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A RFID-Based Monitoring System for Characterization of Perching Behaviors of Individual Poultry

Kailao Wang
Iowa State University

Kai Liu
University of Pennsylvania

Hongwei Xin
Iowa State University, hxin@iastate.edu

Lilong Chai
University of Georgia

Yu Wang
Iowa State University, yuw@iastate.edu

See next page for additional authors

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Abstract

Perching is a natural behavior of poultry. However, it is difficult to distinguish individual birds in a large group in order to relate perching behavior to health condition or productivity. To enable such research, this study developed and validated a radio frequency identification (RFID)-based automated perching monitoring system (APMS) for characterizing individual perching behaviors of group-housed poultry. The APMS consisted of a RFID module, a load cell module, and a round wooden perch. The RFID module was comprised of a high-frequency RFID reader, three customized rectangular antennas, and multiple RFID transponders. The load cell module was comprised of a data acquisition system and two load cells supporting the two ends of the perch. Daily number of perch visits (PV) and perching duration (PD) of individual birds were used to delineate perching behavior. Three identical experimental pens, five hens per pen, were equipped with the monitoring system. Two RFID transponders were attached to each hen (one per leg) and a distinct color was marked on the bird's head for video or visual identification. Performance of the APMS was validated by comparing the system outputs with manual observation/labeling over an entire day. Sensitivity and specificity of the system were shown to improve from 97.77% and 99.88%, respectively, when using only the RFID module, to 99.83% and 99.93%, respectively, when incorporating weight information from the load cell module. This study revealed that the APMS has an excellent performance in measuring perching behaviors of individual birds in a group. The APMS offers great potentials for delineating differences in perching behavior among hens with different social status or health conditions in a group setting.

Keywords

Load cell, Laying hen, Welfare, Precision livestock farming

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Poultry or Avian Science

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Authors

Kailao Wang, Kai Liu, Hongwei Xin, Lilong Chai, Yu Wang, Tao Fei, Jofran Oliveira, Jinming Pan, and Yibin Ying

2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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A RFID-Based Monitoring System for Characterization of Perching Behaviors of Individual Poultry

Kailao Wang[1,2], Kai Liu[3], Hongwei Xin[2,*], Lilong Chai[4], Yu Wang[2,5], Tao Fei[6], Jofran Oliveira[2], Jinming Pan[1,*], Yibin Ying[1,7]

[1]Department of Biosystems Engineering, Zhejiang University, Hangzhou, Zhejiang, China

[2]Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa, USA

[3]Department of Clinical Studies - New Bolton Center, University of Pennsylvania, Kennett Square, PA, USA

[4] Department of Poultry Science, University of George, Athens, GA, USA.

[5]Department of Agricultural Structure and Bioenvironmental Engineering, China Agricultural University, Beijing, China

[6]Department of Food Science and Human Nutrition, Iowa State University, Ames, Iowa, USA

[7]Zhejiang A&F University, Hangzhou, Zhejiang, China

[*]Corresponding authors: Hongwei Xin, phone: (1) 515-294-4240; e-mail: hxin@iastate.edu; Jinming Pan, phone: (86)-571-88982282; e-mail: panhouse@zju.edu.cn.

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ABSTRACT. *Perching is a natural behavior of poultry. However, it is difficult to distinguish individual birds in a large group in order to relate perching behavior to health condition or productivity. To enable such research, this study developed and validated a radio frequency identification (RFID)-based automated perching monitoring system (APMS) for characterizing individual perching behaviors of group-housed poultry. The APMS consisted of a RFID module, a load cell module, and a round wooden perch. The RFID module was comprised of a high-frequency RFID reader, three customized rectangular antennas, and multiple RFID transponders. The load cell module was comprised of a data acquisition system and two load cells supporting the two ends of the perch. Daily number of perch visits (PV) and perching duration (PD) of individual birds were used to delineate perching behavior. Three identical experimental pens, five hens per pen, were equipped with the monitoring system. Two RFID transponders were attached to each hen (one per leg) and a distinct color was marked on the bird's head for video or visual identification. Performance of the APMS was validated by comparing the system outputs with manual observation/labeling over an entire day. Sensitivity and specificity of the system were shown to improve from 97.77% and 99.88%, respectively, when using only the RFID module, to 99.83% and 99.93%, respectively, when incorporating weight information from the load cell module. This study revealed that the APMS has an excellent performance in measuring perching behaviors of individual birds in a group. The APMS offers great potentials for delineating differences in perching behavior among hens with different social status or health conditions in a group setting.*

