A depth camera-based system for automatic measurement of live cattle body parameters

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Abstract. Many studies have purposed in order to measure live animal body characteristics using RGB-D cameras. However, most of these studies were made only for specific body measurements in interactive manner. A deviation from the expected animal body characteristics can indicate ill thrift, diseases and vitality. Currently, the farm manager can measure the body characteristics manually. Manual measuring generally requires a lot of labor, and it is, therefore, time consuming and stressful for animals. In this work we propose a non-intrusive depth camera-based system for automatic measurement of various cattle body parameters such as linear and integral characteristics along directional lines and local areas, geodesic distances, perimeters of cross sections, etc.

1. Introduction

New fast and high-quality methods of animal expert evaluation have been developing due to growing interests in the national economy [1, 2]. In order to increase productivity in agriculture, objective and everyday assessments of physiological condition and productivity of animals in livestock complexes are required. Because of high labor expenses and inaccuracy (due to subjectivity) of traditional methods of expert evaluation, the development of new methods for automatic expert assessment of animals exploiting modern high technology in engineering is an important scientific and practical task.

Automatic 3D processing methods used for different characterisation parameters and behavioural categories in cattle are described in [1, 2]. 3D computer vision systems have been most commonly applied as non-invasive and cheap ways to detect behaviour, group and individual features for cows. One of the main goals in livestock automation research is developing and testing 3D computer vision systems in commercial farm. Also, automatic adjustment of algorithms as cows grow or change reproductive status, monitoring and changing features of livestock during the whole period of husbandry is another task of research in computer vision. The monitoring systems should work in livestock farms with changing and challenging ambient situations, e.g. temperature, moisture, dust and light changes. Furthermore, there are major practical challenges in automation of individual livestock monitoring. Individual animal identification can be achieved using radio frequency tags or different feature detection algorithms. However, the main problem of the systems is animal scare due to unfamiliar noise, presence
of overhead devices, which disrupt normal behaviours. Today the main goal is to develop complete real time systems for monitoring cow behaviours according to their nature and taking account the changes in environmental parameters to allow detection of behavioural alterations. Also, the development of operability, automated, easy and friendly real-time systems is another task.

The main purpose of measuring animals and evaluating their exterior using measurements is to make the assessment more accurate and to get rid of subjectivity that takes place with visual evaluation. The most important measured features estimate body proportions of animal or its linear growth. Comparability of measurements is achieved by the fact that they are taken in the same way for all animals.

A scale is used to assess the breeding value of sires, cows and young animals for annual appraisal by exterior and constitution, which includes the hip height (cm) [3]. Five-eight measurements are taken to control the growth and development of animals under production conditions; the number of measurements can be significantly increased for research purpose to study the weight and linear growth performance. Usually 12 measurements are taken to record cattle in the herd books of breeding animals: withers height, back height, hip height, chest depth, chest width, loin width, hip joint width, oblique length of the body, backside length, sciatic hill width, chest girth, metacarpus girth. The number of measurements increases to 28, and sometimes to 52 or more when examining large groups of cattle associated with the breed and formation.

Scheme of the main measurements is as follows:
1. Withers height is defined as the highest point at the withers;
2. Hip height is the height of the highest point at the sacrum;
3. Oblique length of the body is from the extreme anterior point of the protrusion of the humerus to the extreme posterior internal protrusion of the sciatic hill;
4. Straight length of the body is (horizontally) from the vertical line tangent to the extreme anterior point of the humerus, to the vertical line tangential to the extreme posterior internal protrusion of the sciatic hill;
5. Chest girth is the vertical tangent to the back corner of the shoulder blade.

This paper addresses the following research problems: 1) on the base of multi-sensory data, real-time creation of the 3D model of cattle; 2) the design of a system for automatic measurement of morphological characteristics of animals according to the 3D model with accuracy exceeding existing measurement systems; 3) the design of technology and system for automatic integrated assessment (value) of each farm animal, taking into account all the previous measurements of morphological characteristics of constitution and exterior, breed and origin, productivity and development, quality of offspring and reproductive ability.

