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DESIGN CRITERIA FOR DEVELOPING AN AUTOMATED LIVE-BIRD TRANSFER SYSTEM

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ABSTRACT

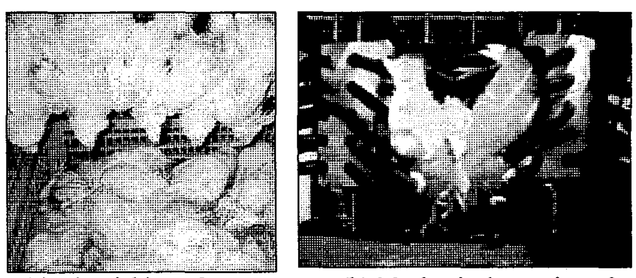
This paper presents the design criteria for developing machines to automate the process of transferring singulated live birds from a moving conveyor onto a processing line without causing damage or stress. The process includes inserting both legs of the bird into a shackle, flipping and hanging it for subsequent processing. Specifically, the paper illustrates the operating principles of the transfer system and describes the method for manipulating the leg kinematics for shackling. Unlike the traditional articulated robotic arm where the actuations are applied directly through the joint angles, the legs of a live object can only be manipulated indirectly. In addition, natural objects are typically characterized by varying sizes and shapes in batch processing and their natural reflexes (or voluntarily motion) contribute to the overall dynamics. The design criteria have been verified experimentally with live broilers (meat chickens) in a realistic environment. It is expected that the analytical model presented here would provide an essential basis for the design, analysis and control of the transfer mechanism.

1. INTRODUCTION

Many industries processing natural products require that live objects be transferred from conveyors to moving processing lines. The repetitive task of transferring live objects is often laborious, unpleasant and hazardous. In the poultry industry, the task requires individuals to grasp a live broiler by one or both legs and insert both legs into a shackle on a moving conveyor line typically running at speeds of 180 shackles per minute. The birds are usually moved to a dark room to quiet them down in order to facilitate grasping and hanging them. The dark room, a combination of high-speed conveyors, dust, feathers, pecking and scratching from the birds creates a hazardous working environment with the potential for a variety of injuries. 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. As a results, the live-bird transfer task is an ideal candidate for automation.

Over the past two decades, a number of ideas were proposed to hang live broilers on shackles. Parker (1974) developed a method of loading the poultry into a shackle before transported from the farm. The same shackle becomes a part of the transport coop structure on which the poultry is restrained during transport. At the processing plant, the shackle with the poultry suspended is loaded directly on the conveyor for further processing. Parker's method has the advantage of reducing the amount of labor required in the overall operation of removing the poultry from the farm to the processing plant. Several studies (Kettlewell *et al.* 1985; Scott, 1993), however, have suggested that birds held stationary suffered more carcass bruising (particularly bruised drumsticks and broken wings) than they suffer when transported unrestrained. For this reason, developed poultry harvesters are designed to drive birds into module crates that allow multiple birds to move around within the crate and to adjust heat loss by altering posture during transport.

An alternative suggestion was to gas stun/kill the birds before hanging them on the shackle. While it potentially eases manual grasping and hanging processes as the broilers become non-reactive, the attempt to automate non-reactive birds would essentially lead to a notorious bin-picking process as shown in Figure 1(a). Bin picking poses no difficulty for human operators, as they are able to visually locate the legs among the overlapping birds, and they use a combination of hand-eye coordination and touch to correctly hang the birds on shackles. Attempts to use vision systems and/or tactile systems that essentially duplicate the human processes have proved more costly and unreliable than desired in high-speed batch processing. In addition, any unexpected delay between the (manual or automated) hanging and the neck cutting/bleeding processes could result in damaging the product.



