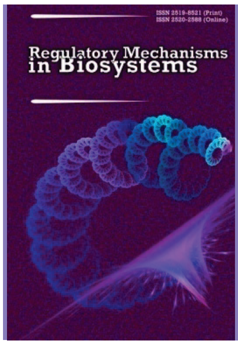


Regulatory Mechanisms in Biosystems

ISSN 2519-8521 (Print)
ISSN 2520-2588 (Online)
Regul. Mech. Biosyst.,
2024, 15(2), 259–266
doi: 10.15421/022438

Assessing cows' mobility to determine their comfort state

E. B. Aliiev*, A. P. Paliy**, O. V. Korkh***, V. V. Mykytiuk*,
R. V. Petrov****, O. G. Stockiy****, I. V. Levchenko****, E. V. Rudnytskyi****

**Dnipro State Agrarian and Economic University, Dnipro, Ukraine*
***Institute of Experimental and Clinical Veterinary Medicine, Kharkiv, Ukraine*
****Livestock Farming Institute of NAAS, Kharkiv, Ukraine*
*****Sumy National Agrarian University, Sumy, Ukraine*

Article info

Received 04.03.2024
Received in revised form 10.04.2024
Accepted 23.04.2024

Dnipro State Agrarian and Economic University, Sergei Efremov st., 25, Dnipro, 49600, Ukraine. Tel.: +38-068-861-44-37. E-mail: aliev@meta.ua

Institute of Experimental and Clinical Veterinary Medicine, Pushkinska st., 83, Kharkiv, 61023, Ukraine. Tel.: +38-066-225-34-34. E-mail: paliy.dok@gmail.com

Livestock Farming Institute of NAAS, Tvarynnykiv st., 1A, Kharkiv, 61026, Ukraine. Tel.: +38-063-924-47-35. E-mail: korhoksana@gmail.com

Sumy National Agrarian University, G. Kondratyeva st., 160, Sumy, 40021, Ukraine. Tel.: +38-066-392-79-28. E-mail: romanpetrov1978@gmail.com

Aliiev, E. B., Paliy, A. P., Korkh, O. V., Mykytiuk, V. V., Petrov, R. V., Stockiy, O. G., Levchenko, I. V., & Rudnytskyi, E. V. (2024). Assessing cows' mobility to determine their comfort state. Regulatory Mechanisms in Biosystems, 15(2), 259–266. doi:10.15421/022438

Milk production and breeding of highly productive cows using modern innovative technologies have led to specific unfavorable combinations of technological factors in how cows are kept, which has significantly increased their susceptibility to developing various pathological processes in the musculoskeletal system. Lameness is the most common pathology. It is important to note that this information is based on objective evaluations and scientific research. The article is devoted to developing methodological approaches to determine the comfort state of cows based on mobility assessment. When determining the comfort state of a cow, in particular, the detection of diseases of the musculoskeletal system, a three-dimensional image of the animal was used, the position of the specified points of the animal's body was determined (tracking), the kinematic indicators of the movement of these points were calculated, the degree of bending of the animal's back during movement was assessed, complex mobility indicators were calculated, and the calculated complex mobility indicator was compared with the reference one. Based on the research results, a structural and technological scheme of a system for determining the comfort state of an animal based on the assessment of its mobility was developed, and software for video recording of movement was created. The step length, maximum step height, step duration, posture, and free state, as well as the speed of movement of healthy animals, those with single lesions and hoof ulcers were determined, and, as a result, the dynamics of changes in the accelerations of nodal points in the joints for each body link of healthy cows was revealed. The key variables of the biomechanical model for assessing the limbs of cattle (cows) are substantiated. The value of the specific force of the support reaction acting on the hooves of cows was determined: the highest value (9.8 N/kg) was observed for the concrete surface, the lowest (5 N/kg) – for rubber mats. The practical examples of the complex relationship between welfare indicators (lameness), elements of physiology (mobility), and technology (floor type) presented in the publication are recommended to be effectively used in monitoring the results of detecting gait disorders in animals and evaluating its effectiveness even in the early stages of the disease. The prospect of further research is to determine the comfort state of animals depending on environmental and climatic conditions.

Keywords: cows; musculoskeletal system; lameness; hooves; mobility; floor type.

Introduction

Worldwide, cattle remain an important agricultural animal for the dairy and meat processing industries (Geletu et al., 2021; Rodionova et al., 2021). However, the animals are increasingly exposed to a variety of diseases. These have a significant impact on their physiological state and productivity from the time of birth, the beginning of their use for production, and until the end of their lives (Bicalho et al., 2016).

The rapid development of breeding to increase milk productivity in the late 20th and early 21st centuries and the ever-increasing consumer demand for dairy products made it possible to significantly increase not only lactation milk yield but also the udder volume of cows. This was a cause of their discomfort, reduced mobility, and gait disorders (Gross, 2023). This led to an increase in the incidence of limb disorders, especially in the hind limbs, due to the increased pressure of the total body weight on the lateral toes (Bicalho & Oikonomou, 2016).

Disorders of the musculoskeletal system in cows negatively affect milk yield and reproductive potential, cause changes in feeding behavior, and lead to an increase in the incidence of metabolic and digestive diseases (Norring et al., 2014). Lameness is usually associated with early culling of animals, a decrease in live weight, and ultimately a decrease in the economic value of carcasses (Fjeldaas et al., 2007). In addition, lameness is often a sign of significant limb pain and compromises the physiological condition of the animal (Dyer et al., 2007). Instead, some scientists (Mill et al., 1994) emphasize that these problems can be largely avoided by implementing regular planned preventive measures, as well as timely and successful treatment of sick animals. It should be noted that the solution to the current problems of modern livestock production requires a comprehensive systematic approach (Arvidsson et al., 2022; Kappes et al., 2023).

Based on the results of a comprehensive evaluation of cow gait locomotion, a unique system of criteria was proposed and the basic principles of its definition were formulated (Sprecher et al., 1997). These developments were later used to study lameness in cows (Cook, 2003; Espejo et al., 2006). Currently, the effectiveness of the proposed system for evaluating limb disorders is the subject of many publications, both scientific and reference. In particular, some authors consider cow lameness in the general characterization of milk production technologies, while others focus on deeper aspects of solving this problem (Tadich et al., 2010; Thomsen et al., 2012). However, despite numerous studies and considerable experience of dairy professionals, the importance of certain factors is still largely ignored by scientists and has not been fully proven. These factors also play a key role in shaping the physiological state of animals and assessing limb diseases, taking into account modern methodological approaches. They are based on advanced statistical and computational methods that can be successfully used to further predict their productivity (Phillips & Morris, 2000; De Belie & Rombout, 2003).

An animal moving on the ground creates a dynamic biomechanical system known as the zoomorphic mechanism, which has its own characteristics. The physiological state of the animal, together with its locomotor activity, is a key element of housing technology (Murato et al., 2023). Modern standards of cattlekeeping require a comprehensive analysis and implementation of the basic biomechanical principles of animal movement interaction with machinery and facilities as means of production (Duncan & Meyer, 2019).

