USE OF A 3D IMAGING DEVICE TO MODEL THE COMPLETE SHAPE OF DAIRY CATTLE AND MEASURE NEW MORPHOLOGICAL PHENOTYPES

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ABSTRACT

Monitoring of body weight variation, body condition and/or morphological changes allows optimal management of animal health, production and reproduction performance. However, due to implementation difficulties (handling, time consumption, investments), this type of monitoring is not very common within commercial farms. The development of three-dimensional imaging technologies is an interesting solution to meet these needs. The purpose of this study was to develop, test and validate a device (Morpho3D) offering the possibility of recording and analysing complete 3D forms of dairy cattle. To evaluate the performance of this tool, manual measurements were performed on 30 Holstein dairy cows: height at withers (HG), chest circumference (TP), chest depth (PP), hip width (LH), buttock width (LF) and ischium width (LI). They were compared to those estimated by the Morpho3D device. Correlations coefficients between Morpho3D measurements and manual measurements were 0.89 for PP, 0.80 for LH, 0.78 for TP, 0.76 for LF, 0.63 for LI and 0.62 for HG. For the Morpho3D system, the repeatability standard deviation ranged from 0.34 to 1.89 (coefficient of variation (CV) from 0.26 to 9.81) and the reproducibility standard deviation ranged from 0.55 to 5.87 (CV from 0.94 to 7.34). These values are close to those obtained with manual measurements. This new device offers the possibility of measuring new phenotypes such as the total volume of the animal or the body surface and thus offers new opportunities for new researches and studies.

Keywords*:* 3D imaging, body measurement, dairy cow, precision breeding, sensors

1. INTRODUCTION

Monitoring the evolution of the morphology of dairy cattle allows to adapt feeding, reproduction and general management for optimal operation of the farm. Currently, with the exception of weight, most measurements are done manually (tape, measuring rod) or visually (Heinrichs and Hardgrove, 1987). These measurements, which are time-consuming, are sources of stress and accidents for farmers and animals and rarely available on the farm. Developing precise, automatic and easy-to-use tools to overcome these problems is therefore of interest. Imaging techniques offer interesting alternatives to manual measurements and / or costly methods (Pezzulo et al, 2018). 2D imaging approaches, used in pork with some success (Marchant et al, 1993, Schofield et al, 1998), do not allow approaching the third dimension. In addition, distortion problems, the calibration procedure, the need for multiple cameras and finally the complexity of the 3D reconstruction models have reduced their use. The 3D imaging technologies have thus been used successfully to analyse the Body Condition Score (BCS) of dairy cattle (Fischer et al, 2015, Kuzuhara et al, 2015). Negretti et al (2008), Buranakarl et al (2012), Guo et al (2017) and Pezzuolo et al (2018) have also developed 3D image technologies with the aim of obtaining a 3D image of the whole animal, but many problems remain. Pezzuolo et al (2018), used low-cost portable equipment based on the Microsoft Kinect v1 sensor, and concluded that their method still requires a lot of engineering to enable the automatic collection and extraction of data satisfactorily. A new device (called "Morpho3D") has been developed to easily capture the complete shape of cows and measure their morphological traits. Measurements obtained with this device were compared with values collected directly from live animals. To validate the method, repeatability and reproducibility were also analysed.

2. MATERIAL AND METHODS

2.1 Device

The device tested is installed in the dairy experimental farm of INRA-UMR PEGASE located in Le Rheu (France). The system comprises of a total of 5 camera sensors, each in combination with a laser projector emitting at 650 nm to limit the risks to humans and animals. The pairs 'camera-laser' are installed on a mobile portico (Figure 1), set at 0.40 and 1.77 m above the ground on both sides and a fifth in the middle of the top of the portico. The portico moves at an average speed of 0.5 m s^{-1} from back to front and returns to its original position at an average speed of 0.3 m s^{-1}. 80 photos per second and per camera are recorded only during the first way of the portico (Le Cozler et al. 2019a). To secure the entire device, four stainless steel cables mark the movement of the cows. Animals can also be blocked by a self-locking head door if necessary.

