Computers and Electronics in Agriculture 72 (2010) 48–52

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Digital image analysis to estimate the live weight of broiler

Md. Bazlur R. Mollah[a,*], Md. A. Hasan[b], Md. A. Salam[c], Md. A. Ali[a]

[a] Department of Poultry Science, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[b] Bhaluka Farms Ltd., Kazi Farms Group, Sarkerpara, Tetulia, Panchagarh, Bangladesh
[c] Department of Aquaculture, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

ARTICLE INFO

Article history:
Received 12 August 2009
Received in revised form 16 January 2010
Accepted 11 February 2010

Keywords:
Broiler
Image analysis
Weighing system

ABSTRACT

Computer assisted digital image analysis was performed to investigate the possibility of estimating body weight of live broiler. To achieve the stated objective, 100 Arbor acres broiler chicks were reared under standard rearing condition and 1200 digital images were captured from 20 randomly selected broilers during the 7–42 days growing period. The captured images were analyzed by raster image analysis software (IDRISI 32) to determine the broiler body surface area and developed a linear equation to estimate weights of the broiler from its body surface-area pixels. The developed weight predicted equation based on surface-area pixels was $\log W = 1.060406(\log P) + 0.173756(\log A) - 2.029268$ (W = estimated body weight, P = surface-area pixels and A = age at weighing) and the degree of goodness of fit of this equation was 0.999. The relative error in weight estimation of broiler chicken by image analysis, expressed in terms of percent error of the residuals from surface-area pixels was in between 0.04 and 16.47. On the other hand, the estimated body weights were not significantly ($p > 0.05$) difference from manually measured body weights up to 35 days of age. Thus, the development of a practical imaging system for weighing live broiler is feasible.

1. Introduction

Body weight is one of the most important parameter that provides valuable information about growth, uniformity, feed conversion efficiency, occurrence of diseases in a flock and necessary to forecast some days in advance the average weight and spread of weights at slaughter (Lott et al., 1982; Turner et al., 1984; Flood et al., 1992). Weighing of birds allow farmers to know whether the birds are following expected growth curve and give an indication of the management quality. Therefore, an accurate estimate of average weight and the range of weight distribution of the flock throughout the growing period help in scheduling broiler pick-up and slaughter (Ross and Davis, 1990).

Conventionally, the average weight of a flock is estimated by manual weighing a random sample of birds or in the best-equipped poultry houses by automatic perch weighing. Traditional method of weighing generally involves the simple procedure of penning a group of birds, catching and weighing them singly or in groups. To obtain a true representation of the body weight of the flock, careful attention is necessary to the size and distribution of the sample of birds drawn for weighing. At least 5% birds need to weigh and these birds be taken equally from every pen in the house or from every block of cages. When large numbers of chicken weights are obtained, this conventional method is labor intensive, time consuming (Ali, 1993), stressful to birds (Newberry et al., 1985; Doyle and Leeson, 1989), subject to transcription errors and prone to human error (Feighner et al., 1986). Heavier and less mobile broilers caught more regularly, thus influencing the average body weight measured for the flock (Blokhuis et al., 1988).

In contrary, automatic perch weighing system is able to overcome many limitations of the conventional weighing system. Automatic perch weighing involves introduction of one or more platforms in the broiler house that are connected to a data analysis unit. Feighner et al. (1986) reported that implementing an automatic weighing system resulted in a substantial reduction of time necessary for data acquisition and analysis compared with manual weighing. However, automated perch weighing system still have problems that need to overcome. For example, the design of the platform is critical in that the platform must attract representative number of birds each day but not be so acceptable that birds having mounted on it and stay for longer period (Turner, 1981). The other difficulties with perch weighing system are obstructions with litter, damage during cleaning of the house and need for frequent recalibration.

