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A pattern recognition approach for detecting and classifying jaw movements in grazing cattle

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ABSTRACT

Precision livestock farming is a multidisciplinary science that aims to manage individual animals by continuous real-time monitoring their health and welfare. Estimation of forage intake and monitoring the feeding behavior are key activities to evaluate the health and welfare state of animals. Acoustic monitoring is a practical way of performing these tasks, however it is a difficult task because masticatory events (bite, chew and chew-bite) must be detected and classified in real-time from signals acquired in noisy environments. Acoustic-based algorithms have shown promising results, however they were limited by the effects of noises, the simplicity of classification rules, or the computational cost. In this work, a new algorithm called Chew-Bite Intelligent Algorithm (CBIA) is proposed using concepts and tools derived from pattern recognition and machine learning areas. It includes (i) a signal conditioning stage to attenuate the effects of noises and trends, (ii) a pre-processing stage to reduce the overall computational cost, (iii) an improved set of features to characterize jaw-movements, and (iv) a machine learning model to improve the discrimination capabilities of the algorithm. Three signal conditioning techniques and six machine learning models are evaluated. The overall performance is assessed on two independent data sets, using metrics like recognition rate, recall, precision and computational cost. The results demonstrate that CBIA achieves a 90% recognition rate with a marginal increment of computational cost. Compared with state-of-the-art algorithms, CBIA improves the recognition rate by 10%, even in difficult scenarios.

1. Introduction

Nowadays, the management of livestock grazing systems requires accurate measurement of animal feeding behavior to monitor their health and welfare, as well as to improve the efficiency of resource management. In this regard, much effort has been put into finding suitable techniques for monitoring the feeding behavior of ruminants. A long-term analysis of such behavior distinguishes two major activities: rumination and grazing, which last from few minutes to hours. On a short-time scale, these activities are composed by a sequence of three jaw movements: bites, chews and chew-bites (Ungar et al., 2006; Milone et al., 2012). A grazing bite includes the apprehension and severance of forage, while a grazing or rumination chew includes the crushing, grinding and processing of ingested pasture. The chew-bite is another grazing event that results from the overlapping of chew and bite events in the same jaw movement. While the number and characteristics of jaw movements change according to animal and environmental factors, monitoring them can provide useful indicators of animal health, welfare, nutritional status, and feeding activities (grazing and rumination) (De Boever et al., 1990).

Early strategies for monitoring feeding behavior were based on direct observation and in recent times by visualization of video recordings. However, both methodologies are costly and impractical for monitoring large herds (Milone et al., 2009). In last decades, other methods based on pressure sensors, accelerometers and microphones have been studied (Andriamandroso et al., 2016). Most of them focus on recognizing long-term activities (rumination and grazing) rather than individual jaw movements. Detection of jaw movements can be performed with nose-band pressure sensors (Nadin et al., 2012; Zehner et al., 2017) and accelerometers (Tani et al., 2013; Oudshoorn et al., 2013; Andriamandroso et al., 2016) but the available results indicate that classification requires further development to be reliable and automatic. In addition, a separate classification of chews, bites, and chew-bites cannot be done because the compound chew-bite cannot be

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identified by these methods. By contrast, several studies have shown that acoustic monitoring can overcome these limitations.

An accurate tracking of animal diet can be accomplished by analyzing the sounds related to jaw movements (Alkon and Cohen, 1986; Alkon et al., 1989; Laca et al., 1992; Ungar et al., 2006). Biting and chewing sounds are produced while plant structures are comminuted by jaw movements. The sound is transmitted, filtered and modified by the bones, cavities and soft tissues of the animal's head. It can be recorded and collected in a non-invasive way without affecting the natural behavior of animals (Laca et al., 1992; Klein et al., 1994; Nelson et al., 2005). However, acoustic analysis is a complex task, particularly in noisy environments like cattle barns, and known applications usually show high computational-cost.

Among automatic recognition systems based on sound analysis, just few of them deal with detection and classification of jaw movements problem. Milone et al. (2012) developed an algorithm based on hidden Markov models, that hereafter will be referred as CBHMM (Chew-Bite Hidden Markov Model), for detecting and classifying jaw movements. Using probabilistic models and spectral-domain features it achieves up to 85% recognition rate, but it shows a high computational cost. Navon et al. (2013) implemented an algorithm for event detection that used a machine-learning technique to analyze time-domain features of ingestive sounds. The algorithm achieved up to 94% detection rate. However, the event classification (bite, chew and chew-bite) was not performed in this work.

The development of a recognition system based on analysis of acoustic signals should consider the following situations:

1. Input sound signals are affected by environmental noises, which can degrade the signal-to-noise ratio (SNR) and diminish the overall system performance. For instance, trends (low-frequency time-varying noises) are more intense when cattle stay in barns, where there are more noise sources (e.g. machinery and other animals) that are also intensified by the room reverberation.
2. Recognition of ingestive events is a combination of detection and classification. Former methods showed that detection can be successfully performed with high accuracy whereas classification typically requires more powerful methods to achieve high recognition rates.
3. Precision livestock farming area aims at low-cost algorithms in order to embed and execute them in real-time within low-performance wearable devices. In this way, the monitoring system could be scaled for its application on large herds.