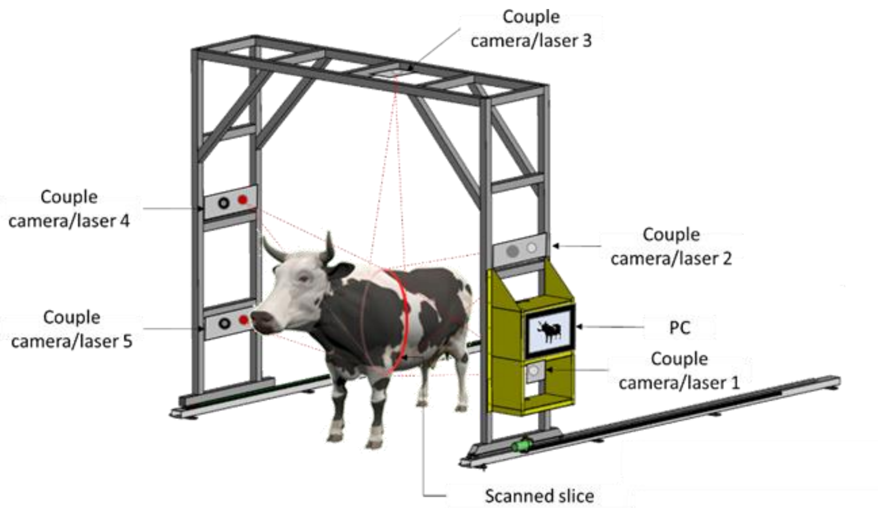

Figure 1. The Morpho3D scanning system

The images of the laser bands projected on the animal are captured by their corresponding camera and sent to a computer to reconstruct the 3D information. The images of each camera are first processed to build point clouds and the complete 3D reconstruction of the animal is performed by recording and merging the multiple views of the 3D data from the point clouds of the 5 camera-laser pairs (Figure 2). A distance threshold is set to ignore points too far from the camera and not belonging to the animal. An example of the living animal process is available at https://vimeo.com/219370900.

Free software for processing and editing 3D triangular meshes was then used to clean the data (Meshlab, Cignoni et al, 2008). A Poisson surface reconstruction algorithm was applied to construct a triangulated mesh and perform shape smoothing (Kazhdan and Hoppe, 2013). The different stages of the treatment are shown in figure 3.

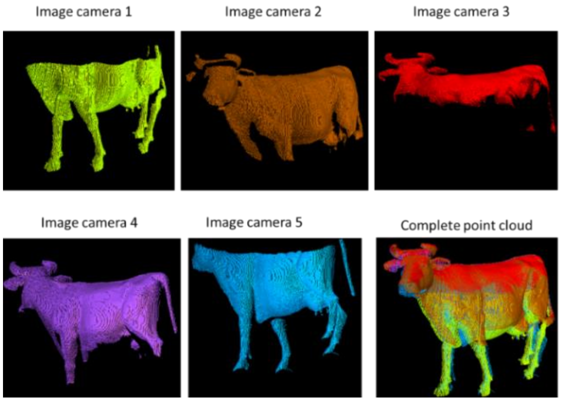

Figure 2. Point cloud reconstruction

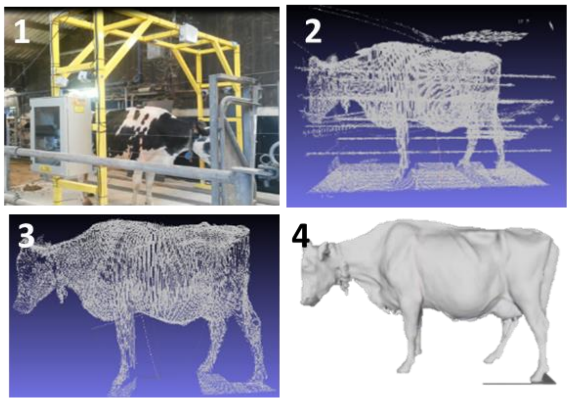

Figure 3. From Acquisition to Final Data: Image 1: Data Acquisition. Image 2: Raw cloud. Image 3: Cloud after cleaning. Image 4: final image after normalization and Poisson reconstruction.