It should be added that the biomechanics of the animal's locomotor system is of paramount importance in animal husbandry technologies. In turn, the development of technological aspects of zootechnical biomechanics of cattle breeding begins with this issue. Usually, only those problems of zootechnical biomechanics of the locomotor system of cows are considered that are important for the technological biomechanics of their maintenance in dairy farming (Bradtmueller et al., 2023). Undoubtedly, the key factors in the cow housing environment are the support surface in the areas where they are kept, the quality of the bedding material, and the type of flooring. Knowledge of the movement patterns and mechanical interactions of animals in different housing environments is important for increasing their productivity and rationalizing human labor. In this regard, the study aimed to develop methodological approaches to determine the state of comfort of cows based on the assessment of their mobility.

Materials and methods

The experiments performed on animals comply with the current legislation of Ukraine, in particular, Article 26 of the Law of Ukraine of 16.10.2012 No. 5456-VI "On the Protection of Animals from Cruelty", as amended as of 04.08.2017, "General Ethical Principles for Animal Experiments" adopted by the First National Congress on Bioethics (Kyiv, 2001), international bioethical standards, including the materials of the IV European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Purposes (Strasbourg, 1985) (Simmonds, 2017).

The experiments were conducted on a population of 1000 cows in the production conditions of the dairy complex "Chumaky" LLC in Dniprovskyi district, Dnipropetrovs'k region. The farm has a milking parlor of the "Autorotor" type with 32 milking stations (GEA Farm Technologies, Germany). From the total number of dairy cows, 132 cows of the Holstein breed of European selection, aged 2–3 lactations, with an average live weight of 488 ± 45 kg were selected for the study. The experimental animals were housed in a free-standing box system on deep straw bedding in typical 200-head facilities converted from poultry houses using the latest dairy cattle housing technologies. Cows were grouped in sections according to physiological status and age. The study of the changes in the dynamic indicators of the zoomorphic mechanism during movement was carried out at the time of the cow's exit from the milking parlor and its movement along the corridor. The motion analysis system, which included a Kinect digital video camera (Microsoft Corporation, USA) with the ability to record in two data streams, RGB and Depth, was placed at a distance of approximately 6.7 m from the plane of movement. The camera was oriented along its vertical and horizontal axes and 90° from the plane of motion to record the sagittal kinematics of the plane of one step per gait. During the recording process, it was planned to determine the kinematic data of the spatial and temporal parameters of the cow's step, the angular range of joint movement, displacement, and limb speed.

At the beginning of the study, a multi-link scheme was used to develop a mathematical model of the biomechanics of cow limb movement in the sagittal plane. Each link was sequentially connected to the other according to the point-joint principle. The mass and inertia characteristics of each link were assumed to be similar to those of the hindlimb and forelimb elements. The length of all limbs (denoted as li) was defined as the distance between the axes of rotation and the centers of the joints. In the simplified model, the centers of mass (denoted as mi) were assumed to be on the links. Forces from the neck and head were not considered in the system of this model to ensure the simplicity of modeling (Fig. 1).

The position of the system was determined by generalized angles ψ_i. The system was subjected to opposing muscle forces F_i and gravitational forces mig for each link of the system. For the presented model, only biceps muscles were considered. We assume that six groups of biceps muscles are involved in the process of limb position stabilization. We assume that the supporting reaction force F_0 acts on the hooves and depends on the type of ground.

The process of cattle (cows) movement can be described by a system of Lagrange equations of the second kind (Mestdag et al., 2011):

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\psi}_i}\right) - \frac{\partial T}{\partial \psi_i} = Q_i,\ i = 1..6\ , \qquad (1)$$

where t – time (s); Q_i – generalized forces (N•m); $\dot{\psi}_i$ – generalized speed (m/s); T – the kinetic energy (J); ψ_i – generalized angles.

The kinetic energy of the system under consideration can be represented as follows:

$$T = \sum_{i=1}^{6} \frac{m_i l_i^2 \dot{\psi}_i^2}{2} + \sum_{i=1}^{6}\sum_{j=1}^{6} \frac{m_j l_i l_j \dot{\psi}_i \dot{\psi}_j}{2} \cos(\psi_i - \psi_j)\ , \qquad (2)$$

where l_i – the length of each link (m); m_i – mass of each link (kg).

The generalized force can be calculated as follows:

$$Q_i(t) = \overline{F_i}(t)\frac{d\overline{r_i}}{d\psi_i}\ , \qquad (3)$$

where F_i – the acting force (N):

$$\overline{F_i} = F_{ix}\overline{e_x} + F_{iy}\overline{e_y}\ , \qquad (4)$$

r_i – the radius vector of the centers of mass (m):

$$\overline{r_i} = \overline{e_x}\sum_{j=1}^{i} l_j \cos\psi_j + \overline{e_y}\sum_{j=1}^{i} l_j \sin\psi_j\ , \qquad (5)$$

F_{iy}, F_{ix} – the corresponding projections of forces on the axes OY and OX; e_x, e_y – vectors of unit length along the axes OX and OY. The projections of the forces of equation (4) can be calculated as follows:

$$F_{ix} = \begin{cases} m_i a_{ix} - F_{0x},\ i = 1,6; \\ m_i a_{ix} + F_{(i-1)x},\ i = 2..5; \end{cases} \qquad (6)$$

$$F_{iy} = \begin{cases} m_i a_{iy} - F_{0y} + m_i g,\ i = 1,6; \\ m_i a_{iy} + F_{(i-1)y} + m_i g,\ i = 2..5; \end{cases} \qquad (7)$$

where a_i – acceleration, m/s^2;

$$\overline{a_i} = \frac{d^2\overline{r_i}}{dt^2} = a_{ix}\overline{e_x} + a_{iy}\overline{e_y}\ , \qquad (8)$$

F_{0y}, F_{0x} – the corresponding projections of the resistance reaction forces on the OY and OX axes; g – free fall acceleration, m/s^2; a_{iy}, a_{ix} – the corresponding acceleration projections on the OY and OX axes.

Based on the above general model of the dynamics of the zoomorphic mechanism (Lagrange's equation of the second kind) and using the tools of the 3dsMax program (Autodesk Inc., USA), we developed a method for determining the centers of mass, moments of inertia, and forces of interaction of discrete and smooth links of the structural and morphological parts of the biomechanical model of cattle (cow) movement and its interaction with elements of the technological environment (Fig. 2). It was established that a number of the obtained kinetic parameters (subject to their further refinement) are necessary to substantiate the technical and technological support for determining the comfort state of cows in the system of operational management of the dairy herd.

