PAPER • OPEN ACCESS

A comparison of low-cost techniques for three-dimensional animal body measurement in livestock buildings

View the article online for updates and enhancements.

A comparison of low-cost techniques for three-dimensional animal body measurement in livestock buildings

A Pezzuolo[1,*], D Giora[1], H Guo[2], Q Ma[2], S Guercini[1] and F Marinello[1]

[1] Department of Land, Environment, Agriculture and Forestry, University of Padova, 35020 Legnaro (PD), Italy.
[2] College of Land Science and Technology, China Agricultural University, Beijing 100083, China.

E-mail: andrea.pezzuolo@unipd.it

Abstract. Data about health and development of animals are still now mostly collected through manual measurements or visual observations but these kinds of methods of collecting data are causes of several problems. Alternatively, optical sensing techniques can be implemented in order to overcome limitations arising from manual contact measurements. The present research discusses metrological analysis of Structure from motion (SfM) photogrammetry approach, low-cost LiDAR scanning and Microsoft Kinect v1 depth camera to three-dimensional animal body measurement, with specific reference to pigs. Analyses were carried out on fiberglass model to get rid of animal movements. Scans were captured based on a segmented approach, where different portion of the body have been imaged during different frames acquisition tasks. The obtained results demonstrate the high potential of 3D Kinect. LiDAR show a higher RMS value respect to Kinect and SfM most probably due to the collection approach based on single profiles rather than on surfaces. Anyway, the RMS of relative noise ranges between 0.7 and 4 mm, showing a high accuracy of reconstructions even for the others techniques.

1. Introduction

Frequent monitoring of animals' body condition is helpful in order to allow for early recognition of health anomalies and consequently decrease the amount of complications related to animal diseases or other stress factors [1-4]. However, such approach is expensive in terms of labor and may be stressful both for the animals and stockman [5].

To overcome such problems, optical methods have been proposed in the last years [6] as a fast non-contact and approach for animal body analysis [7]. Thus optical techniques permit reduction of stress typically induced by manual measurements and at the same time allows fast multi-parameters analysis [8].

Many researches have investigated on three-dimensional reconstruction methods based on optical systems [9-12]. Different kind of optical sensor have been used for agricultural and livestock applications, like for example 2D cameras, but there is a growing interest for 3D sensors, like TOF (Time of Flight) or CTS (Consumer Triangulation Sensor) systems [13].

Some works already mentioned application of the Microsoft Kinect sensor in agriculture [14] and livestock applications [15]. Maki reported quantification of body condition scoring after application of Kinect sensor on cows [16]; McPhee reported results on rump fat and muscle score from low and high muscled Angus cattle [17], while Kongsro reported weight estimation results from two different pig breeds (Landrace and Duroc) in the 20-140 kg interval based on volume information [18].

An alternative approach involves the use of Light Detection and Ranging (LiDAR). LiDAR systems can measure the distance between the sensor and the objects around it very quickly, enabling the construction of three-dimensional point clouds [19]. Through the application of appropriate algorithms, these point clouds can be used to digitally reconstruct and describe the structure of areas [20] or objects of interest with high levels of precision [21-22].

Another promising application of 3D reconstruction that could be implemented in agriculture and livestock's applications is Structure from Motion (SfM). Based on photogrammetry, SfM technique consists in taking photos of the object from all possible angulation and points of view all around the object [23]. Several studies had used this technique in order to collect data about plant's phenology [24], soil topography and roughness [25], but SfM technique could be also implemented for livestock applications [26].

However, available literature is lacking with regard to the metrological performance: this is limiting very much actual application of the methods, since it is not clear how much 3D data can support or replace manual measurements also with reference to different positions of animal body.

