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An Automated Method for Monitoring Footpad Health of Cage-Free Hens

Abstract

Footpad lesion or dermatitis is a common poultry condition that can negatively influence chickens' production, welfare, and health. However, no automated tool for monitoring footpad dermatitis (FPD) in live chickens is currently available. Besides broiler chickens, footpad dermatitis could happen in broiler breeders and cage-free egg layers as well. The objective of this study was to develop and optimize deep learning models to monitor hens' footpad health including footpad dermatitis and bumblefoot. In recent years, the YOLO (You Only Look Once) family models have gained significant prominence due to their exceptional speed and accuracy in object detection tasks. In this study, the YOLOv5x, YOLOv5s, and YOLOv5m were trained for bumble foot detection (BFD) and YOLOv7 and YOLOv8 models were extracted from GitHub Ultralytics for analyzing FPD. The new models were tested in cage-free layer facilities. By using deep learning models, the precision of bumblefoot detection and the footpad dermatitis detection reached 93.7% and 95%, respectively. The results show that the YOLOv8l outperformed other models in FPD detection, with higher recall (96.6%), mAP@0.50 (97.0%), and F1-score (95.0%).

Introduction

Footpad dermatitis (FPD) is a common poultry condition that can negatively influence chickens' production, welfare, and health. FPD, also called pododermatitis (Figure 1; de Jong and van Harn, 2012), is a widespread condition affecting laying hens. It is characterized by the development of inflammatory lesions, ulcers, and necrotic tissue on the plantar surface of the hens' feet. The FPD condition is often influenced by a combination of environmental factors (e.g., litter quality), stocking density, and overall health management (Shepherd and Fairchild, 2010). The FPD lesions can cause pain and discomfort in affected birds, impacting their walking and access to feed and water resources. Such challenges could further lead to reduced body weight, decreased egg production, and heightened veterinary expenditures. FPD could happen for 100% of chickens for poorly managed flock and is severely devaluating the billion-dollar poultry industry in the USA (9 billion chickens at farm gate value of $35 billion in 2023) and the world (USDA, 2024). Besides broiler chickens, FPD has been reported on cage-free laying hens (there are over 100 million cage-free hens in the US currently) due to poor litter quality (UEP, 2023). Currently, there is a lack of method for monitoring poultry FPD automatically. Bumblefoot (pododermatitis, footpad dermatitis, or foot rot) is the term used to describe a common bacterial infection and chronic inflammatory reaction in a chicken. It is clinically characterized by swelling, abrasion, hyperkeratosis, and ulceration of the digital pad, planta metatarsal region, or both. Bumblefoot compromises the foot's internal tissues, including the mesoderm, tendons, and bones, leading to laminitis (inflammation and damage that affects feet and can lead to lameness), synovitis (acute to chronic systematic disease caused by *Mycoplasma synoviae* infection), osteomyelitis (an inflammatory condition leading to infection of the bone), and ultimately death if left untreated. Cage-free hens and breeders spend a lifespan of 60-80 weeks or longer on litter floor, which may lead to bumblefoot under poor bedding quality (Figure 2).

Figure 1. Footpad dermatitis in broiler chicken (photo credit: Aviagen).

