Proceedings of the 1998 IEEE
International Conference on Robotics & Automation
Leuven, Belgium • May 1998

AUTOMATED SINGULATING SYSTEM FOR TRANSFER OF LIVE BROILERS

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ABSTRACT

This paper addresses the problems of automating the process of transferring live broilers (meat chickens) from a conveyor to a moving shackle line. Specifically, we focus on establishing the criteria for designing for an automated system for singulating and orienting the birds for subsequent transferring to a moving shackle line. Since both the mechanical forces and the bird's natural reflexes contribute to the overall dynamics as the bird passes through the singulator, an experimental prototype singulator has been developed to facilitate the study of bird's natural reflexes to mechanical singulation. The system has been experimentally demonstrated and evaluated with live birds at the Gold Kist research farm and at a poultry-processing plant in Georgia. It is expected that the results will provide significant insights to the design and control of future mechanical singulators.

1. INTRODUCTION

Broilers or meat chickens that are reared in large groups up to 30,000 birds in environmentally controlled houses. They are typically transported from the growing farm to the poultry processing plant at 5-8 weeks of age, when they weigh about 1.25 – 3kg. Food is usually withheld for 8-12 hours, water 1 hour before catching to reduce risk of carcass contamination at the processing plant.

The process of transferring live birds from a conveyor to a moving shackle line is a laborious, unpleasant and hazardous job. The task requires individuals to grasp a live bird by one or both legs and insert both legs into a shackle on a moving conveyor line. Conveyors typically run at speeds of 180 shackles per minute and require about 8 people to fill the lines with birds. The birds are usually moved to a dark room to quiet them down to facilitate grasping and hanging them. The dark room, in combination with high-speed conveyors, dust, feathers, pecking and scratching from the birds provides for a hazardous working environment and has the potential for a variety of injuries. There is the potential for workers to suffer injuries if they get their hands or fingers caught in the moving shackle line. There is also the possibility for a variety of respiratory and visual ailments resulting from the high level of dust and feathers that come off the birds. The birds tend to flail about when they are caught which sometimes results in cuts and scratches which can easily become infected in that environment. The unpleasantness of this task sometimes results in high turnover rates at some plants, which requires constant retraining of new employees. In addition, it is also extremely difficult to attract new workers to the job. This makes the live-bird transfer task an ideal candidate for automation.

Over the past two decades, a number of ideas were proposed to catch birds in large quantities by means of a machine at the farm and hanging live birds on shackles on processing plant kill lines. The ideas range from shackling the birds at the farm to the use of birds' natural reflexes and gas stunning to ease manual hanging. Extensive reviews of prior work in related areas can be found in a number of references (Kettlewell *et al.* 1985; Scott, 1993; Thornton, 1994). Perhaps, the most relevant outcome of the poultry harvester development efforts is the development of the contra-rotating bristles for singulating, which allows live birds to be counted electronically (Briggs *et. al*, 1994). However, unlike the poultry harvester where the rotating bristles are designed to drive the birds into a cage at the farm, the birds must be orientated to allow grasping of legs for transferring them live onto moving shackles at the poultry processing plant. Heemskerk (1992) observed that spraying water or gas under the abdomen of the bird causes them to stand up, making it easier to grasp their legs. Keiter (1992) claimed that when birds are rotated on an incline, they naturally orient themselves to face up the slope. Recently, a method to automate hanging of live birds, similar to that commonly used in the cattle and pork industries where the animals are herded into lanes, was suggested in (Sluis 1996). The method requires a cycle time of 28 seconds for grasping a bird, which is clearly too slow for the typical shackle line speed of 180 birds per minute. No studies have been conducted on carcass injuries on the method of mechanically guiding the birds into a locking mechanism.

Although the demand to automate hanging of live birds at the processing plant has been high, the review has clearly indicated that little or no practical solutions are yet available to adequately address the problems of automating the hanging of live birds. Most studies conducted to date that are relevant to live hang problem have been done on an

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empirical basis and results assessed subjectively. The challenge for the research is to develop design criteria for machines to enable poultry to be handled without causing damage or stress.

