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Determination of body measurements on the Holstein cows using digital image analysis and estimation of live weight with regression analysis

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ABSTRACT

In this study, the body measurements (BMs) of Holstein cows were determined using digital image analysis (IA) and these were used to estimate the live weight (LW) of each cow. For this purpose, an image capture arrangement was established in a dairy cattle farm. BMs including wither height (WH), hip height (HH), body length (BL), hip width (HW), plus the LWs of cows were first determined manually, by direct measurement. Then the digital photos of cows were taken from different directions synchronously and analyzed by IA software to calculate WH, HH, BL and HW of each cow. After comparing the BMs obtained by IA with the manual measurements, the accuracy was determined as 97.72% for WH, 98.00% for HH, 97.89% for BL and 95.25% for HW. The LW estimation using BMs was then performed by the aid of the regression equations, and the correlation coefficient between the estimated and real (manual) LW values obtained by weighing was calculated as 0.9787, which indicates the IA method is appropriate for LW estimation of Holstein cows.

1. Introduction

Since the numbers and capacities of dairy cattle farms are increasing with every passing day, the computer-aided studies for the management of these farms become more important and are widely used in daily life. The management decisions based on live weight (LW), milk production and feed consumption in dairy cattle breeding are significant in terms of reflecting the efficiency of the farm, the care applied in the farm, the feeding level and the present condition of the cattle. The variations in milk yield, feed consumption and LW between two calving of a cow can be observed in Fig. 1. The out-of-range properties negatively and significantly affect the economical efficiency and the resistance of cows to diseases. For instance, the negative variations especially in LWs can indicate health problems, inappropriate environmental conditions or feeding faults; therefore, LW monitoring in dairy cows becomes very important (National Research Council of the National Academies, 2001; Ensminger et al., 1990; Wilson et al., 1997; Tasdemir et al., 2008).

LW is determined by the weighing process performed in cattle farms, especially by constructing a weighing place that will weigh the cows while they are passing or standing still on it. Some problems can be faced with the weighing device in terms of the accuracy of the calibration or proper working due to environmental conditions. A staff should be provided to organize and control the weighing process. Although it is aimed to measure the weight of the animals with minimum stress, minor injuries of cattle can be sometimes encountered during the weighing process. Therefore, the farmers prefer not to allocate place for weighing tools, staff and finance.

The estimation of LW by using BMs has been made for a long time. However, the BMs made on cows may result in dangerous events due to the animals being under stress during the process of forcing the animals to position them for an accurate BM. Additionally; the possibility of having wrong measurements is also very high. Therefore, due to such unfavorable reasons, the farmers accept not keeping abreast of having LW information or perform the weighing process rarely (Wilson et al., 1997; Tasdemir et al., 2008; Enevoldsen and Kristensen, 1997; Heinrichs et al., 1992).

In recent years, computer aided image acquisition and processing techniques are in widespread use in various stock management activities such as digital IA in animal breeding, husbandry, etc. And the image analysis technique has been successfully used to estimate animal body weight indirectly from its dimensions that some of these studies are given in the following.

Visual image analysis and digital image analysis have been applied to determine and follow the body measurements, live weights and growths of pigs, rabbits, chickens and cattle (Negretti et al., 2007; Wet et al., 2003; Mollah et al., 2010; Ozkaya and Yalcin, 2008; Wang et al., 2008; Pastorelli et al., 2006).

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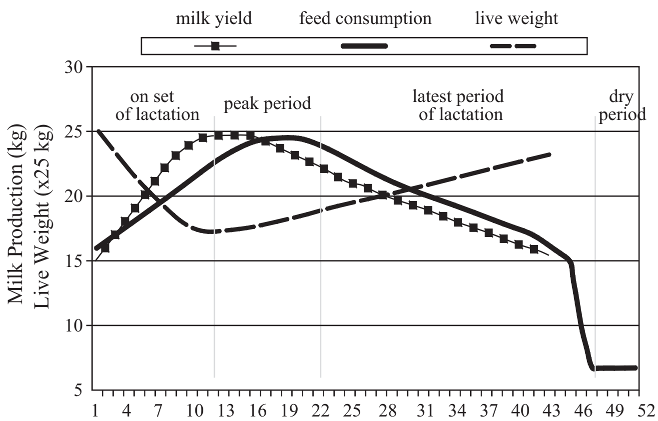

Fig. 1. Period between two calving of a Holstein cow.

Photogrammetric techniques have been successfully used to determine the three-dimensional models of pigs, rabbits and cats (Wu et al., 2004; Karabork, 2009).

Carcass characteristics and weight of beef were determined using the image analysis (Doeschl-Wilson et al., 2004, 2005; Teira et al., 2003).

The body measurements and live weights of the bulls were calculated using digital infrared thermography (Stajnko et al., 2008), and the body condition scoring was performed for dairy cattle by using image analysis (Bewley et al., 2008).

The success of this study will prevent all the aforementioned unfavorable conditions for both cows and the staffs during weighing minimize the errors and increase the sensitivity of the evaluations. Moreover, it will speed up the diagnosis and prevention of possible health problems resulting from feeding.

In this study, it was aimed to evaluate the digital images obtained from cows with developed IA software in order to determine BMs of cows and to estimate LWs using BMs.

2. Materials and methods

This study was carried out in CUMPAS Company dairy cattle farm in Cumra district of Konya city. In this farm, a digital photo platform was set up, the photographs of the Holstein cows ($n = 115$) were taken using Canon EOS400D cameras. The ages of the animals in the first lactation period are between 26 and 36 months, which were weighed with digital weighing tool and whose BMs were taken manually. The digital weighing tool (specially manufactured as TR-BXN-P1500 model number of Taralsa brand with ±500 g precision) used in this study has a portable structure having 350 cm length, 110 cm width with loading ramps that facilitate the entrance and exit of animals, which was surrounded with steel cages and capable of recording the weights (up to 2 tonnes) of the animals into a computer.

