System for measuring movement response of small animals to changes in their orientation

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***Abstract*—The article introduces a novel system for measuring locomotive response of small animals (specifically amphibians and reptiles) to change in their body orientation based on a camera system located on mechanical platform powered by a set of three actuators. The camera system consists of three cameras providing a record three anatomical angles of body segment movements in space. A gyro accelerometer system allowing for measuring angles of the platform orientation in space is also a part of the mechanical platform, together with a computer providing for a precise measuring of body segment angles in anatomical as well as the earth's coordinate systems. We tested this novel method by measuring head rotation of a small reptile via monitoring reflective markers on the animal's body. A part of the work's results is thus a presentation of a method for monitoring animal's head compensatory movements. The assumption for the future is expanding the use of the system for more complex 3D movements, and adding the possibility to measure not exclusively just momentary values, but also angular velocity and segment acceleration for veterinary and medical use.**

***Keywords*—mechanical platform; anatomical angles; animal; camera system; 3D movement**

I. Introduction

Aiming to research the process of detection and processing of stimuli for an organism (especially humans) during a change of its position in space, and securing respective body reaction, method of dynamic posturography using body segment movements records has been introduced especially for medical use. The method relies on monitoring and evaluation of segment movements on a mechanical platform with a focus to study nervous system, vestibular system or musculoskeletal system functions [1]. Simple examinations using platforms providing shift or tilt of the platform's base with the measured subject in one direction are usually used, however more complex and expensive platforms allowing for 3D movement are used for experimental measurements.

Consequently, dynamic platforms can be applied for investigating the accurate motoric coordination related to sensorimotor functions of nervous system, or musculoskeletal system of animals. However, these occasions are exclusively scientific, not used in the field of medicine, or veterinary medicine. Majority of the studies focused on functioning of the nervous system of smaller mammals, or less frequently on amphibians, reptiles or birds. Original measurements were carried out by tilting animals held in hands and recording its movement in pictures, [2], even though this method is considered inaccurate. In order to make measurements more effective, special systems have been developed utilizing tilt platforms. A representative of a typical system is a platform tilting around a set axis. Even though these systems are usually equipped with more than one electric motor or powered manually, measurement and evaluation of the movement is always realized during rotation around a single axis. Body movement on the platform is recorded using MoCap (motion capture) system, which is not a part of the system's construction. A study focused on measuring movement of hares [3] applied such method, where movements were stimulated by manual rotation of the platform whilemarkers on the body were monitored by cameras. Colored contrast markers were placed along the medial axis of spine, neck and head and the camera was set up 2 meters from the subject, while record of the movement was analyzed manually frame after frame. For some experiments with hares, the tilt platforms were additionally equipped with force sensors under the animals, and goniometers used to measure movement [4]. Mounting animals on platforms using holders for body segments is also documented [5], as well as placing animals on a rough platform surface in case of trained animals to prevent them from falling [6].

More complex platforms and MoCap systems were used in studies which investigated the nervous system of domestic cat [7]. The tilting platform system was

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similarly equipped with force sensors under the feet of the subject, however the electric motor control system recorded not only momentary values of angles, but also angular velocity. The animal's movement was recorded by Vicon (VICON Motion Systems, Inc, Lake Forest, CA) MoCap camera system located outside the platform construction and identified the location of reflective markers on the animal's body automatically. Special platforms providing not only rotation, but also translational motion monitoring have also been tested [8]. These types of platforms however offer a smaller range of rotation and position identification accuracy depends on the platform movement, since the MoCap system is located outside the platform. In case of measuring smaller animals than cats or hares (e.g rats or frogs) systems providing only change in body orientation around one axis (i.e. mainly rotation of head around vertical axis) were used. In this fashion, head movement was studied using contrast markers on the head of the animal monitored by a camera placed above the rotation platform, or movement around horizontal axis [9]. However, in order to do comprehensive research on the function and evolution of nervous and vestibular system, there is a need to study body segments of smaller animals, such as amphibians of reptiles of 5 cm in size as well. Standard MoCap systems does not allow measuring the movements of body segments of smaller animals due to marker dimensions and camera accuracy. Another disadvantage is that MoCap systems are not a part of platforms, and therefore do not allow for measuring movements of body segments in relation to each other, if the platform moves extensively around all three axes. It follows that it would be necessary to implement MoCap system as a part of the platform as well as use markers of very small sizes to study more complex movements, which is unfortunately impossible due to active markers reaching their limits in downsizing. Finally, to measure the position of a body segment both in relation to earth's coordinate system and in relation to the platform accurately, it is necessary to know the exact position of the platform base, however a system allowing accurate identification and calibration of the platform's position using sensors mounted directly on the platform has not been developed yet.