The contributions of this paper are briefly summarized as follows: (1) This paper presents a novel design concept and the criteria for automating the singulation of randomly oriented birds on moving conveyor for subsequent transferring processes. (2) Since both the mechanical forces and the bird's natural reflexes contribute to the overall dynamics as the bird passes through the singulator, an experimental prototype singulator has been developed to facilitate the study of bird's natural reflexes to mechanical singulation. (3) The system has been experimentally demonstrated and evaluated with live birds at the Gold Kist research farm and at a poultry-processing plant in Georgia. The results provide significant insights to future design and control of mechanical singulators.

The remainder of this paper is organized as follows: Section 2 presents the design concept of the overall automated live-bird transfer system. Section 3 outlines the operating paramters and the experimental setup is given in Section 6. Experimental results of the birds' natural reflexes to mechanical processes in Section 5. Finally, the conclusions are given in Section 6.

2. DESIGN CONCEPT

Figure 1 shows a conceptual design for an automated system for transferring live birds from a moving conveyor to shackles in a processing line. A typical cycle of the system will begin with the incoming birds unloaded from cages onto a moving conveyor. The conveyor transfers the birds between two sets of contra-rotating fingers that serve two functions. The first function is to cause the birds to stand. The second function is to singulate the birds so that they leave the rotating fingers one at a time. The singulated feed is then led through a cadaver detection system (CDS) consisting of a light emitting diode (LED) and a photo-diode light detector. Each live bird immediately exiting the singulator will be in its standing position distinctly different from that of a cadaver, this information is used to detect and remove cadavers from the feed. The singulated live birds will be directed to a second system of contra-rotating fingers, which gently constrain the bird to allow the transferring operation to take place.

Of particular interest in this live-broiler transfer problem is the design, modeling and control of the singulating manipulator for separating and orienting live broilers into a well-defined single file for subsequent transferring process. The dynamic model of the manipulating system consists of two parts; namely, the forces acting on the broiler as they pass through the system and the broiler's natural reflexes to mechanical singulation. In this paper, the broiler's natural reflexes to mechanical forces have been analyzed experimentally.

In order to characterize the broilers' natural reflexes to the singulation process for a particular design configuration, we have developed a singulating manipulator system as illustrated in Figure 2, which consists of an entry conveyor, a singulating manipulator, and an exit conveyor. Each of cylinders driven by their independent servomotors rotated in opposite direction, which carries n columns of evenly spaced rubber fingers. The singulated broilers are then transferred away on the exit conveyor.

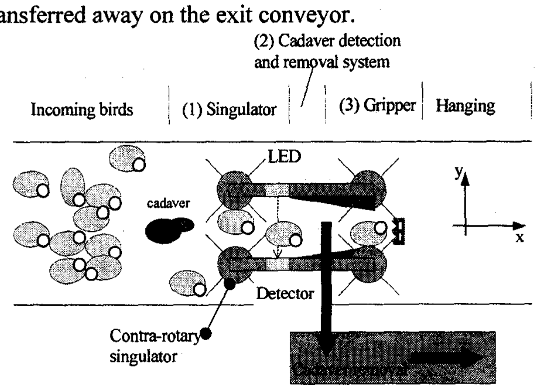

Figure 1 Conceptual schematics

Figure 3 shows the coordinate systems for describing the model of the singulator, where XYZ is the fixed (reference) coordinate frame attached at the center of a rotating cylinder, with its Z-axis pointing along the shaft. The fingers are attached at the circumference of the rotating cylinder, where X_fY_f is a moving coordinate frame attached at the base of the finger. When the finger in contact with the broiler, the reaction force causes the finger to deflect. The finger forces acting on the broiler, which depends significantly on the distance between the two rotating cylinders, cause the broiler to rotate about its body axes as well as to translate in the X- and Y-directions. Parameters affecting the functional performance of the singulating system are

- illumination
- bird's experience through the singulating system
- number of birds clustered on the entry conveyor, M
- the entry conveyor speed, V_1
- conveyor surface friction, μ_1
- the inclination of conveyor, θ
- speed of the rotating fingers, ω
- spacing between the rotating cylinders, D

