Spatial behavior monitoring system based on radio frequency identification for laying hen in large cage aviary unit system

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Abstract

In order to accurately and efficiently analyze spatial utilization and spatial distribution of chickens, and realize the automatic monitoring of vertical space motion behavior in large cage aviary unit system, a spatial behavior monitoring system based on UHF RFID (Ultra High Frequency Radio Frequency Identification) was developed and tested. The monitoring system was mainly composed of passive electronic tag, antenna, UHF reader, industrial computer and bundled software. The optimization of this monitoring system was achieved by combining RFI distance equation and filtering processing method. The monitoring system was used to continuously record 16 chickens for 5 days in large cage aviary unit system, and cameras were recording for manually labeling as a reference. The results showed that: 1) The uniform distribution of RF energy in each layer of the test unit could be ensured when the antenna transmission power was 18.5 dBm. 2) The average accuracy rate of this monitoring system was 87% ± 3%, which basically met the requirements of field test. 3) The used median filtering method with sliding window size n = 5 could significantly improve the accuracy and stability of the system and reduced the lag effect of filtering on the motion change of vertical space. The system accuracy after filtering was 95%. This study will be helpful for monitoring of the vertical space motion behavior of chickens, and analyzing the spatial distribution and facility utilization, which provided scientific basis for improving the production performance and welfare level of chickens in large cage aviary unit system.

Keywords: multi-tier rearing system, three-dimensional space motion, UHF RFID, median filter

Introduction

With the development of the welfare farming model, livestock and poultry health and welfare levels receive more attention. As one of the alternative systems to traditional cage breeding, the multi-tiered non-cage system provides a multi-layer activity space for chickens (Liu Yang and Baoming Li, 2015), which fully satisfies the spatial needs of free movement and behavioral expression (Hartcher and Jones, 2017). However, the spatial design of breeding equipment (Arnould and Faure, 2004), resource distribution (Lentfer et al., 2013) and other influencing factors lead to hindered free movement and restricted behavioral expression of chickens, which affects production performance and animal welfare. Therefore, efficient monitoring and analysis of chickens' spatial distribution and utilization patterns in multi-tiered non-cage system are essential to optimize the system design as well as to improve the production performance and welfare of chickens.

In recent years, individual identification technologies such as machine vision, radio frequency identification and acceleration sensors have been widely used in livestock and poultry research and farming (Lihua Li et al., 2019). Zanon et al. (2021) applied machine vision techniques for recording individual activity behavior of caged chickens. Compared with the cage model, multi-tiered non-cage system provides a wider activity space in a three-dimensional space real-time recording using of the chickens machine vision techniques is more difficult. Traulsen et al. (2016) showed that accelerometer-based technology can also be used to record individual activity behavior, but wearing the sensor will affect the vertical spatial movement of the chicken in multi-tiered non-cage system due to the weight of the accelerometer and the chicken's body size. Radio frequency identification (RFID) technology has the advantages of light weight, small size, and easy deployment in sub-regions. It has been explored in various aspects such as feeding and drinking behavior (Oliveira et al., 2019), egg-laying behavior (L. Oliveira et al., 2019), and activity behavior (Campbell et al., 2018) of livestock and poultry. In-depth research has been conducted on individual chicken behavior under different new welfare farming models. Wang et al. (2019) used high frequency radio identification technology (HF RFID) for monitoring individual chicken roosting behavior based on RFID devices and customized strip antennas. Sibanda et al. (2020) implemented monitoring of chicken activity behavior in a multi-tiered non-cage system based on ultra high frequency radio identification technology (UHF RFID) devices for analysing the relationship between flock activity range and uniformity. These studies mainly monitored the key activity areas of chickens with numerous antenna distribution points, but the actual monitoring range was small and difficult to be promoted for use in commercial farming environments. The use of RFID technology is a more reasonable, easy-to-operate and complete solution for recording individual chicken behavior in multi-tiered non-cage system, especially UHF RFID with more reads and wider monitoring range. However, relatively few studies have been conducted to monitor the vertical spatial movement behavior of chickens in multi-layer non-cage systems, and the deployment of multiple antenna sites limits the commercial application of the system.

