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Automatic reading of Kamars for heat detection in dairy herds

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ABSTRACT

Most existing heat detection systems for dairy cattle are labour-intensive requiring manual inspection of every animal to maximise submission rates. Our solution is to automate heat detection using Kamar HeatMount Detectors and a camera-based recognition system. The goal of our system is to obtain 99% sensitivity and specificity, ensuring that cows that are on heat are rarely missed and over-drafts are kept to a minimum. Trials of various camera prototypes have been undertaken over the past three years, most recently during the artificial breeding period in the Spring of 2009. Over 70,000 images from four farms were taken during the latest trials; these photographs were used to assess the system. When considering photo observations, the fully automated system had an error rate less than 1% across all sites in the latest trial, and reaches our goal of 99% sensitivity and specificity.

Keywords: automatic; heat detection; oestrus; dairy cow; kamar heatmount detector; computer vision.

INTRODUCTION

Correct detection of oestrus (heat) is important on dairy farms with artificial breeding (AB) programmes. A missed heat means a three week delay in inseminations, resulting in lost productivity in subsequent seasons due to an increased calving spread. Unfortunately, modern day dairy herd sizes are often large and farm workers often do not have the required skill or time for accurate visual inspection of every cow during each milking. To ensure submission rates are maximised, farmers often employ heat detection aids such as tail paint or pedometers rather than relying on observation alone. However, many of these aids still rely on manual inspection to determine oestrus.

Tail paint is the most common heat detection method in New Zealand (Holmes *et al.*, 2002), and involves coating the pin bones and tail head with paint. During oestrus the paint is rubbed off as the cow is ridden. This system is effective; the use of tail paint allows for oestrus detection rates of up to 90% to be achieved during the mating period (Holmes *et al.*, 2002). However, tail paint is not without its issues; the amount of paint rubbed off by riding varies between cows. Also, paint is rubbed off as a result of normal activity. Tail paint does not provide a binary yes/no decision as to whether riding has occurred. It relies on a subjective judgment. Furthermore, daily inspection is required to make this judgment.

Pressure sensitive devices such as the Kamar HeatMount Detector® (Kamar Inc., Steamboat Springs, Colorado, USA), MountCount® (DDx Inc., Denver, Colorado, USA), HeatWatch® (CowChips LLC, Manalapan, New Jersey, USA) and Bulling Beacon® (Beacon Marketing, Muswellbrook, New South Wales, Australia) are available as alternatives to tail paint. These devices give a simple yes/no assessment whether mounting has occurred. Some, such as Kamar HeatMount Detectors® or Bulling Beacons®, use a coloured fluid that fills a container when pressure is applied. Others, including MountCount® and HeatWatch®, use electronic circuitry to indicate when a pressure pad has been activated. All of these devices are applied in front of the tailhead, in a similar position to tail paint. In most cases these devices rely on a manual visual check to determine activation. Those that are fully automated provide no alternative means of detecting oestrus when there is a computer system failure.

Activity meters, including pedometers, can also be used for heat detection. These are neck or leg mounted meters that can determine the number of steps taken or some other measure of activity. They are a fully automated system; data from the meters is uploaded to a computer that concludes whether a cow is in oestrus, based on an increase in activity. However, there are two inherent flaws. Both the meter units and the device that reads them must be working to determine activity as the system cannot provide judgments when either component breaks down. Second, activity meters are subject to a high level of false positives because it is difficult to determine whether an increase in activity is due to oestrus or some other reason, such as moving to a fresh break (Harris *et al.*, 2010).

Other less popular heat detection aids are also available, but these methods are either impractical or awkward, and are difficult to automate. However, it would be beneficial to automate common aids, such as tail paint, which have proven performance in heat detection. Automating these methods would reduce time spent by farm staff in heat detection, yet provide reliable results even when automation fails.

