

The Robotic Workbench and poultry processing 2.0

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Implications

- Robotics will allow for a flexible manufacturing to be integrated into the assembly line procedure, allowing for greater agility in the face of changing circumstances. Flexible automation will enable:
 - Dynamic processing lines
 - Scalable manufacturing
 - Hazard mitigation
- The Agricultural Technology Research Program in conjunction with the Georgia Tech Research Institute is exploring ways of reducing the need for human labor in protein processing. By developing routines and algorithms that do not rely on specialty sensors, a single robot with proper support could be designed to accomplish disparate tasking at multiple stages of processing.

Key words: assembly line, flexible automation, poultry processing, robotics

Introduction

Robotic advancements offer an opportunity to change the assembly line paradigm in animal protein processing. With a growing population and the increasing wealth of the global economy, food production technologies will need to advance, and animal proteins will see a larger share in the global market (Van Kernebeek et al., 2016). Protein processing, like most modern industries, relies on an assembly line model for its production. Unfortunately, assembly lines are inherently rigid in their manufacturing methods. They are incapable of accounting for large variations in incoming material quality or changes to processing. These limitations are particularly disruptive for animal protein processing, where incoming materials are of variable size, shape, and quality. An alternative method of manufacturing is the workbench—a single station with all the tooling and materials necessary available for every operation. This method works well for small-scale operations, but, by its very nature, the workbench is not suitable for mass production. The

animal protein processing industry is in a bind, stuck between a rigid method of manufacturing and tight margins for profit.

Although manufacturing has historically relied on fixed automation, robotics, flexible machines that can perform a large variety of tasking have the power to augment the assembly line and herald a new model of manufacturing. With the increased popularity of cobots, relatively small robotic devices designed to directly assist with human functions, fixed automation machines are slowly being replaced by robots capable of a diverse set of tasking (Wright and Schultz, 2018). In an assembly line structure, a sophisticated workbench, a Robotic Workbench, could be devised that can handle a large variety of operations and tasks. Then, rather than relying on machines with limited capabilities, a series of Robotic Workbenches within an assembly line could perform nearly all of the operations necessary for production. This new approach to manufacturing would give rise to an assembly line that could, in real-time, adapt to variations in incoming product or in the quality of the materials being manipulated. This concept of the Robotic Workbench and an agile assembly line can transform a rigid manufacturing process into something that is flexible without sacrificing value. The work that is being done today in researching new robotic techniques could pave the way for a future of protein production that is efficient, diverse, and scalable.

Manufacturing Methods in Industry

Manufacturing is never a single, cut-and-dry method for production. Various techniques need to be employed that suit the individual requirements of a company's products and vision. However, in general, most modern manufacturing exists on a spectrum between two extremes: the assembly line and the workbench. In their synthesized forms, the assembly line focuses on creating a product and material flow, whereas the workbench method operates on a single product from start to finish. Generally, assembly lines are implemented by industries looking to achieve high-volume productions, whereas the workbench approach is more commonly used by individuals or small companies. Each of these methods has its benefits and detriments, and most processing is a mix between the two extremes.

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The assembly line

The assembly line has become the standard in large-scale, high-volume manufacturing. As mentioned, the underlying principle of the assembly line is to view manufacturing as a processing flow. Rather than focusing on a single product from beginning to end, each station within an assembly line is optimized to perform a task or series of tasks repeatedly and efficiently. Then, the product is transported to another location within the factory, usually to another dedicated machine or processing line, and this cycle is repeated until the product is finished. This method of manufacturing reduces the downtime that can arise from changing tooling or tasking and allows for individuals and machines to be specialized to perform a single operation. However, this method is not without challenges. Ensuring that materials can be transported quickly and efficiently is a consideration that may be taken for granted when many manufactured components are standardized, but this process becomes more challenging for irregular components. Conveyor belts, shackles, and numerous other systems might be employed, but each of these has associated considerations that must be taken into account. The challenges of the assembly line are further complicated when a company's product can exhibit different forms during manufacturing, potentially requiring diverse methods of transport between stations. In brief, assembly line manufacturing can lead to incredibly efficient processing as long as the materials are of standardized quality and the required processing is predictable. The efficiency gained by implementing an assembly line is minimized if the incoming materials have a size, shape, or quality outside of a narrow band of tolerances.

