Intelligent Cutting of the Bird Shoulder Joint

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Abstract

Deboning operations are one of the largest users of on-line labor in today's poultry plants. Efforts have been made over the years to automate this function, but to date have achieved only limited success. The main difficulty in this task is its unstructured nature due to the natural variability in the sizes of birds and their deformable bodies. To increase product safety and quality, the industry is looking to robotics to help solve these problems. This research has focused on developing a new method of automating the deboning of bird front halves. If this task can be automated, the technology would naturally be extended to other cuts and trimming operations in poultry and red meat.

To accomplish this goal, the project team has been working for the past four years on the development of a sensor-based intelligent cutting system. This work is based on the development of a model for the cutting of bio-materials that can be extended to the cutting of meat, tendon, ligaments, and bone. When this model is combined with data from the tendon prediction system, the nominal cutting trajectory can be established and adjusted based on the cutting model in conjunction with knowledge of the bird's anatomy.

The value in accomplishing this work would be to not only reduce labor costs but also to increase the yield of breast meat and reduce/eliminate bone chips. It is estimated that an increase in yield of a single percentage point could represent several millions of dollars of additional revenue for each and every plant. Current attempts at automation of the shoulder cut impose several percentage points of yield loss in return for lower labor costs. In the manual process, while generally providing a higher yield of breast meat, the quality of the product varies dramatically based on the skill of the worker, and the labor costs are significantly higher. It is the goal of this work to develop a system that eliminates labor and consistently provides a yield similar to the best manual worker.

The overall vision for this project requires the development of various technology components that will be unified into a single operational system. This includes a system to identify the initial cutting point, a system to specify the nominal cutting trajectory based on the size of that specific bird, a model to predict the location of the joint and shoulder tendons given the position/orientation of the wing tip, a mathematical model of the cutting process that allows the control system to interpret force/torque data and make intelligent motion commands to avoid cutting through the bone, and a robotic platform capable of executing these commands in real-time.

System Overview

The prototype system that has been developed at the Georgia Tech Research Institute (GTRI) is designed to allow the research team to develop and test the various system components. Figure 1 illustrates the major hardware components. The ABB robot is not used for any of the cutting tasks, but instead it is only used to move the cone through the cutting system. The cutting system itself consists of two motors that move the blade in the vertical plane only. This plane is perpendicular to the motion of the cone. The cutting system has a force/torque cell mounted at the end of the arm with a static blade located at the end.