The objective of this work was to improve antenna distribution, explore fundamental parameters, and develop the real-time monitoring system of vertical space movement behavior, to provide a scientific basis for efficient management of chickens in roosting system and optimal design of facilities and equipment.

Materials and methods

Test flock with breeding equipment

The commercial generation of Jingfen No.6 egg-laying hens was used. An off-ground large cage aviary unit system was designed independently by China Agricultural University and used throughout the experiment, with the system unit size of 4.8 m × 2.9 m × 3.3 m (Figure 1). The system consisted of four levels of movable platforms and perch bars while each platform was equipped with a food trough and a nipple-type water dispenser. A 1.2 m length of breeding space was partitioned in the off-ground large cage aviary with the dimensions of the test unit being 1.2 m × 2.9 m × 3.3 m. The test cell was closed at one end of each perch over a distance of 0.6 m, and chickens were only allowed to move up and down from the other end, leaving a perch length of 0.6 m available for use.

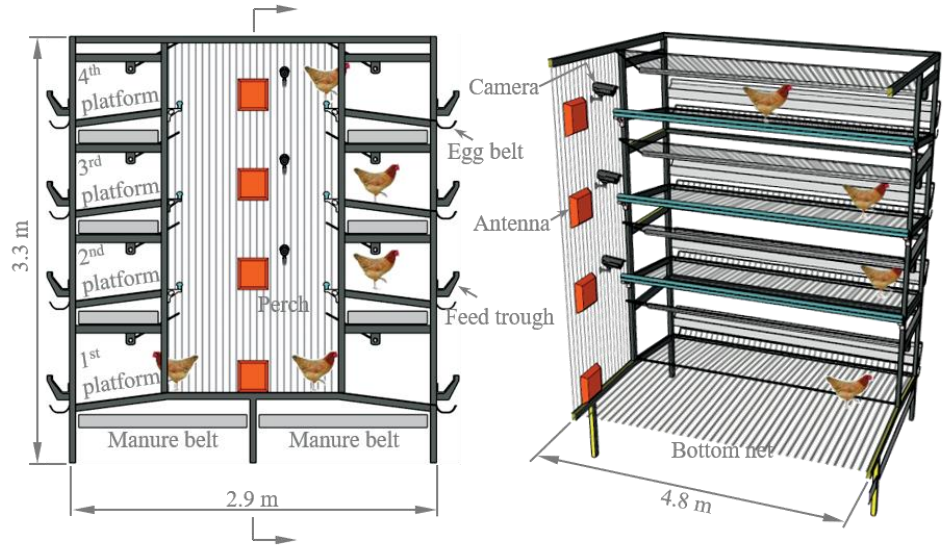

Figure 1: Structure and site photos of the test breeding equipment.

Vertical space motion behavior monitoring system

The vertical space motion behavior monitoring system is composed of two parts: motion behavior acquisition module and data operation module (Figure 2a). The motion behavior acquisition module collects the motion behavior data and consists of passive electronic tag, antenna and UHF read-write. The data operation module controls the collection module start/stop and data storage, and is composed of the industrial control computer containing the program. The system software function flow is shown in Figure 2b.

Four groups of antennas are installed on each level of the platform and fixed on the same side of the wire mesh (Figure 2). The passive electronic label is with the animal marker foot tag is fixed at the ankle of the chicken. The UHF read-write is fixed on the side of the second layer platform and connected with the antenna of each layer through the feed line. The worker control machine is placed outside the test unit and uses the network cable to communicate and power supply with the UHF read-write.

