Poster Session | Others (including the category of JSAM and SASJ)
[6-1130-P] Other Categories (6th)
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[6-1130-P-15] Sound Source Localization in Pig Houses Using Wireless Microphone Array and Its Accuracy by Microphone Arrangements

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Keywords: swine sneezing, respiratory disease, monitoring system, wireless, sound source localization

The recent increase in breeding density due to intensive management of swine leads to an expanding risk of highly infectious respiratory infections. In particular, Porcine Reproductive and Respiratory Syndrome (PRRS) is the main factor inhibiting production in swine farming. Thus, early detection of PRRS is an essential issue in the management of group-housed livestock. In order to achieve early detection, our research group developed a system to detect PRRS automatically. The developed system utilizes a relationship that a frequency of cough and sneezing in swine increases as it is infected by disease, and monitors the sounds in a pig house using multiple microphones to localize the sneezing swine. However, the wiring to connect microphones has been a barrier to deploy a system in pig houses.In this study, we developed a monitoring system using wireless microphones to make the system deployment more flexible. On deploying the wireless monitoring system to a large space, the degradation of the communication quality affects detection of sneezing sound and sound source localization. Therefore, we examined a relationship between an installation position of the wireless microphones and the localization accuracy. Specifically, sound source localization was performed using developed wireless microphones and sound source that emits an actual sneezing sound of swine by changing two parameters: the source-microphone distance (l), and the microphone-receiver distance (d). The obtained results suggest that the measurement error increases as the source-microphone distance (l) increases, while measurement error did not change although the microphone-receiver distance (d) increases. The first result indicates that the localization accuracy was enough (within 0.4 m) when (l) is 4 m or less, and the second result indicates that the wireless microphones can be deployed in a large space. We also deployed the proposed wireless acoustic wave sensor in a pig house to perform a two-week swine influenza infection experiment. In this experiment, the source-microphone distance (l), and the microphone-receiver distance (d) were set as 2 m and 3 m, respectively. We found that the proposed sensor works for two weeks and can localize the sneezing swine within an accuracy of 0.2 m.

Sound Source Localization in Pig Houses Using Wireless Microphone Array and Its Accuracy by Microphone Arrangements

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ABSTRACT

Porcine reproductive and respiratory syndrome (PRRS) is a main factor inhibiting production of swine farming and, early detection of PRRS is an essential issue in the management of group-housed livestock. To achieve early detection, our research group developed a system to detect PRRS automatically, which detects cough and sneezing of swine acoustically using wired microphones. However, the wiring becomes a barrier to deploy a system in a pig house smoothly. In this study, we develop a monitoring system using wireless microphones to make the system deployment more flexible. When deploying the wireless monitoring system to a large space, the degradation of the communication quality affects detection of sneezing sound and sound source localization. Therefore, we analyzed a relationship between an installation position of the wireless microphones and the localization accuracy. To evaluate the proposed system, we performed experiments both in laboratory and pig house. As results, we found that the proposed wireless system reduces the load of workers much for system deployment, Furthermore, the proposed system achieves enough quality of sound source localization, while ensuring the system flexibility.

Keywords: swine sneezing, respiratory disease, monitoring system, wireless, sound source localization

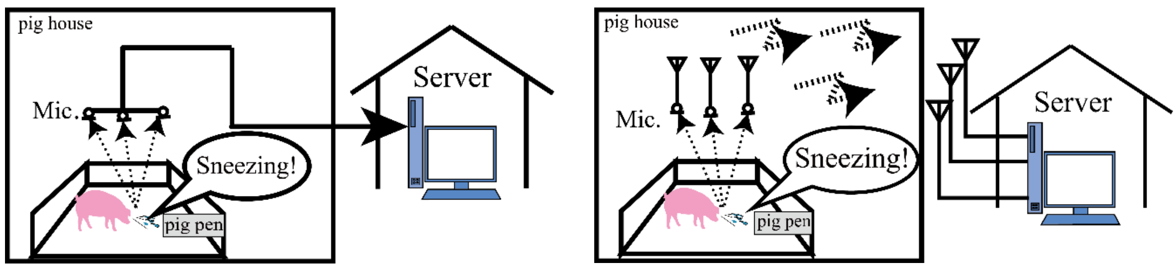
1. INTRODUCTION

Recent increase in breeding density of swine due to intensive management leads to an expending risk of highly infectious respiratory infections (Frost *et al*., 1997). Among them, porcine reproductive and respiratory syndrome (PRRS) is an important swine disease worldwide, since it prevents production in swine farming resulting in the highest economic impact in swine industry (Shimizu *et al*., 1994). Therefore, early detection of PRRS is an important issue in pig farming. To detect PRRS in early stage, several techniques, such as antibody testing (Scott *et al*., 1997), PCR testing (Duinhof *et al*., 2011), and monitoring weight gain (Destajo *et al*., 2007) have been proposed. However, these techniques require high-cost reagents, laboratory equipment, or human resources that become a barrier to utilize these technologies in a commercial pig farm.