The workbench

On the opposite end of the production spectrum to the assembly line is the workbench. The workbench is not as prevalent in industrial manufacturing, but it is common in low-volume operations, such as restaurants. While the assembly line model relies on the product physically moving to specialized machines and dedicated work lines, the workbench typically has a single individual or team manufacturing a product from start to finish. The disadvantages of this method are obvious. The workbench cannot create high throughput. Tools, raw materials, and personnel now need to physically travel to a centralized location and perform multiple operations. However, the benefit of this method is that it is highly flexible. The processing can change on a whim to meet the demands of changing situations. The workbench ensures that solutions are not rigid, and this method can adapt for variations in the incoming product or in the desired output.

Animal protein processing in the modern era

For the past century, food processing has followed other forms of manufacturing as industrialized production has advanced (Barbut, 2010). Assembly line methods are the standard

for creating products, and this mentality has become so ubiquitous that little space exists in manufacturing for change. However, while other sectors of production have increasingly incorporated automation, employing specialized machines that can perform sophisticated tasks, food processing still widely relies on human labor to achieve dexterous and challenging processes (Long et al., 2013). Animal protein processing has not remained stagnant; innovations to methods and machinery have continued to improve (Daley et al., 1993; Wadie et al., 1995), but, unlike other industries, fixed automation approaches are often not suitable to animal protein processing (Barbut, 2015; Khan et al., 2018). As a result, human labor is heavily relied upon within this industry. An example of a chicken processing facility is detailed in Figure 1, developed by Georgia Tech Research Institute, detailing how operations are interconnected and how human labor and machinery are both essential elements.

A major contributing factor behind the discrepancy between the food industry and other manufacturing methods is simple: automation suffers when the incoming product is not standardized. Generalized automation routines will inherently be less efficient at accounting for variations in phenotypic characteristics, such as differences in bone and meat structures (Khodabandehloo, 1989). Food industries must employ human labor to adjust for individual differences in incoming product, or they must process at high enough volumes such that losses arising from automation can be neglected. In ideal circumstances, the benefits of the workbench could be merged with the efficiencies of the assembly line. In many ways, the assembly line is simply a series of workstations that each accomplishes a set of limited tasks. The challenge of the assembly line is that it is inherently rigid. By focusing on the flow of materials throughout a manufacturing process, the assembly line is often incapable of adjusting to large-scale fluctuations.

The Agile Assembly Line

Introducing flexibility into the assembly line, both in product handling and in the flow of materials, would allow for processing methods to account for greater levels of variability. This is the concept of an agile assembly line: a processing flow that can vary based on real-time information of both incoming product and the current conditions within a factory, and the potential of an agile assembly line is possible with the advent of sophisticated robotics. The use of robotics in manufacturing has grown rapidly over the past quarter century (Khan et al., 2018), partially as a result of the industrialization of the assembly line. However, while robots might achieve a multitude of operations given the proper supporting materials, the process of controlling a robot is much more complicated than fixed automation solutions (Kchir et al., 2013, preprint). Robots are susceptible to undesirable motion sets which may cause nonoptimal behaviors (Coleman et al., 2014, preprint) and may even result in damage or injury if proper precautions

