Computers and Electronics in Agriculture 154 (2018) 112–119

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

The effect of different time epoch settings on the classification of sheep behaviour using tri-axial accelerometry

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ARTICLE INFO

Keywords:
Feeding behaviour
Accelerometer
Wireless communication technology
Discriminant analysis

ABSTRACT

Monitoring behaviour of grazing animals is important for the management of grazing systems. A study was run to discriminate between the main behaviours (grazing, ruminating and other activities) of sheep at pasture wearing a halter equipped with an accelerometer (BEHARUM device), and to identify the epoch setting (5, 10, 30, 60, 120, 180 and 300 s) with the best performance. The BEHARUM device includes a three-axial accelerometer sensor and a force sensor positioned under the lower jaw of the animal. The halter was fitted to eight Sarda dairy sheep that rotationally grazed either a spatial association (mixture) or a time association of berseem clover (*Trifolium alexandrinum* L.) and Italian ryegrass (*Lolium multiflorum* Lam.) for 6 h day^{-1}. The behaviour of the animals was also video-recorded. The raw acceleration and force data were processed for each epoch setting to create 15 variables: the mean, variance and inverse coefficient of variation (ICV; mean/standard deviation) per minute for the X-, Y-, Z-axis and force, and the resultant. Multivariate statistical techniques were used to discriminate between the three behavioural activities: canonical discriminant analysis (CDA), and discriminant analysis (DA). To validate the derived discriminant functions, a bootstrap procedure was run. To evaluate the performance of DA in discriminating between the three activities, the sensitivity, specificity, precision, accuracy and Coehn's k coefficient were calculated, based on the error distribution in assignment. Results show that a discriminant analysis can accurately classify important behaviours such as grazing, ruminating and other activities in sheep at pasture. The prediction model has demonstrated a better performance in classifying grazing behaviour than ruminating and other activities for all epochs. The 30 s epoch length yielded the most accurate classification in terms of accuracy and Coehn's k coefficient. Nevertheless, 60 and 120 s may increase the potential recording time without causing serious lack of accuracy.

1. Introduction

Monitoring the behaviour of grazing ruminants is important to understand how animals meet their requirements in pastoral systems and to achieve optimal plant production, animal forage intake and performances (Carvalho, 2013). Since observing animal behaviour is a labour-intensive and difficult task, whether it is performed with direct observations or through video recordings, most research has concentrated on recognizing feeding behaviour of ruminants from animal attached sensors. A type of sensor that has recently become widespread in research studies is the tri-axial accelerometer, since it is small, inexpensive, and easy to wear (Brown et al., 2013).

Accelerometers have been widely used to automatically detect and classify several behaviours in cattle, e.g. *oestrus* detection (Ueda et al., 2011), walking (Robert et al., 2009) feeding and standing activities in a free-stall barn (Arcidiacono et al., 2017), sleeping posture (Fukasawa et al., 2018) and time (Hokkanen et al., 2011), and eating, ruminating and resting activities (Watanabe et al., 2008).

Fewer research studies have been conducted to classify sheep behaviours than cattle behaviours. Umstätter et al. (2008) used integrated pitch and roll tilt sensors, and found that they could distinguish between two categories: active and inactive, with more than 90%

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https://doi.org/10.1016/j.compag.2018.09.002
Received 24 February 2018; Received in revised form 3 July 2018; Accepted 4 September 2018

accuracy. Other studies on sheep behaviour used the collar attached Actiwatch accelerometer system for classifying activity levels and detecting diurnal rhythms (Piccione et al., 2010; 2011). Other authors (Nadimi et al., 2012; Nadimi and Søgaard, 2009) used the ADXL202 accelerometer to detect grazing, lying down, standing, walking, mating and drinking in sheep with a mean accuracy of 76.2%. Alvarenga et al. (2016) successfully identified grazing and non-grazing states, with accuracies higher than 83%, in grazing sheep wearing an accelerometer under the lower jaw. More recently Giovanetti et al. (2017a), positioning a device containing an ADXL335 accelerometer sensor in the same place, were able to classify grazing, ruminating and resting behaviour of sheep at pasture with an overall accuracy of 93%.

Tri-axial accelerometer based devices can acquire and store information internally, thus consuming very little battery power. However, the amount of data that can collected is limited by the size of the memory card within the device. On the other hand, data can be directly transmitted to a central receiver for subsequent processing. This practice, however, requires a high power consumption (Vázquez Diosdado et al., 2015).

The sampling frequency of such devices usually ranges from 8 to 100 Hz, thus producing an enormous quantity of data, proportional to the sampling frequency, which can lead to a rapid depletion of the memory device and to high costs in terms of battery consumption caused by sending and receiving large data sets. These restrictions could be overcome by undertaking some form of preliminary processing of the accelerometer data on the device itself settling and applying to the data stream, for a given sampling frequency, an optimal aggregation window (called epoch).

