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Testing ultra-wideband technology as a method of tracking fast-growing broilers under commercial conditions

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Short title: UWB tracking of broiler chickens

Abstract

Ultra-wideband (UWB) is an indoor positioning technology that has several advantages over current methods of tracking indoor reared broiler chickens, including providing long-term data on movement patterns without the effect of observer presence. More information is needed on the accuracy of this technology under commercial conditions and the effects of wearing an UWB transmitter tag on normal broiler behaviours. Therefore, the main aims of this study were to test the location and distance accuracy of UWB tags, and to determine the effect of wearing backpacks on broiler behaviour and health. In a commercial house, thirty 21-day-old Ross 308 broiler chickens were fitted with an UWB tag backpack. Broilers were then able to move freely among 28 000 conspecifics. In weeks 4, 5 and 6, twenty tagged broilers and twenty untagged broilers were observed for a focal period of 15 mins. Tagged broilers were weighed and gait scored on Day 21 and 37. The flock was slaughtered on Day 39 and data for average final weight were taken from slaughter records. The tags displayed a high level of accuracy, with 85 % recording <50cm from their true location. However, the system consistently overestimated distances. There was no significant difference between the behaviour of tagged and untagged broilers ($p > 0.05$) in weeks 4 or 5. In week 6, tagged broilers spent less time preening than those not wearing a backpack. The average body weight of tagged broilers at Day 37 (2.54kg) was consistent with average flock final body weights (2.40kg) and the distribution of gait scores in week 6 was comparable with previous research. In conclusion, the effects of wearing a backpack on broiler health and welfare appeared to be minor, suggesting that data would be representative of normal movement

patterns. The UWB system showed a high location accuracy but may be limited in accurately reporting distances travelled.

Keywords: UWB tag; Movement; Poultry; Animal behaviour; Animal welfare

1. Background

The way fast-growing broilers make use of space in intensive housing has been of interest for some time, with researchers debating whether chickens in large flocks create home ranges or use the space randomly (McBride and Foenander, 1962; Appleby et al., 1984). However, the methods available for accurately tracking small animals indoors have been extremely limited. Broiler chickens are typically reared in houses that have one level and a floor space of several thousand m². Flocks consist of several thousand broilers allowed to move freely around the available space. To investigate their typical roaming patterns, researchers tend to mark birds in commercial houses (e.g. Appleby et al., 1985; Preston and Murphy, 1989) or rear them in smaller experimental pens (e.g. Arnould and Faure, 2002). Although watching colour- or number-marked birds can tell us about the size of their home ranges, ranging behaviour must be estimated based on the bird's position at certain time points, with long sampling intervals likely to underestimate ranging and distance moved (Estevez and Christman, 2006). Housing birds in experimental pens allows for more control and more intensive observations, including the use of video cameras and image analysis to track movement (e.g. Lewis and Hurnik, 1990; Aydin et al., 2013; van der Sluis et al., 2019). However, it is difficult to replicate the conditions of commercial housing using pens and significant extrapolation is needed to apply any conclusions to industry. In addition to exploring ranging behaviour, tracking individual broilers would allow us to calculate their distance moved and directly monitor broiler activity levels. Although numerous studies have investigated the link between inactivity and several welfare concerns (Bessei, 2006), no research has been able to measure lifetime movement patterns of broilers in commercial housing with any accuracy.