(a) Bin-picking of non-reactive bird (b) Mechanical grasping of live birds

Figure 1: Comparison of active and non-reactive birds

An important aspect of automating the transfer of a live bird from a conveyor to a shackle is the need to consistently present both legs of a properly oriented bird to the shackle. Heemskerk (1992) suggested that spraying water or gas under the abdomen of the bird causes it to stand up, making the bird's legs easier to grasp. Keiter (1992) claimed that when birds are rotated on an incline, they naturally orient themselves to face up the slope. Most of these studies conducted to date that are relevant to the live-bird hanging problem have been done on an empirical basis and results assessed subjectively. For these reasons, we have

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investigated methods of grasping live broilers (Lee, 1999) to facilitate transferring of live birds, leading to the development of a compliant grasper (Lee *et al.*, 1999). As compared in Figure 1, the grasped bird's natural tendency to extend its legs may potentially ease the task of locating the legs. These encouraging results have motivated the author to explore the use of the body-feet velocity difference to manipulate the bird's legs for subsequent processes, which could be electrical or gas stunning. Specifically, this paper provides the following:

(1) the design concept and operational principles of a potentially useful system for transferring live broilers from a moving conveyor to shackles:

This paper is the first to detail the basic principles of using flexible fingers for manipulating the leg kinematics of a live broiler on a moving conveyor. The system has the ability to accommodate a limited range of varying sizes, shapes, and some motion due to the birds' natural reaction to mechanical grasping.

(2) It presents a simulation algorithm for assessing the effects of the design changes on the leg kinematics:

The simulation presented here provides an essential basis for future design optimization and control of the live-object transfer system. As it will be demonstrated in Section 4, the simulation that forms an integral part of the design process to provide a window for the functioning of the leg-kinematics control process could potentially reduce the number of hardware/software configurations to be tested.

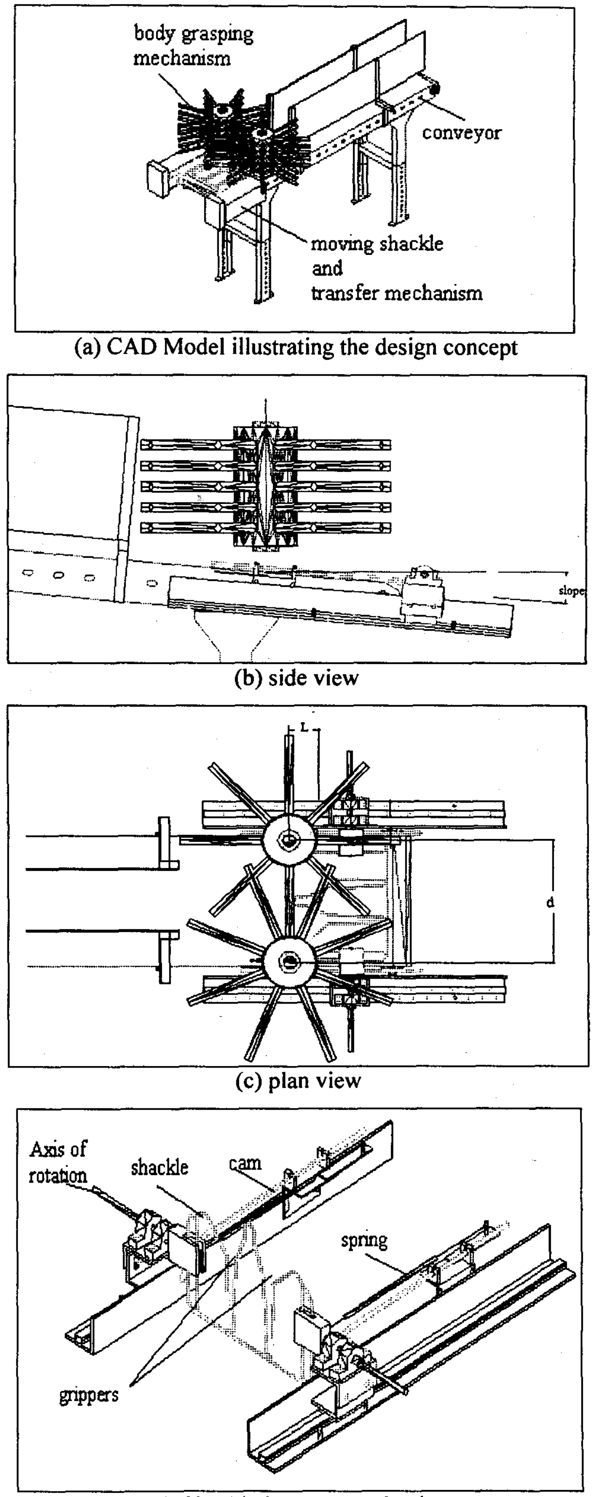
(3) It presents experimental evaluation of the design with a case study involving live broilers.

