A UHF RFID System for Studying Individual Feeding and Nesting Behaviors of Group-Housed Laying Hens

L. Li, Y. Zhao, J. Oliveira, W. Verhoijsen, K. Liu, H. Xin

Abstract. *Enriched colony housing (ECH) is a relatively new egg production system. As such, information is lacking on design parameters to ensure the well-being of the hens and optimal utilization of housing resources. A new system has been developed at Iowa State University that enables automated monitoring and quantification of feeding and nesting behaviors of individual hens in ECH. Ultra-high-frequency radio frequency identification (UHF RFID) is employed to track individual animals. The UHF RFID system consists of four components: antennas, tags, readers, and a data acquisition system. The antennas for monitoring feeding behavior are placed inside the two feed troughs and covered with plastic boards. Each feed trough has six antennas aligned in series covering the length of the feeder. Four additional antennas are placed inside the nest boxes to monitor the nesting behaviors. All 16 antennas are connected to five 4-channel readers, two per feed trough and one for the nest boxes, that are further connected to the hosting computer via Ethernet. Feed and water consumption and egg production are continuously monitored using load cells. This article describes the development and testing of the RFID system for monitoring feeding and nesting behaviors and provides sample data. The system has proven to be able to characterize benchmark feeding and nesting behaviors of individual hens in ECH, such as daily time spent at the feeder and in the nest box, daily frequency of visiting the feeder and the nest box, number of hens feeding and nesting simultaneously, and variability in these behaviors among individual hens. Future applications of the system include assessing the impact of resource allocation and management practices on feeding and nesting behaviors and on the well-being of the hens. This information will provide a scientific basis for optimal design and management of alternative hen housing systems.*

Keywords. *Animal well-being, Enriched colony housing, Feeding behavior, Nesting behavior, UHF RFID.*

Enriched colony housing (ECH) systems for laying hens originated in the 1980s in Europe and were intended to improve animal welfare by allowing the birds more opportunity to express their natural behaviors. Compared with conventional cage housing (CC), ECH features larger space allocation (e.g., 748 vs. 432 cm^2 per hen), larger group size (e.g., 60 hens per colony vs. 6 to 8 hens per cage), as well as perches, scratching pads, and nesting boxes designed to allow laying hens to express natural behaviors (Mench et al., 2011; Zhao et al., 2015). Relative to CC, which has been used for more than half a century, much less is known about the optimal design and operation of ECH. For instance, different opinions and guidelines exist regarding feeder space and nest area requirements for ECH. Some studies call for provision of enough feeder space to accommodate all hens in the colony simultaneously and a minimum of 300 cm^2 of nest space (Appleby, 2004; Bracke and Hopster, 2006; UEP, 2016). The feeder and nest space requirements have a significant impact on the design and management of housing systems. For instance, to allow all hens to feed at the same time, extra feed troughs would be necessary, which can complicate both the housing structure and day-to-day production management. To address these critical questions, methods for quantifying the behavioral and performance responses of animals, especially individual animals in groups, to these design and management factors are imperative (Ben Sassi et al., 2016; Tu et al., 2011).

Animal behavior studies commonly rely on direct visual observation or videotaping, followed by manual analysis. These manual approaches are inevitably laborious, time-demanding, and prone to errors because of subjective interpretation or inattention (Catarinucci et al., 2014). With increas-

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ing emphasis on precision animal farming and monitoring of individual animals on a continuous basis, manual approaches will be a thing of the past. Automated monitoring systems for assessment of animal behavior and well-being, whether for research or in commercial production, will be the norm in the future.

One automated technology is radio-frequency identification (RFID), which uses electromagnetic fields to identify tags attached to objects. This technology has been broadly applied to behavioral monitoring of animals (Brown-Brandl and Eigenberg, 2011; Cappai et al., 2014; Maselyne et al., 2014a, 2014b; Nakarmi et al., 2014; Sales et al., 2015; Samad et al., 2010; Tu et al., 2011). Vouldimos et al. (2010) developed a complete farm management system based on animal identification using RFID technology with mobile wireless networking to track animals and create a repository of animal data records. RFID devices have also been applied to quantify some behavioral traits of laying hens. Nakarmi et al. (2014) developed a novel low-frequency (LF) RFID system for automated quantification of locomotion, perching, feeding, drinking, and nesting behaviors of individual laying hens in a group-housed setting. While this system produced satisfactory behavioral data for individual hens, it worked only for small animal groups of no more than ten hens due to the limitation of LF RFID with relatively slow data-transfer speed. For larger animal groups, faster data-transfer systems are needed to read more animal tags in a short time.

The objective of this research was to design, develop, evaluate, and apply a UHF RFID automated monitoring system for characterization of feeding and nesting behaviors of 60 individual hens in a commercial ECH module. Accuracy of the RFID system was validated through manual labeling of visual observation data.

Materials and Methods

Experimental Hen Room and Enriched Colony Housing (ECH) Module

The experimental room had the dimensions of 11.4 m long × 6.6 m wide × 4.3 m high (figs. 1 and 2). It housed two double-tier ECH modules (Big Dutchman, Inc., Holland, Mich.), with room for two more modules if needed. Two variable-speed exhaust fans (max. airflow rate of 1500 m^3 h^{-1} each) were installed in the back wall to create a negative static pressure in the room. Two perforated intake air ducts were designed to achieve uniform air distribution of the ventilation air, following the instruction of Harmon (2008). Three pairs of programmable LED lights were used to provide the lighting. The two lights of each pair were hung at heights of 1.0 and 1.7 m, respectively, above the floor to light the top and bottom tier colonies.

Figure 2. Photograph of the experimental hen room with enriched colony housing (ECH) modules.

The double-tier ECH module was 3.73 m long × 1.91 m wide × 1.91 m high (fig. 3). The colony in each tier was equipped with perches, nest boxes, and scratch pads. Feed troughs were located on both sides of the colony. Manure was collected on a plastic tarp placed underneath the colony tier and was removed weekly or more often. The normal capacity of the colony was 60 hens. Table 1 shows the resource allowance of the ECH module.

The top-tier colony was instrumented to monitor real-time feed and water use and record egg production (timing and number) via load-cell scales, and to measure the feeding and nesting behaviors of individual hens via the UHF RFID system. Load-cell scales (Rice Lake Weighing Systems, 0 to 30 kg, Rice Lake, Wisc.) were used to continuously (every second) weigh the feeders, the water tank, and the egg collector (fig. 4). The outputs of the individual load-cell scales for each feed trough were combined to obtain the total weight of the feeder.

