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Automatic classification of measures of lying to assess the lameness of broilers

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Abstract

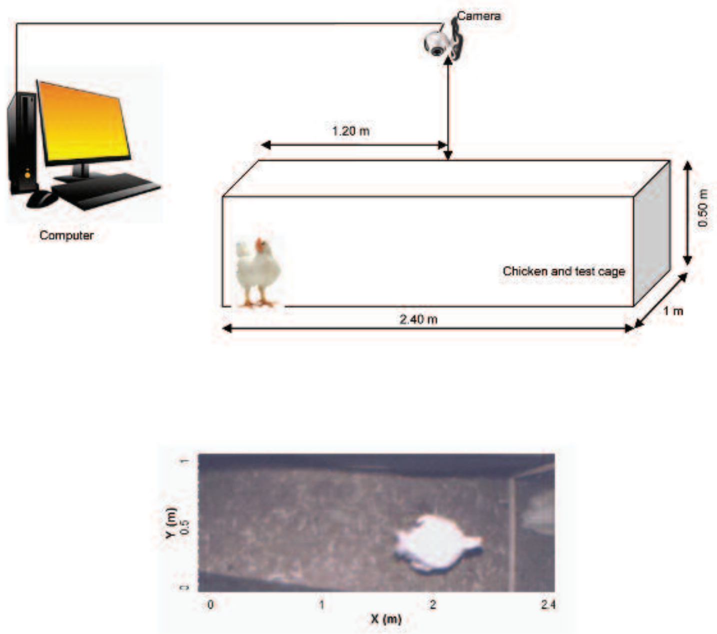
Leg disorders are a major cause of poor welfare in broilers. Previous studies have shown that at slaughter age at least 90% of chickens experienced some degree of gait problems and approximately 30% were seriously lame. In this study, a new and non-invasive technique was developed to automatically assess the lameness of the birds. For this purpose, video surveillance images of broilers with five different pre-defined gait scores were recorded as they walked along a test corridor. Afterwards, the image-processing algorithm was applied to detect the number of lying events (NOL) and latency to lie down (LTL) of broiler chickens. Then, the results of the algorithm were compared with visually assessed manual labelling data (reference method) and the relation between these measures and lameness was investigated. Eighty-three percent of NOL were correctly classified by the automatic monitoring system when compared to manual labelling using a data set collected from 250 broiler chickens. The results also showed a positive significant correlation between NOL and gait score and a significant negative correlation between LTL and gait-score level of broilers. Since strong correlations were found, on the one hand, between two measures and gait-score level of broiler chickens and, on the other, between the results of algorithm and manual labelling, the results suggest this automatic monitoring system may have the potential to be used as a tool for assessing lameness of broiler chickens.

Keywords: *animal welfare, automatic monitoring, broiler chickens, gait score, lameness, latency to lie*

Introduction

The broiler chicken industry has grown steadily over the last 50 years. Genetic selection and developments in feed and management of broiler chickens have resulted in improved efficiency of broiler meat production. At the same time, public concerns with regard to the welfare of these animals have grown as well (McKay *et al* 2000). The most important questions relating to broiler welfare raised in the last two decades are the increasing susceptibility to metabolic and locomotory problems due to fast growth rates and inactivity of the chickens (Bauer *et al* 1996; Bessei 2006). Lameness is a broad term which describes a range of injuries to broiler chickens of both infective and non-infective origin (Thorp & Duff 1988; Swayne & Halvorson 2003). Skeletal disorders in broiler chickens are responsible for significant losses (Cook 2000). In some houses it has been observed that at a mean age of 40 days, over 27.6% of birds showed poor locomotion and 3.3% were almost unable to walk (Knowles *et al* 2008). In the USA in 1998, the cost of these skeletal disorders was estimated to be between 80 and 120 million dollars per year (Bradshaw *et al* 2002). The occurrence of lameness is thought to be strongly correlated with weight and growth rate (Vestergaard & Sanotra 1999). Accelerated growth rates and heavier bodyweights were stated to have an influence on locomotion (Kestin *et al* 2001). A heavy bodyweight requires more from the partially grown skeletal system and leads to abnormal 'gait scores' (Corr *et al* 2003). Moreover, locomotory problems may be painful to the animal and decrease their mobility while increasing secondary problems, such as hock burns and chest soiling (Weeks *et al* 2000). The latency to lie down test (LTL), for assessing the severity of lameness in broiler chickens was described by Weeks *et al* (2002) as the length of time that birds remained standing in shallow water. It was measured and results compared with the results of conventional gait scoring. A highly significant ($P < 0.001$) relationship was seen between the LTL and birds' gait scores (Kestin *et al* 1992; Weeks *et al* 2002). As the original testing procedure, in which the birds are tested in groups, involves a settling-in period, which makes the test too time-consuming to perform on commercial broiler farms, a new test was designed by Berg and Sanotra (2003) to record the LTL. The main difference or advantage of this new test was that the birds were tested individually without visual contact with other birds

