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# The use of stereophotogrammetry to determine the size and spatial coordinates to generate a 3D model of an animal

**Ladislav Libich, Michal Hruška*, Petr Vaculík, Miroslav Přikryl**

*Department of Technological Equipment of Buildings, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic*

**Corresponding author: jabko@tf.czu.cz*

**Abstract**

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This study considers the process of 3D scanning of farm animals using the method of stereophotogrammetry. This involves taking stereoscopic pictures of an animal, from which the spatial coordinates of selected anatomic points on the animal are determined using triangulation. These points are chosen in such a way to make it possible to determine from them the dimensions used in animal breeding databases and to draw a skeleton to be used in generating a 3D model of the animal. The dimensions of the animals were identified from this test group using an analysis of stereoscopic images and these were then compared with measurements done by hand on the same group. It can be said that the process of scanning farm animals in an authentic environment, which can be modified according to the current needs of the required imaging, was verified based on this measurement. This system also allows us to obtain 3D coordinates for further data evaluation and for the possible generation of a 3D model.

**Keywords**: farm animals; dairy cows; stereoscopic pictures; 3D scanning; modelling

The possibilities of digitalizing the model of an animal are not used frequently in animal production at present. They mainly provide the opportunity to determine the size of an animal without actual contact, meaning without the use of classic measurement by hand (Menesatti et al. 2014). These dimensions can be obtained using complex scanning systems, which might be expensive to purchase (Hruška, Nevoral 2013). Also, the provided solution does not directly correspond to the requirements of animal production. The scanning system must therefore be simple in its construction, must be able to obtain relevant and precise data and may not restrict the animal being imaged. It should also be capable of obtaining data from a larger group of animals within a short time-span and provide documents for the simple evaluation of results. These source materials can also be used as information required to automate the production process in animal production (Tasdemir et al. 2009). Stereophotogrammetry, which consists of finding spatial coordinates using passive triangulation, is ideal for obtaining such data (Bewley et al. 2008). Based on the evaluation of the stereoscopic images taken of the group of animals involved in the test, a comprehensive skeleton, accompanied by the points that define the total outer dimensions of a particular animal, can be generated using a 3D drawing programme (Pu et al. 2004). The subsequent use of geometric polygons located on the animal skeleton

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makes it possible to generate a sufficiently comprehensive 3D model that can be used for further applied research.

The 3D animal model can subsequently be used in the sphere of Digital Animal Modelling, which deals with the study of animal movement. In practice, the model obtained can then be used primarily to design technological equipment for breeding farm animals (Jacobs, Siegford 2012). The use of a 3D model here marks a significant simplification of the development process, in which virtual 3D modelling and checking of dimension parameters can be used to the maximum possible extent only within the scope of a modelling programme. This eliminates the need to check proposed equipment using live animals, which is more advantageous and more considerate from the perspective of the philosophy of welfare with regard to the production process of prototypes.

## MATERIAL AND METHODS

The scanning system uses the method of stereophotogrammetry, which enables the optical imaging of an object without the use of active, laser-type elements or added lighting. The calculation of coordinates is carried out in a mathematical expression by passive triangulation (Wu et al. 2003). Another advantage of this method is the simple calculation model, which allows data to be processed at speed.

After obtaining the required data, it is then necessary to choose points of interest on the animals. These points must be sufficiently emphasized on the animals using adhesive targets, the points drawn using a non-detrimental marker, although anatomic points or the prominences of the animals can also be used directly (Negretti et al. 2011). This paper chooses a combination of drawn points with the use of non-detrimental veterinary markers and real anatomic points on the animals. These points were chosen so that their connecting lines represent the basic bodily dimensions of the animals (Sowande, Sobola 2008), used in basic breeding databases (Table 1).