Our solution to automated oestrus detection has been to identify the status of a Kamar HeatMount Detector® device, subsequently referred to as Kamar, using a camera-based recognition system. Kamars are a pressure-sensitive device consisting of a fabric patch and a waterproof bubble. Inside the bubble is a dye pack containing a coloured dye. When pressure is applied, the dye is released and the bubble changes colour. Dye will not appear through knocks and bumps. Pressure must be applied for more than a second before the dye escapes the internal pack. Because of this, it is unlikely that Kamars will burst unless riding has occurred. They provide a binary yes/no decision of whether riding has occurred based on the visibility of dye in the bubble. This makes automation a simple, yet accurate process: the system need only determine whether the Kamar is present, and if it is, whether there is dye visible.

The goal of our system is to reach 99% specificity and sensitivity when considering photo observations, ensuring that false positives are kept to a minimum, and activated Kamars are rarely missed. Due to cost constraints we were unable to test the heat detection performance of Kamars alone in this study. This paper discusses the algorithm results when reading Kamars automatically with a camera-based system.

MATERIALS AND METHODS

Automatic system

In the system described here, a digital camera is suspended above a single bail in a rotary milking shed. The camera is positioned such that when the bail is centred below the camera it will have a clear view of the cow's back. Whilst the actual angle of the camera will differ depending on shed layout, the camera should be able to see from the tail forward for at least 600 mm towards the cow's head. That is, a photograph must encompass all possible locations of a Kamar device. A single photograph is taken of each bail when it is in the correct position below the camera.

The camera uses a fixed-focus lens and manually set aperture. The focus is fixed between one and two metres from the camera, ensuring the pictures are always in focus regardless of cow size. The aperture is set to underexpose most photos. Doing so eliminates background objects that would interfere with recognition of the Kamar. It also ensures that overexposure is rare, even when the unit is placed in an open shed and exposed to direct sunlight.

Once a photograph is taken, it is assessed by a computer algorithm to determine whether a Kamar is present, and if so, whether or not it has been activated. This gives three possible statuses: "Not found", "Not activated" and "Activated". With it being difficult for an algorithm to determine the presence of a white patch on a white surface, such as a standard Kamar on the back of a Friesian cow, non-standard Kamars are used. These Kamars function identically to standard Kamars with the white fabric backing having been replaced by a wider sky-blue backing fabric. The use of blue fabric and a wider patch makes it easier for the algorithm to determine whether a Kamar is present, especially in situations where the patch is excessively dirty.

The algorithm performs two simple steps to determine the Kamar status for a given photograph. First, if there is not enough blue in the image then the status "Not found" is returned. If there is sufficient blue, the algorithm checks nearby for red. The level of red determines "Not activated" versus "Activated". Various image cleaning, cropping and bounding operations are used throughout these steps to ensure that only the Kamar is assessed. It is imperative that blue and red tailpaint are not used in conjunction with this system, since large blocks of colour similar to the Kamar will inevitably provide an incorrect assessment.

The decision to take a photograph, and display of the algorithm's analysis is performed using the Protrack software. Protrack tracks the positions of cows on a rotary platform, and so can determine when the platform is in the best position to take a photo of a given animal. The resulting Kamar status is relayed to the farmer by displaying a visual alert on the Protrack screen. If a draft event is associated with the status, the cow will be automatically drafted into a specific pen after milking.

Various prototypes of this system have been trialled over the past three years, most recently in the Spring of 2009 during the normal period of artificial insemination. The latest trial used a prototype camera surrounded by light emitting diodes (LEDs) and encased in a light aluminium housing. Previous prototypes have used halogen lights and heavy cast steel housings. Unfortunately, the original halogen lighting was prone to bulb failure. When this occurred, the camera took poorly lit photos that the algorithm could not decipher. LEDs were substituted since they are able to survive thousands of hours without replacement.

The first prototypes housed the analysis computer in the same cast steel unit as the camera. Whilst it was extremely robust and could survive a direct impact from a dairy shed's high pressure water hose, the weight and size of the unit meant that two people were required to safely fix the unit into position. Other than tidiness, there was no real reason for the computer to be next to the camera. In the latest prototype design the computer is housed in an electrical cabinet nearby. The cast steel housing that initially held the camera and analysis equipment has been subsequently replaced with a smaller and lighter aluminium hood that contains only the camera and the LED lighting array.

