

**Procedures for measuring 3-D surface area and surface temperature of livestock**

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**Abstract:**

Bio-energetic models of livestock require geometrical properties (*e.g.*, surface area) of animals. Currently, the surface area of animals is estimated from empirical equations based on body weight or assuming the animal as cylinders or spheres. These approximations do not accurately characterize the true geometry of the animal. Similarly, skin-surface temperature predictions from bio-energetic models are validated by taking spot measurements, which neglects the spatial variability of this parameter. In this study, an accurate approach of measuring these parameters is proposed. Based on preliminary results (more data analysis is ongoing), the advantages and disadvantages of various 3-D scanning technologies (photogrammetry, Kinect V1, Kinect V2, Intel® RealSense™ SR300, and Intel® RealSense™ R200) as well as two different procedures for obtaining 3-D surface temperature (thermal projection and thermal photogrammetry) are discussed. Kinect (V1 or V2) is recommended for 3-D scanning of livestock because the sensors are cheap and easy to use. Sense from 3-D Systems (Intel® RealSense™ SR300) does not support large scanning volumes but it is recommended for scanning small animals (or parts of an animal) because it is handheld and the software is easy to use. To scan large animals (*e.g.*, a whole cow) and for advanced users, Intel® RealSense™ R200 is suitable. For 3-D surface temperature, thermal photogrammetry is recommended because it is less error prone than thermal projection.

**Keywords:** 3D scan, bio-energetics, cows, livestock, temperature

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## Introduction

Bio-energetic modeling uses fundamental principles of engineering to predict energy requirements for maintenance, production, and reproduction of livestock in different environmental conditions. Bio-energetic models require surface area of the animal as input. Currently, surface area of animals is estimated from empirical equations based on body weight (Berman, 2003) or from approximating the animal's geometry as a cylinder or sphere (Gebremedhin and Wu, 2016; Gebremedhin *et al.*, 2016; Silva and Maia, 2013; Tuner *et al.*, 1987ab). This approximation does not accurately represent the true geometry of the animal. Similarly, the current procedure for measuring skin-surface temperature of animals is by taking spot measurements (Silva and Maia, 2013). This approach neglects the spatial variability in the skin-surface temperature of the animal. Surface area of animals can be accurately measured using 3-D scanners and spatial variability of skin-surface temperature profiles may be obtained post-processing 3-D scans and measured temperature profiles to create 3-D surface temperature models but the literature contains limited information on these procedures.

The objective of this study was to develop procedures for obtaining surface area and skin-surface temperature that are more accurate and reliable. The procedures include: (1) measurement of surface area using 3-D scanners, (2) measurement of skin-surface temperature using infrared thermography, and (3) development of 3-D surface temperature models by merging surface area and temperature images. Based on preliminary results, the advantages and disadvantages of several 3-D scanning technologies (photogrammetry, Kinect V1, Kinect V2, Intel® RealSense™ SR300, and Intel® RealSense™ R200) as well as two different approaches of obtaining 3-D surface temperature (thermal projection and thermal photogrammetry) are discussed. Herein, we identify the equipment necessary to make the measurements and discuss the procedure to obtain the data but more data analysis is ongoing.

Table 1. Technical specifications of 3-D scanning technologies evaluated in this paper.

	Photogrammetry	Kinect V1 (Xbox 360) <sup>1</sup>	Kinect V2 (Xbox One) <sup>1</sup>	Intel® RealSense™ SR300 <sup>2</sup>	Intel® RealSense™ R200 <sup>2</sup>
Color resolution	Camera dependent	640 x 480 <sup>3</sup>	1920 x 1080	1920 x 1080	1920 x 1080
Depth resolution	Pixels matching dependent	320 x 240 <sup>3</sup>	512 x 424	640 x 480	640 x 480
Range	NA	0.7 to 6 m	-	0.27 to 0.54 m	0.6 to 1.5 m
Software	VisualSFM	ReconstructMe	Kscan3D	Sense software <sup>5</sup>	Sense software <sup>5</sup>
	Autodesk ReMake	Kscan3D Skanect <sup>4</sup>	Windows 3D Scan	Intel RealSense SDK ReconstructMe <sup>6</sup>	Intel RealSense SDK ReconstructMe <sup>6</sup>
Price <sup>7</sup>	Camera price	\$50 (Kinect) <sup>8</sup> \$15 (PC adaptor) <sup>8</sup>	\$100 (Kinect) <sup>8</sup> \$50 (PC adaptor) <sup>8</sup>	\$149 (Intel RealSense Developer Kit) <sup>9</sup> \$199.99 (BlasterX Senz3D) <sup>9</sup> \$399 (Sense <sup>5</sup> ) <sup>9</sup> \$149.99 (Razer Stargazer) <sup>9</sup>	\$169 (Intel RealSense Developer kit)