Keywords. *Load cell, Laying hen, Welfare, Precision livestock farming.*

Introduction

Perching is a highly motivated behavior of poultry. Especially at night, birds have a strong desire to use an elevated perch (Brendler and Schrader, 2016). Compared to conventional cage housing, all alternative housing systems for laying hens, such as enriched colony and cage-free housing that aim to improve animal welfare, are required to provide at least 15 cm perch space for each bird (Council Directive, 1999). So far, many studies have been done in both laboratory settings and commercial farms to assess the benefits and detriments of different perch designs to laying hens. Most studies focused on shape, height, angle of incline, surface material, and arrangement of perch (Brendler and Schrader, 2016; Liu et al., 2018). However, none of them could automatically and continuously monitor/track perching behavior of individual hens in a group.

Generally, the common indicator of a good perch (material or configuration) is preference of its use by the bird. However, data collection of perching preference in most experiments has been performed by manual observations (Brendler and Schrader, 2016), which is time and labor intensive and limited in observation period. Hence, different methods to automatically monitor perching behavior have been developed. Because body weight of commercial laying hens of a given breed is quite similar at the same age, load cells are mostly used to monitor the number of birds on a perch. Liu et al. (2018) used a real-time load cell-based perching monitoring system to automatically calculate the number of birds on perch, average perching duration, average perching trips, and average perching frequency in a laboratory pen. Computer vision is another powerful tool to monitor and quantify animal behavior. Nakarmi et al. (2014) developed an automated monitoring system of individual hens in a pen using 3D computer vision and RFID technology. The system was capable of monitoring individual behaviors such as locomotion, perching, feeding, drinking, and nesting.

Competition in an animal group is often inevitable, where the subdominant animals usually have less accessibility to resources than the dominant ones (Carvalho et al., 2018). In order to safeguard welfare for all animals in a group, it would be necessary to perform individual behavior monitoring (Nasr et al., 2012). Using load cell to monitor perching behavior is reliable, but the shortcoming is its inability to differentiate one bird from another. By applying marks on animals, computer vision can identify individuals in a group (Kashiha et al., 2013). However, it is not practical to mark a large group of birds with different colors or patterns. To date, one of the most popular technologies for identifying individual animals is the RFID technology. It has been applied in animal behavior research of pigs (Adrion et al., 2018), poultry (Li et al., 2017), cattle (Adrion et al., 2017), and sheep (Barnes et al., 2018).

In this research, we developed an Automated Perching Monitoring System (APMS) using RFID technology and load cells. The incorporation of RFID with load cell in the APMS not only allows to determine the perching events of the group, but identifies which birds are involved in performing the perching behavior (e.g., perching duration or PD – time spent on perch, perch visit or PV – the number of times a hen uses the perch in a given period). The system performance was validated by comparing the APMS results with manual observations or human labeling. One potential application of the APMS is to help identify individual birds in a group that are either socially disadvantaged or having certain health issues through real-time monitoring of their perching behaviors.

Materials and Methods

Automated Perching Monitoring System (APMS)

Perch

A round wooden perch of 1.2 m in length and 3.5 cm in diameter was used in the system. The usable length for perching was narrowed to 1.0 m using two triangle blockers (fig. 1).