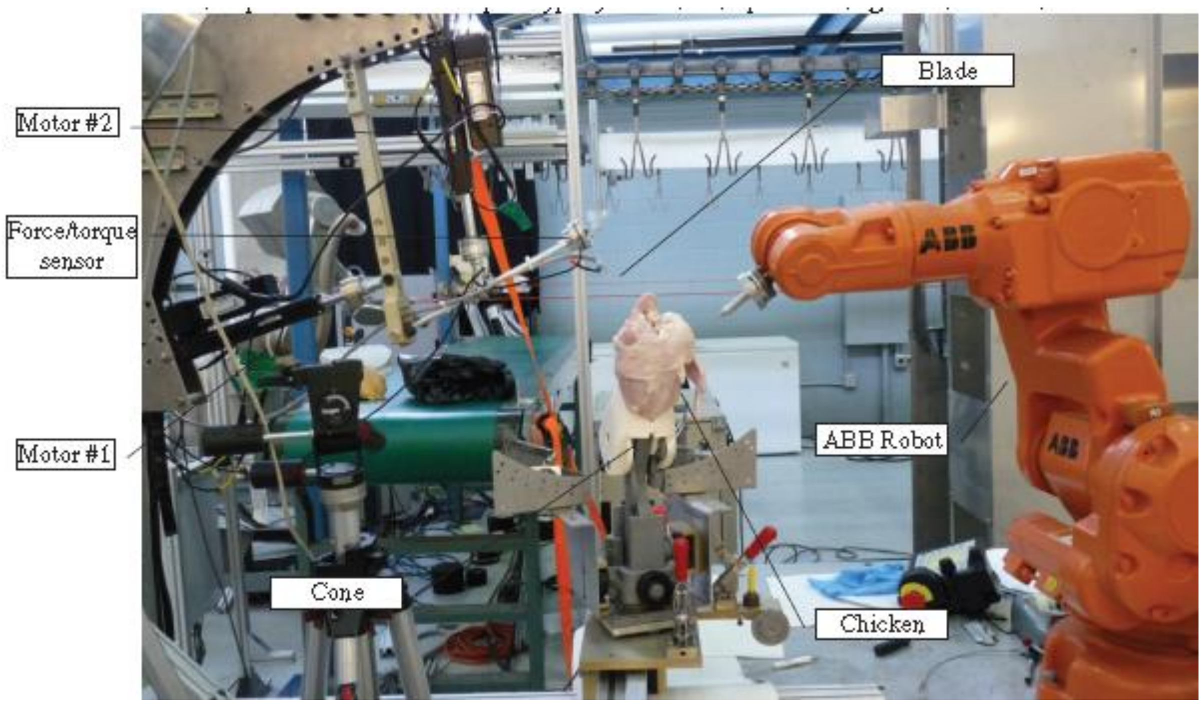

Figure 1 - System Overview

The system uses a vision system (not shown in this figure) to predict the position of the shoulder tendons. This data is then communicated to the robot controller that moves the knife such that it will be above the shoulder tendon once the bird moves into the cutting position. An inductive sensor is used to locate the cone as it is moved by the ABB robot through the cutting cell. Once the sensor detects the cone, the controller waits a predefined amount of time (based on the velocity of the moving cone) until it begins to move the blade down. The blade then follows a predefined trajectory that has been customized for that bird based on the vision data. Once the blade enters the meat, the controller begins to look for the bone as it follows the predefined trajectory. Once the bone is detected, the controller switches to a force control algorithm to guide the blade along the bone without cutting into the bone. This prevents the creation of any bone fragments. Once the blade has completed the cut around the bone, the system then switches to a different control algorithm that guides the blade along the scapula bone without the generation of any bone chips.

One of the major driving forces of this system is the time required to actually perform the cutting motion. The plunge of the knife blade into the meat must occur in less than 0.1 seconds. This is due to two major factors. First, the main tendon runs very deep around the shoulder bone. Second, in order to minimize yield loss, it is critical that the knife enter as close to the shoulder joint as possible.

The system that is shown in Figure 1 is not the final commercial system. GTRI envisions the final system to be integrated into a commercial system. The workspace of the prototype system is much larger than is ultimately necessary. The final system should consist of two small motors that make the small motions required to make the cuts. A force/torque sensor will be required to provide the necessary data for the control system.

Calculation of the Initial Cutting Point

GTRI has pioneered a novel approach to the identification of the bones and tendons with the shoulder joint. The proposed system addresses many of the factors that account for the variability of the tendons and joint in the bird. This includes natural variations in the bird anatomy and the deformation of the bird as well as the unpredictability of the placement of the bird on the cone.

The concept developed at GTRI utilizes a system to identify three key points on the bird. From these locations, a software algorithm is able to predict the location of the tendons and thus the initial cutting point for the shoulder cut. This method is accurate to approximately ±3 mm. This is sufficient for the robot to begin the cut.

The initial approach is to use 3D machine vision by utilizing stereo cameras. These measurements could possibly be made by other means such as a mechanical technique especially if this could be integrated with the cutting device; however, a non-contact optical approach is also attractive for proving the concept.

An imaging cell consisting of a dome was constructed and two stereo cameras mounted to allow for observation of the required reference points which were: the left and right wing body intersection points and the keel tip. Sample images were collected in the imaging cell and preliminary algorithms developed to locate these points. This was done by first locating a region in which we would expect to find the reference point and then following along the edge of the wing to identify the transition from the wing edge to the body. The procedure is shown in Figure 2 with a dot to identify the chosen reference point. This point is then given as a three-dimensional position relative to a reference frame in the stereo camera.

