Applied Animal Behaviour Science 119 (2009) 203–209

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Optical flow patterns in broiler chicken flocks as automated measures of behaviour and gait

Marian Stamp Dawkins [a,*], Hyoung-joo Lee [b], Corri D. Waitt [a], Stephen J. Roberts [b]

[a] Department of Zoology, University of Oxford, South Parks Road, Oxford OX1 3PS, UK
[b] Department of Engineering Science, University of Oxford, Parks Road, Oxford OX1 3PJ, UK

ARTICLE INFO

Article history:
Accepted 14 April 2009
Available online 12 May 2009

Keywords:
Chicken welfare
Video analysis
Optical flow

ABSTRACT

The aim of this study was to test the hypothesis that valuable on-farm outcome measures of broiler (meat) chicken welfare can be derived from optical flow statistics of flock movements recorded on video or CCTV inside commercial broiler houses. 'Optical flow' describes the velocity of image motion across an eye or camera and statistical patterns can be derived automatically and continuously throughout the life of a flock. We provide descriptive statistics (mean, variance, skewness and kurtosis) of optical flow of 10 intensively housed commercial broiler flocks between the ages of 32 and 35 days. There were no significant correlations between any of these measures and flock mortality. However, all four measures were correlated significantly with the % of birds in a house showing poor walking (high gait scores). Furthermore, these gait scores were highly negatively correlated with the % of time chickens spent walking and with their stride rate (no. of strides/min), as measured by focal behaviour analysis of individual birds from the same video records. The results suggest that optical flow measures have the potential to be used as an adjunct or even a substitute for gait scoring on commercial farms with the added advantage that the measurements could be made continuously throughout the life of a flock, are fully automated, completely non-invasive and non-intrusive and do not involve the biosecurity risk of having people visiting different farms to carry out gait scoring. The correlations between gait scores and optical flow also suggest that gait scoring itself has an objective basis.

1. Introduction

In response to the growing world-wide demand for chicken meat (FAO, 2006), modern breeds of broiler chicken have been heavily selected for high juvenile growth rate and efficiency of food conversion (Arnould and Leterrier, 2007; Bessei, 2006; Estevez, 2007; Renemam et al., 2007). However, this commercially valuable fast early growth rate is now associated with major welfare problems, notably inability to regulate oxygen supply leading to cardiovascular failure (Baghbanzadek and Decupere, 2008; Julian, 1998), lameness or difficulty in walking (Kestin et al., 1992; Sanotra et al., 2001; Bradshaw et al., 2002; Knowles et al., 2008) and obesity resulting in the need for feed restriction in the parent birds (Bessei, 2006; D'Eath et al., 2009; Renemam et al., 2007).

Proposals for improving chicken welfare have included better lighting (Blatchford et al., 2007; Kristensen et al., 2006), environmental enrichment such as perches (Tablante et al., 2003), opportunities for exercise (Bizeray et al., 2002; Reiter, 2006), genetics (Arnould and Leterrier, 2007; Dawkins et al., 2004), reduced stocking density (SCAHAW, 2000) and improved air and litter quality (Dawkins et al., 2004; Estevez, 2007; Jones et al., 2005; Meluzzi et al., 2008). Determining objectively whether

* Corresponding author. Tel.: +44 01865 271215; fax: +44 01865 310447.
E-mail address: marian.dawkins@zoo.ox.ac.uk (M.S. Dawkins).

0168-1591/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.applanim.2009.04.009

these factors genuinely do improve bird welfare in a commercial setting, however, depends critically on having clearly defined and measurable welfare 'outcomes' by which commercial flocks can be judged (Blokhuis et al., 2008; Edwards, 2007; Veissier et al., 2008; Whay, 2007). Not all measures of welfare, which may give valuable information in a research environment are suitable as routine, on-farm assessment outcomes (Boitreau et al., 2007). Corticosteroid levels (Lane, 2006) or use of a plate to record weight distribution of a walking bird (Corr et al., 2003) for example, are valuable indicators of welfare when research resources and time are available, but are unsuitable for mass use on a daily basis on commercial farms. To qualify as a useable welfare 'outcome' for producers and auditors, a welfare measure has to be easy to use, inexpensive, automated, quantitative and robust as well as validated against other, possibly less accessible, measures (Sørensen et al., 2007). It also has to have the joint agreement of producers, scientists and consumers, who may not always agree (Napolitano et al., 2007).