The present study proposes a metrological implementation and analysis of 3 low-cost techniques: Microsoft Kinect v1 depth camera, Structure from motion (SfM) photogrammetry approach and LiDAR sensor for reconstruction of pig body. These techniques were applied to an animal fiberglass reference for quantifying the performances of such approach in terms of range, resolution, noise and process time analysis

2. Materials and Methods

2.1. Fiberglass reference
The experimental part of the research consisted in a preliminary validation of the 3 low-cost techniques. To this end, a fiberglass reference artefact resembling the actual shape, posture, colour and dimensions of a real pig was implemented. As typically done in the case of optical instrumentation [6] diffused light condition was used, with an average illuminance of about 400 lux.

2.2. Structure from motion and data processing
SfM is a method based on the estimation of the motions of a camera to allow reconstruction of three-dimensional point-clouds, through the following steps: (*i*) image features detection and description, (*ii*) feature descriptor matching between image pairs, (*iii*) robust pairwise geometry estimation, and (*iv*) 3D point triangulation and transformation of the relative camera poses to a common coordinate frame.

A commercial camera was implemented for collection of images needed in pig SfM reconstruction. Specifically, a Nikon D5100 camera was used, featuring a 23.6×15.6 mm CMOS sensor with a 4928×3264 pixels' resolution and a lens with a 35mm focal length.

For animal side reconstruction, data were collected at a distance between the camera and the animal ranging between 0.7 and 1.0 m; a total of 50 frames were taken, from withers to buttock and from the top of the back to ground.

Three-dimensional reconstruction was carried out through commercial software (AgiSoft PhotoScan, version 1.3.1) allowing reconstruction of three-dimensional point clouds through Structure-From-Motion technique.

2.3. Microsoft Kinect v1 and data processing
For the present research, a commercial Kinect depth camera was implemented for collection of images. Microsoft Kinect is based on coordinate functioning of an infrared laser emitter with an infrared camera and an RGB camera. Three-dimensional reconstruction is achieved through a triangulation process: a diffraction grating splits the infrared laser into a given pattern which is

projected onto the scene. The infrared camera than collect the pattern and compare it with the projected one: local shifts are put together to generate a disparity map, where larger shift values correspond to positions further from the sensor and, conversely, lower values correspond to positions closer to the sensor.

However, it has been shown that the output of the sensor is not linear [14] as a consequence, specific calibration procedures have to be carried out. To this end, a substitution method was implemented: a set of references surfaces featuring hemispherical elements and resembling cow body portion geometry was produced and measured. Therefore, hemispheres with radii ranging between 50 and 125 mm and between 150 and 250 mm were implemented for the calibration of the head sensor and of the body sensor respectively.

Three-dimensional data from the Kinect sensor were post-processed by means of commercially available software (SPIP™) undergoing the following operations: (*i*) outliers' management, (*ii*) overlapping images (stitching) and (*iii*) surface generation.

2.4. LiDAR and data processing

LiDAR is a remote-sensing technique for the measurement of the distance between the sensor and a target. Manufactured by Slamtec, RPLidar A3 is a 360° 2D laser scanner with a distance range of 0.15m to 25m, sample rate of 16000 p/s with a scan rate of 20Hz. The laser used has a wavelength of 785nm and 3mW power adhering to FDA Class I laser safety regulations. It is connected to the processor via USB. RPLidar A3 was selected due to its affordable price, the environment of operation, scanning range and weight.

Data were post-processed by means of commercially available software (SPIP™) undergoing the following operations: (*i*) outliers filtering, (*ii*) profiles alignment and (*iii*) surface generation.

3. Results and Discussions

3.1. Methods performances

The discussed applications can benefit from relatively low-cost technologies. The cost range of the instruments is between some tens of Euro (Microsoft Kinect v1 or standard 2D cameras) up to a few hundreds of euros (LiDAR); processing and 3D reconstruction can be carried out through free or low-cost software.

Compared with 3D Kinect imaging, it can be noticed how SfM is still limited by relatively long processing time (needed to produce the 3D model using just 2D images), however such performance is constantly increasing thanks to the availability of computer with faster and better performing processors (Tab.1).

