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A regularity-based algorithm for identifying grazing and rumination bouts from acoustic signals in grazing cattle

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A B S T R A C T

Continuous monitoring of cattle foraging behavior is a major requirement for precision livestock farming applications. Several strategies have been proposed for this task but monitoring of free-ranging cattle for a long period of time has not been fully achieved yet. In this study, an algorithm is proposed for long-term analysis of foraging behavior that uses the regularity of this behavior to recognize grazing and rumination bouts. Acoustic signals are analyzed offline in two main stages: segmentation and classification. In segmentation, a complete recording is analyzed to detect regular masticatory events and to define the time boundaries of foraging activity blocks. This stage also defines blocks that correspond to no foraging activity (resting bouts). The detection of event regularity is based on the autocorrelation of the sound envelope. For classification, the energy of sound signals within a block is analyzed to detect pauses and to characterize their regularity. Rumination blocks present regular pauses, whereas grazing blocks do not. The evaluation of the proposed algorithm showed very good results for the segmentation task and activity classification. Both tasks were extensively analyzed with a new set of multidimensional metrics. Frame-based F1-score was up to 0.962, 0.891 and 0.935 for segmentation, rumination classification, and grazing classification, respectively. The average time estimation error was below 0.5 min for classification of rumination and grazing on recordings of several hours in length. In addition, a comparison for rumination time estimation was done between the proposed system and a commercial one (Hi-Tag; SCR Engineers Ltd., Netanya, Israel). The proposed algorithm showed a narrower error distribution, with a median of −2.56 min compared to −13.55 min in the commercial system. These results suggest that the proposed system can be used in practical applications.

Web demo available at: http://sinc.unl.edu.ar/web-demo/rafar/.

1. Introduction

In recent years, much effort has been put into the development of animal monitoring applications for precision livestock farming. Monitoring of foraging behavior is key to ensure the fulfillment of the basic health and welfare requirements of grazing cattle and to improve the efficiency of pasture-based production systems (Hodgson and Illius, 1998). Foraging activities, particularly grazing and rumination, occupy most of the animal's day. Thus, the continuous monitoring of such behavior can help retrieve individual status information for each animal, build a log, detect emerging diseases or the onset of estrus, and optimize pasture and animal management. For example, decreased rumination is interpreted as an indicator of stress (Herskin et al., 2004), anxiety (Bristow and Holmes, 2007), or disease (Welch, 1982). Conversely, an increase in rumination time is associated with more saliva production and improved rumen health (Beauchemin, 1991).

Cattle foraging behavior is mainly composed of grazing and rumination times. Grazing can cover from 25% to 50% of the day and rumination, from 15% to 40% (Kilgour, 2012). The grazing process involves searching, apprehending, chewing, and swallowing herbage. Rumination includes bolus regurgitation, chewing, and deglutition. While grazing, the animal moves its jaw continuously with no predefined interruptions or sequence of events. By contrast, a typical rumination phase involves chewing for 40–60 s and a 3-to-5 s interruption during bolus deglutition and regurgitation (Hodgson and Illius, 1998; Trindade et al., 2011; Benvenutti et al., 2016). During both activities,

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jaw movements (or masticatory events) are performed rhythmically with a frequency that ranges from 0.75 to 1.20 events per second (Andriamandroso et al., 2016). The masticatory events are biting, when herbage is apprehended and severed; chewing, when herbage is comminuted; and a compound movement called chew-bite, when herbage is severed and comminuted in the same jaw movement (Laca et al., 1992; Ungar and Rutter, 2006; Galli et al., 2017). Events have a length close to 1 s, whereas activity bouts can last from minutes to hours. Thus, foraging behavior is characterized by events (short timescale) and activities (longer timescale).

Many strategies have been proposed for monitoring foraging behavior, but they are limited by several factors (Andriamandroso et al., 2016; Delagarde et al., 1999; Hodgson and Illius, 1998). For instance, foraging behavior could be measured by direct observation or by watching video recordings. However, these methodologies are extremely time-consuming and unfeasible for large herds; besides, it is very difficult to collect data in pasture-based systems over long periods of time. To be of practical use, monitoring should be performed in a fully automatic and noninvasive manner so as not to disturb the normal behavior of the animal. In addition, the system should be capable of working continuously and keep accurate measurements from days to weeks.