With broiler chickens, outcome measures of welfare that fulfil some of the above criteria include mortality, which is recorded on a routine basis by producers, and mass screening of external measures of bird health that can be carried out at the slaughter plant. For example, birds that have discoloured legs (hock burn) and lesions on their feet (pododermatitis) reveal that they have been standing or sitting on wet, soiled litter (Broom and Reefmann, 2005) and a welfare outcome standard can be specified as the requirement that flocks must not exceed a certain % of leg and foot damage (Haslam et al., 2006). But low levels of mortality and lack of external tell-tale signs of damage on dead birds do not adequately define what most people mean by 'welfare' (Dawkins, 2008), nor do they enable corrective measures to be taken during the life of a flock. What is urgently needed are automated welfare outcomes that can be applied to living birds, made continuously throughout their lives and used to set standards for producers and breeders to meet.

So far, the most commonly used outcome measure of living birds on a large scale is to observe individual birds walking and then give each one a 'gait score' on a ranked scale (Kestin et al., 1992), but this is very time-consuming and physically demanding if done correctly, the results vary with the person doing the scoring even after training (Butterworth et al., 2007; Webster et al., 2008) and it gives only a 'snapshot' of the welfare state of a flock so that it is often only done as a maximum once or twice for each flock. There is also a biosecurity risk from observers moving between farms.

We here provide evidence that potentially valuable outcome measures of broiler welfare can be derived from the optical flow patterns of broiler flock movements recorded on video or CCTV inside commercial broiler houses. Previous attempts to automate the analysis of video sequences have attempted to track the movements of individual animals, but this is technologically very difficult and can lead to cumulative errors as individual animals are lost or confused with others. 'Optical flow', on the other hand, can be used to describe the mass movement of whole groups of objects or animals since it involves measuring the velocity of image motion in front of an eye or camera (Beauchemin and Barron, 1995; Fleet and Weiss, 2005; Sonka et al., 1999). Whole frames, or sections of frames, containing tens or hundreds of individuals are assessed together. The basic statistical properties of these flow patterns can be derived automatically and continuously from inexpensive equipment. The resulting statistics are quantitative and objective scores that can be made continuously over time. The aim of this paper is to validate these optical flow measures as outcome measures of welfare for commercial broiler flocks.

We tested the hypothesis that simple descriptive statistics of optical flow patterns (mean, variance, skewness and kurtosis) differ between flocks and that these differences are correlated with more conventional measures of welfare such as mortality and % of birds in a flock with poor gaits. Specifically, we expected that there should be a negative correlation between mean optical flow and % of birds with poor gaits. In an attempt to understand how the behaviour of individuals gives rise to the mass effects detected by changes in optical flow, we analysed the same video sequences with focal bird analysis and tested the further hypothesis that the optical flow measures, although detecting mass movements of whole groups of birds, are correlated with behaviour measured at individual bird level, such as sitting and walking.

2. Methods

2.1. Broiler flocks

A total of 10 intensively housed commercial broiler flocks contributed to this study. The flocks contained between 3700 and 40,000 birds and were of one of two commercial strains of broiler chickens. 4 of the flocks were as-hatched (mixed sexes), while 3 were all male and 3 all female. All flocks were raised to maximum target final stocking densities of 32 kg/m^2.

2.2. Recording and video file preparation

Webcams (Logitech 500) attached to laptop PCs were used to record data. Webcams were attached to posts inside the houses at a height of approximately 2 m and at an angle of 70° to the vertical. The video records and gait scores were taken on separate days when the birds were between 32 and 35 days of age. Most of these records were approximately 1 h in length and all were more than 30 min. The exact times, days and durations of the recordings were subject to the normal daily working routine within the houses, commercial decisions about when birds were to be slaughtered, the work schedule of the farm manager, the functioning of the equipment and other unforeseen events such as electrical problems, someone entering the house during a recording, etc. However, as all these variables would also be operating on any commercial farm, the system would have to be robust enough to cope with all of them to be useful.

Video files were recorded in AVI format (Microsoft Corporation, 1997) and then compressed to WMV format to save space at the recording stage. The files were also subsequently converted to an 8-bit greyscale, with 4 frames-per-second (FPS) and a frame size of 320 × 240 for standardisation purposes. Sections of files that had few or no chickens visible, where a person was obviously walking around the house or where the lights were switched off in the house were excluded from the analysis.

