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# Sound Localisation in Practice: An Application in Localisation of Sick Animals in Commercial Piggeries

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## 1. Introduction

Application of sound localisation algorithms requires a good description of the problem to be solved, detailed specifications and the choice of the algorithms that are most suited for that specific application. For the correct choice of the localisation procedure, the objectives of the study or application need to be clearly defined. These objectives are most of the times conflicting (e.g. high accuracy and low computational complexity) and often the choice of the method is not unique. Additionally, the localisation method can be part of a bigger objective (i.e. the application for which the localisation algorithm will be used) and as such, it must be able to interact with the other components of the bigger project. Previous research in relation to localisation of animal vocalisations has focused on localising animals in the wild (e.g. Hayes et al., 2000; Thomas et al., 2002) in order to mainly study animal behaviour. This chapter describes the steps that were followed in relation to sound localisation in commercial piggeries.

More specifically, the objective of this study is to monitor respiratory diseases in commercial piggeries (Fig 1). Similar to the effect on humans, respiratory diseases in pigs result in coughing and in a different sound of coughing due to the different response of the respiratory system when contacting different pathogenic agents. In humans, an experienced physician can identify over 100 different respiratory diseases based on the sound timbre (Korpáš et al., 1996). In animals, veterinarians use a similar approach to detect sick animals when they enter a farm. Their initial impression over the herd is based on visual and auditory observation when they collect information about the welfare, health and productive status of the animals. In this direction, Marx et al. (2003) have studied pig vocalisations related to pain, while Manteuffel et al. (2004) and Schön et al. (2004) have employed vocalisation analysis in livestock farms as a measure of welfare. Similarly,

considerable research has been conducted in the characteristics of pig coughing (e.g. Ferrari et al., 2008), the effect of environmental noise on the cough-frequency features (Van Hirtum & Berckmans, 2003a), in identification of pig coughing based on continuous recordings (e.g. Van Hirtum & Berckmans, 2001) and algorithms have been developed for automatic detection of coughs (e.g. Van Hirtum & Berckmans, 2003b, Exadaktylos et al., 2008a, Exadaktylos et al., 2008b).



Fig. 1. A pen with pigs in a commercial piggery

## 1.1 The problem

Feeding the world with quality assured food remains a significant challenge for the food supply chain within which meat production plays an important role. As countries become more affluent and the world's population continues to rise, demand for meat and other livestock products has grown substantially, according to the Food and Agriculture Organisation (FAO). To be able to satisfy this higher demand for meat products, global animal food production is undergoing a major transformation in the last decades. According to FAO, global meat production was 200 million metric tons in 1999 and an increase of 25% is expected until 2015. Furthermore, in the next 17 years world food production is expected to increase by 62% to feed the world. The highest increase in the 17 years is in meat (42%) (2nd CIGR Conference on Agricultural Research, Iguassu Falls city, Brazil, 2008). This expansion will occur but at the same time with supply, industry will have to deal with concerns over animal and public health from livestock farming and also animal welfare. Finally, this expansion has an important environmental impact.

FAO warns that the risk of disease transmission from animals to humans will increase in the future due to human and livestock population growth, dynamic changes in livestock

production, the emergence of worldwide agro-food networks and a significant increase in mobility of people and goods. In a review of 1407 species of human pathogens, 58% were broadly classified as zoonotic (Woolhouse and Gowtage-Sequeria, 2005), defined by the World Health Organization (WHO) as those diseases and infections which are naturally transmitted between (other) animals and man. Of 177 of 1407 human pathogens that were identified as "emerging", 130 (73%) were zoonotic.

Over the last century, there has been a shift away from livestock production as a highly localised enterprise, where animals were typically born, fattened and slaughtered in the same region. The number of live animals traded for food quintupled in the 1990s, where more than one billion were moved across borders in 2005 (FAO, 2007). Transport of animals from different herds or flocks is ideally suited for spreading disease (FAO, 2002), e.g. the spread of the highly pathogenic avian influenza virus H5N1 in Southeast Asia and the spread of swine influenza viruses in the US.

Crowding of greater numbers of animals into smaller spaces has been identified as a critical factor in the spread and maintenance of disease on the farms (Delgado et al., 2003). In those farms when the environment is inadequate, diseases evolve as endemics at considerable cost and many pathogens are zoonoses (e.g. Strept suis, swine flu, etc. in pigs). Those endemic multifactorial diseases are the major target for drug use in livestock and poultry production. The amount of manure produced by intensive animal husbandry creates a challenge to maintain hygienic standards. Industrialisation of animal production may lead not only to greater animal-to-animal contact, but also to increasing animal-to-human contact, particularly when production facilities border urban areas (Murphy, 1998). Furthermore, Hamscher et al. (2003) demonstrated that antibiotics can also be spread to the environment by dust. Besides environmental effects, there is concern whether the widespread use of antibiotics in animals exacerbates the rising incidence in human pathogens. In the U.S., the society expends US$ 30 billion (more than €20 billion) per year due to the cumulative effects of antimicrobial resistance (Centner, 2003).

In modern pig houses (see Fig 2), animals are grouped in separate compartments ranging in size from 70 animals up to 1000 pigs. Compartments are separately controlled regarding climate control, manure storage, feed supply, etc. Within the same compartment, animals are grouped in pens containing mostly 10 to 16 animals per pen. Pens are separated by 1 meter high walls so that animals have physical contact within one pen but limited contact with animals from neighbouring pens although they are in the same compartment.