Nowadays, the advancement of computer and digital imaging system offer an alternative way to estimate live animal weight indirectly from its dimensions by means of image analysis technique. Image analysis method was successfully used in estimation of body weight (Ali, 1993; Marchant and Schofield, 1993; Brandl

* Corresponding author at: Department of Poultry Science, Faculty of Animal Husbandry, Bangladesh Agricultural University, Mymensigh 2202, Bangladesh.
E-mail address: mbrmollah@yahoo.com (Md.B.R. Mollah).

0168-1699/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.compag.2010.02.002

and Jorgensen, 1996; Schofield et al., 1999; White et al., 2004) and carcass characteristics (Van der Stuyft et al., 1991; Doeschl-Wilson et al., 2004) of pigs, fishes (Lines et al., 2001), height and growth rate of plants (Hyder et al., 2003; Mizoue and Masutani, 2003) and carcass characteristics and composition of beef (Kmet et al., 2000; Nade et al., 2001). Therefore, an accurate means of weighing broilers on a regular basis, which does not cause stress to broilers or require large labor effort would be a great asset to large-scale broiler producers. Therefore, the present study was conducted to investigate the possibility of estimating body weight of broilers with computer assisted digital image analysis.

2. Materials and methods

2.1. Management of experimental birds

One hundred day old Arbor Acres broiler chicks were collected from a local hatchery and reared following the standard management method. In brief, the chicks were identified by metallic wing band, placed randomly in different pens and allowed them *ad libitum* access to a commercial diet and tap water. Growth and image data were collected up to 42 days of age.

2.2. Image and weight data collection

For image acquisition and weight data collection, a special pen was constructed to hold each bird in turn while photographs were taken. This had a floor area measuring 300 mm × 300 mm, so the bird had sufficient space to move and stand freely during image capturing. Sony Cyber-shot (Sony, Japan) digital camera was used to capture individual image of the broilers. The camera was placed centrally above the bird at height of 1.0 m above the floor. This distance was constant for the duration of the experiment, ensuring that the scale of all images to be the same. From 20 randomly selected birds, 10 images was recorded form each of the bird for image analysis at respective day of data collection. To make a clear outline of the birds, a dark background (floor) was used to have strong contrast between the chicken and the background. During the image capturing, sufficient light (200 lx) was provided to achieve a good balance between the outline having shadows.

2.3. Quality of image

Quality of the images is the most important determinant in successful measurement of the body surface area of the broilers. To minimize error attributed to image noise, the values of the image area for each bird was determined as the average area values of 10 replicated digital images. During the image acquisition stage, it was difficult to obtain constant and homogenously distributed illumination over the measuring area. Therefore, the camera was set in auto focusing state to reduce the illumination effects on the image. A typical image typical image of the broiler used for analyses is shown in Fig. 1.

2.4. Image analysis

IDRISI 32 for Windows software for raster image analysis was used to analyze the captured images to determine the number of pixels of body surface are of the broiler. An adaptive threshold was used to isolate the images from the background. Erosion and dilation techniques were applied to avoid discontinuities and isolated areas caused by artifact present in the background (light stains due to faces) and inside the images (shadows from the feathers and the head). The dilation and erosion functions add and erase pixels at the boundaries of the images and consequently remove unnecessary noise. The resulting images were shown on a computer screen with composite color for counting surface-area pixels which served as a variables for estimating the broiler body weight.