59 Using technology, such as GPS (Global Positioning System) and RFID (Radio Frequency
60 Identification) tags, to track and monitor farm animals has become more common in recent
61 years. Standard GPS is not suitable for indoor tracking because the signal can be blocked
62 by roofs, walls and other objects, resulting in a large error range. Even outdoors, GPS lacks
63 the accuracy needed for small chickens (several metres; e.g. Byrne et al., 2017). RFID tags
64 are also used in location studies but they are typically employed to detect proximity rather
65 than overall movement (Taylor et al., 2017). One potential solution to tracking broilers in
66 indoor environments is to use an ultra-wideband positioning system. Ultra-wideband (UWB)
67 is a commercially available radio technology that can provide precision location data, to an
68 accuracy of less than 20 cm, by calculating the time taken for a signal to travel from a
69 transmitter tag to several receivers. Commercial uses for this technology include tracking
70 forklifts in warehouses, recording movement of retail workers and monitoring performance of
71 individual athletes. The UWB tags are now small enough to be considered for use tracking
72 chickens, and their recent testing in free-range (Stadig et al., 2018a,b) and indoor penned
73 broilers (van der Sluis et al., 2019) confirms their potential suitability as a method of
74 monitoring long-term broiler movement. Slow-growing broilers appeared to suffer no long
75 term effects of wearing UWB tag backpacks when reared in floor pens in terms of behaviour,
76 leg health, cleanliness or growth between days 35 to 70 (Stadig et al., 2018a). When placed
77 on penned broilers in an indoor system, UWB tags were moderately accurate in terms of
78 distance measured, and successfully recorded the typical decrease in activity levels
79 expected as birds aged (van der Sluis et al., 2019). Employing this technology to monitor
80 broiler movement under commercial conditions would answer crucial questions about their
81 space use and activity patterns, however there remain several unknowns in using UWB for
82 this purpose. The main aim of this study was therefore to test the use of UWB as a means of
83 tracking fast-growing broilers in indoor housing at a commercial scale. The system's
84 accuracy, in terms of position data and distance data, was assessed, as well as the
85 functionality of using UWB to live-track and locate free moving broilers. In addition, tagged

broilers were monitored for their walking ability and behaviour to evaluate the impact that backpacks had on their health and normal behaviour patterns.

2. Materials and methods

2.1 Ultra-wideband positioning system

The UWB system used in this study was manufactured by SEWIO (Brno, Czech Republic) and supplied by Locatify (Reykjavík, Iceland). The network consisted of twelve receivers or “anchors” and 30 Piccolino UWB transmitters or “tags”. Anchors were screwed to plastic mounts and attached to a metal L-bar which brought them >15 cm from the edge of the house to limit interference from the metal house wall (Figure 1). The twelve anchors were positioned such that the house was split into thirds (Figure 2a), with four anchors facing into the centre of each third. Anchors were placed at a height of 1.9 m, tilted slightly downwards. They were connected and powered through shielded CAT6 ethernet cables, via waterproof sockets installed throughout the house. A desktop with analytics software (SEWIO, Brno, Czech Republic) and a tablet (Huawei, Shenzhen, CN) were connected to the closed Ethernet system, allowing for real-time tracking of birds as the observer moved through the house (Figure 2b).

Without any enclosure, the UWB tags were 29 mm x 37 mm and weighed 14 g. They were powered by CR2450 lithium batteries, which could power tags for several weeks. The tags were placed into padded, waterproof backpacks (Figure 3). The backpacks were 60 mm x 40 mm and were made from a white, matt, flexible, PVC coated fabric (Dunelm Mill, Leister, UK). Together, the backpack and tag weighed a total of 19 g, which was 1.4 % of the weight of the average three-week old broiler (~1.4 kg) and below the recommended 5% for attaching additional weight to an animal (Kenwood, 2001). Wing straps were made of 3 mm braided polyester elastic (Hemline, Dublin, Ireland), and were attached to an adjustable toggle within the backpack to allow alterations to strap length as birds grew. Several versions of the above backpack were tested during pilot trials, using different sizes and

material types. The final version of the backpacks (Figure 3) used in this study proved to be the least aversive to broilers and the most secure over the course of the study.

Based on pilot trials and advice from the manufacturer, tags were set to send position data 10 times per second (sampling rate of 100 milliseconds) and to “sleep” immediately if no motion was detected. The latter function extended the tag battery life in the event that birds spent a prolonged period of time immobile; any motion detected immediately ended the sleep period. Tags were limited in their speed to 1 m/second to limit recording false position data and reduce “noise”, for example removing sudden jumps from one location to a distant position and back within a second. Position Kalman filter and Kalman smoothing were applied to data to reduce noise and improve the quality of movement estimates.

2.2 Animals and housing

This study was conducted between October-November 2019 on a Moy Park affiliated Higher Welfare farm in Northern Ireland. A total of 28 000 Ross 308 broiler chickens were placed in a standard metal-framed house (85 m x 20 m), at a stocking density that did not exceed 30 kg/m². The broilers were placed “as hatched” and were approximately 50:50 male to female. Water and food were supplied *ad libitum*, following commercial recommendations (Aviagen, 2018). Artificial LED light levels were maintained according to EU guidelines (Council Directive 2007/43/EC), with time in darkness increasing by 1 h/day from 1 h at a day old to 6 h on day 7, and then decreasing on day 29 by 1 h/day to 1 h of darkness, which was maintained from day 33 until slaughter. The houses were also fitted with windows that supplied naturally light during daylight hours (approximately 9am – 4pm in this season).