These differences in size and the big number of animals per compartment, allow no punctual and individual animal monitoring. The sound analysis approach that we present in this chapter is able to automatically identify cough signals from a continuous sound registration. In this case, the number of coughing incidents will provide some information about the general respiratory health status of the animals in the compartment. However, it will not give any information as to where the coughs are coming from. Respiratory diseases are not only frequent in piggeries (appearing at least once during every growth period of about 130 days), they are also spreading fast within the group and therefore if we know where a disease is originating in a compartment, the veterinarian may decide to take action in a selective way by managing or treating only those animals indicated in the hazard area.

This selective treatment of animals can have multiple benefits both in the short as well as in the long run. Fewer antibiotics will be used that directly translates to a decreased cost for the farm manager. Healthy animals will not be unnecessarily treated and therefore the meat quality will not be affected by any medicament residuals. Extensive use of antibiotics also

results in fast mutation rate of bacteria. This poses a huge threat to the livestock industry in case the antibiotics fail to evolve as fast. Therefore, fewer and 'on time' use of antibiotics may result in reduction of the mutation rate of bacteria and as a consequence reduction of the chances that antibiotics become ineffective.

Economy of scale, transforms this problem of source localisation to a vital one for the pig-farming industry.
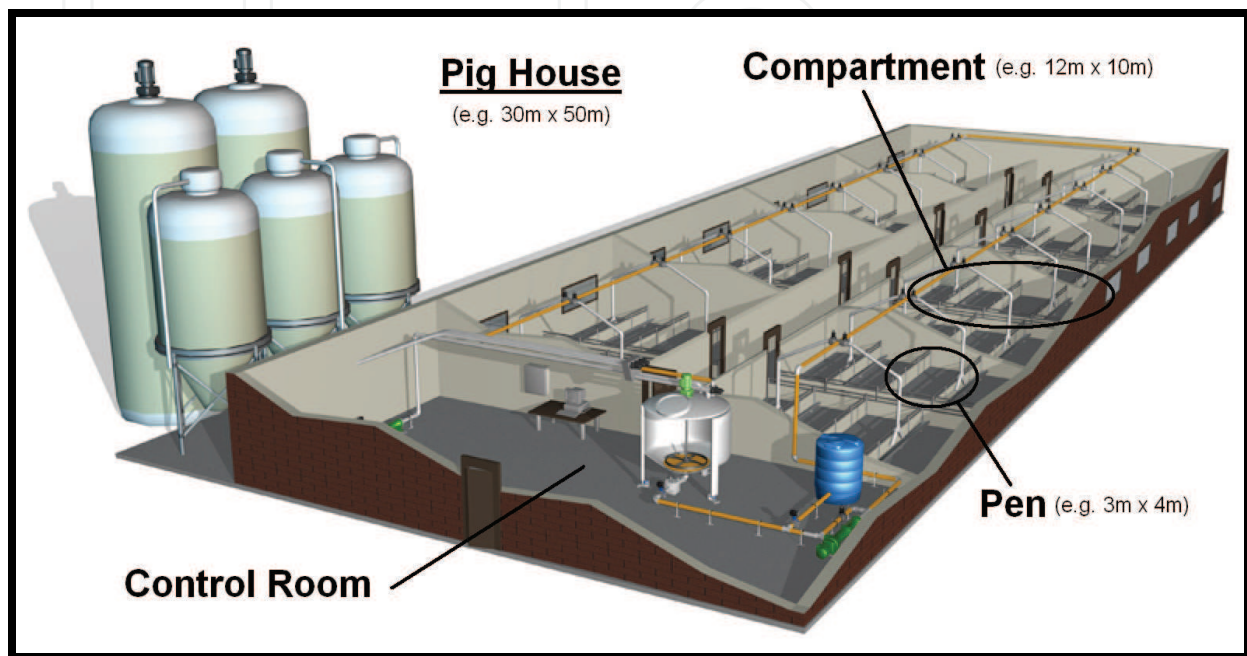


Fig. 2. Schematic overview of a typical layout of a commercial pig house (house > compartment > pen). Schematic courtesy of FANCOM bv. (http://www.fancom.com)

### 1.2 The proposed solution – objective

In order to identify where a disease is occurring within a pig compartment (and more specifically in which pen in a compartment), a system was developed that consists of a real-time sound extraction algorithm, a classification algorithm and a sound localisation algorithm. All three components of the system need to work in synergy in order for the desired outcome, which is the correct localisation of a sick animal in a commercial piggery. The real-time constraint is imposed by efficiency (the farmer or the veterinarian needs to be informed as soon as there is a health issue in a compartment), technical (the data flow is high and makes it impossible to store all the data or communicate it to the veterinarian) and economical (in order to be financially viable for a pig farm, such a system cannot cost more than 0.5€/pig) issues.

### 1.3 Additional restrictions

In intensive commercial piggeries, several housing topologies exist which vary from small compartments housing 70 pigs up to large compartments housing up to 1000 animals, with various ways to split the compartments from each other according to EU directives.

Furthermore, a number of EU directives (e.g. directive 2001/88/EC of 23/10/2001) exist for the amount of space for live animals ranging from 0.15m² for young piglets (<10kg) up to 1m² for larger pigs (>110kg), but this does not imply anything about the topology of the

compartment. The variation in size will also affect the number of the necessary microphones in order to cover the complete space. In addition, the room acoustics will change with time as the animals grow older in cases where the animals are kept in the same space during the growing period, because the pigs will occupy a bigger proportion of the compartment.