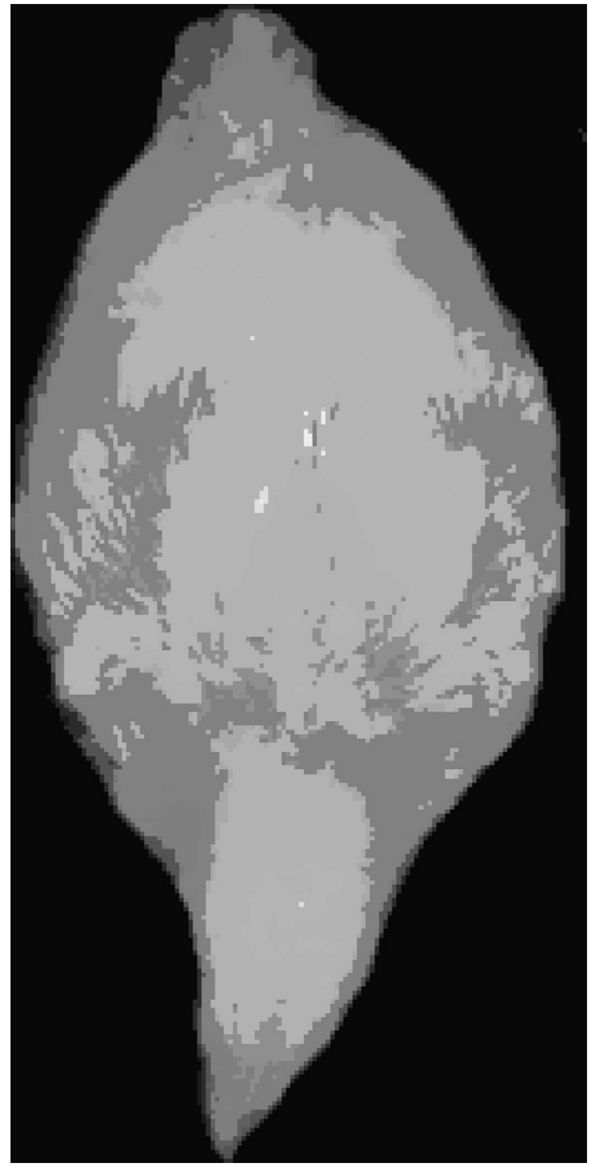

Fig. 1. A typical gray scale image of body surface area of a live broiler.

2.5. Statistical analyses

Calculated pixels data obtained from IDRISI 32 were used as a primary data source. Linear regression model implemented in R (R Development Core Team, 2009) was then applied to the average values of 10 replicated images to examine the relationship between the manual body weight and the number of surface-area pixels. To detect any systematic autocorrelation in the linear regression model, Durbin–Watson and Breusch–Godfrey test were simultaneously used. The results were further used to establish the linear regression equation in which the age was used as a covariate for the estimation of body weight from the number of surface-area pixels.

3. Results

The recorded body weights of the broilers at different stages of growth and their respective body surface area in pixels, measured with a time intervals of 7 days over the 42 days rearing periods are

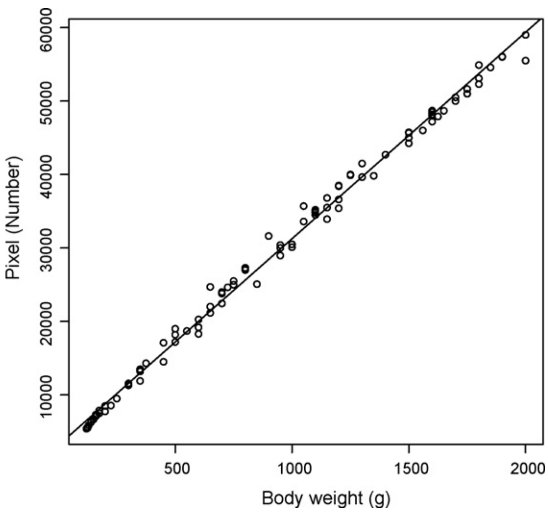

Fig. 2. Scatter plot of body weight and body surface-area pixels.

shown in Fig. 2. The pixel numbers were obtained from the IDRISI 32 software after analyzing 10 replicated images of individual broiler.

Since the relationship between the body dimension and body weight affects the accuracy of weight estimation in two-dimensional measurements, the correlation between the number of surface-area pixels and the body weight was determined. The value ($r = 0.998$) indicated a stronger positive relationship between the body weight and the surface area of the broiler which suggested that the collected raw data could be used to derive an equation to estimate live weight of broiler from the body surface-area pixels (Fig. 2).

