Broiler chickens slaughtered at commercial processing plants typically are hung upside down on moving shackle lines that take them through the various steps of first processing. The hanging is done by teams of people who must pick live birds up from a conveyor or crate, reorient them, and quickly force the shanks of their legs down into a passing shackle. Typically, eight workers hang 180 broilers per minute, or one broiler every 2.5-3 seconds for each worker. The work is physically demanding and repetitious, creating risk of repetitive motion-related injury. Continuous exposure to the airborne dust raised by the wing flapping of birds can promote allergic reactions and respiratory illness. The work environment is often loud and dim. Overall, shackling of broilers is strenuous and disagreeable, making it difficult to find reliable, conscientious individuals to do it. The handling of the broilers can be rough, causing increased fear, struggle and sometimes injury to the bird. Human error is unavoidable, thus occasionally a bird is hung by one leg, or backward, or even a dead bird is hung.

For many years, the broiler industry has wanted to improve the shackling process. Gas killing systems that put crates of broilers through gas tunnels and present them dead for hanging by shacklers can improve the situation by diminishing airborne dust and allowing a brighter environment. Repetitious labor by humans is still required, however. It would be good to automate the process so that little human labor is necessary.

In 1997, a research team comprised of engineers in the G.W. Woodruff School of Mechanical Engineering and in the Georgia Technology Research Institute (GTRI) of the Georgia Institute of Technology (Georgia Tech) and scientists in the Poultry Science Department of the University of Georgia was formed to respond to industry requests for an automated process to replace the human shackling of broilers. Funding for the research has come from the Georgia Agricultural Technology Research Program through the GTRI and from the U.S. Poultry & Egg Association. The goal of the research program is to design and develop an automated system to transfer broilers from a conveyor to a shackle line at current processing line speeds, with a manufacturing cost that would allow a payback in less than a year from labor cost savings. The cost target is to be achieved by light-weight construction with modern materials and software-driven controls integrated with machine vision systems invented at Georgia Tech.

Human workers use complex image processing ability in the brain to identify individual birds from a mass of broilers. They then use complex, image-guided control systems to operate arms and hands as agile compliant graspers to catch birds one at a time (singulation), invert and orient them, and place their legs into shackles passing by at 1.5 feet per second. An automated machine system must accomplish these actions with accuracy and speed equivalent to that of a team of human workers. Previous attempts by inventors to automate the transfer of broilers to shackle lines have failed in part because the technology of the time was not able to cope with the behavioral and physical characteristics of chickens. A purely mechanical solution is unlikely to be successful since machinery with closely defined operational constraints cannot adapt to the array of contingencies presented by living birds. While it is not yet possible to equal the information processing and motor control capability of a human being, we believe...
machine intelligence and machine vision can be used to control properly designed devices to handle individual birds.

In recent years, robots have been developed to find and manipulate specific objects presented on moving conveyor belts. The problem of handling broilers on a conveyor is similar except that the broiler is a living creature. Its postural flexibility and ability to produce behavior greatly increase the array of object configurations presented to a handler. A human handler can react in real-time and gain control of the bird no matter how it acts. Not even an intelligent machine system could cope with all the potential actions of an unrestrained bird. It is necessary to limit the behavioral opportunities of broilers to standardize as much as possible their postural presentation to machine handling devices.

One way to control the behavior of broilers is to kill them, such as is done with a commercial gas killing system. There are difficulties with this approach. A mass of dead birds would create a non-trivial bin-picking problem. Several handling steps guided by machine vision and computer decision-making would be necessary to find, orient and hang each dead bird properly. A machine system probably could not match the speed of a human handler in such a situation. It is unlikely that automated handling of dead birds would achieve the throughput required to preserve product quality and processing efficiency. A machine system would also have trouble separating DOAs from the rest of the killed birds.

It may be helpful to have broilers be conscious during at least part of an automated transfer sequence. Some behavioral attributes of conscious broilers are as follows:

- **Muscle tone.** Birds are not flaccid; limbs provide some resistance to aid engagement by handling devices.
- **Righting response.** Bird maintains upright posture, which aids identification of DOAs.
- **Reflexive reactions.** Bird gives predictable responses to specific stimuli. It might be possible to rely on certain reflexive responses in the automated handling process.
- **Escape behavior.** Bird may produce sudden, strong escape attempts that are difficult to control. These may cause injury and carcass downgrading. It is important to prevent birds from perceiving avenues of escape.