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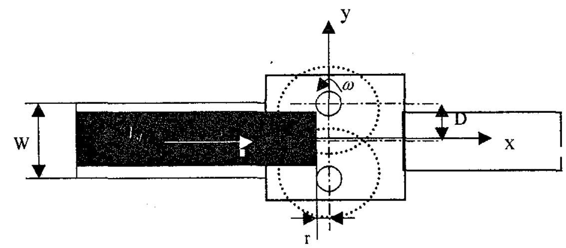
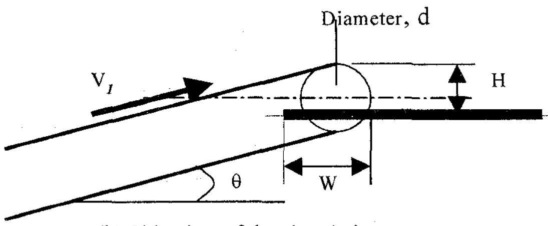
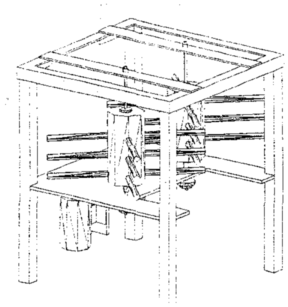
- design configuration of rotating fingers; number, length, and spacing of fingers
- the exit conveyor speed, V_2
- conveyor surface friction, μ_2



(a) Plan view of the singulating system



(b) Side view of the singulating system



(b) Singulating manipulator

Figure 2 CAD model of the singulating system

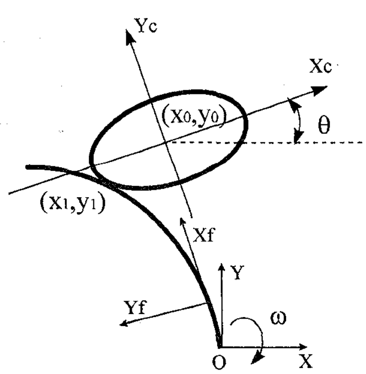
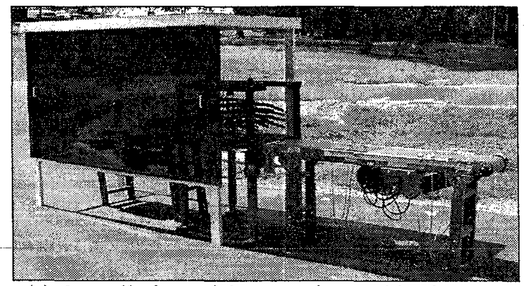


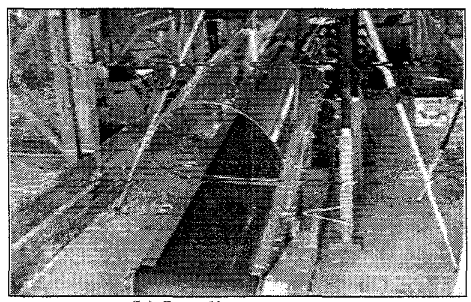
Figure 3 Kinematic model of the finger/ellipse interaction

3. EXPERIMANTAL SETUP

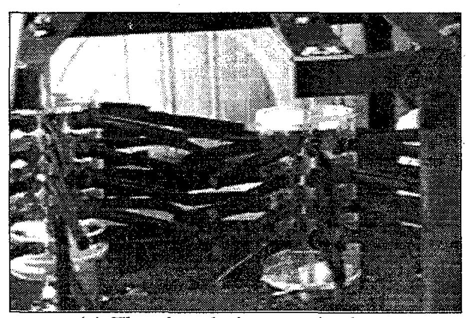
An experimental setup, as illustrated in Figure 2, has been developed at Georgia Tech to facilitate the studies of live birds' reactions to individual mechanical processes involved in the automated live bird transfer problem and to characterize the sensitivity of the design parameters through performance comparison between two design configurations. The experimental prototype is shown in Figure 4. The two designs are compared in Table 1.



