J. Dairy Sci. 96:5723–5733
http://dx.doi.org/10.3168/jds.2012-6460

Implementation of multivariate cumulative sum control charts in mastitis and lameness monitoring

Bettina Miekley,*[1] Eckhard Stamer,† Imke Traulsen,* and Joachim Krieter*
*Institute of Animal Breeding and Husbandry, Hermann-Rodewald-Straße 6, D-24118 Kiel, Germany
†TiDa Tier und Daten GmbH, D-24259 Westensee/Brux, Germany

ABSTRACT

This study analyzed the methodology and applicability of multivariate cumulative sum (MCUSUM) charts for early mastitis and lameness detection. Data used were recorded on the Karkendamm dairy research farm, Germany, between August 2008 and December 2010. Data of 328 and 315 cows in their first 200 d in milk were analyzed for mastitis and lameness detection, respectively. Mastitis as well as lameness was specified according to veterinary treatments. Both diseases were defined as disease blocks. Different disease definitions for mastitis and lameness (2 for mastitis and 3 for lameness) varied solely in the sequence length of the blocks. Only the days before the treatment were included in the disease blocks. Milk electrical conductivity, milk yield, and feeding patterns (feed intake, number of trough visits, and feeding time) were used for the recognition of mastitis. Pedometer activity and feeding patterns were used for lameness detection. To exclude biological trends and obtain independent observations, the values of each input variable were either preprocessed by wavelet filters or a multivariate vector autoregressive model. The residuals generated between the observed and filtered or observed and forecast values, respectively, were then transferred to a classic or self-starting MCUSUM chart. The combination of the 2 preprocessing methods with each of the 2 MCUSUM sum charts resulted in 4 combined monitoring systems. For mastitis as well as lameness detection requiring a block sensitivity of at least 70%, all 4 of the combined monitoring systems used revealed similar results within each of the disease definitions. Specificities of 73 to 80% and error rates of 99.6% were achieved for mastitis. The results for lameness showed that the definitions used obtained specificities of up to 81% and error rates of 99.1%. The results indicate that the monitoring systems with these study characteristics have appealing features for mastitis and lameness detection. However, they are not yet directly applicable for practical implementations.
Key words: disease detection, multivariate cumulative sum chart, wavelet, vector autoregression

INTRODUCTION

In dairy production, the stockman's health management aims for the early detection and intervention of diseases, such as mastitis and lameness. Mastitis and lameness still remain the most frequent and costly diseases in the dairy industry in terms of economics and animal welfare (Kramer et al., 2009). The early detection of and intervention against mastitis and lameness reduces veterinary fees, losses in milk yield (**MY**) and milk quality, and increases the cure rate of the infected animals (Milner et al., 1997).

However, with growing herd size, the classic detection method of visual observations has become more difficult and time consuming. Thus, a need exists to support the farmer's observations by applying improved and automated detection of diseases (de Mol et al., 1997). Automated detection is possible using sensor measurements and information from a management information system.

In industrial and chemical production, the concepts of statistical process control and, more specifically, control charts have already been used as one of the major statistical process control tools (De Vries and Reneau, 2010; Mertens et al., 2011). The availability of regularly recorded data on the variables of dairy production processes creates the opportunity to develop such control charts to support the stockman in his daily management tasks (Mertens et al., 2011). Although the concepts of control charts have been proposed for use in agricultural science since the 1970s (De Vries and Reneau, 2010), they have not been widely applied in this field. Recently, the use of control charts in livestock production has been regaining interest (Mertens et al., 2011). Lukas et al. (2009) and Miekley et al. (2012), for example, used self-starting cumulative sum (**CUSUM**) charts for mastitis detection, whereas de Vries and Conlin (2003) used a Shewhart and a classic CUSUM

Received December 7, 2012.
Accepted June 3, 2013.
[1]Corresponding author: bmiekley@tierzucht.uni-kiel.de

chart for estrus detection. However, the charts of these studies are univariate control charts.