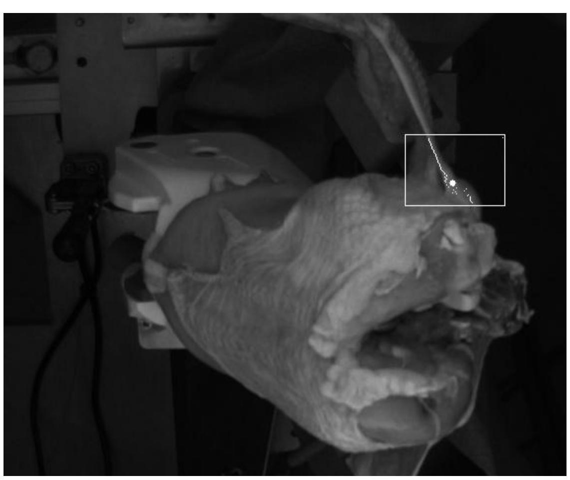

Figure 2 - Location of Key Point on Right Wing

System to Specify the Nominal Cutting Trajectory

Based on a statistical analysis of the data collected from a hundred birds, the team has been able to identify a nominal cutting trajectory for each bird. This trajectory would guide the blade from the clavicle bone to the shoulder, through the shoulder joint, and down along the scapula bone. This trajectory is then offset by the location of the initial cutting points as discussed in the previous section.

The research team has also spent a considerable amount of time studying the various cutting techniques used by workers. Many of these techniques rely on the worker to manipulate the wing during the cut in order to simplify the cut for the worker. While this is obviously optimal for the worker, it does not lend itself to an automated solution. Our approach focuses on minimizing the actuation required of the wing at the expense of a slightly more complicated cutting trajectory of the blade. The rationale for this is simply that the additional cost of the actuation system for the wings does not eliminate the need for any actuators for the blade motion. Thus, for now, the team is focused only on passive wing manipulation.

Mathematical Model of the Cutting Process

The influence of the blade edge shape and its slicing angle on the cutting of biomaterials are formulated and discussed based on the stress analysis. Through modeling the cutting force, an optimal slicing angle can be formulated to maximize the feed rate while minimizing the cutting forces. Moreover, the method offers a means to predict cutting forces between the blade and the biomaterials, and a basis for design of robust force control algorithms for automating the cutting of biomaterials.

An example of this analysis is shown in Figure 3 where the experimental and theoretical fracture forces are compared at various cutting angles of the blade. The results of this data demonstrate a key understanding of the fundamentals of cutting.

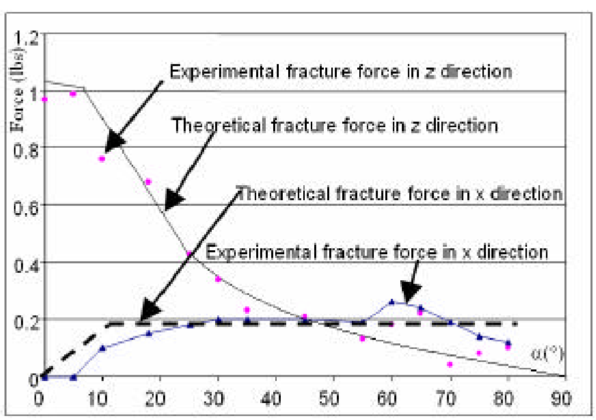

Figure 3 - Fracture Force vs. Cutting Angle

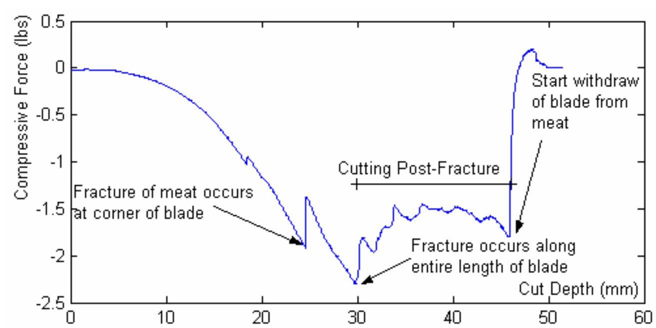

Figure 4 - Compressive Force During Actual Cut of Breast Fillet

Building on this work, the team began to explore the actual cutting forces. An example of the compressive cutting force during an actual cut can be seen in Figure 4. This is the fundamental relation upon which our understanding is based.