The images were analyzed using the IA software developed with Delphi computer programming language to determine the BMs of cows. In this study, the photogrammetry technique was used for IA that manually measured values and the results of IA were compared. Finally, LW was estimated with the regression equations.

The processes of cattle weighing and taking photographs were carried out after the completion of milking and feeding processes of the animals; therefore, the stomach fullness conditions before milking were assumed to be the same. In order to minimize the errors of calculations in the study, similar animals were selected in terms of age, efficiency level, stomach fullness and body condition. The processes such as weighing, photograph taking, body measurement, etc. were repeated. The body measurements obtained manually and IA for dairy cattle, the LW measured with scales and calculated with regression analysis, and the descriptive statistics values for condition scores can be seen in Table 1.

2.1. Digital image analysis and photogrammetry

Recently, there have been developments in image processing systems, techniques and applications. One of the opportunities enabled by these visual applications is the ability of making measurements from the taken images. The machine vision applications in electronic systems have been used increasingly in industrial area day by day. The contactless analysis of substances is preferred more than other methods, because destructions, variations or undesired negative variations might occur on the substance which is measured in contact.

Computer vision is a branch of science which allows information to be investigated theoretically by computer and algorithmically over an image or image sets. Digital image processing and analyzing methods supported by computer have many advantages like saving time, accuracy and economy. The parameters related with objects are measured with digital IA (shape, length, area, angle, grey-tone value, etc.). In raw digital images, the measurements about area, length, etc. can be made in pixels. In order to make these measurements in metric system, the reference points on the image whose metric equivalents are known should be described by the software (spatial calibration) (Tasdemir et al., 2008; Yakar et al., 2010; Aktan, 2004; Tudes, 1996).

The photogrammetric techniques, measuring objects from photographs, have been applied since the late 1800s. Digital close range photogrammetry is a technique for measuring objects directly from their photographs accurately and from the digital images captured with a camera at a close range. Multiple overlapping images taken from different perspectives produce measurements that can be used to create accurate 3D models of the objects. If a digital camera with known characteristics (lens focal length, imager size and number of pixels) is used, it will be necessary to take only two images of the object. However, if the same three object points in both images and a known dimension are indicated, 3D points can be determined in the images. In comparison to the conventional manual methods, the photogrammetry method is more efficient, rapid and considerably safer. All surveyors can obtain precise measurements without accessing each measurement point physically. Digital photogrammetric methods have been successfully applied to projects in archaeology, architecture, automotive and aerospace engineering, accident reconstruction and disciplines (Atkinson, 1996; Cooper and Robson, 1996; Lawson, 1977; Carnobell, 1989; Yilmaz et al., 2008).

2.2. Camera calibration and direct linear transformation

The calibration of the camera is a mathematical calculation procedure for the parameters which should be known in order to bring the metric property into the camera. These parameters are the coordinates of image center point, focal length of the camera, the angles and coordinates of shooting, etc. The effect on the image plane of distortion, which is one of the systematic errors on the image plane, is determined and then the parameters are identified with calibration. These procedures are carried out in order to determine inner geometric, optical characteristics and angular position of the camera with respect to 3D coordinate system. Calibration is defined as finding the relationship between the real value of the measured size and the result of the measuring device. Therefore, knowing the coordinates of the object points, the elements of inner orientation are found (Wang et al., 2008; Karsli and Ayhan, 2005; Besdok and Kasap, 2006; Lucchese, 2005).

Table 1
Descriptive statistics of measurements.

	Mean	Std. error of mean	Minimum	Maximum	Range
Digital weighing tool (kg)	570.209	6.260	409.5	771.0	361.50
Regression prediction (kg)	570.243	6.127	414.1	725.7	311.53
Body condition score	2.937	0.024	2.5	3.8	1.25
Wither height IA (cm)	136.287	0.390	125.0	149.0	24.00
Wither Height MM (cm)	137.774	0.447	126.0	150.0	24.00
Hip height IA (cm)	140.270	0.440	130.0	149.0	19.00
Hip height MM (cm)	140.778	0.387	133.0	152.5	19.50
Body length IA (cm)	164.252	0.591	148.0	181.0	33.00
Body length MM (cm)	162.765	0.702	140.0	179.0	39.00
Hip width IA (cm)	54.192	0.368	45.0	65.0	20.00
Hip width MM (cm)	54.491	0.337	46.0	66.0	20.00

There exist linear, nonlinear and multi-stage calibration methods in the literature. Since the linear method is faster than the others, the most commonly used method is direct linear transformation (DLT) method suggested by Abdel-Aziz and Karara (1971). The reason of preferring and widely using of DLT method is due to its fast and linear solution without any approximate value problem (Abdel-Aziz and Karara, 1971; Tasdemir et al., 2009).

Basic DLT equation is shown in expression (1) with its matrix form:

$$\begin{bmatrix} x_1 & y_1 & z_1 & 1 & 0 & 0 & 0 & 0 & -u_1x_1 & -u_1y_1 & -u_1z_1 \\ 0 & 0 & 0 & 0 & x_1 & y_1 & z_1 & 1 & -v_1x_1 & -v_1y_1 & -v_1z_1 \\ & & & \vdots & & & & & & \vdots & \\ x_n & y_n & z_n & 1 & 0 & 0 & 0 & 0 & -u_nx_n & -u_ny_n & -u_nz_n \\ 0 & 0 & 0 & 0 & x_n & y_n & z_n & 1 & -v_nx_n & -v_ny_n & -v_nz_n \end{bmatrix} \begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_{10} \\ L_{11} \end{bmatrix} = \begin{bmatrix} u_1 \\ v_1 \\ \vdots \\ u_n \\ v_n \end{bmatrix} \quad (1)$$

