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Classification of sheep urination events using accelerometers to aid improved measurements of livestock contributions to nitrous oxide emissions

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ABSTRACT

Livestock emissions account for 74% of nitrous oxide contributions to greenhouse gases in the UK. However, it remains uncertain how much is directly attributable to localised sheep urination events, which could generate nitrous oxide emission 'hot spots'. Currently, IPCC emission factors are mainly extrapolated from lowland grazing systems and do not incorporate temporal or spatial factors related to sheep behaviour and movement. Being able to gather data that reliably measures when, where, and how much sheep urinate is necessary for accurate calculations and, to inform best management practices for reducing greenhouse gas emissions and minimizing emission-based climate change.

Animal-attached movement sensors have been shown to be effective in classifying different behaviours, albeit with varying classification accuracy depending on behaviour types. Previous studies have used accelerometers on cattle and sheep to assess active and non-active behaviours to help with grazing management, although no study has yet attempted to identify sheep urination events using this method.

We attached tri-axial accelerometer sensor tags to thirty Welsh Mountain ewes for thirty days to assess if we could identify urination events. We used random forest models using different sliding mean windows to classify behaviours. Urination had a distinctive pattern and could be identified from accelerometer data, with a 5 s window providing the best recall and a 10 s window giving the best precision. 'State' behaviours considered (foraging, walking, running, standing and lying down) were also identified with high recall and precision. This demonstrates the extent to which the identification of discrete 'event' behaviours may be sensitive to the window size used to calculate the summary statistics. The method shows promise for identifying urination in sheep and other livestock, being minimally invasive compared to other methods, and has clear potential to inform agricultural management practices and policies.

1. Introduction

Agriculture contributes to 10% of the total greenhouse gas emissions in the UK, with 74% arising from nitrous oxide (N_2O) and 51% from methane emissions (DEFRA, 2016). The latter is largely due to enteric fermentation by cattle and sheep (DEFRA, 2016), but N_2O is principally generated in the soil via nitrification and subsequent denitrification. Urine from livestock contains high concentrations of urea which can be hydrolysed in the soil to ammonium and subsequently nitrified. This means that urine patches can act as 'hot spots' for N_2O emissions (Hoogendoorn et al., 2016; Marsden, Jones & Chadwick, 2016). There are uncertainties regarding the estimates of direct N_2O emission levels from urine and dung deposited by livestock, particularly from sheep and extensively grazed systems. Emission factors are currently extrapolated from cattle studies conducted in intensively managed systems (UNFCCC, 2016). The uncertainties surrounding N_2O emissions are also higher because precise measurements that incorporate spatial and temporal factors, along with animal behaviour

Abbreviations: VeDBA, vectorial dynamic body acceleration; VeDBAs, smoothed vectorial dynamic body acceleration; PSD, power spectrum density; StX, StY, StZ, static acceleration on the X, Y, and Z axes; DyX, DyY, DyZ, dynamic acceleration on the X, Y and Z axes; TP, true positives; TN, true negatives; FP, false positives; FN, false negatives

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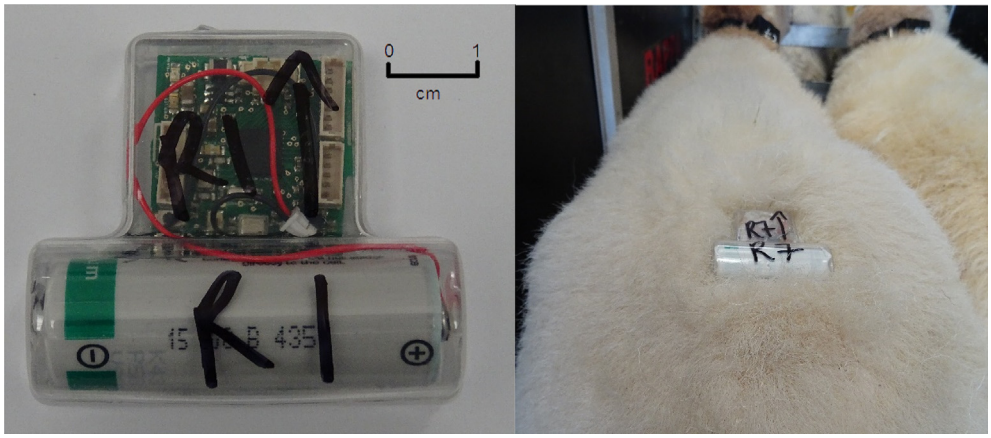

Fig. 1. Rear tag consisting of a Daily Diary and an A cell battery and a tag in position on the rear of the sheep.

and movement, are lacking (DEFRA, 2016). Being able to monitor when livestock urinate and understand any behavioural patterns that elucidate where and how often they urinate would help to reduce this uncertainty. Combining such data with other experimental studies to measure direct N_2O emissions released from soil due to urination in relation to edaphic factors, would enable more accurate calculations and better understanding of its contribution to climate change.