2.3. Production data

The commercial companies concerned supplied their routine data on mortality (%) and leg culls (%).

2.4. Gait scoring

All flocks were visited and individuals gait scored at least once between 32 and 35 days by the same observer using a three point score (0 = completely normal to 2 = unable to walk) (Dawkins et al., 2004; Webster et al., 2008). 50–100 birds were individually scored on each occasion. The observer walked to one of five randomly pre-selected positions in the house, waited for 2 min for the birds to settle and then moved slowly forward, watching the birds from behind as they walked. Each bird was watched as it walked for 10 paces and a score given for each one. A catching frame was not used on the grounds that catching birds in a frame distorts walking. The gait score of the flock was calculated as the % of birds that were scored as ≥1. Gait scoring was always carried out on a different day to the video recordings.

2.5. Bird motion estimation via optical flow

A set of estimated bird motions was extracted from each video file (consisting of a series of image frames) using the optical flow algorithm (Beauchemin and Barron, 1995; Fleet and Weiss, 2005). An optical flow is an approximation to apparent velocities of image motion. Consider a video file that consists of T image frames of 320 × 240 pixels. Each image is divided into 1200 (=40 × 30) 8-by-8 pixel blocks. The algorithm estimates, for each block, a local velocity vector derived by analysis of the frame-by-frame changes between two consecutive image frames at time t and $t+1$. The velocity vector contains two elements, horizontal and vertical, i.e. $v_i(t) = [v_i^x(t), v_i^y(t)]$, for frames at time $t = 1, \ldots, T-1$, and $i = 1, 2, \ldots, 1200$ where i represents the index of the corresponding block. Fig. 1 illustrates an example of calculating the velocity vectors. Panels (a) and (b) are two consecutive image frames taken from a video where a ball is moving to the right. Panel (c) is the scaled temporal difference between pixels of (a) and (b) where the ball moves from the bright arc to the dark arc. In panel (d), velocity vectors are represented by lines from centre points of the set of 8-by-8 pixel blocks. The line length is proportional to the total velocity in the corresponding block and its direction is the estimated direction of object movement within the block. Fig. 2 illustrates a more realistic example of a car moving to the right.

From the velocity vectors, the amount of movement for each block was obtained as the magnitude of the velocity,

