

Signal Processing for Animal Behavior Detection

Colin T. Usher, Dr. Wayne Daley
Food Processing Technology Division
Georgia Tech Research Institute
Atlanta, GA, USA

Dr. Bruce Webster, Dr. Casey Ritz
Poultry Science Department
University of Georgia
Athens, GA, USA

Abstract—Researchers at the Georgia Tech Research Institute and the University of Georgia recently concluded an experiment studying animal reaction to robotic systems. The purpose of this study was to determine if the operation of robots in a poultry grow-out house environment is feasible from an animal behavior perspective. To determine this, an experiment was conducted operating both an aerial and a ground robot in a small-scale grow-out house housing broiler chickens for a typical growth cycle (6 weeks). Humans also interacted with the flock daily. The environment and robots were equipped with cameras and other sensors to record data for the entire duration of the experiment.

The research team established a set of measurable metrics with which to quantitatively assess the impact of operating the robots. These metrics included average avoidance distance, average speed when avoiding, and average recovery time. A software program was developed to assist in the analysis of these metrics.

Analysis shows that there are statistical differences in the average avoidance distance metric but there is no significant difference between the average speeds, or with the recovery time metric, indicating that operating robots in the environment is no more stressful to the chicken than the presence of a human.

I. INTRODUCTION

Before the wholesale operation of autonomous or other robotic systems in confined housing environments, it must first be established that the operation of these devices do not have a deleterious effect on the animals housed therein; neither on their performance or on their well-being. Using broilers as an example there is concern that a fear response could be induced in the animals. Past research has raised a concern that fearful broilers may be less productive (Hemsworth, 1994). While there is a plethora of information available about human-robot interaction (Schultz, 2007), there is a surprising dearth of information about robot-animal interaction. Perhaps the most closely related research was performed looking at robotic shepherding of ducks (Lien, 2004, Vaughan, 1998). Other examples of earlier research include using robots to model animals (Webb, 1995) and exploring mixed societies of robots and insects (Caprari, 2005). However, none of this earlier work concerned itself with the animal welfare, interaction and environmental constraints that would be associated with operating robot systems in a commercial poultry production grow-out house.

In order to evaluate the effects of the vehicles selected for testing, metrics were designed that compared the birds' behavior with the robots in the environment to their behavior with humans in the house; since the farmers must regularly enter the houses to attend to the care of the broilers. The primary assumption is that farmers must enter the house daily to perform routine tasks. Therefore, if the bird's reaction to the robot systems is similar or less than their reaction to the farmers, we can make the argument that the vehicles are not introducing undue stress to the flock. In addition, during all tests, observations were made to ensure that the birds were not exhibiting any behaviors that would indicate stress such as piling or making vocalizations that indicate fear such as predator calls (Evans, 1993). Appropriate statistical tests to compare these measures were utilized to determine the significance of the chosen metrics.

II. MATERIALS AND METHODS

Two robotic systems were deployed and operated in an experimental broiler grow-out house environment to simulate operation of such systems in a real-world setting. The method chosen to evaluate the impact on the animals was to compare the reaction and behavior of the animals with the robots to their reactions to the presence of humans normally in the environment. Several metrics were defined in order to make these comparisons.

A. Experimental Grow Out House Environment

In order to replicate the conditions of a full-sized commercial grow-out house environment, a 24' by 20' room was stocked with 500 chickens. The size and number of chicken provided approximately .75 square feet of space per bird (Fairchild, 2005) when fully grown. This stocking density is similar to the densities expected in a full-sized commercial house. The environment was instrumented with ceiling mounted cameras to cover the entire floor area as shown in Figure 1. In addition, microphones were installed to record the vocalizations of the animals. High definition video and audio was recorded for the entire duration of the experiment.