A variety of equipment with appropriate capabilities can be used to determine the 3D image of cattle. These include a three-dimensional camera, several two-dimensional cameras, or a single two-dimensional camera with an optical emitter and receiver. To be able to identify specific points on the cow's body and assess the curvature of its back, the camera (or one of the cameras) should be located on the side of the animal's path, parallel to it. In our version, with the fixed setting, we recommend using a Kinect device that includes a single color video camera, an infrared receiver, and an emitter, with the depth sensor formed by the latter. This sensor is used to measure the distance from Kinect to each point of the object. The principle of this device is video recording, which can provide both a color two-dimensional video image and a three-dimensional one. The brightness of the points reflects the distance between the device and the object. A computer with specialized software is used to analyze and process the obtained 3D images. The equipment arrangement is shown in Figure 3.

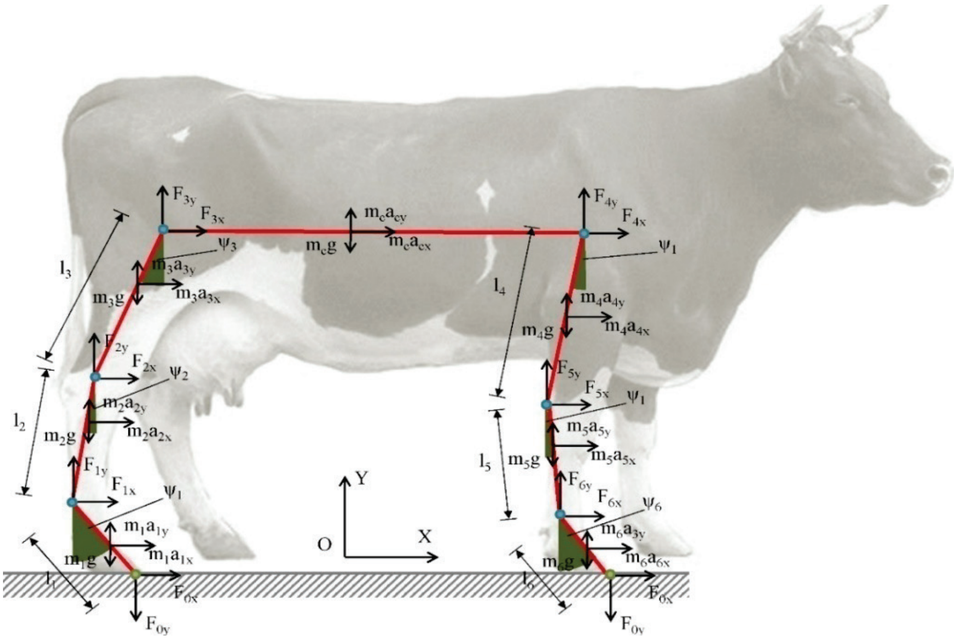


Fig. 1. Biomechanical model of cow limb movement

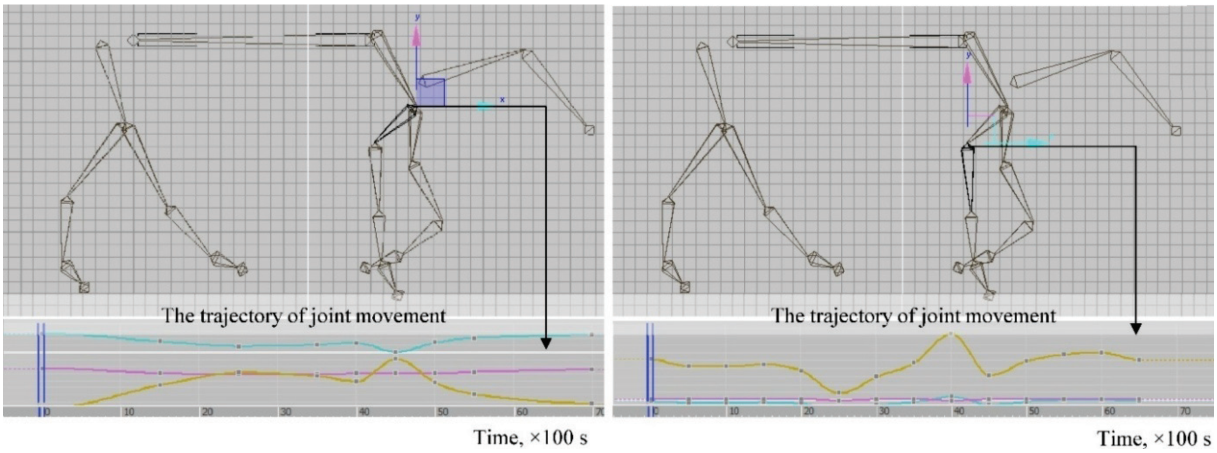


Fig. 2. Discrete models of inter-moving parts of the cow's body

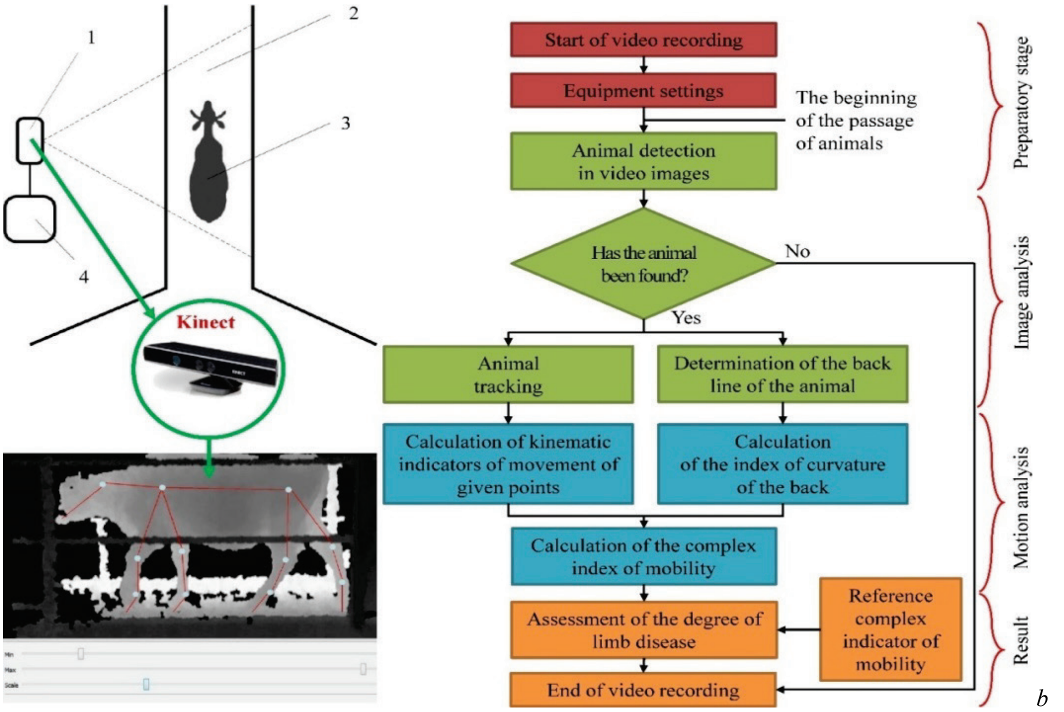


Fig. 3. Equipment arrangement diagram (*a*) and flowchart of the operation algorithm (*b*) of the system for determining the comfort state of cows based on their mobility: *1* – device for obtaining a three-dimensional video image; *2* – corridor; *3* – cow; *4* – computer

The principle of operation of the system for determining the comfort of cows is described as follows. The device for obtaining a three-dimensional image (marked as 1) is placed next to the corridor (marked as 2) along which the cow moves (marked as 3). The part of the corridor that falls within the field of view of the device's camera should be longer than the length of an average animal. The distance between corridor 2 and device 1 should be sufficient to accurately calculate the distance to cow 3 as she moves along the corridor. Before the cow begins to move, device 1 is connected to a personal computer 4 and calibration is performed, including the construction of at least a statistical background model.

