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Estimation of bull live weight through thermographically measured body dimensions

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ABSTRACT

Estimating the live weight of bulls by measurement of body dimensions with thermography and thermal image analysis was studied during progeny testing of the Simmental breed. The experimental group of bulls was measured seven times every 60 days from housing at the average age of 139 days (181 kg) till slaughtering (449 days, 594 kg). Each bull was weighed, manually measured and captured by the thermal camera. This device, together with the image analysis algorithm, proved to be a successful tool for estimating the wither height (Wh) and hip height (Hh) during all seven age classes. The SEE values for Wh decreased significantly during all weighing from 5.49 cm at day 139 to 1.11 cm at day 449 and from 4.99 to 1.76 cm for Hh, respectively. Two linear models for estimating current body weight at different ages were also developed on the basis of the long-term herd data of the Wh (BW1) and Hh (BW2) measurements. A statistically significant relationship ($P < 0.05$) was found for all seven age classes, whereby the R^2_{adj} was varying with the age from 0.11 to 0.66 (BW1) and from 0.15 to 0.74 (BW2). Since the SEE values increased a little from 24.96 kg at day 139 to 33.59 kg at last weighing for the BW1 and from 21.76 to 32.69 kg for the BW2, both models expressed high accuracies. Therefore the thermal camera shows to be a useful tool in estimating live BW, which is of significant importance in reducing stress during progeny testing and beef production.

1. Introduction

The Simmental breed is known for its great meat and milk production potential; thus it is one of the most frequently occurring breeds in the middle European countries. For a constant genetic improvement of the herd, progeny testing represents an important method for the evaluation of selected animals by monitoring and measuring the performance of young bulls (Meuwissen, 1997). Methods for assessing growth by the weighing of animals are therefore an important factor in monitoring production capacity of bull sires according to their inheritance capacity, food conversion, average daily gain and carcass yield all of which subsequently affect the output of the herd.

However, in most cases, weighing is done manually; thus the process often needs at least two stockmen, and takes 3–5 min per bull. In addition, the procedure is stressful for the whole herd, and from an ergonomic point of view, unsatisfactory (Brandl and Jørgensen, 1996). To obtain the highest precision in measuring of bull weight gain, weighing should take place repeatedly in the period prior to slaughter.

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So far, automatic electronic weighing systems in combination with automatic identification equipment, and indirect weight determination from the dimensions of the bull, measured either by tape, callipers or by an image analysis system have been explored to find an alternative to the manual weighing procedure. These methods will be discussed in the following paragraphs.

1.1. *Automatic weighing*

Different automatic weighing systems have been intensively researched in cattle as well as dairy production.

The sophisticated radio frequency identification system was found to be a highly effective tool for documenting bunk attendance, feeding behaviour and weighing of animals on the scale in cattle production, whenever animals were equipped with two separate RF transponders (Schwartzkopf-Genswein et al., 2002).

Cveticanin and Wendl (2004) designed the fuzzy-logic dynamic weighing system for dairy cows based on a mathematical model for simulating a cow's walk, which calculates the body weight with an average error of less than 2%. The simplified two-legged system measures the force to the ground produced by a cow's feet when the animal is crossing the scale. Depending on walking speed and force, a body weight is calculated and compared with the database.

Pastell et al. (2006) described another automatic weighing system made from four strain gauge balance devices installed in a milking robot. The computer program was able to measure the average weight, the weight variation of each leg and the total weight with 90% accuracy.

From many different models, two might be suggested for monitoring of young sires.

1.2. *Weight determination using body measurements*

Since weighing of older bulls represents a rather dangerous job for the stableman, the significant correlation between live weight and the dimensions of the bull has led many authors to study the possibility of estimating body weight from the dimensions of the bull. Heinrichs et al. (1992) indicated that the linear regression of body weight on heart girth had the highest R^2, followed by hip width, body length and wither height (Wh). Although all measurements are highly correlated, the addition of a second body measure contributes some predictive benefit in the estimation of Holstein heifers' body weight. Wilson et al. (1997) also detected the addition of heart girth as a measurement supplementary to Wh as the most important contributor on estimating the body weight of Holstein veal calves.