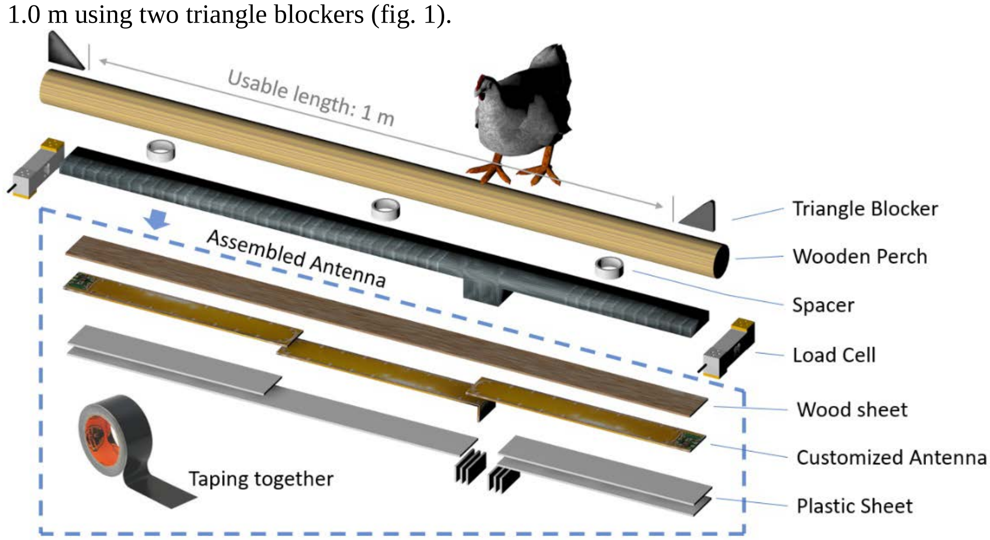

Figure 1. A schematic structure of the automated perching monitoring system (APMS) developed in this study.

RFID Module

RFID technology was used in the APMS to recognize individual birds in the group. Each RFID module consisted of a RFID reader (D-Think_514, 13.56Mhz, ISO15693, Guangzhou D-Think Technologies Inc., China. fig. 2a), three customized rectangular RFID antennas (7.3 cm wide, 37.9 cm long, 0.7 cm thick (fig. 2b), and several RFID transponders (inside coil along axial direction of the transponder. fig. 2c). The antennas and transponders were provided by the same vendor as the RFID reader. The customized antennas were specially designed for the APMS (the width of antenna was narrowed to 7.3 cm) in order to avoid potential physical interference with the bird's perching. The three antennas were assembled in series and fixed beneath the perch (fig. 1) to cover the entire perch length and maintain similar signal strength along the perch. Between the perch and the assembled antenna, three 1.5 cm high spacers were placed to avoid the assembled antenna being too close to the perch, thus interfering with the perching behavior.

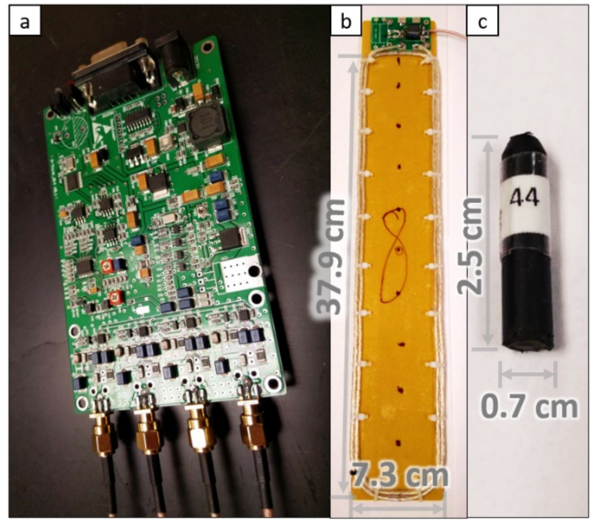

Figure 2. Components of the RFID module. (a) 4-channel HF RFID reader, (b) customized rectangular antenna, (c) RFID transponder.