Air temperature was measured with four thermocouples, two for the hen room, one for the control room (where the

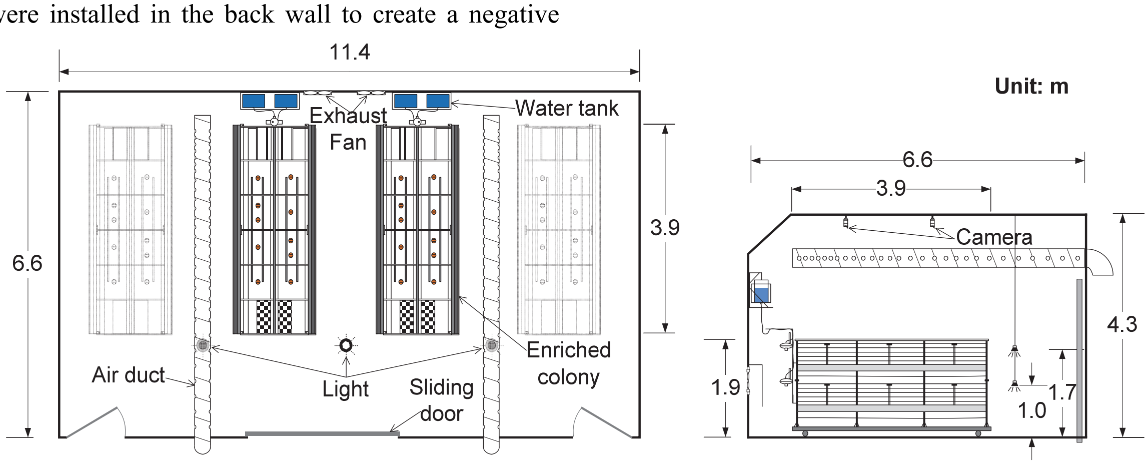


Figure 1. Top view (left) and side view (right) schematic drawings of the experimental hen room.

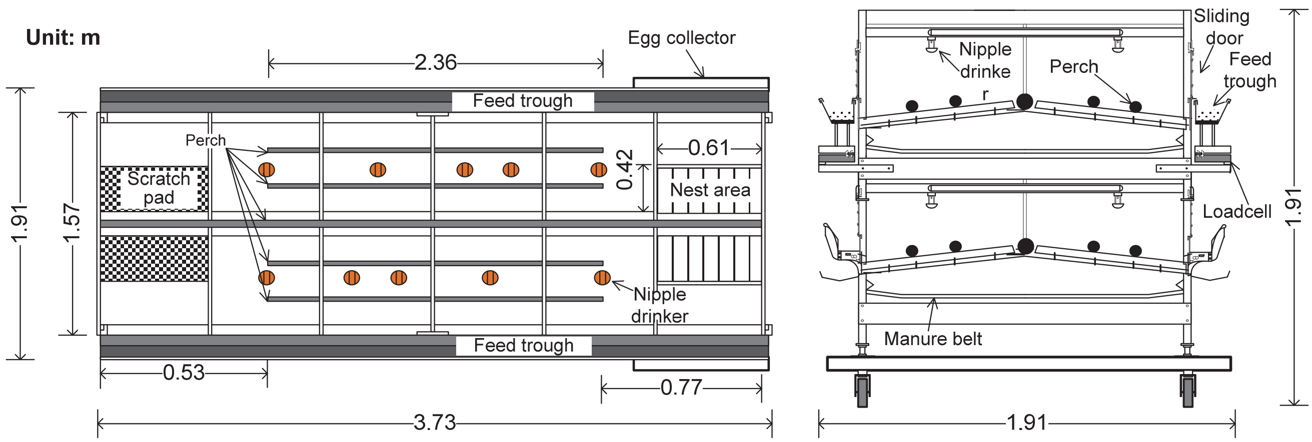


Figure 3. Top view (left) and side view (right) schematic drawings of the enriched colony housing (ECH) module.

Table 1. Resource allowance of enriched colony (60 hens per colony).

Resource	Unit	Allowance
Floor area	cm^2 hen^{-1}	976
Nest box area	cm^2 hen^{-1}	85.4
Nipple drinker	hens $drinker^{-1}$	10
Feeder space	cm hen^{-1}	12.3
Perch length	cm hen^{-1}	15.7

DAQ system was located), and one for outdoor. Relative humidity (RH) measurement of the hen room, collocated with the temperature sensors, was made with RH sensors (model HMT100, Vaisala, Inc., Woburn, Mass.). Carbon dioxide (CO_2) levels at the two locations of the hen room were measured with Vaisala GMT222 CO_2 sensors. The temperature, RH, and CO_2 sensors were regularly checked and calibrated, as necessary. All sensors were connected to a compact FieldPoint module, and the output signals were recorded using a LabVIEW program (National Instruments, Austin, Tex.).

The UHF RFID System

The UHF RFID system (TransTech Systems, Aurora, Ore.) consists of four elements: antennas, tags, readers, and a data acquisition (DAQ) system. Each antenna generates an electromagnetic field that automatically registers the tags within its field (detection range) and sends the tag ID to the DAQ through a reader.

Antennas for the feeders were placed at the bottom of the feed troughs and covered with plastic boards (fig. 5). Each feed trough had six antennas (four SlimLine 8060, 864 to 869 MHz and 902 to 928 MHz, 65 cm long × 8.6 cm wide × 0.8 cm thick each; and two IPJ-A0311-USA, 46 cm long × 8.9 cm wide × 1.9 cm thick each, TransTech Systems, Aurora, Ore.) aligned in series and covering the length of the feeder. The antennas were situated such that the tag (902 to 928 MHz, PT-103, tie-wrap tag passive Gen 2 UHF, TransTech Systems) attached to a hen's neck could be registered when the hen was present at the feeder. Antennas (Square A1030, 30 cm × 30 cm × 0.65 cm thick) for moni-

