Evaluating avoidance distance and fleeing speed of broilers exposed to aerial systems

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Abstract: Intensive labor chores for broiler production could be reduced by using automated systems. However, broilers' response toward automated systems remains unclear. The experiments were conducted to determine the avoidance distance (AD) and the fleeing speed (FS) of 4-8 weeks old broilers toward two aerial systems, a rail with a dummy arm and a drone, operated at different speeds (0.2-1.2 m/s), and heights (0.3-1.8 m) in a commercial broiler house. The broiler AD to a human assessor was also determined for comparison. Results show that the overall mean and standard error (SE) of broiler AD were 63±3 cm for the assessor, 58±1 cm for the rail, and 85±1 cm for the drone. As bird age increased from week 4 to week 8, broiler AD reduced significantly from 82 to 45 cm for the rail but showed no significant change for the drone. As the operational speed increased, broiler AD significantly increased from 54 cm (0.2 m/s) to 62 cm (0.4 m/s) for the rail, and from 81 cm (0.4 m/s) to 89 cm (1.2 m/s) for the drone. As the operational height increased, broiler AD increased from 54 cm (0.3 m) to 57 cm (1.5 m) for the rail and 81 cm (1.2 m) to 88 cm (1.8 m) for the drone. Overall mean and SE of broiler FS were 0.21±0.01 m/s for the rail and 0.65±0.01 m/s for the drone. As bird age increased from week 4 to week 8, the mean broiler FS decreased from 0.47 to 0.07 m/s for the rail and from 0.84 to 0.16 m/s for the drone. Increasing operational speed from 0.2 to 0.4 m/s for the rail and from 0.4 to 1.2 m/s for the drone significantly increased the mean FS from 0.18 to 0.24 m/s and from 0.52 to 0.78 m/s, respectively. Increasing the height of the rail from 0.3 to 1.5 m decreased the broiler FS from 0.27 to 0.16 m/s. However, increasing drone height from 1.2 to 1.8 m retained a similar FS. The outcomes of this study can help to better understand the interaction of broilers with aerial systems and provide insights into the optimization of robotic operational strategies while maintaining good broiler welfare production.

Keywords: aerial automated system, avoidance distance, broiler, drone, fleeing speed
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1 Introduction

Production of broiler chickens in the United States increased significantly in the past decades[1]. Over 42 billion pounds of chicken meat[2] with a value of over $31 billion[3] was produced in 2018 alone. The rapid yearly increase of broiler production has gradually increased the amount of labor required to withstand the growth[4]. Current commercial broiler farms require manual labor to perform daily flock inspections which are laborious and time consuming. A solution to reduce labor and increase production efficiency is to use automated assistance in the broiler houses. Common automated assistance comes in the form of sensors for thermal environment, weight scale, and air quality assessment. These are stationary sensors that only gather information in a localized area inside the poultry house[5-8]. In the recent past, products like the eyeNamic[9] has provided farmers to continuously monitor the behavior of broilers with multiple cameras attached inside the poultry house. On the other hand, using an AV with multiple sensors, i.e. temperature, relative humidity, acoustic, movement or health sensors integrated within itself could also be deployed for welfare and behavior monitoring. The mobility of an AV can also be used to encourage bird activity, to provide a clearance for better floor and mortality visualization, as well as, to aid multiple houses. The potential of AVs in a poultry houses has yet been fully grasped, as most precision livestock farming (PLF) technologies are still under the experimental phase[10,11].

The utilization of robotics in other industries has generated high interests within the poultry industry. Products that are either ceiling mounted, e.g. Poultry Hawk and ChickenBoy, or those operated on the ground, e.g. Octopus and Tibot robots have been recently developed and commercialized to conduct flock maintenances for broiler production[12-14]. Previous studies investigating robotic vehicles[15,16] have suggested that robot usage in broiler farms could provide important information to farmers about problems that may arise in a poultry house. Compared to ground vehicles, aerial automated systems or aerial vehicles (AVs) are receiving more interest since they can be used without direct contact with the birds. However, AVs have predominantly been used in the crop production[17-19], and some in the poultry industry's meat processing and packaging sector[20]. Lack of research regarding robotic and automated systems in commercial broiler houses has limited the poultry industry's confidence with their applications. Furthermore, as animal welfare is of high concern

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nowadays, it remains unknown about the broiler stress or fear that could be induced by the use of AVs.