2.2 Animals and measures

Data were collected between May and June 2017 on 30 Holstein dairy cows, aged 3.0 (+ 1.2) years on average, producing 25.5 (+ 3.6) kg of milk per day. Manual measurements were made directly on cows and this same measurements were estimated on 3D images from Morpho3D device. For both methods, 6 of these 30 cows underwent a series of repeated measurements of the same indicators (6 times each), in order to estimate the reproducibility of the methods. For the estimation of repeatability, a plastic cow model was used. The indicators measured on live animals and images included wither height (WH), heart girth (HG), chest depth (CD), hip width (HW), thirl width (TW) and ischium width (IW). For manual measurements, a tape and a measuring rod were used. In the reconstructed images, measurements were made using dedicated software (Metrux2α®, 3D Ouest).

2.3 Data analysis

Repeatability and reproducibility of the two methods were evaluated. Repeatability makes it possible to evaluate the error generated when estimating an indicator several times on the same sample with the same methodology, in the same environment, over a short period of time. It was estimated by making measurements 6 times the same day, from the same 3D scan of the same animal (plastic model cow). Reproducibility evaluates the same error but under varying environmental conditions. It was estimated by scanning 6 cows, 6 times each the same day, and making the measurements once on each 3D scan. The 3D variations were corrected to account for the effect of animals in extracting ANOVA model residues. The coefficients of variation for repeatability (CVr) and reproducibility (CVR) were evaluated as CVr = (σr / μr) * 100 and CVR = (σR / μR) * 100, where σr and σR are respectively the standard deviations of the corrected 3D measurement for the repeatability and reproducibility datasets and μr and μR are respectively the average 3D measurements of the repeatability and reproducibility data. Similarly, the repeatability and reproducibility of manual measurements were estimated by correcting the variability of the measures for the effect of cows and operators (2 operators performed the same measures). The Anova 1 model then included "cow identity" as a factor in case of repeatability, and the Anova 2 model includes "cow identity" and "expert identity" as explanatory factors of the measure for reproducibility. The correlation analysis between the 3D image measurements and the reference values was performed using the statistical software R, (R Core Team

2013. R Foundation for Statistical Computing, Vienna, Austria) and the analyses concerning repeatability and reproducibility were carried out with the SAS software (SAS institute, 2016).

3. Results and discussion

Comparison between the two methods shows that most manual measurements have values lower than those obtained from 3D images (Table 1). The highest difference was observed for the ischium (difference of 11.2%), while the lowest was noted for the withers height (1.3%).

Table 1. Comparison of measurements manually performed on 30 cows or made from 3D images

Measure	Manual (cm)	Morpho3D (cm)	Error rate (%)	*p*- value
Heart girth (HG)	207.5	221.5	6.3	< 0.0001
Chest depth (CD)	79.4	83.8	5.3	< 0.0001
Wither height (WH)	146.9	148.8	1.3	< 0.003
Hip width (HW)	55.5	54.4	2.0	< 0.02
Thirl width (TW)	51.9	54.4	4.6	< 0.008
Ischium width (IW)	17.4	19.6	11.2	< 0.02

The correlation between the two types of measurements is also high (Table 2). The highest values were observed for chest depth (0.89) and the lowest values for ischium width (0.63). The prominent bones at the hips certainly explain the small differences observed between manual measurements and Morpho3D, as noted by Pezzulo et al (2018). On the contrary, the prominent bones are less visible for the ischium, which may explain the meager performance at this level. For some measurements (Heart girth or chest depth), an overestimation exists because in some cases, the position of the front leg on the image did not allow a satisfactory access. The correlation values between the two approaches are generally lower than those reported by Buranarkal et al (2012) and Pezzulo et al (2018). Buranarkal et al (2012) performed their measurements under laboratory conditions and used visual markings stuck on animals, unusable under commercial conditions. Pezzulo et al (2018) performed their analyses on mean values.