Initially, the linear regression was fitted between the body weight and the body surface-area pixels. As the body weight and pixel data were collected on same broiler over a 42 days growing period, it was assumed that there might be systematic autocorrelation existed in the developed linear model. To address this issue, Durbin–Watson and Breusch–Godfrey test for serial correlations were used. In both the tests significantly lower p value ($p = 6.893 \times 10^{-11}$ for Durbin–Watson and $p = 3.664 \times 10^{-10}$ for Breusch–Godfrey test) indicated that there was systematic autocorrelation existed in the body weight and body surface pixels model. To solve the problem, the raw data were log transformed (Fig. 3) and the age of broiler was added as a covariate in the final linear model ($\log W = 1.060406(\log P) + 0.173756(\log A) - 2.029268$,

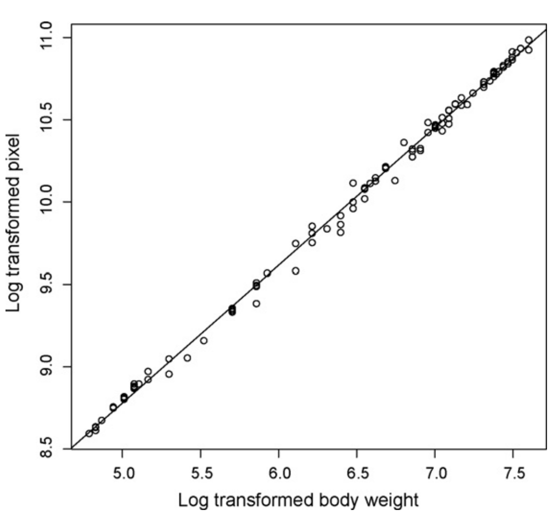

Fig. 3. Scatter plot of log transformed body weight and body surface-area pixels.

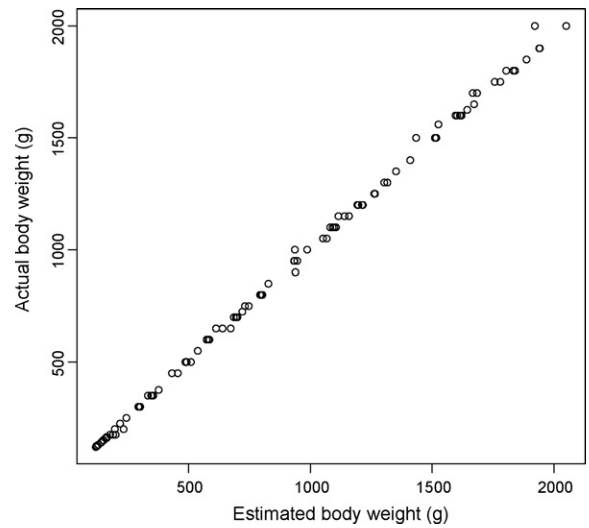

Fig. 4. Scatter plot of manual and estimated body weight of broiler.

W = estimated body weight, P = numbers of surface-area pixels and A = age at weighing). The overall value of determination coefficient (r^2) of the final linear equation was 0.999, indicated high degree of the goodness of fit of the developed equation. The estimated body weight and manually measured body weight were plotted in Fig. 4.

The accuracy of weight estimation equation was determined from the comparison between manually measured and estimated body weight. Comparative efficiencies are presented in Tables 1 and 2. The highest error was 16.47%, whereas the lowest was 0.04%. Although the differences between the manually measured body weight and the estimated body weight were barely ($p = 0.044$) significant at 42 days, the weight differences at other ages were not significantly different ($p > 0.05$) (Table 3).

4. Discussion

The objective of this study was to explore the possibility of digital image analysis to estimate live broiler weight at different stages of its growth. The estimated error of the weighing method by image analysis in the current study was ranged from 0.04% to 16.47%, which is comparable with Schofield (1990) result who obtained 5% estimated error with pigs. There was substantial variation in accuracy with the recorded dimensions of the broiler in this study. However, these variations were inconsistent between broilers and no pattern was observed. The problem was partly overcome by working with the average values of replicated images.