Stress can be caused by environmental conditions, bird handling, or machine usage within the broiler house. Common methods to assess such stress have often been invasive, e.g. physiological analysis of corticosterone levels and heterophils/lymphocytes (H/L) ratios[21,22]. Non-invasive metrics, such as avoidance distance (AD) and fleeing speed (FS), can be viable alternatives for broiler stress or fear assessments. The AD is the distance between an animal and an approaching object at the moment of animal withdrawal, for which a shorter AD reflects less fearful stresses of the animal to the approaching object[23,24]. The FS is the moving speed of an animal within a short period after the onset of withdrawal from the approaching object.

The interactions of broilers with AVs have not been studied thoroughly. Factors such as approaching object, bird age, AV operation speed, and AV operation height are likely to influence the behavioral responses of broilers. Understanding the effect of these factors on broiler-AV interaction may offer valuable statistics for the optimization of future robotic operational procedures. The objectives of this study were to evaluate the AD and FS of broilers to a rail system at speeds of 0.2 m/s, 0.3 m/s, and 0.4 m/s, and heights of 0.3 m, 1.2 m, and 1.5 m; and a drone at speeds of 0.4 m/s, 0.8 m/s, and 1.2 m/s, and heights of 1.2 m, 1.5 m, and 1.8 m. All tests were performed in commercial broiler houses.

2 Materials and methods

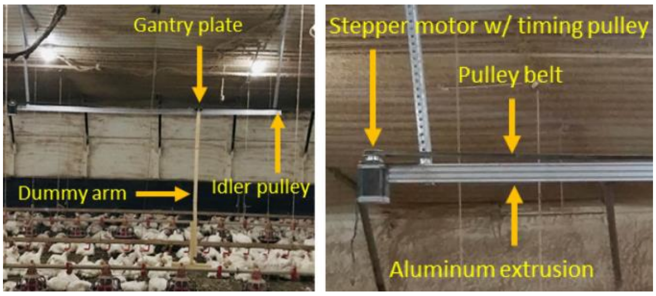
2.1 Housing system and flock management

The commercial broiler farm consisted of two identical houses. Each house measured 120 m×13 m×3 m (L×W×H) with a capacity of 18 700 Ross 708 broilers and a production cycle of 8 weeks. During this experiment, lighting conditions, flock managements and diets followed the typical procedures of the industry.

2.2 Aerial system

2.2.1 Rail system

The rail system consisted of a T-slotted aluminum extrusion, a pulley system, and a gantry plate with a suspending dummy arm made by lumber (Figure 1a). The 3 m long T-slotted aluminum extrusion was horizontally mounted to the ceiling at 2 m high using plated steel slotted angles. The pulley system consisted of a pulley belt and a NEMA 34 stepper motor that was controlled using an Arduino UNO R3 (Figure 1b). To mimic a robotic arm, a length-adjustable suspending lumber 5 cm×15 cm (L×W) was attached to the gantry plate. The movement of the gantry plate and the dummy arm was driven by the pulley system and produced a 66 dB noise level.



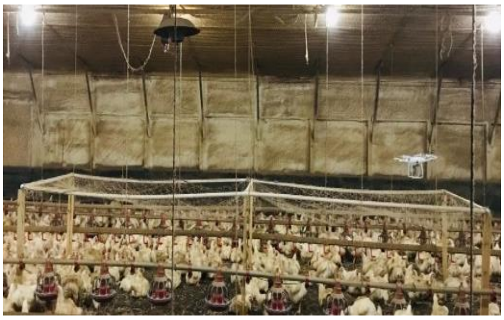
a. Rail system b. Operating system

Figure 1 Rail and operating systems used in this study

2.2.2 Drone system

The drone used was a white DJI Phantom 4 Pro V2.0 (DJI, SZ DJI Technology Co., Ltd, Shenzhen, China) (Figure 2a). It had overall dimensions of 0.5 m×0.4 m×0.2 m (L×W×H) with a total weight of 1.4 kg. It could be operated at a maximum speed and height of 6 m/s and 6000 m, respectively. The intelligent flight battery had a capacity of 5870 mA h and had a battery life of up to 30 min per charge. It was equipped with a 2.5 cm 20-megapixel sensor capable of recording at 4K/60 fps video. The safety system included forward, rearward and downward vision sensors, obstacle sensing, and obstacle avoidance systems. The drone was controlled using the OcusSync remote controller with built-in screen (Figure 2b). The remote controller had a battery life of 5 h and could operate the drone up to 7 km distance. Sending control signals and receiving video signals concurrently was possible with the 5.68 GHz video transmission capability. The low-noise propellers produced 76 dB noise level. A netting system made of nylon fishing net was placed 1 m above the litter floor with a dimensions 6.0 m×1.5 m (L×W) (Figure 2c). This overhead net was used to prevent injuring birds from accidental fall of the drone, while allowing birds underneath to see the drone flying.