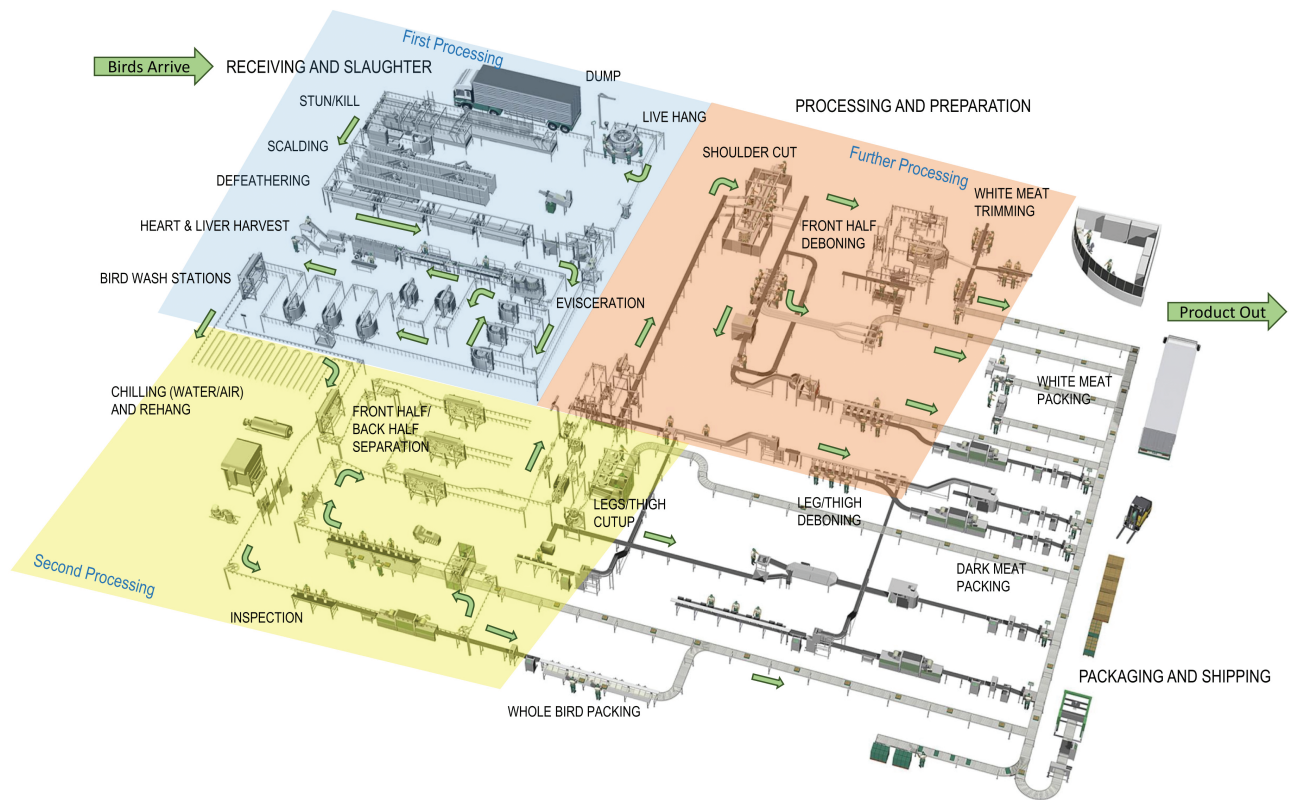


Figure 1. A detailed breakdown of the operating lines within a chicken processing facility.

are not heeded. These dangers are compounded by industrial robots that often are designed either to move heavy objects or to perform rapid motions. The unfortunate consequence of these limitations is that robots are often limited to tasking that could be performed by their fixed automation counterparts.

The rise of cobots

Industries are slowly replacing their dedicated hardware with robots that are capable of performing more sophisticated tasking. However, while the fixed machines have been replaced, the mindset has remained. These robots are often set up and designed to perform routine and unchanging assignments. While robots may have the capability to perform a diverse set of operations, ensuring that safety is maintained in all scenarios is much more challenging. However, this paradigm is changing with the rise in popularity and availability of cobots (sometimes referred to as “CoBots”) (Colgate et al., 1996). An alternative to traditional, industrial robots, cobots are typically smaller robots that are designed with built-in safety considerations (Peshkin and Colgate, 1999). Within the past decade, the advent of cobots has allowed for processes to be developed in which humans and robots operate in adjacent workspaces (Djuric et al., 2016). In this manner, nearly any dedicated machine could be replaced with an adjustable robot without a significant increase in floor space or safety considerations. Industries are beginning to take advantage of cobots by incorporating them into stations that require repetitive tasking

(Rossi et al., 2020). Although these machines are capable of diverse tasking with large workspaces, too often, the mindset established by assembly lines limits these devices: relegating cobots to a narrow set of predictable operations.