Load Cell Module

A load cell (Model 642C, Revere Transducers Inc., Tustin, CA, USA) was installed under each end of the perch (fig. 1) to collect the weight data on the perch. The hardware (NI cFP-2020, and NI cFP-TC-120, National Instrument Corporation, Austin, TX, USA) and software (LabVIEW version 7.1, National Instrument Corporation) of the load cell modules were adopted from an existing setup that had been validated and successfully applied in two previously published perching studies (Liu et al., 2018; Liu and Xin, 2017).

APMS Data Collection and Processing

Three identical sets of APMS were operating simultaneously in the evaluation experiment. All three RFID modules were controlled using the same computer. Data from the RFID modules were collected using a Python program and transferred to the computer through serial port communication. The RFID readers had a maximal registration rate of 15 individual registrations of transponders per second. However, for a more stable output, the reading time interval was set to 2 s. The timestamp and the unique identification keys of the detected transponders were recorded for each reading as the RFID raw data. The load cell modules were controlled by a separate computer. The weight data were sampled at 1-s intervals. Timestamp and total weight on perch were recorded for each sampling. The two computers were synchronized to have the same time clock.

The flowchart of APMS data collection and processing is shown in Figure 3. The APMS data processing was done in a time-delay mode because the RFID raw data and weight data were stored separately in two computers. After the data collection, the RFID data were processed to obtain the corresponding bird identification keys ($Birds_{RFID}$) and the total number of birds on perch determined using the RFID module (NB_{RFID}). The total weight on perch was processed to obtain the number of birds on perch from the load cell module (NB_{LC}), determined by dividing the total weight on perch by average body weight of the birds (Eq. 1). The NB_{LC} data were then used to fine-tune RFID-based data for improved system performance.

Weight or NB_{LC}-Based RFID Data Correction

The RFID raw data correction/improvement was conducted by comparing NB_{RFID} and NB_{LC}. Because of the high reliability of NB_{LC} results, we trusted the verified weight data when disparity existed between weight data and RFID raw data. Hence, when NB_{RFID} was not equal to NB_{LC}, the corresponding RFID raw datum was regarded having error (presumably due to missing RFID transponder readings at this moment) and was made equal to the last RFID value (Eq. 1).

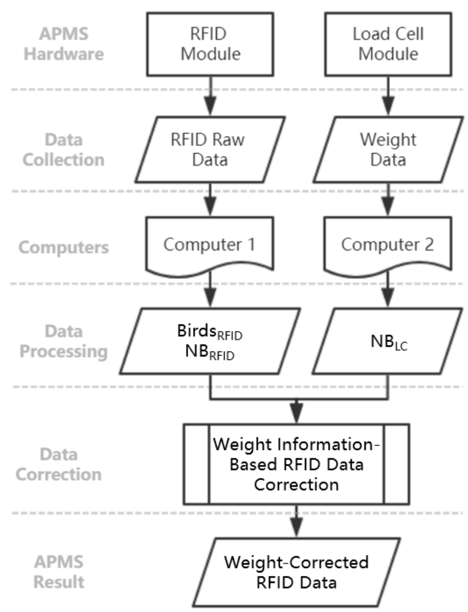

Figure 3. A flowchart illustration of the APMS data collection and processing. $Birds_{RFID}$ is bird identification key detected by the RFID module; NB_{RFID} is the total number of birds on perch as determined by the RFID module; and NB_{LC} is the number of birds on perch as determined by the load cell module.

$$NB_{LC}^{t} = \frac{total \quad weight \quad on \quad perch \quad in \quad time \quad t}{average \quad body \quad weight}$$
$$\begin{cases} NB_{RFID}^{t} = NB_{RFID}^{t-1} \quad , \\ Birds_{RFID}^{t} = Birds_{RFID}^{t-1} \quad , \end{cases} \qquad if \quad NB_{RFID}^{t} \neq NB_{LC}^{t} \tag{1}$$

where NB_{LC}^{t} is number of birds on perch calculated by weight data from load cell module at time point *t*;

$Birds_{RFID}^{t}$ is the bird identification keys detected by RFID module at time point *t*;

NB_{RFID}^{t} is the total number of birds detected by RFID module at time point *t*.