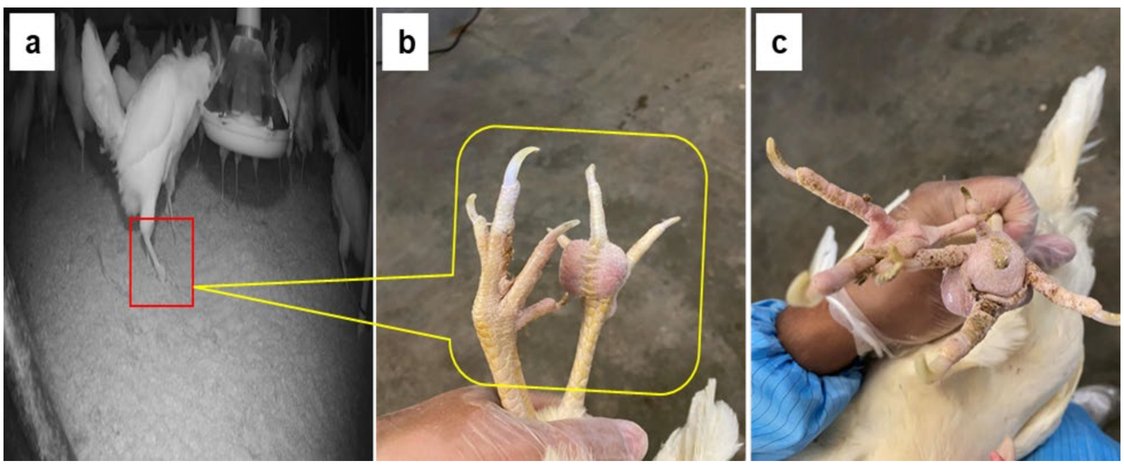

Figure 2. Cage-free laying hen having bumblefoot from a) side view, b) top view, and c) bottom view of the hen's foot (photo credit: Lilong Chai).

Various solutions have been researched to address FPD, including improving litter quality and flock density. Early FPD assessment can also help with timely intervention and reinforce consumer confidence in buying welfare-labeled products. The gold standard manual FPD assessment could be time-consuming and laborious and need skilled welfare assessors, which could limit labor shortages in farm work. Computer vision for data collection and machine learning for data analysis offer an alternative efficient solution for FPD scoring, which can overcome the abovementioned manual assessment drawbacks.

Materials and Methods

To address FPD monitoring challenges, researchers at the University of Georgia developed a machine vision-based method (Figure 3) for scoring footpad score automatically. Early FPD assessment can also help with timely intervention and reinforce consumer confidence in buying welfare-labeled products.

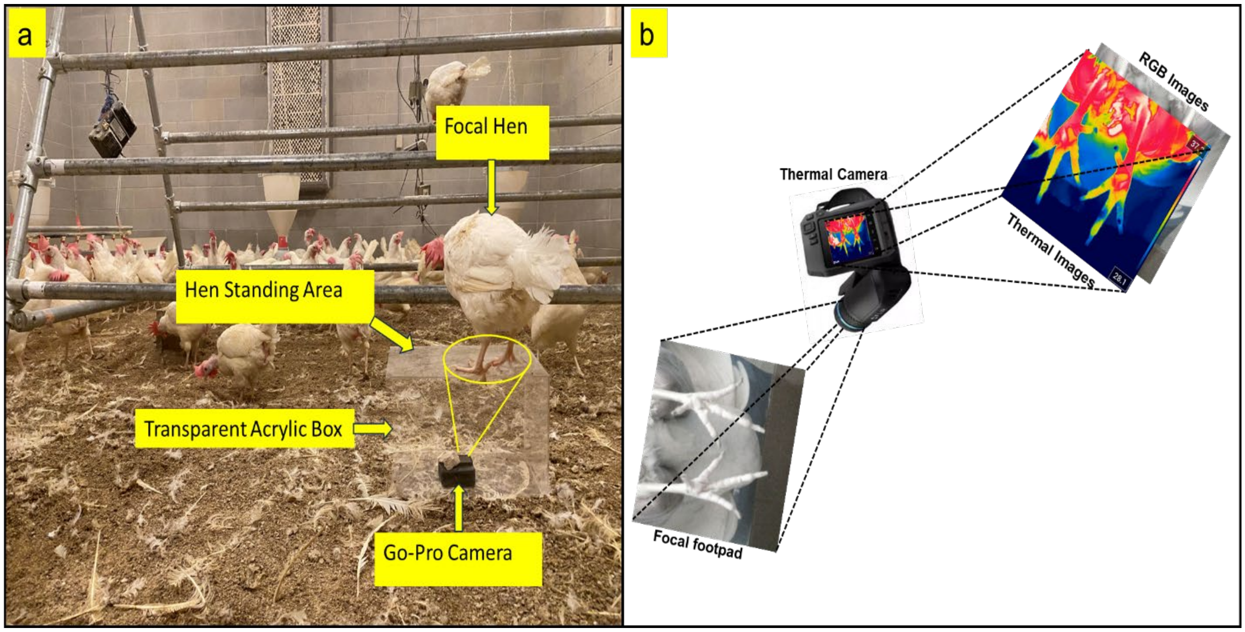

Figure 3. Footpad dermatitis conditions recording setup in cage-free hen housing using a) GoPro camera and b) thermal camera (photo credit: Lilong Chai).