The experiment with live broilers has provided an effective means of verifying the design criteria in a realistic environment. It offers insight into how the birds' natural reflexes contribute to the overall success of the automated transfer of live birds. Along with a discussion of the results, issues to be addressed in the future works are summarized in Section 5.

2. DESIGN CONCEPT

Figure 2 shows the CAD model of a live-bird transfer system that consists of a rotating body-grasper, an inclined conveyor, and a shackle-inverter. The grasper is essentially a pair of drums filled with flexible fingers. The two drums, rotating at the same speed but in the opposite direction, move the bird toward the shackle inverter while the fingers constrain the posture of its body. The conveyor is inclined downward with respect to the rotating axes of the drums so that the bird can extend its legs freely between the grasper and the conveyor. Since the bird tends to keep its feet in contact with the conveyor, the legs of the bird can be manipulated by appropriately controlling the drum speed with respect to the conveyor speed.

In operation, the birds are fed in a single file on the inclined conveyor, as shown in Figures 2(b) and 2(c), toward the body grasper and the shackle inverter. The shackle is pre-tensioned to keep it in place until the legs are engaged in the grippers. Once the legs are inserted in the grippers, both the bird and the shackle are free to travel together. When the bird/shackle combination reaches the end of the conveyor, the momentum along with the gravity, causes the bird to rotate with the shackle. Figure 2(d) shows the CAD model of an inverted shackle.



(a) CAD Model illustrating the design concept

(b) side view

(c) plan view

(d) Shackle inverter mechanism

Figure 2: Automated transfer mechanism

3. OPERATIONAL PRINCIPLES

The success of the automated transfer system depends on (1) an accurate presentation of the legs to the shackle, (2) the application of the velocity input, and (3) the relationship between the shackle and the velocity input.

3.1 Leg-Presentation Kinematics

Figure 3 illustrates the leg kinematics of a bird, where ℓ_1 and ℓ_2 are the lengths of the lower and upper limbs respectively; J_1, J_2 and J_3 are the ankle, hock, and hip joints respectively; θ is the inclination angle of the conveyor; and α is the angle between the rotating axis and the conveyor. In Figure 3, the XY coordinate frame is the reference system assigned at the intersection between the rotating axis of the drum and the conveyor. The X- and Y-axes are directed along and perpendicular to the conveyor surface respectively. As the feet of the bird are in contact with the conveyor, joint 1 travels on the moving conveyor at a velocity V_1.

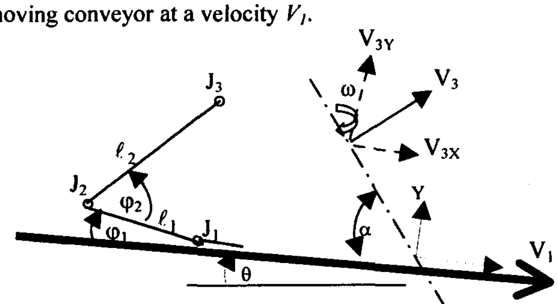


Figure 3: Leg kinematics on moving conveyor

The positions of joints 2 and 3 are given as follows:

$$J_{21} = \ell_1 \begin{bmatrix} -\cos\varphi_1 \\ \sin\varphi_1 \end{bmatrix} \tag{1}$$

$$J_{31} = \ell_1 \begin{bmatrix} -\cos\varphi_1 \\ \sin\varphi_1 \end{bmatrix} + \ell_2 \begin{bmatrix} \cos\varphi_{21} \\ \sin\varphi_{21} \end{bmatrix} \tag{2}$$

where J_{21} and J_{31} are the position vectors of the joints 2 and 3 with respect to joint 1; and $\varphi_{21} = \varphi_2 - \varphi_1 = -\varphi_{12}$. The bird body, grasped between the fingers-filled drums, is translated at a velocity V_3 in the direction perpendicular to the rotating axis. Equation (3) provides a means to determine the kinematics for presenting the legs to the shackle inverter:

$$\begin{bmatrix} \ell_1 \sin\varphi_1 + \ell_2 \sin\varphi_{21} & -\ell_2 \sin\varphi_{21} \\ \ell_1 \cos\varphi_1 - \ell_2 \cos\varphi_{21} & \ell_2 \cos\varphi_{21} \end{bmatrix} \begin{bmatrix} \dot{\varphi}_1 \\ \dot{\varphi}_2 \end{bmatrix} = \begin{bmatrix} V_{3X} - V_1 \\ V_{3Y} \end{bmatrix} \tag{3}$$

where $V_{3X} = V_3 \sin\alpha$ and $V_{3Y} = V_3 \cos\alpha$. Equation (3), a non-linear differential equation, can be numerically solved for the leg's motion, $\varphi_1(t)$ and $\varphi_2(t)$, the solution of which depends on the size of the bird and the drum speed.

3.2 Application of the Velocity Input - Drum Speed

The method for predicting the contact force acting by a rotating finger on the bird can be found in (Lee, 1999). The finger exerts a force f at the contact point as the drums rotate. For a positive grasp, $\mu f_n > f_t$ such that the finger would not slip past the object, where μ is the static coefficient of friction between the object and the finger; and f_n and f_t are the normal and tangential components of the contact force respectively.

To determine the drum speed for a specified body velocity, we model the body of the broiler as an ellipsoid:

$$\frac{x^2}{\eta^2} + \frac{y^2}{\lambda^2} + \frac{z^2}{\gamma^2} = 1 \tag{4}$$

where η, λ, and γ are characteristic radii of the ellipsoid. As the finger rotates, it intercepts the ellipsoid at $y = y_i$ ($|y_i| < \lambda$). The cross-section intercepted by the rotating finger is essentially an ellipse:

$$\frac{x^2}{a_s^2} + \frac{z^2}{b_s^2} = 1 \tag{5}$$

where $a_s^2 = \eta^2[1 - \frac{y_i^2}{\lambda^2}]$ and $b_s^2 = \gamma^2[1 - \frac{y_i^2}{\lambda^2}]$. For a positive, symmetric grasping (with no slip at the contact surface), the bird and the finger have the same velocity at the contact point and thus the bird translates along the centerline between the two drums as shown in Figure 4, where 2s is the spacing between the two adjacent rows of fingers.

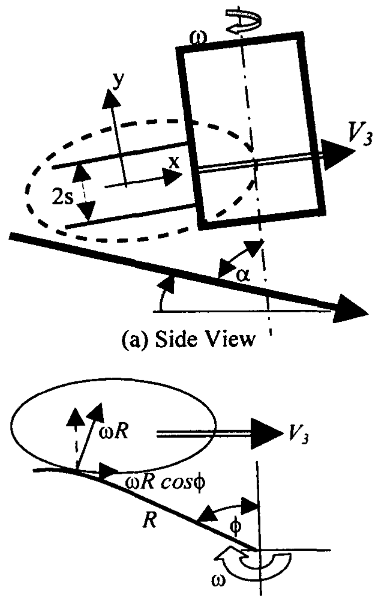


Figure 4: Drum speed determination

Since the broiler and the finger have the same velocity at the contact point, the magnitude of the velocity at joint 3 is

$$|V_3| = |\omega R \cos\phi| \tag{6}$$

where ω is the angular speed of the drum; R is the distance of the contact point from the axis; and the angle ϕ is defined as shown in the plan view of Figure 4. For a small variation of $\omega R \cos\phi$, the drum speed can be approximated by

$$\omega = \frac{2}{d - 2b_s} |V_3| \tag{7}$$

where ω is the angular speed of the drum; and d is the distance between the rotational axes of the two drums.

3.3 Shackle Location and Limiting Input Velocity

When one or both of its legs strike the shackle at point B (see Figure 5), the impact could cause the bird to rotate about B. The stability depends on the shackle position as well as the location of the center of gravity (CG) relative to its feet during the impact. If the CG is ahead of the critical position at which it is directly above the point B during the impact, the momentum togather with the gravity could cause the bird to trip over.