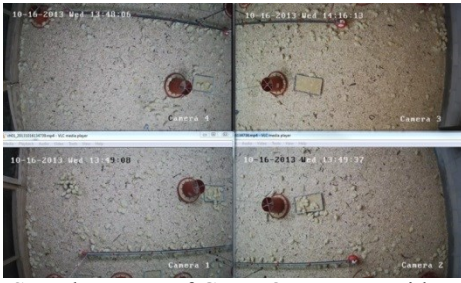


Figure 1 – Sample Image of Grow Out House Video Capture System

B. Robot Systems

A commercially available robot chassis from Super Droid Robots was selected for use as the ground system. This system was retrofitted with a Microsoft Kinect 3D camera and a laptop for data recording. A quad-rotor Parrot AR.Drone2.0 was selected for use as the aerial robot.

C. Test Procedure

The general procedure was to operate both vehicles remotely while observing the progress of the vehicles and the animals to ensure no serious accidental interactions between the birds and the vehicles. Both robots were operated in the experimental house one time each day by the same operator for an entire growth cycle of 6 weeks. Both vehicles traversed the house in the same partial figure-8 pattern illustrated in Figure 2. Attendants also traversed the house once each day in the same pattern, in addition to performing regular maintenance tasks such as stocking feeders and checking equipment.

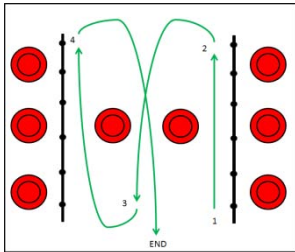


Figure 2 - Vehicle Navigation Path

D. Analysis Metrics

The metrics chosen for the analysis were: Avoidance Distance, Flight Response and Recovery Time. The avoidance distance metric is defined as the average distance between the chicken and the external stimuli, whether it be humans or the robot systems, as it moves throughout the house. The flight response metric is defined as the animal response running away from external stimuli. The mass of movement, their average speed, and distance of travel can all be quantitatively characterized. Finally, the recovery time metric is defined as the average time it takes before the chicken resume “normal” activity after the stimulus leaves the environment. This is accomplished by looking at local densities of the chicken, their movement, and characterizing normal behavior.

E. Analysis Tool

In order to assist in the analysis of the metrics, an image processing tool was developed. This software program detects and characterizes motion in the environment, attempting to capture individual animal movements and trajectories. A screenshot of the tool is shown in Figure 3. Here, the red circles indicate current detected motions, the green circles indicate a chicken that previously was moving, but is currently standing still. Their trajectories are represented as lines emanating from the circles.

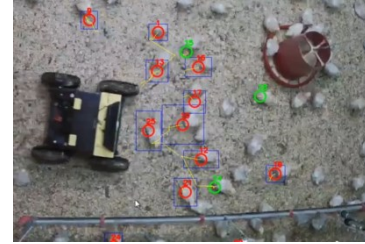


Figure 3 - Image Processing Tool Screenshot

1) Motion Detection Algorithm

The basis of the motion detection algorithms is built upon using motion history gradients (Davis, 1997). Due to their color (especially when young), image segmentation for identifying individual chickens is difficult. Therefore, individual chickens are identified and tracked based solely on their motion. Due to the nature of the environment, simple frame differencing using equation (1) is used to generate silhouettes used in the motion history image. Here, F_n is the current image frame, F_{n-x} is the x^{th} previous frame (typically 2 or more), and F_s is the resulting image silhouette.

$$F_s = |F_n - F_{n-x}| \quad (1)$$

A motion history image is generated using a technique based on (Davis, 1997):

$$MHI(x, y) = \begin{cases} t, & \text{if } F_s(x, y) \neq 0 \\ 0, & \text{if } F_s(x, y) = 0 \text{ and } MHI < (t - d) \\ MHI(x, y), & \text{otherwise.} \end{cases} \quad (2)$$

Here, pixel (x, y) in MHI is set to the current frame time t if pixel (x, y) in F_s contains motion (are non-zero). If $F_s(x, y)$ contains no motion and the motion history image time is less than current time t minus a pre-defined duration d , then $MHI(x, y)$ is set to 0. Else, pixel (x, y) is set to its previous existing frame time. This allows generation of a time/motion gradient image, where motion over time can be extracted. A visualization of this is shown in Figure 4.