In manufacturing industries as well as agricultural science, several quality variables may be controlled simultaneously with one chart, taking any correlation between the variables into account (Hawkins and Maboudou-Tchao, 2007; Waterhouse et al., 2010). Therefore, in industrial process control, multivariate quality control charts have been established. Such multivariate methods use the relationship between the components of a multivariate process to generate more powerful algorithms compared with univariate approaches. The aim is to detect changes in the process that can hardly be detected by a univariate attempt (Bodnar and Schmid, 2007)

Numerous multivariate charts and their extensions are presently available. These charts can be grouped into 3 broad categories, namely Hotelling's T^2, multivariate exponentially weighted moving average, and multivariate CUSUM (**MCUSUM**) charts. Multivariate CUSUM charts have proved particularly powerful (Patel and Divecha, 2010). However, control charts in general are sensitive to trends and autocorrelation within data (Montgomery, 2009). Thus, preprocessing methods (e.g., filters or time series models) play an important role in process control using MCUSUM charts.

Therefore, this paper aims to provide an introduction to the concepts and possible preprocessing methods of MSUSUM charts as well as their applicability in the early detection of mastitis and lameness based on practically recorded farm data. For preprocessing, wavelet filters and multivariate vector autoregressive models were chosen for mastitis and lameness detection, respectively. Besides the classical MCUSUM chart, a self-starting approach of the MCUSUM will be discussed.

MATERIALS AND METHODS

Data

Data used was recorded on the Karkendamm dairy research farm, located in Northern Germany, between August 2008 and December 2010. About 66,000 cow-days from 338 and 315 cows in their first 200 DIM were analyzed for mastitis and lameness detection, respectively. Milk parameters [such as MY and milk electrical conductivity (**MEC**)] have been used for mastitis detection in recent studies (Cavero et al., 2008; Lukas et al., 2009), whereas the activity of cows has been used for lameness detection (Kramer et al., 2009). Recently, feed intake and its corresponding behavior have been reported to be linked to a cow's health status (González et al., 2008; Lukas et al., 2008). Therefore, MEC, MY, and feeding patterns (feed intake, number of trough visits, and feeding time) were used for the recognition of mastitis. Pedometer activity and feeding patterns were used for lameness detection.

Milking took place in a rotary milking parlor manufactured by GEA Farm Technologies GmbH (Bönen, Germany). Cows were milked twice daily. Milk yield and MEC were measured using the Metatron P21 milk meter (GEA Farm Technologies GmbH) at every milking. Activity was measured using pedometers (GEA Farm Technologies GmbH), which recorded activity in 2-h periods. Cows were fed in individual feeding troughs. The feeding trough was developed and installed by the Institute of Animal Breeding and Husbandry, University of Kiel (Kiel, Germany). Each visit to the feeding troughs was recorded and the amounts of consumed feed were accumulated to daily intakes. Extreme values (mainly for the trait feed intake) that deviated by more than ±4 standard deviations were excluded from the data set. To adjust for different timescales between the indicator variables, daily MY, weighted MEC per day, and average daily activity rates were calculated (Table 1). Furthermore, high pedometer activity due to documented and progesterone-measured estrus events was excluded from the data set.

Medical treatments of diseases were documented constantly by veterinarians and farm staff. Different categories for mastitis (e.g., *Staphylococcus aureus* or *Escherichia coli* mastitis) and for claw and leg diseases (e. g. digital dermatitis or sole ulcer) were identified. Due to the low frequencies of diseased cows within these categories, the categories were combined to form cases of mastitis and lameness, respectively. These cases were defined as the target characteristic to be distinguished from the healthy observation in the data. In the case of mastitis, 238 cows without any mastitis treatment during their first 200 DIM as well as 100 treated cows were

Table 1. Descriptive statistics of the traits showing the number of observations (n), mean, SD, and minimum (Min) and maximum (Max) values

Item	n	Mean	SD	Min	Max
Milk yield (kg/d)	62,635	36.2	6.1	8.6	70.7
Milk electrical conductivity (reference values)	63,703	496.2	34.2	320.0	874.0
Activity (contacts/d)	58,898	30.7	10.0	4.5	70.0
Feed intake (kg/d)	48,643	38.5	13.2	2.7	65.8
Time at trough (min/d)	48,642	171.2	58.5	13.0	295.0
Trough visits (no./d)	48,647	44.5	15.6	5.2	117.0