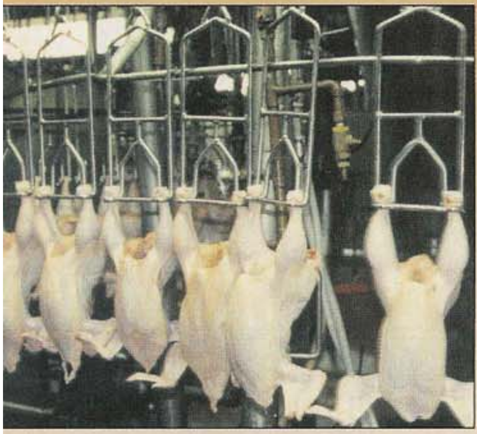
Automated shackling: how close is it?



*By taking a step-by-step approach to the design process and by learning how to manipulate the behavioural and physical characteristics of broilers, researchers in Georgia, USA, have made considerable progress. — **Dr Bruce Webster and Dr Kok-Meng Lee***

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 the conveyor or crate, reorient them and quickly force the shanks of the legs down into a passing shackle. Typically, eight workers hang 180 broilers every minute or one bird every 2.5-3.0 seconds for each worker. The work is physically demanding and repetitious, creating the 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 noisy and dark. As a result, its hard to find reliable, conscientious individuals to do the work. Rough handling of the broilers causes 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 years, the broiler industry has wanted to improve the shackling process. Gas killing systems solve some of the problems but still require repetitious labour.

Replacing humans for shackling

In 1997, a research team was formed, comprising engineers from the G W Woodruff School of Mechanical Engineering and the Georgia Technology Research Institute (GTRI) of the Georgia Institute of Technology (Georgia Tech) as well as scientists in the Poultry Science Department of the University of Georgia. The aim was to respond to industry requests for an automated process to replace the human shackling of broilers. The goal of the research programme was to design and develop an automated system to transfer broilers from a conveyor to a shackle line at current processing speeds, with a manufacturing cost that would allow a pay-back in less than a year from labour cost savings. The cost target is to be achieved by lightweight construction with modern materials and software-driven controls integrated with machine vision systems invented by 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 at 45cm per second.

An automated machine system must accomplish these actions with accuracy and speed at least equivalent to that of a team of human workers. Previous attempts to achieve this have failed, often because of a failure to cope with the behavioural and physical characteristics of chickens. A purely mechanical solution is unlikely to be successful but 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 complicated by the bird's postural flexibility and behaviour patterns, to which a human handler is able to react in real-time and gain control of the bird. Even an intelligent machine system cannot cope with all the potential actions of an unrestrained bird so it is necessary to limit the behavioural opportunities of broilers, standardising their postural presentation to machine handling devices.

Conscious or unconscious?

One way to control the behaviour of broilers is to kill them, such as is done with a commercial gas killing system. There are difficulties with this approach: it would require several handling steps 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; and a machine system would have trouble separating DOAs from the rest of the killed birds.

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

- Muscle tone
- Righting response
- Reflexive reactions
- Escape behaviour.

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 could cause serious problems for automated handling. An automated transfer process requires physical or psychological control of broilers to eliminate voluntary behaviour that would interfere with critical handling steps.

Achievements so far

The design and development of an automated live bird transfer system for commercial broiler plants are a challenging problem. This article outlines our work so far.

We have conceived the automated transfer of broilers to the processing line as consisting of the following necessary steps: singulation; orientation, leg capture and inversion. Each of these 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 on some live-bird harvesters. It is possible to separate broilers from groups presented to the counter-rotation drums and carry them through the apparatus individually. This system requires less space than a series of conveyors and it spaces out singulated birds in a pre-designated manner. We anticipated that proper spacing from singulated birds would be important for final grasping and leg capture.

Initial trials with a prototype singulator were successful although we anticipated the need to make refinements as a result of the design requirements determined by subsequent steps.

Orientation

Broilers exit the singulator facing either forward or backward. Since all carcasses on the processing plant

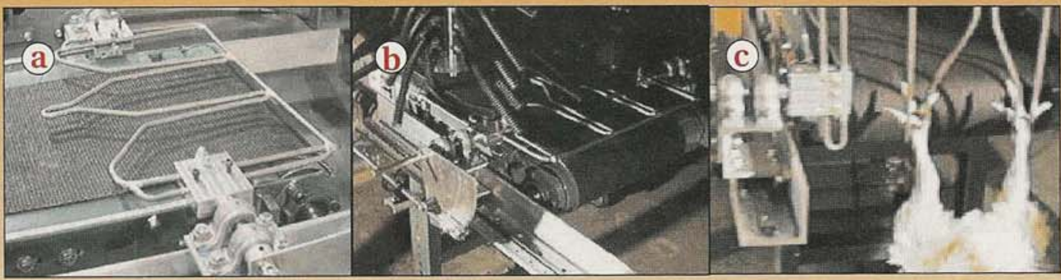


Figure 3. Prototype shackle used with the compliant grasper
(a) prototype shackle and inversion system;
(b) shackle positioned under compliant grasper;
(c) bird hung on rotated shackle

Figure 4. Typical bird posture on approach to the compliant grasper
(a) sit down
(b) sit up
(c) stand

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 the potential to manipulate a bird into an optimum presentation for a shackle. We noticed that when a broiler was clasped gently in human hands and lifted, it would extend its legs to keep a foot in 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 success depended on the posture of the incoming bird (Figure 4), the ability of the bird to see during its approach to the grasper and the transitional speed of the grasper.