(a) Overall view of the experimental basic setup



(b) Loading conveyor



(c) The singulating manipulator

Figure 4 Experimental Prototype

To provide a spectrum of broiler configurations, the system has been experimentally tested with live broilers at the Gold Kist Research Farm and at a poultry-processing plant in Georgia. The primary differences in the test between the two facilities are as follows:

(1) The broilers at the Gold Kist Research Farm are about 5-6 weeks old and weigh between 1.36-1.6kg (3.0-

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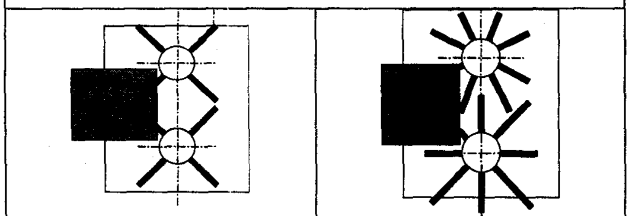
3.6lbs). The broilers at the poultry processing plant are 7 weeks old and weigh between 2.7 and 3.2kg (6-7 lbs.)

(2) The broilers at the processing plant are typically more stressful due to fasting, catching, transporting, and waiting at arrival in cages.

The birds' natural reflexes as they pass through the experimental setup are recorded using video camera recorders for analysis.

Table 1 Comparison of design parameters

PARAMETERS	DESIGN 1	DESIGN 2
Singulator Rotational Speed (rpm)	*150*	*100*
Columns of fingers evenly spaced	*4*	*8*
Spacing between fingers longitudinally	*0.1m or 4 in.*	*0.05m or 2 in.*
Number of fingers per columns	*3/2*	*5/4*
Number of fingers (total)	*20*	*72*
V_1 = 0.12 m/s, h = 0.0875m for d=0.1m, θ = 8.5°, r = 0.025m, conveyor width = 0.3m.		



Design 1 | Design2

4. EXPERIMENTAL RESULTS ON THE EFFECTS OF OPERATING PARAMETERS

The first set of experiments is to determine the nominal values of the operating parameters for the test bed and birds' natural reflexes to moving conveyor towards the rotating fingers. The parameters that may affect their natural reflexes are discussed and illustrated in Figure 2.

Effect of drop-off height

In an initial study, the conveyor inclination θ and the drop-off height h were set to zero. It was observed that the bird gripped on the gap between the conveyor and the singulator to resist the dragging motion of the fingers as illustrated in Figure 2, particularly when the singulator is rotating at a low speed. For this reason, the configuration of the entry conveyor was modified so that the bird is transported into the region within the reach of the fingers. In addition, the conveyor was raised to a level higher than that of the singulator. This design hides the gap avoiding the bird gripping on the gap and facilitates the fingers to wipe the birds through one at a time. It is expected that when the birds' feet lose contact with the floor, they become alarmed and spread their wings. To avoid wings' injuries, the drop-off step is limited to 0.087m (3.5 inches).

Effect of inclination/ surface roughness of entry conveyor

In general, the birds feel more secure when they were placed on rough, non-slippery surfaces than on smooth, slippery surface of plexiglass. Prior studies (by others) have further suggested that birds tend to face uphill when they ride on an inclined conveyor. This natural behavior could be used to orient the birds prior to sigulation. To observe this effect, the inclination of the conveyor, which has a relatively rough surface, was varied up to $\theta = 8.5°$. It was observed experimentally that the inclination of the conveyor tends to discourage the naive birds to walk backward. However, no voluntarily orientation change by the bird was observed on the conveyor (moving at a speed of 0.12 m/s) for the range of inclination $0° \geq \theta \geq 8.5°$. The birds were observed to sit or stand quietly on the moving conveyor.

Effect of conveyor speed

The speed of entry conveyor V_1 depends on two primary factors. The first is to prevent jamming at the entry of the singulator, which could happen if V_1 is too fast with respect to ω. On the other hand, too low conveyor speed V_1 could potentially reduce the throughput. Thus, the speed of the entry conveyor is important when multiple birds are fed through the system. The speed of the entry conveyor is limited by the continuity equation or

$$V_1 < \frac{\omega D}{n_c \cos\theta}$$

where n_c is the maximum number of birds that can be packed across the width of the entry conveyor. For example, if D = 0.2m (8 inches), n_C=3, and θ = 8.5°, the limiting speed of the entry conveyor is 0.12 m/s corresponding to the rotating speed of the fingers, ω = 100rpm, or a maximum throughput of 1 bird per second.