Experimental Pens

Three identical experimental pens each equipped with the APMS (fig. 4) were built in an environment-controlled animal research lab at Iowa State University, Ames, Iowa. Each pen was built with aluminum tubes and metal mesh and measured 1.2 m long × 1.2 m wide × 1.2 m high. To avoid the birds flying out of the pen, a roof made of plastic netting was included. A nest box measuring 53 cm long × 50 cm wide × 43 cm high was built to accommodate the nesting behavior. Wood shavings was used as floor bedding of the pen. A 60-cm feed trough and a drinker with two nipples were installed in each pen. An APMS with 1.0 m usable perch length was installed in each pen to accommodate perching behavior. The perch was 30 cm high and 30 cm away from the back wall of the pen. A surveillance camera (CAM-MC101DV3/2W(3.6), Backstreet Surveillance Inc., Salt Lake City, UT, USA) was installed above each pen to record the birds behaviors.

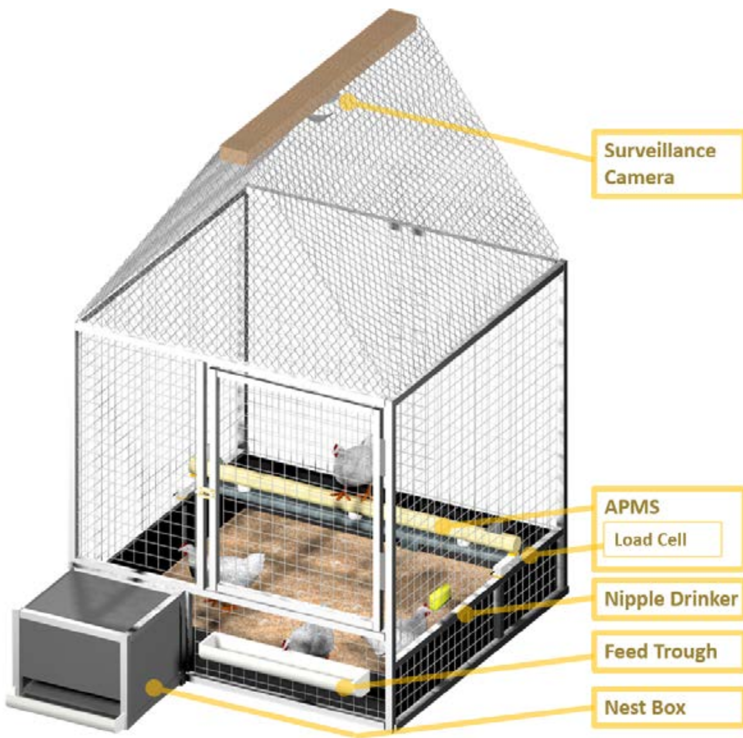

Figure 4. Experimental pen with Automated Perching Behavior Monitoring System (APMS) installed.Characterization Test of RFID Module.

To examine the static-state performance of the RFID module, a test was conducted by manually placing the RFID transponders above the assembled antennas. Three transponders (No. 41, 44, 54) were tested on every assembled antenna with 36 test points (fig. 5). For each test point, the highest detectable distance to the antenna surface was recorded. A python program was used to control the RFID readers. The sampling rate was set to 1 Hz and a 5-s reading period was used for every test position. If no less than three out of the five readings showed the transponder was successfully registering, this placement height was regarded as detectable.

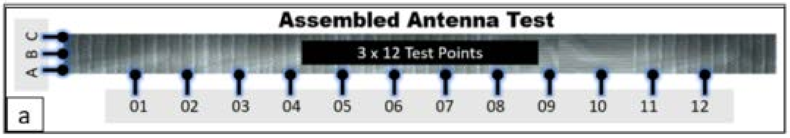

Figure 5. Assembled antenna test.