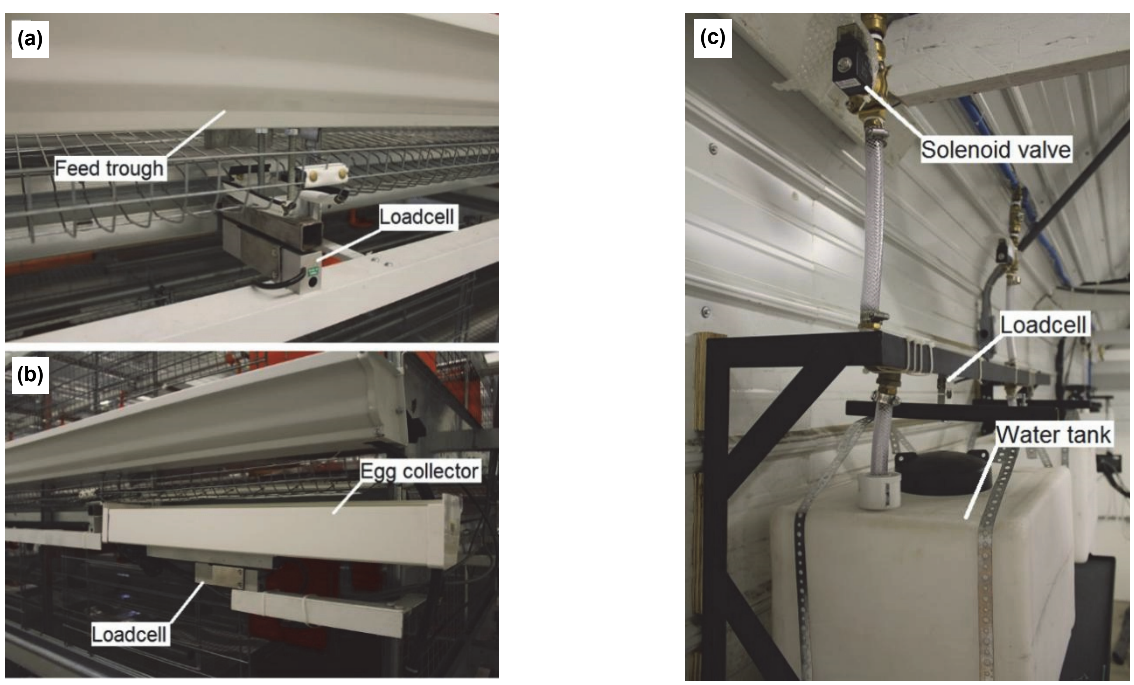


Figure 4. Weighing systems for (a) feed trough, (b) egg collector, and (c) water tank.

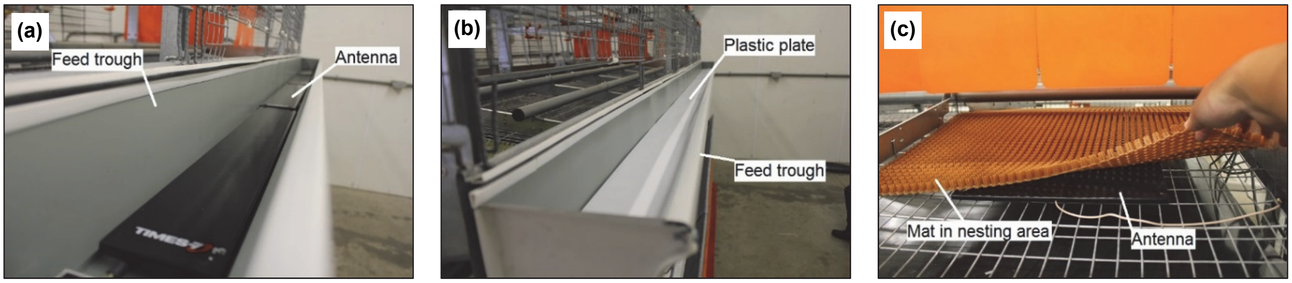


Figure 5. RFID antennas (a) placed in the feed trough and (b) covered with plastic plates, and (c) the nest box antenna covered with mat.

toring the nesting behaviors were placed underneath the nest box mats, two antennas per nest box. All 16 antennas (12 for feeders and 4 for nest boxes) were connected to five 4-channel readers (ThingMagic Mercury M6, 865 to 928 MHz operating frequency, TransTech Systems) that were further connected to the computer via an Ethernet connection (fig. 6).

The readers were connected to a host computer that processed the tag data through an RJ45 (Registered Jack, 10/100 Base-T Ethernet). The tag protocol was EPC global Gen2 (ISO 18000-6C) with digital rights management (DRM). The data acquisition program was written in C# (C Sharp) based on an application programming interface (API), and the data were stored as text files. Data analysis and processing were realized using the SQL server and Excel VBA programs.

Video Observation and Processing

Two cameras (IP Pro 3 Megapixel Bullet, DSS-BFR3MP, Backstreet Surveillance, Salt Lake City, Utah) were installed on the ceiling above the ECH module and used to record the hen behaviors at 2 frames per second (fps). The two cameras were wired to an 8-port power-over-Ethernet (POE-108, Backstreet Surveillance) injector. Video files were stored in 8 terabyte storage (two hard drives) of an NVR system (DSS-NVR5816, Backstreet Surveillance). Each camera covered half of the colony area. Images taken by the two cameras at the same time stamp were extracted from the video files, corrected for distortion, and stitched into one image using a program developed in Matlab (R2015b, MathWorks, Natick, Mass.).

System Performance Tests

Calibration of Load Cells

Egg production, feed consumption, and water consumption were continuously (every second) monitored by the load-cell scales mounted under the egg collector, under the feeders, and above the water tanks. The weights of the egg collectors and water tanks were monitored individually with one calibrated load cell. Each feeder had three scales that were calibrated separately and collectively to develop individual standard curves (by separate calibration) and one combined curve (by collective calculation). Individual and combined standard curves were developed using four weights (1600 g each) that created five load levels (0, 1600, 3200, 4800, and 6400 g). At each load, signals (in V) from the load cells were read every second for 10 to 20 s following stabilization. These signals were averaged and regressed to the corresponding load levels to develop the standard curves.

