BIOSYSTEMS ENGINEERING 160 (2017) 154–169

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Automated calculation of udder depth and rear leg angle in Holstein-Friesian cows using a multi-Kinect cow scanning system

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ARTICLE INFO

Article history:
Received 23 December 2016
Received in revised form
31 May 2017
Accepted 12 June 2017
Published online 27 June 2017

Keywords:
Linear traits
Dairy cattle
Monitoring system
3D object recognition

Low cost off-the-shelf depth sensors Microsoft Kinect have already been used in studies related to body condition determination and lameness detection in dairy cows and the concept of a 3D cow scanning by combining the fields of view of six Kinect cameras being presented. The cow scanner was developed in an effort to remove if possible, the influence of human operators from conformation recording by gathering data on linear descriptive traits using image analysis. In this study, a 3D object recognition pipeline was presented to automatically determine udder and rear leg of cows recorded in free walking. These body parts were then used to calculate the height of the udder bottom above ground and the rear leg angle. Between the manually gathered corresponding conformation recording scores and the calculated traits, medium to high Spearman rank correlation coefficients (0.63 for udder bottom height, 0.67 for rear leg angle) were observed. Between consecutive measurements, the calculating of udder bottom height was highly repeatable (76.9%) and the rear leg angle showed medium repeatability (47.4%) due to variance induced by the phase of the step. Both traits exhibited expected behaviour as udder bottom heights significantly decreased with increasing lactation number and rear legs were significantly straighter in cows with greater sacrum height.

1. Introduction

The development of camera based monitoring devices plays an important role within the field of precision livestock farming, and the number of camera based studies has rapidly increased. Technical advancement and intelligent processing methods were successfully applied to various fields of dairy cow husbandry dealing with lameness classification (Pluk et al., 2012; Van Hertem et al., 2014; Van Nuffel et al., 2015; Viazzi et al., 2013; Zhao, He, & Bewley, 2016), body condition determination (Halachmi, Klopcic, Polak, Roberts, & Bewley, 2013; Kuzuhara et al., 2015; Spoliansky, Edan, Parmet, & Halachmi, 2016; Weber et al., 2014), and behaviour monitoring (Guzhva et al., 2016; Tsai & Huang, 2014). However, the use of camera technology in animal related settings and barn environments comes with several technical challenges, e.g. diffuse light conditions, unpredictable animal movements,

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http://dx.doi.org/10.1016/j.biosystemseng.2017.06.006

Nomenclature

Abbreviation & definition

LOS Line of sight
FOV Field of view
kdm *Kinect depth map*, data format for recording streams of 3D data with a Kinect camera
$c = 0,\ldots,5$ Indices of the six cameras used in the presented system
B_c Averaged background image corresponding to camera c
I Notation for an arbitrary image
mean $(I\neq 0)$ Averaged depth value of all pixels in I which do not hold the value 0
$PX_{\neq 0}(I)$ Number of non-zero pixel in I after segmentation
N_{B_c} Number of images used to calculate B_c that show the empty scenery
YN_mean (I,c) Boolean variable, deciding if the condition on mean $(I\neq 0)$ holds
YN_pixel (I,c) Boolean variable, deciding if the condition on $PX_{\neq 0}(I)$ holds
$P_F(I)$, $P_L(I)$ Number of non-zero pixel in the first (F), respectively, last (L) column of I
YN_propercow (I,c) Boolean variable, deciding if the conditions on $P_F(I)$ and $P_L(I)$ hold
pcd *Point cloud data*, data format for point clouds for use with the Point Cloud Library
PCL Point Cloud Library (Rusu & Cousins, 2011)
X, Y, Z Notations of the coordinate axes
SOR Statistical Outlier Removal
ISS Intrinsic Shape Signature
FPFH Fast Point Feature Histogram
SHOT Signature of Histograms of Orientation
ICP Iterative Closest Point algorithm
fitness score Sum of squared distances of points between source cloud and target cloud in the ICP algorithm
RANSAC RANdom SAmple Consensus algorithm
UD “Udder depth above ground”
RL “Rear leg angle”
L_1, L_2 Lines approximating the upper and lower leg in *RL* calculation
$\overrightarrow{u_1}$, $\overrightarrow{v_1}$, $\overrightarrow{u_2}$, $\overrightarrow{v_2}$ Supporting and directional vectors of L_1, and L_2, respectively
$\mathbb{R}$ The real numbers
D^{UD}, D^{RL} Data sets holding the calculated traits *UD*, respectively, *RL* and information on the recorded cows
cow_mean(*UD*), cow_mean(*RL*) Cow wise mean of *UD*, respectively, *RL*
run_mean(*UD*), run_mean(*RL*) Means of *UD*, respectively, *RL* calculated from the singled out runs of the cows
ID Identification number of the cows
lac_no Lactation number
lac_day Lactation day
milk_kg Milk yield of the last milking prior to recording
milk_min Minutes passed between the last milking and the recording
cow_kg Body weight of the cow after the morning milking on the day of recording
ST^{CR} Sacrum height as scored in manual conformation recording
UD^{CR} Udder depth as scored in manual conformation recording
LS^{CR} Rear leg angle as scored in manual conformation recording
ω^2 Effect size, calculated from fixed effects analysis of variance
ICC Interrater correlation coefficient ICC(1,1) according to Shrout and Fleiss (1979), calculated from random effects analysis of variance
R^2_{UD}, R^2_{RL} Coefficients of determination (repeatabilities) calculated for *UD*, respectively, *RL*

and diminished measurement precision due to surface structures (Salau, Bauer, et al., 2015; Van Hertem et al., 2013). Furthermore, the accepted methods often require manually gathered data and are prone to subjectivity. The presented study focusses on the linear descriptive traits which had been agreed upon for conformation recording (“International Committee for Animal Recording – Conformation recording dairy and beef cattle”, 2015). The primary traits mainly consist of the lengths and angles along the body of the cow and are presented in four (Deutscher Holstein Verband e.V., 2016) or five (“Holstein Association USA, Inc. – Linear Descriptive Traits”, 2014) trait complexes. As the trait complex “udder” is considered most important followed by the complex “feet and legs”, in this study the traits weighted highest within these complexes (Deutscher Holstein Verband e.V., 2016) were chosen for an initial approach to automated conformation recording. The selection of the animals best suited for breeding is currently based on scores that are obtained manually by highly trained classifiers. Scored on scales reaching 9 (Deutscher Holstein Verband e.V., 2016) or 50 (“Holstein Association USA, Inc. – Linear Descriptive Traits”, 2014) points, the traits are suitable for measurement in length units and angles to remove human classifier's influence.

The application of 3D cameras appears a promising technology, because with the information in XYZ coordinates comes with the possibility of calculating accurate lengths and angles on the recorded surface. The Microsoft Kinect camera (“PrimeSense Supplies 3-D-Sensing Technology to “Project Natal” for Xbox 360, 2010; “Kinect for Windows”, 2014) uses the depth measurement principle of “Structured Light” (Andersen et al., 2012) and is thus less susceptible to motion artefacts compared to Time-Of-Flight cameras (Hansard, Lee, Choi, & Horaud, 2012). As a general advantage of 3D cameras, depth value based segmentation can be used. The Kinect camera, therefore, overcomes the problems associated with animal movement and light conditions. As dairy farm applications should not put large financial load on the farmers, there is an additional advantage, Kinect cameras can be bought off the shelf at relatively low cost in contrast to high-resolution