Figure 1



Showing the test corridor and the video recording equipment (upper) and an image of the recorded video (lower).

and the experimental set-up could be transferred between commercial farms. The results of their study also showed a clear negative correlation (r = –0.86; P < 0.001) between time spent standing and gait score. However, these types of existing test are time consuming and the measurements cannot be performed continuously. As a consequence, there is no chance of early detection of lameness when these manual evaluation methods are used. Furthermore, a huge amount of manpower is required, particularly to perform this type of manual test on big commercial farms with more than 100,000 chickens in a broiler house. As an alternative to these manual evaluation methods, the increasing availability of low-cost technology currently makes automated monitoring of animal behaviour feasible. For example, vision technology and associated image analysis, allow animal movements to be assessed to a certain extent. These types of automated method have been validated against traditional methods, such as manual labelling. The accuracy of measurements taken automatically varies between methods but can be increased by combining methods (Rushen *et al* 2012).

The locomotion and posture behaviour of pregnant cows prior to calving was studied by Cangar *et al* (2008). In their study, an automatic real-time monitoring system was used to classify specific behaviours, such as standing or lying (including incidences of motion during lying), and eating or drinking. Leroy established a model-based computer vision system to study the behaviour of hens in furnished cages (Leroy *et al* 2006). Individual behaviours, such as standing, walking and scratching could be recognised automatically and in real time. Furthermore, investigating the movement behaviour of broiler chickens in relation to gait score can serve as a measure for lameness (Aydin *et al* 2010). It is clear from the literature that using video images to analyse individual behaviours is an emerging technology.

A major advantage of this type of automated behaviour monitoring is that measurements can be made continuously throughout the life of a flock, non-invasively and non-intrusively and do not involve the biosecurity risk of having people visit different farms to perform gait scoring (Dawkins *et al* 2009).

The first objective of this study was to investigate the lying behaviour of broiler chickens (total number of lying events and duration of the latency to lie down in broilers) in relation to their gait scores, using an image-based monitoring system under laboratory conditions. The second objective was for it to serve as an additional method for developing an automatic lameness monitoring tool for chickens with different gait scores. By combining this method with other systems, it is possible to develop an automated lameness monitoring tool with higher accuracy. As concluded in the study of Rushen *et al* (2012), these types of automatic system may be combined with other monitoring tools, such as tracking the activity level of broilers (Aydin *et al* 2010) and/or detecting the optical flow patterns of broilers (Dawkins *et al* 2012, 2013) to assess the behaviour and welfare of broiler chickens with greater accuracy.

Materials and methods

Experimental design, video recordings and birds

The experimental set-up consisted of a wooden test corridor, with dimensions 2.40 × 1.00 × 0.5 m (length × width × height). It was placed into the broiler house two days prior to the onset of the experiments in order to prevent broilers being fearful of the new environment (experimental set-up/cage). A digital video camera (Guppy F036C, equipped with a C30811KP 8.5 mm Pentax lens, Allied Vision, Germany) was mounted 2.0 m above the

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ground with its lens pointing downwards and directly above the centre of the corridor in order to give an overhead view of the walking area in the camera image (see Figure 1 [upper]). The camera was connected to a PC (Dell, UK) with a built-in frame grabber (E119932-U, AWM 20276, VW-1) using an IEEE 1394 fire-wire cable. Images were captured with a resolution of 1024 × 768 pixels at a sample rate of 3.5 frames per second. Video recordings were made during five experiments. An image from the output video is presented in Figure 1 (lower).