<sup>1</sup>Information retrieved from Wikipedia Contributors (2017). <sup>2</sup>From Intel® Developer Zone (2017). <sup>3</sup>In lower frame rates, color and depth resolution can reach 1280 x 1024. <sup>4</sup>Commercial software (\$130). <sup>5</sup>From 3D Systems. <sup>6</sup>At the time of this writing, Intel® RealSense™ in ReconstructMe was under development. <sup>7</sup>US dollar. <sup>8</sup>Kinect and adaptor required. <sup>9</sup>Any of these. Not all information is available from the manufacturer (some details are proprietary) and some information was obtained through reversal engineering. The reader is referred to Stimulant (2017) for information on other 3-D scanners.

## Material and Methods

Four Holstein cows and one Jersey cow were kept in tie stalls. Animal-use protocol #2017-0029 was approved by the Institutional Animal Care and Use Committee of Cornell University. Cows were scanned using devices given in Table 1. The 3-D scans were processed in MeshLab (Cignoni *et al.*, 2013). Surface

temperature was measured using an infrared camera (FLIR E8, FLIR Systems, Inc.). The 3-D surface temperature was obtained by either (1) projecting the infrared image on a 3-D surface area using MeshLab (Ranzuglia *et al.*, 2013), or (2) using color images from infrared camera to generate 3-D surface area by photogrammetry in VisualSFM (Wu, 2013 and 2017; Wu *et al.*, 2011) with PMVS/CMVS (Furukawa *et al.*, 2010; Furukawa and Ponce, 2010) and MeshLab (Kazhdan and Hoppe, 2013), and replacing color data by the temperature pseudo-color data in a 3-D surface area using MeshLab. Henceforth, Process 1 will be referred to as *thermal projection* and Process 2 will be referred to as *thermal photogrammetry*.

## Results and Discussion

Photogrammetry is the process of identifying characteristic points in photos, matching these points across different photos, generating a 3-D point cloud, and interpolating surfaces across a 3-D point cloud. Position of points in space are relative to one another. Absolute measurements are obtained through scaling position of points to match the dimensions of a known-length object. 3-D point cloud creation depends on identifying and matching characteristic points, but characteristic points are usually absent in flat homogeneous-colored surfaces. High color gradient objects can be inserted in the scene to improve characteristic point identification/matching. However, low quality, blurry, and/or noisy photos can distort or even prevent identification and/or matching of characteristic points. Digital image filters can be used to improve photo quality (Gonzalez and Woods, 2008). The main advantage of this technique is that it is cheap and easy to use because only a camera or a smartphone is needed. The disadvantages of this procedure include: lack of absolute measurement, dependence on photo quality and characteristic point matching, offline 3-D model creation, intensive computation, and quantity of photos required (usually 50-200 but depends on application). The same advantages and disadvantages apply to thermal photogrammetry.

Photogrammetry software includes Autodesk Remake and VisualSFM. Autodesk Remake is user-friendly, free for education, and handles the whole process from pictures to 3-D models. VisualSFM is a little less user-friendly but is free, more configurable, and handles the process from pictures to 3-D point cloud. For VisualSFM, 3-D reconstruction can be performed in the free software MeshLab.

Kinect V1 and V2 are simple and easy to use 3-D scanners but require the use of a powered PC adaptor and a 3-D scanning software. The main advantage of Kinect V2 over V1 is a higher-resolution color camera, which yields better texture mapping. Their advantage over photogrammetry is that depth data is available at scanning time. Its disadvantage is that when using ReconstructMe (Kinect V1), tracking loss can be an issue. Tracking loss can happen when the scene changes (*e.g.*, animal moves), scene was not captured with sufficient details, and/or camera has moved fast. In some cases, tracking can be recovered by scanning a previously captured part of the scene. In other cases, multiple scans of the same object and post alignment of scans (in MeshLab) would be required. Using Kscan3D (Kinect V1 and V2), shots of the object are captured, and these shots are post aligned in Kscan3D or MeshLab. Major issues are misalignment of meshes and geometrical aberrations due to noise from the camera itself and/or from movement of the object. In such cases, geometrical aberrations and alignment can be manually repaired. Using Windows 3-D Scan (Kinect V2), the frames are all captured first and then processed to generate point cloud and 3-D images. The advantage is reduced computational processing time during scanning. The disadvantages include reduction of quality of scans and lack of feedback on final 3-D surface area during scanning time.