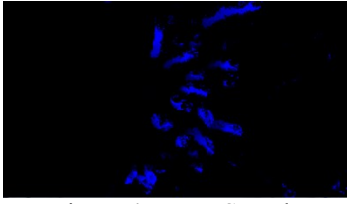


Figure 4 - MHI Sample

Individual motion is segmented by defining an appropriate duration d , based on observational data. A larger duration results in filtering out of slower/meandering motions where a smaller duration captures more discrete/short motions. Adjusting this value was required in order to capture motions of chickens of different ages/sizes.

2) Individual Bird Tracking

Once segmented, each individual motion is labelled and added to a motion object M for tracking. The current location of the motion is defined as the centroid of the detected motion mass. A minimum linear distance L_{min} is calculated between the current motion and all motions in the previous frame. If L_{min} is greater than a threshold t , then motion M_n is assigned a new id, else it is assigned an id from the previous frame's motion object as shown in equation (3).

$$ID(M_n) = \begin{cases} ID(M_{n-1}), & \text{if } L_{min} < t \\ ID(new), & \text{if } L_{min} > t \end{cases} \quad (3)$$

When a motion is detected in the current frame, we are interested in tracking both its current and previous locations. Therefore, the motion object is extended to include all previously detected locations for associated motions as described above. This allows for tracking of trajectories for calculating movement direction, speed, and other metrics.

3) Gross Motion Analysis

Individual motions segmented from the MHI are bounded by rectangles. Gross motion in an image can be calculated by summing the area of all of the rectangles and dividing the result by the area of the entire image as shown in equation (4). Here G is the gross motion, A_n is the area of detected motion n , and A_{img} is the area of the entire image.

$$G = \frac{(\sum_{i=0}^n A_n)}{A_{img}} \quad (4)$$

4) Stimuli Detection

In addition to tracking the individual chicken, we are also interested in locating and tracking the external stimuli (robots and humans). This is required in order to calculate the necessary metrics for the experiment. While advanced techniques exist for feature detection or machine learning to segment the images, a simple color threshold technique was used. The color-space of both the robots and humans was far

enough removed from the rest of the environment that it allowed for a threshold to be applied to the color image for segmentation. Different threshold parameters were required for each stimulus as they were not all similar. The centroid of the detected stimuli is tracked for each frame in order to calculate the metrics required for the experiment.

5) Calculating Metrics

The image processing tool is used for calculating each of the three metrics described earlier. The average distance metric is calculated by recording the linear distance between the detected stimuli and the 5 closest detected motions in each frame for the entire duration of the test. An average is then calculated using the following equation where $D1$ through $D5$ are the linear distances between the stimuli and the 5 closest motions and n is the number of frames.

$$\frac{(\sum_{i=0}^n D1_n + D2_n + D3_n + D4_n + D5_n)}{5n} \quad (5)$$

The flight response metric has several components. A user randomly selects single motions with clearly detected trajectories and the average speed is then calculated in the software by tracking the trajectory of the selected motion in each frame. The frame rate of the recording system is approximately 30 frames per second. The average speed for each motion is then calculated frame by frame and the average speed is determined using equation (6).

$$\frac{\left(\sum_{i=1}^n \frac{\sqrt{(X_{M_n} - X_{M_{n-1}})^2 + (Y_{M_n} - Y_{M_{n-1}})^2}}{30} \right)}{n-1} \quad (6)$$

Here, X and Y are the image coordinates of the detected motion, M_n is the detected motion in the current frame, M_{n-1} is the detected motion in the previous frame, and n is the number of frames.

The gross motion analysis is used for determining both the flight response and the recovery time metric. For the flight response, the maximum detected gross motion during a test is recorded. For the recovery time, the gross motion is stored for each frame and the resulting data can be analyzed to determine the time it takes for the motion in the house to return to normal levels after a stimulus leaves.