A total of 700 Hy-Line W-36 hens were raised in four cage-free housing systems. A GoPro camera with an upward lens was placed inside a transparent box. Individual laying hens were placed on the top surface of the box to acquire RGB images. In addition, a thermal camera was used to record RGB and thermal images of footpads, and the images were manually scored to assess their footpad conditions. Preprocessing techniques (e.g., filtration, separation, and augmentation) were deployed to enhance dataset quality and size. In recent years, the YOLO (You Only Look Once) family models have gained significant prominence and been adapted by the research team to monitor poultry production, health, and welfare (Bist et al., 2023a, 2023b, 2023c, 2024a, 2024b; Subedi, 2023a, 2023b; Paneru et al., 2024; Yang et al., 2024a, 2024b). In this study, the YOLOv5x, YOLOv5s, and YOLOv5m were trained for bumble foot detection (BFD); and YOLOv7 and YOLOv8 models were extracted from GitHub Ultralytics for analyzing FPD. The system was tested in a research cage-free facility at UGA's research farm. Moreover, YOLOv8 models (YOLOv8n, YOLOv8s, YOLOv8m, YOLOv8l, and YOLOv8x) and YOLOv7 models (YOLOv7 and YOLOv7x) were comparatively evaluated for predicting FPD scores. For footpad scoring, we are following the guidelines in Table 1.

Table 1. Evaluating footpad scoring in different footpad conditions (Bist et al., 2024b).

FPD score	**Footpad condition**
Score 0	➢ Normal color.
	➢ No lessons.
	➢ No discoloration or slight area.
	➢ Old scars or no scarring.
Score 1	➢ Mild and/or superficial lesion.
	➢ Footpad discoloration.
	➢ Dark papillae without ulceration.
	➢ Lesion(s) covering less than ½ of footpad.
Score 2	➢ Severe lesions with ulceration and significant damage.
	➢ Dark papillae with ulceration.
	➢ Abscesses and/ or swollen footpad.
	➢ Lesion(s) covering more than ½ of footpad.

For computer model evaluation, the following metrics were applied:

Precision: Precision delineates the accuracy of the bounding box predictions in correspondence with the dataset.

$$Precision = \frac{TP}{TP + FP} \times 100\% = \frac{true\ FPD\ detection\ or\ scored}{all\ detected\ bounding\ boxes} \quad (1)$$

Where TP and FP denote true positive and false positive values, respectively.

Recall: Recall indicates the ability of the model to accurately predict true bounding box measurements within the dataset.

$$Recall = \frac{TP}{TP + FN} \times 100\% = \frac{true\ FPD\ detection\ or\ scored}{all\ ground\ truth\ bounding\ boxes} \quad (2)$$

Where FN denotes false negative value*.*

F1 score: The F1 score, a crucial metric in object detection, encapsulates a weighted average or harmonic mean of both precision and recall (Equation iii). The highest F1 score signifies improved detector performance. Object detection is highly accurate without negative outcomes when F1 score = 100%.

$$F1\ Score = \frac{2 \times Recall \times Precision}{Recall + Precision} \times 100\% \ (3)$$

Mean average precision (mAP): The mAP serves as a pivotal evaluation metric. It gauges the model's detection capabilities, employing an intersection over union (*IoU*) threshold of 0.5 (mAP@0.50) or a wider range of 0.5 to 0.95 (mAP@0.50:0.95).

$$mAP = \frac{\sum_{i-1}^{C} APi}{C} \ (4)$$

Within this equation, AP_i signifies the average precision of the i^{th} category, and C represents the total number of categories.

Results

For footpad dermatitis monitoring, from the tested images, comprehensive analysis confirmed that remarkable performance of the "YOLOv8l-FPD" model in effectively identifying FPD instances (Figure 4). The model's higher recall and mAP scores collectively underscore its proficiency in recognizing FPD instances across diverse scenarios. Each incremental improvement in performance metrics was important in reducing false detections by the model. Overall, the YOLOv8l-$FPD_{Thermal}$ model comparably demonstrated higher performance metrics throughout most of the training process. In this study, the newly trained model YOLOv8l outperformed other models, with higher recall (96.6%), mAP@0.50 (97.0%), and F1-score (95.0%). Additionally, the YOLOv8l-FPD model exhibited a high mAP@0.50 for score 0 (98.0%), score 1 (95.0%), and score 2 (97.9%) and F1-score (95.0%) for all FPD scores.

