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Research Paper

A threshold-based algorithm for the development of inertial sensor-based systems to perform real-time cow step counting in free-stall barns

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Innovative systems and automated computational procedures, such as those based on computer vision or inertial wearable sensors, have recently been adopted to provide effective and accurate monitoring and analysis of cow behaviour and respond to different issues related to cow health and welfare.

In this study, a new and open source algorithm, characterised by a linear computational time, was defined and implemented with the aim to improve real-time monitoring and analysis of walking behaviour of dairy cows. It was applied to a novel inertial sensor-based system composed of low-cost devices, including wearable sensors, open source software, operating with a 4-Hz sampling frequency. The algorithm computed the number of steps of each cow from accelerometer data by making use of statistically defined thresholds. Two vector variables were considered to study the accelerometer signals, i.e., Signal Vector Magnitude and Signal Magnitude Area. Algorithm accuracy was carried out by comparing total error (*E*) and Relative Measurement Error (*RME*), and a sensitivity analysis on the parameters of the computed thresholds was carried out to analyse the variation of the error made by the algorithm.

The results showed that the algorithm produced an *E* equal to 9.5%, and a *RME* between 2.4% and 4.8%. The sensitivity analysis confirmed that the proposed thresholds provided the minimum errors and that *RME* is less suitable than *E* for measuring the accuracy of the step counter. In fact, the underestimated and overestimated numbers of steps counted by the algorithm tended to compensate each other in *RME* computation.

1. Introduction

Animal observations when carried out either directly within the breeding environment or by the analysis of images acquired from video-recording systems are usually costly and time consuming (Alsaaod et al., 2015; Chanvallon et al., 2014; Nielsen, Pedersen, Herskin, & Munksgaard, 2010; Robert, White, Renter, & Larson, 2009). Therefore, other kinds of monitoring systems have been proposed in the last decades

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Nomenclature

Alg_{mod}	version of the algorithm which use mod_{xy} and th_{mod}
Alg_{sma}	version of the algorithm which use sma_{xy} and th_{sma}
mod_{xy}	*Signal Vector Magnitude* of acceleration vector, calculated along *x* and y axis
N^{c}_{step}	computed number of cow's steps by the algorithm
N^{c+}_{step}	overestimation of step count number
N^{c-}_{step}	underestimation of step count number
N^{v}_{step}	number of cow's steps observed in the video-recordings
sma_{xy}	*Signal Magnitude Area* of acceleration vector, calculated along *x* and y axis
th_{mod}	threshold used to discover an high mod_{xy} value of an observation
th_{offset}	threshold used to assign two peaks to different steps
th_{sma}	threshold used to discover an high sma_{xy} value of an observation

such as those based on radio frequency identification (RFID) technology. It makes use of two main electronic components (tags and readers) that exchange information through radio waves. Among automated systems based on RFID technology, those based on ultra-wide band (UWB) technology can identify and locate animal inside the livestock buildings with a higher accuracy then those based on high frequency (HF) and ultra-high frequency (UHF) technologies (Ilie-Zudor, Kemény, Van Blommestein, Monostori, & Van Der Meulen, 2011; Ipema, Van De Ven, & Hogewerf, 2013; Porto et al., 2012; Porto, Arcidiacono, Giummarra, Anguzza, & Cascone, 2014). Although these types of monitoring systems make it possible to track each animal of the herd, they have a high cost that is not always sustainable for farmers. Moreover, their setting up within the breeding environment is often complex in relation to the layout and building characteristics of the barn to be monitored.

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).

Concerning the monitoring of walking behaviour of dairy cows within free-stall barns, the most frequently adopted wearable sensor is the accelerometer. The first accelerometer sensor implemented in smart devices were used to monitor human behaviour and health (Mathie, Coster, Lovell, & Celler, 2004). Later, they were also applied to livestock (Martiskainen et al., 2009).

The pedometer attached to cow's leg is the most used device that is equipped with an accelerometer. It provides a valuable and complete information (e.g., activity indices and step counting) about the periods spent by the animal in 'rest' and in 'restless' activities during its daily routine. It is well known that this information is relevant for early detection of oestrus in dairy cows (Chanvallon et al., 2014; Firk, Stamer, Junge, & Krieter, 2002; Silper et al., 2015) as well as for lameness (Alsaaod et al., 2012; Mazrier, Tal, Aizinbud, & Bargai, 2006). However, the analysis of walking activity by using pedometers needs refinement to improve the accuracy of the step count and obtain its real-time acquisition. Actually, the information provided by pedometers is not available in real time, because the pedometer data is downloaded by the monitoring system only during the milking process (e.g., twice a day). Due to the current widespread use of pedometers, any technical improvement would be valuable for farmers and could be a significant step forward in the enhancement of systems based on wearable sensors.

In this field, there has been an increased focus on real-time cow step counting. However, technical specifications of this kind of systems as well as the code of the step counting algorithm are seldom included in the literature. For instance, in a new version of the algorithm of RumiWatch pedometer (ITIN + HOCH GmbH, Fütterungstechnik, Liestal, Switzerland), proposed by Alsaaod et al. (2015), the authors provided no information about the code of the algorithm, whereas the outcomes of the application of the proposed algorithm were reported in detail as well as other technical features of RumiWatch pedometer. Among these, the sampling frequency of the accelerometer for monitoring walking behaviour, which was equal to 10 Hz, was considered very high by the authors.

Based on the literature previously described, the objective of this work was the definition and implementation of an innovative system to improve monitoring and analysis of walking behaviour of dairy cows. Particularly, the proposed system makes it possible to count cow steps in real time by an 'open' and innovative algorithm based on statistically defined thresholds, sampling frequency of 4 Hz, and low-cost devices with open source software. The use of a 4 Hz sampling frequency, which is the lowest of all the others declared in the literature, would provide several advantages. Among these, the increase of battery duration, the reduction of the space occupied in memory for storage of the data recorded during the research studies, and the decrease of the amount of data to be processed, with the possibility of utilising the step counter algorithm also for RTC (Real-Time Computing). Finally, the easy setting up of the hardware in the cubicle area of the barn is a novelty of this study because the location of desktop computers, and other related devices, is not always possible in the animal occupied zone (AOZ) which is the target area in precision livestock farming studies.

2. Materials and methods

2.1. *The breeding environment and the data acquisition system*

The field experiments were carried out during June 2015 in a free-stall barn for dairy cows located in Sicily. In this study, a group of 14 primiparous cows, which were bred in the central pen of the barn, was selected (Fig. 1).

In the experiment, five Bluetooth Low Energy (BLE) SensorTags, developed by Texas Instruments (USA), were utilised. Before starting the experiment Each SensorTag was activated in