Intel® RealSense™ SR300 and R200 are short and long range 3-D scanners, respectively. They are more portable than Kinect but scanning of black and shiny surfaces is harder. License is required to use Sense software. This software is easy to use and its main limitation is that the maximum scanning volume is small, which means that multiple scans of large animals might be necessary. Intel® RealSense™ SDK provides a larger scanning volume, but it is not user-friendly since it is designed for code developers. ReconstructMe might be an alternative but is still under development.

Thermal projection consists of 3-D scanning of an object and simultaneously capturing temperature data with an infrared camera. The advantage of this approach is that absolute measurements of the object are captured. However, surface temperature pseudo-color images need to be manually aligned with the 3-D geometry. This might result in misalignments and/or lack of temperature data in the 3-D surface temperature.

For 3-D scanning, the use of Kinect (V1 or V2) is recommended because they are cheap and easy to use. For accurate scanning of small animals (or parts of an animal), Sense from 3-D Systems (Intel®

RealSense™ SR300) is recommended because it is handheld and software is easy to use. For advanced users and for scanning large animals (*e.g.*, whole cow), Intel® RealSense™ R200 is recommended. For developing a 3-D surface temperature of an animal, thermal photogrammetry (with inclusion of a known-length object in the scene) is recommended because this avoids misalignments and lack of temperature data.

Figure 1 shows 3-D surface area of a cow, and Figure 2 shows 3-D surface temperature of a cow. These are preliminary data and more data will be shown at the time of the conference.

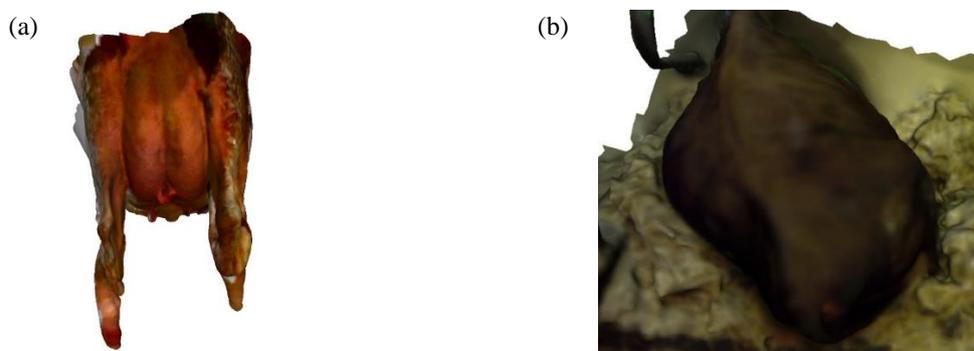


Figure 1. 3-D surface area of (a) udder of a cow obtained using Sense from 3-D Systems, and (b) an image of a cow lying down obtained using Kinect V1 with ReconstructMe.

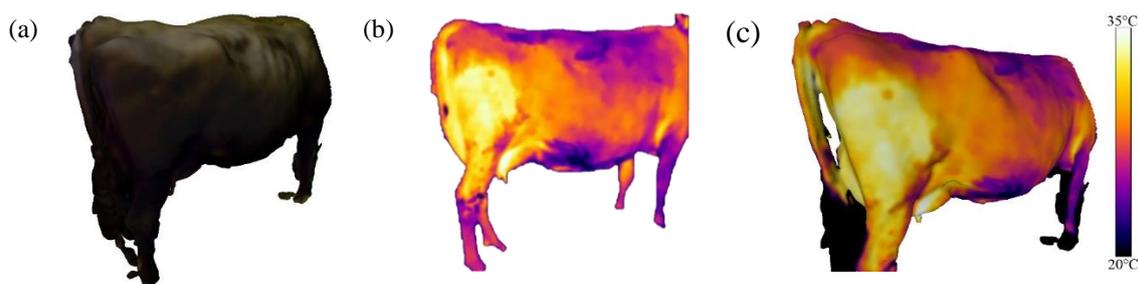


Figure 2. (a) 3-D images of a chest of a cow obtained using Kinect V1 with ReconstructMe, (b) surface temperature measured using infrared thermal camera, and (c) 3-D surface temperature obtained with thermal projection. Black color represents lack of temperature data.

### Conclusions

Procedures for measuring surface area and obtaining 3-D surface temperature of live animals were discussed. These procedures are less error prone than current practice that are using empirical equations to estimate surface area from animal weight and performing spot temperature measurements to infer the surface temperature of the animal.

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