Experimental Birds and Validation of the APMS

Fifteen laying hens (DeKalb White, 35 weeks of age) were used to validate the APMS. These hens were procured from a local commercial cage-free farm and were acclimated for one week in the experimental pens before commencement of the measurements. The average body weight of the hens before the experiment was 1.69 ± 0.11 kg (mean ± SD). Each hen wore two RFID transponders (fig. 6a) on the legs (to increase the system reliability), with one transponder attached to each leg in a perpendicular orientation to the assembled antenna surface to maximize the detectability (fig. 6b). Five hens were randomly assigned to each experimental pen and marked with one of five distinct colors on the head (green, orange, blue, yellow, and pink) (fig. 6c). Feed and water were provided *ad libitum*. Feed was refilled and eggs collected manually at 1500h every day. Air temperature and relative humidity (RH) were controlled at about 22°C and 57%, respectively, in the experimental room. The photoperiod was 16h light (0500 -2100h) and 8h dark. The light intensity at the bird head level was 55 lx in the pen and 1.5 lx in the nest box during the light period. To avoid stress to birds caused by sudden lights on/off, we used a 15-min transitional period before the lights came on and went off (0445h - 0500h, 2045h - 2100h). The light intensity during the transitional periods was 7 lx in the pen and 0.8 lx in the nest box. The experimental protocol had been approved by the Iowa State University Institutional Animal Care and Use Committee (Log # 1–18-8678-G).

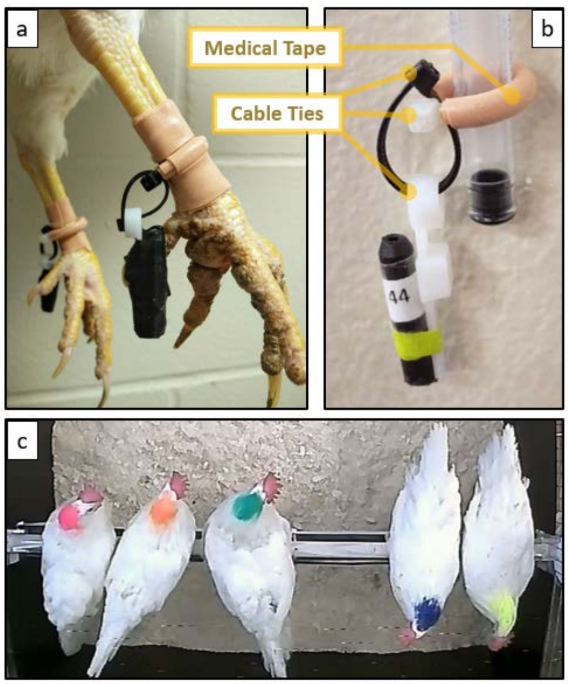

Figure 6. (a) RFID transponder attached to both legs of each hen and (b) method of attaching RFID transponders using three cable ties, and (c) color marking on hen's head.

Validation of APMS Data with Video Observation

The results of our APMS were compared with manual observation of the recorded videos. The manual observation was conducted to find the timestamps when the 15 individual hens jumped on and off the perch in one-day videos (light period of 8th May, 2018, 0500h – 2045h). The timestamps were then used by a MATLAB program to calculate the PV and PD of the 15 individual hens and generated a 1-s interval perching status table for each hen. The APMS performance was quantified in terms of sensitivity, specificity, precision, and accuracy.

Statistical Analysis

Three assembled antennas and three RFID transponders were tested in the characterization test of RFID module. One-way ANOVA test (using P value = 0.05) was applied using MATLAB to determine similarity in performance among the antennas or transponders.

Results

Characterization Test of the RFID Module

The results of the RFID module static test are shown in Figure 7. All three RFID modules had signal valleys at each connection of two adjacent antennas (fig. 1). The detectability in the middle of the assembled antennas was weaker than in the ends, which resulted from signal interference from both antennas at the connection region. Comparing the three RFID modules, we found significantly weaker detectability of the assembled antenna in Pen 1 than in Pens 2 and 3. The lowest detectable distance was 7 cm, while the highest detection distance of Pen 1, 2, and 3 was, respectively, 11 cm, 14 cm, and 13 cm. All the three antennas showed consistent detectability for different RFID transponders.