The transformation relation between the image coordinate system and the object coordinate system is mathematically stated in expression (2) as in the following (Abdel-Aziz and Karara, 1971; Fang-Jenq, 1997):

$$\begin{aligned} u - u_0 &= -\frac{d}{\lambda_u}\frac{r_{11}(x-x_0)+r_{12}(y-y_0)+r_{13}(z-z_0)}{r_{31}(x-x_0)+r_{32}(y-y_0)+r_{33}(z-z_0)} \\ v - v_0 &= -\frac{d}{\lambda_v}\frac{r_{21}(x-x_0)+r_{22}(y-y_0)+r_{23}(z-z_0)}{r_{31}(x-x_0)+r_{32}(y-y_0)+r_{33}(z-z_0)} \end{aligned} \quad (2)$$

In this equation, u_0 and v_0 are the image points of the dot; u and v are the image coordinates of the main point; r_{ij} is the rotation matrix components; x, y, z are the object coordinates in space; x_0, y_0, z_0 are the perspective center; λ_u and λ_v are the unit transformation coefficients; d is the scale factor; L_1 and L_{11} are the parameters of the transformation. After rearranging Eqs. (2) and (3), the Basic DLT is determined:

$$u = \frac{L_1x+L_2y+L_3z+L_4}{L_9x+L_{10}y+L_{11}z+1} \quad v = \frac{L_5x+L_6y+L_7z+L_8}{L_9x+L_{10}y+L_{11}z+1} \quad (3)$$

$L_1, L_2, L_3, \ldots, L_{11}$ coefficients are called as DLT parameters reflecting the relationship between space reference plane and image plane. Eq. (3) is three-dimensional DLT equation not including any optic distortion error of camera lenses. If these errors are taken into consideration, the equation can be formed as in the following:

$$u - \Delta u = \frac{L_1x+L_2y+L_3z+L_4}{L_9x+L_{10}y+L_{11}z+1} \quad v - \Delta v = \frac{L_5x+L_6y+L_7z+L_8}{L_9x+L_{10}y+L_{11}z+1} \quad (4)$$

In this equation, Δu and Δv are the errors resulted from optic distortion (Abdel-Aziz and Karara, 1971; Fang-Jenq, 1997; Goktepe and Kocaman, 2010).

In order to calculate the position of a point in space, it should be viewed from at least two perspectives (from right and left). In this study, the camera calibration parameters necessary for transformation processes were calculated using photogrammetry application and DLT method for IA processes. The 3D (XYZ) body space coordinates corresponding to a pixel (xy) value on the image were also calculated. After calculating the DLT parameters and additional parameters for each image, it became possible to calculate the coordinates of the points on the image.

2.3. Image acquisition and development system

The set up in Fig. 2 was designed and a photo taking environment was built with a lighting system appropriate to have stereoscopic shooting using hardware units. The reference points (coordinates were specified for these points using geodesic methods—i.e. spatial coordinates) with their known coordinates were marked on the places where the cows would pass and be weighed before digital image acquisition stage. During the design stage of the set up, the calibration process of the cameras placed on suitable points was performed to carry out the dimension calculation. In this application, the relationship between 2D image plane and 3D object coordinate system was modeled, and the parameters of the cameras were calculated. Then, the calibration parameters describing the camera were calculated by using DLT method on a camera calibration test area whose 3D coordinates were known. A transformation was performed from 2D image plane to 3D spatial coordinate system with this procedure.

DSLR Remote Pro Multi-Camera v.1.2.1 software was used to support Canon cameras in order to take photos automatically and concurrently, i.e. synchronously, and it was integrated with visual IA software developed by Delphi programming language. Moreover, a sensor of reflection from matter (Telemecanique Osiris XUK5APANL2 Photoelectric Sensor) was used to detect the passing of animals automatically. An electronic circuit was designed to perform automatic photo shooting process when the camera perceives an animal and a computer program was written for the PIC16F877 microcontroller of this circuit (Tasdemir et al., 2010). The synchronous photograph taking was performed automatically and the images were recorded into the computer with the aid of the electronic circuit including four Canon EOS400D cameras and the aforementioned software. Hence, besides the manually measured body dimensions and LWs of each animal, the images taken from side and top views of each animal were all recorded into the computer. Evaluating the photos using IA software by the help of assigned reference measurements at the computer medium, the weights of the cattle were calculated.

2.4. The procedure of defining BMs manually and by IA software

First of all, the WH and HH of cows were measured with a laser meter (Bosch DLE 150 Connect Professional with Bluetooth) and a measuring stick and the BL and HW of cows were measured using a tape measure before being captured by the camera. At the instant of taking the photos of cows, the LW was determined using a digital weighing tool, and the indicator data on the display was saved by the computer (see Fig. 2).

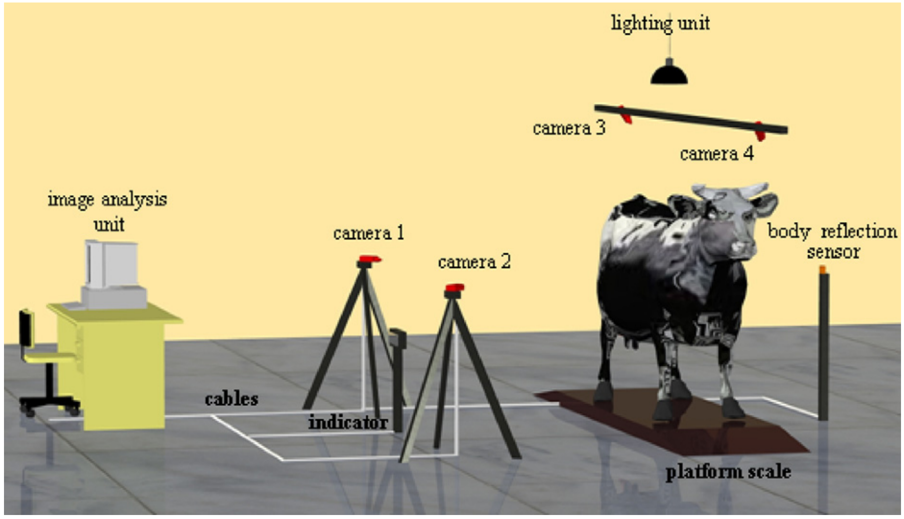

Fig. 2. Block diagram of image taking unit.

