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Automatic cough detection for bovine respiratory disease in a calf house

Lenn Carpentier [a], Daniel Berckmans [a], Ali Youssef [a], Dries Berckmans [b], Toon van Waterschoot [c], Dayle Johnston [d], Natasha Ferguson [d], Bernadette Earley [d], Ilaria Fontana [e], Emanuela Tullo [e], Marcella Guarino [e], Erik Vranken [a,f], Tomas Norton [a,*]

[a] Division Animal and Human Health Engineering, Department of Biosystems, KU Leuven, Kasteelpark Arenberg 30, 3001 Heverlee, Belgium

[b] SoundTalks NV, Kapeldreef 60, 3001 Heverlee, Belgium

[c] Department of Electrical Engineering (ESAT-STADIUS/ETC), KU Leuven, Kasteelpark Arenberg 10, 3001 Leuven, Belgium

[d] Animal and Bioscience Research Department, AGRIC, Teagasc, Grange, Dunsany, Co., Meath, Ireland

[e] Department of Health, Animal Science and Food Safety, Università Degli Studi di Milano, Via Celoria 10, 20133, Milan, Italy

[f] Fancom Research, Fancom BV, Wilhelminastraat 17, 5981 XW Panningen, The Netherlands

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In calf rearing, bovine respiratory disease (BRD) is a major animal health challenge. Farmers incur severe economic losses due to BRD. Additional to economic costs, outbreaks of BRD impair the welfare of the animal and extra expertise and labour are needed to treat and care for the infected animals. Coughing is recognised as a clinical manifestation of BRD. Therefore, the monitoring of coughing in a calf house has the potential to detect cases of respiratory infection before they become too severe, and thus to limit the impact of BRD on both the farmer and the animal. The objective of this study was to develop an algorithm for detection of coughing sounds in a calf house. Sounds were recorded in four adjacent compartments of one calf house over two time periods (82 and 96 days). There were approximately 21 and 14 calves in each compartment over the two time-periods, respectively. The algorithm was developed using 445 min of sound data. These data contained 664 different cough references, which were labelled by a human expert. It was found that, during the first time period in all 3 of the compartments and during the second period in 2 out of 4 compartments, the algorithm worked very well (precision higher than 80%), while in the 2 other cases the algorithm worked well but the precision was less (66.6% and 53.8%). A relation between the number of calves diagnosed with BRD and the detected coughs is shown.

* *Corresponding author.*
E-mail address: tomas.norton@kuleuven.be (T. Norton).

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Nomenclature

P	Audio power
x	Amplitudes of the audio samples
K	Number of audio samples
M	Median frequency (Hz) or time (s)
P1	10th percentile frequency (Hz) or time (s)
P2	90th percentile frequency (Hz) or time (s)
IPR	Interpercentile range frequency (Hz) or time (s)
C	Spectral centroid
X	Energies of the frequency bins
Wf_L	Number of frequency bins
S	Spectral spread
n	Normalised spectral energy
H	Spectral entropy
Fl	Spectral flux

1. Introduction

Bovine respiratory disease (BRD) is a multifactorial disease that is driven by complex interactions of factors associated with the environment, the pathogen, the animal, and management practices (Edwards, 2010; Potter & Aldridge, 2010a). In the dairy and beef sectors, BRD is considered an economically important disease internationally (Johnston et al., 2017; Tennant, Ives, Harper, Renter, & Lawrence, 2014). Once an outbreak occurs, it often leads to morbidity, and mortality in feedlot and veal calves, and in dairy calf to beef/dairy replacement rearing systems (Edwards, 2010; Healy et al., 1993; Pardon et al., 2013; Snowder et al., 2007).

Detecting the disease at an early stage, in order to provide early treatment, requires swift observation of the presence of clinical signs associated with the disease. However, this depends on the farmer's judgement and experience. Given that typical cattle farm sizes have increased significantly over the years, the level of quality attention livestock are receiving is diminishing (Berckmans, 2004). Another problem is that, in practice, farmers and veterinarians tend to underestimate signs of BRD morbidity during their clinical examinations (Potter & Aldridge, 2010b; White & Renter, 2009).