Five experiments were carried out with a total of 250 male broiler chickens (Ross 308) which were obtained from the Provincial Centre for Applied Poultry Research, Province of Antwerp, Belgium. At the start of the rearing period, the animals were treated against infectious bronchitis (IB Primer, Poulvac, Pfizer, UK) and Newcastle disease (NDW, Poulvac). On day 23, the animals were vaccinated against Gumboro (Bursine 2, Poulvac) and 'Newcastle disease' (Hipraviar NDV, Clone, Hipra Benelux NV, Melle, Belgium) in the broiler house via the drinking water. For the first nine days, a pre-starter diet with 23% protein and 2,890 kcal AMEn kg^{-1} (apparent metabolisable energy) was given. From day ten until day 13 a starter diet with 22% protein and 2,794 kcal AMEn kg^{-1}, and from day 14 to day 34 a grower diet with 20% protein and 2,899 kcal AMEn kg^{-1} were provided. During the last days, from day 35 to day 39, a 'finisher' diet was provided with 19% protein and 2,963 kcal AMEn kg^{-1}. Drinking water was available on an *ad libitum* basis at all times. A trained expert gait-scored the chickens and they underwent selection according to their degree of lameness as per the method developed by Kestin *et al* (1992). This ranked lameness in increasing order from gait-score zero (GS0) to gait-score four (GS4) where GS0 is the normal gait. The scoring system primarily assesses walking ability rather than exhaustion, with assessors trained to identify rolling gaits, limping, jerky and unsteady movements and problems with maneuverability. The chart in Table 1 was used by experts to define the gait-score level of broiler chickens.

GS5 chickens were not used in the experiments as these birds are unable to walk due to the severity of lameness. In each experiment, fifty 39-day-old broiler chickens were chosen in such a way that there were ten samples from each gait score. For each of the five experiments, the birds were taken from a compartment of 1,500 and weighed immediately prior to testing. In each experiment, a chicken was placed at the start point in the test corridor and video images of the walking area were recorded for 5 min while the chicken walked from the start to the end point of the corridor, a distance of 2.4 m. This procedure was repeated for all 250 chickens.

Image analysis

The basic image analysis technique used was background subtraction for segmentation of the shape. This technique was used because the camera set-up was fixed and hence the background remained constant over time. Segmentation was performed by subtracting a background image of the empty corridor from each recorded image of the corridor containing a chicken. A pixel for which the difference was above a certain threshold was defined as belonging to the shape of the animal (Leroy *et al* 2006). After this process, the shape of the animal could be characterised using a set of measurable parameters, such as the centre and the area of the shape mask (Leroy *et al* 2006).

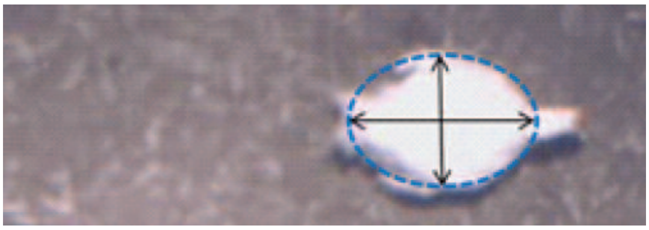
Furthermore, an image-processing algorithm was used to extract a chicken from a sequence of video images, and the centre point, orientation, length and width of the animal in the image were defined by fitting an elliptical shape (Figure 2) around the animal (Leroy *et al* 2006).

Elliptical shapes are simple but widely applicable as an approximation of natural shapes (Birchfield 1998) and their shape can be altered by varying only five parameters: (xc, yc, α, a, b), where xc and yc are the centre co-ordinates, α is the rotation angle around the horizontal axis, and a and b are the lengths of the major and minor axes. This reduces the image-processing time in such a way that it can be used online (Leroy *et al* 2006). The general flowchart of the image analysis and classification procedure can be seen in Figure 3.

Table 1 Scoring chart for broilers.

Gait score	Definition
0	Normal. Smooth stride. Even steps. Foot curls when bird picks it up. Bird is well-balanced and capable of running
1	Uneven stride at times. Foot may or may not curl when bird picks it up. Difficult to identify source of lameness
2	Uneven, irregular, shortened stride. Foot does not curl when picked up. Bird has poor balance and may (or not) use its wings for assistance in walking. Source of lameness is easy to identify
3	Similar to score 2 but bird will remain lying down unless coerced to move, will lie down after several steps and tends to use its wing(s) for balance. Source of lameness is easy to identify
4	Bird reluctant to move and will do so only when it needs to. Bird will only take a few steps and then lie down again. Bird uses its wings to help itself walk. Source of pain is evident
5	Bird is unable to stand or walk. It will shuffle on the ground or 'wing walk' if it needs to move, so wings are typically extended. Birds tend to weigh less than the other birds

Figure 2



The ellipse and the centre point of broiler chickens.