a. Drone b. Remote controller



c. Netting system

Figure 2 Materials used in this study

2.3 Experimental setup and procedure

The broiler-assessor, broiler-rail, and broiler-drone ADs were evaluated at different bird ages, operational heights and operational speeds of the aerial systems. The AD of broilers was tested on one day in 4, 6, 7, and 8 weeks of bird age. Broiler-rail AD was determined by operating the dummy arm at three speeds, i.e. 0.2 m/s, 0.3 m/s, and 0.4 m/s, and three heights above the floor, i.e. 0.3 m, 1.2 m, and 1.5 m. Broiler-drone AD was determined by operating the drone at three speeds, i.e. 0.4 m/s, 0.8 m/s, and 1.2 m/s, and three heights above the floor, i.e. 1.2 m, 1.5 m, and 1.8 m. Both systems were operated on the test days only.

2.3.1 Procedure for broiler-assessor avoidance distance test

Broiler-assessor AD was assessed following the standard procedures described in the assessment protocol for broiler[25]. Specifically, the assessor walked slowly (0.2 m/s) in the open litter area at a distance of 1.5 m from the feeder line. The assessor held his/her hands on their abdomen. When a bird sat near the edge of the feeder line, the assessor turned toward the bird and approached it at a speed of 1 step/s or 0.6 m/s. When the bird turned away and retreated (both feet step aside or back), the distance was measured from the front feet of the assessor to the original sitting position of the bird using a tape measure.

2.3.2 Procedure for broiler-rail and broiler-drone avoidance distance test

The rail and drone systems were manually controlled by an operator at least 5 m away from the test area to avoid assessor interference. The rail system was operated at a specific speed and height, moving forward and backward the length of the rail. The drone was flown at a specific speed and height in a straight line over the middle of the net and back to the original location. The operator monitored the experimental area using the webcam Logitech C615 (Logitech International S.A., Newark, CA) connected to a laptop. Using a tape measure placed at bird level in the image, the pixel-to-distance conversion factor was determined. The recorded videos were converted into (.jpg) picture format using MATLAB (The MathWorks, Inc. Natick, MA), then the ADs were obtained by analyzing the images. The ADs of 21 birds were determined at all treatment combinations (age × rail/drone speed × rail/drone height).

The distance between the bird position at the onset of retreating and the nadir point of the aerial system was considered as the AD (Figure 3). In figure 3, actual lengths of OB, OC, OD, BD, and AS were determined through either manual onsite measurements or pixel-distance conversion in the image. The AD was then calculated using trigonometric equations (Equations (1)-(5)).

$$\tan\alpha = \frac{OB}{OC} \tag{1}$$

$$AB = AS \times \tan\alpha \tag{2}$$

$$OA = OB - AB \tag{3}$$

$$\cos\beta = \frac{OB^2 + OD^2 - BD^2}{2(OB)(OD)} \tag{4}$$

$$AD = \sqrt{OA^2 + OD^2 - 2(OA)(OD)(\cos\beta)} \tag{5}$$

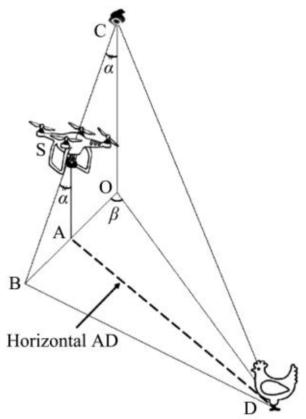


Figure 3 Illustration of broiler-drone avoidance distance.

2.3.3 Procedure for determining fleeing speed

Fleeing speed (FS) is defined as the bird running speed within a short period after the onset of withdrawal from an approaching aerial system[15]. The FS of 21 broilers within the first 0.5 seconds of withdrawal were determined at all bird ages, aerial system speeds, and aerial system heights. After the video files were converted to images, two pictures that were half a second apart when the targeted bird began fleeing were selected. Next, the coordinates of the targeted bird in both images were identified. Then, the distance between the two coordinates was determined and used to calculate the fleeing speed during this period.