Movement of birds is a complex mixture of response to various sources of internal and external stimulation. These physical actions result in regular changes of posture and orientation that consequently influences variation in body dimension measurement, specially the frequent shift of the head's position. A possible solution for the variation is to apply a point distribution model of an animal as described by Cootes et al. (1995) and Tillet et al. (1997), a model based on the physical properties of the animal, which can then be fitted into two-dimensional information for object recognition.

Very active chickens sometime produced poor results and varying images due to dust bathing and stretching out their wings. Sergeant et al. (1998) presented a technique for identifying individual birds by solving a correspondence problem between the frames. Another method is to exclude surface areas that are not within a confidence interval that represent the limits of the area for one bird (Chedad et al., 2003). The image dimensions vary also with different positions of the chickens under the Camera. However, the set up

Table 1
Comparison between the manual and the estimated body weights at 7, 14 and 21 days of age (individual basis).

Bird ID	7 days				14 days				21 days			
	Manual weight (g)	Estimated weight (g)	Difference (g)	Error (%)	Manual weight (g)	Estimated weight (g)	Difference (g)	Error (%)	Manual weight (g)	Estimated weight (g)	Difference (g)	Error (%)
2	150	150.85	−0.85	0.56	500	509.44	−9.44	1.89	900	938.29	−38.29	4.25
6	160	161.40	−1.40	0.88	650	672.86	−22.86	3.52	1050	1066.97	−16.97	1.62
9	150	149.54	0.46	0.30	450	455.59	−5.59	1.24	800	799.69	0.31	0.04
12	125	124.23	0.77	0.62	225	218.45	6.55	2.91	650	639.09	10.91	1.68
14	150	148.36	1.64	1.09	300	296.38	3.62	1.21	700	694.10	5.90	0.84
22	160	159.03	0.97	0.61	500	486.73	13.27	2.65	800	793.45	6.55	0.82
28	150	150.13	−0.13	0.09	300	299.14	0.86	0.29	750	746.79	3.21	0.43
31	150	150.73	−0.73	0.48	375	376.90	−1.90	0.51	800	802.80	−2.80	0.35
35	125	123.64	1.36	1.08	175	200.21	−25.21	14.41	200	232.95	−32.95	16.47
43	140	140.09	−0.09	0.07	350	349.01	0.99	0.28	550	537.48	12.52	2.28
46	160	163.78	−3.78	2.36	300	296.10	3.90	1.30	800	795.01	4.99	0.62
49	130	129.51	0.49	0.38	350	346.23	3.77	1.08	725	720.42	4.58	0.63
50	160	159.03	0.97	0.61	250	244.28	5.72	2.29	600	585.21	14.79	2.47
54	150	150.13	−0.13	0.09	300	293.62	6.38	2.13	800	802.34	−2.34	0.29
57	160	160.21	−0.21	0.13	350	349.01	0.99	0.28	700	700.29	−0.29	0.04
62	165	163.78	1.22	0.74	300	300.98	−0.98	0.33	750	731.27	18.73	2.50
65	140	141.27	−1.27	0.91	350	354.58	−4.58	1.31	650	612.68	37.32	5.74
68	120	118.97	1.03	0.86	200	196.84	3.16	1.58	500	491.88	8.12	1.62
86	125	121.30	3.70	2.96	175	190.12	−15.12	8.64	350	332.82	17.18	4.91
98	175	177.49	−2.49	1.42	300	299.14	0.86	0.29	700	697.20	2.80	0.40

Table 2
Comparison between the manual and the estimated body weights at 28, 35 and 42 days of age (individual basis).