Finally, different wall material (can range from steel to wood or concrete) and the type of floor (fully or partially slatted, straw-bedded, concrete, etc., see EU directive 2001/93/EC for the conditions that the floor needs to fulfil) affect the acoustics of the acquired sounds (e.g. reverberation). Moreover, this variation in size and in the number of housed animals affects the number of the microphones that are necessary to cover the complete space. Consequently, for a system to be used in practice, the localisation system must be easily adaptable to different compartment topologies, construction materials and the number of microphones used.

## 2. Method

To fulfil the specifications that were presented, a practical localisation algorithm has been developed that is based on the Time Difference Of Arrival (TDOA) of the signal in multiple microphones (see Fig. 7 for different microphone arrangements). The algorithm accounts for the noisy environment and the uncertainty in the exact time of arrival of the signal at each microphone. The TDOA extraction algorithm is fully automatic (which is necessary for the real-time application of the system) and has been implemented and applied in field experiments.

More specifically, individual sounds are extracted using an algorithm based on the Hilbert Transform. Using the cough classification algorithm, each sound is detected as cough or not. For the sounds that have been detected as cough, each instance from different microphones is subsequently compared and the TDOA is estimated. Finally, the localisation algorithm is based on a weighted sum function that results in an inverse probability matrix for the position of the sound.

Below, each of the three steps is described in detail.

### 2.1 Extraction of individual sounds

In a pig compartment, the level of the recorded sound can vary considerably. In general, sound of higher intensity will be recorded during the day. Additionally, during feeding (in cases where feed is not provided ad libitum) the intensity of the sounds increases considerably due to movement, competition and the urge of pigs to eat. Also, episodes of increased sound intensity occur when someone is entering the compartment (e.g. Moura et al., 2008). To account for these characteristics of the recordings in a pig compartment, a 2-minute window is used for the analysis. More specifically, sound is continuously recorded and is stored in parts of two minutes for each of the microphones used. Then, each group of the recordings is processed.

It should also be taken into account that environmental noise is constantly present in the compartment. For example, low frequency ventilation noise is almost constantly present as well as social vocalisations of the animals, while the sound of the motors for the feeding system also appears periodically during the day. Since previous research has shown that for the cough identification algorithm, the frequency band 0.1-10 kHz is of the most importance (e.g. Exadaktylos et al., 2008a), low frequency ventilation noise can be eliminated by filtering. In this regard, the recording is initially filtered using a 10th order Butterworth filter

with a passband of 0.1-10 kHz. Depending on the classification approach (e.g. Exadaktylos et al., 2008b), the characteristics of the filter can vary. However, this does not affect the performance of the sound extraction algorithm presented here.

The sound extraction algorithm is using the energy envelope (Oppenheim et al., 1999) of the recording. The calculation of the energy envelope of the recording is done using the Hilbert transform (Oppenheim et al., 1999). The Hilbert transform of a discrete time signal s[k] is defined as:

$$H\{s[k]\} = \sum_{n=-N/2}^{N/2} s[n-k]h[n]\sin^2\left(\frac{n\pi}{2}\right) \tag{1}$$

where $h[k] = \dfrac{2}{k\pi}$, for $k = \pm1, \pm2, \ldots, \pm\dfrac{N}{2}$, h[0]=0 and it introduces a 90° phase shift to the original signal. The procedure that is followed to calculate the energy envelope is summarised in the following

1. Calculate the energy of the recorded signal by taking its absolute value
2. Calculate the Hilbert transform of the energy as described in Eqn. 1
3. Add of the energy signal and the Hilbert transform
4. Calculate the square root of the above summation
5. Calculate the moving average of the square root

For the results presented below a moving average with N=100 is used that has empirically shown to provide a good trade-off between smoothing and phase shift.

Subsequently, a threshold is defined and the part of the continuous recording that exceeds this threshold is considered to be a sound. As mentioned above, variations in the sound intensity are expected throughout the day. To account for these, the threshold is automatically chosen for every recording as the average of the energy envelope of the continuous recording for each microphone.

Next, Fig. 3 shows three instances of the described procedure. It can be observed that just after 0.3 s of the beginning of the recording, a very small segment of the signal (that is not part of the sound that needs to be extracted) exceeds the identified threshold while after 0.49 s a very small segment (that is part of the sound) is below the threshold. To correct these possible errors, a minimum length of a sound has been set (0.25 s) along with the distance between two consecutive sounds (0.05 s). If two sounds are closer, then they are considered to be a single sound.

## 2.1 Estimation of the Time Difference of Arrival (TDOA)

After the individual sounds have been extracted, the Time Difference Of Arrival (TDOA) of the sound at the different microphones needs to be estimated. Fig. 4 presents the same sound as has been received by the different microphones where also the TDOA can be observed.