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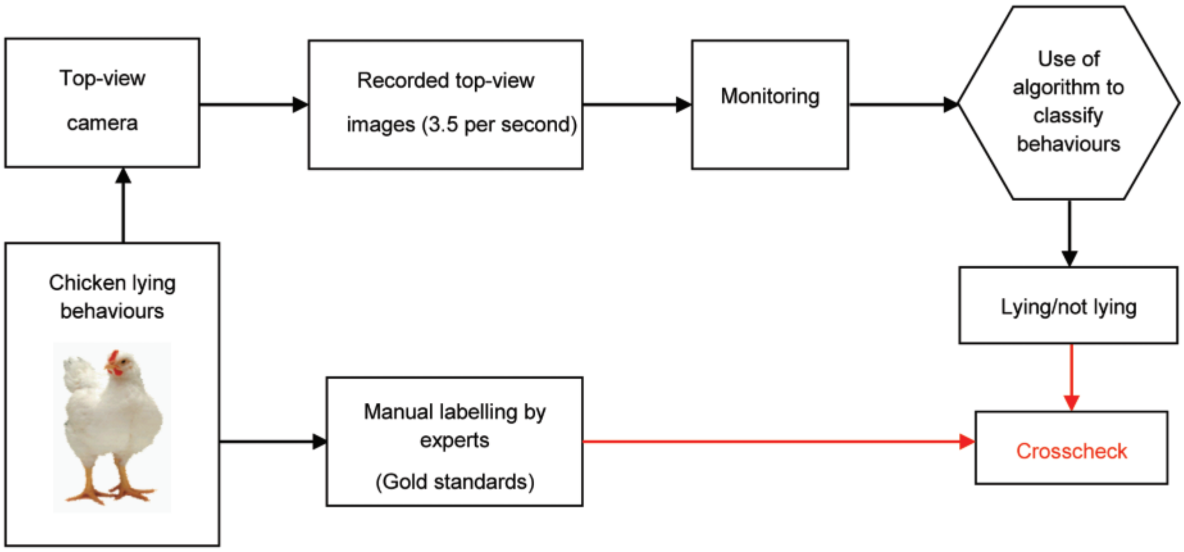
Figure 3



Flowchart of the image analysis and classification procedure.

Table 2 Dynamic variables extracted from the video sequence of the chickens and their description.

Variable name	Description	Units
x-y co-ordinates	x-y co-ordinates of the centre of the animal in the pen as a function of time	m
Walking trajectory	Subsequent positions of the animal's centre-point in x and y co-ordinates	m
Orientation	Subsequent angles of the chicken with respect to the horizontal axis in the image as a function of time	α (degrees)
Back area	Top view area of the chicken	m^2

For initialisation purposes, the centre-point, position, orientation and sizes of the chicken mask obtained from background subtraction were calculated in the first image of each video sequence and fed into the programme. The optimal value of the shape parameters (xc, yc, α, r1, r2) for each image was labelled as posture parameters and stored for further processing (Leroy *et al* 2006). When a certain type of behaviour occurred in the camera image, this caused a distinctive pattern in a number of successive posture parameter values. The posture parameters for each image were computed and the previous values within a certain time window were analysed, so that the window could hold the entire pattern (Leroy *et al* 2006). A first order transfer function (TF) model was used to model the dynamic trajectories of the posture parameters within the time window (Young 1984). Fitting this function to the data within each time window resulted in a set of two dynamic parameters a, b for each posture parameter (Leroy *et al* 2006). Table 2 summarises the dynamic variables that were extracted.

Classification of lying behaviour

The classification procedure involved the variables: orientation change, x and y co-ordinates, and back area of the chicken.

These variables were analysed by applying a sliding window approach. The chickens' behaviour was classified as lying if during the previous window size (3.5 frames per second): i) the slope of the cumulative distance walked was below a certain threshold; ii) the x-y co-ordinates of the geometric centre of the animal were stable, meaning that the fluctuations remained within a certain stability range expressed as a percentage; and iii) the filtered back area of the animal (m^2) exceeded a certain threshold (Cangar *et al* 2008).

If these conditions were fulfilled, the chicken's behaviour was classified as lying. The resulting output from this method consisted of the animal's position, orientation and body configuration as a function of time. Using these outputs, a distinction between lying and standing was made automatically. Latency to lie down (LTL) of broiler chickens was also calculated. Unlike previous studies, this study did not use any kind of disturbing factor, such as water to measure LTL in broiler chickens. The experiments were conducted on a commercial farm. Manual labelling of lying-down events and assessment of the duration of the latency to lie down were carried out by an expert during the experiments.