The photos of each animal from two different side perspectives (by two cameras) and two different top perspectives (by two cameras) were taken at the exit of the milking shed with the aid of this mechanism by synchronizing with Canon EOS400D photo taking units. All the photographs of dairy cows were taken with a total of four cameras. The body measurements of the cows were found through the evaluation of photographs by using IA software. HW was calculated using the images taken by the cameras from the top, and WH, HH and BL were obtained using the images taken from two different side perspectives (see Fig. 3).

Calibration is the process of defining the relationship between the real value of the measured magnitude and the result given by the device measuring that magnitude. In this application, the relationship between the 2D image plane and the 3D spatial coordinate system was modeled and the parameters of the cameras were calculated through the DLT method, and the measurements were performed by using 3D coordinates corresponding to each pixel point. For this objective, a studio shooting environment was formed at the regular passageways of the animals and the markings signifying the coordinates were fixed on those areas. A number of marked points were determined considering all the alternatives. These points were tested using the IA software that was developed for the study and the 3D coordinates providing the most correct results were selected and used in the software. A total of nine points was found to be adequate for evaluating the photos of animals taken from sidelong perspectives and 14 points were found to be adequate for evaluating the images of animals taken from top perspectives. The reference 3D coordinates created for the topside and sidelong perspective environment are presented in Fig. 3.

In the IA software process, the pixels on the top view images that correspond to the 3D points determined on the right and left stereo images were selected through using the mouse. Afterwards, the 3D object coordinates that correspond to these pixels were entered separately for each shooting image from topside. The first matrix (Eq. (1)) that would be used for the camera calibration process was created according to the DLT method. Since 14 points were selected, the created matrix was composed of 11 columns and 28 rows. The second matrix consisted of one column and 28 rows was formed with 14 pixels (x,y) marked on the right and left images according to the DLT model. The same procedure was applied using the side view images, and the matrix (Eq. (1)) was formed with 11 rows and 18 columns for 9 points. The second matrix was formed with the 9 pixels (x,y) marked on the right and left images according to the DLT model. The second matrix consisted of one column and 18 rows (see Fig. 3). Then, camera calibration parameters (focal length of the camera, image center point, perspective coordinates, ω, φ, κ, etc.) were found (for top and side perspectives) both for right and left perspective images using the IA software and through the DLT procedure. The results obtained through the calculations were recorded into the computer for further analysis and transformation.

The next stage for the operation of IA software was the process of finding the 3D (XYZ) coordinates of a desired pixel (xy) point on the image. It is possible to attain the space coordinates directly from the image coordinates through the equations from 1 to 4. A (XYZ) result is calculated corresponding to each pixel point marked on the images using a mouse. The procedure was implemented by using the pixel points marked on the right (x_1,y_1) and left (x_2,y_2) images, and the calibration variables were obtained by using these points. In this way, the transformation process from 2D (xy) pixels to 3D (XYZ) object space coordinates was realized; that is, the XYZ space coordinate values corresponding to a pixel point selected on the image were calculated. When the 3D values corresponding to the second pixel point in the image was determined, the distance between two pixel points was calculated as three dimensional. WH, HH, BL and HW were calculated by analyzing the taken images through the IA software.

2.5. Estimation of LW with multiple regression modeling

The multi-linear regression model was used to estimate the LW by using the previously obtained BMs. In multi-regression equations, there is more than one independent variable that affects one dependent variable.

The regression equation related with sampling is given as follows:

$$y = a_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_n + e_{ij} \quad (5)$$

where y is dependent variable; $x_1, x_2, \ldots, x_n$ are the independent variables; e_{ij} is the environmental error term; a_0 is a constant term; and $b_1, b_2, \ldots, b_n$ are the regression coefficients.

The results of LW estimated with regression analysis were compared with the values obtained by manual weighing processes, and the BMs obtained as a result of IA procedure were compared with the manually measured ones. Then their accuracy was tested as a percentage (Eq. (6)), and the average of all data sets and mean