Measurement accuracy of the overall feed weight in a feeder was compared by using the individual curve method (ICM) versus the combined curve method (CCM). For this test, four stacks of known loads were placed along the feed trough at 1/5, 2/5, 3/5, and 4/5 of the length. Each stack consisted of four known loads (each weighing 375 to 400 g). One known load was removed at a time from each stack, and the remaining weight in the feeder was determined using the ICM or CCM curves. The weights obtained with ICM or

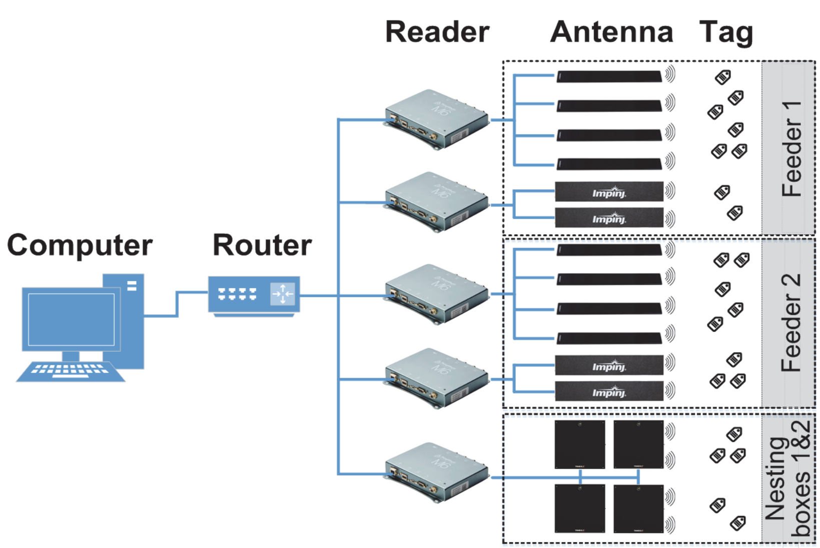


Figure 6. Interfacing of the RFID system components.

CCM were compared to the actual weight, and the differences (measured vs. actual weights) were derived. Accuracy of the load cells for the water tanks and egg collectors was determined by using a standard known weight.

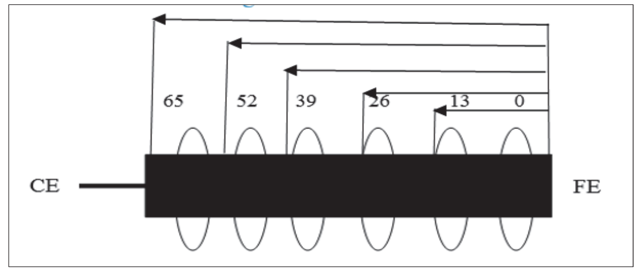
Detection Range of RFID tags

Although RFID antennas have a certain theoretical detection range (30 cm in this case for the feeder antennas), the range greatly depends on the position and orientation of the tags (Finkenzeller, 2003). To determine the detection range of the RFID system in our case, tests were performed that included possible positions and orientations of the tags. The maximum detection ranges for tags placed perpendicular or parallel to the antenna were determined at six evenly spaced locations in the lengthwise direction above the antenna at a power of 31.5 dBm.

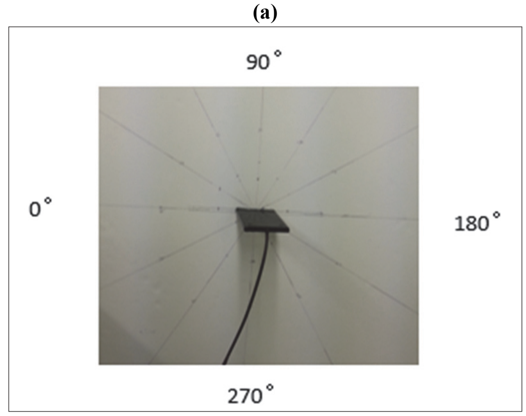
In order to record all the hens when their heads are at the feed trough but avoid detecting signals from hens outside the feeder space (false reading), it is essential to set the power to a value that can read 100% of hens in the height range of approximately 10 cm above the antennas. A total of 66 tags attached to a plastic board at a height of 10 cm above the antennas (i.e., the distance between the bottom and top of the feed trough) and perpendicular to the antennas were used to determine the appropriate power value. Different power values from 31.5 to 0 dBm at 0.5 dBm increments were tested until a satisfying power value was found at which 100% of the tags could be read.

Uniformity of EM Signal across Antennas

To assess variability in detection range among the antennas, two SlimLine 8060 antennas, two IPJ-A0311-USA antennas, and two Square A1030 antennas were randomly selected and examined for detection ranges using the same set of tags. Signals at six points of the SlimLine 8060 antennas were selected from end to end, i.e., at 0, 13, 26, 39, 52, and 65 cm from free end (FE) to cable end (CE) (fig. 7a). Signals at three points of the IPJ-A0311-USA antennas were selected from end to end, i.e., at 0, 23, 46 cm from FE to CE. Similarly, signals at three points of the Square A1030 antennas were selected from end to end, i.e., at 0, 15, and 30 cm from FE to CE. Testing angles around the antennas were 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, and 330° (fig. 7b). At each angle, the maximum distance at which a tag could be registered by the antenna was measured. Single-factor analysis of variance (ANOVA) was performed on each type of antenna using SPSS Statistics v20. This information also served as the baseline for adjusting the antennas power to minimize signal penetration into the colony area, which may lead to false registration of hens near the feeder but not feeding.



(a)



(b)

Figure 7. (a) Six signal points selected from the free end (FE) to the cable end (CE) and (b) 12 radial directions around and perpendicular to the antenna.

Figure 8. RFID tags attached to hens.

LAYING HENS AND VALIDATION OF RFID SYSTEM PERFORMANCE

A total of 60 laying hens (Dekalb white, 66 to 70 weeks of age) were used for the system performance tests. To register the feeding and nesting behaviors of individual hens with the RFID system, each of the 60 hens in the colony wore a miniature tag with a unique ID (PT-103, tie-wrap tag passive Gen 2 UHF, TransTech Systems) on its neck (feeding) and another on its left leg (nesting) (fig. 8). During the test, lost tags were promptly replaced, and the day with lost tags was treated as missing data.

The hens were fed twice daily at 9:00 h and 17:00 h, with no restriction, with the feed provided by the farm that the hens came from. A photoperiod of 17 h light and 7 h dark (17L:7D) was used, as practiced on the farm. Light intensity was 13 to 120 lux across the top tier colony. Eggs laid in the nest boxes rolled into the egg collectors and were manually removed once a day at 17:00 h. Manure was removed weekly. The hens were acclimatized in the colony for at least 5 d before behavioral testing started.