The mentioned drawbacks are eliminated by the designed system including tilt platform and camera system for measuring movement of smaller animals. System also allows rotation of the platform with the subject in all directions, while there is also camera system mounted on the platform to record movements of body segments in anatomical coordinate system. To verify the functions of the designed system, the head of a small reptile has been chosen to test a relevant body segment for future research.

II. System Description and Measurement Methods

A. Description of Body Segments Movement in 3D Space

The platform allows for rotational motion of the animals body in 3D space. The initial position is a horizontal plane and direction of gravitational acceleration. The animal was mounted to the platform in a way ensuring that the three anatomical axes were in accordance with the three main axes of the platform (Fig. 1). Motor subsystem moving the platform was equipped with a set of three motors, to provide movement around the three axes. In case of more complex movements, the real axes of platform rotation perpendicular to sagittal and transversal plane do not match the anatomical planes, but are parallel. For this reason, angular movements of the platform (i.e. angles of rotation) are identical to body tilt angles. The change in the animal's orientation shall be described by Euler's angles – yaw, pitch and roll, (Fig. 1).

Information on momentary values of Euler's angles can be obtained from mechanical goniometers during manual control [3], which is inaccurate, or electronically from the motors' control unit [8], for example using implemented rotational potentiometres, as well as using inertial measurement unit (IMU) placed directly onboard the platform. For our case, we used information from electromotors on their tilt and at the same time IMU to check the platform's tilt angles, i.e. Euler's angles, and the platform's calibration.

To determine the body segment orientation in coordinate system it is neccessary (in case of the head) to define three movement angles in anatomical system of the animal body, which matches the coordinate system of the moving platform. These are – mediolateral flexion (yaw), dorsoventral flexion (pitch) and head rotation (roll), Fig. 1. These angles can be measured by appropriate placing of markers on the animal's head and camera system located directly on the platform. Cameras of the camera subsystem are located in a way ensuring their optical axes are perpendicular to each other, and at the same time perpendicular to sagittal, transversal and frontal axes of the animal placed on the platform.

Markers can have form of reflective plastic stickers [7] or their paper alternative [3]. It is however their disadvantage that they are more expensive and spacious [7], therefore anatomically harmless paint of a contrastive color was applied on the animal skin. Two spots were made for each plane while ensuring they do not coincide with one another as well as ensuring their placement on anatomically fitting parts with minimal interpopulation variability.

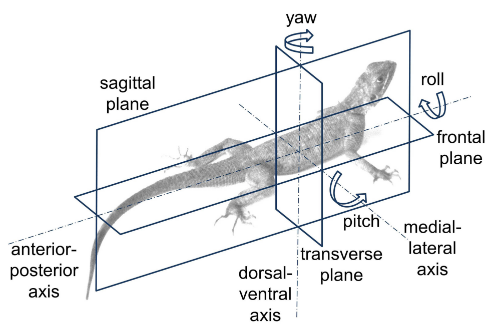

Figure 1. Anatomical coordinate system of the animal and its angular movement in relation to coordinate system related to the direction of gravitational acceleration and earth's horizontal plane

B. Subsystems for Measuring Movement Response

To record animal movement in all three anatomical axes, and at the same time carry out a complex movement of an animal in 3D space, a special system has been designed consisting of several subsystems. Fig. 2 demonstrates a block diagram of the main subsystems for measuring movement response of small animals to change in orientation of their bodies in 3D space.

The basic part of the system consist of the platform with the camera system, IMU, and the mounted animal. The platform is tilted by an actuator unit allowing for a change of all three Euler's angles. The way of the platform rotation is set by user in PC and sent to the data collection and control unit and which is located in a stationary base holding the actuator unit connected to the moving platform, Fig. 3. The control unit sends instructions to the three actuators and simultaneously obtains information about their position. IMU and the set of three mutually perpendicular cameras of the camera subsystem gives information on the momentary values of the platform tilt angles in space and momentary angles of the animal body segment orientation in anatomical coordinate system. IMU and camera subsystem send information on platform's orientation and video record of the animal body segment to the control unit and data collection unit. The control and data collection unit is connected to PC with a data cable to process and determine the platform yaw, roll and pitch angle values as well as the three anatomical angles of the animal body segment orientation.

