Accurate 3D shape recovery of live cattle with three depth cameras

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Abstract. The animal carcass is one of important indicators of the development of young cattles, therefore it is essential to follow it up. Only the animals with sufficient body frame and with well-muscled top can be successfully fattened to high body mass. In this work we propose a prototype of non-intrusive scanning system for recovery of live cattle 3D shape with three depth cameras. To obtain the highest precision in measuring of cattle shape, we use calibrated cameras, curve fitting algorithms for solving the problem of missing data owing to partial occlusion, and algorithms for accurate fusion of point cloud data from three cameras. The measured animal 3D shape can be used, for instance, for automatic and precise estimation of body dimensions of live animals and for predicting the body weight of individual cattle as well as for daily monitoring production capacity of cattle.

1. Introduction
Nowadays, highly productive agriculture requires the design of automated and high-tech methods [1, 2]. The common approach to animal assessment is based on the results of visual inspection, palping the animal, and generally contact measurements. Existing systems for contactless measurements of animal characteristics use exclusively linear characteristics and operate under controlled conditions [3]. To perform the integrated assessment of these linear characteristics is not enough, because three-dimensional morphological characteristics of the animal are not taken into account. Therefore, at the present time expert assessments are carried out subjectively by professional specialists taking into account available linear measurements. The accuracy of such assessments depends on both the experience of a particular specialist and his physical condition. Therefore, it is extremely important to design a system for automatic integrated assessment of animals for pedigree and commercial value, health and use prospects.

A prospective technology of expertise should be based on contactless measurement of the animals characteristics with subsequent data processing. The proposed approach to the development of an expert assessment technology for animals is fundamentally new, because we are going to use modern engineering and scientific advances in computer science, and the human factor is completely excluded from the process of animal evaluation. Existing systems of contactless measurements of animal characteristics are based on 20 years old engineering technologies, and use only linear characteristics for subjective expert evaluation.
Using modern technology has helped farm managers to improve animal production and welfare [3, 4]. There are now many different types of techniques which could be used in new commercially-applicable technology tools for detection of feeding, locomotion, lying, drinking, aggressive and reproductive behaviours of cattle [3, 4]. Most of the studies have focused on the use of CCD cameras: 5 CCD cameras [5], 8 CCD cameras [6], 16 CCD cameras [6]. Application of modern digital technologies in 3D imaging systems (Kinect, TOF cameras) offer further possibilities for improvement: one CCD and one 3D camera [7], one 3D camera [8-13], 2 3D cameras [14, 15], 3 3D cameras [16-18], 4 3D cameras [1, 2], 6 3D cameras [19]. Modern technologies based on 3D shape analysis could use a high precision laser: one laser camera [10], 5 laser cameras [20].

For constructing a three-dimensional model of the cow’s shape, three scenarios of the measurement system are considered: 1) several cameras are fixed on a platform moving along known trajectory around the object (the camera position and the simplified scheme of operation of all algorithmic components of the system are exactly known) [6]; 2) the camera is in hands of a person who passes around the object (the actual situation of measurement in a field) [8, 15]; 3) several cameras capture the animal simultaneously and are fixed on a platform around the gate, through which the animal quickly passes (the actual situation of measurement in a room) [7, 9].

In this paper, a new technology is proposed and an automated expert assessment system for animals is designed. The proposed technology is based on methods of contactless three-dimensional reconstruction of the body surface of animals and parameters of productivity, genetic characteristics and animal health, closely related to features of their constitution and exterior. We use three cameras to capture the animal images simultaneously, the cameras are fixed on a platform around the gate, through which the animal quickly passes.

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

2. Related works
The project [6] treats 3D model generation of cattle for estimating their body condition scores using eight camera system. From the experimental results [6], the authors showed that the estimation of cows’ weights is possible by the proposed eight camera system. Also, 16 camera system can generate better 3D model data of a cow rather than the eight camera system. However, the problem of the proposed system is that the 3D model of cattle is generated manually. Authors consider that it is impossible to generate a perfect 3D model of cattle automatically because of various background and influence of sun shining.

The author [7] proposed an automated algorithm to measure the back posture and detecting lameness in dairy farms based on a 3D camera. The experimetal results were shown that the 3D camera approach can be used to overcome the limitations of the 2D approach, and the 3D camera approach can be used to detect lameness of walking cows. Also, a 3D camera from top view can be useful for automated measuring of back posture to overcome segmentation problems such as shadows and dynamic backgrounds which occur in the 2D side view approach. The 3D camera method also proved to be suitable for an automated lameness detection system since it reached results comparable to the 2D camera method when the back arch segmentation was performed manually.