The fact that a conscious bird has muscle tone and righting responses may simplify identification and removal of DOAs. Reflexive reactions are predictable involuntary responses
to specific stimuli. It may be possible to take advantage of some reflexes to facilitate the handling process. On the other hand, escape attempts and other voluntary actions could cause serious problems for automated handling. An automated transfer process would require physical or psychological control of broilers to eliminate voluntary behavior which would interfere with critical handling steps.

The design and development of an automated live bird transfer system for commercial broiler plants is a challenging problem. This article outlines our work so far. We believe we have made considerable progress; however, this is a long-term project, and our work continues.

Just as shackling by human workers involves several steps, we have conceived the automated transfer of broilers to a processing line as consisting of the following necessary steps: Singulation, Orientation, Leg Capture and Inversion. Each of these steps requires a separate design effort. Thereafter, the steps must be integrated into a smooth-flowing process that can be scaled up to meet commercial industry requirements for throughput, durability and cost.

**Singulation.** Getting objects into single file can be achieved in more than one way. For instance, a series of conveyors of increasing speed can separate massed objects into a line. We settled on a singulator consisting of a pair of counter-rotating drums with rubber fingers similar to the catching heads used on some live-bird machine harvesters. It is possible to separate broilers from groups presented to the counter-rotating drums and carry them through the apparatus individually. The counter-rotating drum singulator requires less space than a series of conveyors and may make it easier to space out singulated birds in a predetermined manner. We anticipated that proper spacing of singulated birds would be important for final grasping and leg capture.

Initial trials with a prototype singulator were very successful. Having satisfied ourselves that singulation can be achieved, we have proceeded to work on the other steps of the automated transfer process. Refinement of the singulation step will be guided by design requirements determined by these later steps.

**Orientation.** Broilers exit the singulator facing either forward or backward. Since all carcasses on the processing plant evisceration line must have the same orientation, the automated transfer system must get all broilers to face in one direction. When this must take place depends on whether the leg capture system can handle birds facing forward or backward, or must receive them facing in one direction only. If leg capture can be achieved regardless of the orientation of bird, it would be simple to rotate shackles once birds were placed in them. If not, the automated transfer system must be able to detect the orientation of a bird and turn it around when necessary before leg capture.

**Image Analysis.** The strength of an intelligent automated object handling system lies in its ability to acquire and use information in real-time to adjust devices to the configuration of the next object to be handled. Image analysis might be necessary to provide important information for the handling of individual birds as they approach the leg capture station. Were it necessary, an image analysis system could identify the orientation of singulated broilers.

**Leg Capture.** The most critical function of an automated live bird transfer system is the location and capture of the legs of a broiler. Most

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**Figure 1.** Initial leg presentation design concept
(a) Front view illustrating schematics
(b) Bird moving backward
(c) Bird moving forward

**Figure 2.** Compliant grasping and shackling design concept
(a) grasping of bird
(b) illustration schematic
of our design effort has focused on this function.

**Leg Presentation.** Leg presentation involves control of a bird so that its legs are delivered appropriately to the leg capture device. In our early attempts at leg presentation, broilers were output from the singulator into a shaped chute that allowed them to stand in the center of the conveyor, but prevented them from sitting down, which many birds would otherwise do (Figure 1). The chute could be elevated gradually to cause greater leg extension. A spring-loaded shackle was placed so as to intercept the legs of a bird traveling down the chute. Since broilers sometimes would stand with one foot forward and too close in line with the other for proper presentation to the shackle, a subsequent design variation of the chute system included a leg-separation rod running the length of the chute from the exit of the singulator. Although tests of the chute with live broilers had some success, we concluded that the system could not be made reliable. The birds had too much freedom to put a foot up on the lower ledge of the chute or step on the leg-separation rod or shackle.

**Compliant Grasping.** Our work with the singulator made us realize that a pair of counter-rotating drums with numerous rubber fingers could act as a compliant grasper able to support the weight of a bird over a distance determined by the diameter of the drums and the length and stiffness of the rubber fingers. We decided to use a compliant grasper to deliver individual broilers into a shackle positioned underneath the grasper (Figure 2). The shackle was spring-loaded to provide resistance to the forward motion of the legs and ran on guides so that once the bird was released from the compliant grasper, the shackle would rotate at the end of the conveyor and invert the bird (Figure 3). The compliant grasper gave us potential to manipulate a bird into an optimum presentation to a shackle. For instance, we noticed that when a broiler was clasped gently in human hands and lifted, it would extend its legs to keep foot contact with the floor. By giving the approach conveyor a downward slope relative to the axis of rotation of the drums of the compliant grasper, it was possible to achieve leg extension to improve the presentation of the legs to the shackle.