The designed system consists of the platform, moving base which (the platform plane) creates a space with dimensions of 200 x 300 mm for placing the animal. Solid stationary base, where the control and data collection unit is placed, has a framework made of aluminium profiles of 30 mm combined with a 1.5 mm thick tin outer layer creates a jacketed space for electric components and connection point to mount the motors of the actuator unit. The outer layer of the framework is complemented by rubber and silicon isolation protecting electronic components against humidity and liquids. Actuator unit consist of three two-phase motors type 603TH88 with a basic step of 1.8° creating a torque of 3 Nm. The three motors of the actuator unit are located in mutually perpendicular axes. Bipolar stepper motors were used running at 128 microsteps per step, with magnetic momentum

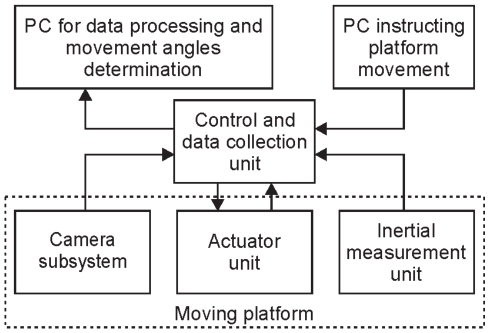

Figure 2. Block diagram of the main subsystems for measuring movement response of small animals to change in orientation of their bodies in 3D space.

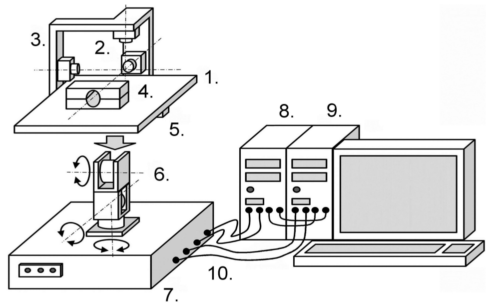

Figure 3. Diagram demonstrating the system measuring body response; 1. Moving platform, 2. Camera subsystem, 3. Camera holder, 4. Animal holder, 5. IMU, 6. Actuator unit, 7. Control and data collection unit, 8. PC instructing platform movement, 9. PC for data processing and movement angles determination, 10. Data cables connecting PC and Control and data collection unit

compensation for steady speed. Fine microstepping ensures smooth acceleration and deceleration to the desired speed. The three angles of tilt and rotation are achieved with an accuracy of 1 microstep, i.e. 0.02°. Calibration and checking of the tilt and rotation angles is done by the control and data collection unit obtaining information from IMU, which combines a three-axis gyroscope, three-axis accelerometer, 16 bit ADC and digital movement processor for accurate monitoring of fast and slow movements in gyroscope ranges of ± 250, ± 500, ± 1000, and 2000 ° / sec, and in accelerometer ranges of ± 2 g, ± 4 g, ± 8 g, and ± 16 g. Ranges of angular movements of the three motors are limited to avoid coincidence between the platform and the base construction. Limiting the range of motor movement is set to 60°, which is a higher value than that used in similar experiments [5], [6]. On the platform there is a light tin holder with rails for the cameras of the subsystem and an animal holder. The camera holder allows for setting the mutual focus and distance of all three cameras to the area of the head to enable watching the markers in as sharp and wide view as possible. All three cameras can move within the range of intersection of transversal and sagittal plane within the range of 80 mm. One camera can be moved within the intersection of transversal and frontal plane within the range of 50 mm, and one camera can be moved within the intersection of sagittal and frontal plane within the range of 100 mm.

C. Method for Determination of Anatomical Angles of Movement

To measure the position of particular segments of an animal (in our case, the head in relation to the trunk), the platform is equipped with the camera system and IMU. To determine these anatomical angles, it is necessary to measure using Euler's angles representing changes in angular position of the platform in space. For this reason it is essential to calibrate the system prior to each measurement. The platform's coordinate system (i.e. Platform orientation in 3D space) is set in accordance with gravitational acceleration and horizontal plane of the earth on the basis of IMU data before each measurement. In order to secure this, IMU was mounted to the platform during assembling in a way that the three main axes of the IMU are parallel with the main platform axes.