During the movement of the cow 3 along corridor 2, an analysis of its movement is performed, which includes several stages (Fig. 3b): video recording, finding the image of the animal, parameterizing it as a near-field object, tracking it, studying the trajectory and evaluating the kinematic indicators of the movement of specific points of the cow, determining a complex mobility indicator and its subsequent comparison with the standard one. Additionally, the absence or presence of a cow's back bend is determined. After processing the data, the degree of musculoskeletal disease of the animal is determined using a scale of points based on a comprehensive mobility index. This process is repeated for each individual that passes through the corridor, being in the field of view of the camera of the device 1. In addition, simultaneously with the analysis of the animal's movement, it is possible to measure the geometric dimensions of the animal, which is further used for the graduation of animals.

Thus, the use of the proposed system allows us to automatically determine the complex indicator of mobility of cattle (cows) and to diagnose diseases of the locomotor system, including its limbs. Assessment of complex mobility index contributes to better formation of herds by productive and age groups of animals. As a result, it serves as a guideline for making strategic management decisions on ways to improve the efficiency of this process.

To implement the process of video recording the movement of a cow, the resulting video image is segmented. That is, in each frame, one or more animals are identified as foreground objects, and the rest of the image is identified as background objects that can be excluded from further analysis. To do this, a separate feature is established that is inherent to foreground objects and allows them to be distinguished in the video image. Usually, this feature is the brightness of the object relative to the background brightness or the color histogram of the object. However, in our case, using one of these features to segment an image from a color video camera does not provide satisfactory animal detection quality. The same animals need to be detected first as background objects and then, as they move along the corridor, as foreground objects.

Therefore, it is advisable to choose the distance from the Kinect device to each of the elements of the video image as the main criterion for segmenting it. Only objects within the corridor should be included in the foreground.

The distance to image elements can be estimated using the depth sensor of the Kinect device. Further segmentation steps, such as the removal of stationary background elements (in particular, corridor fences) and the so-called "camera noise", are implemented using well-known methods of background averaging and the use of connected components (Appiah et al., 2010). The video motion detection software is written in C++ using Qt 4.8.4 (The Qt Company, Finland), OpenCV 2.4 (Intel Corporation, Willow Garage Inc., Itseez Ltd., USA), and OpenNI 1.5.4.0 (Open Natural Interaction, USA) libraries. To develop the video motion detection algorithm, it is advisable to initially implement the software in the form of three separate programs called Kinect_Qt, ONI_to_video, and segmentation.

The centerpiece of the main window is a graphic element (widget) that displays images from the depth sensor of the Kinect device in real-time. Below it, there are three controls that set the displayed distance range and distance resolution, as well as the start/stop button for video recording. If you set the displayed distance range within the corridor along which the cow moves, all objects outside of it (other animals, people, etc.) are not detected by the depth sensor, which simplifies the subsequent image segmentation process.

The Kinect_Qt program consists of four files: main.cpp, which contains the main() function of the program start, manage.h and manage.cpp, which describe the class of the main window of the program, and ONI_video.cpp, which defines the interaction of the program with the Kinect device.

The program creates two files in the process: Images.oni, which contains data recorded by the color camera and depth sensor of the Kinect device, and Video.ini. The latter contains the settings for the displayed distance range, as well as the total number of frames captured and their average frequency. The function of the ONI_to_video program is to convert the data contained in the Images.oni file into two separate video files corresponding to the results of shooting with a color video camera (BGR.avi file) and a depth sensor (depth.avi file), taking into account the settings for the displayed distance range. The source code of the program is contained in one file main.cpp. The program is console-based, i.e. it does not contain any graphical interface elements. The purpose of the segmentation program is to segment the video image recorded in the depth.avi file. The first step is to extract static background elements, in particular the elements of the corridor fence along which the animal moves. For this purpose, it is assumed that during the first 1000 frames (about 30 seconds of recording) the animal does not move along the corridor, i.e. the video image contains a static scene with interferences caused by camera noise. These interferences are eliminated by calculating statistical indicators (mathematical expectation and standard deviation) of the brightness of each pixel of the image for the first 1000 frames and forming a static image based on these data, which is subtracted from each frame of the original video.

The second stage involves the transition from raster images, which are the frames of a video recording, to a set of objects contained in these images. To do this, first, morphological operations of opening and closing are applied to each frame. Then, an automatic analysis of the frames is performed, as a result of which each area of the image with non-zero pixel brightness is represented as a closed contour. Contours whose perimeter length is less than a predetermined value are considered camera noise and discarded. The advantage of representing foreground objects as closed contours is that they can be mathematically described (calculating the contour area, moments, etc.), which makes their further analysis possible.

Using the developed software and processing the data from the Kinect camera sensor, a dynamic skeleton of a cow was formed, which included a set of nodes and links and illustrated its movement along the corridor. This movement was expressed as a set of mathematical expressions. They determine the time pattern of the position of each of the nodal links. In addition to the kinematic parameters of the nodal points of the cow's skeleton, the criteria listed in Table 1 were determined.

Table 1
Experimental research criteria

Criterion	Criterion description
Step length, mm	Horizontal displacement between two consecutive hoof strikes on the ground
Maximum step height, mm	Maximum vertical movement between two consecutive hoof strikes on the ground
Step duration, ms	The time interval between two consecutive hoof strikes on the ground
Posture duration, ms	The time when the hoof is in contact with the ground
Free state duration, ms	The time when the hoof is not in contact with the ground
Movement speed, m/s	Step length/step duration

The mathematical dependencies obtained in the course of experimental studies are as follows:

$$\overline{r_i}(T) = (A_{ix0} + A_{ix1}T + \ldots + A_{ix1}T^n)\overline{e_x} + (A_{iy0} + A_{iy1}T + \ldots + A_{iy1}T^n)\overline{e_y}\ , \quad (9)$$

$$\overline{\vartheta_i}(T) = \frac{d\overline{r_i}(T)}{dt^2} = \vartheta_{ix}(T)\overline{e_x} + \vartheta_{iy}(T)\overline{e_y}\ , \quad (10)$$

$$\overline{a_i}(T) = \frac{d^2\overline{r_i}(T)}{dt^2} = a_{ix}(T)\overline{e_x} + a_{iy}(T)\overline{e_y}\ , \quad (11)$$

where T – position of the joint point of the limb:

$$T = \frac{100 \cdot t}{t_{step}} \quad (12)$$

A_{ix0}, A_{ix1}, …, A_{ix1} – regression equation coefficients; i – sequence number of the cow skeleton node; t_{step} – duration of one step; $\overline{e_x}, \overline{e_y}$ – single vectors; $\overline{r_i}(T)$ – radius vector of the joint point of the limb; $\overline{\vartheta_i}(T)$ – speed vector of the joint point of the limb; $\overline{a_i}(T)$ – acceleration vector of the joint point of the limb.

