Characterizing spatiotemporal and three-dimensional locomotive behaviors of individual broilers for the three-point gait scoring system

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Abstract

Gait scoring is a useful means of evaluating broiler production efficiency, welfare status, bone quality, and physiological traits including leg health status. The research objective was to characterize spatiotemporal and three-dimensional (3D) locomotive behaviors of individual broilers by using deep learning algorithms on RGB and 3D depth top-view images. Ross 708 broilers were placed on a platform specifically designed for gait-scoring and manually categorized into one of three numerical scores. RGB and depth cameras were installed on the ceiling to capture top-view videos and images. Four birds from each of the three gait score categories were randomly selected out of 70 total birds scored for video analysis. Bird moving trajectories and 16 locomotive behavior metrics were extracted and analyzed via the developed deep learning models. The trained model gained 100% accuracy and 3.62±2.71 mm root mean square error on estimating a key point on the back of each broiler, indicating precise recognition performance. Broilers with lower gait scores (less difficulty walking) exhibited more obvious lateral body oscillation patterns and moved significantly or numerically faster and covered more distance in each movement event than those with higher gait scores. In conclusion, the approach presented, which differentiates between selected spatiotemporal and 3D locomotor behaviors, showed acceptable performance for tracking broilers and can be a useful research tool for automating individual broiler gait scoring. Further development with more images is recommended.

Keywords: behavior recognition, poultry, animal welfare, artificial intelligence

Introduction

Gait scoring is critical in evaluating broiler leg health by assessing a bird's locomotive ability (Kestin et al., 1992). Trade associations and governmental agencies, such as the U.S. National Chicken Council and the European Commission, have realized the significance of gait scoring in the broiler industry and provide various recommendations. Among current broiler gait scoring systems, the three-point system (Webster et al., 2008) distinguishes among broilers with no impairment of walking ability (score 0), obvious impairment but still ambulatory (score 1), and severe impairment and being unable to walk without great difficulty (score 2). Despite its utility as a useful tool, the system involves subjective decisions by human gait-scorers.

Computer vision-based scoring systems can provide automated, objective, efficient, and accurate assessment. Group activities within flocks monitored by image processing, such as pixel changes between consecutive frames (Aydin et al., 2010) or statistics of optical flows (Dawkins et al., 2009), have been significantly correlated with broiler gait scores assessed by experts; However, these automated systems did not assess gait scores of individual birds.

Individual monitoring may be expensive and technically difficult for commercial production where tens of thousands of broilers of similar appearance are in a single house, but it can provide detailed and valuable measures within laboratory-scale broiler experiments (Li et al., 2021). van der Sluis et al. (2021) used an ultra-wideband tracking system to characterize individual broiler activity and found significant differences in average moving distances and other derived metrics between broilers with good and suboptimal gait scores. The system required battery-powered tags attached to each broiler and could be expensive for large-scale experiments. Aydin (2017a; 2017b) developed RGB- and depth-based computer vision systems for capturing locomotive behaviors of a broiler walking along a corridor. The step frequency, step length, step speed, lateral body oscillation, and latency to lie were significantly different among broilers with various gait scores. However, the three-point gait scoring system currently used in US broiler industry has not been examined using the RGB and depth sensing.

The study objective was to characterize spatiotemporal and three-dimensional locomotive behaviors of individual broilers with different gait scores measured by the three-point gait scoring method. Deep learning algorithms, depth sensing, and image processing were jointly developed and validated for behavior recognition.

Materials and methods

Animals and gait scoring

The experiment was conducted in the Robert T. Hamilton Poultry Teaching and Research Facility at Iowa State University (Ames, IA). All live bird procedures were approved by the Iowa State University Institutional Animal Care and Use Committee (IACUC #19-322, approval November 2021). A subset of 70 broilers (5 birds/pen from 14 pens) were randomly assigned on day 0 as focal birds and manually gait-scored on a 3-point scale on days 38 and 45. For manual gait scoring, birds were placed on a custom-designed plywood platform (1.8 m long, 0.46 m wide, and 0.30 m high). The platform has 0.15 m start and finish sections on each end of a 1.5-m-long walking space with delineations marked every 0.30 m. Focal birds were placed on the platform start section and traversed the walking space either independently or with encouragement by a researcher waving behind and gently tapping the bird with a ping-pong paddle. Each bird was assigned a gait score of 0, 1, or 2: score 0 indicates the ability to walk 1.5 m with no signs of lameness, score 1 indicates the ability to walk 1.5 m with signs of lameness (obvious unevenness in steps or sitting down at least once), and score 2 indicates an inability to walk 1.5 m.