Enevoldsen and Kristensen (1997) evaluated the use of Wh, hip height (Hh) and width to predict body weight. Seven regression models were developed based on indicators that are relatively simple to obtain, precisely because the anatomical locations are easy to identify.

Willeke and Dürsch (2002) detected a high significant correlation in Hh, heart girth and weight for Simmental heifers, and suggested a third-order polynomial equation as the most appropriate.

1.3. *Determining dimensions by image analysis*

A visual image analysis (VIA) system can provide continuous automatic collection of size and shape data in pigs. Thus, it serves as an accurate means of for reflecting pig live mass and for tracking changes in pig size over time periods that are sufficiently short for commercial use (White et al., 2004).

In order to apply image analysis to the weighing of bulls, the determination of animal body dimensions from images must be possible. Prior to using the image processing, a prediction function should be established using the relationship between body dimensions from acquired images and the live weight of the specific cattle breed. Since the image is only a 2D plain projection of the animal, the loss of one dimension limits the application of such a system to measuring vertical and horizontal dimensions. Therefore the prediction functions should be precise enough to obtain valid information and can be similar to those described in the previous chapter only when the Hh and Wh are included in the polynomial equations.

According to Schaefer and Tong (1998), the thermal expression of warm-blooded animals is highly correlated with various tissue composition characteristics of specific animals, which involve the relative proportions and total quantities of different types of tissue in the animal. Therefore infrared thermal images taken of live animals are suggested for detecting and inspecting the body composition non-invasively.

Kmet et al. (2000) studied the application of image processing for slaughter value analysis on the basis of three images (above, left and rear) captured from 15-month-old, live Simmental bulls. Live weight was found to be highly correlated with a stepwise linear regression model based on the animal shoulder width, lumbar protuberance in the body width, upper body area and rear thigh area.

1.4. *Purpose of investigation*

The primary purpose of our experiment was to develop an image-processing model that can be used for automatic and precise estimation of body dimensions from images of live animals and for predicting the body weight of individual bulls.

However, the Simmental brown–red–white bulls cannot be sufficiently separated from the background on RGB images with the usual algorithms, because the edge of the animal is very difficult to detect with high accuracy. Therefore, the second goal of the research was to evaluate whether a thermal camera is sufficiently sensitive device for capturing the images of the Simmental breed required for detecting and measuring the most important body features.

2. Experimental methods

Data were collected from April 2004 to May 2006 at the Faculty's experimental farm in Rogoza, which is licensed for processing and progeny testing on approximately 400 Simmental bulls yearly. Two pens of 12 bulls were selected from the herd for the experiment. According to the progeny testing requirements, each calf was purchased from local farmers and was

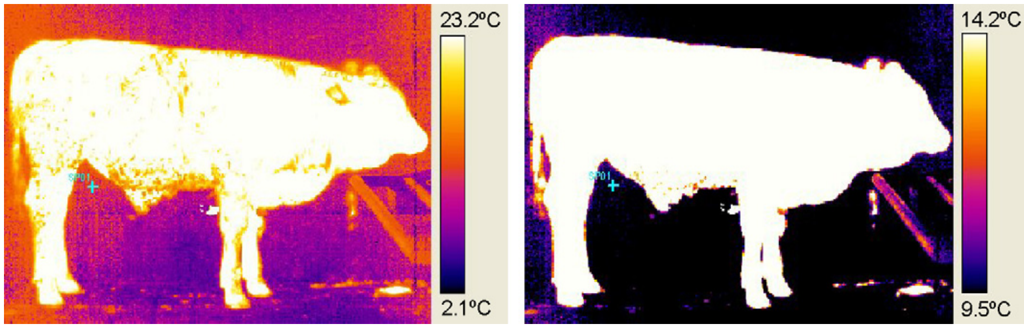

Fig. 1 – Sample thermal images at 320 × 240 pixel resolution showing a 280 kg bull before (left) and after temperature adjustment (right).

first weighed and measured at housing. Then every 2 months the animal was captured by a thermal camera prior to manual measurement. At that time Wh and Hh of each bull were measured manually with a Lidtin rod, and by weighing on the scale. Thus, seven sets of measurements were performed successively from housing until slaughtering at the average age of 449 days.