Validation of RFID Readings with Video Observation

The number of simultaneously feeding and nesting hens detected by the RFID system was compared to that determined by the video system. Hens were identified as feeding when they stood in front of the feeder and their heads faced the feed trough. Similarly, hens were identified as nesting when they were inside the nest box. Accuracy was calculated by the percentage of birds detected with the RFID system compared to the number of hens observed in video images for the same time point. Validations of the feeding and nesting behaviors were performed separately, with 38 and 78 episodes, respectively, during three consecutive days (5:00 h to 18:00 h each day). Specifically, feeding behavior was validated for every hour (with the exception of the first data point loss for the first day). For nesting behavior, because of the large number of birds accessing the nest boxes for oviposition at the same time, 30 min (rather than 60 min) episodes were used for the validation. The images from the two video cameras (each covering half of the top-tier colony) were extracted, undistorted, synchronized, and stitched together using the code developed in Matlab (fig. 9).

Feeding and Nesting Behaviors Monitored Using the RFID System

Time spent at the feeders and nest boxes as well as the maximum and average numbers of simultaneously feeding hens were examined over a 7-day period. With antenna power settings of 18 dBm for SlimLine 8060, 22 dBm for IPJ-A0311-USA, and 25 dBm for Square A1030, which deviated slightly from the power settings in the initial evaluation, the RFID system successfully registered hens when their feet were inside the nest area or when their heads were inside the feeder. However, a hen would not be registered at the feeder when she raised her head to swallow feed or momentarily withdrew from the feeder. Such brief intermittent breaks of up to 30 s were considered part of a feeding event. The 30 s threshold was determined from a histogram analysis of the feeding events from eight random tags that represented high, medium, and low levels of data collection. Time differences between two adjacent readings were determined for each of these tags, followed by generating and examining a histogram of the time differences. The same thresholding process was used to fill time gaps in nesting behaviors. In addition, manual labeling verification was made with eight randomly selected feeding or nesting hens.

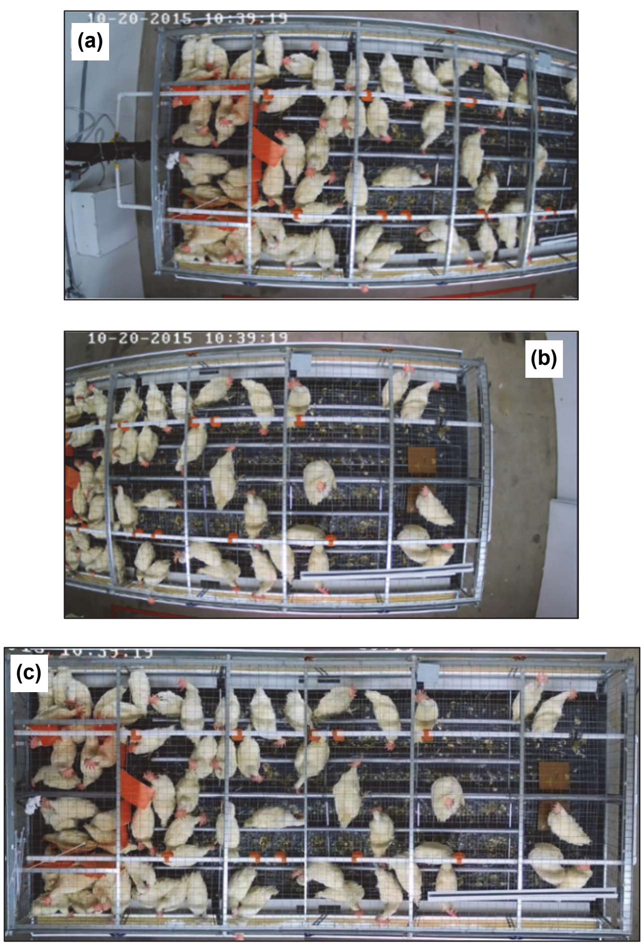


Figure 9. (a and b) Original images recorded by two video cameras and (c) combined undistorted image.

RESULTS AND DISCUSSION

INDIVIDUAL LOAD-CELL SCALE CALIBRATION

Comparison between the measured weights by ICM and CCM versus the actual weights loaded is shown in table 2. Both methods showed good accuracy, with less than 1.3% variation from the actual weight. The CCM had a better accuracy and less offset (0.1% ±0.0%, 3.5 ±1.4 g) and was therefore used to determine the feeder weight.

SAMPLE DATA OF FEED AND WATER USE

Daily profiles of feed and water use for the group were obtained by calculating the changes in the weight of the feeders and water tank, and sample data are shown in figure 10. It can be seen that the hens continued to feed and drink throughout the light period, but no feeding or drinking activities occurred during the dark period. On this particular day, feed use by the 60 hens was 4.8 kg (an average of 80 g hen^{-1} d^{-1}), and water use was 9.1 kg (an average of 152 g hen^{-1} d^{-1}). Egg laying time and egg weight of the hens were also captured by the weighing system.

DETECTION RANGE OF RFID TAGS

The maximal detection ranges were significantly affected by the tag position relative to the antenna (figs. 11 and 12). With the tags in the perpendicular position, they could be detected at up to 85 cm (SlimLine 8060) and 75 cm (IPJ-A0311-USA) above the antenna at the 31.5 dBm power setting. However, with the tags in the parallel position, the maximum height of tag detection was 8 cm (SlimLine 8060) and

Table 2. Weights derived by the individual curve or combined curve methods (ICM vs. CCM) for the load-cell scales versus actual values.

