Cow Body Shape and Automation of Condition Scoring

I. Halachmi,^{*1} P. Polak,[†] D. J. Roberts,[‡] and M. Klopčič[§]

^{*}Institute of Agricultural Engineering, Agricultural Research Organization, Volcani Center, Bet Dagan 50250, Israel

[†]Research Institute for Animal Production, Slovak Agricultural Research Center, 949 92 Nitra, Slovakia

[‡]Scottish Agricultural College Dairy Research Centre, Crichton Royal Farm, Dumfries DG1 4SZ, UK

[§]Department of Animal Science, Biotechnical Faculty, University of Ljubljana, 1230 Domžale, Slovenia

ABSTRACT

The feasibility of including a body shape measure in methods for automatic monitoring of body reserves of cattle was evaluated. The hypothesis tested was that the body shape of a fatter cow is rounder than that of a thin cow and, therefore, may better fit a parabolic shape. An image-processing model was designed that calculates a parameter to assess body shape. The model was implemented, and its outputs were validated against ultrasonic and thermal camera measurements of the thickness of fat and muscle layers, and manual body condition scoring of 186 Holstein-Friesian cows. The thermal camera overcomes some of the drawbacks of a regular camera; the hooks and the tailhead nadirs of a thin cow diverged from the parabolic shape. The correlation between thermal camera's measurements and fat and muscle thickness was 0.47. Mean body condition scorings were 2.18, 2.15, and 2.23, with no significant difference found across the assessment methods. Further research is needed to achieve fully automatic, accurate body condition scoring.

Key words: body condition scoring, thermal camera, dairy cow, image processing

INTRODUCTION

Body condition scoring is a technique to estimate energy reserves of cattle by estimating their fatness or thinness according to a 5-point scale (Edmondson et al., 1989). Body condition scoring is used as a feeding management tool. In high-yielding dairy cows, the peak of daily feed intake usually occurs after the peak of milk output. This asynchrony leads to a period early in lactation when cows cannot meet their energy requirements from ingested feed and mobilize body energy reserves to meet the deficit. This state is commonly known as negative energy balance and is associated with a range of negative health traits (Gillund et al., 2001) and poor

fertility (Dechow et al., 2002). Body condition influences productivity, reproduction, health, and longevity (Heinrichs and Ishler, 1989). However, the current method of measuring BCS is manual and subjective: the scores depend on the person who performs the measurements, and sometimes a given person might give different scores to the same cow, depending on the previous cows seen (Schröder and Staufienbiel, 2006). Manual estimation of BCS is time-consuming in large farms and requires trained labor. Therefore, the development of a device for automatic, objective monitoring of BCS is of economic interest.

Several attempts to automate BCS of dairy cows were reported in the literature. Coffey et al. (2003) captured digital images of the rear aspect of cows and extracted curves manually by using image editing software and a mouse to isolate the lines. Ferguson et al. (2006) recorded multiple images from the rear of the cow at an angle of 0 to 20° relative to the tail head, and 3 nutritional advisors independently assessed BCS from the images. Bewley et al. (2007) used a digital camera placed above a stationary weighing station and identified 23 points corresponding to identifiable anatomical features for potential influences on BCS. These points were used to calculate 15 angles around the hooks, pins, and tailhead. Keren and Olson (2007) used thermal imaging in assessing energy requirements for cattle on pasture. Sharony (2003) patented the application of a digital camera for BCS; it was not a thermal camera and they used a different algorithm, and Kriesel and McQuilkin (2005) patented the application of another nonthermal digital camera for measuring livestock dimensions, but not for BCS determination.

With regard to nonphotographic measurements, Mizrach et al. (1999) measured subdermal fat thickness in dairy cows by digitizing cross-sections of ultrasonic scans. Of 2 sites selected for measurement, one was on the flat area of the rear of the rump between the pin bone and the tailhead, and the other was between the 12th and 13th ribs, below the rump. Williams (2002) described ultrasound applications as a noninvasive method for estimating fat and muscle accretion and body composition in live cattle. Polák (2006) used ul-

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¹Corresponding author: halachmi@volcani.agri.gov.il

Figure 1. A cow contour from bird's eye view; 23 key anatomical points (Bewley et al., 2007) and the location of the ultrasound probe (Mizrach et al., 1999). One = left (l) forerib; 2 = l short rib; 3 = l hook start; 4 = l hook anterior midpoint; 5 = l hook; 6 = l hook posterior midpoint; 7 = l hook end; 8 = l thurl; 9 = l pin; 10 = l tailhead nadir; 11 = l tailhead junction; 12 = tail; 13 = right (r) tailhead junction; 14 = r tailhead nadir; 15 = r pin; 16 = r thurl; 17 = r hook end; 18 = r hook posterior midpoint; 19 = r hook; 20 = r hook anterior midpoint; 21 = r hook start; 22 = r short rib start; 23 = r forerib.

trasound measurements at 5 positions for determining subcutaneous fat and muscle thickness.