The paper is organized as follows. Section 2 discusses related works for 3D automatic measurement of cow. Section 3 describes the proposed system for 3D cow automatic measurement using RGB-D sensors. Results of real experiments are provided in Section 4. Finally, Section 5 summarizes our conclusions.

2. Related works
A reliable system for evaluation of Holstein cows™ morphology and for estimation of their live weight was proposed in [4]. This system can be used efficiently as directly computerized and more precise recording process in comparison to metric measurements, and can solve the problems related to costs, difficulties, staff, risks and stresses encountered during the measuring and weighing of cow.

The authors [5] proposed automated algorithm to measure the back posture and detecting lameness in dairy farms based on 3D camera. The limitations of the 2D approach was overcome by image segmentation fully automated with the 3D camera approach in real time. The proposed system [5] can help to resolve segmentation problems such as the presence of shadows and dynamic backgrounds, which occur in the 2D side view approach.
The study of estimating body condition, body weight, and milk properties using measurements of the back posture in dairy cows from 3D cameras is described in [6]. The proposed technique [6] can solve the problems related to differences in risks, personnel, and stress associated with body condition milking, scoring, and weighing processes. However, the disadvantage of the study is the small number of cows derived from single farm and single lactation period, and no automated, no real time developed system [6].

The project [7] treats 3D model generation of cattle for estimating their body condition scores using eight camera system. However, the problem of the proposed system is that the 3D model of cattle are generated manually. Authors comment that it is impossible to generate a perfect 3D model of cattle automatically because of varying the background and influence of sun shining.

The paper [8] advances towards an automated measurement of functional traits based on 3D cameras. Also, a system based on multi-Kinect scanning passage was proposed to calculate traits from dairy cows [9]. However, automatic detection of points of interest has not been studied. The measuring of walking animals remains a problem because it is difficult and time consuming to force animals to standstill while data collection from different perspectives takes place. Also, the analysis of animal motion to ensure a better choice of recordings to measure traits with regard to the locomotor system, and the automation of body part determination were not studied [9].

The system using automatic cameras to estimate animal body measurements was proposed with a novel robust feature extraction method [10]. The work [11] presents a new breakthrough in finding accurate, objective way to assess live animal traits by capturing curvature as a form of representing body shape from 3D cameras. However, the relationship between muscle skeletal development with the manifestation of traits in steers and effects of genetic composition on trait expression have not investigated. Also, robustness of assessment using the computer vision techniques between measured fat and assessed muscle are not studied with additional data on other breeds and ages for both steers and heifers [11]. Black cattle body shape and temperature measurement system is introduced in [12].

An interactive analysis software for body measurement of livestock cows was successfully developed in [13]. However, the disadvantage of the system is absence of pose normalization because of livestock head pose and data missing issues. Also, the proposed system have not automatically determining the positive direction of pose normalization, measuring tools for geodesic distance, selecting qualified point clouds automatically.

A new system to design 3D model data of a cow using multiple cameras was proposed [14]. However, the system has problem with power-on PC and execute the data capturing. These operations become troublesome because each small box PC does not have any input/output devices such as display monitor and keyboard. Also, shining and backlighting interfere to obtain depth data well. Moreover, it is necessary to enter manually the coordinated calibration image from each device, but this work needs time and much cost.

The paper [15] suggests a novel approach to non-contact measurement for cattle with a 3D camera. The proposed approach has verified for non-contact measurement of adult large physique animals, and it greatly improves the development of animal welfare, healthy growth, animal quality improvement, automated precision feeding, and genetic breeding. However, the authors encountered problem with the different sizes ranging from calves to adult cattle, what difficult to obtain the whole silhouette several times due to the continuous movement of this breed. Also, the authors comment that the partial body model often leads to wrong registration and reconstruction.

A fully automatic computer vision system for dairy cattle locomotion monitoring was proposed in [16].The authors encountered problem of uncontrolled cow traffic. This problem can be solved by adding a selection gate in front of the setup, allowing a minimal time interval between two cows passing. The paper [17] proposed a cow calving monitoring system using 3D camera. However, the disadvantage of this system is a low recognition accuracy because of testing of a small number of cows and a 3D camera.

