Exterior Analysis and Conformation Assessment of Cattle Using Neural Networks and Computer Vision Technology

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Abstract. This study focuses on the development and application of an automated system for conformation assessment of cattle using computer-based technologies, including neural network algorithms and 3D modeling. The aim of this study was to develop a modern method for evaluating animal body conformation using advanced digital technologies, as well as to analyze their exterior and determine the relationship between phenotypic features and genetic potential. The study subjects were Holstein cows bred in Kazakhstan. The methodology included the use of Intel RealSense D456 stereoscopic depth camera, Raspberry Pi 5, and the development of neural models for automatic detection of animal body measurements. Based on the image processing results, the accuracy was 96%, with an average deviation of 7.2 mm. The technology enables automated conformation assessment and provides fast and precise measurement of parameters. The results can be integrated with genomic data to improve selection decisions.

Keywords: gene pool, selection, body type, cow body type index, pelvis area index, stereoscopic depth camera, infrared sensors, 3D imaging, programmable controller.

1 Introduction

Preservation of the gene pool, improvement of existing breeds, and effective use of the best representatives of this agricultural animal genetic group constitute a fundamental challenge for zootechnical science, agricultural specialists, and livestock production technologists. Progress in animal breeding is possible when genetic diversity exists within the population and when outstanding genotypes with high adaptive capacity and suitability for specific rearing conditions are utilized. The initial stage of livestock breeding is the evaluation of breeding value. In the previous century, the breeding value of dairy cattle was assessed primarily through phenotypic indicators, including milk productivity and exterior traits [1-4].

In recent decades, more effective methods for assessing breeding value have been developed, based on molecular genetic markers. A significant breakthrough was the decoding of genomes of major agricultural species (cattle, pigs, and sheep) [5, 6], as well as the use of statistical approaches, particularly the Best Linear Unbiased Prediction (BLUP). Breeding value estimation using BLUP eliminates the influence of non-genetic factors on the variability of selected traits in a population and makes it possible to isolate and assess the genetic component with high accuracy [7-10].

One of the primary objectives for breeders is to ensure stable inheritance of biological traits in pedigree ("model") animals so they consistently transmit desirable characteristics to their offspring. At certain stages of work with genetic groups and entire herds, it becomes necessary to achieve minimal phenotypic and, if possible, genetic variability [11, 12].

High efficiency of cattle breeding value assessment based on genomic evaluation is achievable only when constitutional and conformation characteristics of animals are objectively studied. For specialists, this provides insights into the biological characteristics and economic productivity, advantages and disadvantages, as well as the ability to identify signs of constitutional weakness and determine the breeding value of an animal [12-14].

In countries with developed dairy cattle breeding (USA, Canada, Japan, European states), body type, together with milk productivity, is one of the primary selection traits in dairy breed improvement [15].

The dairy cow type was originally developed by American breeders for Holstein cattle. This type supports high milk yield while maintaining animal health under intensive use and serves as a model for dairy cows in all countries where Holstein breeding is widespread. Conformation traits are closely associated with economic value and rearing efficiency. Accurate evaluation and analysis of conformation traits are essential for determining the genetic benefits of animals [13, 16].

The production type of an animal is considered as an integrated trait shaped by inherited and environmental factors. Such animals are best adapted to specific environmental conditions and optimally express their genetic potential.

A scientific approach and digital technologies enable more accurate determination of an animal's production type. Body type defines the relationship between animals' ability to perform certain functions under intensive farming conditions and to express their genetically determined productivity.

Globally, more than 500 million cattle are evaluated annually for breeding value, conformation, health, and potential for use. However, most measurements and conformation assessments are labor-intensive and subjective [14, 17-22].

The efficiency of cattle breeding largely depends on producing harmonious animals of ideal type tailored to production goals and management technologies. Exclusion of animals with serious conformation defects from selection and process and their timely identification helps prevent accumulation of undesirable genes and their spread within the breed. Conformation typing and exterior analysis are also necessary for standardizing management systems and adjusting feeding and milking programs in industrial production environments.

The development of a comprehensive conformation assessment system using information technologies and computer vision, as well as defining animal biological value and developing methods for predicting productive and reproductive performance at early stages of body development, is a relevant scientific and practical task.

Currently, contactless remote measurement of conformation parameters and exterior analysis using computer technologies is of significant interest in cattle breeding and genetics. They reduce animals' stress responses and shorten the time required for measurement taking.

Improvement of breeding work for dairy cattle and adjustment of feeding and management technologies is possible through modern digital solutions. Software development makes it possible to assess conformation and analyze physiological status of animals at a new professional level, excluding faults and human errors. Using neural network technologies, the software determines body type and constructs an outline diagram.

