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Automated body weight prediction of dairy cows using 3-dimensional vision

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ABSTRACT

The objectives of this study were to quantify the error of body weight prediction using automatically measured morphological traits in a 3-dimensional (3-D) vision system and to assess the influence of various sources of uncertainty on body weight prediction. In this case study, an image acquisition setup was created in a cow selection box equipped with a top-view 3-D camera. Morphological traits of hip height, hip width, and rump length were automatically extracted from the raw 3-D images taken of the rump area of dairy cows (n = 30). These traits combined with days in milk, age, and parity were used in multiple linear regression models to predict body weight. To find the best prediction model, an exhaustive feature selection algorithm was used to build intermediate models (n = 63). Each model was validated by leave-one-out cross-validation, giving the root mean square error and mean absolute percentage error. The model consisting of hip width (measurement variability of 0.006 m), days in milk, and parity was the best model, with the lowest errors of 41.2 kg of root mean square error and 5.2% mean absolute percentage error. Our integrated system, including the image acquisition setup, image analysis, and the best prediction model, predicted the body weights with a performance similar to that achieved using semi-automated or manual methods. Moreover, the variability of our simplified morphological trait measurement showed a negligible contribution to the uncertainty of body weight prediction. We suggest that dairy cow body weight prediction can be improved by incorporating more predictive morphological traits and by improving the prediction model structure.
Key words: dairy cattle, morphological trait, three-dimensional vision, automation, uncertainty

INTRODUCTION

Since 1960, the average farm size has increased in some upper-middle-income countries and almost all high-income countries throughout the world (Lowder et al., 2016). In the Netherlands, for example, the total number of dairy cows kept by farmers increased by 13%, whereas the number of dairy farms decreased by 29%, from 2005 to 2015 (Statistics Netherlands, 2016). Moreover, Dutch dairy farmers increased the average annual milk yield per cow to 8,373 kg in 2015 (CRV, 2016). However, concerns about the welfare of production animals are growing among the general public (Wolf et al., 2016). Consumers significantly influence the dairy industry by choosing premium welfare products (de Graaf et al., 2016). With increasing production per cow and pressure from consumers, dairy farmers must provide intensive and high-standard care to individual cows to maintain high-quality and animal-friendly milk production. Due to farm upscaling, however, it becomes increasingly difficult to manage individual care because of the high number of cows per full-time equivalent and the high labor demand (Barkema et al., 2015). To ease the burden, farmers can choose to purchase available commercial products to automate certain routine labor-intensive procedures, such as milking and feeding (Jacobs and Siegford, 2012). For other procedures, such as health monitoring, available equipment to automate the procedures is less developed. Recent developments in sensor technology offer promising solutions to automate health monitoring by collecting daily information on the physical status of individual cows (Rutten et al., 2013). Continuous monitoring can help farmers gain insight into a cow's changes over time, identify anomalies in their health status, and take necessary actions. Automation of continuous health monitoring will contribute to maintaining high-quality care for individual cows under increasing farm size and production.

An example of health monitoring includes monitoring of the BW of dairy cows. Body weight changes during lactation. This change reflects the energy balance in the cow (Mäntysaari and Mäntysaari, 2015). A long-term negative energy balance could cause problems in

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health and reproduction (de Vries et al., 1999; Collard et al., 2000). To estimate the effect of a negative energy balance, frequently measured BW can be used in farm management (Thorup et al., 2012). Thus, monitoring BW can help farmers to make management decisions with respect to a cow's health status (van der Tol and van der Kamp, 2010). More importantly, the BW of individual cows must be measured and monitored automatically to prevent additional labor input and to ensure farmers have time to maintain high quality and individual care (Maltz, 1997). Often, dairy cows are weighed routinely with automated weighing scales (Alawneh et al., 2011). Such scales, however, are relatively expensive and their electronics are prone to damage in the harsh environment covered with manure and urine and in direct contact with cows (Dickinson et al., 2013). Hence, a low-cost and robust automated weighing system is needed.