Scanning equipment. Equipment (Fig. 1) used in the method of stereophotogrammetry was designed and constructed in order to obtain the required data. This equipment consists of:
– two cameras Nikon J1 fitted with a fixed lens and focal length of 10 mm;
– a base head (own construction);
– a tripod (Manfrotto PRO 055XPROB);
– electronic assurance of the synchronized triggering of the cameras (own construction based on Arduino Uno control panel).

The base head is 1,000 mm in width and thanks to the central opening with a 3/8 Whitworth tap, it is possible to ensure the compatibility of the portal with most photographic tripods.

An important element in the equipment is an Arduino Uno control panel (Arduino AG), which allows the cameras and the computer to communicate with each other and which ensures that photographs are taken from both cameras. The control mechanism is based on the principle of receiving an IR (infra-red) signal, which is sent from the controller to the control electronics. After receiving the signal, the control electronics send the sequence required to photograph the image (according to the camera manufacturer).

IR diodes of 880 nm wavelength are run from the control panel to each camera using a cable and they transfer the order to photograph. The diodes must

Table 1. Dimensions used in breeding databases

| Name of measurement | Description of measurement |
|---|---|
| Frame of the body/withers height | Characterised by height at the small of the back measured using a measuring stick. This measurement can be replaced by the withers height, which should be the same. |
| Width of the back | The description is characterised by the distance between the tops of the ischium. It is considered when viewed from the rear. |
| Width of shoulder joints | Characterised by the distance between the tops of the shoulders. |
| Distance from the ground to the abdominal cavity | The distance from the ground to the first point of the abdominal cavity. |
| Diagonal length of the body | This parameter determines the length of the animal. It is measured using a fixed scale from the shoulder joint to the top of the ischium. |

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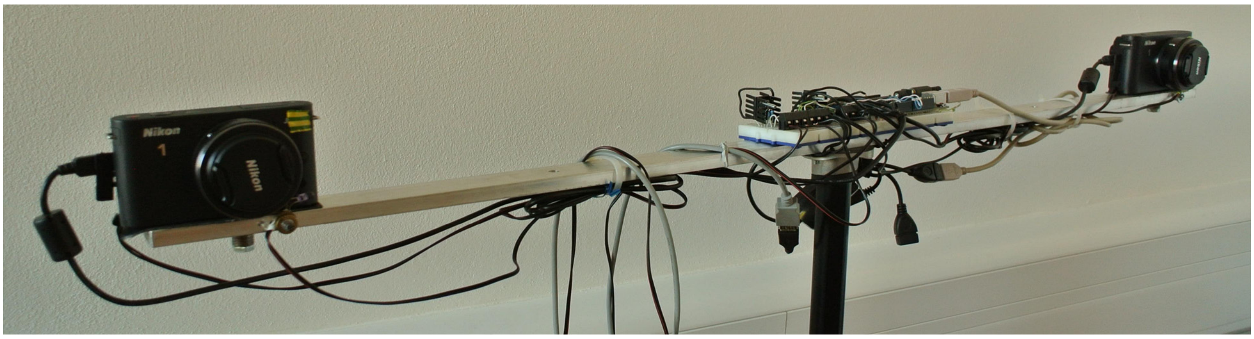

Fig. 1. Scanning equipment

be placed directly by the IR element of the camera so that the signal is as strong as possible. They must also be covered so that there is no reading of the signal intended for another camera. Sending the sequence to both diodes makes sure that photographs are taken at the same time. A deviation is only possible in the first image, before both cameras are harmonized with the sharpening and setting of the exposure. This generally takes between a few hundred milliseconds and a few seconds and might take a different length of time for each camera. After taking the first photograph, however, both cameras have identical conditions for photography and the difference in the exposure time disappears.

