Computers and Electronics in Agriculture 148 (2018) 226–236

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Automatic lameness detection in dairy cattle based on leg swing analysis with an image processing technique

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ARTICLE INFO

Keywords:
Lameness detection
Locomotion score
Leg swing analysis
Computer vision

ABSTRACT

Lameness has become a frequent and serious problem for herd productivity and animal welfare in the dairy industry. As the most significant characteristic of lameness, gait characteristics have been used to estimate lameness by human experts. The objective of this study was to analyze leg swing using computer vision techniques and to develop an automatic and continuous system for scoring the locomotion of cows to detect and predict lameness with high accuracy and practicability. The focus was on quantifying the movement pattern of cows and demonstrating the possibility of classifying lameness using the features extracted from movement analysis. Side-view videos were recorded after the cows were milked. Cows were scored by an expert on a scale from 1 (sound) to 3 (severely lame). The data set included 621 videos from 98 cows. The motion curve was plotted by extracting the position of the moving leg by image processing, and the motion curve was analyzed to generate six features referring to the gait asymmetry, speed, tracking up, stance time, stride length, and tenderness. A box-plot of the features within 3 classes showed that the dataset was nearly linear and separable under the six features and that the cows had different lameness indicators in different lameness stages. The Decision Tree classifier was applied to the dataset, and 2-, 3-, and 10-fold cross validation was used to verify the performance of the algorithm. The accuracy of the classification was 90.18%, and the averages of sensitivity and specificity were 90.25% and 94.74%, respectively. This research demonstrates the feasibility of classifying dairy cow lameness based on the six motion features extracted by leg swing analysis.

1. Introduction

Lameness has become a frequent and serious problem for herd productivity and animal welfare in the dairy industry (Bruijnis et al., 2012). Clinical lameness has a significant impact on milk yield (Ouared et al., 2015) and reproductive performance (Morris et al., 2011). In dairy cattle, the main cause of lameness is claw lesions. Claw lesions can be divided into non-infectious (such as white line disease, sole ulcers, sole hemorrhage, interdigital hyperplasia) or infectious claw lesions (such as digital dermatitis, interdigital dermatitis, heel erosion, or foot rot) (Greenough, 2007). The weight-bearing ability and the mobility of lame cows is reduced because of pain in the uncomfortable hoof or joint (Singh et al., 1993), which prevents normal behaviors (Scott, 1989). Therefore, it is important and necessary to detect early lameness in cows.

Visual observation by the farmer based on locomotion scoring was a common method to diagnose lameness (Flower and Weary, 2009); however, this method is time- and labor-consuming. The visual locomotion scoring method uses qualitative parameters to evaluate the alterations in a cow's gait and posture (Thomsen et al., 2008). Moreover, cows are complex and individually different; as living organisms, they have time-variant dynamic systems (Berckmans, 2008). Furthermore, the anatomy and posture of cows affects most gait variables (Flower and Weary, 2009).

Therefore, gait variables should be calibrated on the basis of cow's characteristics to eliminate cow effects.

Several techniques have been used for automated gait analysis, including force platforms (Rajkondawar et al., 2002), electromyography (Keegan et al., 2003), accelerometer (Pastell et al., 2009), and kinematics modelling (Ceballos et al., 2004; Flower and Weary, 2006). The image processing technique, however, offers a cheap and non-contact method to obtain visual information. Agricam (Linköping, Sweden) has

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https://doi.org/10.1016/j.compag.2018.03.014
Received 11 November 2016; Received in revised form 29 December 2017; Accepted 11 March 2018

developed a Cattle Disease Diagnostics (CaDDi) system by using a pair of FLIR A310 thermal cameras to image the udders of the cows, after which the images can be analyzed to determine whether a cow has mastitis. DeLaval (Tumba, Sweden) developed a 3D camera-based automatic and consistent body condition scoring system. As the use of vision technology in the dairy industry has increased, it has shown great potential to classify lameness (Song et al., 2008). Song et al. (2008) extracted the hoof locations from images, and the average correlation coefficient was 94.8% compared with a manual reference. The study demonstrated the possibility of detecting lameness using image processing technology. Lameness characteristics including step overlap (Pluk et al., 2010), arc of back posture (Poursaberi et al., 2010), and body movement pattern (Viazzi et al., 2013) were designed to describe the body movement and detect lameness in recent studies.

Wadsworth et al. (2016) conducted a lameness expert opinion survey about gait scoring to determine which rank and weight should be given to 6 different gait factors. The results showed that the weights of general symmetry, tracking, spine curvature, head bobbing, speed, and abduction/adduction were 24.92%, 20.38%, 19.81%, 13.77% and 13.12%, respectively. Most the recent studies based on vision technology have focused on the spine arc and head bobbing, which only covers 33.58% of possible lameness information. Therefore, to improve the feasibility of vision technology in lameness detection, it is necessary to explore methods that measure symmetry, speed, tracking, and tenderness as supplements of the current studies. Meanwhile, symmetry can be clearly observed with leg swing (Scott, 1989), and the swing leg lameness is associated with disorder in the limb (Jackson and Cockcroft, 2002). In addition, because over half of the lameness indicators are related to walking performance (Van Nuffel et al., 2009), the analysis of cows' leg swing has the potential to determine lameness and score the locomotion.

