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Embedded system for real-time monitoring of foraging behavior of grazing cattle using acoustic signals

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ABSTRACT

Estimating forage intake and monitoring behavior of grazing livestock are difficult tasks. Real-time detection and classification of events like chew, bite and chew-bite are necessary to estimate that information. It is well-known that acoustic monitoring is one of the best ways to characterize feeding behavior in ruminants. Although several methods have been developed to detect and classify events, their implementation is restricted to desktop computers, fact that confines their application to off-line analysis of a reduced number of animals. In this work, we present the design and implementation of an electronic system specifically developed for real-time monitoring of feeding patterns in dairy cows. The system is based on an embedded circuit to process the sound produced by the animal in order to detect, classify and quantify events of ruminant feeding behavior. The system implements an algorithm recently developed, which was adapted to be executed on a microcontroller-based electronic system. Only the results of sound analysis are stored in flash memory units. In addition to sound information, data from a GPS receiver is also stored, thus building a package of information. A microcontroller with power management technology, combined with a high-efficiency harvesting power supply and power management firmware, enables long operational time (more than five days of continuous operation). The system was evaluated using audio signals derived from the feeding activity of dairy cows that were acquired under normal operational conditions. The system correctly detected 92% of the events (i.e. considering them as possible events without making a classification). When the three types of events (i.e. chew, bite and chew-bite) were considered for classification, the recognition rate was about 78%. These results were obtained using reference labels provided by experts in ruminant ingestive behavior. The technology presented within this publication is protected under the international patent application PCT/IB2015/053721.

1. Introduction

The global dairy industry has undergone profound changes over recent decades in the world. There is a trend in dairy farming toward the automation of processes to reduce the labor and its associated costs (de Koning, 2011). This development is mainly driven by the increment of labor costs relative to capital costs. Automated systems enable dairy farmers to manage larger herds with lower labor requirements and costs (de Koning, 2011). This trend toward automation is suitable for the tendency of increasing herd sizes.

The behavior of animals is a clear indicator of their physiological and physical state (Frost et al., 1997). Eating, ruminating and resting are the main daily activities of ruminant livestock (Hancock, 1954). Monitoring these activities in the field is essential to crucial management decisions in grazing systems. This information allows herd managers to evaluate the feeding conditions of grazing cattle and make decisions about supplement and pasture management. Furthermore, accurate monitoring of foraging behavior of free-grazing cattle is necessary to ensure the welfare and health of these animals. Many efforts have been devoted to develop suitable techniques to address this problem, however the success of these developments has been limited by practical factors (Hodgson and Illius, 1996; Delagarde et al., 1999).

One approach for studying the grazing behavior uses acoustic monitoring. Laca et al. (1992) used acoustic monitoring to study

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the short-term grazing behavior of cattle, the microphone was mounted on the forehead of the animal facing inward. The head bones amplify the ingestive sounds (apprehension and chewing) produced in the oral cavity. Thus, the clarity of the signal obtained allows to detect and classify all jaw movements with high accuracy and reliability (Clapham et al., 2011; Milone et al., 2012; Navon et al., 2013; Chelotti et al., 2016). All reported applications have involved fresh herbage; obtaining promising results about estimation of intake (Laca and WallisDeVries, 2000; Rutter et al., 2002; Ungar and Rutter, 2006; Galli et al., 2006, 2011).

One of the most accepted ways to perform monitoring of ruminant feeding is through the detection of the three most common events of grazing activity: chew, bite and composed chew-bite. Biting includes the apprehension and saving of forage, while chewing action includes the crushing of forage. There is also another event resulting from the superposition of chewing and biting activities but made with the same jaw movement and called chew-bite. The detection and classification of these three types of events is necessary for accurate monitoring of the diet of animals. In this sense, there are few authors who have taken into account the detection and classification of these events, because of the complexity of discriminating the events, especially in noisy environments (Milone et al., 2012; Chelotti et al., 2016).

The procedure followed to monitoring the ruminant feeding activities has two steps: (i) the sound is recorded and stored using a commercial sound recording device, and then (ii) the recorded sounds are analyzed in a desktop computer (Clapham et al., 2011; Milone et al., 2012; Lynch et al., 2013; Chelotti et al., 2016). For short time experiments (Clapham et al., 2011; Milone et al., 2012; Chelotti et al., 2016) the recording devices are not modified. For long-term experiments the recording devices are modified to enlarge their autonomy. For example, Lynch et al. (2013) added five lithium-thionyl-chloride 3.6 V AA batteries to the commercial recorder, which allows 330 h of autonomy for each device.