2.1. *Thermal camera*

The bulls being examined were captured from the side by the AGEMA 570 (Flir Systems^{TM}) thermal camera with an image resolution of 320 × 240 pixels. The emissivity of the object was set to default value 0.98, and the temperature resolution was better than 0.5 °C, which enables precise detection of body heat in any environmental condition. The measurements were performed using cold concrete wall surroundings, which enabled a temperature difference and therefore a sharp edge between the animal and the background on the captured images.

The uncertainty of body edge measurements depends on image resolution and on the position of the animal in relation to the camera. Therefore, for maintaining a constant distance between the camera and the object for all measurements, the animals were guided through a narrow corridor, which also prevented the animals from moving perpendicular to the camera. When the animal was walking though the corridor, we waited until it stood in an appropriate position on the image frame. Such a procedure was possible because the animals were not aware of being captured by the thermal camera.

2.2. *Bull weighing algorithm*

Since a thermal camera supports only its own IMG image format, each series of images was first converted into a BMP format prior to further image processing. As seen from Fig. 1, during this process, the contrast between the bull body and the background was extended by adjusting the temperature scale on each series of thermal images according to the average body temperature and the ambient temperature.

In the following paragraphs the algorithm for determining an animal's measurements will be illustrated with one sample of a bull image (Fig. 2), chosen to be representative for demonstrating the results of the procedure. As seen from the BMP image, the thermal camera was able to separate the bull from the surroundings accurately, so additional image separation was not required.

Prior to every set of measurements a Lidtin rod was captured on the image together with the animal. This was used for pixel/unit calibration, as it ensured a sufficient temperature gradient for the bull body, which was required for automatic image processing. Because the thermal image was relatively small for precise measurements, all calculations were conducted at the subpixel level, which increased the accuracy significantly.

2.2.1. *Regions of interest (ROI) and templates*

The measurements were based on the idea of fixing the tail root (Fig. 2a) and front hoof templates (Fig. 2c) on each image and adjusting the coordinate system accordingly, so that different positions of the animal did not influence the

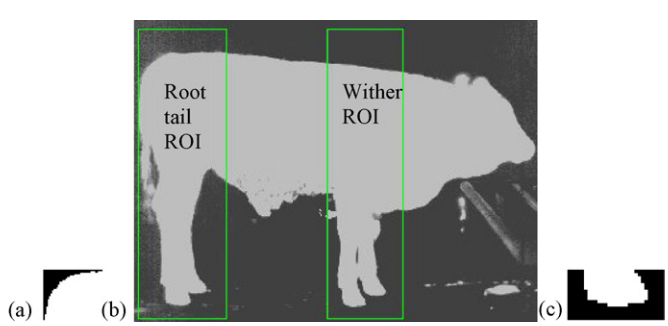

Fig. 2 – Locating a starting point for the coordinate system on each of two ROIs (b) by applying of tail root template (a) and front hoof template (c).