The following steps were taken to determine the cow's comfort level, including the detection of musculoskeletal diseases:

– obtaining a three-dimensional image of the animal;

– determining the position of specified points of the animal's body (tracking);

– calculation of kinematic indicators of movement of the specified points;

– assessment of the animal's back bend during movement;

– calculation of a complex mobility index;

– comparison of the calculated complex mobility index with the reference one.

Determining the kinematic parameters of movement of certain points of the cow's body, especially those characterizing the joints of the limbs, made it possible to quantify and qualitatively assess the degree of lameness. At the same time, taking into account the bending of the cow's back at the time of movement helped to increase the accuracy of detecting diseases of the locomotor system.

The complex mobility index K was determined in connection with the parameters of movement of certain points of the cow's body using the following function:

$$K = f\left(\vec{r}_i(t),\ \vec{\upsilon}_i(t),\ \vec{a}_i(t)\right), \qquad (13)$$

where t – time point (c); $\vec{r}_i(t)$ – radius vector of the corresponding point of the cow's body (m); $\vec{a}_i(t)$ – acceleration vector of the corresponding point of the cow's body (m/s^2); $\vec{\upsilon}_i(t)$ – motion velocity vector of the corresponding point of the cow's body (m/s).

Results

During the veterinary examination of the cows' hooves, it was found that 13 head had single lesions and 14 animals had obvious ulcers on the hooves. For each of these groups of animals, the values of the criteria were determined, as shown in Table 2.

It was found that compared to the group of healthy cows, animals with hoof ulcers had shorter steps, and during the body transfer phase, the hooves did not rise higher. The total duration of steps of cows with hoof ulcers was longer than that of healthy animals. In addition, the animals with hoof ulcers spent an average of 0.22 s longer in contact with the ground (posture duration) and had a slower average speed than healthy cows (0.90 vs. 1.11 m/s, respectively). No differences in criteria were found between healthy animals and those with a single hoof lesion.

Step duration (posture and free state) can be viewed not only as an absolute value, but also as a relative one. Figure 4 illustrates the cyclogram of steps of healthy cows and animals with hoof ulcers. As part of the experiments, we obtained dynamic acceleration rates for each body segment of a healthy cow. A graphical repre-sentation of these results is shown in Figure 5.

Table 2
The value of criteria for assessing the state of cow hooves (x ± SE)

Criterion	The state of the hooves	Value
Step length, mm	healthy	1395 ± 21
	with a single lesion	1393 ± 23
	with ulcers	1300 ± 32
Maximum step height, mm	healthy	96 ± 8
	with a single lesion	97 ± 9
	with ulcers	87 ± 7
Step duration, ms	healthy	1260 ± 30
	with a single lesion	1310 ± 40
	with ulcers	1480 ± 50
Posture duration, ms	healthy	690 ± 30
	with a single lesion	750 ± 30
	with ulcers	910 ± 40
Free state duration, ms	healthy	570 ± 10
	with a single lesion	550 ± 10
	with ulcers	570 ± 20
Movement speed, m/s	healthy	1.11 ± 0.03
	with a single lesion	1.08 ± 0.03
	with ulcers	0.90 ± 0.05

The solution of the system of equations 1–12, taking into account the experimental data on the dynamics of cow joint accelerations, is a complex mathematical process. For this purpose, we used a biomechanical model of the cow's limbs, which was built using OpenSim 3.0 (Simbios, USA), an open-source software (Pandy, 2001; Delp et al., 2007). It is based on the activation and deactivation of individual muscles that generate a force applied to different parts of the bones.

In the process of modeling the movement of the cow's musculoskeletal system in OpenSim 3.0 (Fig. 6), the interaction of its limbs with various types of ground (sand, concrete, straw, sawdust, and rubber mats) was taken into account. Taking into account the rheological characteristics of the floor material, such as the elastic modulus, plasticity coefficient, and shear modulus, we obtained the value of the specific reaction force of the hoof support F_0/m (per 1 kg of animal body weight). The highest specific reaction force was observed on the concrete surface (9.8 N/kg), while the lowest was observed on rubber mats (5 N/kg). The analysis of the data confirms the conclusions that such types of flooring as rubber mats, straw, and sawdust have the most acceptable technological properties for cow hooves.

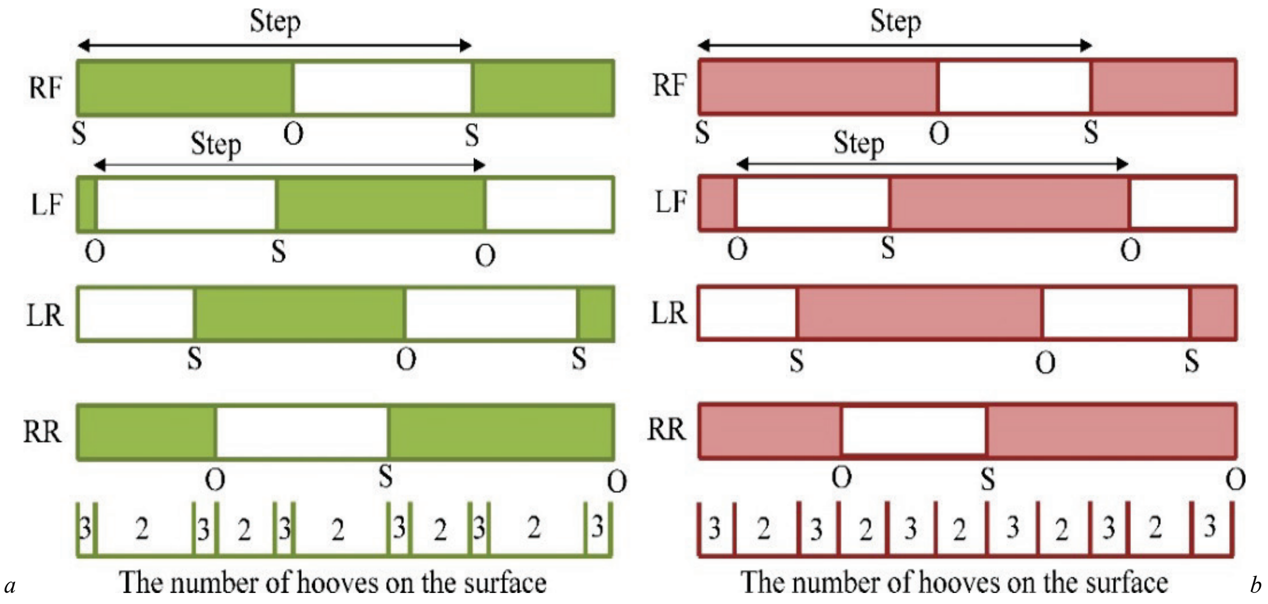


Fig. 4. Cyclogram of cow steps: *a* – healthy cows, *b* – cows with hoof ulcers; RF – right front hoof, LF – left front hoof, LR – left rear hoof, RR – right rear hoof