The Robotic Workbench

Tasking robots is challenging. The detriment of having a system that is extremely dexterous is that decomposing commands into a series of motor controls is difficult. Machines that perform fixed automation often have a limited number of actuators, and the complexity of their processing arises from mechanical and electrical timing combined with sophisticated design elements. Robots, with large numbers of actuators, are more suited for a variety of operations, but the process of controlling these machines is much more complex. However, while instructing robots may be more difficult initially than using dedicated hardware, once the robot is programmed, any similarly designed robot can perform the same series of tasks. This capability is crucially different from traditional automation, where disparate machines will likely have quite different considerations for handling and operations. The implications of using modular, reprogrammable robotic hardware are that a single robot cell could be designed to handle multiple different processing tasks. This paradigm introduces a new concept: the Robotic Workbench. Mimicking a traditional workbench, the Robotic Workbench would be an individual station of advanced robotic hardware and sensors that is capable of diverse tasking. Either it could replace a single process

within an assembly line or it could be made to take several processes and combine them together. At the extreme boundary of robotic capability, one Robotic Workbench with dexterous hardware, advanced sensors, and agile decision-making could perform nearly every task necessary for a processing application, including within the meat industry. Assuming that the hardware and tooling exist, any operation that is performed by fixed automation could be performed by a robot with the appropriate instructions.

The concept of the agile assembly line, a manufacturing method comprised of flexible procedures, is unlocked by the Robotic Workbench. Instead of a set number of lines with dedicated operations, groups of Robotic Workbenches could perform multiple, disparate tasks in series and in parallel. Then, production could shift and flex to accommodate higher demands of specialty products as the needs arise, or the flow of materials could be altered to avert supply shortages and breakdowns. The tasking of these devices would not be predetermined by their position in the line but rather by the product that is placed before them. In this way, the major detriment of the assembly line, its rigidity, would be overcome. Borrowing from the principles behind the workbench manufacturing method, a system could be devised in which individual Robotic Workbenches are linked to perform a sequence of adjustable tasks. Each work cell would be configured by the needs of the assembly line, creating a manufacturing method that is both scalable and adjustable. In this process, if one robotic system suffered a failure, the operations it was performing could be covered by adjacent Robotic Workbenches. Similarly, if the volume of desired product changes, the number of work cells could be adjusted. With this method, robotics can transform a very rigid process into something that is potentially infinitely flexible by incorporating the workbench approach directly into the assembly line model.

Poultry Processing 2.0

The Robotic Workbench method for manufacturing has the potential to change the paradigm of assembly line production; however, where this technology could potentially provide the most benefit is within poultry processing. Assembly lines rely on a narrow band of input and consistent throughput in order to operate at peak efficiency. The flow-like nature of this type of manufacturing means that disruptions at any one workstation have the potential to disrupt the entirety of the line. Naturally, workflows have been developed to mitigate these disruptions with overflow areas and methods to process underflow, but these procedures come at the cost of efficiencies. Furthermore, the higher the potential fluctuations to input, the less optimal the overall system can be. While uncertainties and disruptions exist in any manufacturing pipeline, these disturbances are both expected and expensive in the poultry processing industry, which operates on razor-thin margins (Misimi et al., 2016). The meat industry does not have the luxury of ordering uniform products for protein processing. Oftentimes, while an understanding of the phenotypic and environmental

conditions of the animals is known, the physical characteristics of the animals that arrive for processing will vary greatly. This variation disrupts every system within the assembly line: from the flow of the products to processing methods performed on individual pieces. With the Robotic Workbench method, however, rather than a set of predetermined processes, this system would allow for every incoming piece to be evaluated and for processing steps to be recommended. From this procedure, the optimal yield for each piece can be achieved based on the actual products delivered rather than the expected incoming materials. If, for example, a chicken were to reach a Robotic Workbench with a broken wing, it could be evaluated and alternative operations could be implemented that would mitigate losses. Robotics introduces intelligent decision-making and advanced automation at every stage of processing. Furthermore, with chains of Robotic Workbenches working in conjunction with one another, different processing methods could be implemented based on the quality of the inflow and the desired outputs. Poultry processing depends on animals that have naturally varying features, and the Robotic Workbench empowers an agile assembly line that can account for differences in individual pieces and the processing workflow in general.

