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BIOACOUSTICS: A TOOL FOR DIAGNOSIS OF RESPIRATORY PATHOLOGIES IN PIG FARMS

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1. Introduction

Respiratory pathologies are widespread in intensive pig farms, their incidence and prevalence are high and cough is their principal symptom. The importance of these diseases must be seen on both economical and sanitary level for their high veterinarian intervention costs and to a loss of profit due to higher mortality (15% of cases) [Bauman 2002] or drop of production due to reduced feed conversion and growth rate. It is almost unlikely that a pig will reach the slaughter weight without having sustained any kind of respiratory affection [Leman 1992]. It is also ascertained that detecting illness in individual animals and providing individual care, or group-by-group mass therapy in response to illness, are both not very effective and are costly. It is crucial to investigate cough sounds with the aim of understanding respiratory diseases and use bioacoustics for real time monitoring purposes.

The importance of coughing as a means of prognosis does not refer only to humans, but also to animals. It has been shown that pig vocalisation is directly related to pain and classification of such sounds has been attempted [Marx 2003]. It is also common practice by veterinarians to assess cough sounds in pig houses for diagnostic purposes. In this regard, there have been attempts to identify the characteristics of coughing in animals [Moreaux 1999; Van Hirtum 2002a] and automatically identify cough sounds from field recordings [Aerts 2005; Van Hirtum 2002b; Van Hirtum, 2003 a].

The aim of this work, by comparing different infectious coughs and a healthy one, is improving the labelling of coughs giving physic features to specifics sounds, those characteristics, in a next step, may be inputs for an automatic alarm system based on an algorithm that will recognize cough sounds from an installation in a farm and will provide early warning to the farmer on the welfare status of his herd. Automatic real time monitoring and early detection of these respiratory pathologies can be applied in intensive farms considering the high number of animals hosted.

This can reduce the spread of the disease, save costs and provide information of how to face, in terms of bio security, the problem of prevention and spread of respiratory pathologies.

In this work the term "infectious cough" refers to a cough from a pig with clear signs of a clinical respiratory disease due to a bacterial infection while a "healthy cough" refers to a cough registered from a pig without a repeated clinical evidence. Pasteurella multocida type A and Actinobacillus pleuropneumoniae (App) are opportunistic bacteria, frequently involved in complicating super-infections during the course of respiratory disease in modern pig farming, while the starter agents are instead Mycoplasma hyopneumoniae or Porcine Respiratory and Reproductive Syndrome Virus. Both App and P. multocida are considered able to worsen the physical status through hyperthermia and dyspnoea, related to weight loss in sub clinical form and mortality in acute disease [Chriestensen 2004; Pijoan 1992].

The two types of infectious coughs are used as a model of common pathologies and serve as a reference for describing physical common characteristics of infectious cough sounds.

2. Material and methods

In this work we present a comparison between cough sounds of healthy and sick animals made on a database

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of healthy coughs induced in laboratory conditions and sick coughs collected in field conditions in two affected pig farms fattening compartments.

The pigs affected by pneumonic pasteurellosis derived from an hybrid commercial strain Landrace x Large White + Danish Duroc boar and were, at the beginning of the fattening period, around 40 kg of lbw.

The diagnostic suspect was set on clinical (cough with copious expectorate) and anatomopathological basis when fibrinous and haemorrhagic lobular pneumonia was observed. The definitive diagnosis was performed by isolation of P. multocida type A in pure culture.

The infection was endemic in the experimental groups of animals and clinical evidence is a frequent event in the farm used for cough recording, probably because of the growing unit conditioning environmental situation.

Pigs suffering from pleuropneumoniae due to App, were three months aged and ranged 26-35 kg of lbw at the beginning of the productive phase, reaching 90-100 kg of lbw after 90 days. These pigs belonged to an hybrid line by a cross between Italian Landrace X Large White X Duroc. The main clinical evidence was acute cough with pulmonary oedema and dyspnoea, related to high mortality rate. The observed pneumonia was mostly bilateral with involvement of diaphragmatic lobes and well demarcated necrotic-haemorrhagic lesions, frequently associated with pleurisy. App biotype 1 serotype 2 was regularly isolated in pure culture from these lesions.