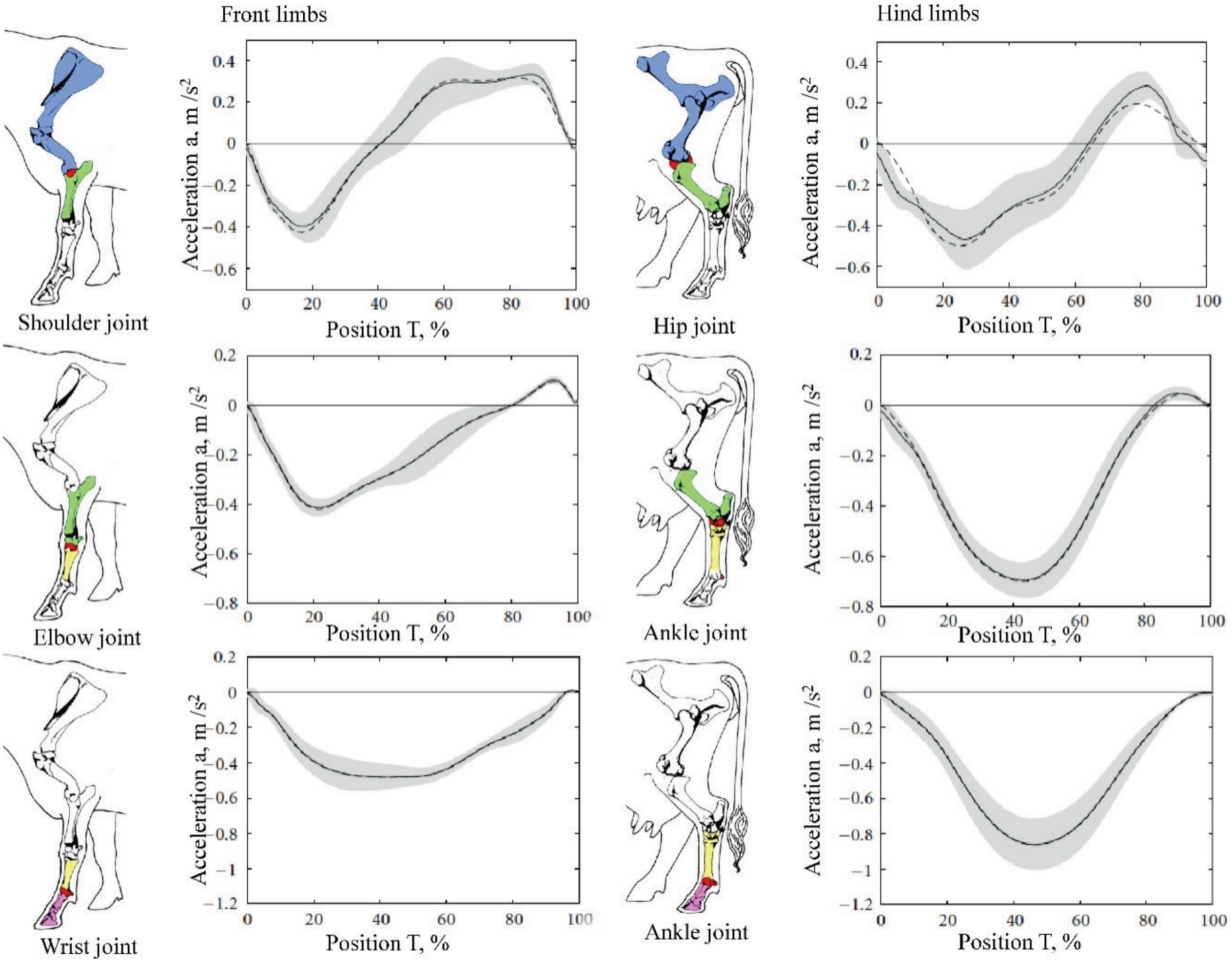
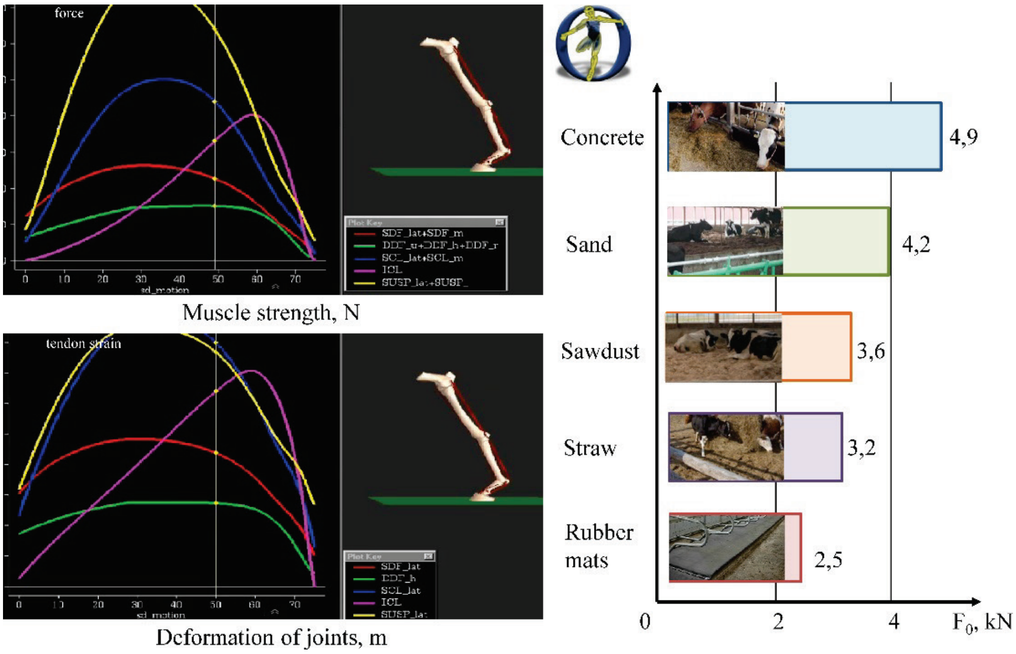


Fig. 5. Change in acceleration a (m/s^2) of points in the joints of the cow's limbs from the position T (%)



Muscle strength, N

Deformation of joints, m

Fig. 6. Peculiarities of changes in the specific reaction force of cow hoof support F_0/m depending on the type of floor

Discussion

Obtaining high-quality milk remains the main task of the livestock industry (Paliy et al., 2020; Castellini et al., 2023). At the present stage of the dairy industry functioning, it is important to determine the physiological state of a cow based on the assessment of its mobility to obtain high-quality milk. This is because the unsatisfactory condition of the hooves leads to a lack of production, reduced reproductive capacity, deterioration of feeding behavior, and an increase in the incidence of metabolic and digestive diseases (Lai et al., 2021).