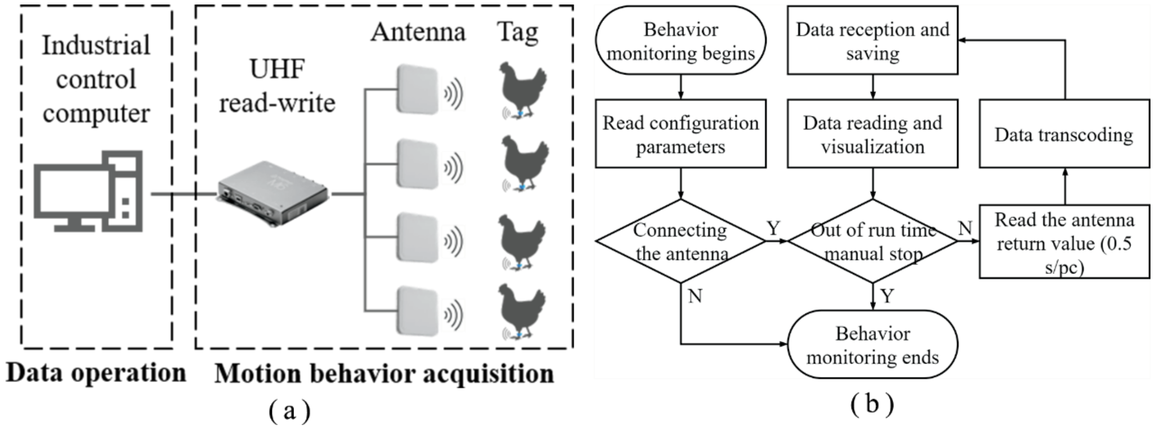

Figure 2: Structure of vertical space motion monitoring system.

System performance testing

To determine the influence of the tag direction on the actual reading range of the antenna, 45 passive electronic tags are arranged in 5 rows and 9 columns (Figure 3). They are evenly distributed on the wall area with the size of 1.2 m×0.7 m (similar to the single-layer channel area of the large cage aviary unit system). The fixed way of the tag is adjusted to the horizontal and vertical antenna direction respectively, and the antenna transmitting power is set to the maximum value of 31.5 dBm. The same antenna is placed at six positions of 30 cm, 60 cm, 90 cm, 120 cm, 150 cm and 180 cm from the wall in sequence, and the number of tags acquired by the reader is recorded at each position. To determine the influence of the transmitting power on the reading range of the antenna, the transmitting power of the antenna is gradually adjusted from 31.5 dBm to 15.5 dBm in 1 dBm increments, and the number of labels acquired by the reader under each transmitting power is recorded.

Four chickens were randomly selected from each layer of the system and transferred to the test cell, for a total of 16 chickens. The chickens were placed on the platform of each layer corresponding to the test unit according to the number of layers where they were originally located. Before the start of the experiment, the animal marker foot tags were connected with the passive electronic tags, and the corresponding serial number coding table was generated. The initial distribution of individual chickens was recorded manually within 30 min after the lights were turned on each day according to different color and marker animal marker foot tags. The vertical spatial movements of chickens were collected using cameras installed on both sides inside the experimental unit. Individual chicken movement behavior data were recorded by manual observation. The vertical spatial movement behavior monitoring system recorded the movement behavior data of individual chickens in the time period of 05:00-16:00 after the lights were turned on and the data were collected continuously for 5 days. The obtained data contain time stamp, passive electronic tag serial number and antenna serial number, and are saved in CSV file format. After data collection, the serial number code table and antenna serial number are queried to generate individual chicken movement behavior data, and the system accuracy is calculated by comparing with manual observation data.

Reflection, scattering and bypassing of antenna signals generates a crosstalk reading in the vertical spatial movement behavior monitoring. Antennas on this layer also read tags on other layers, affecting the accuracy of the system. Chickens needed to pace the perch area to find a suitable landing point before performing vertical space motion. The movement changes slowly and rarely performs fast and frequent vertical space motion. Median filtering can effectively overcome the fluctuation interference caused by accidental factors, and filters the slowly changing measured parameters. Consequently, it can be used for data filtering processing of vertical spatial motion behavior monitoring system. The median filtering moving window n affects the final filtering since the original data are time-varying motion behavior data. If the size of n is too large, it may cause the motion change lag, so the size of n in this experiment are 3, 5 and 7.