Bird ID	28 days				35 days				42 days			
	Manual weight (g)	Estimated weight (g)	Difference (g)	Error (%)	Manual weight (g)	Estimated weight (g)	Difference (g)	Error (%)	Manual weight (g)	Estimated weight (g)	Difference (g)	Error (%)
2	1250	1265.43	−15.43	1.23	1600	1613.66	−13.66	0.85	1850	1887.64	−37.64	2.03
6	1500	1434.08	65.92	4.39	1700	1666.63	33.37	1.96	2000	2050.32	−50.32	2.52
9	1100	1105.01	−5.01	0.46	1300	1303.25	−3.25	0.25	1500	1511.25	−11.25	0.75
12	1150	1158.34	−8.34	0.73	1500	1516.81	−16.81	1.12	1800	1833.58	−33.58	1.87
14	1200	1211.82	−11.82	0.98	1600	1603.08	−3.08	0.19	1850	1887.64	−37.64	2.03
22	1100	1098.35	1.65	0.15	1600	1596.03	3.97	0.25	1900	1939.95	−39.95	2.10
28	1250	1262.07	−12.07	0.97	1600	1620.72	−20.72	1.30	1750	1756.78	−6.78	0.39
31	1000	936.02	63.98	6.40	1500	1516.81	−16.81	1.12	1650	1671.97	−21.97	1.33
35	450	431.44	18.56	4.12	600	574.05	25.95	4.32	850	827.49	22.51	2.65
43	950	945.91	4.09	0.43	1400	1409.80	−9.80	0.70	1600	1618.30	−18.30	1.14
46	1200	1211.82	−11.82	0.98	1700	1684.31	15.69	0.92	1900	1941.78	−41.78	2.20
49	1200	1215.17	−15.17	1.26	1500	1513.29	−13.29	0.89	1650	1671.97	−21.97	1.33
50	950	932.72	17.28	1.82	1500	1515.05	−15.05	1.00	1625	1643.76	−18.76	1.15
54	1300	1315.80	−15.80	1.22	1800	1840.33	−40.33	2.24	2000	1921.58	78.42	3.92
57	1100	1081.72	18.28	1.66	1500	1515.93	−15.93	1.06	1750	1779.62	−29.62	1.69
62	1050	1051.82	−1.82	0.17	1200	1197.20	2.80	0.23	1350	1351.50	−1.50	0.11
65	1100	1091.70	8.30	0.75	1500	1516.46	−16.46	1.10	1650	1671.97	−21.97	1.33
68	700	685.87	14.13	2.02	950	934.50	15.50	1.63	1150	1140.18	9.82	0.85
86	600	581.06	18.94	3.16	1000	986.74	13.26	1.33	1200	1192.81	7.19	0.60
98	1150	1115.00	35.00	3.04	1560	1525.60	34.40	2.21	1800	1804.30	−4.30	0.24

can reduce the distortion effect caused by different angles between the camera and the chicken. In the present experiment, no such precautions were taken.

Estimating live weight from a body area measurement with high variance will reduce the precision of the prediction. Increasing the number of pictures for each chicken could lower the variance of the measurement. In order to obtain a representative sample of images for this study, birds were allowed to move freely within a special pen constructed for image acquisition and the camera was placed above the broilers strategically to make sure that representative images were obtained.

Furthermore, the degree of variation depends on the extent of feathering, lighting and the threshold values of the image. The chicken feather color may create problems, especially birds with different color and feathering pattern and open body patches. In this study, the chicken body surface area was distinguished by making contrast between background and images. Nowadays, the broiler chickens are reared in a very densely populated low lighting condition. Therefore, it is difficult to achieve a clear contrast between the bird and its background in standard rearing conditions. In recent year, night vision camera systems are readily available and able to capture images in a virtually dark condition. Therefore, night shoot camera could be used to solve this issue.

On the other hand, bird undergo for body weight and its position changes throughout the day, thus the time of weighing and image acquisition is important to minimize variation for accurate body

Table 3
Differences between the manual and the estimated body weights (weekly basis).