The prevalence of different types of lesions can vary depending on environmental conditions and farm management practices (Browne et al., 2022). Both biotic and abiotic factors can cause lameness in cattle. The former includes damage to the hoof by pathogenic microorganisms (Wong et al., 2024). Septic processes of the foot in cattle are often polymicrobial. The majority of isolated bacteria are resistant to at least one antimicrobial drug, and more than one-third are resistant to multiple drugs (Walker et al., 2023). Bacterial finger dermatitis is the leading cause of lameness in dairy cows in many countries (Palmer & O'Connell, 2015).

It was found that non-infectious lesions are more common than infectious pathologies of the limbs of productive animals. The most common types of lesions during both grazing and housing are white line lesions, sole hemorrhages, and overgrown claws, with all other lesions having a prevalence of 15% (Browne et al., 2022). However, many questions remain unanswered about how to solve this problem. Today, there is a generalized opinion about auxiliary measures to eliminate the negative impact of lameness on cow performance, but this usually does not always lead to the desired result. Given this, our experimental studies were aimed at developing a new method for determining the comfort state of cows based on the assessment of their mobility, which made it possible to have a controlled impact on the premature culling of highly productive animals. In particular, as part of the first stage of the research, we developed and substantiated a structural and technological scheme for a system to determine the comfort state of an animal based on an assessment of its mobility using video recording of its movements by the Kinect device and our own software. The expediency of using an automated system to monitor the physiological state of cows has been confirmed by other scientists (Hansen et al., 2018). The detection of lameness with changes in mobility is based on the bending of the cow's back, which is an early indicator of discomfort caused by limb disease (Viazzi et al., 2013).

Subsequently, experimental studies were carried out to evaluate the changes in the dynamic parameters of the zoomorphic mechanism during the animal's movement, according to which the trajectories, kinematic, and dynamic parameters of the animal's joints were determined. As a result, the step length, maximum step height, step duration, posture, and free state, as well as the speed of movement of healthy animals and individuals with single lesions and ulcers on the hooves were determined.

Of some interest is the biomechanical model of a cow's limb that we created using OpenSim 3.0. This software package is based on the mechanism of activation and deactivation of individual muscles, which generate a force that is applied to different parts of the bones. When modeling the movement of a cow's musculoskeletal system, OpenSim 3.0 takes into account the interaction of its limbs with different types of ground (sand, concrete, straw, sawdust, and rubber mats). Taking into account the rheological properties of the floor material, such as shear modulus, elastic modulus, and plasticity coefficient, the value of the specific force of the support reaction acting on the cows' hooves was determined. The highest value was observed on the concrete surface (9.8 N/kg) and the lowest on the rubber mats (5 N/kg).

One of the most important preventive factors influencing the quality and growth of the hoof horn and the associated prevalence of hoof disease is the animal's diet. The strength and structure of the hoof horn is influenced by the composition of the feed ration (amino acids, minerals, vitamins, toxic substances that contaminate the feed ration or occur in the feed ration in the form of fungal metabolites) (Langova et al., 2020). An important technological aspect of keeping dairy cows is compliance with the technical component. In this case, the quality of the floor and the coating used directly affects the animal's hoof (Shkromada et al., 2019).

Quantitative assessment of animal locomotion is fundamental in a wide range of disciplines, from biomedical research to behavioral ecology (Gupta et al., 2020).

The results of the presented studies complement the existing data on the assessment of the physiological state of animals using modern video recording tools.

Conclusion

A biomechanical model of the cow's limb movement based on the dynamics of a zoomorphic mechanism (Lagrange's equation of the second kind) has been developed. The simulations of the cow's movement process showed that a number of kinetic parameters obtained at the first stages of simulation modeling are necessary (subject to their further refinement) to substantiate the parameters of technical and technological support for determining the comfort state of cows in the system of operational management of the dairy herd. Methodological approaches to the development of a method of determining the comfort state of cows based on a comprehensive assessment of their mobility using video recording and the created software are substantiated. The dynamic changes in the accelerations of the joint points for each limb of the body of a healthy cow were obtained by determining the step length, maximum step height, step duration, posture and free state, as well as the speed of movement of healthy animals and animals with single lesions and ulcers on the hooves. The key variables of the biomechanical model for cow limb evaluation were validated using the OpenSim 3.0 software package. The value of the specific force of the support reaction acting on the cows' hooves was determined: the highest value (9.8 N/kg) was observed for the concrete surface and the lowest (5 N/kg) – for the rubber mats.

The authors have no potential conflicts of interest regarding the authorship and publication of this paper.

References

Appiah, K., Hunter, A., Dickinson, P., & Meng, H. (2010). Accelerated hardware video object segmentation: From foreground detection to connected components labelling. Computer Vision and Image Understanding, 114(11), 1282–1291.

Arvidsson, A., Fischer, K., Hansen, K., Sternberg-Lewerin, S., & Chenais, E. (2022). Diverging discourses: Animal health challenges and veterinary care in Northern Uganda. Frontiers in Veterinary Science, 9, 773903.

Bicalho, R. C., & Oikonomou, G. (2016). Control and prevention of lameness associated with claw lesions in dairy cow. Livestock Science, 156(1–3), 96–105.

Bradtmueller, A., Nejati, A., Shepley, E., & Vasseur, E. (2023). Applications of technology to record locomotion measurements in dairy cows: A systematic review. Animals, 13(6), 1121.

Browne, N., Hudson, C. D., Crossley, R. E., Sugrue, K., Huxley, J. N., & Conneely, M. (2022). Hoof lesions in partly housed pasture-based dairy cows. Journal of Dairy Science, 105(11), 9038–9053.

Castellini, G., Barello, S., & Bosio, A. C. (2023). Milk quality conceptualization: A systematic review of consumers', farmers', and processing experts' views. Foods, 12(17), 3215.

Cook, N. B. (2003). Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. Journal of the American Veterinary Medical Association, 223(9), 1324–1328.

De Belie, N., & Rombout, E. (2003). Characterisation of claw-floor contact pressure for standing cattle and the dependency on concrete roughness. Biosystems Engineering, 85(3), 339–346.