Previous studies have utilised thermistors in conjunction with GPS to determine the spatial distribution of urination events (Betteridge et al., 2010). These have been modified to include a measure of urine volume and nitrogen content via refractive index (Betteridge et al., 2013; Misselbrook et al., 2016; Shepherd et al., 2016). Flow meters in combination with data loggers have also been used to record cattle urine frequency and volume (Ravera et al., 2015), but all these methods are quite invasive. The use of tri-axial accelerometers attached to a range of animals has proven to be a powerful method for determining animal behaviour (Shepard et al., 2008; Nathan et al., 2012; McClune et al., 2014), although they have not yet been used to specifically detect urination events.

Methods used for analysing accelerometer data vary in terms of variables used to classify behaviours and the precise way the data are processed. Approaches used include template-matching (Walker et al., 2015) and various clustering approaches (Sakamoto et al., 2009; Nathan et al., 2012), with accuracy depending on circumstance. In many clustering methods, the size of window used to summarise the data plays an important role in the accuracy with which the data can be classified (Gjoreski, Gams & Chorbev, 2010; McClune et al., 2014). For example, Lush et al. (2015) used a 5 s window to classify brown hare (*Lepus europaeus*) behaviour resulting in high levels of classification accuracy for running, feeding and vigilance behaviours (> 90%), but less than 50% accuracy for resting, scratching and grooming. Similarly, McClune et al. (2014) used a 2 s window to analyse badger (*Meles meles*) behaviour and classified resting with nearly 100% accuracy, but trotting, walking and snuffling was between 75 and 80% accuracy, while Wang et al. (2015) also used a 2 s window to classify puma (*Puma concolor*) behaviour and achieved greater than 90% classification accuracy for resting, walking, running and trotting, while feeding was 64% and grooming was 0%.

The variation in classification accuracies stem, in part, from the length of time over which a behaviour is expected to occur (Robert et al., 2009). Behaviours, such as running, walking, feeding and resting that tend to occur over extended periods of minutes or longer and regarded as 'state' behaviours (Martin & Bateson, 1993), which facilitates their classification. In contrast, the short duration of many 'event' behaviours (Martin & Bateson, 1993), such as urination, makes them particularly sensitive to the window length used in the analysis (Robert et al., 2009; Alvarenga et al., 2015).

In this study, we used tri-axial accelerometers on Welsh Mountain ewes and then employed random forest models on the data using different sliding mean windows to assess if we could identify urination events. Accelerometers have been used previously on cattle and sheep to define active and non-active behaviours such as standing, lying down, feeding, walking and running using 3, 5, and 10 s windows (Martiskainen et al., 2009; Robert et al., 2009; Marais et al., 2014; Alvarenga et al., 2015). However, this is the first study to attempt to use this approach to determine sheep urination events. Ewes exhibit a characteristic squat when they urinate, hence we hypothesised that a rear-mounted tri-axial accelerometer could reliably identify this behaviour. If successful it would provide a methodology that could improve the accuracy of N_2O emission estimates and help to define how much sheep contribute to greenhouse gas emissions.

2. Material and methods

The study was carried out in a semi-improved enclosed 11.5 ha upland pasture at Bangor University's Henfaes Research Centre, Abergwyngregyn, North Wales (53°13′13.75″ N, 4°0′34.88″ W). We attached a 'Daily Diary' tag (Wildbyte Technologies Ltd, UK) to each of 30 barren Welsh Mountain ewes for 30 d from 12th May to 16th June 2016. Rear-mounted accelerometers were used since accelerometers mounted on a collar were not able to detect urination events. Average sheep weight was 36.8 kg (SD = 6.87 kg) and average age was 4.2 y (SD = 1.2). The work and methods used were approved by Swansea University's Animal Welfare and Ethical Review Group (Reference IP-1516-5) and by Bangor University's College of Natural Sciences Ethics Committee (Ethics approval code CNS2016DC01).

2.1. Daily Diary tags

The Daily Diaries' recorded accelerometer data at 40 Hz on each of the three orthogonal axes; X (surge), Y (sway), and Z (heave). The tags were powered by an A cell battery that was enclosed in a vacuform plastic housing and sealed using Poly Cement (Humbrol, Hornby Hobbies, UK) (Fig. 1). A small patch of wool was sheared from the rump