Field trials

Four farms with rotary milking sheds were used to trial the system during the period of artificial insemination in the Spring of 2009. Three of the trial sites were selected to test the limits of the system. One had poor lighting (A), one had direct sunlight during the day (B), and one was excessively dirty (C). Another site (D), also trialled the system.

Photographs were taken at both the morning and afternoon milking for all farms except Farm B. Farm B only used the system in one milking session during the morning session, because they were concerned at a high number of overdrafts due to use of red tailpaint. The system was active over the entire insemination period for a minimum of four weeks on each farm. All four farms commenced inseminating in October. Each farm had a different number of animals participating in the trial: Farm A had approximately 500 animals, Farm B had 400, Farm C had 700 and Farm D had 300. The number of animals checked at each milking session varied because some were in stand down after mating, and others suffered, and recovered from, health issues unrelated to the camera system. The number of animals seen each day is not a problem for our system: it is able to take a photograph and return the assessment within two seconds, well before the next bail moves into position.

Each photograph taken by our system was stored along with the algorithm's assessment, the identity of the animal, the site name, and the time and date. Each was then visually assessed by at least two independent people from a pool of six. An assessment included the status of the Kamar as to whether it was present or not found, the level of activation of the Kamar bubble (0%, 10%, 25%, 50%, 75%, and 100%), the colour of tailpaint, if any, on the cow, and whether the bubble was damaged, obscured or partially out-of-frame. If the two assessors did not have matching assessments, the photograph was checked by an independent committee of experts for a final judgment.

For our analysis, a score of 50% or higher is considered activated. Lower visual scores are considered "Not activated" because Kamars may be partially burst for a variety of reasons. These reasons include leakage, poor placement and insufficient mounting. However, anecdotal evidence during the trial suggested that Kamars that were faulty in some way only burst to around 25% unless mounting had occurred, hence the choice of 50% as the threshold for activation.

Over 10,000 photographs from each of the four farms have been doubly-assessed and quality checked. Photographs where the bubble was obscured, damaged or partially out-of-frame were excluded. In some cases this was due to poor camera alignment: if the camera was not angled far enough forward, a small cow standing forward in a bail would either be missed or the Kamar would be only partially visible. The alignment was usually corrected at the first opportunity; there were only two occassions where realignment occurred after more than a week had passed.

All sites were instructed not to use red or blue tailpaint for the duration of the trial, although they were free to use any other colour of tailpaint. Despite this, there were incidences of red or blue tailpaint at all of the sites, and 1,180 images were excluded as a result. Images were also excluded if the bubble was obscured or partially out of frame, since it was not possible to visually determine the correct status of the Kamar. In most excluded photos, the algorithm would say "Not activated" if it could see blue due to an obscured Kamar bubble or blue tail paint, or "Activated" if there was red touching the blue of the Kamar, such as when the Kamars were glued on over the top of existing red tail paint. Overall, 2,164 images were excluded.

RESULTS

In total, 71,764 photographs were available to assess the accuracy of the algorithm. Table 1 shows the accuracy of the system for each Kamar status. In total, our system managed an accuracy of 99.7% with a sensitivity of 98.8% and specificity of 99.7%. These results are not significantly different from a perfect result when tested using the chi-squared significant test (sensitivity $P = 0.574$, specificity

TABLE 1: Results of visual assessment (reality) of cows on heat versus algorithm assessment of cows on heat using a Kamar HeatMount detector.

Assessment	Algorithm assessment				Total
	Activation	Activated	Not activated	Not found	
Reality	Activated	1,238	14	18	1,270
	Not activated	170	69,261	30	69,461
	Not found	0	13	1,020	1,033
Total		1,408	69,288	1,068	71,764

P = 0.448) and they reach our goal of 99% specificity and sensitivity.