The house was bedded with straw crumb at the beginning of the cycle, and additional chopped straw was distributed at the farmer’s discretion to maintain litter condition. The farm was supplied with 46 plastic wrapped straw bales which were cut open to allow birds access to the straw as an environmental enrichment (see Baxter et al., 2018 for photos). Platform perches were suspended from the roof, three on one side of the house and four on the other.

The perches were available to the broilers until clearing. As was standard on this farm, broilers were thinned (partial depopulation) during week 5 (Day 31) before all remaining birds were cleared in week 6 (Day 39).

2.3 Data collection

Thirty broilers were selected and fitted with numbered UWB tag backpacks on Day 21 of the rearing cycle. The backpack numbers were assigned to each broiler on the system, allowing for individual identification. Broilers of this age were chosen to ensure they could cope with the additional weight of a backpack and they were large enough for the backpack to sit between their wings. Two backpacks fell off during the study and one was removed due to wing rubbing. The remaining backpacks ($n = 27$) were taken off on Day 37, prior to slaughter on Day 39. The thirty selected broilers were chosen from 10 pre-determined areas of the house (5 central and 5 edge), with three broilers displaying a gait score of 0 or 1 chosen from each section. Broilers were gently fitted with backpacks that had been adjusted based on their size and watched for 5 min to ensure no prolonged abnormal behaviours. The farm was visited every other day during the 15 day experimental period and all broilers were located and assessed for any issues with the backpacks on each visit. On the evening of Day 30, tagged broilers were corralled in one area of the house so that they were not included in the thinning process. Their access to the full area of the house resumed on Day 31 after thinning was completed.

2.3.1 Tag location accuracy

The location accuracy of 30 tags was tested twice, once when tags were mounted on broilers on Day 21 and once in an empty house once broilers had been cleared. For the first test, each time a chicken was fitted with a backpack they were placed on the ground and the tags location on the UWB map (SEWIO, Brno, Czech Republic) noted as X and Y coordinates, which were the distance from the back of the house and left side of the house,

respectively. The tags true location was then recorded by an observer using a laser distance meter (Tacklife, Guangdong, CN) to record the same coordinates.

2.3.2 Tag distance accuracy

Once the tagged broilers had been released, there was no way to accurately compare the true distance they moved with the distance recorded by the tags. Therefore, a practical test of tag distance accuracy was performed by a researcher holding a tag and moving on a measured route around the house. The distance moved by the researcher and the distance recorded by the software were then compared. The test was repeated 10 times, with the route varying in distance and the time it took to complete (Table 1). The variation in time was to allow for periods of immobility, which were assumed to occur repeatedly while tags were on chickens.

2.3.3 Behavioural effects of wearing a backpack

Behavioural observations of tagged and untagged broilers were made in weeks 4, 5 and 6. Twenty tagged broilers were randomly chosen as observation birds from the 30 tagged birds. Each week the tagged broilers were located and observed for a focal period of 15 min. At the end of the focal period, the bird closest to the tagged focal bird's tail was chosen as a sample untagged broiler and was also observed for a focal period of 15 min. The next tagged broiler was then located, and so on. Each of the 20 tagged broilers and a sample of 20 untagged broilers were observed by the same observer each week, with a total of 10 h of observations split over two consecutive days. The order that the tagged broilers were located and observed was kept the same each week, to avoid time of day influencing their behaviour. Behaviours (Animal Behaviour Pro app, Kent University, UK) were categorised as either foraging (ground pecking from a standing/walking position), preening, resting (sitting with eyes closed, head under wing or head laying on the ground), sitting, standing or walking.

2.3.4 Broiler health

All tagged broilers were weighed and scored twice for gait (0-5; Kestin et al., 1992); on Day 21 when the broilers were fitted with backpacks and on Day 37 when the backpacks were removed. Flock measures of body weight were taken from post-slaughter production records.

2.4 Statistical analysis

All analyses were conducted using SPSS (v25). Comparison of broiler behaviour with and without a backpack (N=36) was made using Mann Whitney U tests within each week. There was very little foraging and no statistical analysis was performed for this behaviour. The effect of age on the tagged broilers (n=18, 2 broilers lost their tags over the course of the study) was analysed using a Friedman's ANOVA. Pearson's correlation was used to assess the relationship between recorded and true distance. Significance was set at $p < 0.05$.