Examples of Georgia Tech Research Institute's contributions

For nearly 50 yr, the Agricultural Technology Research Program (ATRP) together with Georgia Tech Research Institute (GTRI) has worked to improve the poultry and agricultural spaces for Georgia and the world at large. GTRI researchers are experimenting with new ways to bring cutting-edge technology into the poultry processing space. The Robotic Workbench will never be realized if the technology cannot be demonstrated in individual components, and researchers within GTRI have been working to forward the vision of augmenting robotics to perform tasks previously monopolized by human labor. These projects use the latest in robotic software, hardware, and algorithms. Combining open platform solutions, such as the robotic operating system (Quigley et al., 2009), off-the-shelf hardware, and custom routines, GTRI is working to create solutions that can benefit the poultry industry. A small example of these projects is listed within this section.

Autonomous rehang. A practical example of a task where robotics would be useful within poultry processing is in the rehang stage. In most American poultry productions, chicken With-Out-Giblets (WOGs) are chilled in water in order to preserve meat quality. As part of this process, the birds are removed from the shackles and submerged in water. Then, to perform further processing, the birds need to be placed back onto shackles (hence, the “rehang” stage). Currently, this operation is performed almost exclusively by hand (Researchers focus on automating the chiller re-hanging process, 2009). However, this action represents an intense physical challenge for operators. Line speeds can run at approximately a hundred birds per minute (Barbut, 2010), so, even with multiple people

performing this task simultaneously, every person is responsible for hanging a four- to eight-pound bird every few seconds. Furthermore, the relative position and orientation of the bird are not predictable. A fixed, automated solution would have to be extremely contrived in order to handle all conceivable bird poses. The rehang stage of poultry processing is a prime example of an operation that would benefit from a mechanized solution but does not work well with fixed automation.

To introduce automation into the rehang stage, researchers at GTRI have been experimenting with advanced robotic techniques. These areas of study including deep learning and precision robotic controls to create an automated solution for the rehang procedure (Walker et al., 2021) based on previous experiments with chicken pose estimation (Joffe et al., 2019). A vision system with an Intel RealSense RGB-D (color and depth) camera observing a WOG can determine the placement of the hocks (equivalent to the knee bones in humans) in three-dimensional space. Then, a Universal Robots manipulator with a specialty gripper can lock the hock in its grasp and place the bird back onto a shackle, as shown in Figure 2. The identification is performed in less than a second using deep learning techniques (Ren et al., 2015), and the entire manipulation is done over the course of approximately 30 s. Initial results have shown that the sensing, identifying, and grasping components are reliable and can be performed repeatedly. A system like this could someday relieve human operators from this laborious task. This technology is, in many ways, still in its infancy. Only one leg is hung, as opposed to both the legs, and the system is too slow for industry use. However, this technique demonstrates some of the capabilities that are only achievable with modern robotics.

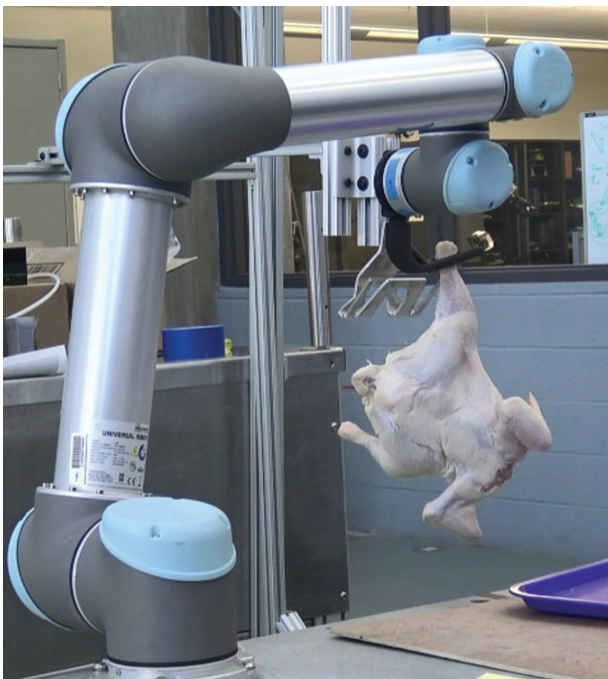


Figure 2. Demonstration of a completely autonomous robotic rehang.