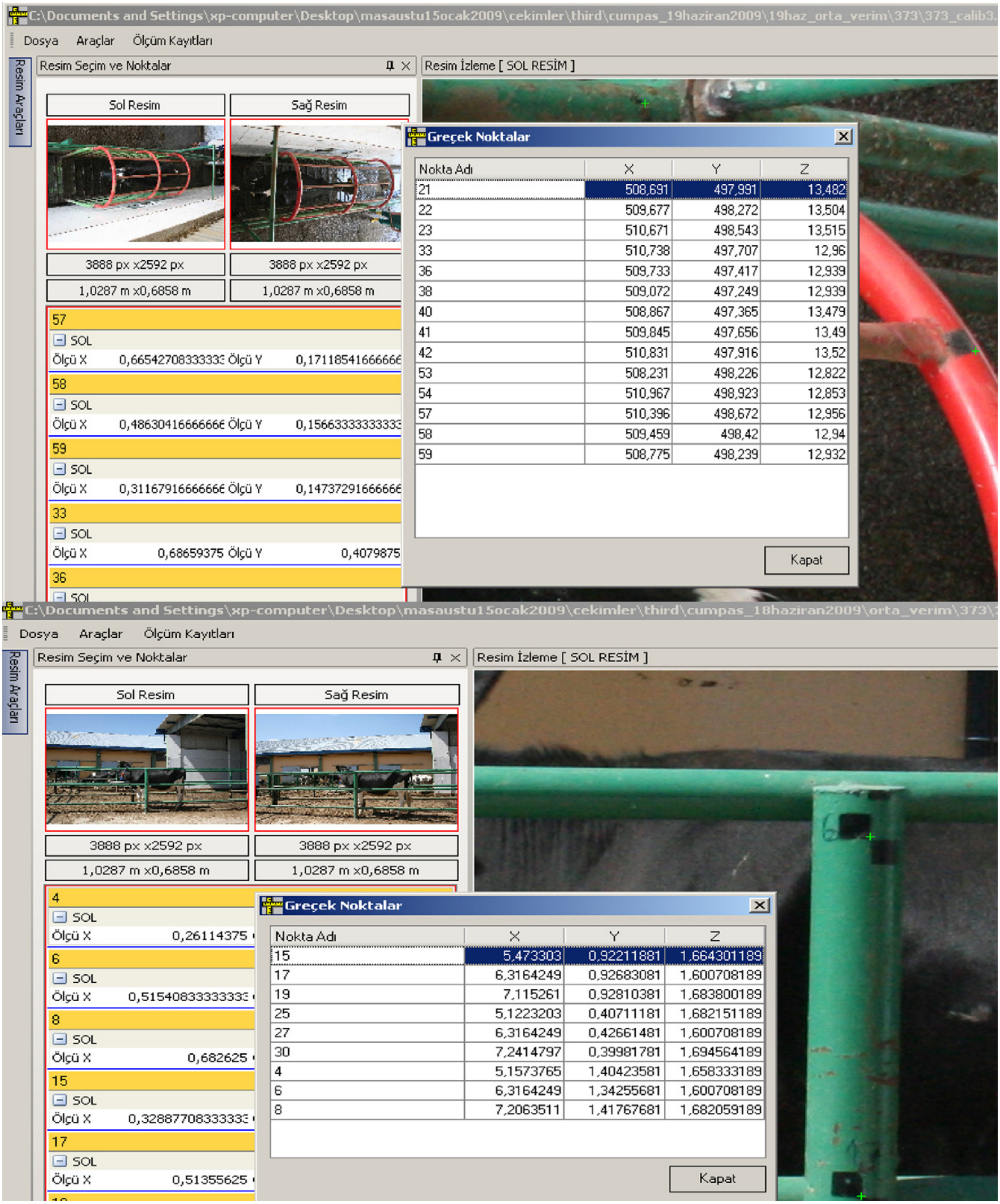

Fig. 3. Entering the 3D reference points used in evaluating the photographs taken from topside and sidelong (stereo and synchronized) into IA software.

relative percentage errors were calculated (Eq. (7)) (Kirby et al., 2004):

$$P_{\text{err}} = \frac{|D_{\text{m}} - D_{\text{p}}|}{D_{\text{m}}} * 100\% \tag{6}$$

$$A = \frac{1}{n}\sum_{i}^{n} P_{\text{err}} \tag{7}$$

where P_{err} is the prediction percentage error of data set i; D_{p} is the predicted D by data set i; D_{m} is the measured D corresponding to data set i; A is the model prediction mean relative error; n is the

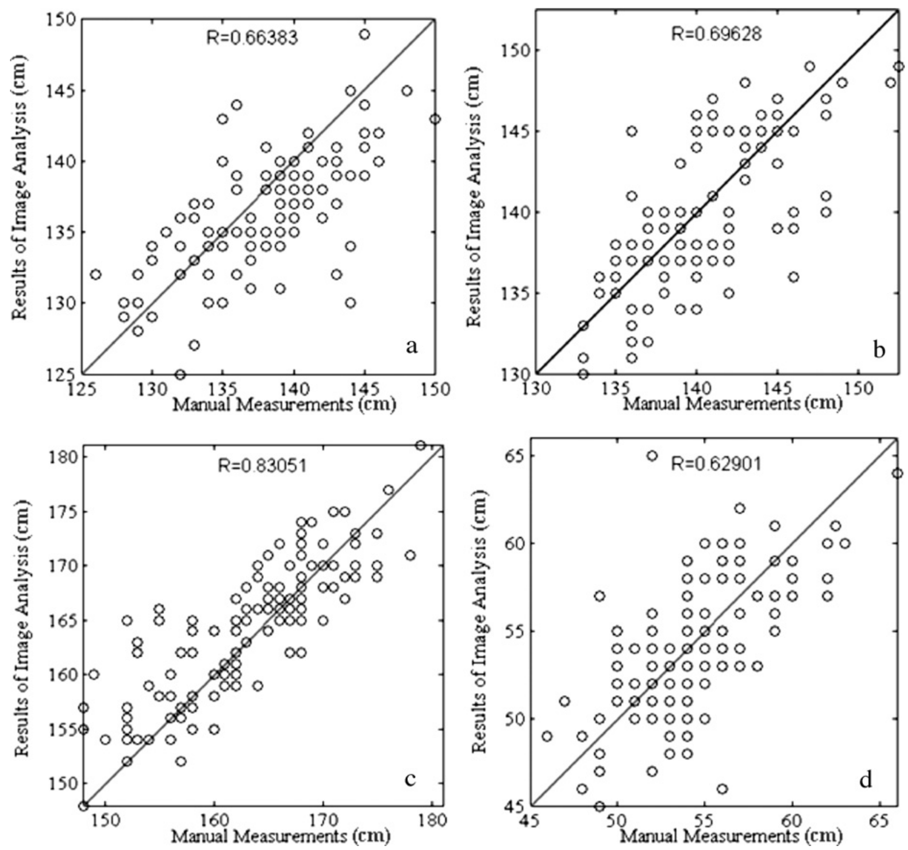

Fig. 4. The relationship between manual measurements and the values of IA for WH (a), HH (b), BL (c) and HH (d).

total number of measurements; *i* is the measurement predicted for a specific run.