The second factor to be considered is the natural reflexes of the birds entering the system. In a preliminary study, a bird was fed through the singulator on the conveyor at a speed of approximately 0.5m/s. The bird, given no time to react, was observed to enter the singulator in the same direction as it was fed in. The test was repeated with two other birds but at a slow conveyor speed of 0.12 m/s. Both the birds were fed in sitting position but one after another. The first approaching bird was observed to stand up and turn away from the singulator before coming in physical contact with the revolving fingers. The low conveyor speed apparently gave the birds ample time to react. The birds, however, stood passively backward on the moving conveyor towards the rotating fingers. This instantaneous reflex provided the system fingers an opportunity to wipe the birds through the singulator. Both the singulated birds left the revolving fingers one at a time in the backward direction.

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Effect of multiple clustered birds on entry conveyor

Several tests were conducted using a group of six clustered birds. It was observed that the first naive bird, with a good view of the singulator, stood up and turned around to avoid visual contact with the revolving fingers. The remaining birds reacted in the similar fashion due to a combination of the following reasons; namely, visual contact, agitating action of the wiping fingers, as well as being pushed by other birds. All the six birds were separated as they left the singulator.

The last bird that had more time to turn back and walk away from the singulator but was finally pulled through the singulator by the rotating fingers. It is expected that in a commercial situation where a large number of birds are transported on the conveyor, there is little opportunity for the bird to walk away.

Effect of bird's experiences

When six naïve birds were fed through the system, they were observed to voluntarily turn away from the revolving fingers. Practically, most of the naive birds exited the system backward. The same phenomenon was observed when the birds were put through the second time. However, when the birds were fed through the revolving fingers more than twice, their behaviors at the entry to the singulator were somewhat less predictable. Although most of the "experienced" birds would turn backward to avoid the agitating effects of the rotating fingers, some became less fearful, and passed through the system passively. Quite often, the last bird made multiple attempts to walk away. Consequently, the orientations of these "experienced" birds exiting the revolving fingers are often less repeatable.

Effect of illumination

To examine the effect of the illumination on incoming birds, the light intensity was reduced by means of a red filter, the birds were observed to be rather passive on the conveyor until they were in physical contact with the rotating fingers or pushed by the adjacent birds. The exit orientations were observed to be relatively non-uniform.

5. EXPERIMENTAL COMPARISON OF TWO DESIGN CONFIGURATIONS

Two design configurations have been studied. The first allows the bird to orient itself and the second aims at fully constraining the bird during the singulating process. Their parameters are compared in Table 1. The observations are summarized as follows:

5.1 Design Configuration 1

Most of the naïve birds enter the singulator backward to avoid the agitating effect of the fingers if they are given time to react. Controlling the loading conveyor speed provides a means to regulate the reaction time required. However, when birds are clustered on the conveyor, there were situations that some were pushed into the singulator sideways or in the forward direction.

When the naïve birds are given adequate space between fingers as in the case of the first design configuration, they tend to voluntarily re-orient themselves. Thus, both the rotating fingers and the bird itself contribute to the resultant motion.

Figure 5 compares three different poses as the broiler passes through the singulator. The corresponding settling distance and time are given in Table 2.

When the bird enters the singulator in the forward direction, it spreads its wings in an attempt to fly through the singulator. As a result, it tends to move with a much larger momentum than other entering poses.

When the bird crosses the singulator backward, its motion is more predictable and typically settles in a shorter distance and time than the forward entering pose.

In some occasions, the bird is pushed into the singulator sideway and tends to resist the fingers' motion as shown in Figure 5(c). However, the bird generally re-orients itself and allows the system to push it through.

Table 2 Effect of entry poses

Entering pose	Settling distance	Settling time
Forward	0.4-0.5m (16-20inches)	1 second
Backward	0.2-0.25m (10-12 inches)	0.67 second
Side	0.2-0.25m (10-12 inches)	1.5 seconds

5.2 Design Configuration 2

Unlike the design configuration 1 where the bird could feel the drop-off step as it walks backward, in design configuration 2 the lower layers of the fingers lift the bird's legs up before the legs reach the end of the conveyor. Once the bird's legs lose contact with the conveyor, it spreads its wings but the upper layers of densely spaced fingers exert a firm grasp on the bird. As a result, the bird is carried and moved forward between the fingers by the singulator.

