Computers and Electronics in Agriculture 134 (2017) 124–134

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

Development of a threshold-based classifier for real-time recognition of cow feeding and standing behavioural activities from accelerometer data

C. Arcidiacono, S.M.C. Porto *, M. Mancino, G. Cascone

University of Catania, Department of Agriculture, Food and Environment (Di3A), Section: Building and Land Engineering, via S. Sofia n.100, 95123 Catania, Italy

ARTICLE INFO

Article history:
Received 7 November 2016
Received in revised form 16 January 2017
Accepted 23 January 2017
Available online 3 February 2017

Keywords:
Cow feeding activity
Cow standing activity
Precision livestock farming
Building for dairy farming
Thresholds
Sensors

ABSTRACT

Change in feeding behaviour is one of the indicators useful to help identifying when animals become ill. The need to analyse a large number of animals at a time due to the increase in the herd dimension in intensive farming has led to the use of automated systems. Among automated systems, inertial sensor-based systems have been utilised to distinguish behavioural patterns in livestock animals.

In this study, a new approach based on statistical analyses of accelerometer data, which were collected from wearable sensors fixed at the cow's collar, was defined and developed in order to define thresholds suitable for real-time classification of cow feeding and standing behavioural activity. The obtained classifier could be implemented within a software tool of a movement sensor-based system composed of low-cost devices. Accuracy of the classification was assessed by computing specific indicators: *Misclassification Rate*, *Sensitivity*, *Precision*, *Specificity*, *Quality Percentage*, *Branching Factor*, and *Miss Factor*. The results showed that the classifier produced the following values of the indicators: 5.56%, 93.33%, 95.45%, 95.56%, 89.36%, 0.05, and 0.07, respectively.

The proposed threshold-based classifier allows for monitoring individual cows automatically and continuously and it is suitable for Real Time Computing Applications, since it does not require high computational time and resources.

1. Introduction

According to one of the principles of animal welfare, "good feeding" improves animal comfort and well-being and indicates whether a management system is well designed or not (Burow et al., 2011; Grant and Albright, 2000; Praks et al., 2011; Executive Agency for Health and Consumers, 2013). Since changes in feeding behavioural activity are increasingly recognised as a useful indicator of cow's health and welfare, the monitoring of changes in feeding activity may be useful in early detection and prevention of diseases.

The observation of feeding behaviour of animals is usually carried out directly by operators within the breeding environment or by the visual analysis of images acquired from video-recording systems. Since these two monitoring systems are usually costly and time consuming when they are not automated (Abdanan Mehdizadeh et al., 2015; Berckmans, 2004), other kinds of systems such as those based on radio frequency identification (RFID) technology have been proposed in the last decades. It utilises transponder tags that identify each animal individually and localise it during the feeding activity (e.g., during the visit at the feeding alley). Among automated systems based on RFID technology, a higher accuracy is achieved by those based on ultra-wide band (UWB) technology compared to those based on high frequency (HF) and ultra-high frequency (UHF) technologies (Frondelius et al., 2015; Ipema et al., 2013; Porto et al., 2014, 2013, 2012; Schwartzkopf-Genswein et al., 1999; Tullo et al., 2016). The main disadvantages of the application of these systems are their high cost, which is not always sustainable for farmers, as well as the complex setting up in relation to the layout and building characteristics of the barn.

Feeding behaviour is studied also during the animal outdoor activities by using Global Positioning Systems (GPSs) that enable continuous and automatic tracking of an animal's position (Ungar et al., 2005) and an accurate recognition of cow's activities (Godsk and Kjærgaard, 2015). However, GPSs are not easily applicable for the indoor analysis of feeding behaviour due to signal weakening.

Recently, other monitoring systems based on wearable sensors are being utilised more and more widely due to their low cost and easy integration with other ICT devices (e.g., computers and wireless networks) (Arcidiacono et al., 2017). Wearable sensors are suitable for detecting events related to animals (e.g., change in

* Corresponding author.
E-mail address: siporto@unict.it (S.M.C. Porto).

http://dx.doi.org/10.1016/j.compag.2017.01.021
0168-1699/

acceleration, change in angular velocity, and change in sound waves or pressure due to chewing activity) or changes in the microclimate of the animal occupied zone (e.g., air temperature and relative humidity, and atmospheric pressure).

With regard to the analysis of feeding behaviour of dairy cows, the most used wearable sensors are pressure sensors and accelerometers.

With reference to pressure sensors, in two experimental tests that were carried out by Ruuska et al. (2015) dairy cows were equipped with a RumiWatch noseband sensor. The data acquired by the sensor were compared with those obtained by two other monitoring systems, i.e., a system for continuous recording of cow's behaviours (Experimental test 1) and a system suitable for the control of the visits to the automated feeders (Experimental test 2). In these tests the output of the RumiWatch algorithm was assessed, however no information was provided about its features. Moreover, since the pressure sensor was placed in the noseband of the halter, the system was more invasive than other wearable sensors.

Martiskainen et al. (2009) carried out data acquisition from an accelerometer fixed to the collar of 30 cows in order to classify their behavioural activities by using a Support Vector Machine (SVM). However, the use of the SVM requires a training phase to reach a high level of accuracy in behaviour recognition.