**Mathematical description and calibration**. The mathematical expression of stereophotogrammetry draws on the method of passive triangulation. The angles of the intersecting straight lines must first be determined. The lines cross at the desired point and are defined by a horizontal and vertical angle. The angles have to be determined from equations (1) and (2), done for each camera. Eqs (1) and (2) are for the camera on the left.

$$UW_{WcamL} = \left(\frac{2 \times P_w - W}{W} \times \tan\left(\frac{a_W}{2}\right)\right) \quad (1)$$

$$UW_{HcamL} = \left(\frac{2 \times P_H - H}{H} \times \tan\left(\frac{a_H}{2}\right)\right) \quad (2)$$

where: $U_{WcamL}$ – horizontal angle (°); $U_{HcamL}$ – vertical angle (°); $P_H$ – position of a point on the photograph in pixels from above (px); $P_W$ – position of a point on the photograph in pixels from the right (px); $H$ – total height of the photograph in pixels (px); $W$ – total height of the photograph in pixels (px); $a_H$ – vertical angle of the shot (°); $a_W$ – horizontal angle of the shot (°)

After determining the angle, it is then necessary to determine the vectors of the lines that intersect at the desired point. After substituting the parameters known from the photographs, it is possible to compile a simple equation that describes the relations for obtaining the points of space $X$ and $Z$ (Eqs 3 and 4). This uses classic trigonometry and it is possible to determine the coordinates of the points of a triangle (Fig. 2) in the Cartesian system when knowing the angle and two dimensions of the triangle.

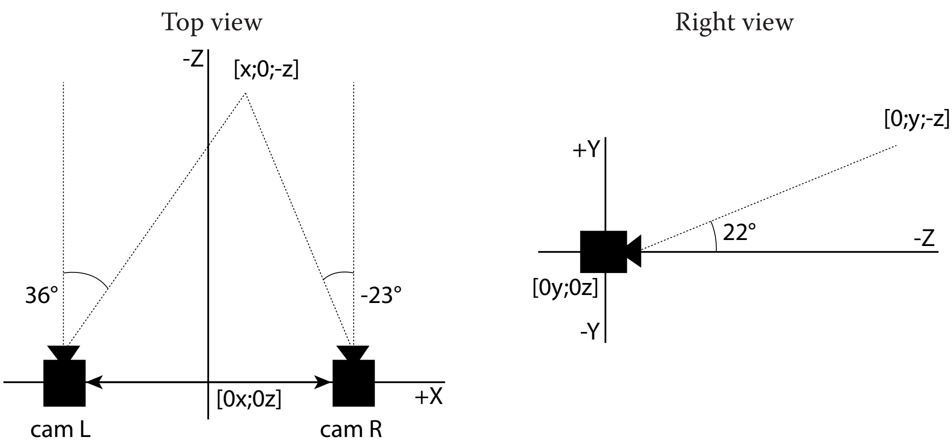


Fig. 2. Findings of spatial coordinates

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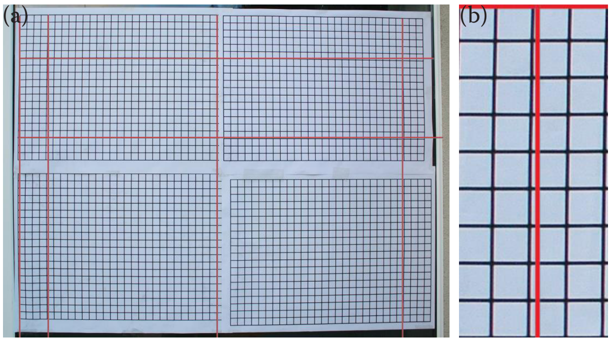


Fig. 3. Calibration grid (a) and detail of the curvature of the lens (b)

With respect to the fact that one dimension of the triangle is missing, this needs to be balanced by the other equation obtained from the second photograph. For this reason stereophotography is based on obtaining data from a minimum of two photographs.

$$X + Z \times \tan(U_{WcamL}) = X_{camL} \quad (3)$$

$$X + Z \times \tan(U_{WcamR}) = X_{camR} \quad (4)$$

where: $X$, $Z$ – desired coordinates (–); $U_{WcamL}$ – horizontal angle of view from the camera on the left (°); $U_{WcamR}$ – horizontal angle of view from the camera on the right (°); $X_{camL}$ – position of camera on the left on base at axis $X$ (450 mm) (mm); $X_{camR}$ – position of camera on the right on base at axis $X$ (450 mm) (mm)