Clinical signs associated with BRD are cough, nasal discharge and tachypnoea (Ozkanlar et al., 2012; Potter & Aldridge, 2010b). Cough sounds can thus be used as a biomarker for BRD in calves. For example, for infection with the parainfluenza-3 virus, coughing often tends to be the first visible clinical sign (Allan, Pirie, Selman, & Snodgrass, 1978) making it a very suitable biomarker for swift detection of outbreaks. An advantage of monitoring bioacoustics, such as cough sounds, using microphones is that it is performed non-invasively, and hence does not influence the animals' normal behaviour. Another advantage is that one microphone can monitor many individuals, making such systems affordable to farmers. However, a single microphone is unable to identify the origin of the emitted sound, hence is unable to identify the individual that coughed.

Van Hirtum, Aerts, Berckmans, Moreaux, and Gustin (1999) first published a study on cough detection in pigs, which was followed by additional studies refining the pig cough detection algorithms (Chedad et al., 2001; Chung et al., 2013; Exadaktylos, Silva, Aerts, Taylor, & Berckmans, 2008). However, these studies are limited to laboratory conditions where the individual sound events were manually extracted. The ratio of cough to non-cough events is therefore more balanced, which does not correspond with real-life situations where there are much more non-cough events. More recently, a commercial tool showed it was possible to detect infected pigs 2–12 days before a farmer or veterinarian (Berckmans, Hemeryck, Berckmans, Vranken, & van Waterschoot, 2015).

Recently, Ferrari et al. (2010) and Vandermeulen et al. (2016) studied the application of sound monitoring techniques for calf cough detection. Ferrari et al. (2010) characterised cough and metallic sounds, which are frequently encountered due to the use of metal fences, gates, and racks in calf housing facilities, and investigated acoustic differences between them. The authors showed that there was a significant difference between the duration, fundamental frequency, and amplitude of both sounds and hence they concluded it was possible to discriminate cough sounds from metal rack sounds using these features.

During the development of an algorithm to automatically detect cough sounds, a reference dataset of cough sounds is needed. This dataset is obtained by manually observing and annotating sound recordings (Aerts, Jans, Halloy, Gustin, & Berckmans, 2005; Tullo, Fontana, & Guarino, 2013). Studies under lab conditions result in high quality sounds as the recording device is placed close to the animal (Chung et al., 2013; Guarino, Jans, Costa, Aerts, & Berckmans, 2008) and sounds were recorded of each individual animal (Chung et al., 2013; Exadaktylos et al., 2008). However, in a commercial environment the animals will be monitored in a group and the recording device will be further away. This will result in less clear sound events and overlapping sounds.

Vandermeulen et al. (2016) developed an algorithm for the automatic detection of coughing sounds in calves with a focus on more real-life environments. Similar to the algorithm of Van Hirtum et al. (1999) and Exadaktylos et al. (2008), the Euclidian distance between the power spectral density of a specific sound and a reference dataset of coughs was used for classification. However, to cope with changing environments, the reference dataset needed to be calibrated in order for the algorithm to perform well when going to another compartment. The main problem is that this calibration step required coughs to be manually labelled when enrolling the algorithm in another environment, which is time consuming and difficult, if not impossible, to implement in real-farm situations (Kashiha et al., 2013; Oczak et al., 2013). Techniques that remove the need for this step need to be developed in order to achieve a technology that can work in realistic environments.

Instead the objective is to use general features which describe the characteristics of the cough event independent of the environment it is recorded in. Therefore, features which are less susceptible to noise are explored (Cortopassi, 2006).

Given the previous rationale, the aim of the present study is to develop an algorithm that distinguishes cough sounds from other sounds found in commercial calf rearing facilities. A key innovation of this study is a new approach that obviates the need for calibrated reference labels during monitoring.

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