Table 2. Coefficient of correlation and P-value, between manual measurements and those obtained on 3D images

Measure	Coefficient of correlation	*p*- value*
Heart girth (HG)	0.78	< 0.001
Chest depth (CD)	0.89	< 0.001
Wither height (WH)	0.62	< 0.001
Hip width (HW)	0.80	< 0.001
Thirl width (TW)	0.76	< 0.01
Ischium width (IW)	0.63	< 0.01

** test of Student*

The repeatability and reproducibility values are quite similar between methods (Table 3). For data from 3D images, the σr ranged from 0.34 to 1.89 (CV 0.26 to 9.81) and σR from 0.55 to 5.87 (CV from 0.94 to 7.34).). Using manual measurements, the σr ranged from 0.21 to 1.32 (CV 0.11 to 10.30) and σR ranged from 0.49 to 1.19 (CV 0.42 to 4.46). According to Fischer et al (2015), measurement methods with repeatability and reproducibility CVs below 4% can be considered as interesting methods, which is the case in this study. Many authors stress the important effect of the animal's position on the fluctuations of the measurements made and the importance of selecting, often manually, the best images to limit undesirable variations (Kmet et al. 2000; Stajnko et al. 2008). Fischer et al (2015) also showed the impact of animal's position in the work done to estimate BCS by 3D imaging. But only a few authors went so far as to qualify (repeatability, reproducibility) the method tested.

Another important point that can change the quality of the images and therefore ultimately the repeatability and reproducibility of measurements, is the environment (Tscharke and Banhazi. 2013). Indeed, most technologies are sensitive to daylight and are conducted in controlled light conditions. Similarly, the control of animal movements to obtain exploitable images is a crucial point.

An estimate of the time spent per method to obtain all the values of the indicators used was carried out and corresponded to 2.5 and 14 minutes for the manual and automatic systems. In the second case, the acquisition is fast (6 s on average) but the time needed to analyse and get the final results was about 14 min. It is clearly possible to reduce this time in the future through the optimization of models and equations

Table 3. Repeatability and reproducibility of body measurements obtained directly from animals (Manual) or 3D images (Morpho3D). A plastic cow model was used for the repeatability study and 6 cows were used for the reproducibility study.

CVr and CVR are respectively the coefficients of variation for repeatability (CVr) and reproducibility (CVR), σr and σR the standard deviations of the corrected 3D measurement for the repeatability and reproducibility datasets and μr and μR the average 3D measurement of the repeatability and reproducibility data.

Measure		Repeatability			Reproducibility		
		μr (cm)	σr	CVr (%)	μR (cm)	σR	CVR (%)
Heart girth (HG)	Manual	194.2	0.21	0.11	204.2	0.86	0.42
	Morpho3D	195.8	1.89	0.97	221.1	5.87	2.63
Chest depth (CD)	Manual	75.1	0.42	0.56	79.1	0.49	0.62
	Morpho3D	76.5	0.44	0.58	84.4	0.92	1.09
Wither height (WH)	Manual	129.1	1.04	0.80	148.9	1.07	0.72
	Morpho3D	131.1	0.34	0.26	148.6	2.12	1.42
Hip width (HW)	Manual	39.8	0.35	0.88	55.5	1.01	1.82
	Morpho3D	39.9	0.67	1.68	58.6	0.55	0.94
Thirl width (TW)	Manual	50.9	0.36	0.71	50.8	1.19	1.82
	Morpho3D	52.6	0.34	0.64	55.5	1.82	3.28
Ischium width (IW)	Manual	12.8	1.32	10.30	17.3	0.77	4.46
	Morpho3D	17.5	1.78	9.81	15.4	1.13	7.34

4. Conclusion

This new technology is very promising. Despite a longer time of obtaining the final result, the 'animal handling' part is very short, limiting the risk of accidents for humans and animals, which is interesting for other productions where the handling of animals is more delicate (suckler cattle for example). The automation of the various phases of the acquisition process (cleaning, reconstruction and automatic measurement) is a major concern. The development of a new technology based on a 'one shot' may be a solution to solve the problem of moving animals. The possibility of obtaining a 3D image of the whole animal makes it possible to consider many valuations: automatic BCS, automated morphological score for animal selection, estimation of body weight, measurement of the surface and / or the volume of the animal (Le Cozler et al. 2019b).