2.4 Statistical analysis

Effects of bird age, rail/drone speed, rail/drone height, approaching object, as well as the two-way and three-way interactions on broiler AD and FS were analyzed using the Generalized Linear Model (GLM) in SAS 9.4 (SAS Institute, Cary, NC). The levels of age consisted of 4, 6, 7, and 8 weeks for broilers. The levels of rail/drone speed factor were 0.2, 0.3, 0.4 m/s and 0.4, 0.8, 1.2 m/s, respectively. The levels of rail/drone height factor were 0.3, 1.2, 1.5 m and 1.2, 1.5, 1.8 m, respectively. The levels of approaching object included assessor, rail and drone. The mean separation was performed using a multiple comparison procedure of Tukey's honestly significant difference (HSD). Four models were used (Equations (6)-(9)). Models 6 and 7 were to examine the effects of age, approaching object and the two-way interaction (age × object) on AD and FS, respectively; while models 8 and 9 were used to determine the effects of age, speed, height, and its two-way interaction (age × speed and age × height) on AD and FS, respectively. Significant difference was defined as p<0.05.

$$AD = Age + Object + Age \times Object \tag{6}$$

$$FS = Age + Object + Age \times Object \tag{7}$$

$$AD = Age + Speed + Height + Age \times Speed + Age \times Height \tag{8}$$

$$FS = Age + Speed + Height + Age \times Speed + Age \times Height \tag{9}$$

3 Results

3.1 Factor affecting avoidance distance and fleeing speed of broilers

Table 1 provides the statistical analysis results of the four models. For model 6, the differences in mean ADs between the assessor and aerial systems depended on age since there was a significant interaction between age and object (p<0.0001). Model 7 shows the differences in mean FS depended on the age since there was a significant interaction between age and object (p<0.0001). Model 8 shows that both broiler-rail and broiler-drone ADs were interactively affected by age, speed, height, and the two-way interaction (age × height). Model 9 shows that broiler-rail FS was interactively affected by age, speed, height, and the two-way interaction (age × speed). The broiler-drone FS was interactively affected by age, speed, the two-way interactions (age × speed and age × height).

Table 1 Statistical analysis for factors of broiler avoidance distance (AD) and fleeing speed (FS)

Response		Factor		Model
AD*		Age	<0.0001	6
		Object	<0.0001	
		Age × Object	<0.0001	
		RMSE*** (cm)	34.1	
FS**		Age	<0.0001	7
		Object	<0.0001	
		Age × Object	<0.0001	
		RMSE*** (m s-1)	0.28	
	Object			
AD*	Rail	Age	<0.0001	8
		Speed	0.0513	
		Height	0.0269	
		Age × Speed	0.3199	
		Age × Height	0.0099	
		RMSE*** (cm)	35.5	

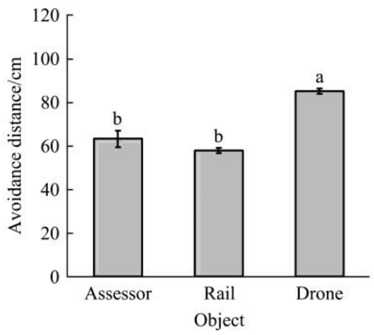
Response	Factor			Model
AD*	Drone	Age	0.0009	8
		Speed	0.0275	
		Height	0.0222	
		Age × Speed	0.6235	
		Age × Height	0.0027	
		RMSE*** (cm)	32.7	
FS**	Rail	Age	<0.0001	9
		Speed	0.0094	
		Height	<0.0001	
		Age × Speed	0.0222	
		Age × Height	0.9169	
		RMSE*** ($m\ s^{-1}$)	0.24	
	Drone	Age	<0.0001	
		Speed	<0.0001	
		Height	0.6018	
		Age × Speed	<0.0001	
		Age × Height	<0.0001	
		RMSE*** ($m\ s^{-1}$)	0.25	

Note: * AD: Avoidance distance of broilers; ** FS: Fleeing speed of broilers; *** RMSE: Root mean square error.

