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Movement Analysis to Associate Broiler Walking Ability with Gait Scoring

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Abstract: The genetic development of the commercial broiler has led to body misconfiguration and consequent walking disabilities, mainly at the slaughter age. The present study aimed to identify broiler locomotion ability using image analysis automatically. A total of 40 broilers that were 40 d old (male and female) were placed to walk on a specially built runway, and their locomotion was recorded. An image segmentation algorithm was developed, and the coordinates of the bird's center of mass were extracted from the segmented images for each frame analyzed, and the unrest index (UI) was applied. We calculated the center of mass's movement of the broiler walking lateral images capturing the bird's displacement speed in the onward direction. Results indicated that broiler walking speed on the runway tends to decrease with the increase of the gait score. The locomotion did not differ between males or females. The proposed algorithm was efficient in predicting the broiler gait score based on their displacement speed.

Keywords: computing image analysis; gait score; unrest index

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1. Introduction

Broilers are one of the fastest-growing and cheapest animal protein sources among farmed species. Broiler meat is usually affordable, low in fat, and faces few cultural barriers. The largest broiler meat producer countries are the USA (20.2×10^6 metric t/year), Brazil (13.8×10^6 metric t/year), and China (14.6×10^6 metric t/year). The world production of broiler meat reached 100.8×10^6 metric t/year in 2020 [1].

Artificial selection of the domestic chicken (*Gallus gallus domesticus*) has led to derived morphology, physiology, and behavior different from its red jungle fowl ancestor [2,3]. Since broiler body conformation has changed, so has the center of body mass, implicating locomotor issues and a lack of well-being in intensive production [4]. When a bipedal animal (including broilers) walks, it generates a specific force over the floor that is a function of its weight and the way it lays the feet on the ground. The movement during locomotion changes the center of mass of birds, changing both kinetic (e.g., ground reaction forces) and kinematic data (e.g., stance and stride duration) [5]. During walking, the leg acts as a solid strut so that the body's center of mass rises over the leg and reaches a maximum in the middle of the stance phase while the opposite leg swings forward. Walking gaits are efficient because there is an alternating transfer between the body's potential and kinetic energy within each stride. Physical abilities influence locomotion in broilers, and healthy broilers walk freely inside the house [6,7].

According to Dawkins (2017) [8], the most straightforward definition of "good welfare" is that the animal is healthy and has what it wants and needs. Therefore, when lameness denies the animal the possibility of accessing feed and water or leading to pain, it is an important sign of a lack of welfare [9]. Locomotor issues also impact broiler performance and may be associated with meat quality reduction [10] and high flock mortality [11].

Quantification of gait can be made by determining kinematic parameters such as linear walking speed, acceleration, stride and step length, angular parameters (velocities, accelerations), and range of motion of joints. Observational gait analysis allows the comparison among sample populations [4,12]. The observational gait scoring method developed by Kestin et al. (1992) [13] is possibly the most widely adopted worldwide. In this approach, the bird's walking ability is graded between 0 (perfect walking) to 5 (unable to move). Inter and intra-observer variation is a limitation of visual gait scoring by humans that the automated assessment can solve by providing robust, quantitative data.

With the decrease in labor in rural areas, broiler on-farm task automation is a necessary change. In the current literature, there are ideas for the development of new algorithms to provide the basis of process automation built on broiler behavioral patterns [14–16]. However, the broiler gait automatic assessment is still challenging since just partial answers were reached [17–20].

The present study aimed to identify broiler walking ability and associate it with the gait score based on the recorded images and movement analysis.

2. Materials and Methods

The current study is part of a large project that investigates the automatic assessment of broiler welfare. The field experiment was endorsed by the UFGD Animal Ethics Committee (Protocol n. 030/2013).