The study [18] predicted dairy cow body weight with automatically measured morphological traits using 3D camera. Low quality problem of this prediction associated with the prediction model and the
quality of automated morphological trait measurement. Also, selecting predictive traits, improving
model structure, or combination thereof were not studied. This model is not yet suitable for monitoring
of body weight and detecting anomalies in cow’s health status because of quality of automated
morphological trait measurement, choice of model input variables, and type of prediction model.

A system for non-invasive extraction of quantitative parameters for body cow three-dimensional
analysis was proposed in [19]. The system evaluated the hip distance, body length and height, chest
girth, depth, back slope, and head size of cow. The proposed method clearly needs pre-industrialization
engineering activity to allow automatic data collection and extraction. However, the effects of prolonged
dust exposition on an infrared camera and presence of high vibrations levels have not been studied in
[19].

A system for a body condition classification model was proposed using extracted features from
multiple 3D cameras [20]. This study is a necessary step to fully automated system in order to
continuously measure dynamic variations in body fat reserves of cows [20].

A new scanning technology for assessing animal morphology was proposed [21]. The main problem
of the system is no real time image processing. Also, the disadvantage of the system is absence of
automation of image analysis: cleaning, reconstruction and extraction of measurements. Moreover, the
system has no automatic estimation of visual body condition, morphological scoring for selection
purposes, body weight, surface area and volume, body surface area.

3. The proposed system
In this section, we describe the proposed system for 3D cattle automatic measurement using RGB-D
sensors.

3D reconstruction with multiple ICP consists of the following steps:
1. Estimate rough poses of three Kinect cameras and extrinsic parameters using initial rigid
   transformation matrix in the Iterative Closest Point (ICP) algorithm [22].
2. Registration of a RGB and depth data from the three Kinect cameras.
3. Improving the quality of the depth map by depth denoising algorithm based on cascade
   mechanism [23]. It is necessary step because the depth map provided by RGB-D cameras is often
   noisy due to imperfections associated with infrared light reflections, and missing pixels in the
depth map.
4. Creation of a point cloud \(PC_i, i = 1, ..., 3\) using RGB and depth data from the three Kinect
   cameras.
5. Detection and matching of global key points in RGB and depth data of \(PC_i\) and \(PC_{i-1}\) with
   Intrinsic Shape Signatures 3D (ISS3D) keypoint detection algorithm [24].
6. Remove outliers with the RANSAC [24].
7. Compute transformation matrix with the ICP algorithm using the associate 3D points of inliers
   with initial estimation for the rotation and translation matrix from an initial rough estimate of the
   camera poses.
8. Perform point cloud fusion \(PC_i, i = 1, ..., 3\) to generate the 3D model of cattle [25].
9. Perform the 3D mesh form point cloud of cattle [25].

The proposed system for 3D cow reconstruction enables high quality 3D measurements of motion
farm animals. Our computer-based system was located on the passing-ways of cattle (entrance and exit
gate 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. A problem of the measuring
of walking animals is solved in the proposed system, as it is difficult and time consuming to force
animals to standstill while data collection from different perspectives takes place.

The measurement scene is shown in Fig. 1. Kinect cameras are placed on the right and left sides of
the cow at distance of 2 meters from the cow, and the third Kinect camera is placed above the cow at
height of 3 meters from the ground.
The proposed system for 3D cow automatic measurement using 3D model consists of the following steps:

1. 3D model alignment (Fig. 2). After the 3D model of object is aligned, it is possible to automatically make all measurements according to our models (Fig. 3).

2. Automation of measuring withers height. We choose the maximum distance from the floor to the cut points parallel to the OYZ plane at distance of 80 cm along the axis OX (Fig. 4).

3. Automation of measuring back height. We do the same thing with distance of 160 cm along the axis OX (Fig. 4).

4. Automation of the another measurements of the object height, body lengths, chest depth and width, back width, in hip joints and in the sciatic hills is based on the search for specific markers of points (attached by a zoologist to the cow) in RGB image of the object, and also in the translation of coordinates in 3D space in the colored point cloud (Fig. 5).

5. Automation of measurement of chest girth is reduced to calculation of the perimeter of the section model parallel to the YOZ plane at distance of 90 cm along the axis OX (Fig. 6).