The final Eq. (5) is the final determination of the spatial coordinates of the point at which the above-mentioned lines intersect. The components of the coordinates of the desired point in space can be calculated in this simple form from the data calculated from the photographs.

$$\text{point} = \left[X\ ;\ Z = \frac{-x_{camR} - X}{\tan(U_{WcamL})};\ Y = \tan(uH) \times Z\right] \quad (5)$$

where: $X$, $Y$, $Z$ – spatial coordinates (–); $X_{camR}$ – position of the camera on the right on axis X (px); $U_{WcamL}$ – horizontal angle of view from the camera on the left (px); $uH$ – vertical angle of view (both cameras must have the same) (°)

These equations and the procedure described above allow us to obtain the coordinates of the point in space. These can be further used to work with, meaning determining their position and distance in relation to/from each other.

**Calibration of the equipment**. The apparatus must be calibrated before measurements are taken in order to obtain accurate data. Calibration must be done in order to eliminate structural and technological errors in the cameras and to set the equipment at the required distance, at which imaging will be done. Calibration also serves to check the functioning of the apparatus as a whole. Calibration may be mechanical and mathematical. For mechanical calibration, it is important to observe the rules of stereophotogrammetry – to make sure that the axes of the centre of the lenses of the camera are parallel to each other and the cameras themselves are on a common base. The distance of the focal points of the two cameras to base must be known.

Mathematical calibration consists of eliminating errors caused by production deformation of the optics and certain inaccuracies caused by mechanical setting when positioning the cameras. It is also necessary to ensure correction of the tangential and radial geometric distortion (curvature) of the lens (Huttner et al. 2011).

Tangential distortion is caused by the technical construction of the lens, although the precision of modern-day procedures in the production of lenses makes it possible to ignore this deviation. Radial distortion determines the movement of a point on the image by radial distance, i.e. the distance measured from the centre of the photograph taken to the edge of the image. This calibration is done using a calibration table or using calibration targets that are aimed into space and all required values, such as dimensions, distance etc., are known. This test table (Fig. 3a) must be placed and measured at approximately the same distance at which the real object is to be scanned later and the deviation of distortion determined using the images.

Calibration and identifying deviations are done on a trial and error basis. A stereoscopic image of the calibration grid (Fig. 3a) is taken from a distance of 3 metres, which is roughly the distance at which the scanned animals are moving. One image from the pair is chosen for the final calculation (specifically the one on the left), as the calibration image, and final calculations of deviations are done using the image on the right, meaning by how many pixels the coordinates move in contrast to the real image.

For the sake of illustration, several red lines are indicated in Fig. 3a, having been drawn on to the image digitally. If the lens do not exhibit any distortion, these lines would copy the photographed square walls. The distortion of the lens is evident

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Fig. 4. A pair of source photos taken stereoscopically – left part: from left angle of veiw (a) and right part: from right angle of view (b)

at the first glance. A detailed representation is seen in Fig. 3b, where the increasing deviation from the original reticule photographed can be seen.

This deviation must be eliminated to ensure the proper functioning of scanning or a constant must be determined that puts the coordinates of the required pixels in the right positions (Tasdemir et al. 2011). If this deviation is not eliminated and the object is situated in a part of the photograph where the deviation is clear, deviations of up to tens of centimetres could occur in measurements.

The final part of calibration consists of taking images of a real object whose dimensions are known. The ascertained deviations are applied to a correction of the measured dimensions of the real object. The error rate in a static, real object is somewhere around ±2.08 mm when using this calibration.