Age (days)	Manual weight	Estimated weight	Difference	p-Value[a]
7	147.250	147.175	0.076	0.836
14	335.000	336.779	−1.779	0.426
21	688.750	686.037	2.713	0.482
28	1065.000	1056.559	8.441	0.135
35	1430.500	1432.513	−2.013	0.654
42	1641.250	1655.221	−13.971	0.044

[a] Paired t-test was performed to know whether there was any statistically significant difference between the manual and the estimated body weights.

weight estimation. According to Lokhorst (1996) mean body weight shows a diurnal pattern. At the beginning of the night birds are heaviest. At the end of the night and the morning they defecated ate and drank. Therefore, the weight recorded during the morning and at night there will be a tendency to underestimate mean body weight compared with that during daytime weighing. Turner et al. (1983) suggested providing a period of subdued lighting of 2 h before feeding during which the weighing system would operate. Fast growing broilers are significantly heavier in the evening than in the morning (Reuvenkamp, 1991). Obviously, it is essential to record the time of day when the bird is weighed, monitored and corrected to a standard time. The diurnal pattern is most unlikely to be true in case of broiler chickens where 24 h lighting and *ad libitum* access to feed is the normal practice. Due to 24 h light pattern, the influence of diurnal fluctuation on body weight was ignored in the present study.

Using digital imaging equipment for weighing broilers provides a number of benefits, including activity measurement and general surveillance. The most important advantage is that image analysis is a remote sensing device and inspection does not cause any additional stress. A brief image acquisition time is needed to take measurements from a significant sample, that is, at least 5% of the flock (Anonymous, 1992).

Nowadays, digital camera systems and image analysis techniques are well established, robust, relatively cheap and can form the basis of a real-time observation system. There is a clearly considerable potential benefit with the image based weighing of live broiler and larger field trial with different strains is well justified.

Since the precision of live weight estimation depends on many factors, such as breed, age, type of image analysis techniques and the variation with repeated measurements, no single model is perfect to use as predictor of body weight from the image data. Therefore, further study on this area is required in order to develop a prototype for weighing live broiler, explain limit variation among birds and calibration of the body surface area/weight relationship.

5. Conclusion

The objective of this study was to explore the possibility of digital image analysis to predict live broiler weight at different stages of its growth. Although the precision of live weight estimation depends on many factors, however, the presented data indicated that the development of a practical imaging system for weighing broiler is feasible. Further work is required on control of image quality by, for example, careful position of the camera and lighting and development of image analysis software to locate and measure the relevant areas of the broilers.

References

Ali, N.M., 1993. Variance in pigs dimensions as measured by image analysis. In: Livestock Environment, Fourth International Symposium, University of Warwick, Conventry, England, pp. 151–158.

Anonymous, 1992. Live bird weighing simplified. Poultry International 6, 44–50.

Blokhuis, H.J., Vranken, J.W., Aerts, J.M., Berckmans, D., 1988. Do weighing figures represent the flock average? Poultry International 4, 17–19.

Brandl, N., Jorgensen, E., 1996. Determination of live weight of pigs from dimensions measured using image analysis. Computer and Electronics in Agriculture 15, 57–72.

Chedad, A., Aerts, J.M., Vranken, E., Lippens, M., Zoons, J., Berckmans, D., 2003. Do heavy broiler chickens visit automatic weighing systems less than lighter birds? British Poultry Science 44, 663–668.

Cootes, T.F., Cooper, D.H., Taylor, C.J., Graham, J., 1995. Active shape models—their training and application. Computer Vision and Image Understanding 61, 38–59.

Doeschl-Wilson, A.B., Whittemore, C.T., Knap, P.W., Schofield, C.P., 2004. Using visual image analysis to describe pig growth in terms of size and shape. Animal Science 79, 415–427.

Doyle, I., Leeson, S., 1989. Automatic weighing of poultry reared on a litter floor. Canadian Journal of Animal Science 69, 1075–1081.

Feighner, S.D., Godowsky, E.F., Miller, B.M., 1986. Portable microcomputer based weighing systems: applications in poultry science. Poultry Science 65, 868–873.

