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Lameness detection based on multivariate continuous sensing of milk yield, rumination, and neck activity

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ABSTRACT

The objective of this study was to develop and validate a mathematical model to detect clinical lameness based on existing sensor data that relate to the behavior and performance of cows in a commercial dairy farm. Identification of lame (44) and not lame (74) cows in the database was done based on the farm's daily herd health reports. All cows were equipped with a behavior sensor that measured neck activity and ruminating time. The cow's performance was measured with a milk yield meter in the milking parlor. In total, 38 model input variables were constructed from the sensor data comprising absolute values, relative values, daily standard deviations, slope coefficients, daytime and nighttime periods, variables related to individual temperament, and milk session-related variables. A lame group, cows recognized and treated for lameness, to not lame group comparison of daily data was done. Correlations between the dichotomous output variable (lame or not lame) and the model input variables were made. The highest correlation coefficient was obtained for the milk yield variable ($r_{MY} = 0.45$). In addition, a logistic regression model was developed based on the 7 highest correlated model input variables (the daily milk yield 4 d before diagnosis; the slope coefficient of the daily milk yield 4 d before diagnosis; the nighttime to daytime neck activity ratio 6 d before diagnosis; the milk yield week difference ratio 4 d before diagnosis; the milk yield week difference 4 d before diagnosis; the neck activity level during the daytime 7 d before diagnosis; the ruminating time during nighttime 6 d before diagnosis). After a 10-fold cross-validation, the model obtained a sensitivity of 0.89 and a specificity of 0.85, with a correct classification rate of 0.86 when based on the averaged 10-fold model coefficients. This study demonstrates that existing farm data initially used for other purposes, such as heat detection, can be exploited for the automated detection of clinically lame animals on a daily basis as well.

Key words: dairy cow, lameness, behavior, sensor data

INTRODUCTION

Lameness is defined as a deviation in gait resulting from pain or discomfort from hoof or leg injuries and disease (Flower and Weary, 2009). Lameness is a major health and welfare issue in modern intensive dairy farming (Cha et al., 2010; Lievaart and Noordhuizen, 2011; Bruijnis et al., 2012). Prevalence rates depend on many different factors, such as housing, management, feed, and breed (Cramer et al., 2009; Dippel et al., 2009; Barker et al., 2010). Cramer et al. (2009) showed that 99.3% of the herds had at least one cow with a lesion that caused lameness. The mean herd-prevalence was 28.1% (range = 0–83.8%) and cow-level prevalence was 25.7%. Barker et al. (2010) found a within-herd prevalence of 36.8% (range = 0–79.2%). Farmers frequently underestimate the lameness prevalence in their farm (Leach et al., 2010; Potterton et al., 2011; Sarova et al., 2011).

The most common method to obtain a herd lameness prevalence rate is visual locomotion scoring (Flower and Weary, 2009). This procedure is subjective (Channon et al., 2009; Flower and Weary, 2009), time-consuming (Thomsen, 2009), and costly. Therefore, visual locomotion scoring is hardly done for large herd sizes; rather, it is often done on a sample of the entire herd (Main et al., 2010). On Israeli dairy farms, lame cows are treated after clinical diagnosis by the veterinarian or claw trimmer to whom suspected cows are presented. This procedure is preceded by visual identification of lame cows by a trained herdsman, who usually observes a deviance in gait when walking the cows to the milking parlor. The cows identified as suspiciously lame are brought to a trained veterinarian or claw trimmer, who will make the actual clinical diagnosis of the lameness. If the suspected cow is confirmed as lame, adequate treatment is applied.

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Lameness has a negative effect on fertility and reproduction rates (Walker et al., 2010; Alawneh et al., 2011). The effect of lameness on animal behavior and performance is also well described. Live weight (Alawneh et al., 2012), milk fat (van Straten et al., 2011), milk yield (Green et al., 2002; Archer et al., 2010; Reader et al., 2011), and behavior such as activity (Blackie et al., 2011; Pavlenko et al., 2011; Reader et al., 2011) were all found to change by a lameness incidence or foot lesions. Continuous monitoring of these parameters could result in an automated lameness detection tool.