The relevance of recording data, in term of resource management and animal welfare, for long periods of time has lead to the development of devices and wireless sensor networks for agriculture applications (Abbasi et al., 2014). In the recent years, several devices have been developed. For example, Greenwood et al. (2014) discussed the challenges of hardware and software for wireless sensor networks development required for the collection of data from different types of sensors, the management and analyses of the very large volumes of data. Then, they developed pasture intake research platform to provide detailed estimates of pasture consumption by individual animals through chemical markers and biomass disappearance, reinforced with video recordings of animal behaviors. Panckhurst et al. (2015) developed a position tracking system for livestock compose by a solar-powered sensor tag and a base station. The system is able to provide a configurable wireless connection triggered and managed by the base station, reducing the overall power consumption of the tags and allowing typical transmission range of 500 m.

In spite of all these recent developments, to the best to our knowledge, there is no portable device able of analyze in real-time the sounds produced by ruminants to detect and classify grazing events. Given the high cost involved in storing and transmitting large volumes of data, there is a need for a system capable of performing on-line processing and storing the statistical results in text files. Therefore, there exists a need to develop sensor technology for monitoring animal feeding activities in real-time while withstanding their environment. Following advances in electronics we developed and built an electronic device, consisting of a directional electret microphone, a solar panel, rechargeable batteries and an electronic circuit with small form factor that can be stored in a small case, and it is also able to operate long-terms under any weather condition. The embedded device introduced in this work has the advantages of easier mounting to the animal, lack of complex wiring between sensors and device, low weight and small form factor.

The paper is organized as follows: Section 2 introduces the developed embedded system, describing the hardware architecture and software organization. The implementation of the algorithm is discussed at the end of this section. The database used and methods employed to validate the system operation are introduced in Section 3. The results obtained from the operation of the embedded system are presented and discussed in Section 4. Finally, the conclusions are given in Section 5.

2. Material and methods

An embedded processing system was developed to estimate the representative parameters of animal feeding behavior by processing the sounds produced by the animal during its feeding activities (i.e., ruminating and grazing) and storing the corresponding statistical results. The signal processing and analysis are performed in a microcontroller that implements the detection and classification algorithm proposed by Chelotti et al. (2016) in combination with signal processing for signal conditioning. The microphone capture the sound that is conditioned and processed within the microcontroller and the information obtained is stored in a flash memory. The microphone is placed on the forehead of the animal, covered by a rubber band that protects the microphone from adverse weather conditions (e.g., wind, rain) and attenuates the external noises. The device is located on the neck just behind the head, to prevent the impacts from another animal, while the connection with the microphone is short (Fig. 1).

The parameters of animal feeding activity are obtained by detecting and then identifying the type of event (chew, chew-bite or bite) and quantifying its parameters (number of events, duration, energy, amplitude). These information is accumulated during a period of five minutes and integrated with the time and position of the animal into a package of information. Then, this package is stored into a flash memory and communicated to the system through a configurable wireless connection managed by a base station, thus reducing the overall power consumption of the tags and allowing typical transmission of 500 m.

2.1. The embedded design

A microcontroller (MCF51JM128, NXP Semiconductors) was chosen for this application based on its availability in the local market, power consumption, computational power, analog ports, communication resources (SPI, USART and USB), internal clocking resources and a real-time clock module. The sound produced by the animal is sensed with an electret microphone facing inward on his forehead (Fig. 1a). The signal produced by the microphone is conditioned by an analog circuit that limits the signal bandwidth, in order to maximizes the signal-to-noise ratio (SNR). This circuit is comprised three stages (Fig. 2):

1. A low-pass filter that limits the signal bandwidth to 1 kHz, in order to be able to subsample the signal and reduce the computational load of subsequent stages. It is implemented through a cascade of four second order filters (TLV2784, Texas Instruments Inc) following a Sallen-key topology,
2. An amplifier with AGC (MAX9814, Maxim Integrated) applies an automatic controlled amplification to signal in order to maximizes the SNR, avoiding signal distortions and clipping