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Lameness detection challenges in automated milking systems addressed with partial least squares discriminant analysis

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ABSTRACT

Lameness causes decreased animal welfare and leads to higher production costs. This study explored data from an automatic milking system (AMS) to model on-farm gait scoring from a commercial farm. A total of 88 cows were gait scored once per week, for 2 5-wk periods. Eighty variables retrieved from AMS were summarized week-wise and used to predict 2 defined classes: nonlame and clinically lame cows. Variables were represented with 2 transformations of the week summarized variables, using 2-wk data blocks before gait scoring, totaling 320 variables (2 × 2 × 80). The reference gait scoring error was estimated in the first week of the study and was, on average, 15%. Two partial least squares discriminant analysis models were fitted to parity 1 and parity 2 groups, respectively, to assign the lameness class according to the predicted probability of being lame (score 3 or 4/4) or not lame (score 1/4). Both models achieved sensitivity and specificity values around 80%, both in calibration and cross-validation. At the optimum values in the receiver operating characteristic curve, the false-positive rate was 28% in the parity 1 model, whereas in the parity 2 model it was about half (16%), which makes it more suitable for practical application; the model error rates were, 23 and 19%, respectively. Based on data registered automatically from one AMS farm, we were able to discriminate nonlame and lame cows, where partial least squares discriminant analysis achieved similar performance to the reference method.
Key words: lameness detection in automatic milking system, animal welfare, pattern recognition, partial least squares discriminant analysis

INTRODUCTION

Automatic milking systems (**AMS**), also called robotic milking, were implemented in the 1990s to reduce labor costs in dairy herds. By 2010, almost 10,000 farms had adopted AMS worldwide (de Koning, 2011); more than 2,000 are located in the Netherlands, whereas Denmark, Norway, and Sweden have around 1,000 farms each (Bisaglia et al., 2012; Landin and Gyllenswärd, 2012). However, increasing numbers are foreseen in northwest Europe (Steeneveld et al., 2012). The frequency of the cows' voluntary visits to the AMS is a major determinant of production efficiency (Ketelaar-de Lauwere et al., 1996; Borderas et al., 2008; Lyons et al., 2013). Thus, an alarm from the AMS is generated when the cows' milking parameters deviate markedly from the expected pattern.

Recurrent evidence exists that painful conditions in the claws will reduce AMS visits (Klaas et al., 2003; Bach et al., 2007; Jacobs and Siegford, 2012). In the case of subtle pain though, the cow may merely reduce the number of AMS visits sporadically and she may eat less, leading to decreased milk production and compromised health and fertility.

Detecting even subtle painful conditions could be important for the herd manager interested in early and accurate intervention. Pain in the claws is difficult to assess under field conditions. Usually, the cows will avoid pain by changing their walking behavior (i.e., become lame). Signs of lameness have been associated with substantial financial losses (Sprecher et al., 1997; Blowey, 1998; Green, 2009) and constitute important indicators of reduced cow welfare (von Keyserlingk et al., 2009). In the traditional milking parlor, the personnel can detect behavioral changes visually when collecting cows for milking or when cows are leaving the parlor at least twice per day. In AMS, individual daily inspection is needed to detect subtle signs of lameness and this will be time consuming and, thus, costly. Therefore, it is highly relevant to develop automated systems to identify cows experiencing lameness.

Automatic milking systems generate large amounts of data on milking, feeding, and physical activity parameters. Disease treatments may be recorded and more constant cow characteristics, such as breed, age, and stage of lactation, are updated automatically (Jacobs and Siegford, 2012). These data are often the basis for