3.2 Avoidance distance

3.2.1 Broiler-assessor vs. broiler-rail and broiler-drone avoidance distance

Figure 4 shows the Tukey's HSD multiple comparison results of broiler-assessor, broiler-rail, and broiler-drone ADs when birds were exposed to the objects on the test days only. Broiler-assessor, broiler-rail, and broiler-drone ADs were respectively in the ranges of 55-78 cm, 45-82 cm, and 78-91 cm. Statistical analysis showed that broiler-drone ADs were significantly greater than both broiler-assessor and broiler-rail ADs;



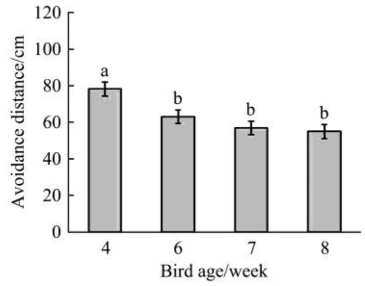
Note: Means sharing the same letter do not differ significantly at $p<0.05$. Birds were exposed to the object on test days only.

Figure 4 Avoidance distances (mean ± standard error) of broilers to approaching human assessor, aerial rail, and drone

but there was no significant difference between broiler-assessor and broiler-rail ADs.

3.2.2 Broiler-assessor avoidance distance

The mean broiler ADs to the assessor were 78 cm at week 4, 63 cm at week 6, 57 cm at week 7, and 55 cm at week 8 respectively (Figure 5). After week 4, the birds did not show any significant change in AD as they got older.



Note: Means sharing the same letter do not differ significantly at $p<0.05$. Birds were exposed to the assessor on test days only.

Figure 5 Avoidance distances (mean ± standard error) of broilers to an approaching assessor at different bird ages

3.2.3 Broiler-rail avoidance distance

The mean broiler-rail ADs were 82 cm at week 4, 54 cm at week 6, 51 cm at week 7, and 45 cm at week 8 (Figure 6a). With increasing age, the AD decreased significantly. As for the operational speed of the rail, broiler ADs were 54 cm for 0.2 m/s, 59 cm for 0.3 m/s, and 62 cm 0.4 m/s (Figure 6b). As the speed of the rail increased, the AD increased significantly. As for operational height of the rail, broiler ADs were 54 cm for 0.3 m, 63 cm for 1.2 m, and 57 cm for 1.5 m, respectively (Figure 6c). As rail operational height increased from 0.3 to 1.2 m, the AD increased significantly; however, there was no significant change when increased rail height from 1.2 to 1.5 m.

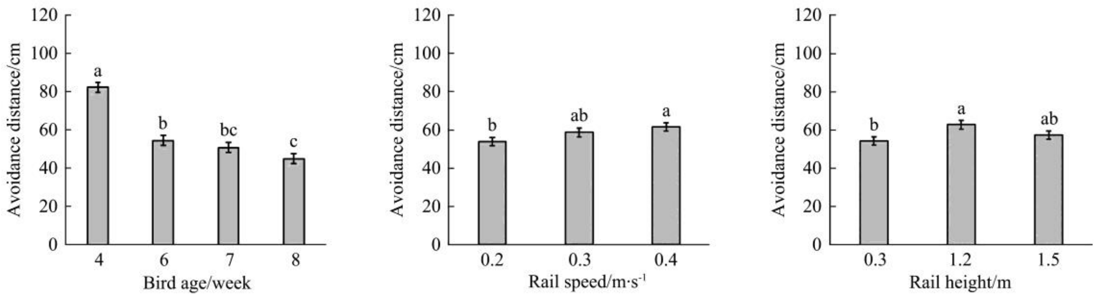
3.2.4 Broiler-drone avoidance distance

The mean broiler-drone ADs were 91 cm at week 4, 88 cm at week 6, 78 cm at week 7, and 84 cm at week 8 respectively (Figure 7a). There was a significant difference of AD as the birds got older through week 7. Broiler-drone ADs were 81 cm at 0.4 m/s, 85 cm at 0.8 m/s, and 89 cm at 1.2 m/s of drone operational speed (Figure 7b). Operating the drone at a higher speed increased broiler-drone AD significantly. At drone operational heights of 1.2 m, 1.5 m, 1.8 m, broiler ADs were 81 cm for 1.2 m of drone operational height, 87 cm, and 88 cm, respectively (Figure 7c). As the height of drone operation increased, the broiler AD also increased significantly.