6) Shortfalls

The image processing tool has several shortcomings. For example, assigning identifiers for motions as described earlier is not directional, therefore it is possible for motion ID's to change from one detected motion to another when a new motion is detected in close proximity to an existing one. In addition, when individual small motions converge, they tend to merge, making tracking of these difficult. The software has been modified to accommodate merging motions by

continuing to track individual motions in the merged mass, but this is not always perfect. Several approaches such as probability based ID assignment based on trajectories can be implemented to improve these shortfalls. Currently, manual observation of the tool is used to remove outliers and select the best data-set possible for determination of the metrics.

III. RESULTS

At the conclusion of the test, the image processing tool was used to generate results for each of the metrics described earlier. Two way ANOVA tests were run on each of the metrics to determine if there are statistically significant differences between each stimulus. These tests showed that there was a significant difference between the robots and the humans for the distance metric, but no significant difference for both the flight response and the recovery time metric.

1) *Avoidance Distance Metric*

The analysis shows that over the course of the grow-out the chickens avoided the ground robot with an average distance of 2.22 feet with a standard deviation of 0.54 feet. They avoided the air robot with an average distance of 3.13 feet with a standard deviation of 1.21 feet. Day 12 and day 25 were noted as outliers due to crashing of the air vehicle during the test. They avoided the humans with an average of 2.86 feet with a standard deviation of 1.13 feet. Figure 5 below shows the results from this analysis for the majority of the grow out period.

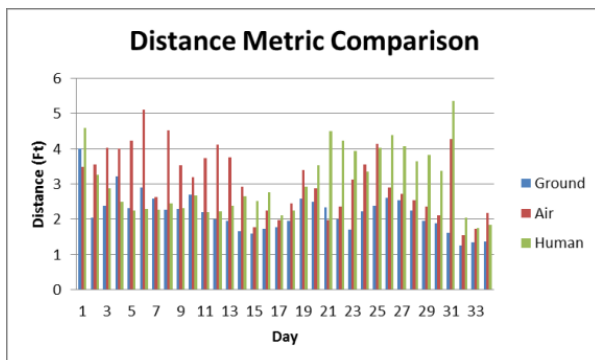


Figure 5 - Avoidance Distance for all Stimuli

2) *Flight Response Metric*

Figure 6 shows the average speed of the chickens as they actively avoided the stimuli. The flight response metric showed no significant difference in the data between each of the stimuli. While the overall mass of movement and distance of travel was also observed, only the average speed portion of the flight response metric is illustrated herein for brevity.



Figure 6 - Flight Response Average Speed Metric

3) *Recovery Time Metric*

In all cases, the gross motion in the house recovered almost instantaneously after the stimuli stopped moving. Figure 7 shows a plot of the gross motion data for a single operation of the ground robot in the house. The Y-axis represents the gross motion as a percentage of the entire house. The left and right sides of the graph show very low movement values, the peaks represent movement in the house as the chickens actively avoid the robot.

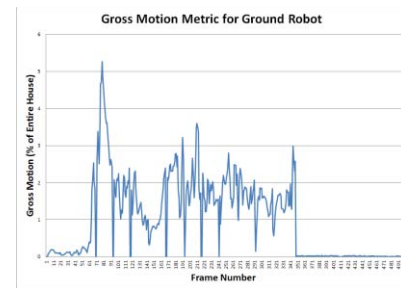


Figure 7 - Gross Motion Metric for Ground Robot

CONCLUSIONS

An image processing tool for motion analysis was developed for the purpose of determining animal reaction to the operation of robot systems in a poultry house. The team's analysis shows that there is no detrimental effect on the chicken due to operation of robotic systems in the house as compared to human interaction. In fact, the data appears to show that the chickens tend to react less to the robot systems than to humans, specifically with the avoidance distance metric. This indicates that the birds adjusted to the vehicle operation, becoming more comfortable with them as opposed to the humans.

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