Optimizing the epoch setting, without compromising classification accuracy, could imply a number of advantages. Short epoch settings could increase the labour involved in processing data, deplete the memory device, decrease the battery duration and may also cause erroneous attribution activities during processing. Actually, if an epoch shorter than the period of time an activity occurs is used, the number of false positive classifications for dynamic activities could increase probably due to transitioning between different activities or body shifts during static activities (Robert et al., 2009). Conversely, optimized longer epoch settings might reduce the memory depletion and increase the battery duration without compromising the performance of the sensor. Nielsen (2013) distinguished grazing from non-grazing behaviour with a 3D activity sensor that correctly classified the behaviours of dairy cows with a relatively high accuracy when the epoch was set at 5 s, 5 or 10 min. Other authors, as Vázquez Diosdado et al. (2015), while classifying lying, standing and feeding behaviours in dairy cows, reported a small increase in the decision-tree classification algorithm performance at the largest window size of 10 min if compared with 1 and 5 min epoch settings. In the present research, a customized tri-axial accelerometer based sensor, able to either store data in a micro SD card or send them to a remote computer, was used. In the future perspective of data pre-processing in the device itself, determining the optimum device settings before field application is crucial, because they could impact on monitoring system accuracy as well as on the effective battery and memory life.

The objectives of this study were: (1) to develop an algorithm based on the multivariate statistical analysis to discriminate the main behaviours (grazing, ruminating and other activities) of sheep at pasture equipped with a customized tri-axial accelerometer based sensor named BEHARUM; (2) to determine the performance of the algorithm in terms of accuracy, sensitivity, specificity, precision and Coehn's k coefficient, at different epoch settings (5, 10, 30, 60, 120, 180 and 300 s); and (3) to select the epoch that optimizes the system accuracy of the device.

2. Materials and methods

2.1. Experimental site and animal management

The study was conducted at Bonassai experimental farm of the agricultural research agency of Sardinia (AGRIS Sardegna), located in the NW of Sardinia, Italy (40° 40′ 16.215″ N, 8° 22′ 0.392″ E, 32 m a.s.l).

The animal protocol below described was in compliance with the EU regulation on animal welfare and all measurements were taken by personnel previously trained and authorized by the institutional authorities managing ethical issues both at Agris Sardegna and the University of Sassari.

The study is part of an experiment conducted in spring 2016, from 1 March to 9 May, with 48 mature lactating Sarda dairy sheep that rotationally grazed berseem clover (*Trifolium alexandrinum* L.) and Italian ryegrass (*Lolium multiflorum* Lam.) for 6 h day^{-1}. Two grazing treatments were used: a mixture of berseem clover and Italian ryegrass, and two monocultures (berseem clover and ryegrass) grazed in succession. In the latter case, the sheep grazed the first 3 h on the clover and the last 3 h on the ryegrass. The ewes were machine milked twice daily at 0700 h and 1500 h. During milkings, they were individually fed in the milking parlour with commercial concentrate (500 g ewe^{-1} day) split into two meals. In the remaining daytime, the animals were kept indoors and group-fed 500 g ewe^{-1} of ryegrass hay and 300 g ewe^{-1} of alfalfa hay in separate troughs. On four occasions (test days) during the experiment, eight ewes (four per treatment), with an age of 3.1 ± 1.6 years (mean ± standard deviation), live weight of 41.3 ± 2.8 kg, lactation stage of 73 ± 6 days in milk and milk yield of 2062 ± 362 g ewe^{-1} day^{-1}, were used. On each test day, after the morning milking, the ewes were carried on a trailer to the experimental plots and equipped with the BEHARUM device before the six hours of access to pasture. At the end of the grazing session, the BEHARUM devices were removed from the animals.

2.2. Description of the BEHARUM device and feeding behaviour recording

The BEHARUM device includes a halter equipped with a three-axial accelerometer sensor and a force sensor positioned under the lower jaw of the animal. Animal head and jaw movements are detected through accelerations measured in the X (longitudinal), Y (horizontal) and Z (vertical) axes (Fig. 1) and force exerted by the opening jaw.

The sensors, inserted in a micro-electromechanical compact system (MEMS) with on-board peripherals, sample raw accelerations and force at a frequency of 62.5 Hz, and convert them, through an analogue-to-digital converter with a resolution of 8 bits, in digital levels ranging from 0 to 255. Then the microcontroller selects three converted values per second per axis (Giovanetti et al., 2017a) and force sensor. The converted data could be sent (LoRa wireless system) to a nearby computer receiver equipped with an antenna or to a remote computer through a local server using the GSM services, as well as recorded in a micro secure digital (SD) card inserted in the MEMS.

A software package (DAS Client, Electronic System), installed on the computer, activates or deactivates the BEHARUM device and manages data acquisition. In this experiment, we adopted the recording of acceleration and force data on micro SD card.

On each test day through the 6 h of access to pasture, the feeding behaviour of sheep equipped with the BEHARUM were video recorded, one at time, during accelerometer deployment by fixed camera (Sanyo Xacti VPC-TH1, Sanyo Electric Co., Ltd. OSAKA, Japan). Video recordings of each animal lasted 20–25 min. The internal clock of the camera was synchronised with the internal clock of the computer. This ensured both the camera and accelerometer were synchronized in time to allow accurate annotation of the accelerometer data after behavioural recordings were made.