Statistical analysis

The statistical analysis was carried out on 50 video data sets per experiment with ten data sets belonging to each of the gait-score groups. In total, 250 data sets were used to investigate the differences in lying behaviour between the gait-score groups. The Friedman test, which is a non-parametric test that compares the columns without the row effects, was used to analyse the effects of gait score on birds' lying

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behaviour. In the test sample, size and dependencies did not affect the test results. Following the Friedman test, the Dunn test was applied to define the statistical differences between the gait scores. The Dunn post-test compares the difference in the sum of ranks between two columns with the expected average difference (based on the number of groups and their size). Subsequently, the results from the proposed algorithm were compared with manual labelling results by performing a linear regression analysis. The calculations were performed using the Statistics Toolbox of Matlab (The Math Works, Massachusetts, USA).

Results

Classification of lying

Five experiments were carried out on a total of 250 male broiler chickens (Ross 308) with the average weight of 2.13 (± 0.14) kg to find a relationship among the number of lying events, latency to lie and the lameness of broiler chickens. The birds were handed manually to the start point of the corridor. The general behaviour of birds under the test condition was similar to others as the testing corridor was placed in the broiler house two days previously. They were already motivated to join other chickens because of the crowd psychology, ie there was only one direction in which birds could see and join conspecifics.

The proposed automatic monitoring tool made it possible to measure body variables such as back area, centre-point and body contour (Table 2). The line in Figure 4 shows an example with x and y co-ordinates at the centre-point of a chicken in the walking corridor. The figure gives a good indication of the changes in the x and y direction of the walking corridor during the experiment.

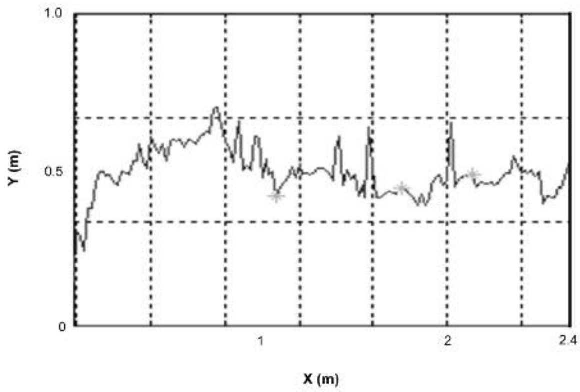
A change in orientation (rotation angle around the horizontal axis) was a clear indicator of animal activity. There were certain occasions in which the birds' orientation changed, even though its centre point did not; this signified a clear movement but no displacement.

The x-y co-ordinates and the speed of the centre point, together with the orientation of the main axis of the chicken, were plotted as a function of time in Figure 5. The x-y co-ordinates indicated the specific position of the chicken in the corridor at a specific time. Little variation in the x-y co-ordinates indicated that chicken movement was limited. During those periods the chicken was either standing and not moving or lying down. Acceleration (mm s^{-2}) was another representation of the chickens' movements.

Not surprisingly, the speed was approximately zero during lying periods (see Figure 5). Variations in the x-y co-ordinates over time and a speed greater than zero signified that the chicken was moving. This movement could be an indication of walking or could be indicative of lateral movements while in the lying position.

The percentage of correctly classified lying behaviour for 250 chickens can be seen in Table 3. The x-y position, back area and acceleration, in particular, demonstrated a strong correlation with manual labelling of the lying and standing behaviour.

Figure 4



An example of the changes in x and y co-ordinates during experiment.

When the slope for the cumulative distance was high, the animal was standing and moving. On the other hand, when the slope was close to zero, the chicken was lying or standing still. While lying, the back area was greater than while standing or walking. Compared with manual labelling, the image analysis method correctly classified total lying events in 250 chickens with an average accuracy of 83%.

A linear regression test was performed to define the coefficient of determination between the number of lying events obtained by the proposed algorithm and the number of lying events obtained by manual labelling, which resulted in $R^2 = 0.993$ ($P < 0.05$). Afterwards, the relationship between the latency to lie down (LTL) obtained with the algorithm and LTL obtained by manual labelling was investigated and the coefficient of determination (R^2) was found to be 0.997 ($P < 0.05$).