After the calibration, the pitch, yaw and roll angles are measured as well and at the same time, information on these is obtained from the three motors, which verifies the accuracy of the reached pitch, yaw and roll angles.

Considering that the camera holder is mounted to the platform holding the three cameras (cameras are mutually perpendicular and at the same time parallel with the three main axes of the platform) enables us to record the movement of points in planes respective to planes perpendicular to the main axes of the platform. Under the condition that the animal body is placed on the platform correctly, it is possible to record movement of segments in anatomical planes of the body, i.e. sagittal, frontal and transversal, Fig. 1.

In case of frequency rate for the record, we chose 30 fps due to recording slow compensation movements of reptiles, and as well due to steady data saving to the control and data collection unit and PC data processing and movement angle determination. Defender G-lens 2577 HD720P cameras with high definition of 720p, 10x digital zoom and suitable focus distance starting at 3 cm were used. The resolution was set at 320x240 pixels to speed up the data saving process. The camera's angle of view is 56°, which enables a scope of a significant part of a small animal in a particular anatomical plane. Tests have proven that geometrical distortion of of the view are neglible, taking into consideration the resolution, distance from the object and the size of markers, and do not affect the angle calculation. Angular movement of segments recorded by cameras is determined using contrast markers placed on a suitable anatomical point. In case of a need to only record the evolution of the anatomical angle of a segment, i.e. The change during measurement, precise placing of the makers is not necessary.

Determination of the rotation of a segment in a particular plane is given by the position of two markers on a segment (e.i. anatomical points) of the body and the setting of a camera. Lets suppose the angle calculation supposing an anatomical axis defined by two markers placed on the head and physical axis defined by the tilt of a camera, while that is parallel with the main axis of the platform. Cameras are set particularly (during assembly process) so that their picture matches a particular plane and at the same time two axes of a 2D picture, i.e. physical axis of the picture – vertical and horizontal, are parallel with the main axes of the platform. Fig. 4 demonstrates an example of two markers on the head and its placement on the platform to record mediolateral flexion, or, angular movements in the frontal plane. The angle between the anatomical axis and horizontal picture is an angle between v vector given by a camera setting in accordance with the platform axes an u vector representing coordinates of points. The angle between the vectors is given by software according to (1).

$$\Theta = \arccos \frac{u \cdot v}{|u| \cdot |v|}, \tag{1}$$

Equation (1) is given by $u = (a_x - b_x, a_y - b_y)$, $v = (1, 0)$, while a_x, b_x points are coordinates of two points/markers on the x axis, and ay, by are coordinates of two points/markers on y axis of a picture

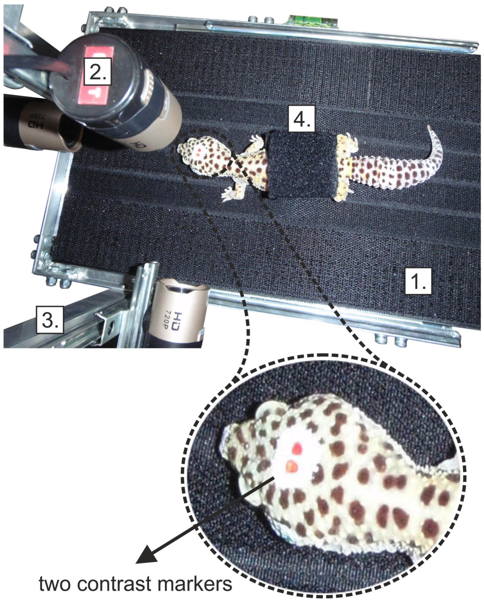

Figure 4. An example of measuring the animal's compensation movements in relation to the platform; 1. Platform, 2. Camera subsystem, 3. Camera holder, 4. Small animal holder

from one of the cameras, [10], [11]. These marker coordinates are detected on pictures automatically based on the contrast between their color and the skin color, algorithm for calculation of the marker coordinates is described in more detail in [12] and used in calculation software created in MatLab. Detection of the marker is based on setting the color tolerance on the scale from 0 to 255 for all three color segments in RGB spectre, conversion of the detected pixels to a binary mask and using k-means algorithm to detects middles of the resulting pixel poles. This calculation is utilized when calculating movement angles in all three anatomical planes, or, three pictures of a simultaneous record from cameras in the subsystem. It uses data processing and movement angles determination PC while records from cameras are coupled with data on the position of the motors and IMU in the control and data collection unit.

