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Sensor data on cow activity, rumination, and ear temperature improve prediction of the start of calving in dairy cows

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ABSTRACT

Management during calving is important for the health and survival of dairy cows and their calves. Although the expected calving date is known, this information is imprecise and farmers still have to check a cow regularly to identify when it starts calving. A sensor system that predicts the moment of calving could help farmers efficiently check cows for calving. Observation of a cow prior to calving is important because *dystocia* can occur, which requires timely intervention to mitigate adverse effects on both cow and calf. In this study, 400 cows on a Dutch dairy farm were equipped with sensors. The sensor was a single device in an ear tag, which synthesised cumulative activity, rumination activity, feeding activity, and temperature on an hourly basis. Data were collected during a one-year period. During this period, the starting moment of 417 calvings was recorded using camera images of the calving pen taken every 5 min. In total, 114 calving moments could be linked with sensor data. The moment at which calving started was defined as the first camera snapshot with visible evidence that the cow was having contractions or had started labor. Two logit models were developed: a model with the expected calving date as independent variable and a model with additional independent variables based on sensor data. The areas under the curves of the Receiver Operating Characteristic were 0.885 and 0.929 for these models, respectively. The model with expected calving date only had a sensitivity of 9.1%, whereas the model with additional sensor data has a sensitivity of 36.4%, both with a fixed false positive rate of 1%. Results indicate that the inclusion of sensor data improves the prediction of the start of calving; therefore the sensor data has value for the prediction of the moment of calving. The model with the expected calving date and sensor data had a sensitivity of 21.2% at a one-hour time window and 42.4% at a three-hour time window, both with a false positive rate of 1%. This indicates that prediction of the specific hour in which calving started was not possible with a high accuracy. The inclusion of sensor data improves the accuracy of a prediction of the start of calving, compared to a prediction based only on the expected calving date. Farmers can use the alerts of the predictive model as an indication that cows should be supervised more closely in the next hours.

1. Introduction

Up to one-third of calves born on dairy farms are born after *dystocia*, and have increased risks of disease and mortality (Barrier et al., 2013). Severe *dystocia* causes stillbirth in 49% of cases and calves born after *dystocia* are 1.5 times more likely to develop a disease during the first 120 days of age (Lombard et al., 2007). For cows, the likelihood of conception decreases as the number of days open increases (Fourichon et al., 2000), and culling risk is higher (Rajala-Schultz and Grohn, 1999) within a lactation that starts with a *dystotic* calving. Moreover, *dystocia* increases the risk of damage to the uterus and infections, which increases the risk of metritis (Rajala-Schultz and Grohn, 1999; Schuenemann et al., 2013; Sheldon et al., 2009). *Dystocia* is therefore, a health and welfare problem for both cows and calves. High calf mortality can also be seen as an image problem for the whole dairy sector.

Risk factors for *dystocia* include biology of the cow (e.g., breed and parity), calf gender (Norman et al., 2010) calf weight and management (e.g., housing and pre-calving movement) (Mee et al., 2014; Piwczynski et al., 2013). Farmers can influence these risk

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factors through management, for instance, by changing their breeding strategy but also by human supervision during the calving process. Lombard et al. (2007) observed that 24% of stillbirths occurred with unassisted calvings. Supervision during the calving process, which enables appropriate intervention, is therefore likely to reduce the number of stillbirths and other health and welfare effects that *dystocia* has on calves and dairy cows (Barrier et al., 2013; Mee et al., 2014).

Farmers currently only have the expected calving date on which to base the decision to supervise cows more intensively. The true calving date varies between 267 and 295 days after a successful insemination (Inchaisri et al., 2010), whereas the expected calving date is on average 280 days post insemination. Hence it is challenging for farmers to correctly determine which cows should be supervised more often or more intensively, and when appropriate interventions are needed. Farmers thus have to visually check pregnant cows that approach their expected calving date and this increases the work load for a farmer.

There are several behavioural and physiological parameters associated with the start of calving, that can be monitored automatically by sensors. Feeding and ruminating behaviour of dairy cows decreases gradually in the last two weeks before calving and drops suddenly at calving (Bar and Solomon, 2010). Sensors seem capable of detecting these changes (Bar and Solomon, 2010; Bucher and Sundrum, 2014; Schirmann et al., 2013). Time spent on feeding also decreases, dry matter intake tends to decrease slightly (Schirmann et al., 2013; Bucher and Sundrum, 2014), and activity changes in the 24 h before calving (Clark et al., 2015; Miedema et al., 2011b; Saint-Dizier and Chastant-Maillard, 2015). Titler et al. (2015) demonstrated that an activity index could be used to predict whether a cow would calve in the 6 h following an increase in the activity index. Previous studies have shown that temperature (measured at the vulva, rectum, and rumen) decreases during the 24 h prior to calving (Saint-Dizier and Chastant-Maillard, 2015). Ouellet et al. (2016) have shown that all these parameters, which can be measured by sensors have value for the prediction of calving.