Actual Weight (g)	ICM Derived Weight (g)	ICM Difference from Actual Weight (g)	ICM Difference from Actual Weight (%)	CCM Derived Weight (g)	CCM Difference from Actual Weight (g)	CCM Difference from Actual Weight (%)
6185.7	6205.9	20.2	0.3	6189.9	4.2	0.1
4635.7	4656.0	20.3	0.4	4640.3	4.6	0.1
3085.1	3105.2	20.1	0.7	3089.0	3.9	0.1
1542.6	1562.8	20.2	1.3	1544.0	1.4	0.1
Mean ±SD	-	20.2 ±0.1	0.7 ±0.4	-	3.5 ±1.4	0.1 ±0.0

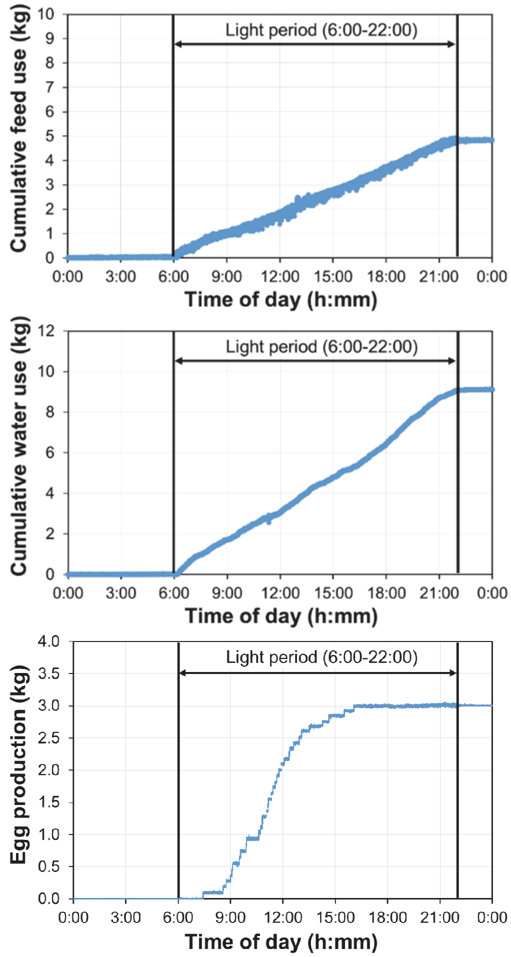


Figure 10. Sample profiles of cumulative feed and water use and egg production for 60 hens in the enriched colony housing as measured by the load-cell scale systems.

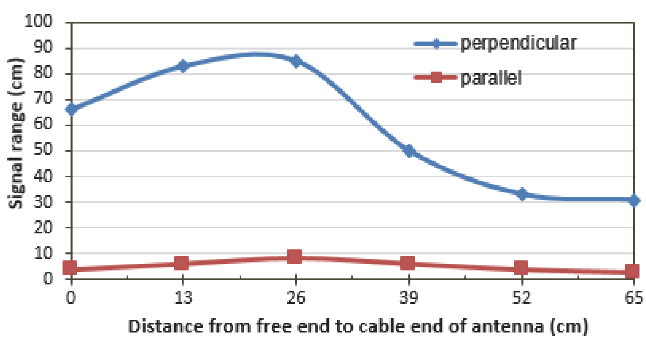


Figure 11. Detection range distribution for 65 cm long SlimLine 8060 linear polarized antenna with two tag orientations (perpendicular to or parallel with the antenna) at 31.5 dBm power setting.

6 cm (IPJ-A0311-USA). Because the position of the tag on a hen's neck may change throughout the day, an 8 cm detection range would not be adequate to ensure registration of hens at the feeder. Thus, the tag was attached to a collar and parallel to the hen's neck, which means that the tag would be perpendicular to the antenna when the hen's head entered the feed trough and during most feeding activities. In addition, the detection range changes along the antenna length, with the signal being weakest at the cable end. To better cover the weak signal points in the feed trough, the free end

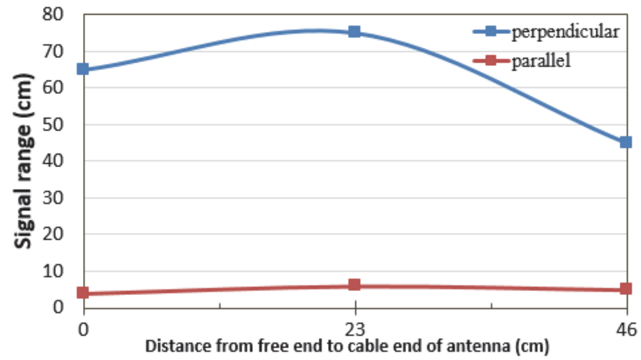


Figure 12. Detection range distribution for 46 cm long IPJ-A0311-USA linear polarized antenna with two tag orientations (perpendicular to or parallel with the antenna) at 31.5 dBm power setting.

of the each antenna was positioned next to the cable end of the adjacent antenna.

Figure 13 shows the percentage of tags registered by an IPJ-A0311-USA antenna with power settings of 20.0, 21.0, 22.0, 23.0, and 31.5 dBm at five heights above the antenna. All 66 tags were detected directly above the antennas in a feeder, while fewer than 10% were registered at 50 cm above the antennas. As the power decreased, so did the percentage of detected tags. Figure 13 shows that 22 dBm was the minimum power needed to achieve 100% detection of tags at 10 cm above the antenna.

The SlimLine 8060 antenna had a wider detection range than the IPJ-A0311-USA antenna, as shown in tables 3 and 4. As a result, continual adjustment of the antenna power was made during the tests with hens. With power settings of 18 dBm (SlimLine 8060) and 22 dBm (IPJ-A0311-USA), the RFID system successfully registered hens when their heads were inside the feeders but not when their heads were raised to swallow feed nor when they momentarily withdrew while standing in front of the feeder.

SIMILARITY AMONG ANTENNAS

The detection ranges around the SlimLine 8060, IPJ-A0311-USA, and Square A1030 antennas are shown in tables 3, 4, and 5, respectively. No significant differences were detected within the same type of antenna ($p > 0.05$). This operational characteristic made it possible to apply the same power to all the readers, thereby simplifying the system settings.

VALIDATION OF RFID READINGS WITH VIDEO OBSERVATION

A threshold time of 30 s for inclusion of RFID data in a single behavioral event (feeding or nesting) was identified to obtain 95% coverage of the data collected by the RFID system, as shown in figure 14. This 30 s threshold was verified visually for feeding and nesting behaviors. Visual observations revealed that it took the hens 68.1 ±12.5 s (mean ± SD, n = 8) to leave the feeder, perform other activities (e.g., scratching, perching, drinking water, nesting), and return to the feeder. Similarly, it took the hens 95.1 ±23.5 s (mean ±SD, n = 6) to leave and return to the nest box (two of the eight randomly selected birds did not return to the nest box

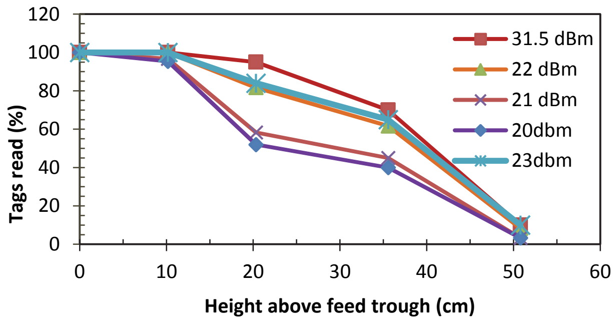


Figure 13. Detection of the RFID tags by an IPJ-A0311-USA antenna at different power levels.