The compliant grasping system was studied first for birds that faced forward as they approached the grasper. From a series of tests, we learned that the posture of the incoming bird (Figure 4), the ability of the bird to see during its approach to the grasper, and the translational speed of the grasper all affected the success of leg capture.

Since object handling solutions are simplest to engineer when object presentation is standardized, tests were conducted to learn how to control the posture of broilers at the entry to the compliant grasper. It was found that hooded broilers almost always would sit down on the approach to the compliant grasper. Non-hooded broilers would often stand or sit up, causing
the outcome of the handling by the compliant grasper to vary. It not being practical to hood broilers for commercial processing, control of broiler behavior by suppression of vision was evaluated using dim blue light in a wavelength spectrum to which chickens are relatively insensitive. Most of the broilers tested in blue light sat down on the approach to the compliant grasper. However, the fact that some birds did not sit down highlights the importance of having leg capture technology able to handle postural variation, if full control of bird posture proves not to be possible.

It was during tests of hooded vs. non-hooded broilers that it was discovered that the translational velocity of a bird through the grasper had a profound effect on the success of leg capture. Translational velocity is the difference between the speed of body of the bird in the grasper relative to the speed of the conveyor and is a function of the angular velocity of the rotating drum, the distance between the rotating axis and the center line between the two drums, the width of the bird, the angle between the rotating axis and the conveyor surface, and the conveyor velocity.

The lowest translational velocity produced the highest rate of success regardless of whether birds could see or not. The intermediate translational velocity produced better success when birds were hooded. Since the time taken to pass through the compliant grasper was in the order of 0.5 second, a positive translational velocity of four inches/second or 10 inches/second would mean that the bird’s body is pushed ahead of its feet (which remain in contact with the conveyor) by two or five inches, respectively, at the exit for the compliant grasper. When the translational velocity is too great, the bird is forced too far forward and tends to trip over the shackle.

**Leg Kinematics.** The discovery of the significance of translational velocity took us to a new level in the design of the automated transfer system. An appropriate translational velocity has the effect of lifting a bird’s body up and forward over its feet. The shanks assume a more vertical position, augmenting the effects of leg extension due to the downward slope of the conveyor. By understanding the parts of a broiler’s leg as a series of linkages that are constrained to move within certain limits relative to one another, it is possible to model the leg kinematics to predict the effects of different translational velocities. The results of leg kinematic modeling have been programmed into the computer software that controls the compliant grasper. The strength of this approach is that the compliant grasping process can be tailored for each broiler based on information acquired as the bird approaches the grasper. With intelligent computerized control of the motor operating the compliant grasping mechanism, the handling of a bird is not limited to a single translational velocity. Profiles of translational velocities designed to optimize the handling of different sizes of broilers have been programmed into the compliant handling control software. These profiles have been proven in tests to be more effective at presenting birds to a shackle than the use of constant translational velocities.

The use of translational velocity profiles tailored to individual birds may require real-time image processing of birds as they approach the compliant grasper. It may be important to know the size, posture and time of arrival of an oncoming bird. Width of the broiler can be calculated from top-view images as depicted in the previous discussion of orientation. To determine posture, video images of broilers passing in front of a retro-reflective background in dim blue light
were processed. Neural network analysis of side-view images can identify posture even in dim light conditions. Time of arrival of the broiler at the compliant grasper can be determined by the triggering of a beam switch.

**Further Design of Compliant Grasper.** The compliant grasping mechanism used to this point in the study was simply a pair of counter-rotating drums fitted with many rubber fingers that ran continuously as birds were conveyed toward it. Since the grasper operated continuously, there was no control of the points of impact made by the rubber fingers on a bird’s body. This would cause grasping forces and application of translational profiles to vary among birds. Large birds would be grasped too tightly if the center of the body happened to line up with opposing columns of rubber fingers at the mid-point of travel through the grasper. This sometimes induced the bird to struggle. Excessive grasping force risks bruising and carcass downgrades. The uncontrolled positioning of the fingers also occasionally caused the fingers to interfere with the operation of the shackle.

The next step in the study was to improve the compliant grasping operation. The best way to grasp a broiler gently, yet hold it firmly, would be to cradle it between columns of rubber fingers so that its body is held much as it would be in a pair of human hands. This would require synchronization of the arrival of the broiler with the movement of the counter-rotating artificial hands. It also would require positioning of the fingers such that the contact force was always sufficient to hold even a small bird, but that the flexural capacity of the fingers would easily accommodate a large bird, within a reasonable range of bird size. An angle that is too narrow can fail to properly embrace a large broiler, whereas one that is too wide may cause fingers to miss a small broiler.