2.1. Data Recording

A total of 300 1-day old chicks, mixed-sex (Cobb 508), were reared according to the breeders' guidance in an experimental house. When the broilers reached 40 days old, 20 males and 20 females were randomly selected (totaling 40 birds). An experienced animal scientist accessed each broiler's gait using the 0 to 5 scoring system [21]. The gait score (GS) 0 (GS0) was provided to sound birds. The gait score 1 (GS1) meant the broiler had an identifiable gait deficiency but looked as though it had less movement than the sound broilers. The selection criterion of gait score 2 (GS2) was that the bird revealed a noticeable locomotor deficiency that had little influence on its mobility [22]. The gait score 3 (GS3) were broilers with mild lameness with identified gait weaknesses that altered their capacity to move. The lame broiler had a gait score 4 (GS4). The gait score 5 (GS5) indicates severely lame birds.

After carefully choosing the birds, they were separated by GS to represent the array of scores, and video footage was produced. The objective was to study the broilers, which deliver a clear description of the pre-defined scores. The broilers could select their speed, and both speed and acceleration were considered in retrospect at the analysis level. The videos were taken in a specifically built platform 1 m long and 0.30 m wide, with a flat surface covered with 8 cm of litter substrate (rice hulls), the same material the broilers had in the rearing house. Although we recorded all the broilers walking, not all videos were suitable for analyzing the walking speed since broilers somehow feared the novel assembled environment. The derivative of the space gives the speed traveled in time. By discreetly dividing the path walked by the time spent, we obtain the speed. We considered that the distance traveled by the bird on the runway was 100 cm, divided by the time it took the bird to complete the path. However, the birds naturally slow down, stop for a few moments, and continue their way. This was neither avoided nor neglected. The unrest index (UI) [23] calculates the distance traveled between two frames in cm. By setting the time between two frames, it is possible to calculate the speed, and in the current study, we used a frequency of 1 Hz (1 frame/s). If the bird was still, such a distance was zero (or very close to zero) and was not considered to calculate the average UI for this bird. The birds' ability to walk was assessed by the average UI in the video. We considered all the frames that the birds walked in, regardless of the interruptions and "resting" moments. Table 1 shows the number of broilers we could use the videotapes for in each gait score.

Table 1. The number of videotaped broilers used to analyze the walking velocity related to the gait score.

	Gait Score					
	GS0	GS1	GS2	GS3	GS4	GS5
Gender						
Male	1	3	2	3	2	2
Female	3	1	2	1	2	2

The video footage background was a blue barrier placed to give appropriate contrast with the broiler. The platform was sealed with a translucent acrylic wall 50 cm high. The birds were encouraged to walk on the runway, and the video footage was done in .mp4 format with the speed of 30 frames/s (FPS) using a video camera (Sony® Handycam Memory Flash PJ200, Sony Corporation, Tokyo, Japan) equipped with specific lenses to rectify the parallaxes effect (Lens Carl Zeiss® Vario-Tessar® Carl Zeiss, Oberkochen, Germany) with 2.8 mm opening. The video camera was set up on a tripod at a 1 m distance from the platform directly facing the runway. Such a studio arrangement was previously described in [20].

The overall schematic of the study is shown in Figure 1.

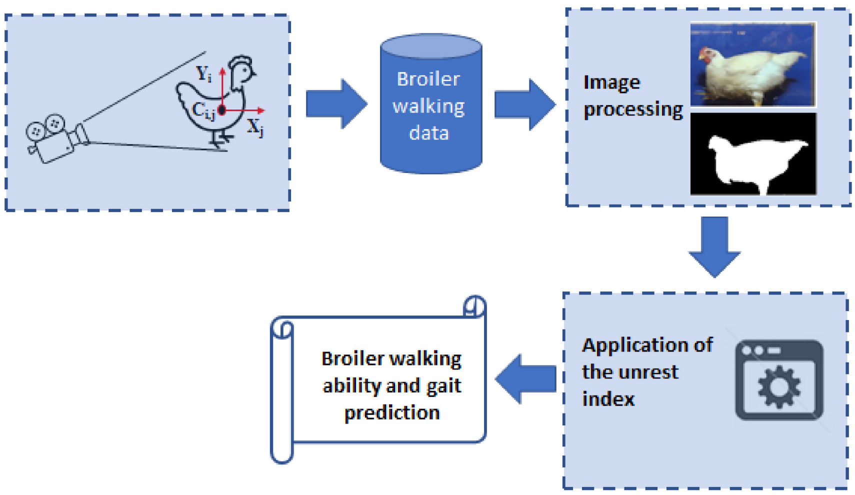

Figure 1. Schematic of the study to predict broiler walking ability.