5. Acknowledgements

The authors thank all those involved in the project, especially the technicians from the experimental station who took great care of the animals. The Morpho3D project is supported by the CASDAR National Fund, an Incentive Credit from the INRA Phase Department and the ANR DEFFILAIT Program.

References

Buranakarl, C., Indramangala, J., Koobkaew, K., Sanghuayphrai, N., Sanpote, J., Tanprasert, C., Phatrapornnant, T., Sukhumavasi, W., Nampimoon, P., 2012. Estimation of body weight and body surface area in swamp buffaloes using visual image analysis. Journal of Buffalo Science. 1, 13–20.

Cignoni, P., Callieri, M., Corsini, M., Dellepiane, M., Ganovelli, F., Ranzuglia, G., 2008. MeshLab: an open-source mesh processing tool. In: Sixth Eurographics Italian Chapter Conference, pp. 129–136.

Fischer, A., Luginbuhl, T., Delattre, L., Delouard, J.M., Faverdin, P., 2015. Rear shape in 3 dimensions summarized by principal component analysis is a good predictor of body condition score in Holstein dairy cows. Journal of Dairy Science. 98, 4465–4476.

Guo, H., Ma, X., Ma, Q., Wang, K., Su, W., Zhu, D., 2017. LSSA_CAU: an interactive 3d point clouds analysis software for body measurement of livestock with similar forms of cows and pigs. Computers and Electronics in Agriculture. 138, 60–68.

Heinrichs, A.J., Hargrove, G.L., 1987. Standards of weight and height for Holstein heifers. Journal of Dairy Science. 70, 653–660.

Kmet, J., Sakowski, T., Huba, J., Peskovicova, D., Chrenek, J., Polak, P., 2000. Application of video image analysis in the slaughter value estimation of live Simmental bulls. Archiv Tierzucht Dummerstorf 43, 411–416.

Kuzuhara, Y., Kawamura, K., Yoshitoshi, R., Tamaki, T., Sugai, S., Ikegami, M., Kurokawa, Y., Obitsu, T., Okita, M., Sugino, T., Yasuda, T., 2015. A preliminarily study for predicting body weight and milk properties in lactating Holstein cows using a three dimensional camera system. Computers and Electronics in Agriculture. 111, 186–193.

Le Cozler, Y., Allain, C., Caillot, A., Delouard, J. M., Delattre, L., Luginbuhl, T., & Faverdin, P., 2019a, High-precision scanning system for complete 3D cow body shape imaging and analysis of morphological traits. Computers and electronics in agriculture, 157, 447-453.

Le Cozler, Y., Allain, C., Xavier, C., Depuille, L., Caillot, A., Delouard, J. M., ... & Faverdin, P., 2019b), Volume and surface area of Holstein dairy cows calculated from complete 3D shapes acquired using a high-precision scanning system: Interest for body weight estimation. Computers and Electronics in Agriculture, 165, 104977.

Marchant, J.A., Schofield, C.P., 1993. Extending the snake image processing algorithm for outlining pigs in scenes. Computers and Electronics in Agriculture. 8, 261–275.

Negretti, P., Bianconi, G., Bartocci, S., Terramoccia, S., Verna, M., 2008. Determination of live weight and body condition score in lactating Mediterranean buffalo by Visual Image Analysis. Livestock Science. 113, 1–7.

Pezzuolo, A., Guarino, M., Sartori, L., Marinello, F., 2018a. A feasibility study on the use of a structured light depth-camera for three-dimensional body measurements of dairy cows in free-stall barns. Sensors 18, 673. https://doi.org/10.3390/s18020673.

Schofield, C.P., Marchant, J.A., White, R.P., Brandl, N., Wilson, M., 1999. Monitoring of pig growth using prototype imaging system. Journal of Agricultural Engineering Research. 72 (3), 205–210.

Stajnko, D., Brus, M., Hocevar, M., 2008. Estimation of bull live weight through thermographically measured body dimensions. Computers and Electronics in Agriculture. 61, 223–240.

Tscharke, M., Banhazi, T.M., 2013. Review of methods to determine weight and size of livestock from images. Australian Journal of Multi-Disciplinary Engineering. 10, 1–17.