The energy envelope of the signal will be used to estimate the TDOA for each microphone. To get a clearer view of the starting point of a signal, the energy envelope is normalised to have values between 0 and 1. The normalised energy envelope of the same signal as has been received at different microphones is presented in Fig. 5. Defining a threshold as the minimum average value of the energy envelope signals, the arrival time of the signal at each microphone is defined as the time that the energy envelope is exceeding the threshold. Then the TDOA can easily be estimated.
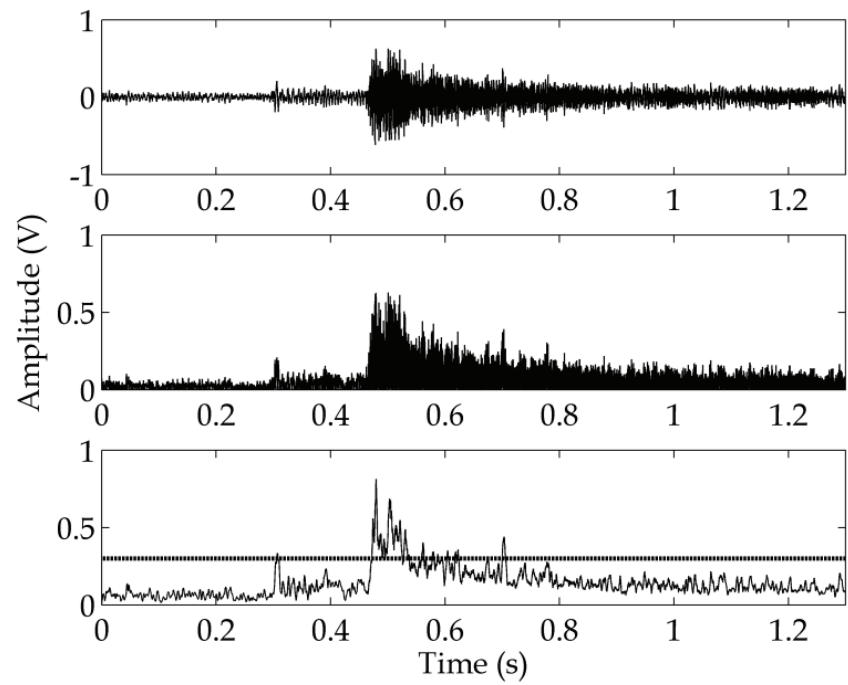
Fig. 3. Three steps in the procedure for extracting a single sound from a continuous recording. The initial/filtered signal (top), the energy of the signal (middle) and the energy envelope (bottom). The automatically chosen threshold is also shown as a horizontal dotted line (bottom)
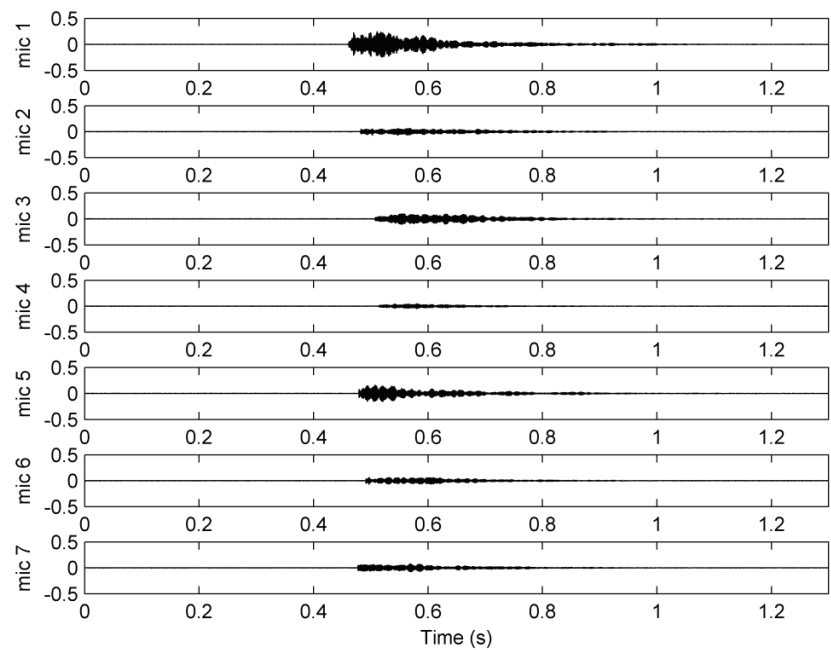


Fig. 4. The recordings of the same signal at 7 microphones in a pig compartment. The amplitude of the signal is in Volts

## 2.1 Sound localisation

Having estimated the TDOA of the signal at each microphone, the position P that the sound has originated from will be calculated.

By multiplying the TDOA with the speed of sound (343.4 m/s at 20°C), a distance $d_\tau$ (distance of the time delay) is calculated. Let us define $d_{p,1}$ and $d_{p,2}$ the distance between the source and microphones 1 and 2 respectively. For the perfect case where the times of arrival have been exactly identified, $d_\tau$ equals the absolute difference between $d_{p,1}$ and $d_{p,2}$. However, the simplicity of the algorithm for estimating the TDOA would not result in a difference that is exactly zero.

To estimate the probability that a sound originates from a specific point, the test field is divided into a grid with the necessary resolution. In this case, we have a resolution of 0.1m that is considered adequate of our application since the objective is to identify the pen in which the sick animal is located and treat all the animals in the same pen (and maybe those of the neighbouring pens) and not only the sick animal. Even if the algorithm provides more accurate results, the movement of the pigs makes the additional accuracy unnecessary. Then the following weight is calculated for every point of the grid:

$$w_{(k,l)} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left| \left( d_{(k,l),i} - d_{(k,l),j} \right) - d_{t(i,j)} \right|$$  (2)

where $w_{(k,l)}$ is the weight at position $(k,l)$, $\left( d_{(k,l),i} - d_{(k,l),j} \right)$ is the difference in distance between position $(k,l)$ and microphones i and j, $d_{\tau,(k,l)}$ is the time delay distance between the signal as it arrived at microphones i and j, and n is the total number of microphones that are used. A visual 3D representation of the normalised w matrix is given in Fig. 6. In this graph, the inverse probability that the sound has originated from a point is given. The lowest point identifies the point in the grid from which the sound has most probably originated.