This technology for measuring and analyzing exterior traits offers several advantages:

• neural-network-based gates with high mobility and functionality;
• high measurement accuracy;
• elimination of human-related errors;
• no need for manual data recording;
• immediate result.

The need to create an automated system for assessing exterior arises in selection and in determining process parameters, which require verified data on the current condition of animals [23].

In this regard, the aim of our study was to develop a method for examining animal conformation using digital technologies and computer vision, to analyze the results of objective exterior assessment of cows and replacement heifers, and to examine the patterns of phenotypic trait formation in the realization of the genetic potential of dairy cows under specific environmental conditions.

2 Materials and Methods

The development of software for determining body conformation parameters and analyzing the physiological status of animals based on exterior was carried out using scientific experimental studies from 2024 to 2025. The study subjects were Holstein cows bred at agricultural enterprises of the Republic of Kazakhstan. The sample included 450 first lactation cows and 200 replacement heifers (daughters of the analyzed cows). The main data on animal origin and milk productivity were taken from production and zootechnical records, as well as the electronic database of the Information Analytical System (IAS).

Cow conformation was assessed between the 90th and 150th day of lactation; replacement heifers were evaluated at 10-12 months of age. We selected the following measurements: height at withers, height at hips, chest depth, chest width, width at hips, straight length of the pelvis area, straight body length, and cannon bone circumference. These parameters most accurately describe the animal's dimensions (carcass). Following the recommendations of Professor V. O. Vitt, we selected measurements, the ratios of which remain relatively constant with age and thus characterize the hereditary conformation type formed under specific environmental conditions. To calculate body indices, we used measurements that change in parallel during ontogenetic development, allowing the index itself to remain relatively stable [24].

3 Results and discussion

To provide a more objective assessment of animal conformation type, we calculated the exterior index (1) and the pelvis area index (2) using formulas developed by S. D. Batanov and I. A. Baranova:

$$CI = \frac{\sqrt[4]{V_{animal\ trunk} \cdot CC}}{HW} \qquad (1)$$

where the animal trunk volume is determined using the truncated pyramid formula:

$$V_{animal\ trunk} = \frac{1}{3} \cdot SBL \cdot \left((WH \cdot PL) + \sqrt{CD \cdot CW \cdot WH \cdot PL} + (CW \cdot CD)\right),$$

where CI – conformation index; SBL – straight body length; WH – width at hips; PL – pelvis area length; CD – chest depth; CW – chest width; CC – cannon bone circumference; HW – height at withers (cm).

$$PAI = \frac{\sqrt[3]{V_{pelvis\ area}}}{SBL} \qquad (2)$$

where pelvis area volume is also determined using the truncated pyramid formula:

$$V_{pelvis\ area} = \frac{1}{3} \cdot RL \cdot \left((WH \cdot LD) + \sqrt{LW \cdot PL \cdot WH \cdot LD} + (LW \cdot PL)\right),$$

where RL – rump length; LD – loin depth; LW – loin width (cm).

Exterior parameters were determined using 3D image processing of animals (Fig. 1). To obtain 3D images, Intel RealSense D456 long-range depth cameras were used. The depth camera consists of two infrared sensors (camera) and an infrared projector used to calculate the depth of objects within the field of view. The infrared sensors detect infrared radiation, while the infrared projector projects an invisible infrared dot pattern onto objects. The infrared sensors record distortions in this pattern caused by the varying distances of the objects. 3D images of animals are produced using triangulation. The calibrated camera, along with the known positions of the projector and sensors relative to one another, analyzes the displacement of each dot in the pattern. The angle of light reflection from the object is calculated. Based on this angle and the distance between the projector and sensors, the distance (depth) of each point is determined, creating a 3D representation of the object.

The cameras are connected to a programmable Raspberry Pi 5 board equipped with a quad-core Broadcom BCM2712 Arm Cortex A76 @ 2.4 GHz processor and up to 16 GB of RAM. The Raspberry Pi 5 processes input images from the cameras and allows saving measurement data obtained from these images into a separate file.