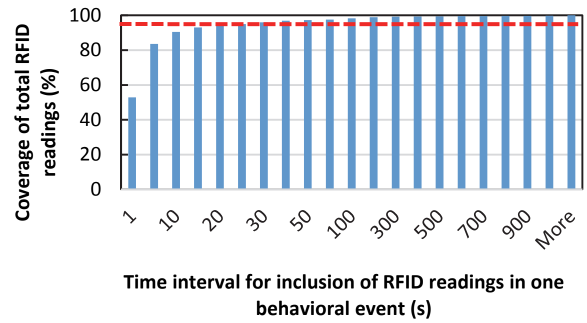


Figure 14. Coverage of RFID readings versus time interval for inclusion in one behavioral event. The dashed line indicates 95% coverage of the RFID readings.

Table 3. Tag detection range (cm) around two SlimLine 8060 antennas (A1 and A2) at 31.5 dBm power setting.

Angle Around Antenna	Distance between Free End and Cable End of Antenna											
	0 cm		13 cm		26 cm		39 cm		52 cm		65 cm	
	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2
0°	36	36	49	49	49	49	41	41	31	31	18	18
30°	50	50	62	62	60	61	39	39	30	30	19	19
60°	62	62	70	70	79	78	50	50	30	30	19	19
90°	66	66	83	83	85	85	50	50	33	33	21	21
120°	62	62	74	74	80	80	50	50	31	31	19	19
150°	52	51	62	62	60	60	38	38	28	28	19	19
180°	41	41	52	52	52	52	44	45	29	29	17	17
210°	31	31	41	40	53	53	29	28	21	21	15	16
240°	38	39	49	49	52	52	26	26	21	21	18	18
270°	32	32	42	42	42	42	30	31	25	25	21	21
300°	30	30	40	40	39	39	28	28	20	21	18	18
330°	32	32	45	45	43	43	27	27	21	21	15	15

Table 4. Tag detection range (cm) around two IPJ-A0311-USA antennas (B1 and B2) at 31.5 dBm power setting.

Angle Around Antenna	Distance between Free End and Cable End of Antenna					
	0 cm		23 cm		46 cm	
	B1	B2	B1	B2	B1	B2
0°	33	33	39	42	33	32
30°	48	47	52	55	29	28
60°	60	62	69	70	40	42
90°	63	65	72	75	40	45
120°	58	60	70	72	40	40
150°	50	54	50	53	28	29
180°	42	44	42	45	25	34
210°	31	29	33	35	19	18
240°	39	38	43	45	17	16
270°	32	30	35	35	21	20
300°	30	28	32	33	18	18
330°	35	33	35	35	17	17

during the 5 min visual verification period). The 30 s threshold was used to fill the time gaps in the RFID readings when characterizing feeding and nesting behaviors (e.g., feeding or nesting duration, and frequency of feeder and nest box visit).

The results obtained with the RFID system were compared against video observation for both feeding and nesting behaviors. The overall accuracy of the RFID system relative to the video observation was (mean ±SD) 92.1% ±6.4% (n = 38) for feeding behavior and 91.4% ±1.7% (n = 78) for nesting behavior, demonstrating reasonable effectiveness of the RFID system. This performance was comparable to the result of Thurner et al. (2008), who reported an average identification rate of 89.8% using HF transponders to register

Table 5. Tag detection range (cm) around two Square A1030 antennas (C1 and C2) at 31.5 dBm power setting.

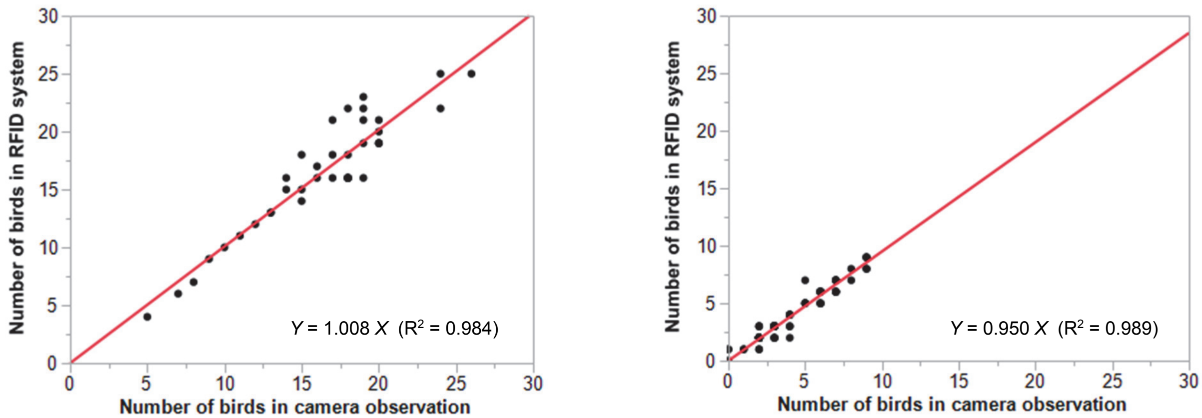
Angle Around Antenna	Distance between Free End and Cable End of Antenna					
	0 cm		15 cm		30 cm	
	C1	C2	C1	C2	C1	C2
0°	0	0	0	0	0	0
30°	10	9	18	18	22	23
60°	6	6	15	15	20	20
90°	5	5	6	6	18	18
120°	9	8	18	17	16	16
150°	13	13	22	21	15	16
180°	0	0	0	0	0	0
210°	7	6	0	0	0	0
240°	5	5	0	0	0	0
270°	6	6	0	0	0	0
300°	6	6	0	0	0	0
330°	8	8	0	0	0	0

laying behavior of individual hens. Sales et al. (2015), using a passive LF RFID system, reported detection rates (mean ±SD) of 91.0% ±2.6% for trials with groups of hens and 85.8% ±8.0% for trials with individual hens when measuring total compartment (1.2 m × 1.2 m × 1.2 m) occupancy. Reiners et al. (2009) reported an identification rate of 97.3% using an HF RFID system for identification of individual weaned piglets (20 animals in a group) at the feed trough.