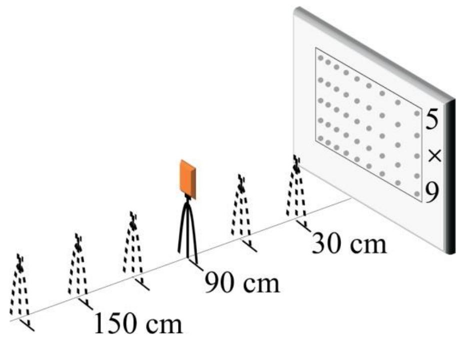

Figure 3: Schematic diagram of tag arrangement and antenna position.

Data processing

Using the Shapiro-Wilk test for normality test. Normal distributed data were expressed using the mean ± standard deviation. Non-normal distributed data were expressed using the median value and interquartile spacing. The spatial distribution of different layers of the chicken flock was statistically analyzed using the Kruskal-Wallis test for independent samples (non-normally distributed data) with a non-parametric test. After filtering and denoising the original data, different sliding window size filtering method divided the data into four groups. Statistical analysis was performed using the Firdman test for correlated samples (non-normally distributed data). All statistical processing was done by SPSS 25.0 statistical software, and graph drawing was done by Origin 2018 drawing software, and the results of the analytical test were indicated by $P<0.05$ showing significant differences.

Results and discussion

Reading range measurement results

The number of tags read by the reader under different tag directions as shown in Figure 4a. In different positions, the horizontal direction of the tag reading quantity change amplitude is small. The tag reading quantity at the lowest position, which is 30 cm, is 41 reads. The number of tags read in the vertical direction varies more, the lowest number is at 180 cm, with only 18 reads. There are peaks in the number of tags read and distance variation under different tag directions. The peak of the horizontal direction tag reading quantity corresponds to the distance of 120 cm, the peak of the vertical direction tag reading quantity corresponds to the distance of 60 cm. Therefore, in order to ensure that the reader can read more tags during the test, the antenna and the tag distance of 60 cm is choosen. The number of tags read by the reader under different transmitting power as shown in Figure 4b. The results show that, with the reduction of transmitting power, the number of tags read in different directions shows an overall decreasing trend. In order to make the uniform distribution of RF energy in all layers, to ensure that the antenna reading range can completely cover the layer and will not read other layers, the number of reads needs to be 0 at the maximum position of the tag and the antenna. At the transmitting power of 20.5 dBm and 18.5 dBm, the vertical and horizontal direction tags meet the requirements respectively, and no tag is read after continuously reducing the transmitting power. To ensure that the numbers of reads are all zero, the antenna transmitting power is chosen to be 18.5 dBm.

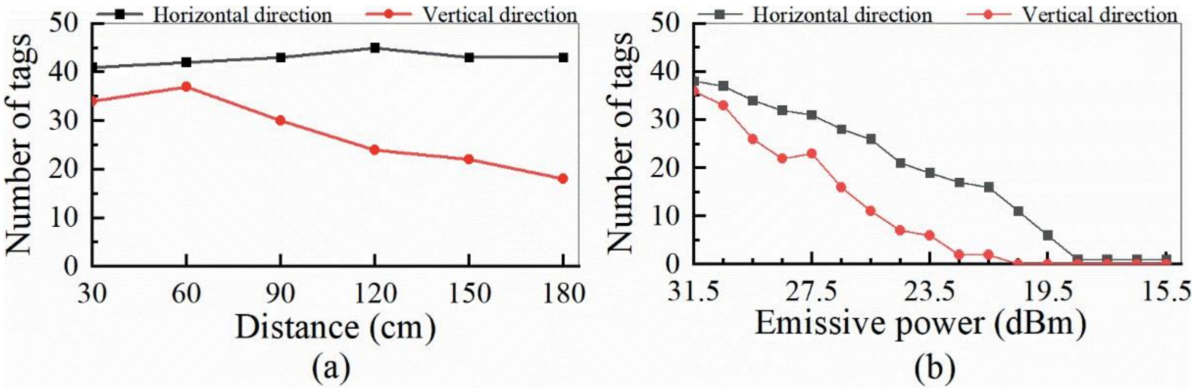

Figure 4: Number of tags read in different directions and different emissive power.