3. Results

3.1.1 Tag location accuracy

The recorded location of each tag corresponded well with the tag's true location, with no tag reporting a distance of $>1\text{m}$ from its true location (Table 2). The tags tended to be slightly more accurate when recorded in an empty house compared to when mounted on a chicken, with 93% and 97% of recorded locations within 50 cm of the true location (for X and Y coordinates respectively), compared to 93% and 77% when mounted on a bird. However, the tags recorded location accurately reflected the location of tagged broilers on days the system was used to locate birds and check the fit of the backpack. Throughout the study, the observer was able to easily locate all tagged birds using the live-tracking information visible on the tablet.

3.1.2 Tag distance accuracy

The UWB system's ability to accurately report distances was poor, with recorded distances generally overestimating the true distance (Table 1). None of the tests were able to report a distance within 1 m of the true distance moved ($n = 10$). Overestimation varied from 2m to 45 m further than the route travelled. There was, however, a significant positive correlation between true distance and recorded distance ($r(8) = 0.778$, $p = 0.008$; Figure 4).

3.1.3 Behaviour effects of wearing a backpack

Overall, there was very little difference observed in the behaviour of tagged and untagged birds (Figure 5). Behavioural changes were apparent immediately after the backpacks had been fitted for the majority of broilers. Pecking at the equipment, rolling and crawling were all observed after initial release. However, these changes were temporary, and broilers appeared to acclimatise quickly. During the first focal observation period, 48 h after backpacks were fitted, there was no significant difference seen in any behaviours between tagged and untagged birds. There was also no difference observed in week 5. In week 6, the only behaviour to be influenced by wearing a tag was preening, with more preening performed by untagged birds (mean = 57.27s, SEM = 13.79) compared to tagged birds (mean = 18.20, SEM = 6.07) in the final week (tagged mean rank = 14.61, untagged mean rank = 22.39; $N = 36$; $U = 92$; $p = 0.025$). For the tagged broilers, time spent resting increased as broilers aged, with significantly more resting in the final week compared to week 4 ($p = 0.018$) and week 5 ($p = 0.001$; Figure 6). There was also a tendency for preening to be affected ($p = 0.07$), with levels of preening decreasing as birds aged (Figure 6). No other behaviours measured during the observation period were significantly affected by age ($p > 0.05$).

3.1.4 Broiler health

One tagged broiler was culled due to a severe gait abnormality on Day 37. No other tagged broilers died or were culled during the study. The average body weight of tagged birds at 21 days old was 0.99kg (SD=0.10, min= 0.80kg, max=1.15kg, n=30) and at 37 days old was 2.54kg (SD=0.37, min=1.90kg, max=3.42kg, n=27). Distribution of gait scores revealed a general worsening of gait in older birds. All birds chosen for tagging (n=30) had a gait score of 0 (70%) or 1 (30%) on Day 21. By Day 37, gait scores (n=27) ranged from 1-4, with no birds displaying a gait score of 0, 48% displaying a gait score of 1, 41% displaying a gait score of 2, 7% displaying a gait score of 3 (two birds), and 4% displaying a gait score of 4 (one bird, culled on day 37). Flock production data gathered at slaughter on Day 39 showed that broilers had an average weight of 2.4kg.

4. Discussion

An UWB system was successfully used in this study to track the movement of free-roaming broiler chickens reared in indoor housing. Location data received from tags was suitably accurate, with 85 % of tags reporting a location of <50 cm from their true location, and all tags reporting a location <1 m from their true location. Live tracking allowed researchers to consistently locate individual tagged broilers in a 1700 m² house stocked with 28 000 birds. The UWB system appeared to be less suitable for accurately measuring distances travelled by the tags, however there was a positive correlation between recorded distance and true distance moved by an observer. Broilers tolerated the UWB backpacks well, displaying little change in behaviour patterns and no abnormal increases in gait score.