Video and image acquisition

A web camera (V-U0040 Webcam, Logitech International S.A., Lausanne, Switzerland) and RGBD camera having four channels of red, green, blue, and depth (Intel® RealSense™ Depth Camera D435, Intel Corporation, Santa Clara, CA) were installed ~2.39 m above the platform to capture top-view videos and images, respectively. Videos were recorded at a resolution of 1,920 × 1,280 pixels at a sampling rate of 30 frames per sec (fps); video files were stored in AVI format every 20 min. Concurrent with videos, RGB and depth images were separately recorded at a resolution of 640 × 480 pixels at 10 fps. All recordings were automatically saved using the open-source Python-based library, OpenCV. Two PCs were used, one (Intel® Core™ i7-4770 CPU @ 3.4 GHz processor, 8.0 GB installed RAM, and 64-bit Windows 10 operating system) for recording videos and the other (Intel® Core™ i5-6500 CPU @ 3.2 GHz processor, 8.0 GB installed RAM, and 64-bit Windows 10 operating system) for recording RGB and depth images.

Algorithms

The overall process of characterizing behaviors of interest is depicted in Figure 1. Videos and RGB images were first pre-processed to remove unnecessary regions, then labelled using a deep learning-based graphical user interface (GUI), DeepLabCut (Nath et al., 2019), with an assigned key point on each bird's back. A deep learning model in the DeepLabCut was trained, and videos and RGB images were analyzed with the trained model for extracting key points on broilers' backs. Then an embedded tracking algorithm in DeepLabcut tracked individual broilers between adjacent frames of videos or RGB images via detected key points. The depth information of the key points was obtained by linking the depth images with correlated spatial information in RGB images. Extracted video and depth information was used to characterize spatiotemporal and three-dimensional broiler locomotive behaviors. The image processing package in Python and DeepLabCut are compatible with RGB-type files but not depth image files. Therefore, depth images were processed based on extracted coordinate information of each bird on corresponding RGB images. The RGB images captured by the RGBD camera were of lower resolution and frame rate than videos captured by the web camera, complicating the spatiotemporal behavior analysis.

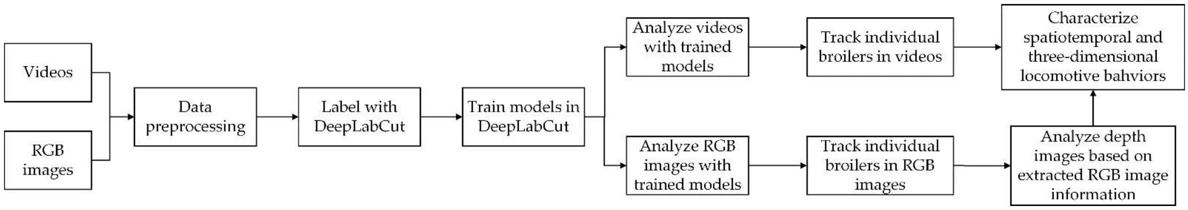

Figure 1: Overall process for characterizing spatiotemporal and three-dimensional locomotive behaviors of broilers

Model development and behavior analysis

The video and image files with bird locomotive behaviors and gait scores were manually selected. A total of four video episodes were randomly selected for each gait score, with each episode lasting 0.5 to 3.5 min. Four birds with score 2 were first identified, and then an equal number of scores 0 and 1 was used to match for statistical analysis. A total of 60 frames were extracted from each video for the DeepLabCut development. The ratio of training to testing images was set to 80:20. A training sequence involved starting with a select dataset until training loss performance metrics stalled, and then more image samples were supplemented to the dataset and the process repeated until optimal loss performance was reached. Accuracy and root mean square error (RMSE) were used to assess the final performance of the trained algorithm.

Four locomotive behavior metrics were analyzed based on the extracted coordinates of the key point for each bird: linear traveling speed, linear moving acceleration, forward-moving duration, and half-cycle duration of lateral body oscillation. Averages and maxima of these metrics on X, Y, and Z coordinates were statistically analyzed with significance level of $P \leq 0.05$, so that behavioral difference of individual broilers with various gait scores could be understood. The statistical analyses were conducted with One-way ANOVA using the PROC MIXED statement in the Statistical Analysis Software (SAS 9.3; SAS Institute Inc.). Least square mean comparisons of the behaviors were conducted using Fisher's least significant difference.

Results and discussion

The DeepLabCut embedded with the trained ResNet101 model achieved 100% accuracy in recognizing key points on the back of a broiler as it moved across the platform. The average RMSE was 4.0±3.3 mm for score 0, 3.9±2.6 mm for score 1, and 3.1±2.0 mm for score 2 (Figure 2), with an overall RMSE of 3.6±2.7 mm. This indicates that the trained deep learning-based platform accurately identified the region of interest and was appropriate to use for video analysis.