None of the above studies effectively addressed the automation of BCS determination. Therefore the aim of the present study was to advance the development of an apparatus and methods for automatic and objective monitoring of body reserves. The hypothesis tested was that the body shape of a fatter cow is more likely to be round than that of a skinny cow; therefore, a parabolic shape may fit better. The hooks and the tailhead nadirs of a skinny cow diverge from the rounded shape defined by the parabola.

MATERIALS AND METHODS

Data

Data for this study were collected at the Scottish Agricultural College, Crichton Royal Farm in Dumfries, Scotland, UK, in September 2007. The study involved 186 cows.

Statistical Terms and Methods

The abbreviations **STD**, **SE**, and **MAE** stand for standard deviation, standard error, and mean absolute

error statistics. The deviation of the cow contour from the fitted parabola was expressed in MAE. Matlab (2005) software was used to calculate the cow contour, MAE, and the STD. Each cow was sampled during 3 successive days at the same time—0500 to 0700 h at the milking parlor exit, after the morning milking. The values averaged over 3 d were used for cross correlation with image data and presented in Figures 4 to 6. The validation test was performed by comparing the results with human observations and ultrasound measurements. The SPSS software was used to calculate nonparametric Spearman's rho correlation coefficient and ANOVA. "Reference numbers" stands for the human observations (i.e., manual BCS measured by 2 BCS technicians, and ultrasound BCS measured by using ultrasound).

Anatomic Terms

The anatomic terms used in this study are as follows: Hooks are the point of the hip; the most lateral point of the ilium also known as the tuber coxae or coxal tuber. The tailhead is the dorsal aspect of the root of the tail. The pins are the caudal point on the floor of the pubis, also known as the tuber ischium, or pin bone. The Latin names are described by Schröder and Staufenbiel

Figure 2. A thin cow (left, cow number 1358) and a fat cow (right, cow number 1640). Upper pictures are the model inputs: thermal images taken from overhead. Lower pictures are the model outputs: cow contour vs. fitted parabola. The fat cow (1640): manual BCS = 3.0, ultrasound-measured fat plus muscle thickness = 74 mm (3.52 in BCS units). Model thermal BCS = 3.50. The thin cow (1358): manual BCS = 1.25, ultrasound-measured fat plus muscle thickness = 40 mm (1.44 in BCS units). Model thermal BCS = 1.3.

(2006): anterior coccygeal vertebrae (tailhead), tuber sacrale (hook bones), and tuber ischia (pin bones); see Figure 1.

Ultrasound

The reference numbers for determining body reserves were the thicknesses of the muscle and fat layers, and the manually assessed BCS. The thicknesses were measured ultrasonically with a Sonovet 2000 instrument (Medison, Korea), fitted with a 96-element PB-MYL 2–5/1 170-mm linear probe, operating at 2 to 5 MHz. The sonogram of the longissimus dorsi muscle (LDM) was obtained between the 12th and the 13th vertebrae. The thickness of the fat was taken as the distance between the dorsal fascia of the LDM and the ventral skin layer. The thicknesses of the fat and muscle layers (in millimeters, the so-called Tot_mm) were related to the 1 to 5 BCS scale by:

$$\text{Ultrasound scoring} = 5 \times [\log(\text{Tot_mm}) - 3.6] \quad [1]$$

in which Tot_mm was the thickness of the fat and muscle layers (in millimeters, not pixels), and the numbers 5 and 3.6 normalized the ultrasound units into the 1 to 5 BCS scale. Use of the log function compressed

the wide variation found in our ultrasound measurements.

The location between the 12th and the 13th vertebrae was selected because this point provides both easy recognition and the presence of subcutaneous fat and muscles. We assume that subcutaneous fat and proteins from muscles are mobilized to support milk production, especially in lactation peak. Therefore, changes in the volumes of subcutaneous fat and muscles, as indicated by the measured thickness between the bone and the skin at this point, may be correlated with changes in the BCS.