On the other hand, it was found that the acoustical information can also become an important indicator of PRRS. Specifically, it has been reported that the increase of frequency of sneezing and cough of swine increase as the swine is infected by PRRS (Shimizu *et al*., 1994 and Exadaktylos *et al*., 2008). Hence, methods of sound source localization of cough sounds (Silva *et al.*, 2008) and sneezing sounds (Kawagishi *et al.*, 2014) have been proposed to gather information about the health of swine automatically. A procedure of sound source (sneezing swine) localization is as follows; (1) several microphones are deployed in a pig house, and the internal sound of the pig house is continuously monitored, (2) when a pig sneezes, a sneezing sound is recorded by microphones, (3) the system detects the sneezing sound and calculates time-difference-of-arrivals (TDoAs) of multiple signals by calculating cross-correlation function between receiving signals, and (4) localizes the sound source from direction-of-arrival (angle-of-arrival) using TDoAs and position of the microphones.

Although sound source localization in pig houses has been found to become a viable alternative that achieves early detection of PRRS, there exists a margin for improvement especially in the transmission of acoustic signals recorded by the microphones. In the existing system [Fig. 1(a)], the microphones are connected to the system by wire, which becomes a barrier to deploy the system in pig house that requires human resources and time (wires of length 5–10 m should be placed near a ceiling of the pig house to avoid damages by swine and daily work). If we can remove such wiring by transmitting acoustic signals using radio wave [Fig. 1(b)], we can make the sound source localization system more flexible. However, the quality of the sound source localization would be affected by the quality of wireless radio transmission. Hence, in this study, we design a sound source localization system using wireless microphones and evaluate the quality of the sound source localization by changing two parameters; the source-microphone distance (l) and the microphone-receiver distance (d). Furthermore, we deploy the system in a pig house and perform monitoring for two weeks.

The remaining of this paper is as follows. Section 2 overviews the existing sound source localization system and the proposed (wireless) system. Section 3 evaluates the quality of the proposed sound source localization system in a laboratory. Section 4 evaluates the performance of the proposed system in a pig house. Section 5 concludes this work.



(a) (b)

Figure 1. Outline of acoustic monitoring system of swine; (a) existing and (b) proposed (wireless) system.

2. OVERVIEW OF SOUND SOURCE MONITORING SYSTEM

2.1 Existing (wired) sound source monitoring system

Figure 2 shows the existing (wired) sound source monitoring system. As shown in the figure, we set K microphones (K: positive integer and K=3 in the figure) at relative position of (x_k, y_k) (k = 0, 1,…, K-1). A relative position of the sound source is set as (x_s, y_s). When the sound source emits the sound (sneezing sound), the sound propagates and recorded by the microphones [the recorded sound at microphone #k is defined as $r_k(t)$]. The server judges whether $r_k(t)$ contains a sneezing sound or not by comparing the recorded signal and template (sample of sneezing sound) in the frequency domain. If the sneezing sound is detected, the server calculates cross-correlation functions between $r_k(t)$ and $r_m(t)$ ($m = 0, 1, \ldots, K$-1 and $m \neq k$), $s_{km}(t)$, where

$$s_{km}(t) = \sum r_k(n) r_m(t-n). \tag{1}$$

Then the server calculates time-difference of TDoAs, u_{km}, by measuring the peak shift of $s_{km}(t)$. Finally, the server finds (x_s, y_s) that satisfies the following simultaneous equation for all m and k.

$$\sqrt{(x-x_m)^2+(y-y_m)^2} + cu_{km} = \sqrt{(x-x_k)^2+(y-y_k)^2}. \tag{2}$$

Note that the above equation represents a hyperbolic curve determined by (x_k, y_k), (x_m, y_m) and u_{km}, as shown in Fig. 3, and c is a sound velocity.

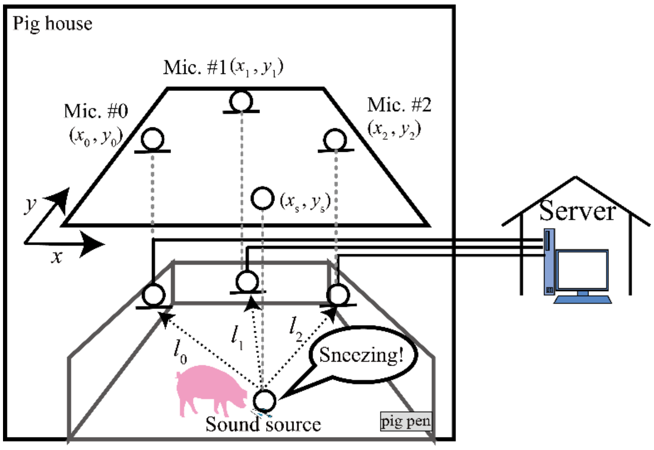


Figure 2. Existing (wired) sound source monitoring system.