The automation of lameness detection or gait scoring is an important topic in research and several different approaches have been developed. Studies focusing on ground reaction forces (Pastell et al., 2008; Liu et al., 2011), pressure sensitive walkways (Maertens et al., 2011), and accelerometers (Pastell et al., 2009; Chapinal et al., 2011) measured the asymmetry of the gait when walking. These approaches used the diversity in weight bearing on each leg for lameness detection. Other studies used computer vision to analyze the gait automatically. These studies focused on gait parameters such as back arch curvature (Poursaberi et al., 2010), step overlap (Pluk et al., 2010), and hoof release angle (Pluk et al., 2012). Each of those studies introduced an additional tool or sensor in the farm to detect lameness automatically.

The use of sensors is widespread in modern dairy farming, which makes continuous monitoring of the individual in the herd possible. However, the large pool of existing data on the farm is not extensively used. Estrus detection based on animal behavior is a well-described research item (de Mol et al., 2001; Holman et al., 2011; Jonsson et al., 2011) and found its way to the commercial market. Studies on mastitis prediction (de Mol and Ouweltjes, 2001; Kramer et al., 2009), calving time prediction based on a diurnal pattern analysis (Maltz et al., 2011), and lameness incidence (Kramer et al., 2009; Ito et al., 2010) were also reported. Ito et al. (2010) found that measures of lying behavior alone were not sensitive diagnostics for lameness detection, and, hence, they suggested using these automated measures of lying behavior in a multi-pronged approach for lameness detection. Kramer et al. (2009) reported high within- and between-cow variability, which made their fuzzy logic lameness detection model not suitable for practical use.

The diurnal rhythm affects animal behavior and farm routine. A correct management of the photoperiod affects dairy cow performance and health (Dahl and Petitclerc, 2003). Feeding and milking time influence the time budget of a dairy cow (Devries and von Keyserlingk, 2005; Belle et al., 2012). The photoperiodic effect on lying time was used to detect calving time of dairy cows (Maltz et al., 2011). Besides a diurnal analysis of the behavior data, discrimination was made between the daytime and nighttime period. Behavior during nighttime was found to be a better predictor for calving time in the study of Maltz et al. (2011).

To our knowledge, no attempt has been done to automatically detect lameness based on a combination of 3 sensor based variables (milk yield, neck activity, and ruminating time) and a diurnal pattern analysis of these variables. The aim of this study was to develop a mathematical model based on correlated variables measured with existing low-cost sensors to detect clinical lameness based on behavioral and milk performance data.

MATERIALS AND METHODS

Animals and Housing

Data were gathered from Refet HaEmek, a commercial Israeli dairy farm located in kibbutz Yifat. The milking herd consisted of 1,100 Israeli Holstein milking cows. The average parity in the herd was 2.6 ± 1.6 lactations, with a replacement rate of 33%. The annual milk production was 11,500 kg/cow. The herd contained 11 production groups according to parity, lactation stage, reproduction status, and health status (group size = 96 ± 12 cows). Cows with severe diseases, such as acute mastitis and clinical lameness, were housed in a small, separated group referred to as the hospital group (15 ± 4 cows). All cows were housed in a separate no-stall, fully roofed, open cowshed with dried manure bedding material. Each cowshed had a post-and-rail feed fence on 1 side of the barn and the area near this feeding lane was paved in concrete. Stocking rate was, on average, 19.3 m^2/cow in each production group (Figure 1).

All cows were milked 3 times per day (at 0300, 1100, and 1900 h) in a 2 × 32 parallel milking parlor. Each milking session took about 6 h. The production groups were brought one-by-one to the waiting parlor to avoid group mixing. During each milking session, not more than 2 groups were in the waiting area. Cows in early lactation were milked first, then the primiparous groups, followed by multiparous cows, and lastly the hospital group.

Each milking session was done by 4 workers; 3 workers milked the cows and 1 worker (pusher) brought the cows to and from the milking parlor. Cows with a deviation in gait and suspected as lame were identified by the cow pusher, as he had the best view on cow's locomotion. The cow pusher was a trained herdsman, but did not receive any specific training in locomotion scoring or lameness detection. The cows suspected as lame by the pusher were presented the next day to