As an alternative to the use of scales, BW can be predicted based on morphological traits that are significantly correlated with weight, such as heart girth (Heinrichs et al., 1992), withers height (Tasdemir et al., 2011), and hip width (Enevoldsen and Kristensen, 1997). These morphological traits are typically measured manually. In addition to being labor intensive, the measurement process can be stressful to cows (Dickinson et al., 2013). To automate the morphological trait measurement, new techniques, such as computer vision, have been explored (Tasdemir et al., 2011; Marinello et al., 2015). With computer vision, morphological traits are defined and measured as distances or areas among pre-identified anatomical landmarks on the surface of a cow's body (Kuzuhara et al., 2015). These anatomical landmarks are typically clearly visible, such as some bone structures (e.g., hip bones and spine) that clearly protrude from their surrounding region (Kawasue et al., 2013). Identifying anatomical landmarks with computer vision is the basis for automatically measuring morphological traits and their derivatives.

Currently used computer vision techniques to measure dairy cow morphological traits include 2-dimensional (**2-D**) vision, thermal vision (Stajnko et al., 2008), stereo vision using multiple calibrated 2-D cameras (Tasdemir et al., 2011), and 3-dimensional (**3-D**) vision using one or multiple 3-D cameras (Marinello et al., 2015; Salau et al., 2016). Images taken in 3-D vision, in contrast to 2-D vision, show a clear depth difference between a cow and the background. This difference can significantly simplify the background segmentation (Rosell-Polo et al., 2015). Moreover, images taken in 3-D vision include depth information on the body surface, whereas 2-D and thermal images include only body contour and cross-sectional area information. Additionally, certain morphological traits quantified using 3-D vision are more strongly correlated with manually measured reference values compared with stereo vision (Tasdemir et al., 2011; Marinello et al., 2015). Lastly, compared with a single 3-D camera, the costs for multiple 2-D or 3-D cameras and a subsequent recording synchronization system are substantially higher (Kuzuhara et al., 2015).

In this case study, we chose to quantify dairy cow body morphological traits by automatically processing images taken in a 3-D single-camera vision system. The error produced in the automated image processing will produce an error in the quantification of morphological traits, which in turn might have considerable consequences for BW prediction. The objectives of this study were to quantify the error of BW prediction using automatically measured morphological traits in a 3-D vision system and to assess the influence of various sources of uncertainty in BW prediction.

MATERIALS AND METHODS

Image Acquisition

In December 2015, 3-D images of 30 lactating Holstein cows (i.e., one image per cow) were acquired at a commercial dairy farm in the Netherlands. The farm had a freestall barn equipped with automatic milking systems (**AMS**, Astronaut A4, Lely Industries N.V., Maassluis, the Netherlands). Near one of the AMS, an image acquisition setup was constructed (Figure 1). The setup was placed next to the exit of the AMS so that cows could enter it immediately after milking. The setup consisted of a cow selection box, an electronic weighing scale, a 3-D camera, and a computer that connected and controlled the setup.

A cow selection box (Grazeway, Lely Industries N.V) was built with automatic entrance and exit gates. Near the exit gate, a cow identification (**ID**) receiver (long-range wireless base unit, SCR, Netanya, Israel) was mounted on the side of the box. The receiver automatically identified the cow in the setup through an ID tag (HR-LD, SCR) around its neck. The floor of the box was an iron plate (2.8 × 0.8 × 0.15 m) attached to an electronic weighing scale (AllScales, Hank Maas B.V., Veen, the Netherlands). One load cell was attached to each corner under the iron plate, and all 4 could weigh up to 1,500 kg with a measurement precision of 0.5 kg. These load cells were connected to a digital weight indicator that showed a stable weight every second when the difference between the currently measured weight and the previous weight was no more than 1 kg.

A 3-D camera (Kinect Sensor for Windows version 2, Microsoft, Redmond, WA) was mounted on the metal