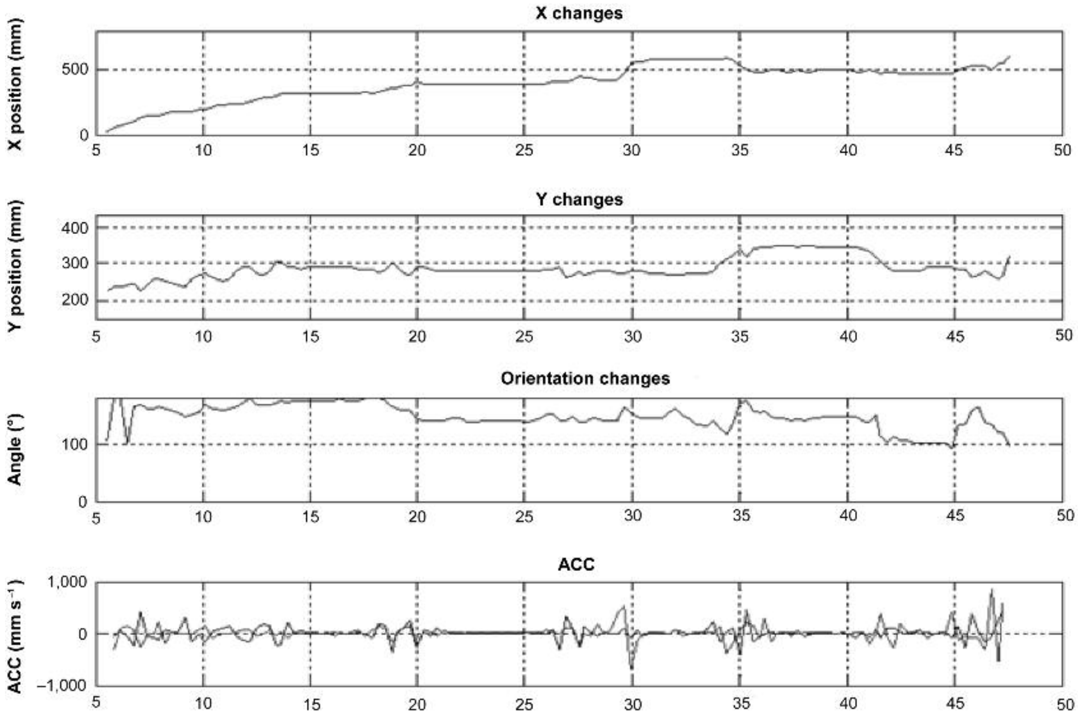
Assessment of LTL in relation to gait score

The results of the algorithm were analysed statistically for differences between the different gait-score levels. As shown in Table 4, the mean (± SD) number of lying events (NOL) in GS3 and GS4 was significantly ($P < 0.05$, $\chi^2 = 286.80$, $z = 1.96$) higher than in GS0, GS1 and GS2 (Figure 6).

Moreover, there are no significant differences between GS0, GS1 and GS2 in terms of the number of lying events (NOL). The LTL was also evaluated and the results were presented in Table 4. Mean (± SD) lame chickens with GS3 and GS4 sit down significantly ($P < 0.001$) earlier than those with GS0, GS1 and GS2 (Figure 7).

The range of LTL values recorded were 19.06–45.16 s for gait score 0, 15.08–37.14 s for gait score 1, 16.02–35.09 s for gait score 2, 5.16–18.11 s for gait score 3, and 1.66–6.24 s for gait score 4. The results showed a high negative correlation ($R^2 = -0.987$ and $P < 0.001$) between NOL and LTL (Figure 8). However, the velocities of the birds were also recorded to assess the NOL and LTL of broiler chickens. The results were, respectively, 51.20 (± 2.93), 50.33 (± 2.78), 47.58 (± 2.84), 29.30 (± 2.51) and 13.16 (± 0.89) mm s^{-1} for GS0, GS1, GS2, GS3 and GS4.

Figure 5



An example of the X position, Y position, orientation and speed changes of a single chicken during experiment.

Table 3 The number of correctly classified lying events of broilers using image analysis.

Exp no	NOL (Algorithm)	NOL (Manual labelling)	Accuracy (%)
1	126	118	84
2	120	115	81
3	118	111	80
4	135	128	88
5	129	113	82
Mean	**126**	**117**	**83**

NOL: Number of lying events

Table 4 NOL and LTL of broiler chickens with different gait scores obtained from proposed algorithm.

Gait scores	Mean (± SD) NOL	Mean (± SD) LTL (s)
0	16 (± 2)[a]	28.69 (±11.30)[a]
1	17 (± 1)[a]	25.27 (± 09.43)[a]
2	16 (± 1)[a]	23.56 (± 07.86)[a]
3	34 (± 2)[b]	11.15 (± 05.46)[b]
4	43 (± 3)[c]	03.33 (± 01.75)[c]