2.2. Image Processing

The videos were recorded with a camera positioned on the birds' side, and it was restricted to walking on a delimited path. A blue background was used to improve the bird's contrast in the scenes, as shown in Figure 2. The recordings had variable durations, according to the difficulty the birds had walking on the platform.

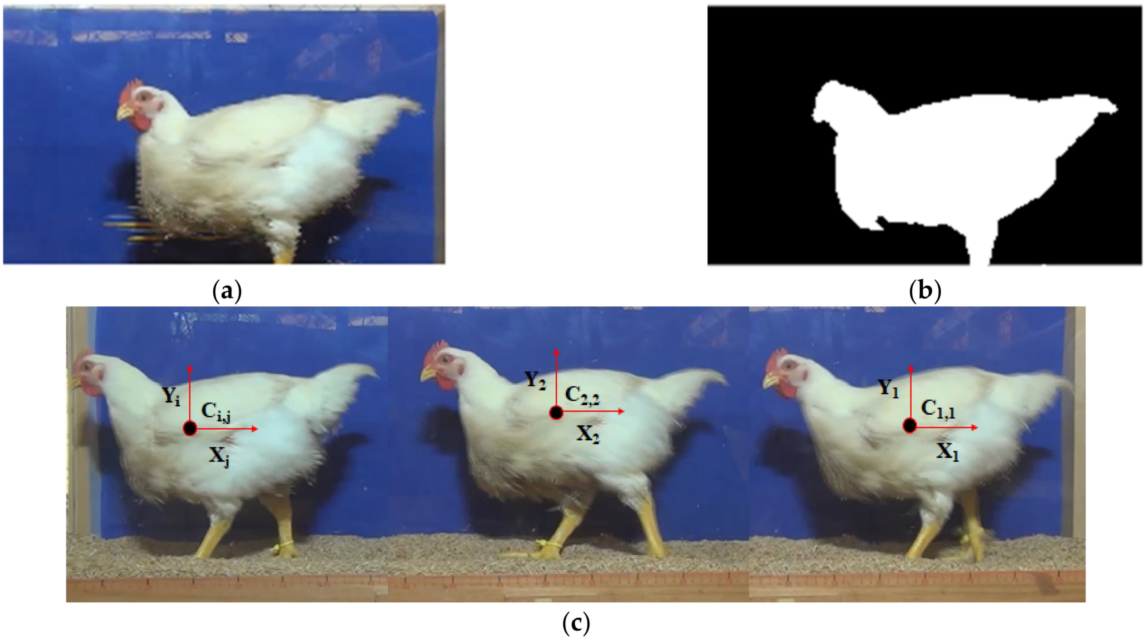

Figure 2. Original (**a**) and segmented (**b**) images of the broiler walking the defined path to assess the gait score and the displacement of the center of mass (**c**). $C_{i,j}$ is the center of mass in the frame i,j.

The image pre-processing included the removal of the images where the broilers did not walk. The duration of the video was variable, even within each GS. This variation was not relevant since the unrest index of the moments the birds stopped was not considered. Those who needed much encouragement to walk on the runway were also not considered in the analysis, justifying the reduction from 40 birds at the beginning of the study to a total of 24 evaluated birds.

