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A motion and image analysis method for automatic detection of estrus and mating behavior in cattle

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ABSTRACT

Estrus detection in cattle is very important for breeding management. The detection results help determine the optimum time for artificial insemination. The success of estrus detection not only increases conception rates but also raises milk production for the herd. The proposed image processing method to detect cows in heat from video is passive and therefore does not require devices to be attached to the cow's body. The observed scene is a commercial dairy farm, where Holstein cattle are reared in roofed cowsheds.

The proposed method is based on the inherent behavior of cows in heat which is characterized by a cow following another cow before mounting it for a short period of a few seconds. A region of interest was first determined around image locations where high levels of motion occurred across the video frames. Foreground segmentation then follows to partition the moving target object from the region of interest in each image frame. The following and mounting behaviors are identified based on the changes of moving object lengths. When an estrus event is declared, the detected event is recorded into the computer to be verified later. The detection system observed 20 cows in a cowshed from the top view. Over the period of 800 h (80 days at 10 h each day), only 0.33% of video frames detected were false positive indicating the system was reliable at detecting mating and estrus behavior from the video frames. Using the method the farmer is required to view the recorded video frames for approximately 2 min per day to confirm that the detection results are true estrus events. The proposed method is capable of real-time detection of mating and estrus behavior speeds with a processing rate of 35 fps.

1. Introduction

Image processing has been an important technique for a wide variety of applications in different industry sectors, such as defect inspection in manufacturing, surveillance in security industry, traffic control and monitoring in transportation. Surveillance is also important in agriculture. The existing agriculture applications of image processing are mostly based on the analysis of single (or still) images of the interested objects by their colors, textures, shapes or geometric features. This paper proposes a non-contact image processing method for detecting cattle mating behavior from video.

Image processing techniques have been applied to livestock farming management for weight estimation, lameness detection and identification. Arias et al. (2004) evaluated different segmentation methods to obtain the cow's contour, and extracted geometric features from the contour. A feedforward neural network is then used for weight estimation. Tscharke and Banhazi (2011) reviewed image segmentation and recognition methods that determine the weight of livestock. McCarthy et al. (2010) estimated weights of cattle based on body length and area of an isolated cow in the image. Ferdous et al. (2011) proposed an automatic weight estimation of pigs using image processing. It automatically selects frames from video streams with optimum animal posture for accurate weight estimation.

For lameness detection, the quality of cow's gait and posture was assessed by cow's hoof locations (Song et al., 2008), back posture (Poursaberi et al., 2010) and body movement patterns (Viazzi et al., 2013) from single still images. For cattle identification, Morio et al. (2003) recognized individual Holstein cows by their black-and-white marking patterns. Kim et al. (2005) recognized Holstein cattle by imaging body patterns. A neural network is trained to identify individual cows based on the downscaled body pattern images. Kim et al. (2004) also identified Japanese black cattle that do not have black-and-white markings on the bodies. They evaluated the cow's face image with a neural network.

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In cattle farming management, detecting the signs of estrus is very important for reproductive success of a herd as it can determine an optimum artificial insemination time and thus results in increased conception rates for the herd. The most observable sign of estrus is the female–female mounting behavior in a herd of dairy cows. The primary sign of estrus occurs when the female stands immobile and allows other cows to mount her. A cow in estrus may also try to mount other females not in heat. This gives the secondary behavioral sign of estrus (Yager et al., 2013). There are various commercially available devices used to detect estrus in the herd. A pressure switch that contains a dye can be affixed to a cow. If the cow is mounted, pressure on the device causes the dyes to mix and creates a visible color change. An electronic pressure-sensitive device can also be attached on the tailhead of a cow to record the number of occurrences that the cow is mounted. Tail painting or chalking is also commonly used. It covers the tailhead with bright colored paint or chalk. When the paint or chalk is rubbed off, it indicates the cow has been mounted. Dye, paint or chalk must be reapplied when it has been used for the cow. In order to automatically read color changes of the painting, Del Fresno et al. (2006) proposed a color image segmentation method to segment paintings from the lumbar area of cows. Geometric features, including area, dispersion, major- and minor-axis lengths, are extracted from the segmented region, and simple fuzzy logic rules are used for classification.

Electronic pedometers or acceleration sensors (Roelofs et al., 2005; MacKay et al., 2012) attached on cows' necks measure the amount of walking activity associated with estrus. Temperature sensors (Redden et al., 1993; Ipema et al., 2008) can measure a cow's core temperature, and the change of temperature is used to indicate estrus. The commercially available devices discussed above must physically attach to the cow. It may trigger false alarms when the attachment is smeared from the contact with the environment. Some of the indicators, such as temperature or movement, are indirectly associated with the sign of estrus. They may be affected by some other factors such as illness, and result in false readings. The sensing devices are also relatively expensive for dairy farmers.