The above mentioned relation which was used to calculate the three anatomical angles of movement can be also used to calculate the angle of segment movement in 3D space, i.e in relation to horizontal gravitational acceleration. Considering that the control and data collection unit sends information on the platform position, or the whole animal body (yaw, pitch and roll angles) to data processing and movement angle determination PC, it is possible to use it to calculate the yaw, pitch and roll of the respective segments, as long as the anatomical angles in the platform plane are known. In case of basic calculation of a single-axis rotation, which is the only used method to measure movement [5], [6], body segment angles in space for its respective planes are calculated by a mere sum or difference betwwen the anatomical angle and the platform movement angle. Body segment angles in space are thus calculated based on the knowledge of the platform angle in global coordinate system and the animal in anatomical coordinate system.

D. Selection of Measurement Conditions and Experiment Results

Gradual movement around all three axes is examined to test the system, however we primarily focus on study of the head movement in sagittal plane and controlled change of orientation in the pitch angle of the platform, where the most significant compensation movements of the head can be expected. As for the selection of measurement conditions, the platform can be moved periodically by various types of the course of angular velocity, e.g by sinus course of angles (with frequency of 0.5 or 1 Hz and an amplitude of $\pm$ 20°) or linear course (between $\pm$20°), so called ramp-and-hold mode, as used in [3]. In the research of animal movement, sinus course if used less frequently than linear course. Sinus course (with frequency of 1 Hz) was used e.g also in [5], [9] (with frequency of 0.25-%.5 Hz and acceleration of 100°/s2). In [4] or [9], linear course was used together with tilt range of $\pm$ 20°. Tilts are therefore usually symmetric in relation to the initial horizontal position of the platform. Maximum values of tilt angles can reach up to 40° in healthy subjects, in case of roll and pitch angles, [5], [6]. By evaluation of pitch angles, even +90°/-90° angle was used, however the movement of subjects was carried out manually and the movement record step was 20°, instead of electronically powered platform [2]. In some studies of animals (e.g cats), one may come across lower angles, such as 6°, [7], [8] or $\pm$1° to $\pm$20° [9]. Lower values (from 3° to 7°) are however used rather in cases of studying postural stability in humans, due to higher COM position compared to quadripedal animals, where the base support is greater, and therefore there is not a risk of balance loss by higher tilt values, [13], [14], [15]. Initial or final phase of linear change can be defined by the maximum reached angle value or setting the period of angular movement of the platform, [5], [6]. Certain values of angluar velocities then correspond to such movement. In [3], [8], [7], 40°/s angular velocity was used, in [5], higher values, such as 50°/s were used. These values are comparable with those used in studies of humans, 36°/s to 50°/s, [13], [14], [15]. Since the mentioned cases discuss study of dynamic effects, i.e velocities are greater, the velocity was high enough to reliably cause automatic postural response (APR) in subjects. The total measurement time therefore lasted for a few seconds only, e.g. max 3 s [7] for one noncyclic movement. From the above-mentioned, we select movement angles for preliminary testing on a greater scale, ranging between +20°/-20°. The angular velocity was selected to be 1.5°/s to 5°/s to study movement response. These values can be of course modified and entered before an experiment in the user interface of the platform movement PC. The basic setting of the movement can be adjusted in the interface either directly (setting the velocity of the movement and the range of movement in respective axes) or by loading a file in .txt or .xls format with a table of the succession of the angle values desired at a particular time.