The cow calving monitoring system using the 3D camera was suggested to detect the increasing number of posture changing before calving and to predict the calving time [12]. The proposed system can work in night time under various illumination conditions. Therefore, it can be applied to measure other calving features such as tail up and so on. However, the proposed system cannot detect abnormal behavior in cow calving process, and the recognition accuracy by using more cows and using multiple cameras are not discussed [12].

The work [13] predicted dairy cow body weight with automatically measured morphological traits using 3D camera and achieved the performance similar to that of manual and semiautomated methods. The accurate prediction depends on quality of automated morphological trait measurement, the choice
of model input variables, and type of prediction model. The monitoring short-term body weight variation or detecting anomalies in cows’ health status are impossible in the proposed system [13].

A fully automatic computer vision system for dairy cow locomotion monitoring was proposed in [9]. The disadvantage of the system is a cow traffic which affected to the success rate of the system, and daily and cow-individual variations due to the cow traffic. Also, the system performance is affected by parity of the cows, lactation stage, and recording duration.

3D object recognition system was presented in [1] and applied to body parts of dairy cows. An automated measurement of functional traits with 3D cameras was proposed. The results could be considered as a successful approach towards automating conformation recording.

The system of calculating traits from dairy cows using multi-Kinect scanning passage is presented in [2]. In the paper [17], a low cost instrument has been proposed as non-invasive extraction of quantitative parameters for body cow 3D analysis. A novel robust feature extraction method was designed in [11] using automatic cameras to estimate body measurements with minimum interference in daily activities of animals.

A novel approach of contactless measurement for cattle body dimensions with a 3D camera was proposed in [10]. The approach [10] is the feasibility of non-contact measurement of for 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 measuring system [10] does not take into account different sizes from calves to adult cattle.

An interactive 3D software for body measurement of livestock with similar forms of cows was proposed in [15]. A novel idea of integrating pose normalization and segmentation into the input data processing pipeline is the main difference comparing with traditional measuring instruments. However, the method of pose normalization does not robust to livestock head pose and data missing issues.

A new scanning technology for assessing animal morphology was proposed in [20]. A method of body measurements of the Holstein cows was proposed in [5] by using digital image analysis for evaluation of the Holstein cows’ morphology and for estimation of their live weight. Machine vision technology of considering body condition score and included all extracted features from multiple 3D cameras in the 3D model is presented in [18].

3. The proposed system

In this section, we describe the proposed system for 3D cow reconstruction based on the use of multiple Iterative Closest Point (ICP) [21].

3D reconstruction with multiple ICP consists of the following steps:

1. Estimate initial rough of three Kinect cameras poses and extrinsic parameters using initial rigid transformation matrix in the ICP algorithm [22].
2. Registration of RGB and depth data from the Kinect cameras.
3. Improve quality of the depth map by applying depth denoising algorithm based on a cascade mechanism [23]. It is necessary this step because the depth map provided by the RGB-D camera is noisy due to imperfections associated with infrared light reflections, and missing pixels appearing as black holes in the depth maps.
4. Creation of a point cloud $P_{Ci}, i = 1, \ldots, 3$ using RGB and depth data from the 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) and Scale Invariant Feature Transform 3D (SIFT3D) keypoint detection algorithms [24].
6. Remove outliers with the correspondence rejector 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 the general 3D model of cow [21].
9. Perform 3D mesh from point cloud of cow [21].

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 the cows (entrance and exit gates of milking parlors, in front of automatic feeding units) in order to prevent unfavorable problems that may occur for both cows and personal during the weighing process. A problem of measuring of walking animals is solved by the proposed system, as it is difficult and time consuming to force animals to stand still while data collection from different perspectives takes place.

The measurement scene is shown in Fig. 0. Kinect cameras are placed on the right and left sides of the cow at a distance of 2 meters from the cow, and a third Kinect camera is placed above the cow at a height of 3 meters from the ground.

![Figure 1. The measurement scene with three Kinect cameras.](image)

Synchronization is a real problem for automated process for capturing RGB-D data using Kinect cameras. The situation worsens if the capture process uses large number of devices (2, 3, 6 or more RGB-D devices like Kinect v2). Some researchers suggest the use of a small box PC and connect to each Kinect sensor [19]. Start of the capture synchronization is performed using UDP/Multicast communication in local network between each small box PC and master PC. Authors [19] have achieved average delay about 86 ms, but their system has the following problems: synchronization of starting capturing, shining and backlighting do not allow to obtain depth data well, it is necessary to enter manually coordinated calibration image for long time. Our approach for synchronization of capturing is free of such problems [19]. The scheme of synchronization of data capturing is shown in Fig. 1. Each of the RGB-D cameras (Kinect v2) is connected to a laptop. All laptops are connected to the local network. When the program starts, each laptop synchronizes time with one time server. Automation of the recording start process is implemented in a similar way, by sending TCP packages over the local network. Each device captures about 20 frames of the animal during its passage in front of the camera. The resulting point clouds are stored first in RAM of laptops, then dumped to the hard disk with the exact time of receiving each point cloud. Since time on laptops is synchronized, it is possible to select the best point clouds correspondence between the three devices.
4. Experimental results