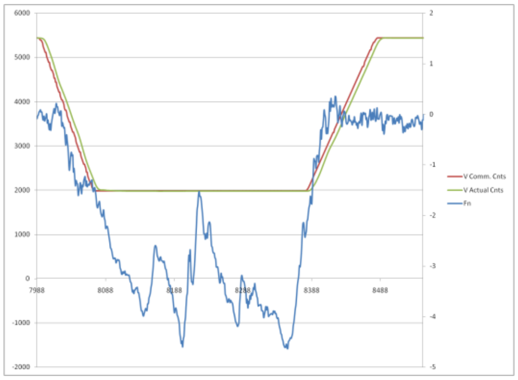

Figure 5 - Normal Force to Blade During Cut

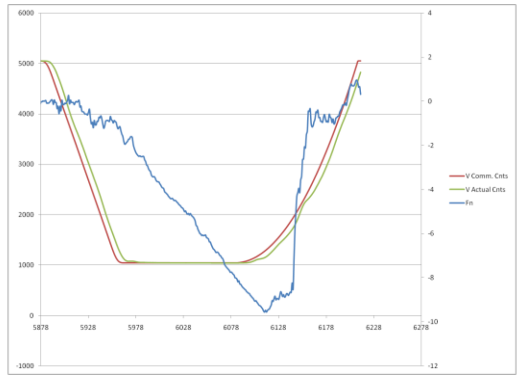

Figure 6 - Normal Force to Blade During Cut

However, the actual cutting data is very complex. The data in Figure 5 and Figure 6 shows the force normal to the cutting blade as it cuts through the shoulder joint. The vertical axis on the left is the encoder counts of the vertical motor: this roughly represents the vertical motion of the blade (8,000 counts per inch).The vertical axis on the right side represents the force. The horizontal axis is time in milliseconds (0.001 sec.). It is important to note that the humerus bone was cut in each of these tests. The data reflects the extreme variations in data and conditions that exist during each cut. While it is impossible to completely model the entire cutting process, it is possible to use our understanding based on Figure 4 to interpret the data.

It is this interpretation of the data that has allowed GTRI to develop an algorithm to identify the bone at the point of very first contact of the blade with the bone. It is relatively simple to put a threshold value in the controller that says if the force exceeds four pounds then assume the blade has made contact with the bone. Unfortunately, by this point, the blade is so far into the bone that if you try to extract the blade from the bone while the bird is moving on the cone line, then you will almost always generate a bone chip or fragment. This is a key technological advance in this work.

Testing

The system has just now begun to undergo extensive testing. Initial testing of the shoulder tendon prediction algorithm shows that the system is able to consistently predict the location of the tendon to within ±3 mm. This allows the system to initially locate the position of the tendon, and then the bone detection system can detect when the blade contacts the bone (without cutting through the bone).

The system has been used to perform a large number of cutting experiments in order to collect data on the actual cutting forces (see Figure 5 and Figure 6). Because the robot was only using the position-based control algorithm, the blade actually cut through the humerus each time, and sometimes it would cut along the scapula bone. However, what the tests did show was that the trajectory defined for the blade did allow the blade to cut through the shoulder joint and then move along the scapula bone every time. This means that a simple two degree-of-freedom blade mechanism is sufficient for the cutting process.

Preliminary testing of the bone detection algorithm has shown the ability of the computer to identify the bone prior to actually cutting into the bone. In our very preliminary testing, the algorithm was able to detect the humerus or the coracoid bone. The maximum observed depth of cut on the bone during this test was less than 2 mm. The actual force control algorithm that is required to guide the blade around the bone has yet to be developed. This is the subject of the current research project at GTRI.

Conclusion

GTRI has been working for several years to address a critical need for the poultry industry: automating the shoulder cut while maximizing yield without generating bone chips or fragments. The team has constructed the first integrated work cell capable of testing and evaluating the ideas developed at GTRI. While the work is still 2 years away from its first real system testing, the preliminary results are promising. The individual component systems are demonstrating the desired results. However, there are still significant questions that remain.

The most significant remaining question is the development and implementation of a force control algorithm to guide the blade around the humerus bone without cutting through the bone. The team has been modeling a force control algorithm in simulation and expects to test the system at the end of this calendar year. Once this has been demonstrated, the team will begin to apply the core technology to all parts of the shoulder cut: clavicle to the shoulder joint, through the shoulder joint, and along the scapula bone.

The immediate goal of the project is to be able to demonstrate the system performing the cut through the shoulder joint and along the scapula using the combination of position and force control. The system will allow us to test at a rate of one bird every two minutes – the system is actually performing the cut at actual line speed, but time is required to manually load and unload each carcass, manually move it into the imaging cell, and then attach the ABB to the cone to move it through the cell at line speed. The team is also planning to perform a yield analysis in order to begin the process of understanding the impact automation has on yield. Finally, in the following year, the entire shoulder cut will be integrated into the test cell. This will provide the best opportunity to quantify the risk of bone chips and the yield improvement of the system.