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Automatic cow lameness detection with a pressure mat: Effects of mat length and sensor resolution

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ABSTRACT

While previous research has shown the potential of automatic lameness detection by means of a pressure mat, these systems are currently not adopted in practice due to their high cost and low on-farm applicability. Therefore, the aim of this study was to investigate to what level the size (0.61×4.88 m) and resolution (0.0127×0.0127 m) of the pressure mat can be reduced without significant loss in lameness detection performance. To this end, standard gait variables were calculated based on adapted datasets in which the available data had been reduced to simulate the effects of a decreasing mat length and sensor resolution. These extracted gait variables were then used in a linear discriminant analysis to classify cows as non-lame, mildly lame or severely lame. This analysis indicated that the measurement zone length must be at least 3.28 m to successfully monitor one complete gait cycle, while the size of each individual sensing element should not be larger than $2.58 * 10^{-3}$ m^2 to avoid an increase in the misidentification of imprints. When these limits were taken into account, the obtained overall lameness detection accuracy was not worse than that of the original system.

1. Introduction

Economically, lameness is one of the most important health problems in dairy cattle and seriously affects cows' welfare (Booth et al., 2004; Algers et al., 2009). Lame cows produce less milk (Green et al., 2002; Hernandez et al., 2005), have a longer calving interval (Hernandez et al., 2001; Garbarino et al., 2004), require extra effort and labor time from the farmer and often need costly treatment performed by a veterinarian or hoof trimmer (Bruijnis et al., 2010). Bruijnis et al. (2010) simulated cow characteristics of 500 herds and estimated lameness costs to add up to $4899 per year on a farm with 65 cows, which means a loss of $75 per cow per year. Preventing, detecting and treating lameness timely can reduce these costs and improve the cows' welfare (Leach et al., 2012). Visual lameness detection, however, is difficult as cows tend to hide pain because of their stoic nature (O'callaghan et al., 2003). Moreover, most farms do not perform such regular locomotion scoring, because it is time consuming and requires a minimum level of training from the observer (Brenninkmeyer et al., 2007; March et al., 2007). Also, with an increasing number of animals per caretaker (Bewley et al., 2001), the available time to monitor the cows is decreasing proportionally (Horseman et al., 2013). Automatic lameness detection systems could therefore support the farmer in detecting the cows that need treatment.

Several researchers have focused on the development of automatic lameness detection systems (ALDS) that provide the farmer with an objective lameness status for each cow. Van Nuffel et al. (2015b) reviewed the different sensor systems that have been considered for this purpose and classified these as load cells (Rajkondawar et al., 2002; Neveux et al., 2006; Pastell et al., 2006; Thorup et al., 2014), pressure mats (van der Tol et al., 2002; Maertens et al., 2011), vision techniques (Flower et al., 2005; Poursaberi et al., 2010; Pluk et al., 2012; Van Hertem et al., 2014), pedometers (Mazrier et al., 2006), accelerometers (Munksgaard et al.; O'Driscoll et al., 2008; Pastell et al., 2009; Chapinal et al., 2011) and other sensor data available on farm such as milk yield, milk colour, electrical conductivity, concentrate

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intake and rumination (Liberati and Zappavigna, 2009; de Mol et al., 2013; Kamphuis et al., 2013; Van Hertem et al., 2013; Garcia et al., 2014).

Although the first experiments with ALDS date from 2002, only one system (StepMetrix®, BouMatic, Madison, WI, USA) is commercially available since 2008. This low level of uptake of ALDS in dairy practice might be explained by the fact that most studies on lameness detection have concentrated on sensor development and data interpretation, rather than on integration of economic information and decision making (Rutten et al., 2013). Another reason could be that system developers still face some challenges to solve practical problems concerning the sensor systems: pressure plates and pressure mats used in a walkway require a considerable amount of free space in the barn to measure gait variables on walking cows (Rajkondawar et al., 2002; Maertens et al., 2011). Also, the presence of manure, water, and cows walking on it creates a harsh environment which requires a robust system. Camera systems using side view require a large amount of space for setup, as well as the final image quality is often affected by lighting conditions and mixed backgrounds (Poursaberi et al., 2009; Van Hertem et al., 2013; Viazzi et al., 2014). 3D-cameras overcome problems with large space requirements, shadows and continuously changing backgrounds incurred with 2D-cameras, but are sensitive to natural light, have a small field of view and are only able to measure a few gait variables (Viazzi et al., 2014; Vázquez-Arellano et al., 2016; Abdul Jabbar et al., 2017). Since cows need to walk at their own pace, a walkway similar to the one used for pressure mats is needed. Also, camera systems might be influenced by dirt and insects sitting on the camera lens. On the other hand, pedometers and accelerometers have the advantage that they don't require any dedicated farm space, and some farms are already equipped with such sensors (Steeneveld and Hogeveen, 2015). Pressure plates and pressure mats are expensive sensors, while cameras can be much cheaper. Pedometers and accelerometers have a relatively low cost per piece, but the total investment can run high as each cow has to be equipped with a sensor. The two main disadvantages of pressure mats and pressure plates – spatial requirements and high cost – should be minimised to facilitate their adoption in dairy practice, and should therefore be considered during system design and development.