In a later study, other researchers (Ueda et al., 2011) utilised a uniaxial accelerometer, named Kenz Lifecorder Ex (LCEX; Suzuken Co. Ltd., Nagoya, Japan), which was fixed to the collar of 8 Holstein dairy cows in a grazing production system. The feeding behavioural activity was studied by using the intensity of the movement recorded by the device in order to determine the eating time (min/d) that is one of the factors, together with biting rate (bite/min) and bite mass (g of DM/bite), utilised to compute DMI (Dry Matter Intake). In a recent study, Delagarde and Lamberton (2015) assessed the Plus version of the Lifecorder device by fixing it to the collar of six cows in order to measure the following activities: grazing, ruminating and so-called 'other activities', i.e., drinking, walking without biting or searching, resting, and social interaction. However, no information was provided about the features of the algorithm and no accelerometer data were available in both studies (Delagarde and Lamberton, 2015; Ueda et al., 2011).

Oudshoorn et al. (2013) reported the accelerometer data related to cow's feeding behavioural activity. An accelerometer device combined with bite count was proposed to evaluate the grass intake of dairy cow at pasture. Acceleration threshold values during feeding activity were defined. However, these outcomes were related to grazing cows, which show different postures during feeding activity compared to cows bred inside a barn.

According to several researchers, in the near future accelerometers are the most 'promising' sensors among the devices studied in the literature because they are commercially available and low-cost products. However, there is still work to be done in this field in order to design models and systems that are suitable for discriminating all the animal's behavioural activities with a good accuracy (Berckmans, 2004).

Accelerometer-based monitoring systems that utilise acceleration threshold values to study feeding behaviour are valuable because they have several advantages. Among them, they do not require a training phase as for SVM-based systems, they are not invasive for the animal if the sensor is applied to the collar and, finally, once the thresholds values are determined the computational cost of the classifier for automated monitoring is lower. Until now, acceleration threshold values during the feeding activity have been defined only for grazing cows (Oudshoorn et al., 2013).

On this basis, the main objective of this research study was to develop a method based on statistical analyses of accelerometer data in order to define thresholds suitable for the discrimination of cow's feeding activity from standing in a free-stall barn. Moreover, the proposed method utilised data acquired by an inertial sensor-based system composed of low-cost devices, with a 4 Hz sampling rate and it did not require high computational time and resources in order to be suitable for utilisation in RTC (Real-Time Computing).

2. Materials and methods

2.1. The system components of the data acquisition system

The system hardware was composed of five Bluetooth Low Energy (BLE) *SensorTags* (Texas Instruments, USA) and a single-board computer *Raspberry Pi* (Raspberry Pi Foundation, UK) equipped with a 8 GByte SDHC card, a USB-BLE adaptor, a USB-Wi-Fi adaptor, and a USB power supply, which was utilised as data acquisition unit. In this study, the tri-axial accelerometer (Kionix KXTJ9) with a range of ±8 g and a sample rate of 4 Hz, which is one of the sensors included in the SensorTags, was used for data measurement.

The system software included both a freeware and a specifically developed software tool. In detail, the Raspbian operating system and Python v2.7.6 development environment were installed on the SD memory of the Raspberry Pi. A Python script, which utilises the BLUEZ v5.4 libraries and the Pexpect v3.3 module, was specifically developed to manage the BLE connections with the sensors and the storage of the related accelerometer data in text files (.csv format), on the SD card. Moreover, for each SensorTag the developed Python script registered the disconnection and reconnection events between the Raspberry Pi and the SensorTags in a log file saved in the memory card of the Raspberry Pi and kept updated the list of temporary disconnected devices. During a disconnection event, instead, accelerometer data was stored neither in the SensorTag nor in the Raspberry Pi.

The validation system was a video-recording system composed of 10 video cameras and a computer, both connected to two switches by Ethernet cables. A unique panoramic image of the area of interest with a 1280 × 1960-pixel resolution was generated by a specific software from the snapshots acquired by this system (Porto et al., 2015). Finally, the results acquired by the movement sensor-based system were compared with those obtained from the visual analyses of the cow's behaviour performed on the panoramic images by a skilled operator.

2.2. The experimental tests

The field experiments were carried out during June 2015 in a free-stall barn for dairy cows located in Sicily. In this study, the central pen of the barn, which housed a group of 14 primiparous cows, was selected.

Based on the daily time budget usually spent by a dairy cow in a free-stall barn (Grant and Albright, 2000), the data acquisition system was operated for 5 h during the time intervals when cows were in standing or feeding (Porto et al., 2017), i.e., between 13:00 and 18:00.

The SensorTags were shielded prior to be installed on the animals by providing a water-proof protection, which was composed of a bubble wrap and a water-resistant plastic bag. The protected tag was inserted into a plastic case equipped with a Velcro closure, a belt loop, and an adhesive label, which contained the identification code of the SensorTag.

Five cows of the study group were selected for the experiment and a plastic case, which contained the activated SensorTag, was fixed to the collar of each cow through the belt loop (Fig. 1),