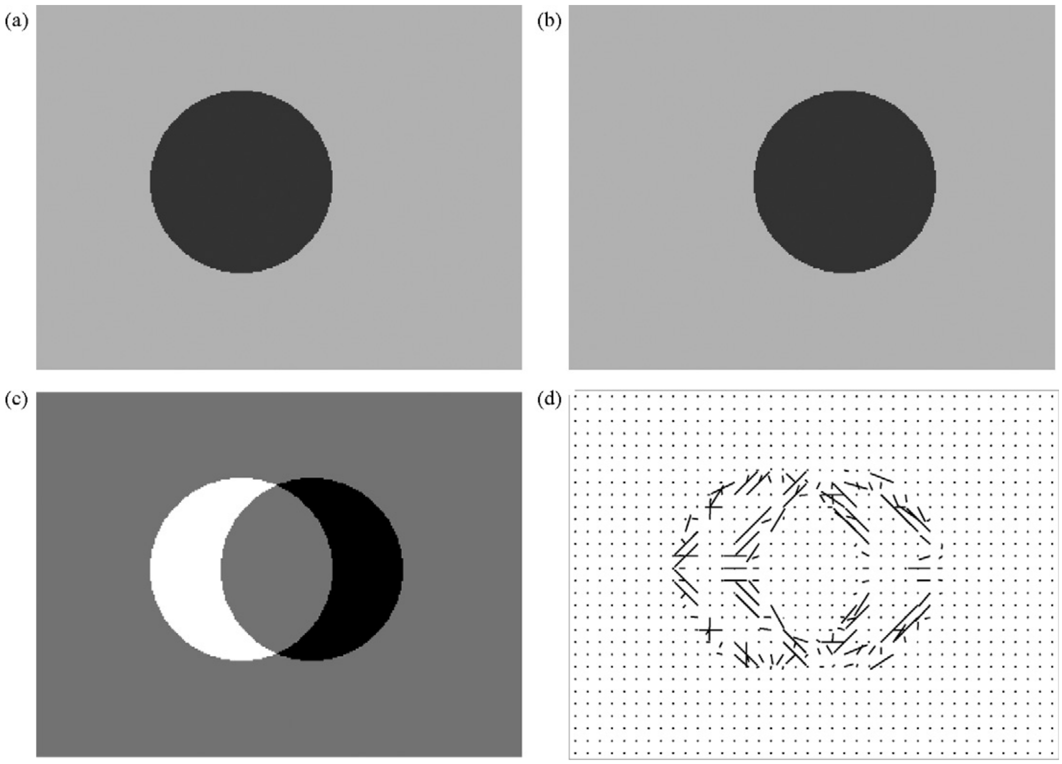

Fig. 1. A diagrammatic example of calculating velocity vectors using the optical flow algorithm. (a) Image frame at time t. (b) Image frame at time $t+1$. (c) Difference between (a) and (b). (d) Velocity vectors.

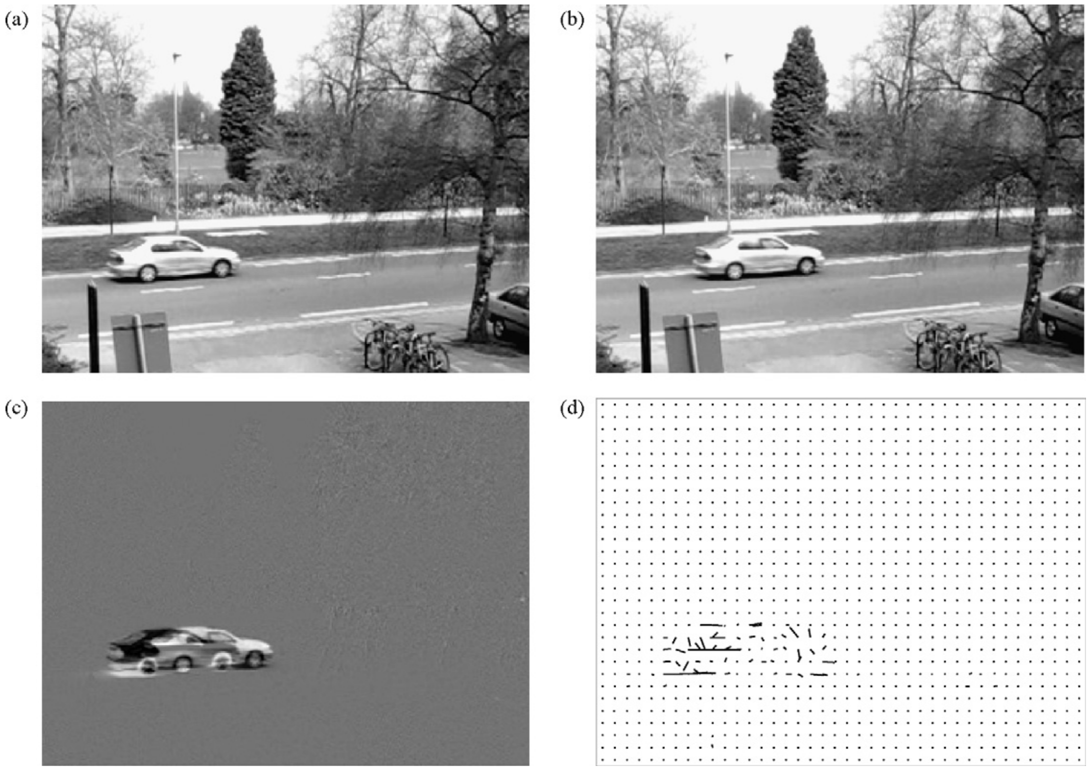

Fig. 2. A realistic example of calculating velocity vectors using the optical flow algorithm. (a) Image frame at time t. (b) Image frame at time $t+1$. (c) Difference between (a) and (b). (d) Velocity vectors.

