve the accessibility to technology over what we experience today. This could be through innovative solutions like the MFC noted earlier, or it could be through new business/ownership models for equipment, for example.

TRAINING AND EDUCATION

Work forces of the future in the food sector and meat processing will require a different set of skills than today. They will need education and competence to operate automatic equipment, perhaps in addition to knowledge of the food products themselves. Today, there is no qualification that specifically trains a worker to operate robotic equipment to cut meat; but that equipment exists, and it is just a matter of time before more advanced (and, hopefully, ubiquitous) systems arrive.

IMPROVED COMPARISON MODELS

The current emphasis on automation performance will not help small- and medium-scale processors contribute to sustainability goals, and if they remain the only benchmarks that we consider, then it will be difficult to effect the change needed. In the future more holistic life cycle models should be incorporated, ones which better account for a range of parameters. Those can include the typical factors, of course (e.g., resource consumption, cost, space), but they should also factor in improved robustness, flexibility, and scalability.

DISCUSSION AND CONCLUSION

Global development has increased attention on *flexibility* in meat processing, both in terms of the overall process, as well as in the products themselves. Such traits could be more relevant in the future than the raw performance metrics we have become used to. As the market for meat becomes increasingly international—with consumption in China, for example, growing rapidly—product portfolios increase to meet the demand of new consumers. This is challenging for commercial automation solutions to handle; however, novel, robot-driven approaches are under development and becoming ready for wider adoption. Apart from economic considerations, robots will be required to overcome labor shortfalls, as well as contributing to making food processing safer, cleaner, and more sustainable.

There is much that can be done to improve automation and its penetration into food (and meat) processing; agriculture is certainly not the only part of the agrifood ecosystem that needs automation. For interested engineers, entrepreneurs, innovators, and creators, food processing is a treasure trove waiting to be discovered. For other stakeholders (e.g., end users, policy makers) robotics offers huge opportunities that, a decade ago, one could only dream of. Innovation will only succeed through good discussions, where new technologies are adapted to the conventional practices and conventional practices are adapted to new technologies—if only we can dare to think and be different.

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