The leopard gecko (Eublepharis macularis) was selected for the purposes of the system testing, and the focus was on the measurement of the relative movement of the head in relation to the body. The

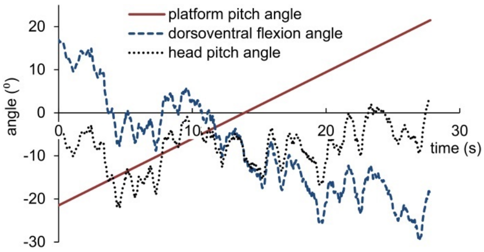

Figure 5. An example of a diagram measuring head movements of the gecko in the sagittal plane of its body

body of the subject was placed in a way that the longitudal axis corresponded to the longitudal axis of the platform (Fig. 4. Relative angles of the head movement in relation to the platform are determined by markers placed on the head, i.e two markers on the upper part of the head, two on the front part, and the last two on the side part of the head. Gecko was placed on the platform, and a gradual and sequenced rotation were performed, starting with mediolateral axis, then anterioposterior and dorsoventral axis. Before the actual measurement, calibration of the system to horizontal plane took place, i.e the information from IMU was used to set the main platform axes with the direction of gravitational acceleration and horizontal plane axes. Then parameters of the platform movements were entered into platform movement PC and software carrying out the platform movement was run, and head movement was recorded by the camera subsystem, platform movement by IMU. Control and data collection unit sends the measured data into the data processing and angle movement determination PC. The output from the latter is the information on flexion angles (dorsoventral and mediolateral) and the rotation angle. Based on the information on the relative head angles in relation to the platform and angles of platform movement in earth's coordinate system (i.e. platform pitch angle) it is possible to calculate the head movement in relation to the earth's horizontal line, i.e. the head pitch angle, Fig. 5.

III. Discussion

A special device with a moving platform was constructed for measuring active and passive movements of body segments of small animals, especially for the precise measurement of static and dynamic postural reflexes as a response to changes in the body orientation in three mutually perpendicular axes. If we compare the designed system with other systems, in the case of [3] only manual positioning together with a lower video frequency was used. Another shortcoming in [3] system is that the recorded was processed manually, i.e markers were marked manually in the pictures. The software we created enables detection of contrast markers automatically, which speeds up the processing of the record. Another advantage in our study is that sticker markers are not used, since the skin of a subject is painted, which again facilitates experiments and makes them cheaper. Our system also avoids complications with measuring very small animals (under 10 cm of length) by mounting them directly on the platform. Instead of using mechanical sensors for monitoring angles used in [4], our system is contactless, or non-invasive, and more suitable for measuring 3D movement. Compared to MoCap systems used for measuring animal movements based on electromagnetic principle [9], [16], for example Fastrak (Polhemus, Colchester, VT), accuracy of our system is affected by electronic parts such as actuator unit motors.

When it comes to the designed and used method, this was a basic method of a single axis rotation in accordance with [3] or [4] adjusted for measuring slow movements of reptiles. Measurement of head movement of smaller reptiles on a rotating platform with camera system mounted on it is an original and so far not utilized method. Recording head movement of mammals was mentioned for example in [8] and [16], however their designed construction of the system and measuring methods did not allow for measuring relative and absolute values of head movement angles in all three anatomical planes. An advantage of our system is that the used method of single axis rotation was only a testing method, in future the system may be used to study more complex movements of an animal in space. For further research into movement, there is an option of cyclic repetition of transition between stationary (or extreme) platform positions lasting a few seconds, e.g. in accordance with [5], [6], while cyclic movement is not limited by the number of cycles, however only by setting the desired complex movements in platform movement PC. The device can be theoretically used to record movements of an animal lasting several hours if required, and this could be controlled via the Internet, so that the animal is not affected in any way. Measuring also allows for repetition of identical tests under the same conditions, and a long term data collection [7]. As well, the system can be used for measuring movements of animals trained to track targets, optionally on a moving platform, as stated in [16].

Conclusion

The article presents a new system for measuring movement response of small animals to change in their body orientation, based on a camera system located on a moving platform powered by three actuators. The system was tested for measuring head rotation of a small reptile using digital camera system record of three angles of movement, which has not been described before. A part of the results is therefore also a presentation of a method for measuring accurate compensatory movements of animals. Device with a moving platform for measuring movements of small animals allows for determination of anatomical angles of head movement in anatomical coordinate system during the change of the animal's body orientation in space, therefore the new system is dedicated to measuring movements of small animals within the scope of veterinary and scientific use, and enables determination of pathological states in attitude of the animal. Therefore, there is an assumption of future testing of the system for evaluation of more complex 3D movements, and its upgrade with the possibility of determination of not only momentary values of angles, but also angular velocities and segment movement acceleration for veterinary and scientific use.

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