Delp, S. L., Anderson, F. C., Arnold, A. S., Loan, P., Habib, A., John, C. T., Guendelman, E., & Thelen, D. G. (2007). OpenSim: Open-source software to create and analyze dynamic simulations of movement. IEEE Transactions on Biomedical Engineering, 54(11), 1940–1950.

Duncan, N. B., & Meyer, A. M. (2019). Locomotion behavior changes in peripartum beef cows and heifers. Journal of Animal Science, 97(2), 509–520.

Dyer, R. M., Neerchal, N. K., Tasch, U., Wu, Y., Dyer, P., & Rajkondawar, P. G. (2007). Objective determination of claw pain and its relationship to limb locomotion score in dairy cattle. Journal of Dairy Science, 90(10), 4592–4602.

Espejo, L. A., Endres, M. I., & Salfer, J. A. (2006). Prevalence of lameness in high-producing Holstein cows housed in freestall barns in Minnesota. Journal of Dairy Science, 89(8), 3052–3058.

Fjeldaas, T., Nafstad, O., Fredriksen, B., Ringdal, G., & Sogstad, A. M. (2007). Claw and limb disorders in 12 Norwegian beef-cow herds. Acta Veterinaria Scandinavica, 49(1), 24–35.

Geletu, U. S., Usmael, M. A., Mummed, Y. Y., & Ibrahim, A. M. (2021). Quality of cattle meat and its compositional constituents. Veterinary Medicine International, 2021, 7340495.

Gross, J. J. (2023). Dairy cow physiology and production limits. Animal Frontiers, 13(3), 44–50.

Gupta, S., Marchetto, P. M., & Bee, M. A. (2020). Customizable recorder of animal kinesis (CRoAK): A multi-axis instrumented enclosure for measuring animal movements. HardwareX, 8, e00116.

Hansen, M. F., Smith, M. L., Smith, L. N., Jabbar, K. A., & Forbes, D. (2018). Automated monitoring of dairy cow body condition, mobility and weight using a single 3D video capture device. Computers in Industry, 98, 14–22.

Kappes, A., Tozooneyi, T., Shakil, G., Railey, A. F., McIntyre, K. M., Mayberry, D. E., Rushton, J., Pendell, D. L., & Marsh, T. L. (2023). Livestock health and disease economics: A scoping review of selected literature. Frontiers in Veterinary Science, 10, 1168649.

Lai, E., Danner, A. L., Famula, T. R., & Oberbauer, A. M. (2021). Pleiotropic loci associated with foot disorders and common periparturient diseases in holstein cattle. Frontiers in Genetics, 12, 742934.

Langova, L., Novotna, I., Nemcova, P., Machacek, M., Havlicek, Z., Zemanova, M., & Chrast, V. (2020). Impact of nutrients on the hoof health in cattle. Animals, 10(10), 1824.

Mestdag, T., Sarlet, W., & Crampin, M. (2011). Second-order dynamical systems of Lagrangian type with dissipation. Differential Geometry and its Applications, 29(1), S156-S163.

Mill, J. M., & Ward, W. R. (1994). Lameness in dairy cows and farmers' knowledge, training and awareness. Veterinary Record, 134(7), 162–164.

Murato, Y., Hayama, Y., Kondo, S., Sawai, K., Yamaguchi, E., & Yamamoto, T. (2023). The probability distributions of the movement of dairy and beef cattle in Japan: A data note. BMC Research Notes, 16(1), 153.

Norring, M., Häggman, J., Simojoki, H., Tamminen, P., Winckler, C., & Pastell, M. (2014). Short communication: Lameness impairs feeding behavior of dairy cows. Journal of Dairy Science, 97(7), 4317–4321.

Paliy, A., Naumenko, A., Paliy, A., Zolotaryova, S., Zolotarev, A., Tarasenko, L., Nechyporenko, O., Ulko, L., Kalashnyk, O., & Musiienko, Y. (2020). Identifying changes in the milking rubber of milking machines during testing and under industrial conditions. Eastern-European Journal of Enterprise Technologies, 107, 127–137.

Palmer, M. A., & O'Connell, N. E. (2015). Digital dermatitis in dairy cows: A review of risk factors and potential sources of between-animal variation in susceptibility. Animals, 5(3), 512–535.

Pandy, M. G. (2001). Computer modeling and simulation of human movement. Annual Review of Biomedical Engineering, 3, 245–273.

Phillips, C. J. C., & Morris, I. D. (2000). The locomotion of dairy cows on concrete floors that are dry, wet or covered with a slurry of excreta. Journal of Dairy Science, 83(8), 1767–1772.

Rodionova, K., Paliy, A., & Khimych, M. (2021). Veterinary and sanitary assessment and disinfection of refrigerator chambers of meat processing enterprises. Potravinarstvo, 15, 616–626.

Shkromada, O., Paliy, A., Nechyporenko, O., Naumenko, O., Nechyporenko, V., Burlaka, O., Reshetnichenko, A., Tsereniuk, O., Shvets, O., & Paliy, A. (2019). Improvement of functional performance of concrete in livestock buildings through the use of complex admixtures. Eastern-European Journal of Enterprise Technologies, 101, 14–23.

Simmonds, R. C. (2017). Chapter 4. Bioethics and animal use in programs of research, teaching, and testing. In: Weichbrod, R. H., Thompson, G. A. H., & Norton, J. N. (Eds.). Management of animal care and use programs in research, education, and testing. 2nd ed. CRC Press, Taylor & Francis, Boca Raton. Pp. 1–28.

Sprecher, D. J., Hostetler, D. E., & Kaneene, J. B. (1997). A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance. Theriogenology, 47(6), 1179–1187.

Tadich, N., Flor, E., & Green, L. (2010). Associations between hoof lesions and locomotion score in 1098 unsound dairy cows. The Veterinary Journal, 184(1), 60–65.

Thomsen, P. T., Munksgaard, L., & Sørensen, J. T. (2012). Locomotion scores and lying behavior are indicators of hoof lesions in dairy cows. The Veterinary Journal, 193(3), 644–647.

Viazzi, S., Bahr, C., Schlageter-Tello, A., Van Hertem, T., Romanini, C. E. B., Pluk, A., Halachmi, I., Lokhorst, C., & Berckmans, D. (2013). Analysis of individual classification of lameness using automatic measurement of back posture in dairy cattle. Journal of Dairy Science, 96(1), 257–266.

Walker, K. E., Middleton, J. R., Gull, T., Payne, C.A., & Adkins, P. R. F. (2023). Bacterial culture and susceptibility of samples taken from septic foot lesions of adult beef cattle. Journal of Veterinary Internal Medicine, 37(2), 757–765.

Wong, N. S. T., Malmuthge, N., Gellatly, D., Nordi, W. M., Alexander, T. W., Ortega Polo, R., Janzen, E., Schwartzkopf-Genswein, K., & Jelinski, M. (2024). Characterization of the hoof bacterial communities in feedlot cattle affected with digital dermatitis, foot rot or both using a surface swab technique. Animal Microbiome, 6, 2.