3.3 Fleeing speed

3.3.1 Broiler-rail vs. broiler-drone fleeing speed

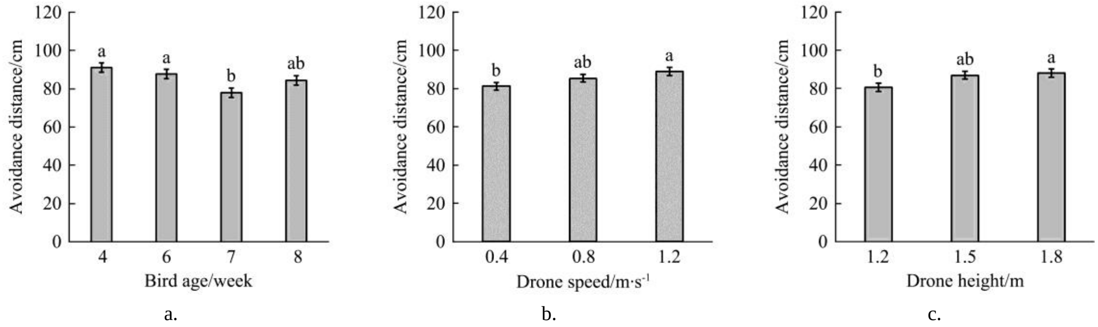
Figure 8 shows the Tukey's HSD multiple comparison results of broiler-rail and broiler-drone FSs. Mean broiler-rail and mean



a. b. c.

Note: Means sharing the same letter do not differ significantly at $p<0.05$. Birds were exposed to the rail on test days only.

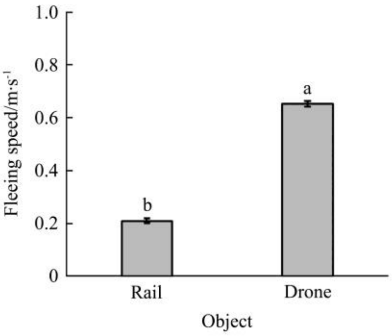
Figure 6 Avoidance distances (mean ± standard error) of broilers to an approaching aerial rail at different bird ages (a), and rail operational speeds (b) and heights (c)



Note: Means sharing the same letter do not differ significantly at $p<0.05$. Birds were exposed to the drone on test days only.

Figure 7 Avoidance distances (mean ± standard error) of broilers to an approaching drone at different bird ages (a), and drone operational speeds (b) and heights (c)

broiler-drone FSs were 0.21 m/s and 0.65 m/s, respectively. Statistical analysis showed that broiler-drone FSs were significantly greater than broiler-rail FSs.



Note: Means sharing the same letter do not differ significantly at $p<0.05$. Birds were exposed to the object on test days only.

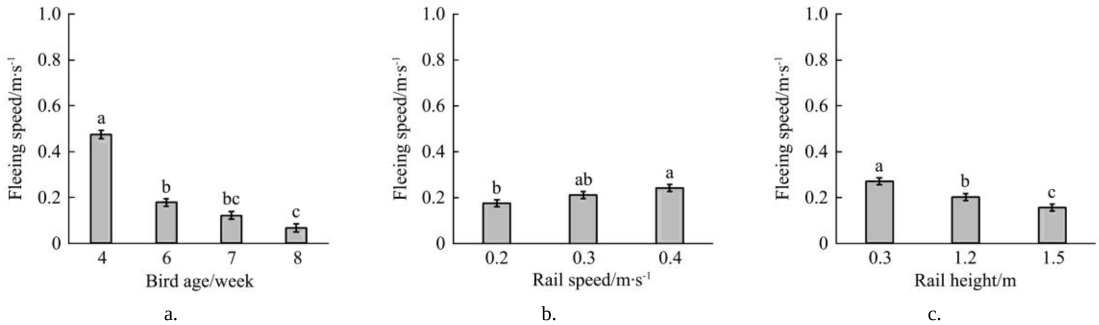
Figure 8 Fleeing speeds (mean ± standard error) of broilers to approaching aerial rail and drone

3.3.2 Broiler-rail fleeing speed

Mean broiler-rail FSs were 0.47 m/s at week 4, 0.18 m/s at week 6, 0.12 m/s at week 7, and 0.07 m/s at week 8 respectively (Figure 9a). The broiler FS decreased significantly for older birds. The broiler-rail FSs were 0.18 m/s for 0.2 m/s, 0.21 m/s for 0.3 m/s, and 0.24 m/s for 0.4 m/s of rail operational speed (Figure 9b). With increasing speed of the rail, the broiler FS also increased significantly. At the heights of 0.3 m, 1.2 m, and 1.5 m, broiler FSs were 0.27 m/s, 0.20 m/s, and 0.16 m/s, respectively (Figure 9c). As the rail operational height increased, the broiler FS decreased significantly.