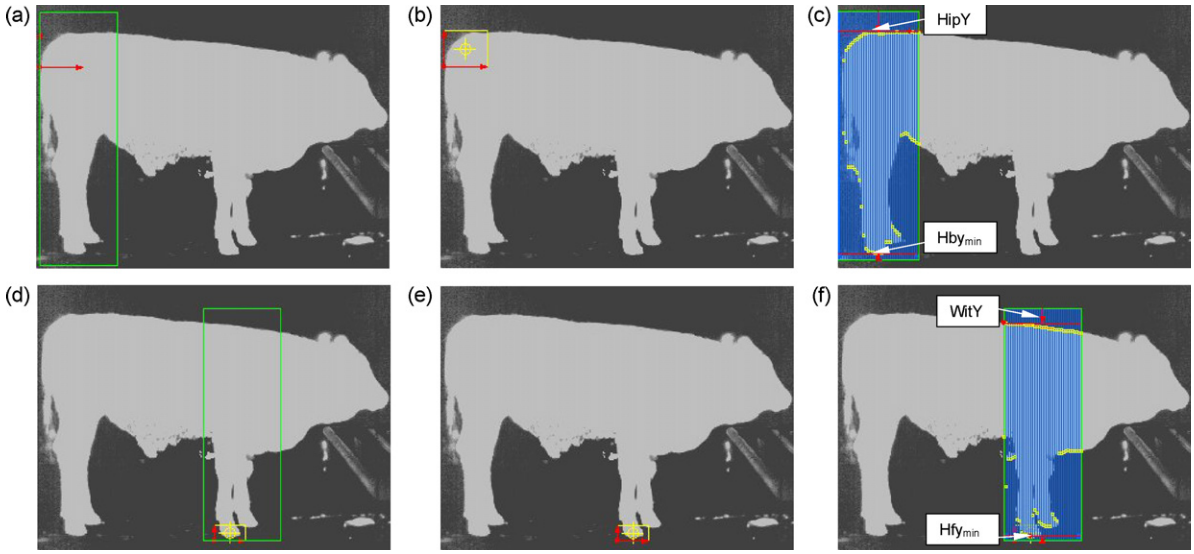

Fig. 3 – The procedure for measuring wither and hip: (a) tail root ROI, (b) fixing new root coordinate, (c) hip height measurement, (d) wither ROI, (e) fixing front hoof coordinates, and (f) wither height measurement.

measurements. However, in order to block positioning of false points, locating the tail root was limited to the tail root ROI and the front roof to the wither ROI.

As shown in Fig. 2, a tail root ROI and a wither ROI image were defined on the each image uniformly. Thus, a template image containing the sample of tail root was applied on to the tail root ROI in the first stage. Once the tail root was located on the ROI, the new coordinate system was fixed to the animal's tail root (Fig. 3b), whereby the bottom left corner of the tail root template was given the coordinates (0,0).

A similar procedure was applied for locating the front hoof template (Fig. 2c) on the wither ROI (Fig. 3d).

2.2.2. *Estimating Hh and measuring the hip*

Before determining the Hh, the hip (HipY) had to be found on the boundary, whereby HipY was assumed to be a small saddle point on the boundary. Therefore, for describing and locating it, a second-order polynomial mathematical model was developed (Fig. 4—red line), which fit the boundary quite well (Fig. 4—blue line). However, by estimating the first derivate of Y points, not one extreme was detected; thus, for the selection of saddle points, the following relational and logical operations were additionally carried out:

$$\text{HipY}\ldots y'_{(i)} = 0 \quad \text{and} \quad y''_{(i-1)} > 0 \quad \text{and} \quad y''_{(i+1)} < 0$$

Once the HipY was detected, the Hh was defined as the vertical distance between the HipY and the most bottom part of the back hoof (Hby_{min}), which also matched with the bottom part of the tail root ROI (Fig. 3c).

2.2.3. *Estimating Wh and measuring the wither*

The procedure for estimating the Wh is also based on two points of the wither ROI; thus the wither point (WitY) first had to be found on the upper part of the boundary layer. Since it was assumed to be a local maximum point inside the wither ROI, another second-order polynomial mathematical model (Fig. 5—red line) was developed, which fit the real wither accurately (Fig. 5—blue line). After processing the first derivate of

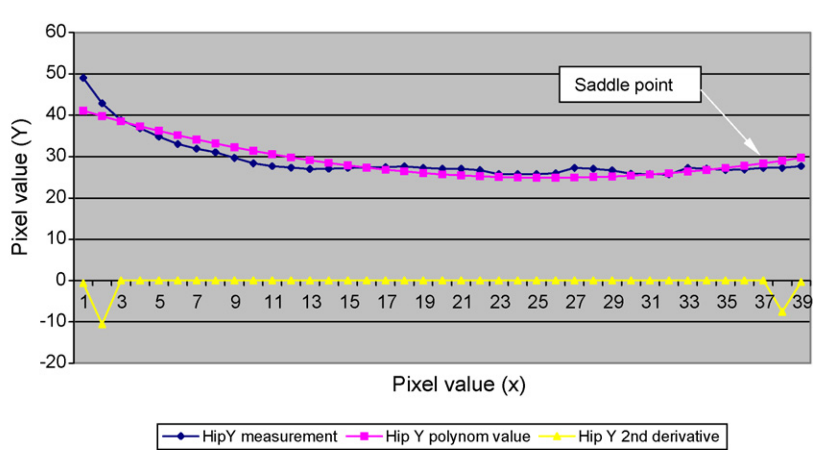

Fig. 4 – A second-polynomial mathematical model (red) for detecting the hip on the boundary layer (white). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

