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Comparison of grazing behaviour of sheep on pasture with different sward surface heights using an inertial measurement unit sensor

Leifeng Guo[a,*], Mitchell Welch[b,d], Robin Dobos[c,d], Paul Kwan[b], Wensheng Wang[a]

[a] Agriculture Information Institute, Chinese Academy of Agriculture Science, Beijing 100086 China
[b] School of Science & Technology, University of New England, Armidale, NSW 2351 Australia
[c] NSW Department of Primary Industries, Livestock Industries Centre, University of New England, Armidale NSW 2351 Australia
[d] Precision Agriculture Research Group, University of New England, Armidale NSW 2351 Australia

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ABSTRACT

Grazing is the most important activity that ruminant livestock undertake daily. A number of studies have used motion sensors to study the grazing behaviour of ruminant livestock. However, few have attempted to validate their approaches against various sward surface heights (SSH). The objectives of our study were to: (1) identify and compare the effects of different SSH on the grazing behaviour of sheep by analyzing data collected by a collar mounted Inertial Measurement Unit (IMU) sensor; (2) calculate the relative importance of the extracted features on grazing identification and compare the consistency of the selected features across various SSH; (3) validate the robustness by using classifiers trained from the dataset with specific SSH to distinguish the grazing activity on the datasets from different SSH; and (4) visualize the classification results of grazing versus non-grazing activities on various SSH. Linear Discriminant Analysis (LDA) was chosen as the classification method, while Probabilistic Principal Component Analysis (PPCA) was used to reduce dimensionality of the feature space for visualization of the results. Experimental results revealed that (1) our approach achieved high classification accuracy of grazing behaviour (over 95%) on all the epochs regardless of SSH; (2) Mean of accelerometer *Z*-axis, Entropy of accelerometer Y-axis, Entropy of accelerometer *Z*-axis, Mean of gyroscope X-axis and Mean of gyroscope Y-axis were the top 5 features that contributed most in classifying the grazing versus non-grazing activities and there were consistent trends in features across the three SSH; (3) there was enough robustness when the trained LDA classifier on a specific SSH was used to classify behaviour on different SSH; and (4) there existed a clear linear boundary between the data points representing grazing and those of non-grazing behaviour. Overall, our research confirmed that IMU sensors can be a very effective tool for identifying the grazing behaviour of sheep and there is enough robustness to use a trained LDA classifier on a specific pasture SSH to classify grazing behaviour at different SSH pastures.

1. Introduction

Grazing is the most important daily activity that ruminant livestock undertake. The ability to detect and understand the grazing patterns of free-ranging livestock is critical for monitoring the weight gain of individual animals, managing available biomass within the landscape (Delagarde and Lamberton, 2015) (Ueda et al., 2011). Oudshoorn et al. (2013) investigated the use of accelerometer sensor to estimate grazing time which was further combined with bite frequency data to model grass intake. The pasture grazed by ruminants can vary widely in height, density and chemical composition. Experiments conducted on cattle by Chacon et al., (1978) showed that the sward characteristics, such as pasture height and herbage per-unit of height, could influence grazing behaviour. In particular, it was demonstrated that the average bite size varied according to the sward characteristics.

Because of the nature of grazing systems, the continuous observation of animal behaviour is labor intensive and time consuming. Even with the assistance of video surveillance equipment, in most situations the manual approach is simply not feasible. A number of attempts have been made to design an automatic system for detecting and recording the grazing behaviour. A resistive noseband sensor that detected the jaw movement related to grazing was designed by Penning (1983). The noseband was placed around the jaws of an animal and a voltage was applied to it, a change in voltage occurred proportional to the movement of the jaw. A miniature, four-channel cassette recorder was used to record the signal changes. The recordings were analyzed by a

* Corresponding author.
E-mail address: guoleifeng@caas.cn (L. Guo).

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microcomputer to determine the activities of either grazing or ruminating. Since then, a number of alternative grazing behaviour recording systems (Penning et al., 1984; Matsui and Okubo 1991; Rutter et al., 1997) have been developed based on the sensor similar to that described by Penning (1983). However, less accuracy estimation, extremely complex placement, and high rate of data loss largely limited its further development and application.

In recent years, the introduction of small, energy efficient, micro-electro-mechanical systems (MEMS) inertial sensors to the market has enabled researchers to develop automated tools that have more practical form-factors that can monitor animal behaviours for long periods. A tri-axial accelerometer to register the animals' acceleration and changes in head inclination to distinguish between resting, eating and walking on undulating pasture in Central Germany and on a rugged mountainous pasture in northern Oman was used by Moreau et al. (2009). The true recognition of activities detected by the corresponding analysis ranged from 87% to 93% for eating, 68% to 90% for resting and 20% to 92% for walking. The use of a tri-axial activity logger to distinguish grazing behaviour from non-grazing behaviour in dairy cows was validated by Nielsen (2013). Sensitivities of 83.6% and 85.5%, specificities of 79.9% and 82.1% and precisions of 74.6 and 77.6% were obtained by using the 3D activity sensor for 5 s and 5 min respectively. GPS and activity sensor data were collected periodically (Augustine and Derner, 2013) and integrated with direct observations of collared cattle grazing on semiarid rangeland in eastern Colorado to discriminate between grazing and non-grazing behaviours. A binary classification tree was used to correctly remove 86.5% of the non-grazing locations, while correctly retaining 87.8% of the locations where the animal was grazing.