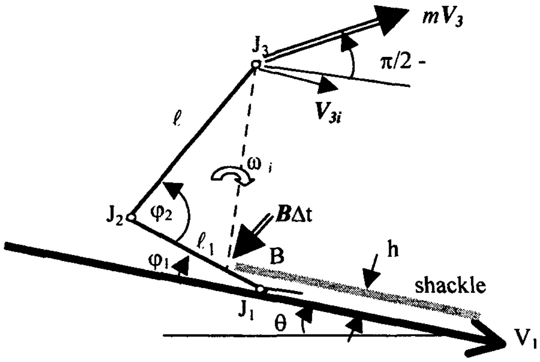


Figure 5: Kinematics at the point of impact

In order to prevent the bird from toppling over, it is desired to derive an expression for the limiting value of V_3. We make the following assumptions in the subsequent derivation: (1) Based on the observation of a bird's posture in equilibrium, the bird's CG is approximated at the mid-point between its hip joints. (2) The impact at B is assumed to be perfectly plastic. (3) The mass of the paw is negligible. (4) The only impulsive force external to the bird is the impulse reaction at B.

The position vector of the point B with respect to joint 1 is

$$\boldsymbol{J}_{B1} = \begin{bmatrix} -h\cot\varphi_1 \\ h \end{bmatrix} \tag{8}$$

where h is the spacing between the shackle and the conveyor.

$$\boldsymbol{J}_{3B} = \boldsymbol{J}_{31} - \boldsymbol{J}_{B1}. \tag{9}$$

We apply the principle of impulse and momentum to the bird about B. Together with the bird's rotational inertia $I_z = \frac{1}{5}m(\eta^2 + \lambda^2)$ where m is the mass of the bird, we have

$$V_3 = \frac{J_{3B}^2 + \frac{1}{5}\left(\eta^2 + \lambda^2\right)}{Y_{3B}\sin\alpha + X_{3B}\cos\alpha}\omega_i \tag{10}$$

where $J_{3B} = |\boldsymbol{J}_{3B}|$; and X_{3B} and Y_{3B} are the X- and Y-components of $\boldsymbol{J}_{3B}$ respectively. With the application of cosine rule, we have

$$J_{3B}^2 = \left(\ell_1 - \frac{h}{\sin\varphi_1}\right)^2 + \ell_2^2 - 2\left(\ell_1 - \frac{h}{\sin\varphi_1}\right)\ell_2\cos\varphi_2 \tag{11}$$

The body should not have any kinetic energy when the CG is directly above B in order to prevent the bird from toppling over. We apply the principle of conservation of energy between the initial and the critical positions:

$$T_i = mgJ_{3B}(1 - \cos\beta) \tag{12}$$

where the kinetic energy at the instant of impact is given by

$$T_i = \frac{1}{2}mV_{3i}^2 + \frac{1}{2}I_z\omega_i^2 = \frac{m}{2}\left[J_{3B}^2 + \tfrac{1}{5}(\eta^2 + \lambda^2)\right]\omega_i^2 \tag{13}$$

where $\beta = \tan^{-1}\left(\frac{|X_{3B}|}{|Y_{3B}|}\right) - \theta$ and $X_{3B} \le 0$. We substitute Equations (13) into Equation (12), which yield

$$\omega_i^2 = 2g\frac{J_{3B}[1 - \cos\beta]}{J_{3B}^2 + \frac{1}{5}(\eta^2 + \lambda^2)} \tag{14}$$

Thus, the limiting magnitude for the velocity V_3 is given by

$$V_3 \le \frac{\sqrt{2gJ_{3B}(1 - \cos\beta)\left(J_{3B}^2 + \frac{1}{5}\left(\eta^2 + \lambda^2\right)\right)}}{Y_{3B}\sin\alpha + X_{3B}\cos\alpha} \tag{15}$$

which is a function of the leg presentation at the impact.

For constant V_1 and V_3, this presentation (or the joint angles) can be expressed in terms of input velocity difference as

$$\varphi_2 = \cos^{-1}\frac{\ell_1^2 + \ell_2^2 - (X_{31}^2 + Y_{31}^2)}{2\ell_1\ell_2} \tag{16}$$

$$\varphi_1 = \tan^{-1}\frac{Y_{31}}{X_{31}} - \tan^{-1}\frac{\ell_2\sin\varphi_2}{\ell_1 - \ell_2\cos\varphi_2} \tag{17}$$

and

$$\begin{bmatrix} X_{31} \\ Y_{31} \end{bmatrix} = \boldsymbol{J}_{31i} + \begin{bmatrix} (V_{3X} - V_1)(t - t_i) \\ V_{3Y}(t - t_i) \end{bmatrix} \tag{18}$$

where $\boldsymbol{J}_{31i}$ is the initial leg posture before entering the grasper.