In this section, computer simulation results of 3D cow reconstruction with the proposed system using RGB-D cameras 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, Orenburg, Russia. Ten Hereford cattles were group-housed in the measurement passing hall of the experimental farm.

To evaluate the performance of the proposed system, we carried out point cloud fusion and 3D reconstruction of live cattle. Fig. 3 shows RGB images and depth maps of the cattle captured by three Kinect cameras. Fig. 4 shows point clouds captured by the Kinect cameras.
Figure 4. Point clouds of the cattle captured with three Kinect cameras.

The metric of evaluation the performance of the proposed system is the root mean square error (RMSE) of measurements. Corresponding RMSE values calculated for each pair of three views with the proposed system using SIFT3D and ISS3D keypoint detection algorithms are shown in Table 1. ISS3D keypoint detection algorithm yields the best result in terms of the RMSE.

| KDA               | Left and top views | Right and top views |
|-------------------|--------------------|---------------------|
| SIFT3D            | 3.2e-03            | 2.1e-03             |
| ISS3D             | 2.5e-03            | 1.4e-03             |

Table 1. Results of measurements with the proposed system utilizing SIFT3D and ISS3D keypoint detection algorithms (KDA) for each pair of three views of the cattle.

The feature matching results of each pair point clouds are shown in Fig. 5 for each pair of the three views of the cattle. The small circles indicate that the keypoints detected in both point clouds separately, and the lines indicate the matches. The results show that there are a lot of correct matches after applying the RANSAC. We also used the passthrough filter by Z and Y axes.

Figure 5. 3D keypoint matching result in the proposed system with ISS3D keypoint detection algorithm.

Finally, we use point cloud fusion to generate the 3D model. Fig. 6 shows 3D reconstruction of the cattle obtained in the proposed system and 3D mesh model of the cattle. The 3D models are fine and accurate.
The experiment has shown that the proposed system for 3D object reconstruction is able to provide accurate 3D cow model with a low RMSE.

We performed experiments to predict the live weight (LW) of a cattle based on the obtained measurements of heart girth (HG) and height at the withers (HW). Ten cattle were weighed (kg), and their HG (cm) and HW (cm) were measured. There are three methods for estimating of approximate cattle weight [25].

The first method (M1) of predicting LW by measuring the HG using the regression equation is as follows:

\[
LW = 5.3 \cdot HG - 465,
\]

where 465 is a constant with HG of 192 cm and higher. The model M1 predicts the average LW of 84-100% of their true-live weight for the overall data with a root mean square error of 102 kg corresponding to 16% of the mean LW.

The second method (M2) for predicting the LW is based on the regression equation [25]:

\[
LW = 4.87 \cdot HG - 444.07.
\]

The model M2 predicted the average LW of 96-100% of their true-live weight for the overall data with a root mean square error of 27 kg corresponding to 4.3% of the mean LW.

The third method (M3) for predicting the LW is based on the regression equation [25]:

\[
LW = 4.08 \cdot HG + 1.61 \cdot HW + 1.42 \cdot Age - 520.9
\]

The best model M3 to predict LW of 99-100% of their true-live weight for the overall data with a root mean square error of 3 kg corresponding to 0.5% of the mean LW.

The experiment has shown that the proposed system for the 3D object reconstruction is able to predict accurately the live weight of cattle based on the obtained measurements.

5. Conclusion
In this paper, we presented a prototype of non-intrusive scanning system for recovery of live cattle 3D shape with three depth cameras. Our computer-based system is located on the passing-ways of cows using three Kinect cameras. The proposed system for 3D cattle reconstruction is based on multiple ICP and enables high quality 3D measurements of motion farm animals. The measured animal 3D shape can be used, for instance, for automatic and precise estimation of body dimensions of live animals and for predicting the body weight of individual cattle as well as for daily monitoring production capacity of cattle. The experiment has shown that the proposed system for recovery of live cattle 3D shape with three depth cameras is accurate in terms of RMSE. Also, the experiment has shown that the proposed system for 3D cattle reconstruction is able to predict accurately the live weight of a cattle based on the obtained measurements.
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