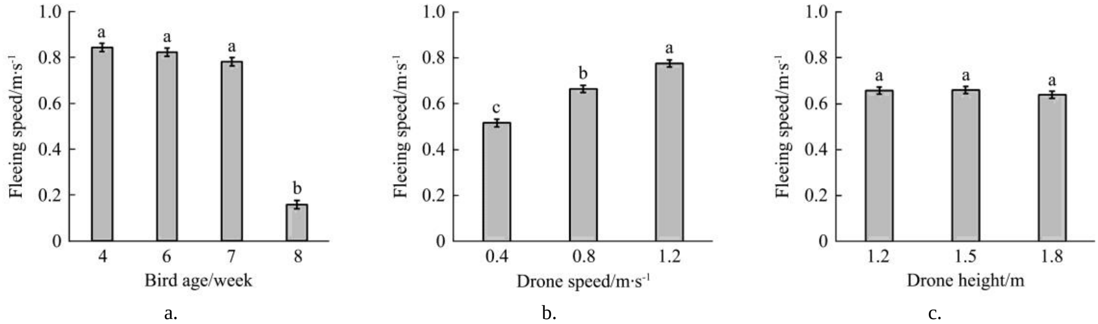
3.3.3 Broiler-drone fleeing speed

The mean broiler-drone FSs were 0.84 m/s at week 4, 0.82 m/s at week 6, 0.78 m/s at week 7, and 0.16 m/s at week 8, respectively (Figure 10a). Broiler-drone FS did not have a significant change until week 8. The broiler FSs were 0.52 m/s for 0.4 m/s, 0.66 m/s for 0.8 m/s, and 0.78 m/s for 1.2 m/s of drone operational speed (Figure 10b). Broiler FS increased at a faster drone operational speed. At drone operational heights of 1.2 m, 1.5 m, and 1.8 m broiler FSs were 0.66 m/s, 0.66 m/s, and 0.64 m/s, respectively (Figure 10c). The change in operational height had no significant effect on the broiler-drone FS.



Note: Means sharing the same letter do not differ significantly at $p<0.05$. Birds were exposed to the rail on test days only.

Figure 9 Fleeing speeds (mean ± standard error) of broilers to an approaching aerial rail at different bird ages (a), and rail operational speeds (b) and heights (c)



Note: Means sharing the same letter do not differ significantly at $p<0.05$. Birds were exposed to the drone on test days only.

Figure 10 Fleeing speeds (mean ± standard error) of broilers to an approaching drone at different bird ages (a), and drone operational speeds (b) and heights (c)

4 Discussion

Evaluation of broiler AD and FS as affected by bird age and AV operational strategies have yet been conducted in a commercial broiler house. The results from this study showed that these factors either independently or interactively affected the broiler AD and FS. The findings from this study suggest the importance of such factors to understand and optimize robotic automation for broilers. A key goal in this study was to provide baseline results of a broiler to approaching objects using a non-invasive assessment known as AD, for which a higher value suggests a greater stress/fearfulness of broilers.

Broiler-assessor AD has been widely studied for broilers of different strains and at different bird ages. The average broiler-assessor AD in our study was 78 cm, which was shorter than 111 cm reported by Usher et al.[16]. The discrepancy could be because the current study was conducted on a commercial farm, as opposed to the lab-scale experiment by Usher et al.[16]. In lab-scale tests, the birds could be more observant of the objects (e.g. due to limited space, inspection noise, etc.), thereby starting to withdraw at a longer distance. However, the results correlated well with a similar study performed on a commercial scale by Parajuli, Huang[15], who reported a similar AD of 83 cm. Compared to broilers, studies involving laying hens have shown larger AD variations among studies and at different bird ages. Brown hen-assessor AD ranged from 15-150 cm for 20-70 week old birds[26] and 109-131 cm for 28-66 week old birds[15]. White hen-assessor AD ranged from 320-343 cm for 36-60 week old birds[27] and 91-100 cm for 27-70 week old birds[28]. The reported hen-assessor ADs were generally longer than broiler-assessor ADs, possibly because laying hens are more vigilant and active than broilers.