In an ideal context, the above algorithm is simplified to finding the position P in which the weight $w_P$ is zero. However, this would require an exact estimation of the TDOA. In contrast, this algorithm can produce accurate results (with an accuracy of about 1 m) without an exact estimation of the TDOA. This can also be seen in Fig. 6 by examining the shape of the 3D curve. If there was a very accurate estimation of the TDOA, the curve would have the value zero at its lowest point and monotonically increase as it goes away from that point. However, in this particular example, this is the case only for an area around the global minimum. Going further, the curve has local minima and maxima that contradict the ideal expected behaviour.

## 3. Results

### 3.1 Localisation of triangle sounds

To test the accuracy of the developed algorithm, triangle sounds were produced in a pig compartment with known dimensions and microphone positions as in Fig. 7. Triangle sounds are used for the development and tuning of the algorithm because they are sharp enough and provide the best case that could occur in practice. Later, the algorithm is tested in a real situation.
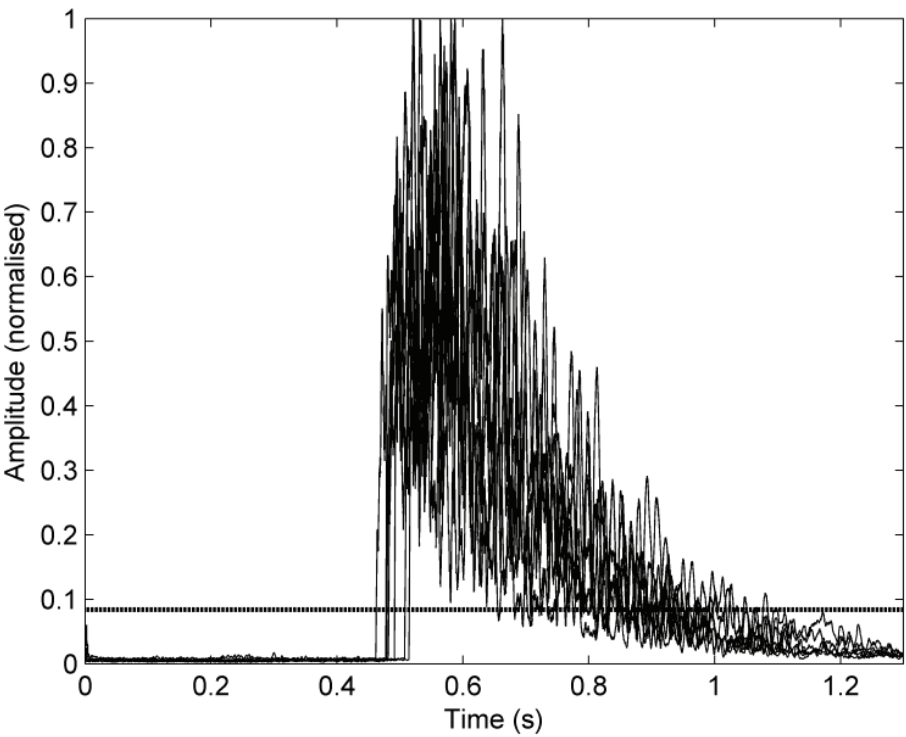
Fig. 5. Normalised energy envelope of a sound received by different microphones (solid lines). The automatically detected threshold is also shown (horizontal thick dotted line)
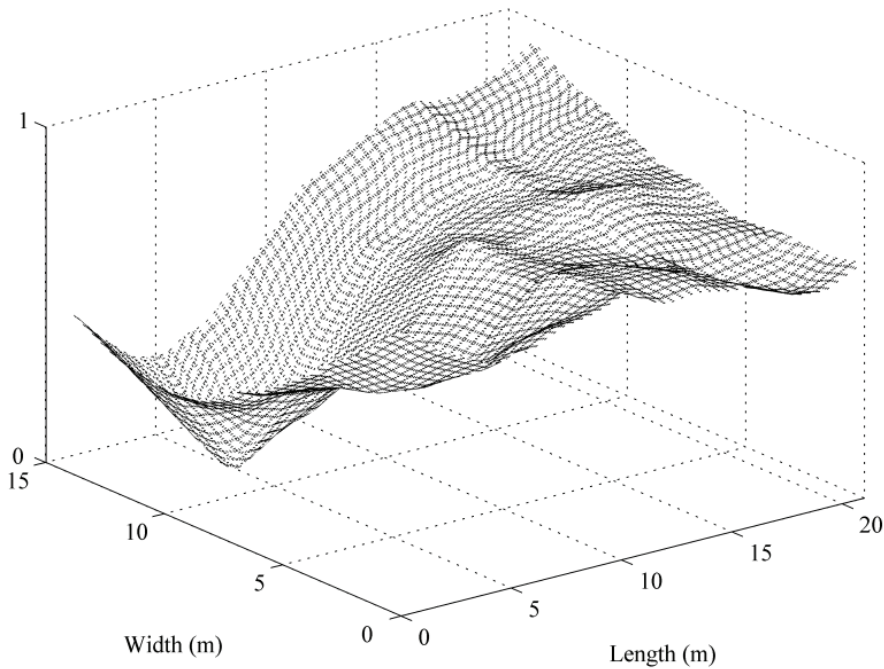
Fig. 6. Visual representation of the weight at every point of the grid. The lowest value on the graph is the estimated position from which the sound originated