A high level of location accuracy was required from the UWB system in this study, both to confirm the suitability of UWB as a method of tracking broiler chickens and, more crucially, to allow for tagged broilers to be located once they had been released. When tested in an empty house, the accuracy of the tags was high. Even allowing for any human error in measuring using the laser meter, an average of 95 % of recorded locations were <50 cm

from their 'true' location. Position data were slightly less accurate when the tags were fitted onto a chicken (~85 % <50 cm), a finding also reported by Stadig et al. (2018a). It is possible that proximity to broilers caused interference in some way, increasing the error. However, all tagged broilers were consistently located throughout the study using information from the UWB system, which suggests that any serious deviation from their true location was minor or temporary. Overall, the median error when tags were tested in an empty house was 0.17m and when mounted on broilers was 0.18m. This is comparable with Stadig et al. (2018b), who found a median error of 0.29m when testing UWB tag accuracy across different free-range environments.

There was a clear tendency for the UWB system to overestimate the distances travelled by tags, with the error varying between 2m to 45m overestimation in this study. We found no obvious trend in error rate depending on the length or duration of the route travelled. When mounted on broilers, van der Sluis et al. (2019) reported a similar issue with tag distance overestimation but found that the error was greater when broilers moved short distances. It is likely that minor deviations are recorded by the UWB system as small movements, even in static animals. In animals that are sedentary, such as broilers, this discrepancy is likely to be more marked. This is a shortcoming of UWB which may be resolved with further work on anchor alignment and tag accuracy. van der Sluis et al. (2019) suggest that their sampling rate (6.91 s) may have both contributed to the "noise" around less active tags and caused underestimation of distances when tags are more active, because some positioning data may have been missed. The sampling rate used in the current study was substantially higher (100 milliseconds), which may explain why our average overestimations were significantly larger than those recorded at a lower sampling rate (144% average overestimation vs 10%). However, similar to van der Sluis et al. (2019), we found a significant positive correlation between the distance recorded and the distance travelled. This suggests that, although accurate distances are currently difficult to determine, it would still be possible to compare the distances travelled by individuals as a way of identifying general trends. When

monitoring tagged broilers over time, lower distances travelled are recorded as broilers aged, which is reflective of their typical reduction in activity (van der Sluis et al., 2019).

One risk of using body sensors to monitor animal behaviour is that the sensors themselves may change the animal's physical appearance, behaviour patterns or interactions with conspecifics. The behaviour of laying hens can be changed by several forms of identification, including leg tags and wing tags (Dennis et al., 2008). For wild birds, wearing body sensors can impact their behaviour, resource use and reproductive success to a varying degree (e.g. Pietz et al., 1993; Garrettson et al., 2000; Suedkamp Wells et al., 2003). However, domestic fowl and turkeys do appear to habituate well to wearing backpacks (Nenno and Healy, 1979; Daigle et al., 2012; Buijs et al., 2018). Pre-laying (Daigle et al., 2012) and 18-week-old laying hens (Buijs et al., 2018) showed only temporary changes in behaviour after being fitted with body sensors, with reductions in feeding, increases in nest box use, and interaction with the equipment only apparent in the few days after sensors were fitted. Slow-growing broilers, which are often more similar in conformation to laying hens than to fast-growing broilers, also showed only temporary behavioural changes when a 36 g backpack was fitted (Stadig et al., 2018b). The backpacks used in this study were significantly lighter, ~19 g, and fitted significantly earlier than those in Stadig et al. (2018b; Day 21 vs Day 35). We also found that most broilers reacted to the backpacks immediately after they were fitted by preening, rolling and crawling. However, wearing a backpack did not appear to affect the behaviour of broilers compared to untagged conspecifics in week 4 (48 h post-fitting) or week 5. In week 6 there was a reduction in preening in the tagged birds compared to those not wearing a backpack, which may indicate that wearing a backpack limits the broilers ability to effectively preen, although it is difficult to quantify the impact this would have on their welfare and normal movement patterns. Anecdotally, researchers did not observe tagged broilers interacting with the tags on any visits to the farm and they were seen perching, dustbathing and playing during the study. It should be assumed that fitting a backpack onto a broiler will affect its behaviour in some way during its lifetime, however our

results suggest that these effects are minor and that data from tagged broilers is largely representative of their untagged conspecifics. A particular challenge in fitting a backpack onto young fast-growing broilers is that their body size and conformation changes rapidly during the study period. There were occasional incidences of wing rubbing, but backpacks were checked regularly and wing straps adjusted if this occurred.