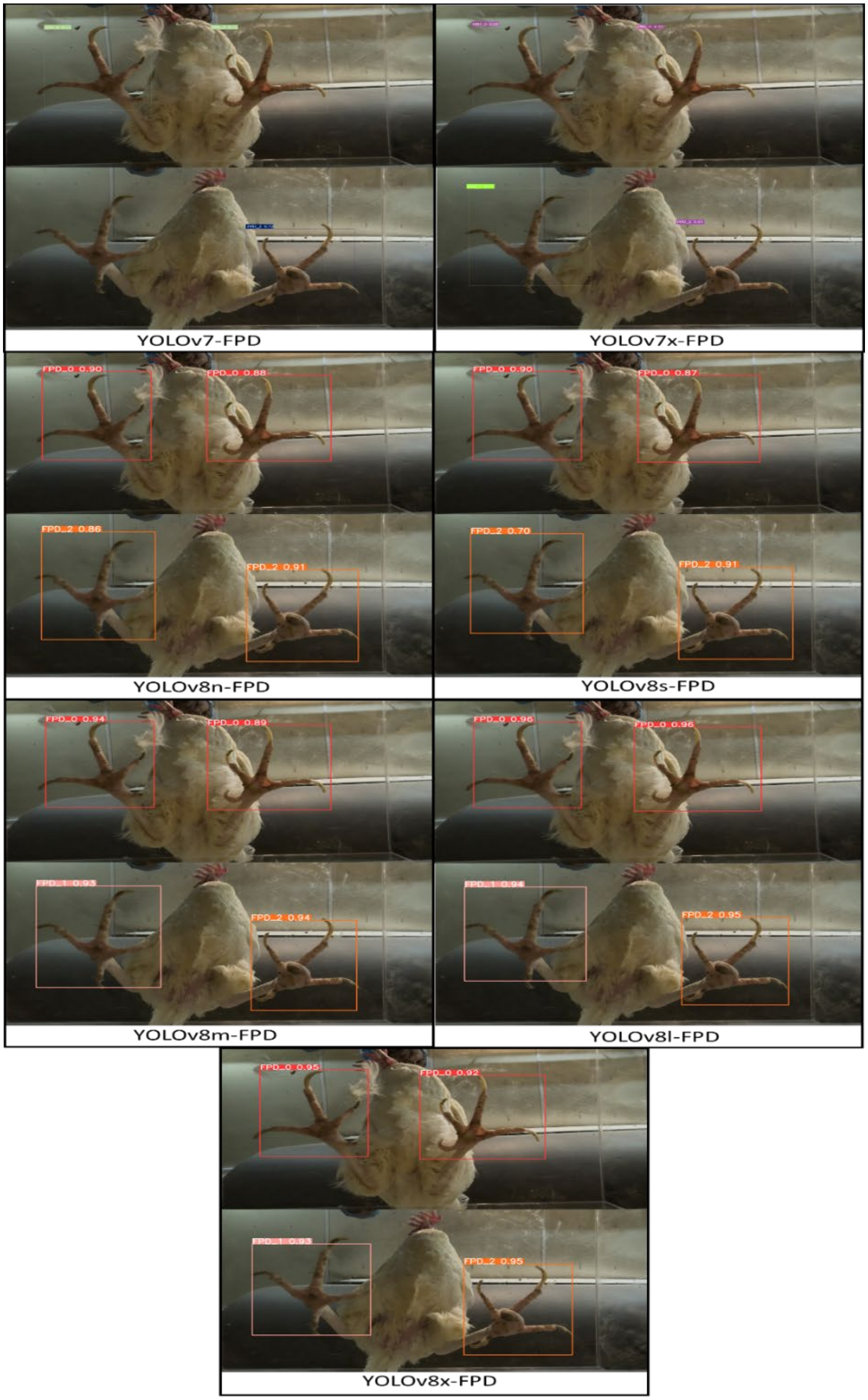

Figure 4. Comparison of detected footpad dermatitis score across various models in test datasets (photo credit: Lilong Chai).