Farmers attach great importance to the economic profitability when considering investing in sensors that support health management (Rutten et al., 2013). A costly ALDS will reduce the economic value of the detection system, and even nullify the benefit of an early detection that such system is aimed at. Moreover, on most farms no free space is available, hence the installation of an alley-based setup as needed for walk-over devices or camera systems can be difficult (Van Nuffel et al., 2015b). Systems that require too much space or adaptations in barn design might involve extra implementation costs or require a farmer to give up one or more cow places, and hence might have a repelling effect towards the farmer. Therefore, to improve the future adoption in practice, ALDS development should take these negative system characteristics into account.

Since the Gaitwise pressure mat is based on an existing sensor originally intended for application in human medicine (Maertens et al., 2011), the sensor provides very detailed information at a high cost. As this cost is too high to justify the investment for most dairy farms, it should be reduced. Because cows need to walk normally during monitoring, enough space (2 m) before and after the sensor was required, resulting in a total minimum length of about 10 m. Therefore, making the system smaller and more compact would also be beneficial for its adoption in practice. Both goals can be achieved by reducing the number of sensors. This can be done by decreasing the length of the active surface and by using larger sensors, resulting in a smaller sensor resolution and hence, fewer sensors. However, while applying these adaptations, the performance of the lameness detection system based on the gait variables derived from the sensor data should remain acceptable. Since no minimum sensitivity and specificity have been determined yet for ALDS, a sensitivity of 80% and specificity of 99% as used for automatic mastitis detection systems (Hogeveen et al., 2010) could be set as a goal.

Therefore, the objective of this study was to examine to what extent the Gaitwise pressure mat could be downscaled without significant loss in lameness detection performance. The challenge for downscaling entails following research steps: (1) to investigate the minimal length of measurement zone needed without decreasing the performance of the lameness detection system, and (2) to investigate to what extent larger sensors could be used without compromising the system's lameness detection performance.

2. Materials and methods

2.1. The Gaitwise system

The Gaitwise system was developed at the Institute for Agriculture and Fisheries Research (ILVO), Belgium, based on a large pressure sensitive mat which allows to measure different types of variables that describe cow gait and claw-floor interaction (e.g. spatial variables, time variables and force measurements). These variables provide the most direct way of measuring cow gait for automatic 'locomotion scoring' of walking cows. Based on the available technology, a pressure sensitive mat used in human medicine research which provided information on the location, timing and relative pressure level of limbs contacting the measurement zone was selected (Maertens et al., 2011). The sensor has a spatial resolution of 1.27×1.27 cm (or a surface of 1.6 cm^2), a frequency of 60 Hz and an active measurement surface of 48 by 384 sensors (61 by 488 cm) that registers the position of the hooves on the ground in an X,Y-plane (CIR Systems Inc., 2015).

The raw data of each measurement contains the time (T), location (X,Y) and relative force (F) of each sensor in the grid that has a changed pressure value compared to the previous readout. From these raw data, hoof imprints are defined, which are then used for calculation of gait variables (Maertens et al., 2011; Van Nuffel et al., 2013). Basic gait variables consist of 8 *within-imprint* variables formed by the stance time and average pressure of each leg, and 12 *between-imprint* variables defined by the distances from the left hind (LH) leg to the right hind (RH), right front (RF) and left front (RF) leg in the X, Y and T dimensions. Inconsistency variables are calculated based on the average value and standard deviation of the basic gait variables, and hence represent the stride-to-stride fluctuation of the respective basic gait variable. Specific gait variables include variables that describe the asymmetry between hind and front legs based on the basic gait variables, as well as step overlap, abduction and speed. The current Gaitwise sensor provides sufficient information of at least two complete gait cycles in 96% of the measurements, which are needed to calculate inconsistency variables based on *between-imprint* variables. For all other variables, at least one full gait cycle – i.e. two imprints of each leg, hence minimum eight in total – is needed to allow calculation.

2.2. Data collection

Lameness and gait data of 45 lactating Holstein cows were collected during seven months on the ILVO experimental farm. Cows included animals with different ages and parities, as well as different lactation stages.

Lameness was scored visually on a scale from 1 to 3 by a trained observer based on the presence of different lameness attributes