For Experiments 1 and 3, six microphones were positioned against the walls at a height of 2 m, while Experiment 1 had an additional microphone hanged in the middle of the compartment at the same height. In Experiments 2 and 5, only a fraction of the compartment was covered with the microphones either hanged or placed against the wall at a height of 2 m. In Experiment 4, the microphones were hanged 2 m above the ground above the pens. Finally, in Experiment 6, two microphones were focused on half of the compartment while two more were placed over the corridor collecting sounds from the complete compartment. All experiments had a duration of 15 minutes with a total recording of 41 triangle sounds at known positions.

Each continuous recording was processed with the algorithms described above, the individual sounds were automatically extracted and location of the sound was estimated. In all cases, the real position of the triangle sound was within the area that is defined by the microphone positions. An overview of the average error is given in Table 1, while Table 2 presents the detailed results for Experiment 1.

It can be seen that the maximum error in all the experiments is less than 2 m and the average less than 1 m. This level of accuracy is considered adequate for this specific application because the vet only needs to know in which pen sick animals are, so that only animals in that pen and maybe in the two neighbouring pens are treated. Animal movement makes it impossible to identify the exact animal that is coughing because a possible alarm can only be provided after a significant increase in the number of coughing sounds. With the current accuracy of the algorithm, it is possible that a cough is identified in a neighbouring pen than the one it has occurred. This is still acceptable because in practice most probably pigs in neighbouring pens will also be treated since most of the time two adjacent pens share the same trough and animals are in close contact.

|              | Maximum Error (m) | Average Error (m) | Standard Deviation (m) |
|--------------|-------------------|-------------------|------------------------|
| Experiment 1 | 1.98              | 0.49              | 0.44                   |
| Experiment 2 | 1.70              | 0.74              | 0.52                   |
| Experiment 3 | 1.41              | 0.78              | 0.28                   |
| Experiment 4 | 0.92              | 0.70              | 0.19                   |
| Experiment 5 | 0.60              | 0.34              | 0.16                   |
| Experiment 6 | 1.08              | 0.75              | 0.22                   |

Table 1. Overview of the performance of the localisation algorithm for the different experiments

## 3.2 Localisation of real coughs in a livestock house

Using the microphone topology of Experiment 1, sound was recorded using 7 microphones for 3h. During the recording period an expert was using audio-visual observation being in the livestock house to observe the compartment and identified the pens in which every one of the coughs occurred. Subsequently the same expert listened to all the recordings from which 19 cough attacks, counting for a total of 179 individual coughs, were extracted. The number of individual coughs in a cough attack varied from 2 up to 23 coughs.

The sound extraction and localisation algorithm was then applied to the extracted cough attack signals. The individual coughs were automatically extracted and localised. The position of the cough attack was then defined as the average of the position of each of the coughs.
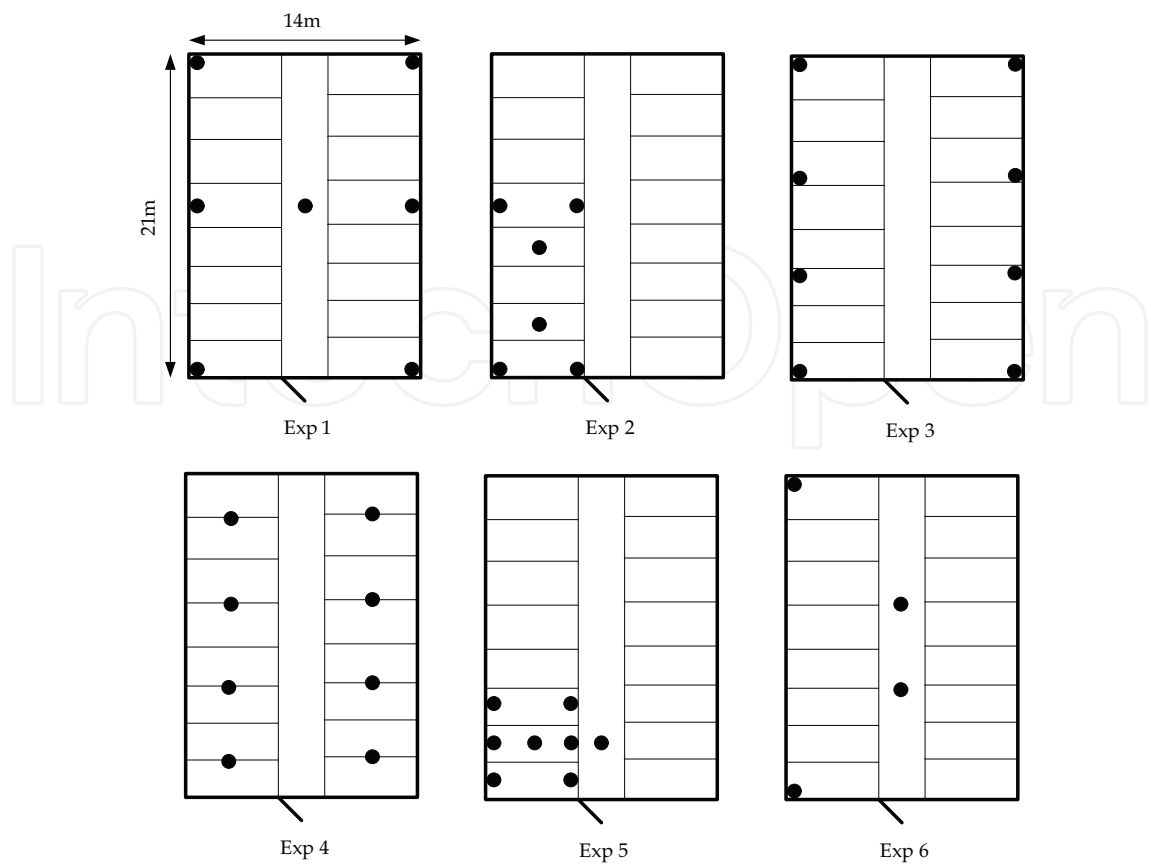
Fig. 7. Top view planimetry of multiple boxes for a swine building with dimensions 14x21m. Microphone positions are indicated with dots for each of the conducted experiments