A more accurate prediction of the start of calving than the expected calving date would enable farmers to identify when a cow requires intensive supervision. This will help ensure appropriate intervention when needed and reduce the workload for the farmer from unnecessarily checking cows. Although studies have shown that sensor data has value for the prediction of calving, an independent validation of the accuracy of such a prediction has not been studied yet. Furthermore, an evaluation of the additional value of sensor data compared to the expected calving date is also missing in the literature. In this study, rumination, activity, and temperature measured automatically by a single sensor are used to predict the start of calving in dairy cows by (1) evaluating at which moment, relative to the start of calving, sensor data has predictive value, (2) exploring the potential value of sensor data in addition to the expected calving date in estimating the start of calving, and (3) developing an independently validated model that predicts the start of calving.

2. Material and methods

2.1. Gold standard definition

The definition of the start of the calving process is essential for the development of a model that predicts the calving moment. The moment of actual calving is not informative for a farmer, as potential *dystocia* should be detected and resolved shortly after the start of calving. The start of the calving process is therefore a better moment to generate an alert for calving. This study defined the start of the calving process as the first camera snapshot with visible evidence that the cow was having contractions or had started labor. When a born calve was seen on camera the start of calving could be deduced by scrolling back in time. The moment as defined in the current study refers to the start of the second stage of parturition were the foetus is expelled (Parkinson et al., 2001b). The most notable signs are visible abdominal muscle contraction and movement of ears and head that indicate pressure to expel the foetus. Typically the cow is lying down on her side (lateral recumbency), but standing upright is possible. Date and time of this camera snapshot were used as the gold standard for the start of the calving process, defined at the respective hour.

2.2. Data collection

On a commercial Dutch dairy farm, 400 cows were equipped with Agis SensOor sensors (Agis Automatisering B.V., Harmelen, The Netherlands). These sensors are 3D-accelerometers attached to the ear tag of the cow and report rumination, feeding, activity, and temperature on an hourly basis (Bikker et al., 2014). Data were collected from September 1, 2013 until November 1, 2014 from late gestation dairy cows housed in a straw bedded pen.

The dairy farmer was asked to record the date and time at which he had noticed a cow had calved. The start of the calving process as defined for this study was assigned by manual evaluation of snapshot images taken by a video camera every 5 min. The farmer-recorded estimates of the calving moment were used to reduce the amount of images that were screened. Animal husbandry students (BSc, van Hall-Larenstein, Leeuwarden, the Netherlands) were instructed to use the camera images to determine the exact start of the calving process for each cow. In total, 414 cows calved; exact calving moments were determined for 240 of these cows by screening images. Of these 240 calving moments, 90 belonged to heifers. The farmer only equipped these heifers with sensors post-partum as part of normal management procedure. Consequently, these 90 calving moments had no sensor data available. The remaining 150 calving moments had sensor data available and were used for further analysis.

2.3. Expected calving date

Insemination records were used to calculate the expected calving date at 280 days post insemination for each cow. Expected calving dates were required to fall within a period from three weeks before to three weeks after the actual calving date. This method was based on the generally accepted average gestation length of 280 days (Parkinson et al., 2001c) in combination with the three week interval for ovulation (Parkinson et al., 2001a). If an expected calving date did not fall within this six-week period, it was assumed that the insemination did not lead to a calving and the expected calving date was therefore assumed missing. If an expected calving date fell within this six-week period, the expected calving date was used to estimate the number of days to expected calving date (*DTC*). This variable is negative in the days prior to the expected calving date and zero at the expected calving date.

2.4. Sensor data

For each hour of the day, the SensOor system assigns the minutes within that hour to one of the five following sensor parameters (Var_i): ruminating ($i = 1$), eating ($i = 2$), active ($i = 3$), highly active ($i = 4$), or not active ($i = 5$). These five sensor parameters are measured by a single sensor. The sum of the five sensor parameters adds up to a total of 1 h. This means, for instance, that 1 min spent on rumination cannot be spent on being active. Therefore,