$m_i(t) = \sqrt{(v_i^x(t))^2 + (v_i^y(t))^2}$. Then, the spatial mean, variance, skewness and kurtosis were obtained as a snapshot of birds' movements in each image frame as follows:

$$\text{Mean}: \quad \mu(t) = \frac{1}{B}\sum_{i=1}^{N} m_i(t)$$

$$\text{Variance}: \quad \sigma^2(t) = \frac{1}{B-1}\sum_{i=1}^{N}(m_i(t)-\mu(t))^2$$

$$\text{Skewness}: \quad \gamma_1(t) = \frac{(1/(B-1))\sum_{i=1}^{N}(m_i(t)-\mu(t))^3}{\sigma^3(t)}$$

$$\text{Kurtosis}: \quad \gamma_2(t)\frac{(1/(B-1))\sum_{i=1}^{N}(m_i(t)-\mu(t))^4}{\sigma^4(t)} - 3$$

where B is the number of blocks, i.e. 1200 in our implementation. These four measures were obtained sequentially for each frame in the video files for $t = 1, \ldots, T-1$, resulting in a four-dimensional time-series data set. Finally, the four optical flow measures were averaged over the time period to give a summary of each flock. The average optical flow measures were used in the analysis of which we detail in the sections below.

2.6. Behaviour

The same videos that were used for the optical flow analysis were also used for focal animal sampling using JWatcher (Blumstein et al., 2000). A random frame was chosen at least 10 min from the beginning and the end of a video with a random number generator (www.random.org), to allow birds to settle down and to avoid the impact of human disturbance on locomotion. A transparent acetate sheet was divided into 30 squares (4.9 cm × 4.2 cm) and was placed over the video screen. Squares were randomly selected as above to identify focal birds (one bird per square). For each video, six randomly chosen birds were identified, three sitting down and three standing or walking. Both sitting and standing birds were observed because we wanted to measure both the % time sitting and standing and also the characteristics of walking, such as stride rate, as this would be what a gait scoring observer would see. The behaviour of each of these six focal birds was then recorded for up to 10 min. The following behaviours were recorded: sitting, lying, walking, the number of walking bouts (a bout was defined as the onset of when a bird started walking until it came to a standstill of more than 2 s), the number of strides per walking bout and the stride rate (number of strides/min). From this data from six birds, the mean durations (+S.D. and CV) of sitting and walking was calculated for that record, as well as the mean no. of strides/bout and stride rate.

2.7. Statistical correlations

To investigate the relationships between the 'welfare' measures, we conducted correlation analysis (Hogg and Craig, 1995). Suppose that we have two variables X and Y, from each of which n samples have been drawn, i.e.

$\{X_1, \ldots, X_n\}$ and $\{Y_1, \ldots, Y_n\}$. A linear correlation coefficient between the samples from the two variables is obtained as follows:

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

where $\bar{X}$ and $\bar{Y}$ are the sample means of the variables, respectively. The correlation coefficient ranges from −1 to +1. A value close to +1 suggests that the two variables have a strong positive relationship, while a value close to −1 indicates a strong negative relationship. On the other hand, if the value is close to zero, the relationship is considered weak or even nonexistent. To determine the significance of the relationship, the following statistic is calculated:

$$\frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

which has a t-distribution with $n-2$ degrees of freedom.

3. Results

3.1. Optical flow, mortality and gait scores

There were no significant correlations between optical flow measures and either % flock mortality or % leg cull (Table 1), although there were significant positive correlations with the optical flow skewness and with the kurtosis for % flock leg cull. However, all four optical flow measures were significantly correlated with gait score. Mean and variance showed strong negative correlations, whereas skewness and kurtosis showed positive correlations.

3.2. Behaviour and gait scores

To try to understand what the optical flow measures were actually picking up, we next looked at the behaviour shown by the chickens on the same videos from which the optical flow measures were taken. Higher mean flows are associated with greater activity (Table 2) (walking and rate of striding), but only one of the correlations was significant (between rate of striding and the optical flow variance). On the other hand, there were highly significant correlations between behaviour and gait scores (Table 3). Poor gait scores within a flock were significantly negatively correlated ($r = -0.93$) with % time the focal birds in the video spent walking and with stride rate or how fast the birds were walking ($r = -0.82$).

Table 1
Correlation coefficients (r) between optical flow measures and mortality, leg culls and gait scores recorded for 10 different flocks between 32 and 35 days of age. Gait scores are expressed as the % of the flock recorded as having gaits greater or equal to 1 on a score of 0, 1, 2 (see text).

	Optical flow measures			
	Mean	Variance	Skewness	Kurtosis
% Flock mortality	−0.3016	−0.3278	+0.5584	+0.5056
% Flock leg cull	−0.4193	−0.3742	+0.6562*	+0.6417*
Gait score	−0.9254**	−0.9063**	+0.9018**	+0.8853**

* $p < 0.05$.
** $p < 0.01$.