Several ground and aerial robotic systems have been developed to assist poultry production for migrating birds, ventilating litter, sanitizing houses, reducing floor eggs, inspecting birds' health, and more[12-14,29]. However, applications of these robotic systems could be hampered, partly due to concerns on potential bird stress and fear that may be induced by the robots. Therefore, it is imperative to examine the baseline poultry behavioral responses to robots, which may help to understand and optimize the robot operation while reaping the benefits of automation. Since the birds may react uniquely to different types of robots, two types of aerial robot system were investigated in this study. Our results of broiler-drone ADs were similar to that reported by Usher et al[16] in a lab-scale test with broilers at 4-week age. Unfortunately, the operational parameters and type of the drone system were not specified in the previous study, which makes it impossible to address the similarity in ADs between the two studies. The broiler-drone ADs was consistently higher than the broiler-rail AD across all bird ages. We assume this discrepancy is caused by the difference in operations of the drone and the rail. The drone was operated faster and higher than the rail. As a result, some may assume that the drone may have been perceived as an aerial predator by the birds. Furthermore, the noise produced by the drone was greater compared to rail. Thus, broilers may treat the drone as a bigger threat, thus avoiding it from a longer distance. Correspondingly, the bird might have adapted overtime during the testing day, resulting in a consistent distance. Though a couple of rail robots have been commercialized[12,29], there is no study regarding bird responses to the rail robot other than the current one. Our study, for the first time, reported the mean broiler-rail ADs of 58 cm. Though shorter broiler AD means less bird stress and fear, a reasonable AD is preferred especially for robot applications that require clearance areas for particular certain tasks, e.g. bird migration, litter ventilation, etc.

Broiler FS could be a metric for evaluating bird stress and fear, however, it has not been adapted into any welfare assessment protocols. We found that broiler FSs to the aerial robots were 0.18-0.24 m/s for the rail and 0.52-0.66 m/s for the drone, which were either comparable or slower than the broiler FS to a ground robot (0.50-0.58 m/s) reported by our recent study[28]. Some skeptics stated that aerial robots may induce greater stress to broilers because they assumed birds are naturally scared of flying predators, e.g. eagles. However, our results do not support the aforementioned statement. According to our observation, the broilers did flee away from the aerial robots, but the avoiding behavior seemed not to differ from that toward the ground robot. The fast-growing broilers may suffer locomotor skeletal problems including varus and valgus deformities, osteodystrophy, dyschondroplasia, and femoral head necrosis[30]. The broilers with leg abnormalities have to reduce locomotion and spend more time lying and sleeping, which in turn decreases ossification of the bones and exacerbate skeletal problems. It has been reported that locomotor skeletal problems can be alleviated when broilers have been exercised under experimental conditions[30]. The research results showed that operating aerial and ground robots may encourage the birds to move at speeds ranging from 0.18 to 0.66 m/s. However, the ideal speed and extent of exercises remain yet to be explored.

Assistance towards manual labor can come in different ways. A ground robot could help with litter ventilation, floor eggs, mortality, and inspection at bird level[12,13]. On the other hand, aerial systems can provide an overhead view of the poultry flock to evaluate the environmental conditions without the potential of contact with animals[29,31]. Some challenges of the current drone include the short battery life, flying instability under high wind speed conditions, and difficulty in collision avoidance to hanging cables for heaters, feeders, and drinkers. Aerial rail systems can be installed and bypass obstacles; however, each system can only serve in one house, which would require significant investments for a farm with multiple houses.

5 Conclusions

In this study, ADs and FSs of broiler-assessor, broiler-rail and broiler-drone were determined at different bird ages, AV operational speeds, and heights. It is concluded that these factors either independently or interactively affected the broiler ADs and FSs. Overall broiler-rail ADs were shorter than broiler-drone ADs, suggesting less aerial system induced stress with a rail than a drone. However, longer ADs with a broiler-aerial system would still have the advantage of being able to conduct various environmental assessments that require certain clearance areas. Overall broiler-rail FS was considerably slower than broiler-drone FS, compared at any age, operation speed, or operation height. The information obtained in this study offers valuable data to understand the interaction of broilers with AV systems, as well as provide an outlook of optimizing robotic operational strategies in a future commercial broiler farm.

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