The location of the probe is on the back near the spinal column on the assumed line between 12th and 13th ribs. The probe and the spinal column created an acute angle. The background of the muscle edges in the sonogram is the vertebra, the LDM, and the intercostal muscle. Muscle thickness is the distance between body of the 13th vertebra—represented by a specific V-shape in the sonogram—and the dorsal surface of the LDM, measured perpendicularly from the top of the sonogram.

Manual Body Condition Scoring

The manual BCS was assigned according to a 5-point scale by 2 different technicians (Edmondson et al.,

Figure 3. An algorithm for automatic evaluation of thermal body condition score (TBCS). The algorithm incorporated the following tasks: (a) extracting cow frames from the video with the MoviePlus4 software (Serif, 2007); this was the only task that was performed manually (broken line arrow—). (b) Cropping the place where the cow was expected to be found, with the `imcrop` function (Matlab, 2005). (c) The black cursors, temperature numbers, etc., were erased by using the `roifill` function (Matlab, 2005), (d) the `Imcontour` function (Matlab, 2005) found the unique cow individual boundary, and (e) the `polyfit` function (Matlab, 2005) fitted a parabola to that boundary. MAE stands for mean absolute error between the cow contour and its fitted parabola. If the cow is thin, the cow contour has protrusions that result in a high MAE. A fat cow is characterized by round-smooth contour, and then the MAE is lower.

1989). The BCS assessment and the ultrasound and thermal camera measurements were performed in the same week.

Thermal Camera and Image Processing

A model InfraCAM SD thermal camera (FLIR Systems Inc., Wilsonville, OR) equipped with a focal plane array detector with resolution of 120×120 pixels and a spectral range of 7.5 to $13 \mu\text{m}$ was attached to the barn ceiling, above the weighing scale at the exit of the milking parlor. The cows were identified electronically by means of the radio frequency identification technique. The antenna was built into the weighing scale.

The video imagery from the camera was divided into frames by using Movie Plus 4 software (Serif, 2007). The frames were manually examined to select the best frame from each cow. Identified frames—those that were associated with a cow number and that matched the timing of the cow on the scale—were fed into Matlab (2005) software for image processing analysis. Each frame contained 787×576 pixels, from which a 1.3-MB bitmap graphic file was generated. Figure 2 presents the raw thermal images of 2 typical cows, one fat and one thin. The images were read with the `Imread` function then converted to a gray scale by using the `Rgb2gray` function. The black cursors that indicate the points of temperature measurement were erased by using the `Roifill` function. The place where the cow was expected to be found was cropped from the original picture to a specified rectangle by means of the `Imcrop` function. The `Imcontour` function was used to define each unique cow's boundary, and the `Polyfit` function was used to fit a parabola to the boundary of each individual cow. The visual difference between fat and thin cows is presented in Figure 2: it can be seen that for a fat cow, only the tailhead diverges from the rounded shape of the fitted parabola, whereas there are many deviations from this shape with a thin cow. The "distance from a parabola" was converted to the 1 to 5 BCS scale by

$$\text{TBCS} = 5 \times 9 \times (1/\text{MAE}) \quad [2]$$

in which MAE stands for mean absolute error; TBCS stands for thermal BCS; 9 is the best fit reached in our herd (i.e., only the tailhead diverged from the parabolic shape); and 5 is the normalization factor from model output to 1 to 5 on the BCS scale. The deviation of the cow contour from the fitted parabola was expressed in MAE units. Thus, the hypothesis tested in this study is as follows: If a cow is fatter, her body shape is more likely to be round and the parabola might fit the cow's shape better; therefore, the MAE would be smaller.

Figure 4. The link between the thermal camera scoring and the manual BCS.

Figure 5. The link between the thermal camera BCS and the scoring as measured ultrasonically.

Conversely, if a cow is thin, her body shape is less round, and therefore, the MAE is larger.

The entire image process flowchart is presented in Figure 3: it can be seen that the process is automatically executed apart from 1 manual phase—the selection of the best frame for each cow, which requires further programming.

Treating Artifacts

Only 9 cows were removed from the database because of wrong positioning of the cow below the camera: hooks out of sight or the cow not aligned as required. Five cows were removed from the ultrasound database because of a large deviation between their measurements made on the first day and those made on other days. Such deviation could be attributed to wrong cow identification or incorrect location of the ultrasound probe on the animal. The total number of cows removed from the database for these reasons was 14 ($n = 186 - 14 = 172$).