Therefore, the objective of this study was to explore the possibility of extracting gait characteristics by analyzing leg swing using computer vision techniques and thereby develop an automatic and continuous system for lameness detection. First, image processing was explored for extracting the leg swing features. Second, lameness classification based on the leg swing features was studied, and the classification performance was verified against the expert score.

2. Materials and methods

2.1. Animals and housing

Video data were acquired at a commercial dairy farm located in Shaanxi, China. A group of Holstein Friesian cows was used for the experiment. The cows were housed in a free stall barn with 30 × 3 (rows) cubicles bedded with sand. The cows were in late lactation and aged from 3 to 5 years. Hoof trimming was conducted twice a year before and after the summer season (April and November). The cows were milked three times a day in a swing-over milking parlor with 6 milking claws, and the average yield is approximately 7000 kg/305d per cow. An alley connected the exit of the parlor to the free stall barn. The alley was only open after milking. The videos were captured after the second and third milking before sunset; therefore, every cow passed the camera once or twice a day. The videos were captured from the side view while the cows were passing through the alley. The width of the alley was 2 m with a solid concrete floor. The camera was placed on a feeding shed with at height of 1.8 m from the floor. The distance between the camera and cow was 35 m (Fig. 1). There was a water trough in the alley, which was 8 m away from the vision field. Between the camera and the cows was an open pasture area, and the videos were recorded before the cows entered that area (35 m × 35 m). The background of the videos was the wall of the milking parlor. The cow walked freely through the alley without operators.

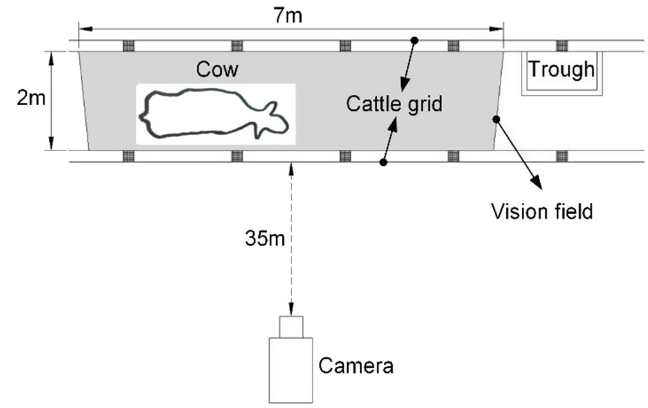

Fig. 1. Experimental setup.

2.2. Image acquisition

An integrated web camera (Hikvision Inc., Zhejiang, China) was used to record videos of the cows. The videos were acquired over a period of 8:00 h to 18:00 h on sunny days from July 9 through August 5, 2013. The orientation of the camera was perpendicular to the alley. By adjusting the focal distance of the camera, the width of the vision field was set to 7 m to ensure that the video contained 2 gait cycles. The frame rate and code rate were set to 25 fps and 2000 kbps, respectively. The resolution of the image was 704 pixels w × 576 pixels h. The acquisition of each video was manually controlled. It began once the whole cow appeared in the video and ended when the cow reached the end of the vision field. The cows were identified by manually reading their ear tags when the videos were captured.

To ensure each image had sufficient brightness for processing the algorithm, the videos were captured during the daytime on sunny days. Seven rainy days were avoided during video capture because the image became unclear when it was raining. Each video was checked manually, and 36 videos containing cows that stopped or slipped were discarded. The final dataset contained 621 videos from 98 different lactating Holstein cows. The number of measurements per day was approximately 31/d. Each cow was captured 6 times during the period on average. The videos were captured after the second milking and the third milking before sunset. Therefore, the videos were mainly from the second milking. The videos covered approximately 20% of the group every day, due to the cow overlapping, stopping, and abnormal behaviors. The dataset was used to analyze the results, discuss the distribution of features in classes, and evaluate the performance of the classifier.

2.3. Reference locomotion scoring method

A trained herd staff member evaluated the gait by watching the videos of the cows after the cows were captured and then recorded scores based on the presence of one or more of the lameness indicators, including irregular gait in time or place (Winckler and Willen, 2001), reduced tracking up (Flower and Weary, 2006), reduced speed (Manson and Leaver, 1988), tenderness (Manson and Leaver, 1988), increased abduction (Manson and Leaver, 1988), arced back and head bobbing (Breuer et al., 2000). The cows that did not show any of the lameness indicators were given a score of 1. The cows with one lameness indicator were scored 2. When cows had a severe lameness indicator or multiple lameness indicators, they were assigned a score of 3 (Van Nuffel et al., 2009). To test the repeatability of the observer, 64 videos (10% of the dataset) were randomly selected from the dataset, and each of them was scored twice. The kappa value of the scorer was calculated. The number of samples with scores of 1, 2, and 3 was 177, 282, and 162, respectively. During the experiment, 73% of the cows changed