Table 1. Comparison of costs and working times of 3D techniques

Technique	Instrumentation costs[1] [EUR]	Scanning time[2] [min/animal]	Processing time [min/animal]	Body-Parameters extraction [min/animal]
Structure from Motion	50-500	0.3-0.5	90-240	45
Kinect v1	80-150	0.5-0.7	30	30
LiDAR	500-2000	5-7	60	30

[1] Not including tripod, frames, computer and analysis software.
[2] Includes only time to collect data or capture images.

Furthermore, the scanning performance of 3D techniques was repeated at different working distances defined on the basis of actual fiberglass reference measurement, in the range 400-2000 mm.

In general, both horizontal and vertical resolutions normally worsen with the distance (Tab. 2). In the case of SfM, such effect can be reduced taking advantage of proper magnification optics, while is more evident in case of fixed zoom or low-resolution cameras. In the context of LiDAR measurement,

the resolution in the slow scanning direction is a function of the number of analysed profiles, but can be as low as 5 mm or even less in most of cases. Finally, Kinect v1 can provide the highest resolution at 0.4 m from the target surface, but rapidly decreases as the distance overcomes 1 m.

Table 2. Comparison of typical achievable x-y-z resolutions with sensors placed at different distances from the target

Distance [mm]	Horizontal resolution (x×y×z) [mm]		
	Structure from Motion	Kinect v1	LiDAR
400	3×3×2	0.65×0.65×0.7	0.4×5×2
1000	3×3×2	1.14×1.14×2	0.8×5×3
2000	3×3×2	1.95×1.95×4	1.6×5×4

Noise and linearity were used to get information about the accuracy of the analyses; they were estimated on a flat surface (roughness <50 μm) and were computed respectively as root mean square (RMS) and maximum deviation from the mean plane.

The obtained results (Tab. 3), in term of noise, demonstrate the high potential of 3D Kinect. LiDAR show a higher RMS value respect to Kinect v1 most probably due to the collection approach based on single profiles rather than on surfaces. SfM exhibits a high variability in terms of linearity: this is due to the fact that such performance depends as much on the accuracy of the processing software, which might difficult in case of flat surface without features or discontinuities useful for the reconstruction.

Maximum detectable slope depends on the capacity of the instruments to capture reflected radiations. This is somehow difficult in the case of Kinect v1 and LiDAR sensors, where extreme slopes could deviate laser beams out of the objective. On the contrary, SfM is not suffering from steep slopes in the target surface, since it relies on multiple repositioning of the camera.

Performances for all of the systems are in general fully acceptable, especially in the case of adult animals where extracted body parameters are typically as big as a few tens of centimetres (Fig. 1).

Table 3. Comparison of performances of 3D techniques

	Structure from Motion	Kinect v1	LiDAR
RMS Noise[1] [mm]	1.0-2.5	0.7-1.2	2.1-4.0
Non-linearity[1] [mm]	10-50	3-6	10-15
Maximum detectable slope [°]	90[2]	45	60-80

[1] Measured on a reference flat surface (RMS roughness <50μm)
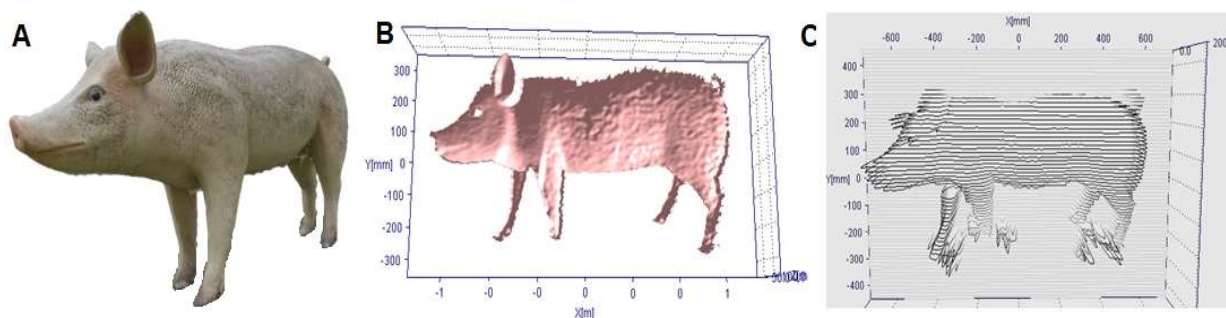[2] Unlimited due to camera repositioning