Wearing backpacks had no obvious risk to the broiler's health during the study. One tagged broiler displayed a severe gait issue on Day 37 and was culled, however there were no other deaths among the tagged broilers. Their average final body weight at 37 days (2.5kg) was consistent with the flock average at slaughter (39 days; 2.4kg). The walking ability of tagged broilers worsened as they aged, which was to be expected (Bessei, 2006; Baxter et al., 2018), but the distribution of gait scores was considered normal for week 6. The majority of broilers were scored 1 or 2 (48% and 41%, respectively) which is comparable with previous studies (e.g. 53% and 41% displaying gait scores of 1 and 2 respectively in Baxter et al. (2018) and 47% and 29% with scores of 1 and 2 respectively in Bizeray et al. (2002)).

This UWB system is commercially available but required some technical knowledge and expertise to install. Further comparisons of anchor numbers and placement, tag settings and analysis procedures under commercial broiler conditions would likely make this technology more accurate and accessible. Overall, once the system had been set up, it functioned well in an indoor environment. Tags not housed in their initial plastic casing did not appear to be damaged by the environmental conditions, although the humidity did lead to rust developing in the anchor sockets which had to be replaced. Locating each tagged broiler using the tablet and a dummy tag was effective, rapid and significantly easier than identifying a marked individual among several thousand birds. The scale of broiler chicken production presents significant challenges for scientific research, and as such, many studies are carried out on a smaller experimental scale. However, understanding how conditions effect individuals under commercial conditions and being able to monitor individual broilers throughout the production cycle would provide highly relevant information for industry.

341

342 5. Conclusions

343

344 The ultra wideband positioning system employed in this study was successfully used to

345 locate individual tagged broilers that had been released into a commercial flock. The tags

346 showed a high level of location accuracy but the system consistently overestimated

347 distances travelled. The positive correlation between recorded distance and true distance

348 suggests, however, that it could be used to determine whether differences exist between

349 groups. Broilers adapted quickly to wearing a backpack and showed only minor changes to

350 behaviour, with no influence on general activity levels, walking ability or final body weights.

351 In conclusion, UWB appears to be an accurate method of tracking the location of indoor

352 reared, fast-growing broilers without significantly impacting their normal behaviour patterns.

353 Such technology would allow for precise, long-term observations without the impact of

354 observer presence.

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360 Ethical approval

361 The study was approved by the School of Biological Sciences (Queen's University Belfast)

362 Research Ethics Committee (reference number: QUB-BS-AREC-19-005).

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Figures

Figure 1. UWB anchor placement on the wall of the broiler house. The anchor is screwed to a wall mount which is attached to a metal L-bar to limit interference from the metal house wall. Anchors are connected and powered via waterproof sockets.

Figure 2. (A) - A floor diagram of the commercial house used in this study, with anchor placement (red circles). Lines radiating from the circles indicate the direction of the anchor. (B) – a screenshot showing the real-time location of tagged broilers around the house.

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453 Figure 3. A three-week-old Ross 308 broiler chicken wearing an UWB tag housed in a
454 backpack. Backpacks were 60mm by 40mm, made from white PVC coated material, with
455 adjustable elastic wing straps and a total weight of 19g.

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Figure 4. Plot of the correlation between the true distance walked by an observer holding an UWB tag and the distance recorded by the ultra-wideband ((UWB) software. Dots represent each individual test. Dashed line represent the shape of the correlation if both methods had recorded the same distance.

Figure 5. Comparison of the behaviour of tagged and untagged broiler chickens between weeks 3-6 of the production cycle.

Figure 6. The behaviour of tagged broilers in weeks 3, 4 and 5 of the production cycle. Different letters denote significance at $p < 0.05$.

Table 1. Variation between the distance an observer moved while holding an UWB tag (true distance) and the distance recorded by the UWB software (recorded distance). Error (metres), % overestimation (OE), and means for both are presented.

Test	True distance (m)	Time taken (min)	Recorded distance (m)	Error (m)	% OE
1	3	1	9.33	6.33	211
2	3	5	20.07	17.07	569
3	10	5	17.57	7.57	76
4	10	10	15.66	5.66	57
5	15	10	27.3	12.3	82
6	15	15	16.09	1.09	7
7	20	10	49.76	29.76	149
8	20	15	46.53	26.53	133
9	30	15	31.9	1.9	6
10	30	20	75.46	45.46	152
Mean				15.4	144

Table 2. Location accuracy of UWB tags either placed on the floor of an empty house or mounted on a broiler chicken using a backpack. Tag location was measured as distance from the back (X) and left side (Y) of the house, comparing the recorded tag location with their true location. Percentage of measurements with an error lower than <1m, <50cm, <10cm and <5cm compared to their true location.