4. DESIGN CRITERIA AND EVALUATION

In order to provide a quantitative measure for evaluating the performance of a live-bird transfer system design in a realistic processing facility, we define the following measures:

- ***Average Hanging-Performance-Index*** *($\overline{HPI}$):*
  The HPI value, which ranges from 0 to 5, is a measure how well the bird is hung:
  HPI=0– when the bird is hung by two legs,
  HPI=1– when the bird is hung by one leg and one hock,
  HPI=2– when the bird is hung by two hocks,
  HPI=3– when the bird is hung by only one leg,
  HPI=4– when the bird is hung by only one hock, and
  HPI=5– if the bird escapes hanging.
- ***% Success*** (%S) = % of birds hung with HPI<3
- ***% Failure*** (%F) = % of birds escape handing (or HPI=5)

Since a detailed discussion of the compliant grasping mechanism design can be found in (Lee; 1999 and Lee *et al.*, 1999), this study focuses on the following design parameters that could potentially affect the system performance: (1) the conveyor inclination, (2) the angle between the axis and the conveyor surface, (3) the location of the shackle with respect to the drum axes, and (4) the operating drum speed with respect to that of the conveyor. These parameters must be designed along with considerations of the bird's visual responses to mechanical grasping and manipulation.

4.1 Entry Posture

It is desired to keep the variability of the birds' initial postures and natural reflexes to mechanical processes as uniform as possible in order to minimize the demand on the control efforts of the transfer system. Based on the following observations, we choose "sitting" as a preferred entry posture:

1. As food is usually withheld for 8-12 hours, water 1 hour before catching to reduce risk of carcass contamination at the processing plant, most of the birds are expected to be weary.
2. Birds tend to sit when they are in darkness.
3. In order to avoid the fingers from swiping the legs, it is desired to have the bird sit as it enters.

Preliminary experiments using live birds have suggested that birds dislike (and become panic on) slippery surface. With an inclined plane where the coefficient of friction between the surface and a sitting bird was estimated experimentally to be $\mu = \tan 25° = 0.4768$, the bird's tendency was to sit when the surface is moderately inclined (15° or less), apparently to lower its CG for stability. When the downward-inclined plane was moving, the bird was observed to lean back (sit up) in order to maintain its balance. Too large an inclination angle or a conveyor speed caused the bird to become nervous.

4.2 Design Parameters and Operating Speed

For a specified conveyor inclination and speed, the velocity of the bird body must satisfy the following constraints imposed by the location of the shackle as shown in Figure 6:

1. The bird's body must be lifted over the shackle.
2. The shackle must grip the lower limbs of the bird.

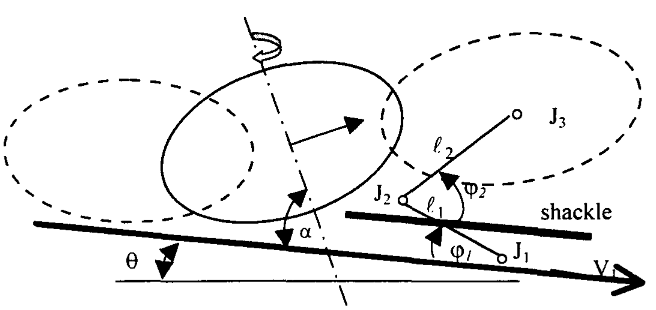


Figure 6: Trajectory specification and motion constraints

The parameters that could be designed to satisfy the constraints include the angle between the conveyor and the drum axes, the rotating speed of the grasper, and the location of the shackle. To reduce the number of hardware/software configuration combinations to be tested, a simulation algorithm has been written based on the equations detailed in Section 3. The effects of the design changes on the leg kinematics were studied using simulation. 4. The values of the design parameters estimated are summarized in Table 1. As illustrated in Figure 7 for a given conveyor speed of 0.375m/s, a relatively low body-velocity will result in two problems: (1) significant pressure on the hock joint, and (2) the insufficient lift of the hock joint. On the other hand, too high a body-speed will cause the bird to topple over the shackle.