Flood, C.A., Koon, J.L., Trumbull, R.D., Brewer, R.N., 1992. Broiler growth data: 1986–1991. Transactions of the ASAE 35, 703–709.

Hyder, P.W., Fredrickson, E.L., Remmenga, M.D., Estell, R.E., Pieper, R.D., Anderson, D.M., 2003. A digital photographic technique for assessing forage utilization. Journal of Range Management 56, 140–145.

Kmet, J.T., Sakowski, J., Huba, D., Peskovicova, J.C., Polak, P., 2000. Application of video image analysis in the slaughter value estimation of live Simmental bulls. Archiv fur Tierzucht 43, 411–416.

Lines, J.A., Tillet, R.D., Ross, L.G., Chan, D., Hockaday, S., McFarlane, N.J.B., 2001. An automatic image based system for estimating the mass of free-swimming fish. Computer and Electronics in Agriculture 31, 151–164.

Lokhorst, C., 1996. Automatic weighing of individual laying hens in aviary housing systems. British Poultry Science 37, 485–499.

Lott, B.D., Reece, F.N., McNaughton, J.L., 1982. An automated weighing system for use in poultry research. Poultry Science 61, 236–238.

Marchant, J.A., Schofield, C.P., 1993. Extending the image process algorithm for outline pigs in scenes. Computer and Electronics in Agriculture 8, 261–275.

Mizoue, N., Masutani, T., 2003. Image analysis measure of crown condition, foliage biomass and stem growth relationships of *Chamaecypais obtusa*. Forest Ecology and Management 172, 79–88.

Nade, T., Karnuah, A.B., Matsuda, Y., Hirabara, S., Fujita, K., 2001. Estimation of carcass composition from the cross section at ribloin of Japanese Black steers by computer image analysis. Animal Science Journal 72, 313–320.

Newberry, R.C., Hunt, J.R., Gardiner, E.E., 1985. Behaviour of roaster chickens towards an automatic weighing perch. British Poultry Science 26, 229–237.

R Development Core Team, 2009. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0, http://www.R-project.org.

Reuvenkamp, B., 1991. Goede ervaringen met hennen wegen in etagestallen. Pluimveehouderij 21, 18–19.

Ross, C.C., Davis, N., 1990. Sensors in poultry housing. Poultry International 2, 26–30.

Schofield, C.P., 1990. Evaluation of image analysis as a means of estimating the weight of pigs. Journal of Agricultural Engineering Research 47, 287–296.

Schofield, C.P., Marchant, J.A., White, R.P., Brandl, N., Wilson, M., 1999. Monitoring pig growth using a prototype imaging system. Journal of Agricultural Engineering Research 72, 205–210.

Sergeant, D.M., Boyle, R.D., Forbes, J.M., 1998. Computer visual tracking of poultry. Computer and Electronics in Agriculture 17, 249–261.

Tillet, R.D., Onyango, C.M., Marchant, J.A., 1997. Using model-based image processing to track animal movement. Computer and Electronics in Agriculture 17, 249–261.

Turner, M.J.B., 1981. Performance monitoring of animals using on-line computer in animal production. Occasional Publication of British Society of Animal Production 5, 41–46.

Turner, M.J.B., Gurney, P., Belyavin, C.G., 1983. Automatic weighing of layer-replacement pullets housed on litter or in cages. British Poultry Science 24, 33–45.

Turner, M.J.B., Gurney, P., Crowther, J.S.W., Sharp, J.R., 1984. An automatic weighing system for poultry. Journal of Agricultural Engineering Research 29, 17–24.

Van der Stuyft, E., Schofield, C.P., Randall, J.M., Wambacq, P., Goedseels, V., 1991. Development and application of computer vision for use in livestock production. Computer and Electronics in Agriculture 6, 243–265.

White, R.P., Schofield, C.P., Green, D.M., Parsons, D.J., Whittemore, C.T., 2004. The effectiveness of a visual image analysis (VIA) system for monitoring the performance of growing/finishing pigs. Animal Science 78, 409–418.