RESULTS

This chapter compares between the thickness of the body reserve as measured by (1) the manual BCS, (2) the ultrasound (US), and (3) the thermal camera (TBCS). The chapter is divided into 2 sections: (a) validation by visual analysis and (b) statistical validation.

Visual Analysis

Figure 4 shows the correlation between the TBCS and the manual BCS: the regression line slope should tend to 45° and the intersect should approach 1, 1. Because the TBCS is a continuous scale but manual BCS

Figure 6. The link between the body condition scoring as measured ultrasonically and the manual BCS.

Table 1. Statistical validation—descriptive and ANOVA comparisons of thermal, ultrasound, and manual BCS

Item	Manual BCS	Ultrasonic BCS	Thermal BCS	Item	Sum of squares	df	Mean square	<i>F</i> (2,454)	<i>P</i> -value
Mean	2.18	2.15	2.23	Between groups	0.505	2	0.253		
SE	0.03	0.05	0.05	Within groups	140.450	454	0.310	0.815	0.443
n	172	172	172	Total	140.955	456			

is categorical, distribution at each BCS for the TBCS can be seen in Figure 4.

Figure 5 shows the correlation between the TBCS and the US. The regression line slope should tend to 45°, and the intersect should approach 1. Figure 6 shows the correlation between the US and the manual BCS results. Boxplots (Figure 7) provide a visual summary of the 3 BCS methods.

Statistics

The significance value of the *F*-test in the ANOVA table is 0.443; thus, no significant difference found across the BCS assessment methods (Table 1). The difference between group means was not significant (Table 2). However, the means of each BCS level (Table 3) suggest that the US was less accurate in the range 2.00 to 2.25 BCS and the thermal BCS was less accurate in 1.75 and 2.50 BCS cows.

The correlation coefficient between the manual and the thermal scoring was 0.315 (Table 4). The highest correlation (0.471) was found between the thermal and the ultrasound results. The manual BCS had a constant shift of 0.25 score, technician 2 was higher. The correlation between the 2 technicians was 0.78.

DISCUSSION

Coffey et al. (2003) found that the correlation between tail head curvature and condition score was 0.55, and that between pin bone and BCS was 0.59. In the present case the correlation between the manual BCS and the TBCS was 0.315, and that between the TBCS and the ultrasound measurements was 0.471. The difference between the findings of Coffey et al. (2003) and the present results can be attributed to the respective numbers of cows ejected from the databases.

In the present study only 9 cows, which had hooks or tailheads outside the field of view of the camera lens, were removed from the database. In contrast, Coffey et al. (2003) reported that out of 190 cows, only 36 yielded images suitable for data extraction; these authors advocated development of the body shape parameter. Perhaps if more cows had been filtered out of the present database our present correlation might have been higher. The correlation between the 2 observers was 0.78, which is in agreement with the findings of Ferguson et al. (2006), whose correlation coefficients between observer 1, on one hand, and observers 2, 3, and 4, on the other hand, were 0.78, 0.76, and 0.79, respectively.

The thermal camera's zoom should capture most of the cow back. Those cows where the hooks were outside the visible area were most likely to be expelled from the model. This result is in agreement with Bewley et al. (2007), who also found the hooks were the easiest to identify and that the angles around the hooks and tailhead had the highest correlations with BCS. Edmondson et al. (1989) found that the correlations between BCS and hook posterior angle, between BCS and hook angle, and between BCS and tailhead were 0.52, 0.48, and 0.31, respectively. Lowman et al. (1976) obtained lower but still significant correlations between BCS and all 3 body traits: 0.46 between BCS and hook posterior angle, 0.33 between BCS and hook angle, and 0.19 between BCS and tailhead. Higher camera mounting or a wider-angle lens might improve our results, and a 3-D picture, obtained by means of an additional camera, could further improve the accuracy of the device. The main advantage of using a thermal camera rather than a regular digital camera lies in the ease of recognition of cow patterns; in our case almost all the cow images were suitable for analysis.