Figure 1. Snapshot of 3D model reconstruction: (A) Structure from motion; (B) Microsoft Kinect v1 and (C) LiDAR.

4. Conclusions

The present research proposes a metrological analysis of 3 low-cost techniques for pig body measurement and non-invasive extraction of quantitative parameters.

Preliminary tests carried out on fiberglass model have shown:

1. Microsoft Kinect v1 is the most cost effective technique, but present application must consider sensitivity to light especially in outdoor environment.
2. Structure from Motion can provide 3D reconstructions with a high resolution, which can be applied for a quantitative extraction of body-parameters, however, the processing time is still relatively long.
3. Low-cost LiDAR is better suited for extraction of specific profiles/sections, requiring precise alignment between animal and sensor source.
4. An application to live animals poses limitations, mainly ascribable to the movements of the animals. Specific approaches will be the object of future developments, oriented to the identification of optimal measurement positions and to the consequent minimization of scanning times.

References

[1]   Tsai D and Huang CY 2014 A motion and image analysis method for automatic detection of estrus and mating behaviour in cattle *Comput. Electron. Agric* **104** 25–31

[2]   Salau J, Haas J H, Junge W and Thaller G 2017 Automated calculation of udder depth and rear leg angle in Holstein-Friesian cows using a multi-Kinect cow scanning system *Biosyst. Eng* **160** 154–169

[3]   Nilsson M, Herlin A, Ardö H, Guzhva O, Åström K and Bergsten C 2015 Development of automatic surveillance of animal behaviour and welfare using image analysis and machine learned segmentation technique *Animal* **9** 1859–1865

[4]   Veissier I, Mialon M, Sloth K H 2017 Early modification of the circadian organization of cow activity in relation to disease or estrus *J. Dairy Sci* **100** 3969–3974

[5]   Da Borso F, Chiumenti A, Sigura M and Pezzuolo A 2017 Influence of automatic feeding systems on design and management of dairy farms *Journal of Agricultural Engineering* **48** 48-52

[6]   Dubbini M, Pezzuolo A, De Giglio M, Gattelli M, Curzio L, Covi D, Yezekyan T and Marinello F 2017. Last generation instrument for agriculture multispectral data collection *CIGR Journal* **19** 158-163

[7]   Pezzuolo A, Guarino M, Sartori L and Marinello F 2018 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(2)** 673

[8]   Nilsson M, Herlin A, Ardö H, Guzhva O, Åström K and Bergsten C 2015 Development of automatic surveillance of animal behaviour and welfare using image analysis and machine learned segmentation technique *Animal* **9** 1859–1865

[9]   Wongsriworaphon A, Arnonkijpanich B and Pathumnakul S 2015 An approach based on digital image analysis to estimate the live weights of pigs in farm environments *Comput. Electron. Agric* **115** 26–33

[10] Menesatti P, Costa C, Antonucci F, Steri R, Pallottino F and Catillo G 2014 A low-cost stereovision system to estimate size and weight of live sheep *Comput. Electron. Agric* **103** 33-38

[11] Wang Y, Yang W, Winter P and Walker L 2008 Walk-through weighing of pigs using machine vision and an artificial neural network *Biosyst. Eng* **100** 117–125