The algorithm had a positive predictive value (PPV) of 91.9%, and a negative predictive value (NPV) of 100%. The PPV was lower than desirable, meaning there will be approximately one incorrect assessment in every ten "Activated" or "Not found" assessments made by the algorithm. However, 151 of the 170 "Not activated" Kamars assessed as "Activated" were partially burst, but were below our 50% visual "Activated" threshold. Also, draft events should occur for both an activated or missing Kamar in order to check for oestrus, so the 18 activated Kamars assessed as "Not found" by the algorithm will still result in correct drafting in a complete system.

Many of the errors are due to overexposure, such as direct sunlight on the cow's back; underexposure, such as with a dirty camera lens and/or lights in a dark shed; or sunrise and sunset. These factors can be mitigated by ensuring the camera and lights are always clean, and by shading off the area. Some errors were also caused by dirt. Over time the patches tended to change colour as they were soiled. This colour change resulted in the algorithm not correctly identifying the Kamar, and returning "Not found". This was especially a problem for activated Kamars that had become dirty through mounting. Our attempts to change the algorithm to combat the colour change resulted in visual statuses of "Not found" being missed. This adversely impacted on the sensitivity of the system. Since the same drafting behaviour was required for "Not found" and "Activated" Kamars, the algorithm makes no attempt to combat significant Kamar patch colour change.

DISCUSSION

To the best of our knowledge, no other automated oestrus patch reader system exists in New Zealand other than the Massey University reflective patch invention (Alawneh *et al.*, 2006). This invention uses a camera-based recognition system together with novel oestrus detection strips (ODS). The ODS are comprised of reflective strips covered in black paint, attached to cows using Ados F2 glue (Alawneh *et al.*, 2006). The strips are akin to tail paint in that riding behaviour removes the black paint to reveal the reflective strip underneath. Their trial involved a herd of 480 cows, split between a control group where oestrus was detected using tail paint and visual observation, and the camera system group. The ODS and camera system achieved a sensitivity and specificity of 85% and 99.6% respectively, in comparison with the control group score of 78% and 98%. Although our system has a higher sensitivity and comparable specificity, the Massey system was evaluated using pregnancy records and represents the accuracy of the "full" system. At the time of writing, pregnancy records were not available for our system.

The main difference between our system and the Massey University system is that the ODS require a subjective judgment. The amount of paint that is rubbed off when an animal is in oestrus will vary, unlike Kamars which provide a yes/no decision depending on whether the dye pack has burst. Both systems have provisions for missing patches. This is especially important because it is important to ensure that no heats are missed as a patch may be lifted off during vigorous riding activity.

Xu *et al.* (1998) published a study on the efficiency of the HeatWatch® system for oestrus detection, versus visual observation and tail paint. Their study showed that a specificity of 98.4% and sensitivity of 94.6% was achieved by visual observation and tail paint, whereas HeatWatch® achieved 91.7% and 100% respectively. A larger study of tail paint for oestrus detection showed a specificity of 99.7% and sensitivity of 94.7% (Macmillan & Curnow, 1977).

A recent study of pedometer and other activity meter heat detection systems has shown it is possible to obtain heat detection accuracy of 78% and higher, when additional variables such as milk yield are taken into account (Harris *et al.*, 2010). De Mol *et al.* (1997) reported a sensitivity of 95% and specificity of 94% using a similar set of explanatory variables as in Harris *et al.* (2010). However, in both cases the high number of false positives would make the system cumbersome to use in practice.

CONCLUSION

During the period of artificial insemination in the Spring of 2009, the camera-based recognition algorithm has proven to be accurate at detecting the status of Kamar heat patches. Our system managed a sensitivity of 98.8% and a specificity of 99.7%, when considering the algorithm alone. While there were some hardware and software issues identified that will need to be resolved in the future, our system still achieves an accuracy level that met our expectations. Problems with tail paint and camera alignment that resulted in images being excluded can be easily resolved using standard operating procedures in association with the automatic system.

Further investigation is required to determine the full system accuracy, including the accuracy of drafting and the pregnancy rate when using artificial insemination on detected heats. We are confident that our algorithm detects the status of a Kamar to a level that would be suitable to use in practice.

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