Table 1 Simulation Parameters

Location of grippers' entry	L=150mm (6 in.), h=25mm (1 in.)
Finger spacing:	2s = 50mm (2 in)
Drum radius:	81.25mm (3.25 in)
Spacing between axes:	d= 362.5mm (14.5 in.)
Conveyor parameters:	α=82.5°; θ=7.5°; V_1=0.375 m/s (15 in/s)
Average bird size:	2η=195mm; 2λ=112mm; 2γ=132mm
Average lengths of the leg:	ℓ_1 =72mm (2.9 in); ℓ_2 =95mm (3.8 in)
Typical "sit-down" posture:	φ_{1i}=0°; φ_{2i}=45°

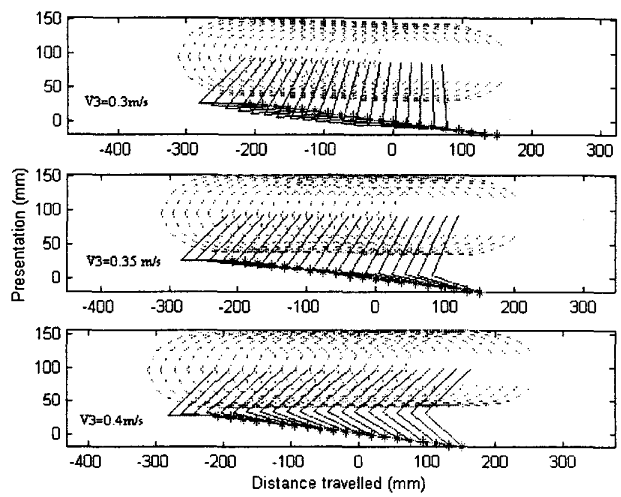


Figure 7: Trade-off between pressure on hock joint and stability

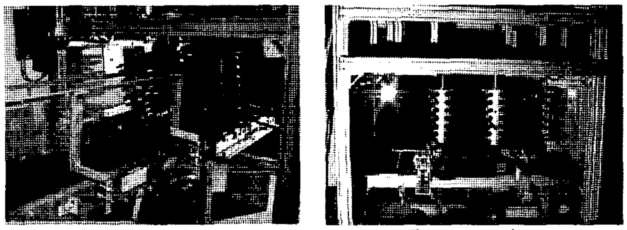
4.3 Experimental Verification with Live Birds

Figure 8 shows the experimental test-bed used in evaluating the transferring system design, where θ and α can be independently adjusted. Specific values of the parameters were determined using a hybrid design technique of computer simulation and experimentation involving live broilers. Twelve different experimental trials were conducted with 120 novice broilers (57 female and 63 male) from a poultry processing plant to examine the key parameters that significantly affect the birds' entry-posture and to evaluate the system performance. These broilers' characteristic dimensions are summarized in Table 2.

Table 2 Bird Characteristics

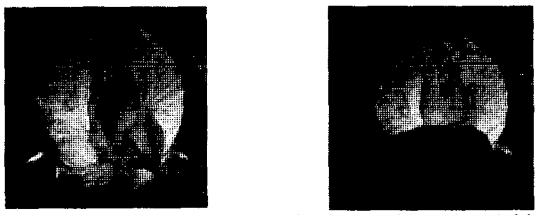
	Female (57 birds)		Male (63 birds)	
	Mean	Std. dev.	Mean	Std. dev.
Weight (kg)	1.56	0.12	1.76	0.18
Body height, mm (in)	110 (4.4)	10 (0.4)	115 (4.6)	12.5 (0.5)
Body length/height	1.7	0.1	1.7	0.2
Body width/height	1.2	0.1	1.2	0.1

The experimental trials involved three conveyor angles (θ=0, 7.5°, and 15°) and two shaft-conveyor angles (α=75 and 90°) and in each pair of angles, the entry postures with and without bird's vision (Figure 9) were experimentally compared. For each of the 12 trials, 10 birds were used. The bird was placed on a 6-foot (1.8m) conveyor moving at 0.375m/s (or 15 in./s). Its presentations before entering the grasper at 1.2m (or 48 in.) from the point of drop-off and after inverting the shackle were imaged for analysis.