Robotic deboning. Of all the processes within a poultry processing facility, deboning and trimming are perhaps the most demanding and crucial steps that can take place (Zhou et al., 2009). Modern Americans prefer to buy poultry products that have had secondary processes completed rather than buying an unprocessed bird. These secondary processes include: removing the breast meat, removing the thigh meat, and separating the wing meat. These create high-value items that are crucial for protein manufacturing (Heck, 2006). Every ounce of waste in these stages is costly, and bone fragments that can result from cleaving operations are hazardous (Zhou et al., 2007). Separating meat from the bone is performed with a series of precision cuts that slice sinew and tendons. Attempts have been made to use fixed automation techniques to perform these steps, but natural variations in the product ensure that these methods sacrifice quality for efficiency.

Researchers at GTRI have been combining the latest advancements in robotics and sensing to try to tackle deboning (Hu, 2019). This is an area of development that scientists and engineering researchers have been attempting in various forms for over three decades, and, with the rise in robotic techniques and ATRP's support, GTRI researchers have successfully demonstrated this procedure with an automated solution, which is shown in Figure 3. Using a pair of Universal Robots manipulators (one for each wing of the bird), and a set of Intel RealSense cameras, the cutting path necessary for shoulder deboning is dynamically calculated and then implemented in real time. GTRI researchers have shown this method to be effective at producing yield comparable to human operators in lab environments as well as in a processing plant operating at 15 birds per minute. The success of this project has been the result of years of effort, but this technology is now ready to begin industrial integration.

Extended reality (XR) cone loading. The action of cone loading in poultry processing also requires robust handling. Similar to rehang, in cone loading, the bird exists in a semi-processed state (this time as a front half, including rib cage, breast meat, and wings), and the product needs to be placed onto a cone from a bin, conveyor belt, or chute. In this application, it is very difficult to identify viable places for grasping. The bird is semi-deformable and can present itself in multiple different configurations. Once again, the standard solution within the poultry industry is to use human labor to lift the bird from its preprocessing space onto a cone. This application is another example of the unintended consequences of implementing the assembly line model: it is imperative that the product travels throughout the manufacturing area, but, because the product undergoes several transformations while being processed, finding a consistent way to transport the material is nontrivial and requires human intervention.

Another project within GTRI, also funded by the ATRP, has found a potential solution to the cone loading problem. Using a virtual reality space and implementing extended reality (XR) technologies, the scene occupied by the front half can be viewed by a human operator. Then, this operator can decide

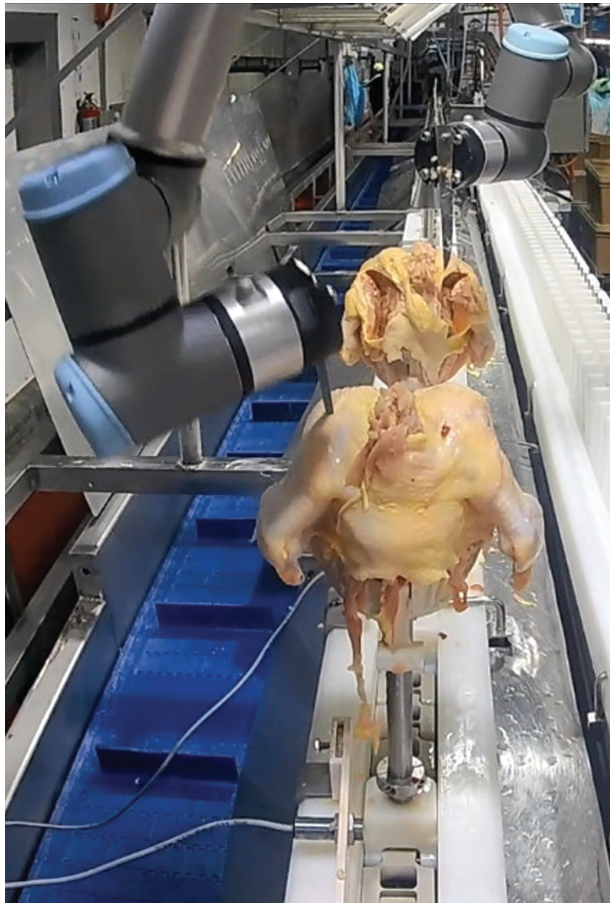


Figure 3. Deboning demonstration using autonomous robotics.