The performance of three newly developed deep learning models (i.e., YOLOv5s-BFD, YOLOv5m-BFD, and YOLOv5x-BFD) were compared (Figure 5) in detecting hens with bumblefoot in CF environments. The results show that the YOLOv5m-BFD model had the highest precision (93.7%), recall (84.6%), mAP@0.50 (90.9%), mAP@0.50:0.95 (51.8%), and F1-score (89.0%) compared with other models. The observed YOLOv5m-BFD model trained at 400 epochs and batch size 16 is recommended for bumblefoot detection in laying hens. This study provides a basis for developing an automatic bumblefoot detection system in commercial CF houses. This model will be modified and trained to detect the occurrence of broilers with bumblefoot in the future.

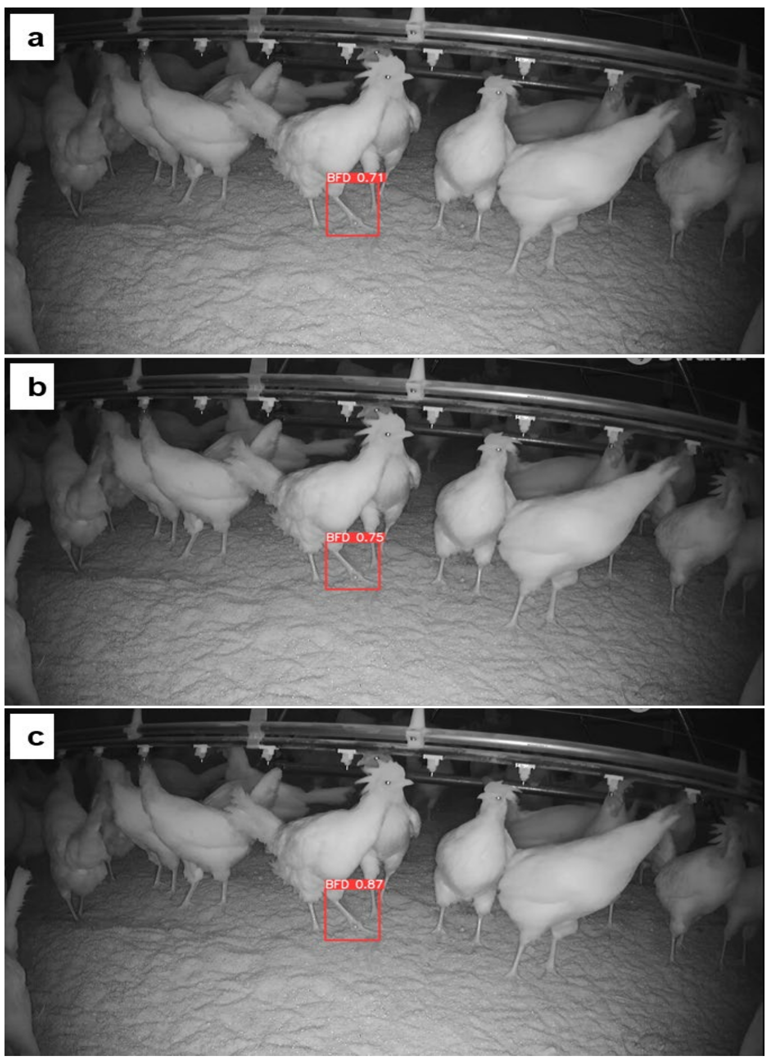

Figure 5. The bumblefoot detection results of a) YOLOv5x-BFD, b) YOLOv5s-BFD, and c) YOLOv5m-BFD. The figure with rectangular box represents the legs were detected with the bumblefoot. BFD-bumblefoot detection (photo credit: Lilong Chai).

Conclusion

This study presents a comprehensive FPD scoring and detection analysis, including valuable insights and performance metrics of different YOLOv5, YOLOv7 and YOLOv8 models. Despite the challenges posed by variables like the presence of manure and environmental factors, the YOLOv8l-FPD model performed better in accurately detecting and scoring FPD conditions. The YOLOv8l-FPD model resulted in higher recall, mAP, and F1 scores across varying image settings, and scoring detection underscores its proficiency and reliability. The proposed technique can be useful for non-invasive automatic FPD scoring and further improve automation levels and animal welfare in the egg industry.

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