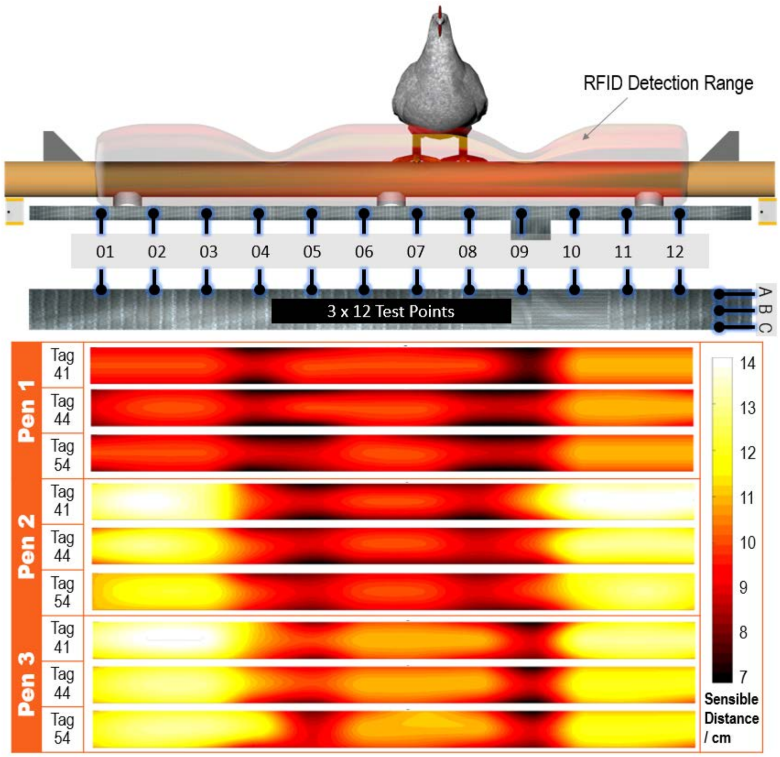

Figure 7. Detectable distance of the RFID transponders with the three serially-assembled antennas across the perch span in the three pens.

APMS Validation

Manually Observed Perching Information

We manually observed one day of video data (8th May, 2018, 0500h - 2045h) and summarized the individual perching behavior of the 15 hens. The individual PV and PD of the 15 individual hens are shown in Figure 8. During the 15.75-hr light period, the hens showed a PV of 36 ± 21 (mean ± SD) and a PD of 2:41:03 ± 1:52:54. The scope (volume and diversity) of the data was considered adequate for validating the APMS.

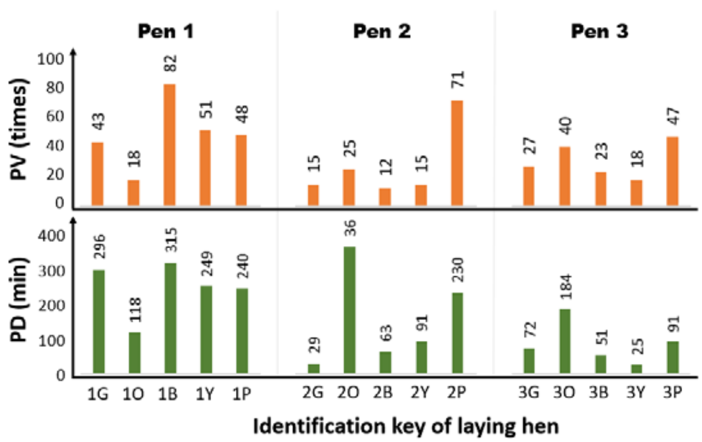

Figure 8. Perch visit (PV) and perching duration (PD) of 15 individual laying hens by manually observing videos during 0500h - 2045h, 8th May, 2018. Identification key: the number stands for pen and the letter stands for each of the five colors (Green, Orange, Blue, Yellow, Pink).