In addition to the direct comparison, a regression analysis was performed to relate the results from the two measurement systems. Validation of the RFID system for the feeding behavior assessment showed that the correlation coefficient between the RFID and camera systems was 0.984 (slope of 1.008 ±0.017), reflecting good agreement between the two measurement methods (fig. 15). A high correlation coefficient of 0.989 (slope of 0.950 ±0.014) between the two methods was also found for the nesting behavior analysis (fig. 15).

Sample Data of Feeding and Nesting Behaviors Monitored with the RFID System

Figure 16 shows the average time spent at the feeder by the 60 hens over the course of seven experimental days. A summary of the feeding behavior data (time spent plus number of hens feeding simultaneously) is listed in table 6. The daily time spent at the feeder by the hens (mean ±SD) was 310 ±92 min hen^{-1} d^{-1}. Cook et al. (2005) found that hens housed at different stocking densities (348, 387, 426, and 465 cm^2 hen^{-1}) in conventional cages had a daily feeding



(a) (b)

Figure 15. Relationship of values obtained with the RFID system versus video observation for (a) the number of feeding hens (feeding behavior) and (b) the number of hen using the nest (nesting behavior).

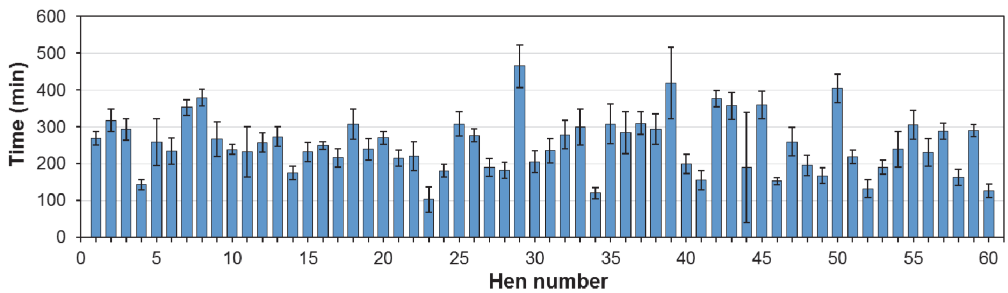


Figure 16. Daily time spent at the feeder by each of 60 hens in enriched colony housing over a 7 d period (vertical bars are standard deviations).

Table 6. Feeding behaviors of hens in the enriched colony housing.

Day	Total No. of Hens	Time Spent at Feeder (min hen^{-1} d^{-1})	No. of Hens Feeding Simultaneously (% total)	
			Maximum	Average
1	60	326	42 (70%)	19 (32.2%)
2	60	313	34 (57%)	19 (31.0%)
3	60	315	37 (62%)	19 (31.2%)
4	60	303	37 (62%)	18 (30.0%)
5	59	300	33 (56%)	18 (29.8%)
6	59	301	34 (58%)	18 (29.8%)
7	59	311	35 (59%)	18 (30.8%)
Mean	60	310	36 (61%)	18 (30.7%)
SD	0.5	9	3 (4.4%)	1 (0.8%)

time of 180 to 240 min. Persyn et al. (2004) reported that individually housed 77-week-old hens showed a mean daily feeding time of 198 ±24 min. Compared with the previous conventional cage tests, the hens in the current ECH and with larger feeder space showed longer feeding time. Huon et al. (1986) qualitatively reported that increasing feed trough space (presumably improving welfare) resulted in longer feeding-bout duration and feeding time.

The maximum number (mean ±SD) of hens feeding simultaneously was found to be 36 ±3, corresponding to 61% of the total hen population in the colony (table 6). Appleby (2004) called for feeder space of at least 12 cm hen^{-1} and allowing all hens to feed simultaneously. Based on the results of this preliminary study, all hens never ate at the same time. Further research is therefore warranted to quantify the feeder space needed by group-housed hens, especially in alternative hen housing systems that feature enrichments (perches, scratch area, etc.).

As indicated by the data in figure 17, the hens displayed a daily nesting time of 56 ±45 min. This result parallels the report by Stämpfli et al. (2011), who found that birds can spend 10 to 90 min when laying an egg.

Assessment of the impact of feeder space on feed and water use and egg production with the system is ongoing and

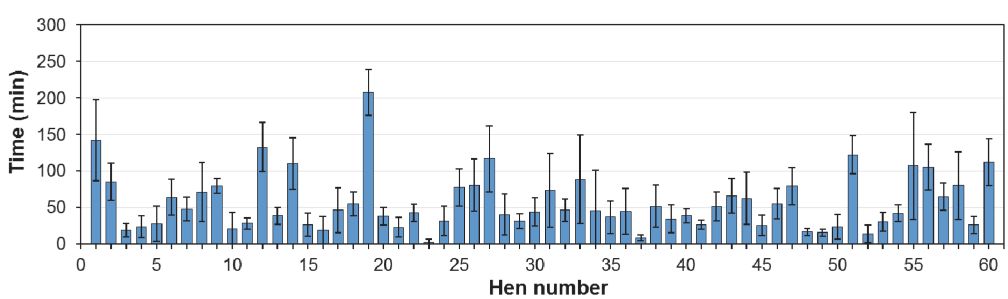


Figure 17. Daily average time spent in the nest box by each of 60 hens in enriched colony housing over a 5 d period (vertical bars are standard deviations).

will be presented in future articles. Nesting behaviors obtained with this monitoring system, such as time spent in the nest boxes and oviposition time and place, were presented in a separate publication (Oliveira et al., 2016).

CONCLUSIONS

A UHF RFID system for characterizing feeding and nesting behaviors of individual hens in an enriched colony setting has been developed and tested. The performance of the RFID system was validated by a video system. The results demonstrated that the system can be used to characterize dynamic poultry feeding and nesting behaviors. The system allows for assessing the impact of housing and management factors, such as feeder space and stocking density, on feeding behaviors and feed intake of laying hens, and the number of hens feeding at the same time. The resulting information will contribute to the development or improvement of guidelines for housing system design and management to ensure animal welfare and efficient use of resources.

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