(a) Side view (b) Front view

Figure 8: Experimental test-bed



(a) Bird with vision (b) Covered by a hood, bird in complete darkness

Figure 9: Bird with and without vision (in sitting posture)

Entry Posture

The observed postures are compared in Table 2, where each conveyor-inclination trial includes 20 birds regardless of the α values. The results show that the bird's visual reflex has a significant effect on its posture before entering the grasper. Of the 60 birds tested without vision, over 80% of the birds were found to sit still as they entered the grasper; and the preferred conveyor inclination was found to be $\theta = 7.5°$ at which all 20 birds maintained a sitting posture as shown in Figure 9(b).

Table 3 Entry Postures (V_1=0.375 m/s or 15 inches/s)

	With Vision			Without Vision		
	θ=0°	θ=7.5°	θ=15°	θ=0°	θ=7.5°	θ=15°
sit down	35%	25%	5%	80%	**100%**	85%
sit up	45%	50%	75%	10%	**0%**	10%
stand	20%	25%	20%	10%	**0%**	5%

Numerical simulation

The effects of the size-variation on the relative location of the CG and the lift of the hock joint were studied numerically for the range of birds characterized by $(175, 100, 112)_{min}$, $(195, 123, 133)_{mean}$, and $(212, 137, 162)_{max}$ where $(2\eta, 2\lambda, 2\gamma)$ are in mm. The trade-off's have led to a preferred nominal drum-speed of 21.5rpm at α=75°. The results are summarized in Table 4.

Table 4 Effects of bird size (ω=21.5rpm, α=75°)

Bird Size	Minimum	Average	Maximum
V_3 m/s (in/s)	0.353 (14.13)	0.341 (13.62)	0.322 (13.04)
b_s mm (inch)	49 (1.95)	68 (2.37)	76 (3.03)
X_{3B} mm (inch)	−1.25 (−0.05)	−16.5 (−0.66)	−34 (−1.36)
Y_{21} mm (inch)	25 (0.99)	19 (0.761)	10.9 (0.44)

Experimental Evaluation

The results are compared in Table 5, each of which involved 10 hooded birds (without vision) and the drum speed, measured experimentally, was 21.5±1.5rpm. The two α values are 75°, a preferred value among simulation trade-off's, and 90° at which the drum axes are perpendicular to the conveyor and thus the lift is only provided by the speed difference V_3-V_1. Table 5 compares the results of the six trials. As expected, the entry posture and the two inclination angles have significant effects on the performance of the transfer system. The best performance has been the trial with θ=7.5° and α=75°, which has a 100% success of hanging all the 10 hooded birds entering with a "sit-down" posture. The corresponding HPI distribution was (HPI=0:3, HPI=1:4, and HPI=2:3).

Table 5 Performance Comparisons ($\overline{HPI}$, %S, %F)

	Vision		Without Vision (hooded bird)	
	α=75°	α=90°	α=75°	α=90°
θ=0°	4.1, 10, 50	4.2, 10, 70	4.6, 60, 10	3.9, 10, 40
θ=7.5°	3.3, 40, 30	3.0, 40, 10	1.0, 100, 0	2.4, 60, 20
θ=15°	3.8, 20, 50	2.2, 80, 10	2.9, 40, 20	2.5, 60, 10

5. CONCLUSIONS

The design concept and operational principles for developing an automated transfer system have been developed. The system uses the body-feet velocity difference to manipulate the leg posture of the bird moving on a conveyor. The hybrid design technique, a combination of motion simulation and experimentation, has been illustrated involving live broilers. The results show that the birds' visual response to the mechanical grasper and the conveyor inclination for a specified speed and coefficient of friction have significant effects on its entry posture. Simulation was shown to be an effective tool for trade-off between the bird stability and the hock location for a range of size variation. Current efforts are directed toward evaluating bird's vision acuity in different spectral environments, use of a posture-dependent drum speed profile to improve the hanging performance, and developing predictive models to analyze the effect of contact forces on tissue damage and carcass quality.

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