Table 2
Correlation coefficients between optical flow measures and different behaviours for 32–35-day-old chickens.

	Optical flow measures			
	Mean	Variance	Skewness	Kurtosis
% Time sitting	−0.2109	−0.3486	−0.0227	−0.1952
% Time walking	+0.4254	+0.4884	−0.1015	+0.0213
Mean no. of strides/bout	−0.2512	−0.2504	+0.4288	+0.4301
Stride rate (no. of strides/min)	+0.4991	+0.5514*	−0.1390	−0.0198

* $p < 0.05$.

Table 3
Correlation coefficients between gait score and measures of behaviour taken from video.

	Behavioural measures			
	% Time sitting	% Time walking	Stride rate (no. of strides/min)	No. of strides/bout
Gait score	−0.12	−0.93**	−0.82**	+0.248

** $p < 0.01$.

4. Discussion

The lack of correlation between any of the optical flow measures we used and flock mortality may at first sight seem to cast doubt on the value of optical flow as a welfare outcome measure. However, mortality figures reflect birds that are not present in the house and therefore do not appear in the videos, whereas both the optical flow and the behavioural measures from the same video were taken from living birds, as were the gait score measures. Consequently we do not necessarily expect that mortality measures would necessarily be related to what is seen in the videos. More important is to consider what optical flow measures tell us about the welfare of the living birds in the video.

The high correlations between gait scores and all four statistical measures of flow (mean and variance negative; skewness and kurtosis negative) suggest that these simple optical flow summary statistics may indeed be capable of extracting from the flock some of the same features of flock welfare as are gathered by people visiting houses and scoring individual birds on how well they walk. If substantiated with further data on more flocks and baseline data on the flow patterns in flocks of different ages, breeds, and stocking densities, this approach could provide a supplement or even substitute for gait scoring but with the advantage that it cuts out the biosecurity risk of having people actually visiting chicken houses. Furthermore, by having cameras in broiler houses continuously, there could be an objective daily record of the state of all flocks whereas gait scoring can only be done on an irregular basis. As an aside, the significant correlations between gait score and optical flow also provides support for the process of gait scoring itself, at least with a three-point score (Dawkins et al., 2004; Webster et al., 2008). Gait scoring has been criticised as subjective and difficult to apply in practice (Butterworth et al., 2007) but the fact that at least a three-point score correlates so well with an entirely automatic and objective statistical measure indicates that it may be more objective than had previously been supposed. Furthermore, gait scores were highly correlated with behaviour such as walking and stride rate recorded from the video, which again suggests that gait scoring does pick up objectively measurable bird variables.

Although the correlations between optical flow measures and behaviour (Table 2) are in the expected directions (higher flow being associated with more walking, less sitting and a higher stride rate), only one of the correlations is statistically significant, suggesting that the flow patterns are actually a complex end result of several different process operating at the individual bird level.

It is also important to point out that we confined our analysis to birds within a very restricted age range (32–35 days) and that further work is needed before this methodology can be extended generically to birds of other ages, sizes or stocking densities. It is also clear that further work is needed to understand how chicken behaviour gives rise to the observed motion patterns. In particular, more work is needed to interpret kurtosis and skewness of the flows, both of which describe the tendency of a population to depart from single central mode, and which may in the future yield important information about.

We believe that this optical flow approach has potential applications in a wide range of other situations that involve long-term remote monitoring. Most attempts to automate the analysis of video sequences of groups or herds of animals have adopted some version of a 'tracking' approach, in which individual animals in a flock or herd (or people in a crowd) are identified and followed through time (MacCormick, 2002). While this approach has had considerable success with dealing with a small number of easily identifiable animals (Rabaud and Belongie, 2006; Wills et al., 2003), it runs into problems with groups consisting of tens or hundreds of individuals, those problems including occlusion and computational overload. Optical flow detects group-level properties without the need for individual tracking and yet, as we have shown, potentially provides an inexpensive and simple way of monitoring the properties of individuals such as their ability to walk.

5. Conclusions

Automated measures of optical flow, taken remotely from video cameras inside commercial broiler houses have the potential to provide continuous 'outcome' measures of the welfare state of the flock. While this approach still needs work and further validation, we have shown that optical flow measures are highly correlated with gait scores and so have the possibility to become a useful adjunct to the much more labour intensive process of gait scoring in broilers, with the major advantage that it could potentially be used to give continuous outcome measure on living birds throughout their lives.