According to the rules of stereophotogrammetry, 20 first lactation cows of the Holstein cattle breed were photographed. Points of interest were marked on the animals using a veterinary marker (Kerolan Colour spray; Raidex, RED, 500 ml) that is non-detrimental to health. Each animal was photographed several times from various angles, which resulted in several paired photographs for each animal. The most optically suitable photographs were chosen to obtain spatial coordinates. The stereoscopic pairs of photographs had to be checked to see whether the desired points of interest were visible on the left- and right-hand images. Several pairs of photographs related to each animal were obtained, and from them, spatial coordinates and calculated dimensions.

In order to verify the accuracy of the method, the data thus obtained were compared with the measurements carried out by hand on the same group of animals and authoritative deviations were subsequently determined. The results of measurements by hand, carried out according to the methods of breeding databases (Svaz chovatelů holštýnského skotu ČR 2009) were determined as the starting ones. The percentage expression of the total average deviation of digitalized data from measurements by hand was 1.03%. To ensure greater accuracy, the

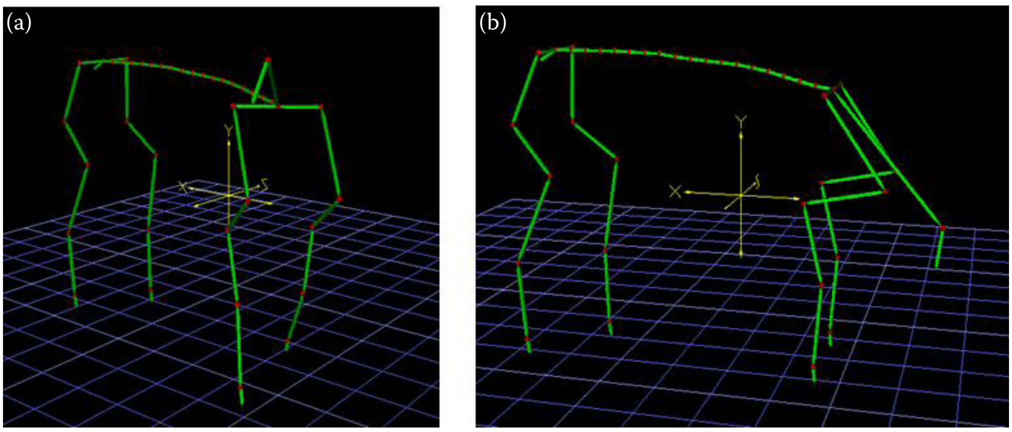


Fig. 5. Digital skeleton model (a) and (b)

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average measurement error was determined for various bodily dimensions. A comparison of values for measurements of the animals, withers height is shown in Fig. 4. This measurement exhibits the smallest deviation as a result of the precise measurement of the withers height and the area of the floor level. It is clear from the graph that the photograph values are usually smaller than the values measured by hand. This difference could be a result of the different position of the animals in light of the fact that the animals were photographed when walking as normal. By contrast, measurement by hand was carried out in a box with max. efforts made to keep the animal in an upright position with raised head.

The biggest deviations are found in the dimensions of the diagonal length of the body (Fig. 5a and Fig. 5b). It was shown for this dimension that it is very difficult to determine the right extreme points for measuring diagonal length and that better orientation points have to be found for future measurements.

## RESULTS AND DISCUSSION

The spatial coordinates of dairy cow number (complete) were experimentally visualized in the Tecnomatix Jack programme (Tecnomatix Siemens, version 7.0), which is primarily intended to deal with the ergonomic positions of humans. It involves drawing points in space, which are subsequently joined, as can be seen in Fig. 6. Drawing the points consists of displaying using coordinates *x*, *y* and *z*, which were obtained from photographing. Only for the parts which could not be photographed with one pair of cameras (the reverse side of the hip and shoulder joint) were the coordinates additionally calculated by moving the z element according to the photographed dimensions of the width of the animal (Evers-Senne et al. 2004).

A skeleton defined in this way allows us to determine certain basic movements of the animal, as can be seen in the image, where you can also see the subsequent joining of the vertebrae in order to define movement.