The healthy cough was induced by inhalation of citric acid in Belgian Landrace x Duroc piglets weighing between 20 and 40 kg. For the database of non infectious coughs we utilize the ones collected in the study of Moreaux in 1999. They inducted cough in healthy animals, free of respiratory diseases, by inhalation of citric acid. The nebulisation of citric acid stimulates the cough receptors directly resulting in coughing. The experiments were conducted with individual healthy animals (for more information on material and method and the data acquisition process see Moreaux 1999.

For the audio signal acquisition 7 microphones (Monacor ECM 3005) were used with a frequency response of 50-16000 Hz, connected via preamplifiers (Monacor SPR-6) to an eight channel analogue to TDIF interface unit (Soundscape SS8IO-3). The Soundscape unit, which allows for simultaneous recording of 8 channels, was connected via a TDIF cable to a PCI audio card (Mixtreme 192). All recordings were sampled at a sample rate of 44.1 kHz with a resolution of 16 bit. All microphones were hanged in the stable.

The healthy cough sounds were caused by a temporary irritation of the upper respiratory tract. On the contrary the sick ones were caused, in Pasteurellosis case, by a deep bacterial infection of the lungs since the infectious process starts at the alveolar bronchiole junction producing exudates and in the App disease by a lung lesion with large red-blue areas in the upper diaphragmatic lobes with an overlying pleurisy.

For recording and labelling of the cough sounds in both lab and field Adobe Audition 1.5 was used, for the signal processing (length and fundamental frequency of sounds) Matlab 7.1 and SAS statistical package 2004 for the statistical analysis (GLM procedure). After recording cough sounds in field condition, in different days, according to the moment in which the spread of the pathology was in acute phase, a labelling of the coughs has been done. The labelling of the coughs it is a manual essential procedure to extract cough sounds we were interested from the audio files collected. The maximal criteria used to recognize sounds was the identification of the sudden increase of amplitude in the spectrum of recordings and the following decrease. This recognition was made both visually and acoustically by the operator using Adobe Audition program (the labelling procedure).

The sorting of the cough sounds, according to the class they belonged, allowed a superior sound analysis. The characteristics of the cough sounds were identified in both time and frequency domain to analyse features concerning duration and peak frequency of the signals. The spectrograms of the coughs where built using a Hanning windowing function with a length of 40 ms and 20 ms overlap. The signal incoming from the microphone was band pass filtered between 100 Hz and 10800 Hz to get rid of the low frequency noise.

Comparisons between healthy and sick coughs sounds have been made by considering the duration of the signal and the energy in the frequency content. Figure 1 illustrates the three parameters investigated to study the length of sound signals.

A, B and C in figure 1 have been calculated over all the acoustic signals even if only A and C were compared between the three classes of sounds.

For every single cough signal the peak frequency (frequency with maximal energy content) was calcu-

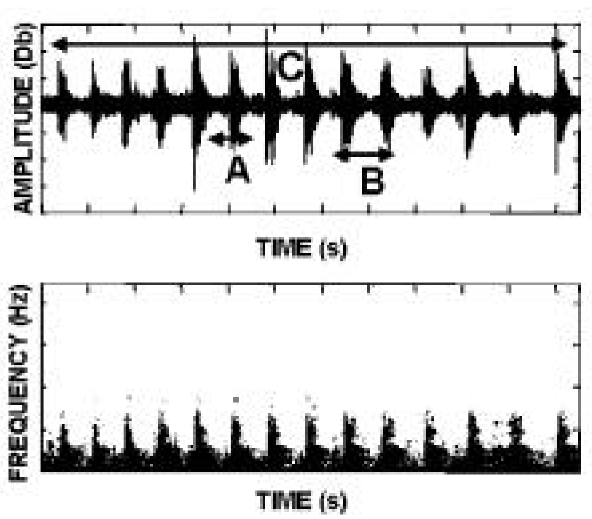

Fig. 1 - Pig cough attack (14 hits showed) represented in time domain (above) and in frequency domain (below).The arrows indicate the parameters studied. A) length of a cough, B) time between two cough, C) total length of the cough attack.

lated. The analysis of variance, one way anova, (SAS; GLM) has been done, on both the length of single coughs and length of cough attacks and on the peak frequency values, among the three classes of signals to evaluate the certain interclass distinction in time and frequency domain.