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the alarm lists, which should be addressed daily by the herd manager. However, lameness detection systems currently available seem far from being implemented worldwide on commercial farms, as studies on these systems often rely on relatively small sample sizes and a limited number of farms (Rutten et al., 2013). Logistic regression and linear discriminant analysis have been applied in animal and veterinary science for classification of animals, as diseased versus nondiseased, based on potential predictors (Greiner and Gardner, 2000; Heald et al., 2000; Nielsen et al., 2012). The AMS provides a series of potential predictors often larger in number than the cows available in most farms. Traditional approaches, such as the abovementioned logistic regression and discriminant analysis, may be inefficient or biased due to multicollinearity and overfitting (Ye and Zhao, 2010; Serrano-Cinca and Gutiérrez-Nieto, 2013). Multivariate methods (e.g., principal component analysis) have also been used for analysis in the animal science field (Bro et al., 2002; Dumas et al., 2005; Miekley et al., 2013), often focusing on data reduction (Sloth et al., 2003; Gorzecka et al., 2011). Based on automated data collection in dairy herds, pattern recognition has been the objective in several studies using principal component analysis, neural networks, or classification trees (Nielen et al., 1995; Klaas et al., 2004; Cavero et al., 2008; Ghotoorlar et al., 2012; Piwczyński et al., 2013).

Partial least squares discriminant analysis (**PLS-DA**) is a common tool used in classification in cases where multicollinearity is an issue (Vong et al., 1988; Wold et al., 2001; Chong and Jun, 2005). It allows investigation of hundreds or thousands of variables by using visualization tools to screen and understand complex data. Traditional applications of univariate analyses aim at detecting single or few predictors (e.g., logistic regression). Instead, PLS-DA comes as an attractive approach to finding latent patterns in a truly multivariate phenomenon, where many variables are correlated with each other but none is a good lameness indicator alone.

The aim of this investigation was to explore robotic milking-related variables potentially associated with clinical lameness. The objectives of this feasibility study were to (1) explore the usefulness of PLS-DA for lameness detection based on automated recordings of cow activity and milking process from an AMS herd and (2) suggest relations between these patterns and signs of lameness.

MATERIALS AND METHODS

Farm

We selected a commercial Danish dairy farm with 150 milking cows, free cow traffic, and 2 robotic milking units [voluntary milking system (VMS); DeLaval International AB, Tumba, Sweden] corresponding to 2 groups. There was a separate section with deep bedding (straw) for fresh cows and another one for dry cows. Only cows in the 2 freestall groups (robots) were lameness scored to ensure scoring under the same conditions. The farm had freestalls with mattresses and shavings, and a slatted floor maintained by a cleaning robot 8 times per day. The milking cows were automatically fed a TMR 7 times per day at 0200, 0600, 1000, 1200, 1400, 1800, and 2200h. On average, 67 cows were assigned to each robot. The cow breeds were Danish Holstein (13%), Danish Red (21%), and crossbred (66%). The cows were trimmed by a hoof trimmer every 4 mo and also by the staff at drying-off. At the beginning of the study, lactation number ranged from 1 to 7, 40% were first parity, and cows were milked on average 2.3 times per day, with a 9.2-h median milking interval (interquartile range: 5.4 h) and producing a median of 11.0 kg of milk per milking (interquartile range: 5.6 kg). Cows were, on average, at 153 DIM (range: 2 to 632 DIM).

Data Collection

Gait scoring of all milking cows was done by the first author weekly for 5 wk in autumn 2012 and for 5 wk in spring 2013 inside the freestalls by gently encouraging each cow to walk along the alleys. Asymmetric gait was assessed using a 4-point scale adapted from DairyCo (Kenilworth, UK; Reader et al., 2011): score 1 = even, long, and fluid strides (nonlame); score 2 = uneven steps, but the limbs favored were not obvious (nonlame); score 3 = 1 or more limbs favored obviously (lame); and score 4 = very reluctant to put weight on 1 or more limbs (severely lame). The first and the second author did an agreement study in the first week of the trial, whereas all gait scores used in the models were from the first author. The first author had limited experience in lameness scoring and the second author had several years of experience, although with a 5-point scoring system. The overall error rate of both intra- and interobserver agreement (between the first and second author) was around 15 to 20% when using a dichotomized classification of lame versus nonlame (detailed information presented in the Results section). We calculated the kappa statistic as an index of observer agreement with linear weighting and unweighted, respectively, for the 4- and binary-category results (Sim and Wright, 2005). Daily data obtained from the farm database (VMS Client 2009, v. 8.40; DeLaval International AB) was summarized week-wise, where the week was defined as d 1 to 7, with the gait scoring done on d 7. For the milking data, in every week (day 1 to 7),