An image segmentation algorithm was developed, and the coordinates of the bird's center of mass were extracted from the segmented images for each frame analyzed, and the unrest index (UI) proposed by Del Valle et al. (2021) [23] was applied. The UI is based on the Hausdorff distance (dH, in pixels). The Hausdorff distance is a boundary-based metric that assesses the maximum distance of a model point to the nearest edge pixel and is widely used in image segmentation [24,25]. However, to transform the unrest index values in cm, a proportionality factor was applied to the equation described in [23], based on the camera's distance and the CCD sensor's resolution (a function of the number of pixels and their size relative to the projected image). The Equations (1) and (2) adopted in the present study are described below.

$$UI_{(i,i-1)} = k.\left[\max\left\{dH\left(F_{(i)}, F_{(i-1)}\right),\ dH\left(F_{(i-1)}, F_{(i)}\right)\right\}\right] \quad (1)$$

where UI $_{(i,i-1)}$ is the poultry bird unrest index between two sequential frames, dH is the Hausdorff distance, and k is the proportionality factor defined in Equation (2).

$$k = \frac{2H\tan(\alpha/2)}{w} \quad (2)$$

where H = the distance from the recording camera to the moving target (1 m), α = the camera lens opening angle (0.5), and w = the sensor CCD horizontal resolution (1920 px).

When applied to videos with only one bird, the unrest index corresponds precisely to the path that the bird's center of mass traveled between two frames under analysis, but in both directions (x, y). The index also captures the vertical movements of moving up and down (during the broiler walking, Figure 2c). As the index is calculated between frames with a 1 s window, the calculated UI corresponds to the gait speed in cm/s. Since the difficulties of assessing the broiler's gait score when recording the videos were already known, statistical analysis was applied to verify the unrest index's explanatory power, comparing it with the predetermined gait classification to evaluate the broiler gait score.

A graphical analysis of the intervals of the UI was performed as a function of the GS using 95% confidence. The means of UI were compared between the corresponding GS using the Tukey test at 5% significance. All analyses were done using the software Minitab 19.

3. Results

Results are presented following the data acquisition. First, we present the video information from the broilers' locomotion ability with a determined gait score. Second, we introduce the results from the video analysis, applying the UI.

Unrest Index

Figure 3 shows the evolution of the movement speed of the birds, calculated from the UI. This speed expresses the center of mass's movement in the x and y-axis of the broiler walking's lateral images, therefore, capturing the bird's displacement speed in the onward direction.

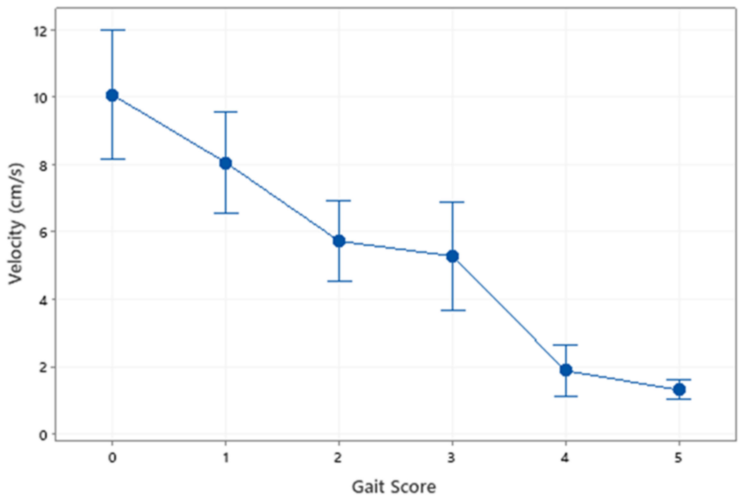

Figure 3. Confidence interval graph using the broiler walking velocity values of the unrest index and known gait scores.

It seems that the broiler displacement velocity calculated from the unrest index indicates that there is a tendency to decrease with the increase of the gait score. The ANOVA test was applied to the data, and there was a significant difference ($p < 0.05$) in the velocity between the GS recorded. Table 2 shows the test of means applied to the displacement velocity measured in each gait score. It appears that the UI was only able to differentiate the birds' extreme and intermediate GS.

Table 2. The average walking velocity (cm/s) observed differences in the broiler footage with different known gait scores.

Gait Score	n	Mean
0	29	10.0580 [a]
1	40	8.4469 [a]
2	52	5.9642 [b]
3	46	4.8037 [b]
4	56	2.2732 [c]
5	48	1.2861 [c]

Different letters indicate a significant difference by the Tukey test ($p < 0.05$). n = number of sequential frames.