Automatic monitoring systems have been developed based on different sensing technologies: motion sensors, noseband pressure sensors, and microphones. The most commonly used motion sensors are accelerometers (González et al., 2015; Arcidiacono et al., 2017; Giovanetti et al., 2017; Martiskainen et al., 2009) and inertial measurement units (Andriamandroso et al., 2017; Smith et al., 2016; Greenwood et al., 2018). These systems typically seek to recognize a broader set of activities, such as rumination, grazing, resting, drinking, and walking. An activity is determined by postural analysis of the animal, where the sensors are used to estimate the relative position and motion of its head and body. However, this strategy can confuse activities that share the same posture. For example, resting can be easily confused with rumination, which can be performed while the cow is standing or lying on the ground. A better strategy for recognizing ruminating, eating, and drinking activities is the use of noseband pressure sensors (Rutter et al., 1997; Rutter, 2000; Nydegger et al., 2010; Zehner et al., 2017; Werner et al., 2018). The IGER Behavior Recorder was a pioneer development using these sensors. Recently, the RumiWatch system was used to analyze housed and free-ranging cows during one- and two-hour sessions. This yielded very good results, but further studies are required on continuous long-term monitoring. By contrast, acoustic monitoring has proven to be reliable for recognizing short-term ingestive events in free-ranging cows (Laca et al., 1992; Galli et al., 2011; Clapham et al., 2011; Navon et al., 2013; Milone et al., 2012; Galli et al., 2017; Chelotti et al., 2016; Chelotti et al., 2018). A popular monitoring system that includes a logger with a built-in microphone is the Hi-Tag system (SCR Engineers Ltd., Netanya, Israel). However, the sound signal processing is exclusively focused on monitoring rumination in housed cows (Schirmann et al., 2009; Goldhawk et al., 2013). No long-term acoustic monitoring of foraging activities has yet been studied for free-ranging cows.

In this study, an algorithm is proposed for identifying grazing, rumination, and resting bouts from acoustic signals. The algorithm provides the start and finish times of each activity block by analyzing the input signal. It is based on the periodic characteristics of jaw movements during grazing and rumination. Jaw-movement sequences, and the occurrence of interruptions, differ greatly between activities. During grazing, bites, chews, and chew-bites are heterogeneously distributed in time with irregular interruptions. Conversely, rumination presents homogeneous phases of chews interrupted by bolus deglutition and regurgitation. The algorithm has two stages. First, the complete recording is analyzed to delimit the blocks of the signal that show periodical jaw movements. The absence of such periodicity defines discarded blocks (resting bouts). Second, the delimited blocks are further analyzed to detect and characterize the interruptions, thus defining which activity corresponds to each block.

The identification of rumination and grazing bouts can be seen as a particular case of continuous activity recognition problem. In this context, recognition systems are typically assessed with standard performance metrics, such as sensitivity, specificity, precision, or correlation coefficient (concordance, Pearson, or Spearman) (Sokolova et al., 2009; Werner et al., 2018; Zehner et al., 2017). However, to use these metrics the problem of continuous activity recognition must be reformulated as a classic classification problem, where input data is mapped to a single category. Unfortunately, restating the problem to conform to standard metrics can be misleading and can produce confusing results (Ward et al., 2011). In this study, we propose the use of a new set of multidimensional performance metrics, which provides a detailed description of the recognition process at multiple timescales. This allows for a more accurate assessment of the strengths and weaknesses of the proposed recognizers.

2. Materials and methods

Grazing and rumination are activities with quasiperiodic characteristics. The proposed *regularity-based algorithm* aims to use this discriminative information to provide grazing and rumination bouts. Two main stages are involved in the offline recognition process: activity segmentation and activity classification (Fig. 1). The complete recording is first analyzed to delimit the blocks of the signal that show regular events (jaw movements). A short sliding window on the envelope of the sound signal is used to analyze this regularity. Demarcation of the activity blocks also defines blocks of no activity (resting bouts), which correspond to silence or noisy intervals. Autocorrelation is a well-known technique that has been useful to detect periodicity in noisy signals (Oppenheim and Schafer, 2011) and it will be used in this stage. During classification, activity blocks are further analyzed to detect interruptions and to characterize their regularity. The energy of the sound signal within a block is analyzed to detect sudden drops, which are related to the interruptions. Regular interruptions are related to bolus deglutition and regurgitation during rumination. Grazing does not show interruptions corresponding to this particular regularity, although it may present irregular interruptions by searching a new plant or patch.

2.1. Segmentation by regularity

Segmentation is based on regularity of masticatory events during grazing and rumination. The analysis of the envelope of the sound signal can reveal these events and their periodicity. Envelope

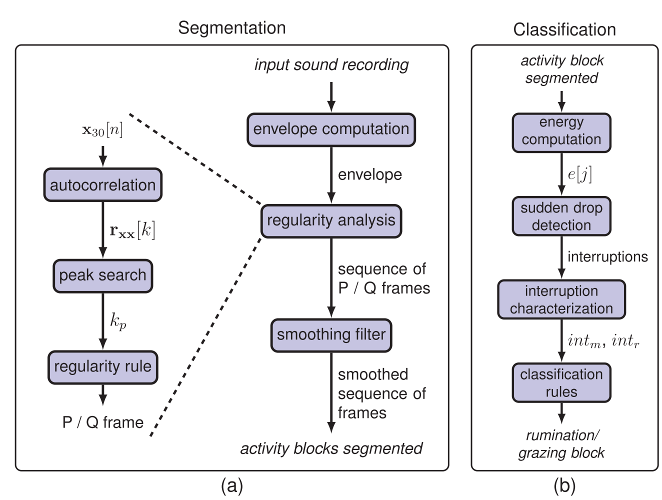

Fig. 1. Tasks of (a) segmentation and (b) classification stages for the proposed algorithm. Steps of regularity analysis during segmentation are also detailed.

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