[12] Azzaro G, Caccamo M, Ferguson J D, Battiato S, Farinella G M, Guarnera G C, Puglisi G, Petriglieri R and Licitra G 2011 Objective estimation of body condition score by modeling cow body shape from digital images *J. Dairy Sci* **94** 2126–2137

[13] Vázquez-Arellano M, Griepentrog H W, Reiser D and Paraforos D S 2016 3-D imaging systems for agricultural applications - a review *Sensors* **16** 618-626

[14] Vázquez-Arellano M, Reiser D, Paraforos D S, Garrido-Izard M, Griepentrog HW 2018 Leaf Area Estimation of Reconstructed Maize Plants Using a Time-of-Flight Camera Based on Different Scan Directions *Robotics*, **7**, 63

[15] Pezzuolo A, Guarino M, Sartori L, González L A and Marinello F 2018 On-barn pig weight estimation based on body measurements by a Kinect v1 depth camera *Comput. Electron. Agric* **148** 29-36

[16] Maki N, Nakamura S, Takano S and Okada Y 2017 3D Model Generation of Cattle Using Multiple Depth-Maps for ICT Agriculture. In Conference on Complex Intelligent and Software Intensive Systems 768–777

[17] McPhee M J, Walmsley B J, Skinner B, Littler B, Siddell J P, Cafe L M, Alempijevic A. 2017 Live animal assessments of rump fat and muscle score in Angus cows and steers using 3-dimensional imaging *J. Anim. Sci* **95** 1847–1857

[18] Kongsro J 2014 Estimation of pig weight using a Microsoft Kinect prototype imaging system *Comput. Electron. Agric* **109** 32–35

[19] Sanz-Cortiella R, Llorens-Calveras J, Escolà A, Arnó-Satorra J, Ribes-Dasi M, Masip-Vilalta J, Camp F, Gràcia-Aguilá F, Solanelles-Batlle F, Planas-DeMartí S, Pallejà-Cabré T, Palacin-Roca J, Gregorio-Lopez E, Del-Moral-Martínez I and Rosell-Polo J R 2011 Innovative LIDAR 3D Dynamic Measurement System to Estimate Fruit-Tree Leaf Area *Sensors* **11** 5769-5791

[20] Rottensteiner F and Briese C 2002 A new method for building extraction in urban areas from high-resolution LIDAR data *Remote Sensing and Spatial Information Sciences* **34** 295-301

[21] Rosell J R, Llorens J, Sanz R, Arno J, Ribes-Dasi M, Masip J, Escolà A, Camp F, Solanelles F and Gràcia F 2009 Obtaining the three-dimensional structure of tree orchards from remote 2D terrestrial LIDAR scanning *Agr. Forest. Meteorol* **149** 1505-1515

[22] Hosoi F, Nakabayashi K and Omasa K 2011 3-D Modeling of tomato canopies using a high-resolution portable scanning lidar for extracting structural information *Sensors* **11** 2166-2174

[23] Westoby M J, Brasington J, Glasser N F, Hambrey M J, and Reynolds J M 2012 Structure from Motion photogrammetry: A low-cost effective tool for geoscience applications *Geomorphology* **179** 300-314

[24] Jay S, Rabatel G, Hadoux X, Moura D and Gorretta N 2015 In-field crop row phenotyping from 3d modeling performed using structure from motion *Comput. Electron. Agric* **110** 70-77

[25] Javernick L, Brasington J and Caruso B 2014 Modelling the topography of shallow braided rivers using Structure-from-Motion Photogrammetry *Geomorphology* **213** 166–182

[26] Pezzuolo A, Milani V, Zhu D, Guo H, Guercini S and Marinello F 2018 On-Barn Pig Weight Estimation Based on Body Measurements by Structure-from-Motion (SfM) *Sensors* **18** 3603

[27] Savio E, De Chiffre L, Schmitt R, 2007 Metrology of freeform shaped parts *CIRP Annals Manufacturing Technology* **56** 810-835