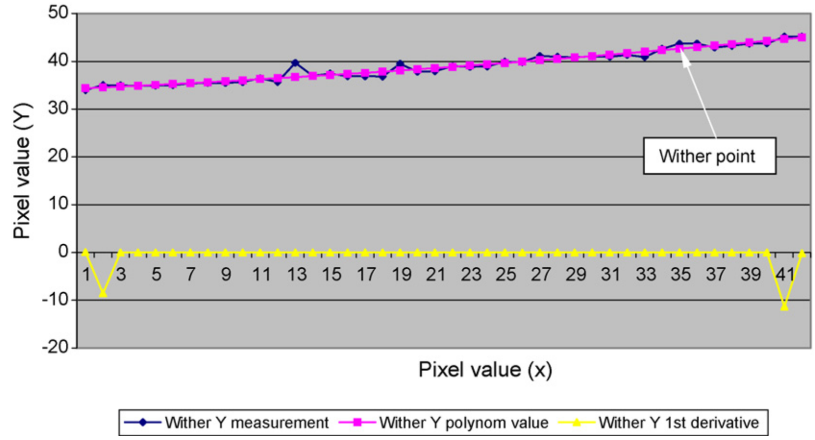

Fig. 5 – A second-polynomial mathematical model (red) for detecting the wither on the boundary layer (white). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

Y points on such a model, the minimum extreme points were calculated (yellow line) and compared to the measurement data according to the following relational and logical operations:

$$\mathrm{WitY}_x \ldots y'_{(i)} = 0 \quad \text{and} \quad y''_{(i-1)} > 0 \quad \text{and} \quad y''_{(i+1)} > 0$$

After the wither point (WitY) was located, the Wh itself was calculated as a vertical distance between the wither point (WitY) and the most bottom part of the front hoof ($\mathrm{Hfy}_{\min}$) on the boundary layer. As can be seen in Fig. 3f, the $\mathrm{Hfy}_{\min}$ was assumed to be the lowest point of the wither ROI.

2.2.4. *Estimating weight*

In performing estimation the live weight of experimental animals, different models were developed for each age class on the basis of the 5-year data set for the given Simmental herd, which included measurements of the main body characteristics of 1897 animals (Table 1). Since, at the Faculty's experimental farm in all years of progeny testing, the bulls were in fact the sons of eight bull sire lines, the herd was genetically relatively unique at all times. Therefore, it was assumed that one could estimate the live body weight of the group of experimental bulls quite well based on previous measurements.

Table 1 – Mean body weight (kg) and body measurements (cm) of Simmental bulls at different ages ($n = 1897$)

Age (days)	Bw		Wh		Hh	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
131	187	21.47	104	3.57	109	3.11
221	304	48.71	110	4.79	118	3.36
262	367	54.42	116	4.5	123	3.83
322	460	58.51	123	3.89	129	3.68
381	516	38.53	127	3.41	133	3.06
413	548	44.85	128	3.4	134	3.18
448	592	26.79	132	3.04	137	2.96

As already reported by Enevoldsen and Kristensen (1997) and Heinrichs et al. (1992), the Wh and the Hh were identified as the most significant body dimensions for estimating the bull body weight; therefore, in our research experiment two similar regression models were also chosen to be investigated for estimating the body weight of each age class:

$$(\mathrm{BW1})\mathrm{Bw} = a + b\,\mathrm{Wh}, \qquad (\mathrm{BW2})\mathrm{Bw} = a + b\,\mathrm{Hh}$$

The individual records of Wh and Hh were applied together with the models developed for estimating body weight and for evaluating the procedure's accuracy.

Various commercial programs for performing the above-described procedure do exist, among them, the IMAQ Vision 6.1.1 and Labview 7.0 from National Instruments®, which were used in our research. Statistical analyses of results obtained manually and by thermal imaging were performed using the SPSS Package Program 11.0 (SPSS Inc.).