Most research surrounding the automatic monitoring of livestock behaviour has been on cattle (Yoshitoshi et al., 2013) and more specifically within the dairy industry. There are currently a number of commercial systems available, such as the MooMonitor (MooMonitor, 2017) and the SCR Dairy system (SCR Dairy, 2017). They provide functionality that includes grazing and rumination monitoring. However, to our knowledge, no commercial systems are available that are designed for monitoring the grazing behaviour and the welfare of sheep. Related research has found that there are significant differences in grazing behaviour between sheep and cattle in terms of movements that can be sensed by inertial sensors. Similar wave-forms from the accelerometer outputs in sheep and cattle during grazing were reported by Chambers et al. (1981), but they found higher variability in the peak acceleration values in the waveforms produced by devices on sheep.

The objective of this current study was to identify and compare the effect of different sward surface heights (SSH) on the accuracy of the detection of grazing behaviour of sheep through the use of data collected from a collar mounted IMU sensor. To achieve this, the following three steps were carried out in succession, including (1) identify relevant signals in the raw accelerometer and gyroscope data and extract the discriminative features from the signals; (2) discriminate grazing from non-grazing activities at different SSH by applying linear discriminant analysis (LDA) classification on the extracted features; (3) compare the accuracy of classifying grazing activities under pasture with short, medium and tall SSH; (4) apply trained LDA classifier from a specific SSH to the other dataset from a different SSH to validate the robustness; and (5) visualize the linear classification of LDA by dimensionality reduction from PPCA.

2. Materials and methods

2.1. Hardware

A sparkfun Razor development board was used to collect the IMU data. The board includes a programmable 32-bit ARM Cortex-M0 microcontroller (running at 48 MHz) coupled with an invensense MPU-9250 9 degrees-of-freedom IMU that provides a three-axis accelerometer, a three-axis gyroscope and a three-axis magnetometer. The development board also provides a secure-digital card module for data storage. The development board was powered using a 1200 mAh lithium-polymer battery. The IMU was programmed to sample data at a rate of 20 Hz with an acceleration range of 2 g. Readings were sampled using signed 16-bit integers, providing a resolution of 16,384 readings per g. The microcontrollers' in-built real-time clock was used to generate timestamps for each reading. This clock was synchronized to the video cameras to ensure that the IMU signal could be matched to the video recording. The ARM Cortex-M0 microcontroller was chosen as the platform because of its low power consumption, high speed and its capability to run algorithms on-board while collecting data at a high sampling rate. This will be useful for future work where classification algorithms will be deployed to the device in addition to wireless transmission hardware to constant live monitoring.

2.2. Experimental site, animals and management

This experiment was conducted on plots of ryegrass (*Lolium perenne*) near the University of New England in the northern tablelands region of New South Wales, Australia (−30.5, 151.6). A set of three plots were prepared by mowing to different SSH of 2–3 cm (short), 5–6 cm (medium) and 8–10 cm (tall), respectively. Each plot had an area of 72 m^2 (48 m long × 1.5 m wide) and an automatic water trough at one end that was freely accessible by the animals. This study was approved by the University of New England Animal Ethics Committee and followed the University of New England code of conduct for research in meeting the Australian Code of Practice for the Care and Use of animals (AEC17-006).

Three Merino lambs weighing approximately 35 kg were used. They were marked with green, yellow and pink livestock marking paint to be easily identified from video recordings. The sheep were run as one group and allocated to each plot on 16th (short SSH), 17th (medium SSH) and 19th (tall SSH) May 2017, respectively. Behaviours were recorded by a fixed camera positioned at the end of the plot being grazed. The video recordings were stored on an exchangeable SD memory card that provided four hours of recording time. Sheep entered the plots at 0800 h each day and the memory cards were changed at noon of each day to ensure maximum coverage of the surveillance. The IMU sensor was placed into a polycarbonate plastic enclosure and mounted on the neck of the sheep using a polyurethane strap. The collar was chosen as the method for mounting the sensor/logger package as it provided the greatest flexibility for future prototyping. Each IMU was mounted so that the *X*-axis corresponded to the vertical direction, the *Y*-axis corresponded to the horizontal direction, and the Z-axis corresponded to the forward direction (see Fig. 1). Data were downloaded from the IMU

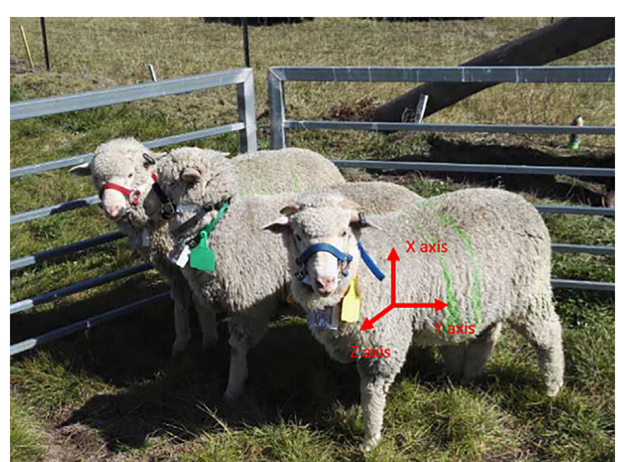

Fig. 1. Location of IMU sensor and its orientation on sheep.