where on the bird the robot should grasp. Following these instructions, the robot will place its gripper at this location and attempt to manipulate the object. This procedure allows for both the human and the machine to use their best qualities to work together in a virtually shared space. The person can provide their real-time decision-making to determine the optimum grip location, and the robot can use its strength and sensors to perform the cone loading. To achieve these actions, an Intel RealSense camera delivers information to the user wearing a VR headset, and then a Universal Robots manipulator performs the grasping, as shown in Figure 4. This project is a perfect example of what can be accomplished by marrying human decision-making with robotic precision and persistence. Performing cone loading is a low-level operation on the processing floor that requires little skill, but it is an important task that cannot be overlooked. By separating a human from a physical location within the assembly line, an operator would be free to direct their attention where needed when applicable.

GTRI and the Robotic Workbench

The aforementioned projects have two underlying threads that bind them together. Each of these projects aims to apply flexible automation to the poultry industry, and each project uses very similar hardware and sensors to complete their tasking. Of course, these projects have their own scope and objectives that



Figure 4. Demonstration of a human-guided grasp of a chicken front half by a robotic device.

they prioritize, but the intention is clear: any of these robotic workspaces could be designed to perform the rehang, deboning, or cone loading operations given the appropriate tooling and support. Within the lens of poultry processing, a series of Robotic Workbenches, each equipped with the appropriate equipment, could be chained together to perform each of these tasks with a scalable and flexible arrangement of robotic operations.

Conclusion

The poultry processing industry, like all major centers of manufacturing, has been pursuing the assembly line model for the past century. However, the assembly line has specific needs and unintended consequences that arise from misuse. In order for the assembly line to operate properly, products and production need to be as predictable as possible. Any deviation to quality or quantity from incoming materials will disrupt operations, and making changes to the assembly line is very costly. Recognizing that dedicated hardware could be replaced with intelligent automation, such as the Robotic Workbench, opens the door for flexible processing and operations.

While a fully robotic manufacturing floor is admirable, it is out of reach for most industries to directly transfer to this methodology. Switching from fixed automation to flexible robotic systems may have appeal, but it is impractical for all systems. Certain processes, especially large-scale, high-volume tasks with repeated motions, are not efficient to replace with current robotic systems. However, the benefit of the Robotic Workbench is that it is inherently modular. Robots can be integrated into assembly line procedures to bolster existing processing methods. Practically, industry at this time will only be looking to replace single systems with robotic automation, thereby perpetuating the cycle of robots being used as dedicated hardware rather than creating flexible workflow environments. However, even this integration will make the task easier to eventually switch into chains of Robotic Workbenches, each of which could be capable of diverse tasking sets, and, in many ways, the food industry and animal protein productions are in a prime position to take the lead in this new

About the Author



Konrad Ahlin is a Research Engineer in Georgia Tech Research Institute (GTRI) and the first R. Harold and Patsy Harrison Research Faculty Fellow in poultry technologies. He received his PhD in robotics from Georgia Institute of Technology and joined GTRI as a research engineer in 2018. His focus is on advanced robotics controls and path planning, and he works closely with the Agricultural Technology Research Program (ATRP), which operates with the intention of integrating new technologies into the agricultural industry of Georgia. He has worked on numerous robotics programs for GTRI, including leaf picking, apple identification, and chicken processing applications. **Corresponding author:** konrad.ahlin@gtri.gatech.edu

nologies into the agricultural industry of Georgia. He has worked on numerous robotics programs for GTRI, including leaf picking, apple identification, and chicken processing applications. **Corresponding author:** konrad.ahlin@gtri.gatech.edu

realm of automation. Traditional manufacturing is fixed in its ways, optimizing its systems until little room is left for gradual improvements or incremental changes. The poultry industry, in comparison, has numerous processes that are still performed by hand, where fixed automation is incapable of replicating the performance of human operators. Researchers at GTRI, with the support of the ATRP, are working to overcome the boundaries of fixed automation and improve assembly line manufacturing for poultry processing. These advancements will result in more efficient methods that save time, energy, and resources. Robotics will dominate manufacturing processes as technologies continue to advance, and the animal protein industry is in an ideal position to lead the way.

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