6. Automation of measurement of circumference of the metacarpus is performed by creating a cut parallel to the XOZ plane. Measurement is performed by calculating of the perimeter of the section model parallel to the axis YOZ at distance of 15 cm along the axis OY (Fig. 6).
Figure 3. 3D point cloud model and 3D mesh model after 3D model alignment.

Figure 4. Automation of measuring withers height and back height.

Figure 5. Specific markers in hip joints and in the sciatic hills attached by a zoologist to the animal.

Figure 6. Automation of measuring withers height and back height.
4. Experimental results
In this section, computer simulation results for 3D cow reconstruction with the proposed system are presented and discussed.

This study was conducted at the Federal Research Centre of Biological Systems and Agro-technologies of the Russian Academy of Sciences. The Hereford cattle were group-housed in the measurement passing hall.

17 measurements were taken of live animals and automatically extracted from the 3D model of animal (Figs. 7, 8, 9): withers height, back height, loin height, hip height, sciatic hill height, chest depth, oblique length of the body, straight length of the body, backside length, chest width, loin width, back width, hip joint width, sciatic hill width, chest girth, metacarpus girth, backside half-girth.

**Figure 7.** Results of automated measuring of the animal: withers height, back height, loin height, hip height, sciatic hill height, chest depth.

**Figure 8.** Results of automated measuring of the animal: oblique length of the body, straight length of the body, backside length, chest width, loin width, back width.
Figure 9. Results of automated measuring of the animal: hip joint width, sciatic hill width, chest girth, metacarpus girth, backside half-girth.

Extracted measurements from 3D model of cattle are slightly different than corresponding real world measurements (Tab. 1). The average measurement difference was 3.6%. The greatest average difference (14.6%) was obtained in chest width measurement. The smallest average difference (2.3%) was obtained in the measurement of back height.

Experimental results show the feasibility of the proposed system, but the obtained results are different from manual measurement. One of the reasons of the difference is caused by the body hair of cattle. During real measurements, the zoologist presses the animal’s hair to the surface (Fig. 10). Therefore it should be consider the length of the cow hair for measuring.

Large differences in measurements are also justified by the movement of the model. Zoologist measures a static animal. The program measures a model built on a moving animal, resulting in difference on measurements in the chest, hip part (movable joints of the animal).

Figure 10. During real measurements, the zoologist presses the animal’s hair to the surface.
Table 1. Results of measurements using the proposed system for 3D cow automatic measurement

| Measurement           | Real (cm) | Our system (cm) | Error (%) |
|-----------------------|-----------|-----------------|-----------|
| Withers height        | 130       | 135             | 3.8       |
| Back height           | 131       | 134             | 2.3       |
| Loin height           | 137       | 141             | 2.9       |
| Hip height            | 134       | 141             | 5.2       |
| Sciatic hill height   | 123       | 123             | 0.0       |
| Chest depth           | 72        | 76              | 5.6       |
| Oblique length of     | 173       | 174             | 0.6       |
| Straight length of    | 150       | 153             | 2.0       |
| Backside length       | 53        | 50              | 5.7       |
| Chest width           | 48        | 55              | 14.6      |
| Loin width            | 61        | 65              | 6.6       |
| Back width            | 58        | 61              | 5.2       |
| Hip joint width       | 55        | 59              | 7.3       |
| Sciatic hill width    | 33        | 34              | 3.0       |
| Chest girth           | 224       | 230             | 2.7       |
| Metacarpus girth      | 21        | 21              | 0.0       |
| Backside half-girth   | 52        | 55              | 5.8       |

5. Conclusion
In this paper, we designed a system for automatic measurement of morphological characteristics of cattle according to the 3D model with the accuracy exceeding existing measurement systems. Our proposed system is a non-intrusive depth camera-based system for automatic measurement of various cattle body parameters such as linear and integral characteristics along directional lines and local areas, geodesic distances, perimeters of cross sections, etc. Our computer-based system was located on the passing-ways of cows using three Kinect cameras. The experiment has shown that the proposed system is more objective and accurate in sense of certainty of indicators compared with visual estimation. Moreover, the objectivity and accuracy of the proposed system are rather relative, since all measurements are associated with known errors.

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