3. Results

During the recording sessions we collected 851 coughs from pigs affected by Pasteurellosis and 186 coughs by APP coming from respectively 91 and 26 cough attacks. The database of healthy coughs previously recorded in lab condition consist of 149 coughs in 11 attacks.

The comparison made over the three classes investigated first of all the duration of the sounds (parameters A and C in figure 1). The average number of coughs in a cough attack was 13 for healthy coughs and 9 and 7 for Pasteurella and App ones (Table 1).

The results, in terms of number of single coughs and attacks, duration, mean duration and standard deviation of the signals, are illustrated in Table 1 and Table 2.

Type of cough	**attacks**	**coughs**	**Min. coughs/ attack**	**Max. coughs/ attack**	**Mean *n* coughs**
Healthy	11	149	4	22	13.54
Pasteurella	91	851	5	25	9.35
App	26	186	3	19	7.15

TABLE 1 - The cough database: number of cough attacks and single coughs in the collected database. The mean number of coughs was not a parameter used for classification purposes.

Type of cough	**Mean duration attack (s)**	**Mean duration single cough (s)**	**SD single cough**
App	5.17	0.53	0.14
Healthy	8.61	0.43	0.10
Pasteurella	6.77	0.67	0.2

TABLE 2 - Duration of both cough attack and single sound signals, standard deviation of mean duration of single coughs.

The analysis lead on the quantitative observation of the number of single coughs act and cough attacks focused in details only with reference to the duration of single coughs and cough attack mostly because those are the parameters that a cough counter algorithm will recognize during continuous screening of the sounds recorded (parameter B, in figure 1 was not used for analysis).

Concerning the differences in length of the three classes of single coughs and attacks investigated one way variance analysis (ANOVA) was performed on the collected data using SAS statistical package (GLM procedure, 2004). The results show highly significantly differences among the classes ($P<0.001$) and lead us to consider the length of these signals as a tool to distinguish sounds. The ANOVA results among the duration of the three classes of cough attack show that the length of the coughs attack has a significantly difference between Healthy and App ($P<0.0387$) and between App and Pasteurella ($P<0.0493$) but not between Healthy and Pasteurella ($P<0.3418$).

The analysis lead over peak frequency of the single cough shows that lung diseases lower the peak frequency of the cough. There is a significant difference between peak frequency of coughs originating from App and Healthy cough sounds (Figure 2). The range for healthy coughs is between 750 Hz and 1800 Hz for peak frequency. For the two lung disorders this is between 200 Hz and 1100 Hz. The peak frequencies of Pasteurella coughs are clearly lower than healthy cough sounds (Healthy VS Pasteurella: $P>0.0062$; significant), but less significant than with App ($P>0.0694$). Highly significant is also the diversity between Healthy and App coughs having $P> 0.00002$.

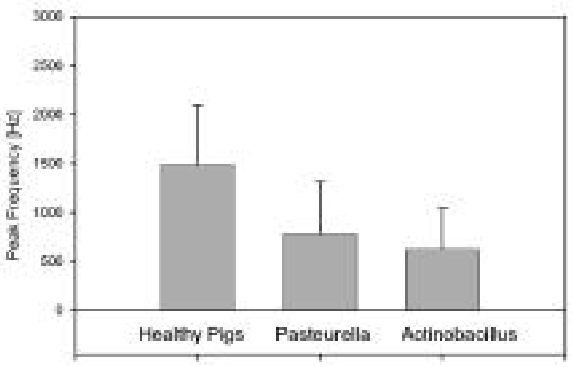

Fig. 2 - Barplot of the peak frequency of the three classes of analysed coughs. The line over the bars indicate the stdev. The difference between the two sick coughs and the healthy one stands in a lower mean of the maximum frequency in sick coughs.