For the cows reared in a cowshed with a limited space, it is very difficult to segment each individual cow in the herd from one single image. The dairy cows studied in this paper are Holsteins, which have distinct black and white markings on their bodies. The random black-and-white patches in a still image also make the extraction of a complete shape of each individual cow extremely difficult. As concluded in Van Hertem et al. (2013), the existing segmentation algorithms are not robust enough to extract the contour of a Holstein cow from dynamic backgrounds, where a group of cows present simultaneously in a natural barn environment.

In this paper, we propose a machine-vision based estrus detection system that does not require any attachment, such as dyes, paints or chalks, to the cattle. The system can free the dairy farmer from checking and replacing the attachment periodically. The proposed method aims at detecting the mating behavior in the cattle, where a cow will follow another cow for a few seconds, and then mounts the cow for a very short period of time. Motion detection in video sequences is first applied to identify the possible mating region in the current image frame. The blob analysis and morphological operations for the detected motion region in the current image are then used to detect the following and mounting behaviors based on the changes of moving object lengths in a video clip. The proposed method incorporates both motion analysis techniques in spatiotemporal videos and image analysis techniques in spatial images to identify the mating behavior in cattle.

This paper is organized as follows: Section 2 first describes the motion detection for extracting possible motion regions from a video clip. This section then presents foreground segmentation and blob analysis for determining the length of a moving object in individual continuous images. The decision rule for estrus detection is finally given. Section 3 presents the experimental results based on 80-day observations from a commercial cowshed. Section 4 concludes the paper.

2. Materials and methods

2.1. Subject and image acquisition

The observed scene of this study is a commercial dairy farm, where Holstein cows are reared in roofed cowsheds. In order to prevent the occlusion of cows in the sensed image, an IP dome camera (Q24 from MOBOTIX) was mounted straightly on the roof of the cowshed so that the behaviors of individual cows can be observed from the top view. The camera was located 4 meters above the ground, and the observed field was $6 \times 4\ m^2$ and contained about 20 cows. The original resolution of a captured image was 1280×960 pixels with a frame rate of 25 fps, and was downsized to 200×150 pixels for fast processing.

2.2. Image processing

The detection rule for cow mating events in video sequences is based on the inherent behavior of cows in estrus. A mating event first shows a cow follows tightly another cow for a few seconds. The "following" behavior yields a moving object with the length of approximately 2-cows in images. The length of the moving object in images will then be changed to roughly 1.5 cows while they are performing the "mounting" behavior. Therefore, a successful estrus detection in video sequences must show a majority of 2-cow length in 2 s (for following behavior), and then a majority of 1.5-cow length in the subsequent 2 s (for mounting behavior).

Fig. 1 shows a video sequence for a herd of cows in the cowshed, where (a)–(d) are the following behavior and (e)–(h) are the mounting behavior. The bounding box in the figure indicates the main moving region in each image frame. Note that the length of the bounding box is changed approximately from two cows in (a)–(d) for the moving object with "following" behavior to 1.5 cows in (e)–(h) for the moving object with "mounting" behavior. The mating behavior detection can now be simplified as finding the minimum bounding box of the moving target object in each image frame of a video sequence. If the length of the bounding box is approximately of 2-cows for 2 s (i.e. 50 frames for 25 fps) and then is changed roughly to 1.5 cows for another 2 s, a mating event is declared and recorded for further verification by the farm breeder. The following subsections describe the image processing details for determining the bounding box in each individual image frame of the video, and the decision rule for mating event detection based on the bounding box lengths.

2.2.1. Motion detection

Cow mating is extremely difficult to detect from one single still image. Since a cow in heat shows following and mounting behaviors, motion analysis is first applied to identify the regions of interest where high levels of motion occurred across the video frames. These locations are referred to as motion regions in this paper. To indicate the time–space information of motions, the spatiotemporal representation of a video is given by

$$E_t(x, y) = \delta_t(x, y) + E_{t-1}(x, y) \cdot \alpha \tag{1}$$

where $\delta_t(x, y) = \begin{cases} C_E, & \text{if } (x, y) \in \text{foreground} \\ 0, & \text{otherwise} \end{cases}$, C_E is an energy constant, and is assigned to each foreground pixel in the current image.