3. Results and discussion

In this study, WH, HH, BL and HW values of animals were both manually measured and obtained by evaluating the IA software. The correlation coefficients between calculated and manually measured BMs were obtained as 0.66 for WH, 0.70 for HH, 0.83 for BL and 0.63 for HW by MATLAB software (see Fig. 4).

The accuracy rates (Eqs. (6) and (7)) between manually measured BMs and the ones obtained as a result of IA procedure were found as 97.72% for WH, 98.00% for HH, 97.89% for BL and 95.25% for HW. When these rates were taken into consideration, it was observed that the WH, HH, BL, HW values obtained as a result of IA procedure was among an acceptable range of accuracy of the manual measurements (MM). As a result of reciprocal comparison between the data groups, the average relative accuracy reached a satisfactory ratio greater than 90% level. This situation indicated a perfect match between the estimated values of IA and the values of manual measurements. Therefore, since the proposed IA model made predictions within an acceptable range of accuracy, and IA can be used as an alternative method for these systems.

The regression equations were obtained with SPSS software by using both manually measured values (Table 2) and the ones obtained as a result of IA (Table 3). These two equation groups were integrated with IA software developed in Delphi programming language and the prediction of LW was performed.

The single and multi regression equations obtained between manually measured body dimensions and LWs, the situation of each variable, the correlation (r) and determination coefficients (R^2) can be seen in Table 2. By using all BMs, the maximum r and R^2 values were obtained as 0.801 and 0.641, respectively (model 1 in Table 2). Heinrichs et al. (1992) used 2625 manually measured data to form multiple regression equations. However, the body measurements were not determined by IA. And this method was not used in this study. It was observed that the results were more accurate and approximate related to the large number of data.

On the other hand, the single and multi regression equations were formed between LWs and the BMs of IA software by using single parameter (WH, HH, BL or HW in order) as seen in Table 3 where r and R^2 were also given. Among these equations (model 12–model 15), the highest correlation value of $r = 0.953$ and $R^2 = 0.909$ was obtained with model 15 in which HW was used. When the LWs estimated by model 15 were compared with those obtained with scales, the average accuracy rates (Eqs. (6) and (7)) were calculated as 96.26%. The closer values of $r = 0.972$ and $R^2 = 0.945$ were obtained with model 8 (WH and HW were used) among the regression equations (model 6–model 11) formed by using two parameters. When the LWs estimated by model 8 were compared with those obtained by weighing, the average accuracy rates (Eqs. (6) and (7)) and the average error rates were calculated as 96.99% and 3.01%, respectively. In the next stage, the multiple regression equations (model 2–model 5) having three parameters were formed, and the highest $r = 0.978$ and $R^2 = 0.957$ values were determined for model 4 in which WH, BL, and HW were used together. The average accuracy rates (Eqs. (6) and (7)) and the average error rates were calculated as 98.13% and 1.87%, respectively.

In the final stage, model 1 in which all the parameters were used was formed. Using all BMs in linear multi regression equation, the maximum r and R^2 values were obtained as 0.979 and 0.958, respectively (model 1 in Table 3). According to this, it can be concluded that the LW takes shape depending on the independent variables (WH, HH, BL and HW) at a rate of 96%. When all of the r

Table 2
Linear effects of manually taken BMs and LW prediction equations.

Model number	Estimation equation (y)	Constant (a_0)	Regression coefficients				r	R^2	P
			WH (b_1)	HH (b_2)	BL (b_3)	HW (b_4)			
1	$a+b_1x_1+b_2x_2+b_3x_3+b_4x_4$	-965.974^{***}	2.725^{*}	2.096^{ns}	3.963^{***}	4.049^{**}	0.801	0.641	0.000
2	$a+b_1x_1+b_2x_2+b_3x_3$	-1025.945^{***}	3.252^{**}	2.825^{*}	4.610^{***}	–	0.781	0.611	0.000
3	$a+b_1x_1+b_2x_2+b_4x_4$	-823.172^{***}	3.805^{**}	3.534^{*}	–	6.822^{***}	0.717	0.514	0.000
4	$a+b_1x_1+b_3x_3+b_4x_4$	-859.102^{***}	3.757^{***}	–	4.127^{***}	4.406^{***}	0.796	0.634	0.000
5	$a+b_2x_2+b_3x_4+b_4x_4$	-908.264^{***}	–	3.924^{***}	4.181^{***}	4.505^{***}	0.790	0.623	0.000
6	$a+b_1x_1+b_2x_2$	-892.661^{***}	5.138^{***}	5.363^{***}	–	–	0.645	0.416	0.000
7	$a+b_1x_1+b_3x_3$	-884.680^{***}	4.750^{***}		4.918^{***}	–	0.772	0.596	0.000
8	$a+b_1x_1+b_4x_4$	-627.483^{***}	5.672^{***}	–	–	7.640^{***}	0.701	0.491	0.000
9	$a+b_2x_2+b_3x_3$	-963.796^{***}	–	5.155^{***}	4.966^{***}	–	0.765	0.585	0.000
10	$a+b_2x_2+b_4x_4$	-729.572^{***}	–	6.256^{***}	–	7.691^{***}	0.691	0.478	0.000
11	$a+b_3x_3+b_4x_4$	-548.598^{***}	–	–	4.871^{***}	5.983^{***}	0.764	0.583	0.000
12	$a+b_1x_1$	-589.489^{***}	8.417^{***}	–	–	–	0.601	0.361	0.000
13	$a+b_2x_2$	-772.867^{***}	–	9.540^{***}	–	–	0.590	0.349	0.000
14	$a+b_3x_3$	-463.782^{***}	–	–	6.353^{***}	–	0.712	0.507	0.000
15	$a+b_4x_4$	-41.843^{ns}	–	–	–	1.395^{***}	0.604	0.365	0.000

* $P<0.05$.
** $P<0.01$.
*** $P<0.001$.
^{ns} Not significant ($P>0.05$).

and R^2 values in Table 3 were evaluated, model 1 and model 4 were found to be more similar to each other. This was due to the evaluation of HH meaningfulness and significance values ($P>0.05$) of the coefficients in model 1. It was observed that these values were not statistically meaningful and the relationship between LW and independent variable HH was not significant. The average accuracy rates (Eqs. (6) and (7)) and the average error rates were respectively calculated as 98.15% and 1.85% for model 1. Model 4 was used instead of model 1 in which HH was determined as statistically non-significant ($P>0.05$). However, since the average accuracy rates, and the r and R^2 values of model 1 were obtained higher than those of model 4, then model 1 was used in IA software and evaluations.