APMS Performance

Table 1. Sensitivity, specificity, accuracy, and precision of RFID raw data and weight-corrected data as compared with the video observed (reference) results of the three experimental pens.

	Pen No.	**Sensitivity [%]**	**Specificity [%]**	**Precision [%]**	**Accuracy [%]**
RFID Raw Data	1	96.23	99.82	99.48	98.88
	2	97.57	99.90	99.52	99.51
	3	99.50	99.91	99.06	99.87
Weight-Corrected Data	1	99.78	99.88	99.66	99.85
	2	99.88	99.96	99.80	99.95
	3	99.84	99.95	99.54	99.94

In Table 1, it can be seen that sensitivity, specificity, accuracy, and precision of the APMS are all commendably high. However, performance of the APMS in pen 1 was relatively inferior to the other two, especially the sensitivity. Since sensitivity represents the ability of the APMS to detect hens on perch, lower sensitivity means higher chances of missing registrations of the transponders when the hens are on perch. As a result, one consecutive PV is more likely broken into two or more, which would be undesirable. With the weight-based RFID data correction, the sensitivity results were improved. The average performance (mean ± SD) of the APMSs was 99.83% ± 0.05 % for sensitivity, 99.93% ± 0.05% for specificity, 99.67% ± 0.13% for precision, and 99.91% ± 0.05% for accuracy. It is worth noting that even without the weight-based correction, performance of the APMS based on the RFID data alone is already very commendable.

Discussion

Initially we taped the RFID transponders directly to the hen's tibia, as done by Nakarmi et al. (2014). However, more transponder registrations were missing than using the current attaching method. The reason was that when a hen changed posture from standing to sitting, the RFID transponder along the tibia would change its orientation to the assembled antenna surface from perpendicular to parallel, which drastically reduces the detectable range. In comparison, using the three cable ties can keep the RFID transponders perpendicular to the antenna surface. One shortcoming of the current method is that the mounting process is more intricate. The cable ties and transponders were non-detrimental to the birds, as no sign of damage was present to the hens' legs or claws after wearing them for almost three months.

For stable detection of the birds at any position on the perch and at the same time no false-detection of birds on the floor, three customized HF-RFID antennas were used in this study. Theoretically, slat-shaped UHF-RFID linear polarized antennas could be an alternative. However, it is important to check if the signal strength difference in lengthwise direction of antenna is acceptable (Li et al., 2017, see fig. 11).

The developed APMS in this study showed a much improved performance compared to other RFID systems applied in animal behavior research to date (Li et al., 2017, Adrion et al., 2017, Adrion et al., 2018, Barnes et al., 2018). First and foremost, with the customized antennas, attachment of the transponders, and load cell data correction (or even without the weigh-based correction), this system demonstrates a set of superior performance indicators. Perhaps the most unique aspect of the APMS is its ability to discern which bird conducts the perching activity, hence its diurnal pattern. This system offers a powerful tool for various studies or precision poultry farming applications involving the need to characterize perching behavior (e.g., an indicator of flock health) or automatic weighing of individual birds.

Summary and Conclusion

An Automated Perching Monitoring System (APMS), being able to characterize perching behaviors of individual poultry in group housing, has been developed and validated in this study. The APMS uses four-channel high-frequency RFID readers, customized rectangular antennas, and passive transponders. The weight information from load cells installed under the perch was used to correct/improve the RFID-based data. Performance of the APMS was validated with manual video observation result. The APMS showed a sensitivity of 97.77% and a specificity of 99.88% when using RFID module only; and the sensitivity and specificity were improved to 99.83% and 99.93% after incorporating weight information from the load cell module to the RFID module. The APMS system showed excellent performance in measuring individual perching behavior of laying hens in our experimental pens. The system will potentially enable us to identify individual hens in a group that have different social and/or well-being status.

Acknowledgments

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