Tag accuracy												
Tag	In empty house						On a broiler chicken					
	True location		Recorded location		Error (m)		True location		Recorded location		Error (m)	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
1	38.24	3.00	38.00	2.97	0.24	0.03	0.95	5.28	0.99	4.83	0.04	0.45
2	27.94	4.08	28.54	3.86	0.60	0.22	5.18	6.73	5.40	6.55	0.22	0.18
3	40.57	17.54	40.62	17.39	0.05	0.15	6.66	6.73	5.60	6.55	1.06	0.18
4	15.86	14.95	15.92	14.53	0.06	0.42	81.51	17.42	81.38	17.25	0.13	0.17
5	33.05	2.16	33.02	1.31	0.03	0.85	84.00	17.21	84.45	16.99	0.45	0.22
6	82.88	16.35	82.95	16.40	0.07	0.05	84.48	19.35	84.43	18.92	0.05	0.43
7	77.62	15.42	77.60	15.48	0.02	0.06	3.89	18.24	3.76	18.70	0.13	0.46
8	76.98	2.54	76.96	2.79	0.02	0.25	3.91	17.46	3.72	17.07	0.19	0.39
9	56.52	17.13	54.58	16.94	1.94	0.19	4.52	18.72	4.28	18.19	0.24	0.53
10	62.79	15.64	62.45	15.37	0.34	0.27	70.25	10.94	70.00	10.59	0.25	0.35
11	62.89	3.47	62.59	3.37	0.30	0.10	3.14	8.41	3.15	7.87	0.01	0.54
12	30.57	17.83	30.55	17.95	0.02	0.12	3.43	6.11	3.54	5.63	0.11	0.48
13	3.52	4.35	3.92	3.98	0.40	0.37	68.83	18.15	68.70	17.73	0.13	0.42
14	84.33	6.96	84.82	7.09	0.49	0.13	69.20	17.22	69.27	16.54	0.07	0.68
15	23.17	17.93	23.44	18.08	0.27	0.15	70.28	17.32	70.10	16.90	0.18	0.42
16	55.97	11.94	55.78	11.98	0.19	0.04	71.22	11.11	71.14	11.22	0.08	0.11
17	46.82	12.10	47.02	12.14	0.20	0.04	1.82	7.32	1.99	7.58	0.17	0.26
18	39.48	7.65	39.42	7.77	0.06	0.12	76.05	10.55	76.11	10.56	0.06	0.01
19	46.30	14.68	46.30	14.97	0.00	0.29	20.36	6.16	20.26	5.60	0.10	0.56
20	76.02	7.61	75.97	7.91	0.05	0.30	20.88	7.03	20.89	6.86	0.01	0.17
21	54.26	5.23	54.57	5.22	0.31	0.01	18.15	6.75	17.90	5.84	0.25	0.91
22	45.78	8.14	45.96	8.20	0.18	0.06	35.16	9.32	35.19	9.27	0.03	0.05
23	23.12	12.94	23.60	12.71	0.48	0.23	35.36	9.78	35.91	10.21	0.55	0.43
24	9.78	5.16	10.19	4.95	0.41	0.21	36.36	9.64	36.27	9.48	0.09	0.16
25	63.93	7.83	63.67	7.88	0.26	0.05	8.88	4.29	8.84	3.48	0.04	0.81
26	34.15	5.85	34.40	5.71	0.25	0.14	8.94	4.31	9.05	4.18	0.11	0.13
27	16.44	12.09	16.87	11.94	0.43	0.15	9.29	4.14	9.28	3.51	0.01	0.63
28	70.72	7.64	70.57	7.85	0.15	0.21	23.52	4.06	23.63	3.61	0.11	0.45
29	38.49	11.31	38.54	11.26	0.05	0.05	21.63	5.61	21.75	5.39	0.12	0.22
30	23.88	10.18	24.23	10.18	0.35	0.00	23.41	4.26	23.30	4.06	0.11	0.20

Percentage accuracy (%)					
		<1m	<50cm	<10cm	<5cm
In empty house	X	97	93	37	9
	Y	100	97	33	17
Mounted on chicken	X	97	93	37	20
	Y	100	77	7	3