Acknowledgements

The work was carried out as part of the BBSRC Animal Welfare Initiative and we would like to thank the BBRSC for supporting this work financially. We would also like to thank Cobb Europe Ltd. for their support and encouragement and John Vincent and Marek Stebbings for help with the video recordings. Hyoung-joo Lee was also supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (KRF-2007-357-D00276).

References

Arnould, C., Leterrier, C., 2007. Welfare of chickens reared for meat production. Prod. Anim. 20, 41–45.

Baghbanzadek, A., Decupere, E., 2008. Ascites syndrome in broilers: physiological and nutritional perspectives. Avian Pathol. 37, 117–126.

Beauchemin, S.S., Barron, J.L., 1995. The computation of optical flow. ACM Comput. Surv. 27 (3), 433–467.

Bessei, W., 2006. Welfare of broilers: a review. World's Poultry Sci. J. 62, 455–466.

Bizeray, D., Estevez, I., Leterrier, C., Faure, J.M., 2002. Influence of increased environmental complexity on leg condition, performance and level of fearfulness in broilers. Poultry Sci. 81, 767–773.

Blatchford, R.A., Mench, J.A., Wakenell, P.S., Archer, G.S., 2007. The effect of light intensity on broiler behaviour and welfare. Poultry Sci. 86 (Suppl. 1), 126.

Blokhuis, H.J., Keeling, L.J., Gavinelli, A., Serratosa, J., 2008. Animal welfare's impact on the food chain. Trends Food Sci. Technol. 19 (Suppl. 1), S79–S87.

Blumstein, D.T., Evans, C.S., Daniel, J.C., 2000. JWatcher. , http://galliform.psy.mq.edu.au.

Bradshaw, R.H., Kirkden, R.D., Broom, D.M., 2002. A review of the aetiology and pathology of leg weakness in broilers in relation to welfare. Avian Poultry Biol. Rev. 13, 45–103.

Boitreau, R., Veissier, I., Butterworth, A., Bracke, M.B.M., Keeling, L.J., 2007. Definition of criteria for overall assessment of welfare. Anim. Welf. 16, 225–228.

Broom, D.M., Reefmann, N., 2005. Chicken welfare as indicated by lesions on carcasses in supermarkets. Br. Poultry Sci. 46, 407–414.

Butterworth, A., Knowles, T.G., Whittington, P., Matthews, I., Rogers, A., Bagshaw, C.S., 2007. Validation of broiler chicken gait scoring training in Thailand, Brazil and New Zealand. Anim. Welf. 16, 177–179.

Corr, S.A., Gentle, M.J., McCorquodale, C.C., Bennett, D., 2003. The effect of morphology on the musculoskeletal system of the modern broiler. Anim. Welf. 12, 145–157.

Dawkins, M.S., Donnelly, C.A., Jones, T.A., 2004. Chicken welfare is influenced more by housing conditions than by stocking density. Nature 427, 342–344.

Dawkins, M.S., 2008. The science of animal suffering. Ethology 114, 937–945.

D'Eath, R.B., Tolkamp, B.J., Kyriazakis, I., Lawrence, A.B., 2009. 'Freedom from hunger' and preventing obesity: the animal welfare implications of reducing food quantity or quality. Anim. Behav. 77, 275–288.

Edwards, S.A., 2007. Experimental welfare assessment and on-farm application. Anim. Welf. 16, 111–115.

Estevez, I., 2007. Density allowances for broilers: where to set the limits. Poultry Sci. 86, 1265–1272.

Fleet, D.J., Weiss, Y., 2005. Optical flow estimation. In: Paragios, N., Chen, Y., Faugeras, O. (Eds.), Mathematical Models for Computer Vision: The Handbook. Springer, New York, pp. 239–258.

FAO (Food and Agriculture Organisation), 2006. Livestock's Long Shadow. FAO, Rome.

Haslam, S., Brown, S.N., Wilkins, L.J., Kestin, S.C., Warriss, P.D., Nicol, C.J., 2006. Preliminary study to examine the utility of using foot burn or hock burn to assess aspects of housing conditions for broiler chickens. Br. Poultry Sci. 47, 13–18.

Hogg, R.V., Craig, A.T., 1995. Introduction to Mathematical Statistics, fifth ed. Prentice-Hall, New Jersey.