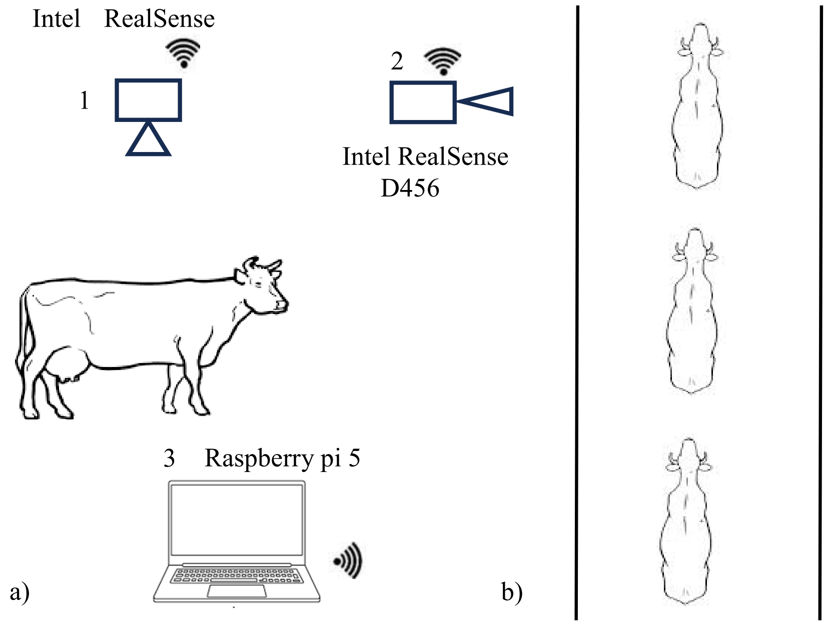

Fig. 1. Contactless measurement of animals; a – side view, b – top view; 1, 2 –Intel RealSense positions, 3 – programmable Raspberry Pi 5 and laptop.

Based on the obtained 3D data and an automated pipeline, a technology was implemented for determining the exterior parameters and body conformation of animals. This approach addresses key tasks: automatic identification of key points on the animal's body, calculation of linear and angular morphometric parameters using these points and the 3D mesh, as well as quality control of measurements through visual validation and repeatability checks. As a result, a comprehensive information database has been formed, allowing automation of measurement and analysis, improving accuracy, reproducibility, and efficiency.

Pipeline layout: frame filtering → measurability classification → key point localization → geometric calculations → self-checks (tolerances, point order) → report generation (JSON/CSV) and visualizations (Fig. 2, 3, 4).

Fig. 2. Extraction of morphological parameters of cattle.

Quantitative indicators from internal runs and pilot tests:

- Animals processed: 650 heads (total, over the period);
- Frames annotated: 840 (valid – 750, discarded – 90);
- Measurability classification: Accuracy 96.8%, Recall 95.1%, F1 = 96.0%;
- Key points (PCK): PCK@0.05 = 92.7%, PCK@0.1 = 97.9%; mean deviation for linear measurements: 7.2 mm at a scale of 1.6 mm/pixel;
- Processing speed: 14–18 fps (GPU RTX 3060), ~2.3 fps (CPU i7-11800H);
- Measurement repeatability (10 repetitions on 15 animals): ±1.5% (standard deviation).

Fig. 3. Processing of morphological parameters of cattle.

Fig. 4. Statistics of morphological parameters of cattle.

Based on the results, it can be concluded that measurement quality depends on shooting conditions, such as lighting, camera angle, and overlaps. Some parameters require additional calibration procedures (scale, animal posture). Further dataset balancing is necessary, especially for complex scenes with difficult-to-distinguish postures and angles.

Despite the challenges in obtaining measurements, the program functions successfully in automatic mode, providing measurements with graphical representations of the information.

4 Conclusions

Contactless exterior assessment allows for minimizing manual labor, avoiding measurement errors, and reducing resource costs for livestock enterprises when studying, analyzing conformations, and assessing the animal's exterior. The system can create a digital copy of the animal and calculate all necessary parameters in a few seconds, comparing exterior parameters and body conformation of the cow and its daughter. Measurement results are automatically saved in the database. Based on these data, it is possible to determine the degree of inheritance of exterior parameters in the mother-daughter pair, which complements genomic evaluation when predicting productive and reproductive qualities of cattle at early developmental stages. Measurement results are automatically saved in the database.

Exterior determination is performed using innovative technologies, including computer vision and artificial intelligence. The machine vision subsystem is capable of collecting and transmitting images of animals to the database, while processing, calculation, and assessment are carried out by neural network algorithms.

Verified data on animal exterior, combined with genomic evaluation results, will be used by breeders to make more effective decisions in animal breeding and to enhance their genetic potential for livestock production with specified characteristics.

5 Prospects for research work

The next stage of the study will involve testing the program under production conditions and finalizing improvements to enhance the quality and speed of image processing. Based on genomic evaluation results and the assessment of cow and heifer conformation types, a computer program will be developed for predicting productive and reproductive qualities of cattle at early developmental stages.

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