The gait score did not differ between males and females (ANOVA, $p > 0.05$), with both genders presenting a decrease in gait speed as the GS increased (Figure 4).

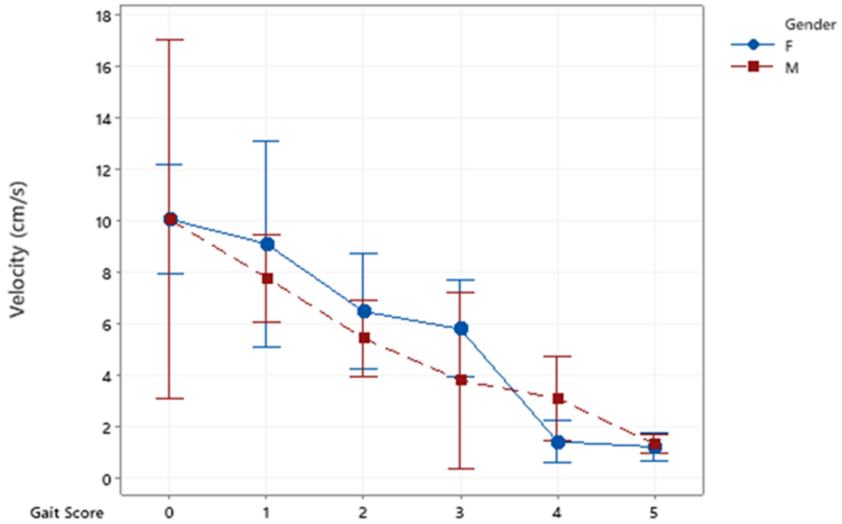

Figure 4. Confidence interval graph using the broiler walking velocity according to the gait score and gender.

4. Discussion

The broilers' walking velocity was evaluated using the unrest index, a new automatic method. It grouped the gait scores into three levels (initial, intermediate, and final), indicating that even if this grouping occurs, the continuous method of evaluating the agitation index in gait can be used for early detection of initial levels (birds with higher speed of movement) and support for birds of the most severe levels of locomotion (birds with a lower velocity of displacement). Other studies have evaluated the birds' gait score using automatic methods and an activity index [11,18,26]. Aydin et al. (2010) [26] investigated the walking activity of 32-day-old mixed-broiler chickens with different gait scores, using gait scores from 0 to 5, using an automatic image monitoring system under laboratory conditions. The authors compared the relationship between the scores quantified by humans and by the automatic image monitoring system and obtained a significant relationship for both methods.

Detailing these results, birds with gait score 3 (GS3) showed more walking movements due to several behaviors (such as going to feeder and drinker and moving around each other) than the other scores in both methods, and also there were differences found between GS0, GS1, and GS2, whereas scores 4 (GS4) and 5 (GS5) had lower walking movements [6,26]. As in the present study, the highest scores (GS4 and GS5) had lower displacement velocities due to the low displacement rate. Aydin (2017) [19] developed an automatic detection system for lameness in broilers. In this previous study, the 39-day-old male chickens were gait evaluated and selected before the experiments according to the degree of locomotion issues (GS0 to GS4). Birds were continuously monitored by a digital camera that was analyzed by an algorithm to detect speed, step frequency, step length, and lateral body sway, including applying a correlation test between the variables and the birds' gait score levels. Their results show that the characteristics were efficient only in detecting lameness from GS3, and the step length of a chicken with lameness (GS4) was shorter than the step length of healthy chicken (GS1), also indicating a lower speed regarding the severity of lameness. In the present study and using the UI at a frequency of 1 frame/s, the speed measurement obtained was in cm/s, and we were able to relate gait score and broiler velocity (Figure 3).

The UI also measures the bird's movement; however, it does so by changing pixels representing the animal between consecutive images according to the movement's intensity. Through image processing, a percentage of the animal's pixels in motion is defined concerning the total number of pixels in the image, and the precision may show temporal and spatial variations as it is affected by the sampling time interval [26]. When comparing the previous study [26] to the UI method used in the present study, the advantage the UI analysis presents is that even if the bird moves around the center of mass, for example, in a rotation where there is no difference in the center of mass, this measure will still return a value greater than zero, which can be applied to flocks or individual birds [23].