4. Discussion and Conclusion

The possibility to make a distinction between pathological and healthy cough sound by physical sound features is shown. As this work improves characterisation of the features of cough, caused by specific agents, in terms of acoustical parameters, it will be useful to improve cough sound labelling as it provides significant differences between cough arising from sick or healthy animals [Ferrari 2008]. Literature in the past already focused on this distinction, but specifically in humans. Van Hirtum showed already several ways to work with pig cough, from the assessment of the cough towards vocalization [Van Hirtum 2002a], through the automated recognition of spontaneous versus voluntary cough [Van Hirtum 2002 b] to the recognition of cough sound by using an algorithm for recognition in lab condition [Van Hirtum 2003 a]; anyway literature on acoustic features of different respiratory diseases is still unknown.

In this paper sound analysis considers features like frequency energy content and duration of cough.

In terms of peak frequency of cough signal sick coughs show a significantly lower peak frequency than healthy coughs (200-1100 Hz for sick and 750-2200 Hz for healthy). This is in contradiction with the findings of Korpas who state that frequencies of 300 Hz to 500 Hz are the most expressive in healthy human coughs whereas in cough sounds of bronchitis the bands between 500 and 1200 are the most expressive [Korpas 1996]. Sound differences in cough between humans and pigs can be explained by differences in the amount of air pushed in through the air pipe or by the dimension and characteristics of the air pipe itself. Other studies, [Van Hirtum 2003b; Ferrari 2008], confirmed our results showing that the peak frequency for healthy pig cough sounds in laboratory conditions is higher than those of sick coughs.

When considering the duration of a single cough, it can be seen that there is a significant difference between the two groups of cough sounds, having a mean duration of 0.53-0.67 s for Actinobacillus and Pasteurella, sick, coughs while 0.43 s was observed for healthy coughs. The trend was also observed by other authors, concluding that the duration of sick cough is longer compared to healthy one due to airways obstruction by infection and inflammation [Van Hirtum 2002b, Van Hirtum 2003b, Ferrari 2008], both in humans and pigs. Possible explanation for this phenomenon is that, beside the correlation of this difference in length due to alteration of the respiratory system, in certain kind of diseases, like Pasteurellosis, the copious production of mucus needs longer cough act to expectorate it. Concerning the duration of a single cough or a cough attack in the whole nothing is found in literature. Further analysis should be done to clarify these findings. Although a connection between the time and frequency domain characteristics and physical system parameters for pig vocalizations is not yet known, the present results indicate that such a connection exists and remains to be determined. By understanding the effect of respiratory airway inflammation and structural changes of its cell walls on cough sounds, information can be extracted about the status of the animals. Not only in laboratory conditions but also in field situations this can lead to an interesting acoustic monitoring system. The acoustics features characterizing a sick cough can be used as inputs for on-line cough counters algorithm. Sound analysis in field conditions provides additional, useful, non invasive objective and quantitative information about the respiratory system and is a candidate for developing automatic on-line health monitoring tool.

It is suggested that the present application integrated in a automatic detection system can be used to continuously monitor animal health and might help in advance animal welfare in pig houses.

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SUMMARY

Cough is the element for monitoring and diagnosis of respiratory disease cause of mortality and loss of productivity in pig houses. In order to prevent as much as possible the outbreak of such diseases the aim of this research is to describe acoustic features of cough sounds originating from infections due to Actinobacillosis and Pasteurellosis and to compare them with healthy cough sounds provoked by inhalation of citric acid. The acoustic parameters investigated are peak frequency [Hz] and duration of cough signals. The differences resulting from the cough sound analysis confirmed a variability in acoustics parameters according to a state of health or disease in the animals. Sound analysis provides physic acoustic features that can be used as tool to label and detect cough in a automatic monitoring system applied in farms.

Keywords: cough, diagnosis, pigs, sound analysis.