3. Results and discussion

3.1. *Estimation of body dimensions*

The summary statistics for means, standard deviations and standard error of estimation for Wh and Hh of the experimental Simmental bulls at different ages at weighing are presented in Table 2. It can be seen that the overall agreement between the hip measurements was generally stronger than for the wither measurements, although in both size measures a significant association was detected in all measurements of progeny testing. The R^2_{adj} values varied from 0.14 at the age of 139 days to 0.43 at the age of 449 days for the hip, and from 0.20 (139 days) to 0.13 (449 days) for the wither. However, the additional regression analysis clearly demonstrated the decrease of SEE hip values during all weighing from 5.49 cm at day 139 to 1.11 cm at the last measurement at day 449, while the SEE wither values varied from 4.99 to 1.76 cm, respectively. The main reason for the better agreement between the hip measures lies in the pose of the animal during the processing. Although, silence and calming conditions were provided during the capturing of images, the back

Table 2 – Mean wither height (Wh) and hip height (Hh) of Simmental bulls measured manually and estimated with thermal camera at different ages ($n = 24$)

Age (days)	Wh_m (cm)		Wh_e (cm)			Hh_m (cm)		Hh_e (cm)		
	$\bar{x}$	S.D.	$\bar{x}$	R^2_{adj}	SEE	$\bar{x}$	S.D.	$\bar{x}$	R^2_{adj}	SEE
139	102	3.54	102	0.200**	4.994	109	3.21	109	0.140*	5.494
207	107	4.83	112	0.10*	4.489	115	3.57	120	0.180*	3.471
261	116	3.23	120	0.233**	2.72	122	3.22	126	0.118*	2.962
317	122	2.92	125	0.152	2.574	129	2.3	129	0.146*	2.908
380	129	3.19	128	0.161*	2.669	133	3.06	134	0.143*	2.482
401	128	4.01	130	0.17*	2.595	135	3.71	135	0.125*	2.600
449	133	3.27	132	0.13*	1.761	138	3.21	137	0.433*	1.111

Wh_m, wither height manually; Wh_e, wither height estimated; Hh_m, hip height manually; Hh_e, hip height estimated.

* $P < 0.05$.
** $P < 0.01$.

part of the bull body remained in most cases in the regular position, while, in contrast, the head and therefore the Wh could vary because of the twisting or kicking of the younger animals.

However, the thermal camera and the algorithm for image analysis were found to be a useful tool for estimating the Hh and Wh throughout the progeny testing in most animals, whereby the accuracy of measuring increases with the age of the animals.

3.2. *Models for estimating body weight*

The linear regression analysis of the relationship between the main body dimensions and the live body weight of 1897 bulls, served for developing two linear models for predicting contemporary BW within each age group during the progeny testing. It can be seen from Table 3 that the overall agreement between the Hh models and the BW were generally stronger than for the Wh measurement models. However, the detail regression analysis shows the falling of R^2_{adj} values in both models: from 0.74 at the first weighing to 0.15 at the last measurement for the hip parameter models, as well as for the Wh parameter models from 0.66 (day 139) to 0.11 (day 449). As was the case for R^2_{adj} values, the SEE values are also generally better for all hip parameter models than for wither models across all the age classes. But all SEE values remain relatively high for all ages, varying between 21.76 kg (139 days) and 32.69 kg (449 days) for hip models and between 24.96 kg (139 days) and 33.59 kg (449 days) for wither models. However, contrary to Heinrichs et al. (1992), the introduction of the wither as a second variable into the hip linear model did not yield a significant growth in R^2 statistics as expected owing to the high co-linearity of the parameters.

Table 3 – Regression between BW and one body measurement over seven measurements during progeny testing ($n = 1897$)

Age (days)	Measurement		Linear model			
	Model	Parameter	Intercept	Slope	R^2_{adj}	SEE (kg)
139	BW1	Wh	−479.054**	+6.635**	0.667**	24.96
	BW2	Hh	−650.738**	+7.793**	0.747**	21.76
207	BW1	Wh	−278.789**	+5.563**	0.525**	27.45
	BW2	Hh	−601.219**	+7.728**	0.641**	23.85
261	BW1	Wh	−512.765**	+7.617**	0.472**	36.85
	BW2	Hh	−708.357**	+8.781**	0.501**	35.80
317	BW1	Wh	−643.789**	+9.052**	0.382**	43.52
	BW2	Hh	−631.324**	+8.755**	0.440**	38.00
380	BW1	Wh	−478.216**	+7.952**	0.403**	39.23
	BW2	Hh	−867.884**	+10.394**	0.516**	38.54
401	BW1	Wh	−500.692**	+8.221**	0.436**	39.03
	BW2	Hh	−605.063**	+8.660**	0.462**	38.11
449	BW1	Wh	−51.39*	+4.165**	0.111**	33.59
	BW2	Hh	−111.773*	+5.207**	0.158**	32.69