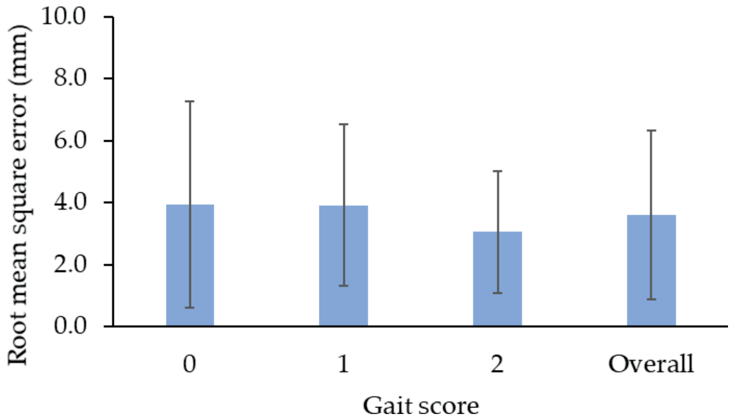

Figure 2: Root mean square error of key points on broilers' back between ground truth and prediction.

The average and maximum of forward-moving duration (FMD, measured in units of time) for score 0 were significantly higher than that of score 1, while the two metrics of half-cycle duration of lateral body oscillation were similar between the two scores. Except for the maximum of half-cycle duration of lateral body oscillation, the other metrics of the moving duration for score 1 and score 2 were similar. Average and maximum values of FMD are plotted as the first series in Figure 3 for each gait score.

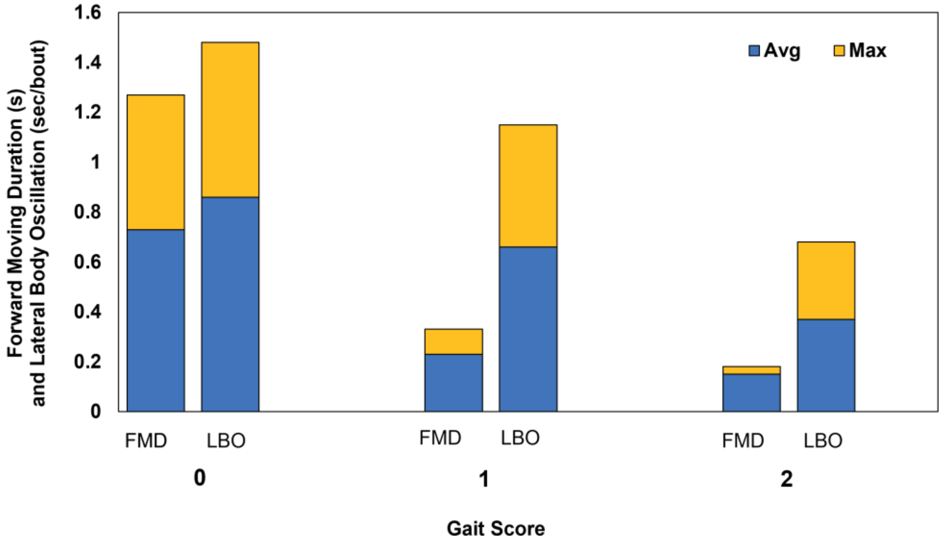

Figure 3: Forward moving duration (FMD) and lateral body oscillation (LBD) of broilers with gait scores of 0, 1, and 2.

On a horizontal plane, the zigzag walking patterns (lateral body oscillation along the forward-motion axis, or LBD, measured in time/bout) were observed for broilers with gait scores 0 and 1 more often than for broilers with score 2, and the zigzag trajectory length of broilers with score 0 was longer than that with scores 1 and 2. The zigzag walking pattern is also associated with lateral body oscillation. Average and maximum values of LBD are plotted as the second series in Figure 3 for each gait score.

The average and maximum of linear forward-moving speed and the average of the linear moving acceleration in the *X* and *Y* (forward, and lateral) directions for score 0 were significantly or numerically higher than those for score 1, and except for the average of linear moving acceleration, those parameters of score 1 were just numerically higher than those for score 2.

Conclusions

Spatiotemporal and three-dimensional locomotive behaviors of broilers were captured and characterized to classify birds by the three-point gait scoring system. Metrics extracted from the RGB and depth images and video sequences were also utilized to evaluate other locomotive behaviors. Deep learning algorithms, depth sensing, and image processing were jointly developed and achieved excellent performance for behavior recognition and gait scoring and can be a useful tool for laboratory-based welfare assessment.

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