The MAE contains measuring errors, but the errors are related with the choice of the parabola. The char-

Table 2. Statistical validation—multiple comparisons (Games-Howell)¹

I category	J category	Mean difference I – J	SE	<i>P</i> -value
Manual	Ultrasound	0.03	0.06	0.851
Manual	Thermal	–0.05	0.06	0.691
Ultrasound	Thermal	–0.08	0.07	0.501

¹BCS measured by manual, ultrasonic, and thermal methods.

Figure 7. Boxplot comparison of thermal, ultrasound (US), and manual body condition scorings. The heavy black line inside each box marks the 50th percentile, or median, of that distribution. The lower and upper box boundaries mark the 25th and 75th percentiles of each distribution, respectively. The whiskers are vertical lines ending in horizontal lines at the largest and smallest observed values that are not statistical outliers. Outliers are identified with an O. Extreme values are marked with an asterisk (*).

acteristics of the parabola are not used in this study. In further research, taking into the equations the characteristics of the parabola in each individual cow may increase the accuracy of the method. In further research, the thermal camera output, together with its body shape parameters should be studied during the entire course of the cows' lactation to compare between different physiological states such as advanced pregnancy, developing of negative energy balance, etc.

The existence of precision in the ultrasound measurement of the thicknesses of fat and muscle is an assumption and not a fact. However, in the process of developing a measuring device, the accuracy must be validated against a reference number. The manual BCS is commonly used but has measurement errors, is subjective, and uses a scale of discrete points (e.g., 1.5,

1.75, 2, 2.5, etc.). Our study aimed to use a continuous scale, but the attempt to correlate continuous-scale findings (i.e., the output of the new device) with those of a discrete-points system (i.e., our reference number) obtained by manual BCS is categorical and leads to statistically inferior results. Grouping the continuous results into discrete clusters might improve the statistics but would impair an important feature of the new device (i.e., the continuous scale). Ultrasonic measurement has a continuous scale, and our initial thought was that it is objective. However, during the study it emerged that an ultrasound operator might influence the results: (1) by not returning to exactly the same measurement location on every cow, and (2) through his interpretation of the ultrasound picture. In further research, the adoption of an objective method is crucial to obtaining higher statistical correlation. Both drawbacks, the discrete-points scale and the subjectivity can be overcome by examination of a large number of cows by several technicians working in parallel.

In further research, TBCS should be validated against carcass composition at a slaughter house rather than BCS. The biology behind the use of thermal methods (the thermal isolation of fat layers) should be understood.

If the new device is to be inexpensive and mobile, it should be possible, after its parameters have been calibrated, to apply it also to beef cattle: on pasture, to support a decision on when to move a group from one grazing field to another; and in feedlots, to help determine the optimal marketing time. The utility of a low-cost, automatic, and accurate BCS in dairy herd management is not in question. However, for genetic purposes, Pryce et al. (2006) stated that there would be little benefit in including BCS as an independent trait in the breeding worth dairy index. In New Zealand BCS is already included as a predictor in the genetic evaluation of fertility; breeding values for BCS will be estimated routinely from the fertility model.

Table 3. Statistical validation—ANOVA comparison of thermal, ultrasound, and manual body condition scorings—with manual BCS levels expressed as classes

		Ultrasonic BCS			
Item	n	Mean	SE	Minimum	Maximum
Manual BCS (classes)					
1.75	28	1.74	0.11	0.62	2.61
2.00	35	2.24	0.11	0.83	3.25
2.25	77	2.04	0.06	0.76	3.35
2.50	32	2.60	0.10	1.41	4.09
Thermal BCS					
1.75	31	1.98	0.10	1.24	3.96
2.00	39	2.08	0.08	1.31	3.28
2.25	72	2.24	0.08	1.28	3.71
2.50	30	2.68	0.14	1.45	4.43

Table 4. Statistical validation—correlation coefficients: comparison of thermal camera, ultrasound, and manual body condition scorings; nonparametric Spearman's rho correlation coefficient

Item	Ultrasound BCS	Manual BCS	Thermal BCS
Ultrasound BCS	1	0.379(**)	0.471(**)
Manual BCS	0.379(**)	1	0.315(**)
Thermal BCS	0.471(**)	0.315(**)	1

**Correlation is significant at the 0.01 level (2-tailed). Reject the possibility of zero correlation.

CONCLUSIONS

A model based on thermal camera and image processing algorithms, intended for evaluation of cows' body reserve, was designed and was implemented on a small number of cows. Results suggest that further study with more cows may lead to a means for automating BCS monitoring. The onus is now on the industry to further develop the methodology described above.

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