Moreover, the significance levels of the relationship between the independent variables (WH, HH, BL and HW) having influence on the dependent variable (LW) can also be seen in column P (significance levels for ANOVA) of Table 2 that the relationship between the variables in the equations was statistically significant and meaningful.

The LWs estimated with multi linear regression equations (model 1) and all the independent variables are given in Table 3. The accuracy rate between estimated and measured weights was calculated as 98.15% by using Eqs. (6) and (7). It was observed that the estimated LW values were close to real LWs, and there was a strong correlation between them. Therefore, this high accuracy rate proves the chance of estimating the LWs of cows with 1.85% error by using multi regression equations (model 1). Moreover, the relationship between them was analyzed with MATLAB software, and the comparison graph given in Fig. 5 indicates the correlation coefficient as $r=0.9787$ that is close to 1 (see Fig. 5). This coefficient shows that there is a strong relationship between these data. Therefore, it can be suggested that the estimation with regression equations can reliably be used to predict the values for LW. As it can be concluded from the rates, the computer-based IA method can be used confidently in order to determine the BMs of animals.

The correlations obtained and the error rates calculated show that the body dimensions obtained through IA provide better results when compared to manually measured body dimensions. This difference arises from the fact that the measurements cannot be performed precisely while measuring the manual BMs due to the problems faced in approaching the animals, and the animal bows, moves and does not stand still during the measurements. Therefore, since such problems result in unreliable BMs and prevent

Table 3
Linear effects of BMs obtained with IA and LW prediction equations.

Model number	Estimation equation (y)	Constant (a_0)	Regression coefficients				r	R^2	P
			WH (b_1)	HH (b_2)	BL (b_3)	HW (b_4)			
1	$a+b_1x_1+b_2x_2+b_3x_3+b_4x_4$	-999.560^{***}	5.151^{***}	0.753^{ns}	2.046^{***}	7.863^{***}	0.979	0.958	0.000
2	$a+b_1x_1+b_2x_2+b_3x_3$	-1485.244^{***}	9.747^{***}	1.568^{*}	3.087^{***}	–	0.961	0.923	0.000
3	$a+b_1x_1+b_2x_2+b_4x_4$	-946.569^{***}	6.194^{***}	1.308^{*}	–	9.026^{***}	0.973	0.948	0.000
4	$a+b_1x_1+b_3x_3+b_4x_4$	-982.308^{***}	5.611^{***}	–	2.147^{***}	8.029^{***}	0.978	0.957	0.000
5	$a+b_2x_2+b_3x_3+b_4x_4$	-737.073^{***}	–	2.133^{***}	2.616^{***}	10.672^{***}	0.971	0.944	0.000
6	$a+b_1x_1+b_2x_2$	-1515.977^{***}	12.558^{***}	2.671^{**}	–	–	0.947	0.897	0.000
7	$a+b_1x_1+b_3x_3$	-1470.347^{***}	10.935^{***}	–	3.350^{***}	–	0.959	0.920	0.000
8	$a+b_1x_1+b_4x_4$	-910.728^{***}	7.117^{***}	–	–	9.429^{***}	0.972	0.945	0.000
9	$a+b_2x_2+b_3x_3$	-1238.059^{***}	–	6.211^{***}	5.705^{***}	–	0.921	0.849	0.000
10	$a+b_2x_2+b_4x_4$	-593.214^{***}	–	3.265^{***}	–	13.019^{***}	0.962	0.926	0.000
11	$a+b_3x_3+b_4x_4$	-599.169^{***}	–	–	3.132^{***}	12.085^{***}	0.968	0.937	0.000
12	$a+b_1x_1$	-1493.732^{***}	15.144^{***}	–	–	–	0.942	0.888	0.000
13	$a+b_2x_2$	-1138.861^{***}	–	12.184^{***}	–	–	0.857	0.735	0.000
14	$a+b_3x_3$	-959.094^{***}	–	–	9.311^{***}	–	0.880	0.774	0.000
15	$a+b_4x_4$	-309.034^{**}	–	–	–	16.225^{***}	0.953	0.909	0.000

* $P<0.05$.
** $P<0.01$.
*** $P<0.001$.
^{ns} Not significant ($P>0.05$).

Table 4
Polynomial effects of BMs obtained with IA and LW prediction equations.