| Sound | Real (x,y) coordinates (m) | Estimated (x,y) coordinates (m) | Error (m) |
|---|---|---|---|
| 1 | (10.8,1.3) | (10.0,1.9) | 1.0 |
| 2 | (10.8,3.9) | (10.8,3.9) | 0.0 |
| 3 | (10.8,6.5) | (12.1,5.9) | 1.4 |
| 4 | (10.8,9.2) | (11.0,9.0) | 0.3 |
| 5 | (10.8,11.8) | (11.3,11.9) | 0.5 |
| 6 | (10.8,14.4) | (11.4,15.0) | 0.8 |
| 7 | (10.8,17.0) | (10.7,17.0) | 0.1 |
| 8 | (10.8,19.7) | (11.2,19.5) | 0.4 |
| 9 | (3.2,1.3) | (0.1,0.1) | 3.3 |
| 10 | (3.2,19.7) | (3.1,19.2) | 0.5 |
| 11 | (3.2,17.0) | (2.0,16.6) | 0.6 |
| 12 | (3.2,14.4) | (3.0,14.6) | 0.3 |
| 13 | (3.2,11.8) | (2.7,11.7) | 0.5 |
| 14 | (3.2,9.2) | (0.1,0.1) | 9.6 |
| 15 | (3.2,6.5) | (2.7,6.3) | 0.5 |
| 16 | (3.2,3.9) | (2.7,4.1) | 0.5 |

Table 2. Detailed results for Experiment 1. The real and estimated positions of each triangle sound are shown along with the localisation error in meters.

The expert that was observing the compartment during the recording identified 1 cough attack in pen number 4, 3 in pen number 5, 6 in pen number 8, 1 in pen number 15 and 8 cough attacks in pen number 16. The automatic localisation result is visualised in Fig. 8 were the black stars depict cough attacks that were estimated to originate from the pen that they actually did and white stars represent cough attacks that were estimated to originate from a neighbouring pen.

The above suggests that 3 cough hazards may exist in the compartment, 2 at the sides of the compartment below the windows (pens 8 and 16) and 1 in the middle of the compartment (around pen number 5). From this experiment, it can be concluded that a good estimate of the areas where coughing animals are located can be estimated using the proposed algorithm.

### 3.3 Fully automatic identification and localisation of pig coughs

As already mentioned above, the objective of the development of this localisation algorithm is to identify the locations of coughing pigs in a pig compartment. To achieve this, the sound extraction algorithm presented above is coupled to a cough identification algorithm and if the acquired signal is a cough then the presented localisation algorithm is used to estimate the position that the sick cough originated from.

This fully automatic algorithm has been applied to the recordings of the previous subsection. Using the algorithm of Exadaktylos et al. (2008b), about 50% of the manually labelled cough sounds were correctly identified by the algorithm and subsequently the result is visualised in Fig. 9, where the dark areas identify potential cough hazards. Although this level of accuracy is fairly low for identification standards, it does present an improvement with the current situation where real-time monitoring is impossible due to the large number of animals per compartment and the big number of compartments in commercial intensive pig farming. Furthermore, it is expected that sick animals will cough repetitively and therefore the system will be able to detect a hazard. Comparison of Fig. 9 with Fig. 8 shows that 2 out of the 3 hazards have been correctly identified. The reason for
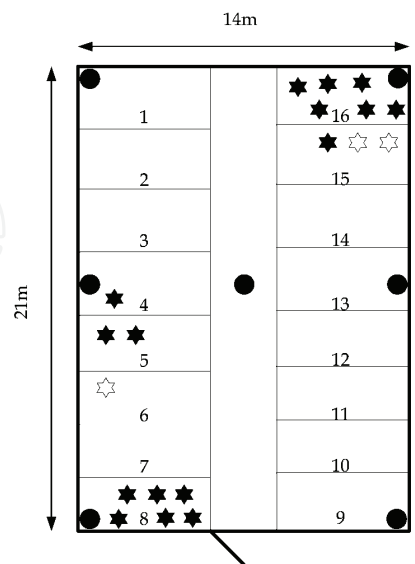