Recently, Chelotti et al. (2016) proposed an algorithm called Chew-Bite Real-Time Algorithm (CBRTA) for detection and classification of ingestive events. The algorithm used heuristic rules derived from expert knowledge, reaching recognition rates up to 97.4% for detection and 84.0% for classification of events at a low computational cost. However, trends in the input signals negatively affect the event detection because it is based on time-varying thresholds. On the other hand, the simple set of rules proposed may not exploit the whole potential of the features employed. For instance, the shape and duration of a detected event are the only features used to differentiate compound events (chew-bites) from simple events (chews or bites), which is an oversimplified representation of the events, leading to poor recognition rate. Thus, it is desirable to consider machine learning techniques that are able to generate optimal decision regions, improving the classification performance at the expense of reasonable increments of computational cost (up to 50% of CBRTA cost), which will imply neglectable effects on the algorithm's computational requirements due to the extremely low computational cost of the CBRTA.

In this paper, a new algorithm called Chew-Bite Intelligent Algorithm (CBIA) is proposed, which seeks to improve the recognition of jaw movements using acoustic signals, even in noisy environments (e.g. inside a barn). This method is based on concepts and techniques derived from signal processing and machine learning areas to analyze the sound signal derived from ruminant feeding behavior. Two databases obtained in different experimental conditions are used to test the algorithm. The computational cost and a cost-benefit analysis of its implementation are also evaluated for its future real-time execution in a low-cost embedded system.

2. Material and methods

Two independent sound databases of ruminant feeding behaviors were used to evaluate the performance of the proposed system. One of the databases was obtained under controlled experimental conditions, showing a high SNR. This database was previously used to evaluate other algorithms, which allows a fair comparison with the algorithm introduced in this work. The second database was obtained in a barn environment, showing a poor SNR due to the presence of noises and reverberations. This database was used to evaluate the influence of the proposed methods under adverse acoustic environmental conditions. During the experiments several signal processing and machine learning techniques were evaluated.

2.1. Databases

The first database (referred as DB1) is the same used by Milone et al. (2012) and Chelotti et al. (2016) for testing CBHMM and CBRTA algorithms, respectively. DB1 was obtained at Campo Experimental J. Villarino, Facultad de Ciencias Agrarias, Universidad Nacional de Rosario (Argentina) during February 2004. The protocols were previously evaluated and approved by the Committee on Ethical Use of Animals for Research of the Universidad Nacional de Rosario. Sound signals from dairy cows grazing either pure alfalfa (Medicago sativa) or pure fescue (Festuca arundinacea) micro-swards at two height levels (tall, 24.5 ± 3.8 cm, or short, 11.6 ± 1.9 cm) were recorded individually in grazing sessions conducted over a 5-day period. Forage species were selected because they differ in sward structure, water content and neutral detergent fiber content (alfalfa, 360 ± 11 g/kg and fescue, 631 ± 6 g/kg), which are factors that have a direct influence on chewing sounds (Duizer, 2001). Two 4–6 year-old lactating Holstein cows weighing 608 ± 24.9 kg, previously tamed and trained, were used. Three wireless microphones (Nady 151 VR, Nady Systems, Oakland, CA, USA) were randomly assigned to animals each day. The microphone was placed facing inwards on the forehead and was protected by a rubber foam (Milone et al., 2009). The distance between the wireless microphone and the receiver was 2–3 m. Micro-swards were established using alfalfa or fescue sown in 4-liter plastic pots, which were attached to a base-board placed inside a barn. Plants were in a vegetative state, and were intentionally manipulated to generate micro-swards that cows could eat with negligible displacement. The sounds were recorded at 44.1 kHz sampling frequency, 16-bit resolution and WAV format. A total of 50 grazing sessions were recorded: 15 from tall alfalfa, 11 from short alfalfa, 12 from tall fescue and 12 from short fescue. Around 50 min of acoustic signals were considered, which approximately corresponds to 3000 jaw movements (13% bites, 64% chews, and 23% chew-bites).

The signals belonging to the second database (referred as DB2) were obtained by another field experiment conducted at Campo Experimental J. Villarino, Facultad de Ciencias Agrarias, Universidad Nacional de Rosario (Argentina) during October of 2014. Project protocols were previously evaluated and approved by the Committee on Ethical Use of Animals for Research of the Universidad Nacional de Rosario. The foraging behavior of five 3–5 year-old Holstein lactating cows, weighing 570 ± 40 kg, grazing alfalfa and fescue mixed pastures, were continuously monitored using a commercial recorder (Sony ICDPX312) to obtain 24 h sound recordings during six days. Sounds of biting and chewing were recorded using a directional microphone mounted over the forehead and covered by an elastic band fastened to a