As soon as the bird is moved through the singulator, it lands on the platform of the singulator, which is 87.5mm (3.5 inches) lower than the conveyor surface. The rotating fingers exert forces primarily on the chest of the bird. The fingers cause the bird to trip backward and flap its wings as it attempts to land. However, once the bird secures its landing with both feet, it scoops down to avoid the rotating fingers and settles in a sitting pose.

A significant difference between the two designs is the birds' ability to orient themselves within the singulator. The results has shown that by appropriately designing the

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fingers, the contra-rotary singulator can be developed as an effective dynamic grasping mechanism which fully constrains and lifts the bird as shown in Figure 6. On the other hand, design 1, which offers the bird some space to maneuver itself, could be further developed as a servo-controlled orientation manipulator based on the knowledge of the bird's natural reflexes.

6. CONCLUSIONS

The design concept of an automated system for transferring randomly oriented live broilers from conveyor to a moving shackle line has been presented. Specifically, the paper has focused on the development of a singulating manipulator for separating and orienting live broiler for subsequent transferring process. A static force model and its role in predicting the dynamics of the singulator have been developed. Since both the mechanical forces and the bird's natural reflexes contribute to the overall dynamics as the bird passes through the singulator, an experimental prototype has been developed to facilitate the study of bird's natural reflexes to mechanical singulation. The system has been experimentally tested with live birds at the Gold Kist research farm and at a poultry-processing plant in Georgia. The results of the tests have been discussed.

ACKNOWLEDGEMENT

This project has been supported by the Georgia Agriculture Technology Research Program and the US Poultry and Eggs Association. The authors would like to thank Drs Micheal P. Lacy and A. Bruce Webster of University of Georgia for their discussions and assistance on birds' behaviors.

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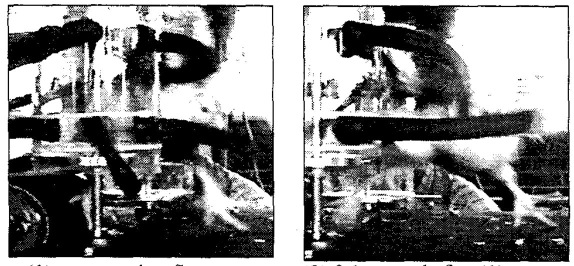
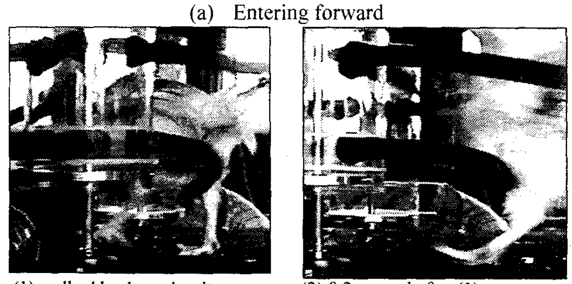


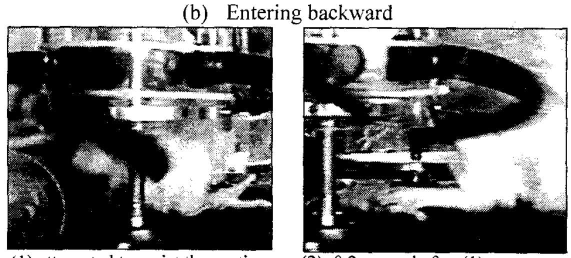
(1) attempted to fly across (2) 0.1 second after (1)

(a) Entering forward



(1) walked backward as it passes (2) 0.2 second after (1)

(b) Entering backward



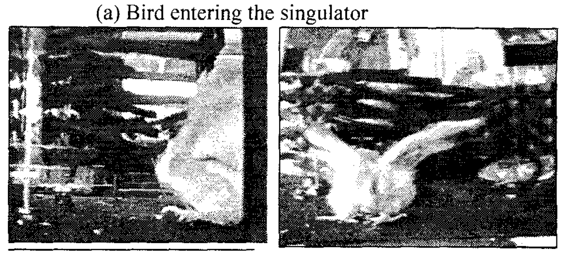
(1) attempted to resist the motion (2) 0.2 second after (1)

(c) Entering sideway

Figure 5 Effect of the birds' entry poses (Design 1)

(1) Side view (2) Front view

(a) Bird entering the singulator



(1) Side view (2) Front view

(b) Bird leaving the singulator

Figure 6 Effect of finger configuration (design 2)

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