Object-handling solutions are simplest to engineer when object presentation is standardised so tests were conducted to gain control the bird's posture. 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. It not being practical to hood broilers for commercial processing, dim blue light was used to suppress vision and most of the broilers did indeed sit down on he approach to the compliant grasper. However, some did not, highlighting the importance of having leg capture technology to handle postural variation where full control of the birds is impossible.

We 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 the 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 centre 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 results when the birds were hooded. Since the time taken to pass through the compliant grasper is in the order of 0.5 second, a positive translational velocity of 10 or 25cm per second means that the bird's body is pushed ahead of its feet (which remain in contact with the conveyor) by 5 or 12cm, respectively, at the exit of the compliant grasper. When the translational velocity was too great, the bird was forced too far forward and tripped 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 augmented 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 effect of different translational velocities. The results of leg kinematics modelling were programmed into the computer software that controls the compliant grasper. The strength of this approach is that the compliant grasper can be tailored for each broiler based on information acquired as the bird approaches the grasper. With intelligent computerised 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 optimise the handling of different sizes of broilers have been proven in tests to be more effective at presenting birds to a shackle than 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. The width of the bird can be calculated from top-view images as depicted in the previous discussion on 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 the 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 towards 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 were grasped too tightly if the centre of the body happened to line up with opposing columns of rubber fingers at the mid-point of travel through the grasper, inducing 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 grasper operation. The best way to grasp a broiler gently yet firmly is 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 synchronisation of the arrival of the broiler with the movement of the counter-rotating artificial hands. It would also require positioning of

Figure 5. Mechanical hand and sideview of the compliant grasping of a broiler

the fingers such that the contact force was always sufficient to hold even a small bird but that the flexural capacity of the fingers should easily accommodate a larger bird. 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 appeared comfortable when cradled in the grasper and did not struggle.

Leg capture

Early attempts to shackle sitting birds resulted in capture of the leg just above the hock joint. A prototype pallet system has been built to work out the design requirements of grasping and leg capture of broilers in continuous series. The pallets, equally spaced, facilitate synchronisation 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 in 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 the foot spacing and leg orientation manifested by broilers.

Broilers placed on plexiglass were photographed from below and leg and foot placements relative to their bodies were measured. Figure 6 shows a picture of one of the broilers and a typical leg placement. As might be expected, the spacing between the legs varied.

Inversion

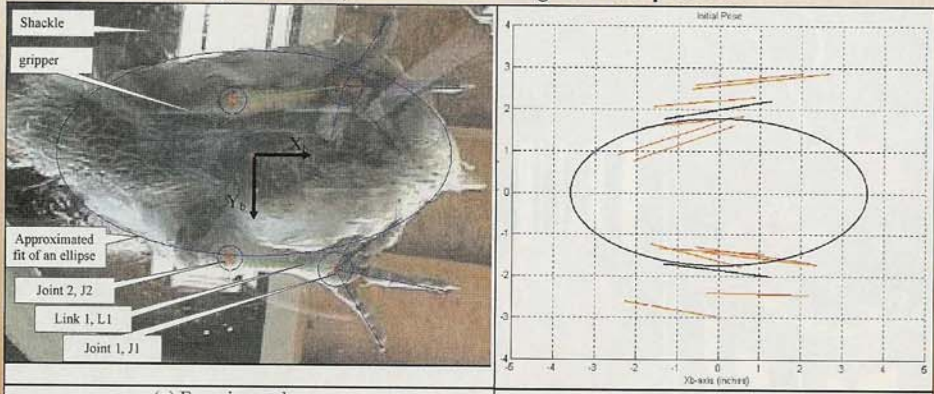
We have done little work on inverting broilers so far because our emphasis has been on capturing their legs, which is necessary before inversion is possible. The prototype shackle used with the compliant grasper and conveyor had a rotating mechanism that tipped birds over the end of the conveyor.

Fear and stress are induced in broilers when they are inverted. It also produces 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 reached 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 next?

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 towards a system with grippers that will lock onto the legs of an upright bird, invert it, release the

Figure 6. Analysis of the bird's leg and foot positions



(a) Experimental setup | (b) Plan view of typical poses legs after delivery to a shackle, and recycle back into position at the compliant grasper. We will finalise our decision on the feasibility of handling forwards 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, an orientation step must be included after the singulation step in an automated transfer sequence.

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

Standard processing lines require that the bird be hung upside down by its legs. 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 in order to induce leg extension, facilitate positive engagement by the leg gripper and eliminate voluntary action by the bird at the critical moment of leg capture. Forced inversion of a conscious chicken causes fear and adds to risk of injury and carcass damage. However, an electrical stun administered in the compliant grasper would enhance animal welfare and perhaps carcass quality relative to the existing commercial situation by minimising aversive handling. The bird would remain upright the whole time it was conscious, whilst leg capture, inversion and transfer would occur after the bird was rendered unconscious. Individual bird stunning would also allow the electrical current delivered to each bird to be standardised. We plan to explore methods to incorporate stunning into the automatic transfer system design.

Once the mechanical designs to accomplish each step of the automatic transfer process have been worked out, they must be scaled up and integrated into a single working system suitable for a commercial unit.

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 manipulate the behavioural and physical characteristics of broilers, we have made considerable progress and we can see the light at the end of the tunnel. — *Dr A Bruce Webster (Department of Poultry Science, University of Georgia, USA) and Dr Kok-Meng Lee (George W. Woodruff School of Mechanical Engineering, Atlanta, USA)*

This article was first published last year in POULTRY INTERNATIONAL's *sister magazine,* WATT *PoultryUSA.*