Figure 5 shows a side-view picture
of a broiler clasped in the prototype compliant grasper. Good leg extension of the broiler is evident. Broilers appear comfortable when cradled in the grasper and do not struggle.

**Leg Capture.** Our early attempts to shackle sitting birds often resulted in capture of the leg just above the hock joint. A prototype pallet system has been built as a test bed to work out the design requirements of grasping and leg capture of broilers in continuous series. The pallets, equally spaced, facilitate synchronization of the bird with the motion of the artificial hands. Three sets of artificial hands have been installed on a pair of counter-rotating drums, allowing three birds to be handled with each full drum rotation. Leg extension is achieved with a drop cam at the location of the grasper, eliminating the need for a downward slope to the conveyor system.

Improved control of the bird with the redesigned artificial hands, coupled with the use of the drop cam with the pallet system appears to have eliminated this problem. However, the configuration of the leg gripping mechanism cannot be established without gaining some understanding of foot spacing and leg orientation manifested by broilers.

Broilers placed on plexiglass were photographed from below and leg and foot placement relative to their bodies were measured. Figure 6 shows a picture of one of the broilers and a graph of typical leg placement. As might be expected, the spacing between the legs varied between broilers, and the forward placement of the right and left feet relative to the center of the body varied even for the same bird. These data have been used to help determine the design characteristics and operational range of a prototype leg gripper.

**Inversion.** We have done little work on inverting broilers so far because our emphasis has been on capturing their legs, which is necessary before inversion is possible. The prototype shackle used with the compliant grasper and conveyor had a rotating mechanism that tipped birds over at the end of the conveyor. Fear and stress are induced in broilers when
they are inverted. They also produce vigorous wing flapping, which increases the possibility of injury. These negative aspects of inverting a conscious bird would be eliminated if the bird were unconscious. On the other hand, wing flapping can slow the fall of a bird and reduce potentially damaging forces in the legs when the bird reaches the bottom of the inversion trajectory. The design criteria of an inversion mechanism will depend on whether birds will be rendered unconscious before or after inversion.

Where To Now?

The leg gripping function is intended to be the final stage in our automated transfer process, transferring inverted birds to a commercial processing line. Our current research is working toward a system with grippers that will lock onto the legs of an upright bird, invert it, release the legs after delivery to a processing line shackle, and recycle back into position at the compliant grasper. We will finalize our decision on the feasibility of handling forward or backward birds at the compliant grasper based on our ability to design a leg gripper able to manage both leg configurations. If not feasible, a orientation step must be included after the singulation step in the automated transfer sequence.

We are also working on the design of the pallet to promote uniformity of posture among birds. We have found that a broiler given secure footing generally will sit on the pallet and ride into the compliant grasper without attempting to escape.

Standard processing lines require that the bird be hung by its legs upside down. In commercial practice, conscious birds are placed by hand into this position and are carried thus through an electrical stunner and to subsequent slaughter and processing. There would be a number of advantages if it were feasible to electrically stun broilers while held within the compliant grasper. An electrical stun at this point would induce leg extension, facilitating positive engagement by the leg gripper and eliminating the possibility of voluntary action by the bird at the critical moment of leg capture. Forcible turning of a conscious chicken upside down causes fear and struggle and adds to risk of injury and carcass damage. An electrical stun administered in the compliant grasper would enhance animal welfare and perhaps carcass quality relative to the existing commercial situation by minimizing aversive handling. The bird would remain upright the whole time it was conscious. Leg capture, inversion and transfer would occur after the bird was rendered unconscious. Individual bird stunning also would allow the electrical current delivered to each bird to be standardized, compared to the variation of amperage received among birds in multi-bird commercial stunners due to differences in electrical contact and resistance, potentially improving carcass quality. We plan to explore methods to incorporate stunning into the automated transfer system design.

Once the mechanical designs to accomplish each step of the automated transfer process have been worked out, they must be integrated into a single working system. There is much to learn about how to achieve processing line speeds and deal with contingencies such as dead birds, missed_transfer, etc. Scale-up to a full size commercial unit would follow, and, no doubt, further design improvement would take place after commercial use of the automated transfer system.

We knew from the beginning that the development of an automated transfer system to place broilers onto a processing plant shackle line would be a challenging task. By taking a step-by-step approach to the design process and by learning how to manage the important behavioral and physical characteristics of broilers, we have made considerable progress. While man challenges still remain, we believe we can see the light at the end of the tunnel.

Kok-Meng Lee, Ph.D., is with the George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0405. A. Bruce Weber, Ph.D., is with the Department of Poultry Science, University of Georgia, Athens, GA 30602-4356.