In studies using optical flow, the ability to detect animal movements in a sequence of frames, considering that the intensity of the pixels remains constant over time and a neighborhood of pixels that move together, this method was used to assess behavior and broiler chickens' gait [14,18,27]. Dawkins et al. (2009) [14] tested mass movements detected by changes in the optical flow of chickens (male and female) from 32 to 35 days of age using a score of three points (GS0 to GS2). Their results indicated higher mean flows for more activity (walking and step rate), with a significant correlation between step rates and optical flow variance. There was a significant correlation between behavior and gait scores. However, the correlation was negative for the lowest gait levels (GS0, GS1), which the stride rate can explain, and the time broilers spent walking [14].

The current study results (Table 2) also indicate that the mean average walking velocity of birds tends to group, as broilers that scored GS0 and GS1 showed the same walking velocity. The same happened with the walking speed of the broilers that scored GS2 and GS3; and GS4 and GS5. Such findings agreed with the research of Garner et al. (2002) [28], in which the authors proposed a modified gait assessment system by removing the intermediate scores previously established by Kestin et al. (1992) [13]. The suggested system applies three levels of walking ability: 0 (a sound broiler that walks ten steps naturally); 1 (an average broiler that walks ten steps with some trouble and shows some unbalance during walking); and 2 (a lame broiler with a walking limitation that sits after one to four steps). A previous study [20] presented another way of solving the assessment of intermediate scores during broiler gait scoring by using paraconsistent logic. However, reducing the degree of uncertainty had limited success for predicting GS1 and GS2 (50 and 70%, respectively).

Dawkins et al. (2012) [15] analyzed mixed-gender broilers' behavior (1–35 days old) using a combination of a low-cost camera and statistical analysis of optical flow patterns. The results indicated that neither the average flow rate nor the variance was significantly correlated with the gait score, justified by the authors by the narrow range of gait scores evaluated in the study, thus reducing the birds' movement analysis parameters.

In the present study, the broilers' movement did not differ concerning gender. The gender differences in gait can be linked to the measured differences in adult birds' morphology [3,29,30]. According to the authors [3,30], in females, the importance is on reproduction, giving forward the onset of egg-laying, which is constant throughout their lives, instead of appearing only in breeding seasons. In contrast, male birds have greater muscle, bone, heart, and blood masses than mature females. However, these distinct dysmorphisms appear when birds are roughly 4–5 months old [2,30]. In commercial broiler production, the gender-mixed flock is slaughtered nearly 40–45 d old, when they have still not reached sexual maturity and, therefore, do not show dysmorphism differences, as in the current study, the displacement velocity did not differ between male and female.

The use of a rapid assessment method for locomotion issues in chickens is critical. Broilers have a short life cycle, and the identification of an abnormal gait might be possible. For instance, a previous study [10] investigated a possible association between wooden breast myopathy and broilers. The authors found that broilers affected by wooden breast myopathy had gait scores higher than the sound broilers in all ages (22, 32, 36, 39, and 43 days). Automated methods of gait assessment could enhance early on-field detection of abnormality and enhance farmer decision-making towards the improvement of animal welfare.

5. Conclusions

The association of broiler walking ability assessed using image analysis techniques associated with the pre-established gait scores had not been previously presented. The gait evaluation is complex and depends on a specialist, and it is not easy to apply on an industrial scale. The image analysis technique adopted in the current study is simple, and the association found between the unrest index and the different classes of gait score allows a machine vision system to be developed to assess broiler walking ability in large-scale production. Therefore, the innovation is the association of the unrest index—which is a straightforward way to assess the walking ability of birds—in the present study, based on the traditional gait score system, which will allow other studies to be developed based on our results.

The unrest index was efficient in predicting the broiler gait score based on their velocity of displacement. Since the birds' movement effectively predicts their displacement, we infer that the birds moved appropriately to feeder and drinker and, therefore, could access feed and water, which is an essential welfare condition.

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