Fig. 8. Localisation result for cough attacks that were manually identified and automatically localised. Black stars show the cough attacks that were localised in the exact pen. White stars show cough attacks that were identified coming from a neighbouring pen.
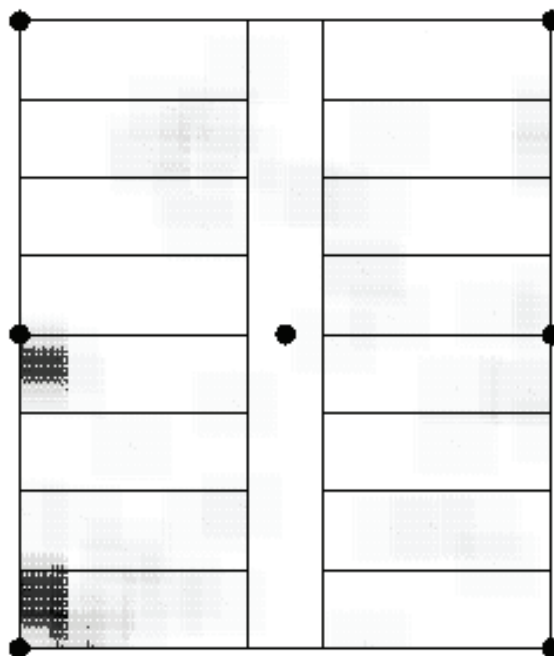
Fig. 9. Result of the combined cough identification and localisation algorithms. The dark areas identify potential cough hazards

not identifying the cough hazard near pen number 16 can be either due to the identification or the localisation algorithm.

In general, coughs are expected to occur repeatedly if an animal is sick or a disease is spreading. Therefore, the relatively low identification ratio (50%) can still be used for practical application of the system. It is claimed that application of the described system can provide a good and quick overview of the respiratory health status in animal housing (Fig. 9) that can lead to better management of the herd.

## 4. Shortcomings and future research

In the present chapter, we have presented the development process for a specific localisation algorithm application. As mentioned above, there are a number of choices to be made in the process about the different components of the system. Clearly, a different approach could include a more sophisticated TDOA detection algorithm and a less robust localisation algorithm. Our choice was based on the fact that many different practical issues (e.g. different building material) would require long calibration procedures for a very accurate TDOA estimation. The simplicity and robustness of our approach should still prove itself under different building conditions. Furthermore, sound deflection and reverberation was not taken into account in this study and is one of the key elements that should be further tested. Techniques to deal with reverberation have been developed (e.g. Marro et al., 1998; Gustafsson et al., 2003) and it is expected that if necessary can be integrated in our system.

The redundancy in the number of microphones used is an acceptable cost for research purposes. However, it may be very expensive in a real commercial setup where the cost needs to be kept below 0.5€/pig. To maintain the algorithm performance and reduce the number of microphones used, existing techniques for improving signal quality can be used. More sophisticated filtering or beam-forming (e.g. Krim & Viberg, 1996) are two options.

However, further development of the localisation algorithm should be performed in parallel with the cough identification algorithm since the individual blocks of the system are coupled. Any distortion or alteration of the signal must be linked with the rest of the steps in the system.

## 5. Conclusion

The present chapter has presented a system that can be used for continuous automatic health monitoring in commercial piggeries. Coughing is the main symptom of respiratory problems in pigs. In order to develop a monitoring system, a cough identification algorithm has been previously developed. In order to identify the pen in which a sick pig is located, a localisation algorithm has also been developed.

The harsh environment of a commercial piggery, along with the differences among the different piggeries requires a simple and robust localisation algorithm that can be individually adapted for the building topology and acoustics. This work has presented the development process, starting from concept, defining the specifications, and finally developing an algorithm for this specific application.

By adapting the identification algorithm, the application of this specific localisation algorithm can be extended to monitor respiratory health and welfare issues in livestock production beyond pigs, such as cattle and poultry.
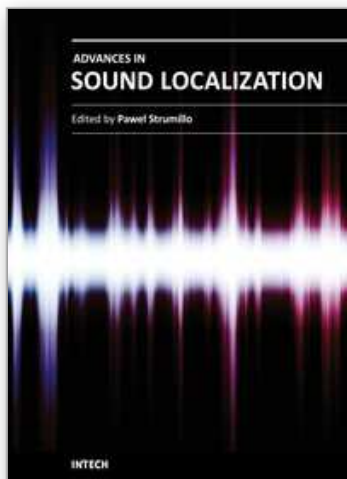
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**Advances in Sound Localization**

Edited by Dr. Pawel Strumillo

Sound source localization is an important research field that has attracted researchers' efforts from many technical and biomedical sciences. Sound source localization (SSL) is defined as the determination of the direction from a receiver, but also includes the distance from it. Because of the wave nature of sound propagation, phenomena such as refraction, diffraction, diffusion, reflection, reverberation and interference occur. The wide spectrum of sound frequencies that range from infrasounds through acoustic sounds to ultrasounds, also introduces difficulties, as different spectrum components have different penetration properties through the medium. Consequently, SSL is a complex computation problem and development of robust sound localization techniques calls for different approaches, including multisensor schemes, null-steering beamforming and time-difference arrival techniques. The book offers a rich source of valuable material on advances on SSL techniques and their applications that should appeal to researches representing diverse engineering and scientific disciplines.

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