* $P < 0.05$.
** $P < 0.01$.

Table 4 – Regression of body weight (kg) of experimental Simmental bulls measured manually and estimated with two models at different ages ($n = 24$)

Age (days)	BWm (kg)		BW1			BW2		
	$\bar{x}$	S.D.	$\bar{x}$	R^2_{adj}	SEE	$\bar{x}$	R^2_{adj}	SEE
139	181	31.19	193	0.667**	24.96	190	0.747**	21.76
207	254	38.78	318	0.525**	24.96	346	0.641**	23.85
261	356	46.98	420	0.472**	36.86	424	0.501**	35.80
317	450	35.9	481	0.382**	43.52	470	0.516**	38.54
380	498	26.68	522	0.403**	39.23	527	0.440**	38.00
401	528	51.15	551	0.436**	39.03	550	0.462**	38.11
449	594	30.29	573	0.111*	33.59	568	0.158**	32.69

BWm, body weight manually; BW1, estimated body weight on Wh measurement; BW2, estimated body weight on Hh measurement.

* $P < 0.05$.

** $P < 0.01$.

3.3. *Estimation of body weight*

Table 4 shows the summary statistics for means, standard deviations and standard error of estimation for the BW of all 24 Simmental bulls according to seven successive measurements. The overall agreement between the manual weighing and the BW2 models (R^2_{adj} from 0.74 to 0.46) was generally stronger than for the BW1 models (R^2_{adj} from 0.66 to 0.43), although both R^2_{adj} values were rather low at day 449. But, the additional regression analysis clearly demonstrated an increase in accuracy with the decreasing SEE values from days 317 to 449, which proved the BW2 models to be more precise than the BW1. The main reason for the better agreement between the BW2 and the live body weight is mainly explicable by the different development of the front and back part of the body from housing till slaughter, whereby the wither grows faster and in a manner less linear in comparison to the hip.

However, the established regression statistics correspond close by to the results of Enevoldsen and Kristensen (1997) on Danish Frisian and Jersey cows, where R^2 varying between 0.80 and 0.89 was reported. Furthermore, the results of our linear regression models also correspond very well with the linear models developed by Wilson et al. (1997) for measuring the body weight of special-fed Holstein veal calves. Since several hundred animals were manually measured in Wilson's experiment, the thermography and image analysis procedure is a feasible and accurate procedure for predicting the body weight of live bulls.

Thus, the indirect estimation of body weight from thermal images represents an accurate procedure that should also be evaluated for other breeds and fodder conditions.

4. Conclusions

The goal of this research project was to develop a processing algorithm based on thermography and image analysis that could provide a precise measurement technique for rapid, objective and accurate evaluation of the main body characteristics and estimation of live body weight of bulls during progeny testing.

The high regression statistics indicate that all models applied in the research estimated the bull weight accurately across the whole observing period, although the BW2 models with Hh as the input parameter appeared to be more precise. The system was proven to facilitate fast, frequent investigation of bulls even in the growing pens without painful stress for the whole herd. However, for extended on-line application in the open field, introduction of the specific BW2 models is preferable to BW1. Thus, for measuring the Wh, a steadier posture of the animal during image capture is required, which is relatively difficult to achieve. This procedure proved to be particularly difficult with young bulls till day 340 since these animals were rather wild in the pens and during measuring on the scales. However, additional optimising of the chosen parameters measured by the thermal camera could even improve predictions of the live weight of young animals.

The algorithms presented herein can be used to estimate the body weight of Simmental bulls during progeny testing under local conditions and do not allow its direct application to other breeds; thus further work is expected to ensue especially in evaluating particular cases.

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