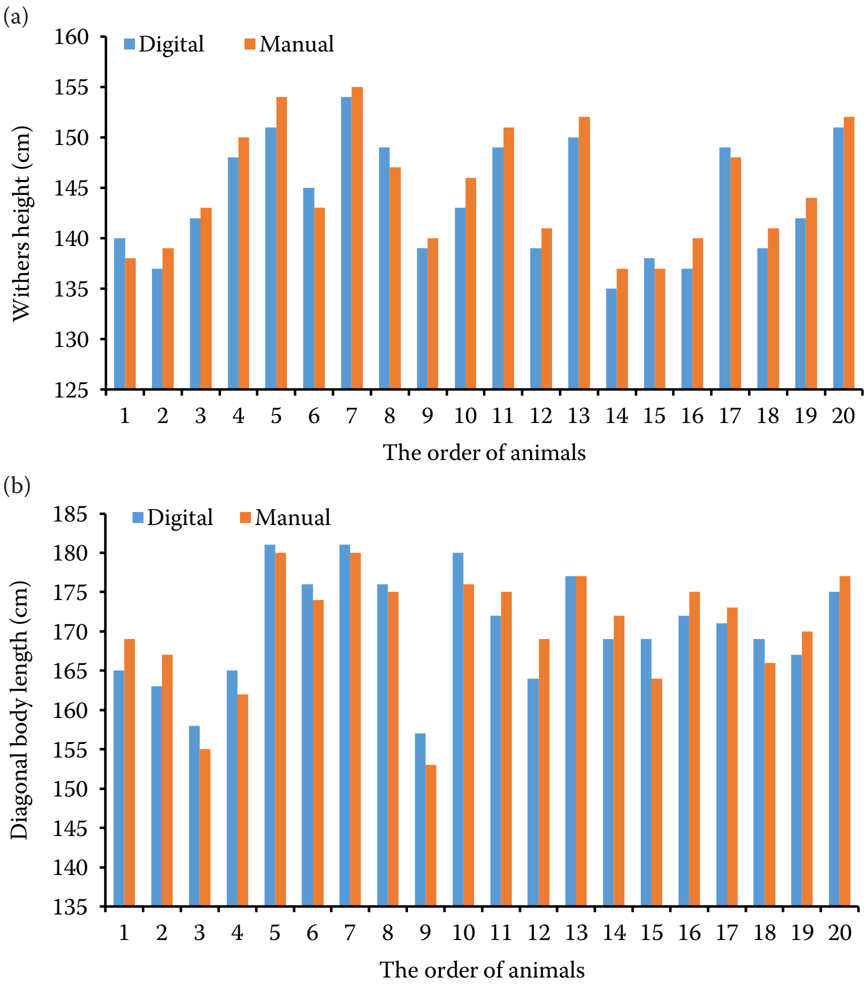


Fig. 6. Withers height difference (a) and (b) diagonal body length difference between manual and digital measurements

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This graphic skeleton will then be used to generate a complete 3D model, which can be used to simulate interaction between the animals and their surroundings. At this point, the model can be used to test possible movement ranges and define the angles of individual joints. It is important to stress that this is not an anatomically precise depiction of the skeleton of the animal, but a biomechanical model of the animal that can be used in the graphic generation of a 3D model of the animal.

## CONCLUSION

This paper resulted in finding a functioning process of 3D scanning that has been tested as part of a real process. The simplicity of the equipment and calculation model as a whole facilitates the fast collection of data and their evaluation. The possibilities of calibrating the equipment makes it possible to modify the equipment to scan various animate and inanimate objects. The results of this paper can be considered as basic data for further elaboration. The twenty animals measured were used for the basic verification of the functioning of the process of the scanning method as a whole. A larger group of animals needs to be photographed for further mathematical results. The dimension-related results obtained in this way, which are suitable for to generate a 3D model, can be statistically connected to breeding databases. However, this connection must be mathematically verified, particularly the dependence of the main dimensions on the overall animal appearance. This verification would provide full information about the dimensions of the animals and improve the quality of the graphic 3D model.

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