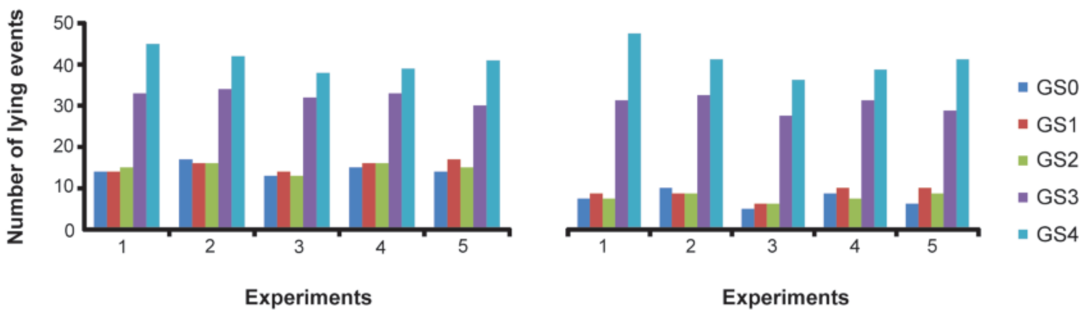
[a,b,c] Mean ranks, within a column, with no common superscript differ significantly ($P < 0.05$).
NOL: Number of lying events; LTL: Latency to lie.

The relationship between lying and gait score is shown in the correlation between NOL, LTL and gait score (Figure 8). The analysis revealed a strong positive correlation ($R^2 = 0.893$) between NOL and gait score and a strong negative correlation ($R^2 = –0.954$; $P < 0.001$) between LTL and gait score.

Discussion

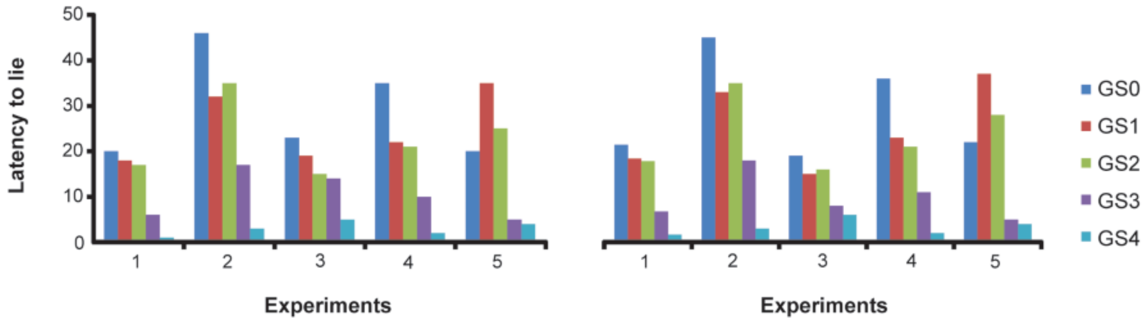
A novel technique using computer vision was developed to automatically collect information relating to the centre-point, body contour, walking trajectory and back area in real time from video footage of broilers (of a broad range of gait scores) that had been individually placed within a test corridor. The variables obtained were then used to automatically classify the number of lying events and latency to lie down. These classified behaviours were then compared with manual labelling by experts. It was found that, on average, 83% of the number of lying events (NOL) from 250 chickens during the experiments could be correctly classified. On the other hand, the results of this study also showed a clear correlation ($R^2 = 0.893$) between gait scores and lying behaviour of broiler chickens; this was similar to the results of Weeks *et al* (2000). As concluded in the study by Weeks *et al* (2000), sound broilers averaged 76% of 23-h lying and this increased significantly to 86% of 23 h in lame birds (GS3). The automatically extracted LTL was evaluated and the results showed a similarity with the results of Weeks *et al* (2002); the lame birds (GS3 and GS4) sat down significantly ($P < 0.001$) earlier than the sound birds. Berg and Sanotra (2003) found a clear negative correlation ($R^2 = –0.86$; $P < 0.001$) between LTL and gait score.