Jones, T.A., Donnelly, C.A., Dawkins, M.S., 2005. Environmental and management factors affecting welfare of chickens on commercial farms in the UK and Denmark stocked at five densities. Poultry Sci. 84, 1155–1165.

Julian, R.J., 1998. Rapid growth problems: ascites and skeletal deformities in broilers. Poultry Sci. 77, 73–81.

Kestin, S.C., Knowles, T.G., Tinch, A.E., Gregory, N., 1992. Prevalence of leg weakness in broiler chickens and its relationship with genotype. Vet. Rec. 131, 190–194.

Knowles, T.G., Kestin, S.C., Haslam, S.M., Brown, S.N., Green, L.E., Butterworth, A., Pope, S.J., Pfeiffer, D., Nicol, C.J., 2008. Leg disorders in broiler chickens: prevalence, risk factors and prevention. PLoS One 3 (2), e1545.

Kristensen, H.H., Aerts, J.M., Leroy, T., Wathes, C.M., 2006. Modelling the dynamic activity of broiler chickens in response to step-wise changes in light intensity. Appl. Anim. Behav. Sci. 101, 125–143.
Lane, J., 2006. Can on-invasive glucocorticoid measures be used as reliable indicators of stress in animals? Anim. Welf. 15, 331–342.
Meluzzi, A., Fabbri, C., Folegatti, E., Sirri, F., 2008. Survey of chicken rearing conditions in Italy: effects of litter quality and stocking density on productivity, foot dermatitis, carcase injuries and meat quality. Br. Poultry Sci. 49, 257–264.
MacCormick, J.P., 2002. Stochastic Algorithms for Visual Tracking. Springer, London.
Microsoft Corporation, 1997. DV Data in the AVI File Format Specification. , http://download.microsoft.com/download/1/6/1/161ba512-40e2-4cc9-843a-923143f3456c/DVAVSPEC.RTF.
Napolitano, F., De Rosa, G., Caporale, G., Carlucci, A., Grasso, F., Monteleone, E., 2007. Bridging consumer perception and on-farm assessment of animal welfare. Anim. Welf. 16, 249–253.
Rabaud, V., Belongie, S., 2006. Counting crowded moving objects. In: Proceedings of IEEE Conference on Computer Vision and Pattern Recognition (CVPR 2006). IEEE Computer Society, New York, pp. 705–711.
Reiter, K., 2006. Behaviour and welfare of broiler chicken. Arch. Geflugel. 70, 613–621.
Renemam, R.A., Rustad, M.E., Robinson, F.E., 2007. Implications of change to commercial broiler and broiler breeder body weight targets over the past 30 years. World's Poultry Sci. J. 63, 457–472.
Sanotra, G.S., Lund, J.D., Ersboll, A.K., Petersen, J.S., Vestergaard, K.S., 2001. Monitoring leg problems in broilers: a survey of commercial broiler production in Denmark. World's Poultry Sci. J. 57, 55–69.
SCAHAW (Scientific Committee on Animal Health and Animal Welfare). 2000. European Commission.
Sonka, M., Hlavac, V., Boyle, R., 1999. Image Processing, Analysis, and Machine Vision, second ed. PWS Publishing, London.
Sørensen, J.T., Rousing, T., Møller, S.H., Bonde, M., Hegelund, L., 2007. On-farm welfare assessment systems: what are the recording costs? Anim. Welf. 16, 237–239.
Tablante, N.L., Estevez, I., Russek-Cohen, E., 2003. Effect of perches and stocking density on tibial dychondroplasia and bone mineralization as measured by bone ash in broiler chickens. J. Appl. Poultry Res. 12, 53–59.
Veissier, I., Bock, B.B., Butterworth, A., Roe, E., 2008. European approaches to ensure goof animal welfare. Appl. Anim. Behav. Sci. 113, 279–297.
Webster, A.B., Fairchild, B.D., Cummings, T.S., Sayer, P.A., 2008. Validation of a three-point gait-scoring system for field assessment of walking ability of commercial broilers. J. Appl. Poultry Res. 17, 529–539.
Whay, H.R., 2007. The journey to animal welfare improvement. Anim. Welfare 16, 117–122 Sp. iss. S1.
Wills, J., Agarwal, S., Belongie, S., 2003. What went where. In: Proceedings of IEEE Conference on Computer Vision and Pattern Recognition (CVPR 2003). IEEE Computer Society, Wisconsin, pp. 37–44.