Estimation equation (y)	Constant (a_0)	Polynomial regression coefficients				SSE	RMSE	r	R^2
		Linear (b_1)	Quadratic (b_2)	Cubic (b_3)	Fourth degree (b_4)				
$a+b_1x_1+b_2x_1^2$	-3127^{*}	39.13^{ns}	-0.08802^{ns}			56940.9	22.55	0.94	0.89
$a+b_1x_1+b_2x_1^2+b_3x_1^3$	147800^{ns}	-3277^{ns}	24.18^{***}	-0.05915^{ns}		43840.8	19.87	0.96	0.92
$a+b_1x_1+b_2x_1^2+b_3x_1^3+b_4x_1^4$	-2779312	82450	-916.4	4.523	-0.008363	31621.2	16.95	0.97	0.94
$a+b_1x_2+b_2x_2^2$	-3478^{ns}	45.55^{ns}	-0.1188^{ns}			135458.3	34.78	0.85	0.74
$a+b_1x_2+b_2x_2^2+b_3x_2^3$	102932^{ns}	-2242.4^{ns}	16.266^{ns}	-0.0391^{ns}		132918.6	34.60	0.86	0.74
$a+b_1x_2+b_2x_2^2+b_3x_2^3+b_4x_2^4$	2436000	-69010	732.3	-3.45	0.006089	131265.2	34.54	0.85	0.75
$a+b_1x_3+b_2x_3^2$	427.3^{ns}	-7.656^{ns}	0.05183^{ns}			115532.3	32.11	0.88	0.78
$a+b_1x_3+b_2x_3^2+b_3x_3^3$	33810^{ns}	-618^{ns}	3.767^{ns}	-0.007529^{ns}		114127.0	32.07	0.88	0.78
$a+b_1x_3+b_2x_3^2+b_3x_3^3+b_4x_3^4$	-1050000	25820	-237.9	0.9731	-0.00149	108553.0	31.41	0.89	0.79
$a+b_1x_4+b_2x_4^2$	-87.57^{ns}	8.05^{ns}	0.07504^{ns}			46595.5	20.40	0.95	0.91
$a+b_1x_4+b_2x_4^2+b_3x_4^3$	-5026^{ns}	281.7^{ns}	-4.956^{ns}	0.03068^{ns}		45032.3	20.14	0.96	0.91
$a+b_1x_4+b_2x_4^2+b_3x_4^3+b_4x_4^4$	-11670	771.3	-18.42	0.1947	-0.0007456	45007.1	20.23	0.96	0.91

x_1 = WH; x_2 = HH; x_3 = BL; x_4 = HW. $^{**}P<0.01$.
* $P<0.05$.
*** $P<0.001$.
^{ns} Not significant ($P>0.05$).

obtaining accurate results in measuring, they should be eliminated through the IA procedure, which can take BMs without touching and approaching to the animal.

In the next step, LW estimation procedures were performed by creating polynomial (quadratic, cubic and fourth degree) equations, in addition to the single and multiple regression equations created by using IA and obtained BMs. When Table 4 is examined, it can be seen that the highest correlation of $r=0.9536$ was obtained for HW in the quadratic effects within the regression coefficient for LW; the highest correlation of $r=0.9563$ was obtained for WH in the cubic effects within the regression coefficient for LW; and the highest correlation of $r=0.9676$ was obtained for WH in the fourth degree effects within the regression coefficient for LW. Examining all the equations given in Table 4, the highest correlation was obtained through the fourth degree regression equation formed with WH. When the obtained correlations in Table 4 are considered, there is a similar directional perfect relationship between WH and LW. Moreover, LW was estimated through the fourth degree regression equation, and the determination coefficient of $R^2=0.94$ was statistically significant and consistent. Table 4 shows the relationship between the LW estimated through polynomial (quadratic, cubic and fourth degree) equations and the BMs obtained through the IA process. Furthermore, SSE (sum square error) and RMSE (root mean square error) values were also calculated that the same relationship was also stated in these error values respectively.

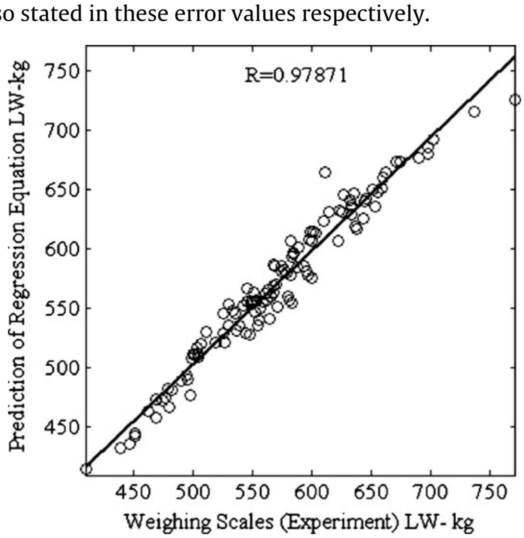

Fig. 5. The relationship between scales and predicted values of LW.

In Table 4, although the correlations in the LW estimated through polynomial (quadratic, cubic and fourth degree) equations are high, the meaningfulness and significance values ($P>0.05$) of the coefficients were evaluated. It is seen that these values are statistically meaningless (random) and the relationship between LW and independent variables is not significant.

4. Conclusions and future work

In this study, it was shown that the BMs of Holstein cows can be obtained by using IA operation. The computer-based IA method appears to be a very reliable system for the evaluation of Holstein cows' morphology and for the estimation of their LWs by means of regression equations. Moreover, this method is viable, quick, effective and very practical on animals to obtain their BMs. Additionally, this approach can be used efficiently as a directly computerized and more precise recording process in comparison to the metric measurements.

The problems related to costs, difficulties, personnel, risks and stresses encountered during the MM and weighing of animal processes will be solved by using the digital IA method. It will be a reasonable solution to study Holstein cows by taking their digital images using a computer-aided system from various directions with different angles at a certain distance. The computer-based system was located on the passing-ways of the cows (entrance and exit of milking parlors, in front of the automatic feeding units) in order to prevent unfavorable problems that may occur for both cows and personnel during the weighing process. Additionally, this method has advantages in terms of being economical, requiring less number of personnel, having unstressed medium for animals, and recording data that can be used for long-term future analyses, statistical studies, etc.

It will be advantageous, especially in big farms where animal growth (weight) should be recorded and monitored daily. Therefore, the observation of LW, especially in big herds, will be carried out more frequently in a more sensitive and objective way. Decreasing the error rates and increasing the sensitivity of evaluations will increase the efficiency of the proposed system and provide the prevention and diagnosis of possible health problems resulting from the feeding program. Moreover, when the difficulties in monitoring all the cows in large dairy cattle farms are considered, it will be better understood that the suggested IA system will provide ease of usage, contribution to management of the herd, and save both time and money.

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