System test verification results

The vertical spatial movement behavior monitoring system collected movement data from 16 test chickens for 5 days, and the accuracy of the system for each test period is shown in Table 1. The average accuracy of the vertical spatial locomotor behavior monitoring system was 87% ± 3%. This result is slightly lower than the accuracy rates of 92% ± 6% and 91% ± 2% reported by (Li et al., 2017) for the feeding and egg-laying behavior monitoring systems. The reason for this is that this study required an antenna reading distance of 0.6 m, which is much greater than the antenna reading distance used in Li et al. (2017). Li et al. (2017) also noted in their study that the tag recognition rate decreases as the reading distance increases. Compared with the behavioral recognition such as feeding and egg laying, the vertical spatial movement of chickens has a wider range, which requires higher accuracy of antenna reading range.

Table 1: System accuracy in different test periods.

Day	Total data	Number of error data	Accuracy
1	49522	1608	90%
2	53699	2486	87%
3	49592	2232	87%
4	49323	1422	87%
5	35397	4163	83%
Mean±S.D.			87%±3%

Filtering and denoising results

The data of vertical spatial motion behavior on the first day were selected and processed by median filtering method, and the filtering and denoising results are shown in Figure 5. The accuracy rates of the original data and each median value filtered processed data are 94% (87%-98%), 96% (88%-99%), 98% (91%-100%), and 98% (93%-100%), respectively. Compared with the original data, the median filtering can significantly improve the system accuracy ($P<0.05$) and can reduce the interquartile spacing when the sliding window size n takes the value of 5 and 7. The median filtering can effectively improve the accuracy of the vertical space motion behavior monitoring system and reduce the data errors caused by crosstalk reading. When the sliding window size n was taken as 5 and 7, there was no significant difference in the accuracy of the system ($P>0.05$). Considering that the filtering process would cause a lag in data changes, i.e., the time node of chicken movement changes would be relatively backward, the sliding window size n was chosen as 5, and the average accuracy of the system was 95%.

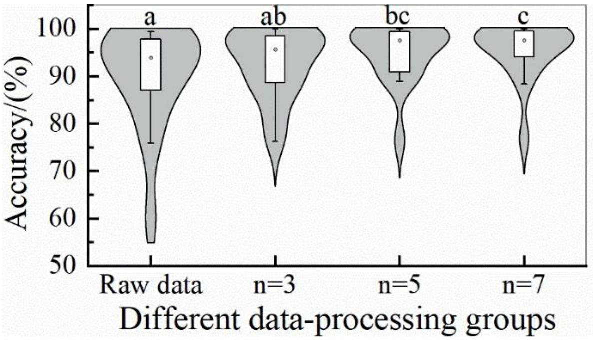

Figure 5: Accuracy of raw data and filtered data.

Conclusions

This paper designed a UHF RFID-based system for monitoring the vertical space movement behavior of chickens. We determined the influence of transmitting power, the tag angle and the distance on the antenna reading range. We solved the problem of missing vertical space movement behavior monitoring in large cage aviary unit system. The system realizes the lossless and fast monitoring of chicken movement behavior. The median value filtering method processed the raw data, which could effectively improve the accuracy of the vertical spatial movement behavior monitoring system and reduce the errors caused by crosstalk reading. When the sliding window size n=5, it could significantly improve the average accuracy of the system to 95 %, and at the same time, it could reduce the lagging effect of filtering processing on chicken movement changes.

Acknowledgements

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