Figure 6



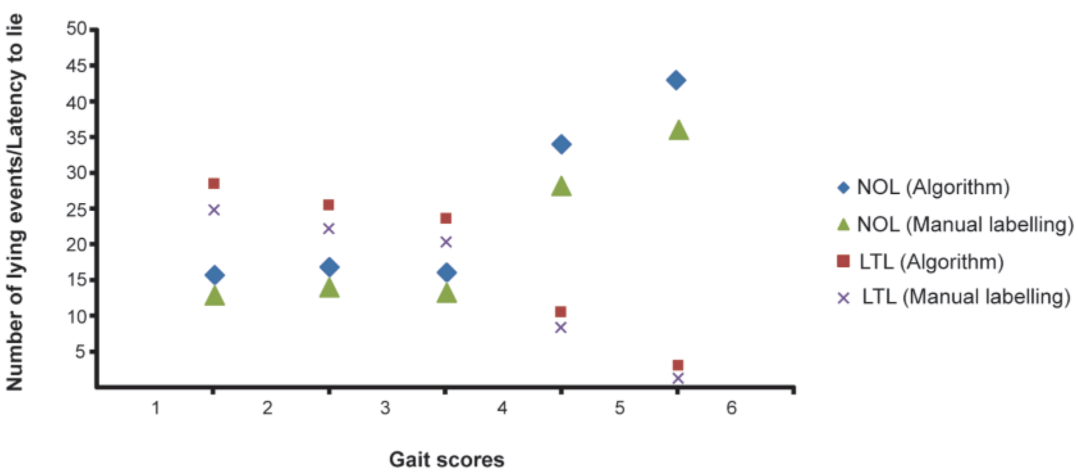
The number of lying events of broiler chickens obtained by (left) manual labelling and (right) algorithm.

Figure 7



Latency to lie of broiler chickens obtained from (left) manual labelling and (right) algorithm.

Figure 8



Correlation between gait scores, number of lying events and LTL measures of broilers and comparison of algorithm output against manual labelling.

Similarly, in this study, a strong negative correlation (R^2 = –0.954) was found between the LTL and gait-score level of broiler chickens. Comparable results were also found by Dawkins *et al* (2009), with gait scores highly negatively correlated with the percentage of time chickens spent walking. The results also showed similarity with the previously published studies (McGeown *et al* 1999; Naas *et al* 2010; Caplen *et al* 2012) in that the non-lame (GS0, GS1 and GS2) broilers walked significantly faster (50 [± 3] mm s^{-1}) than the lame (GS3 and GS4) birds (21 [± 1] mm s^{-1}) ($P < 0.001$).

In this study, only the broiler breed Ross 308 was used, in order to produce comparable data. The results and conclusions of this research apply to the behaviour of Ross 308 chickens, which is the most common breed in Europe. The lying behaviour may be different in other breeds or genetic lines. The classified behaviours were compared with manual labelling by experts. Strong correlations were found between the outcome of the algorithm and manual labelling, leading to the conclusion that the algorithm produces reliable results. However, correct classification of lying down averaged 83%, indicating that there is room for improvement. On some occasions the cumulative distance slowly increased even when the chicken was lying. This could be due to the amount of interference that was accumulated during position measurement or because of real movement of the birds' centre-point while standing. The same conclusions could be drawn when looking at changes in the back area of the bird. To enhance the accuracy of the system, a possible improvement might be to use a high-resolution camera recording with a higher frame rate. Although improvements are needed in order to achieve a better classification rate, the results suggest that this automatic image analysis system has the potential to serve as a tool for monitoring and assessing the number of lying events and latency to lie of broiler chickens in relation to incidence of lameness.

Animal welfare implications

As also concluded by Rushen *et al* (2012), for more accurate identification of the effects of gait score on broiler behaviour, this automatically obtained lying information can be combined with other automatic behaviour analysis systems, such as measuring the activity levels of chickens to detect the degree of lameness (Aydin *et al* 2010) and/or detecting the optical flow patterns in broiler chicken flocks as suggested by Dawkins (2009, 2012). The advantage of this type of automated system is that measurements can be taken continuously during the lifespan of a flock, and that measurement is fully automated, completely non-invasive and non-intrusive and does not involve the biosecurity risk of people visiting different farms to perform gait scoring (Dawkins *et al* 2009). The additional advantage of taking measurements continuously throughout the life of a flock increases the likelihood that such tools can also be used for welfare assessment purposes. For example, an early detection system using these combined automated monitoring systems can be set up in a commercial broiler house to detect lameness before the GS4 and GS5 levels are reached by continuously tracking the different behaviours of broiler chickens.

Conclusion

The main focus of this research was to investigate the relationship among an automatically classified number of lying events, latency to lie and the gait scores of individual broiler chickens in order to assess the lameness of broilers. Eighty-three percent of lying events were correctly classified using this automatic monitoring system for a total of 250 broiler chickens.

Since, on the one hand, strong correlations were found between latency to lie and gait-score level and, on the other, between the number of lying events and gait-score level of broiler chickens, the results suggest that this automatic monitoring system has the potential to recognise latency to lie and the number of lying events in a fully automated and completely non-invasive way. The system has potential but needs further optimisation to improve classification and also requires validation in different field conditions, on different types of chickens and on a larger sample size of broilers. If validation is successful, the monitoring technique developed is a promising tool for analysing lying behaviour and indicating lameness in broiler chickens.

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