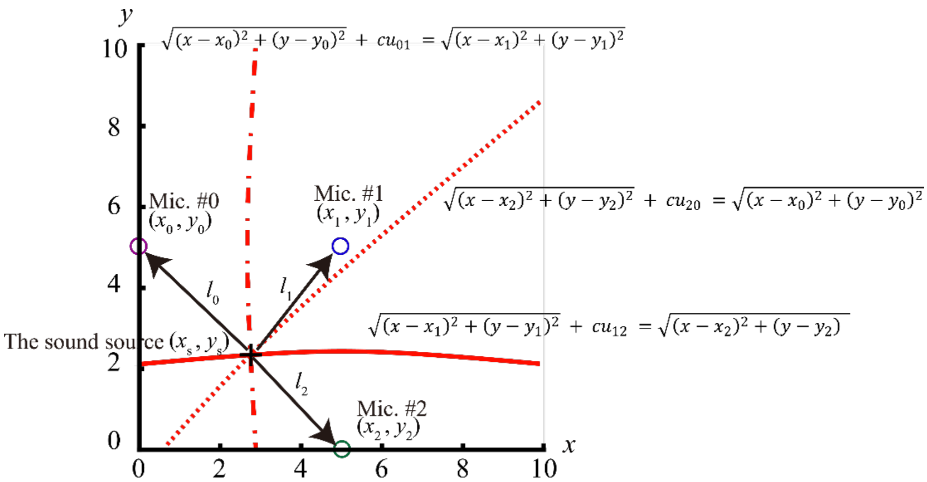


Figure 3. Relationship among (x_s, y_s), (x_m, y_m), (x_k, y_k), and cu_{km} when $K = 3$.

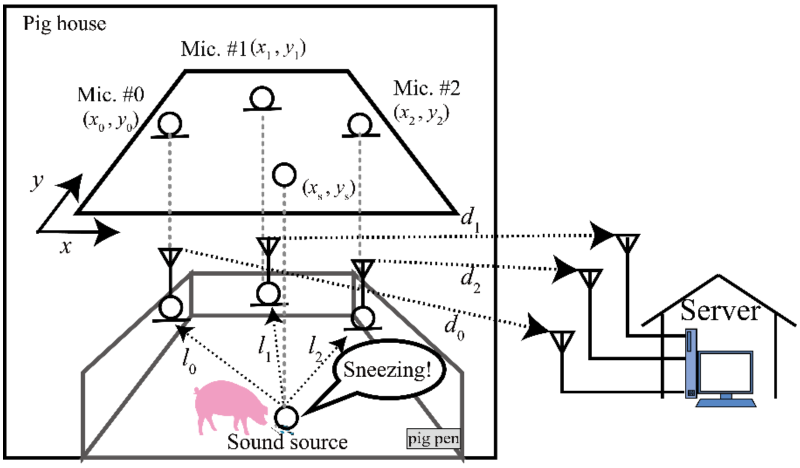


Figure 4. Proposed (wireless) sound source monitoring system.

2.2 Proposed (wireless) sound source monitoring system

In this paper, we design a sound source localization system using wireless microphones, as shown in Fig. 1(b) and Fig. 4. When the sound source emits the sound, the sound propagates and recorded by the microphones. The radio transmitter #k that is connected to the microphone #k modulates the radio frequency of f_k by the recorded sound (frequency modulation) and emits as the radio signal. The radio receiver #k that is connected to the server receives and demodulates the signal from the transmitter #k and the server obtains $r_k(t)$. Note that the radio frequency f_k should be independent to avoid signal interference. A procedure of the sound source localization is the same to that of the existing system. However, in this system, the quality of the sound source localization is affected by two noise sources (environmental noise and transmission noise), as shown in Fig. 4. If the distance between sound source and microphone #k, l_k, becomes large, the system can observe wide area in exchange for the signal-to-noise ratio of $r_k(t)$. Furthermore, if the distance between microphone #k and the server, d_k, becomes large, the system can cover a large pig house in exchange for the signal-to-noise ratio (SNR) of $r_k(t)$. Hence, the quality of the sound source localization of the proposed system should be evaluated by changing two parameters; the source-microphone distance (l_k) and the microphone-server distance (d_k).

3. PERFORMANCE EVALUATION OF THE PROPOSED SYSTEM IN LABORATORY

3.1 Experimental environment

We evaluate the performance of the proposed system in a laboratory. Figure 5 shows the experimental environment. As shown in the figure, the experiment is performed in a room whose size is 7.68×7.35×3.44 (m^3). We set three microphones with a radio transmitter (88-108MHz, diymore) at a height of 1.5 m from the floor. The carrier frequency of each transmitter is 95, 88, and 101 (MHz), respectively. We also put three radio receivers (RAD-P088S, AudioComn) that are connected to the analog-to-digital converter (USB-6221, National Instruments). The signal processing is performed on a server (ThinkPad X250, Lenovo). Furthermore, we set a speaker (S-300HR, TEAC) on the floor as the sound source. As emitting sound, we use a recorded sound of swine sneezing whose sound pressure level is the same of the swine (2.1 Pa).

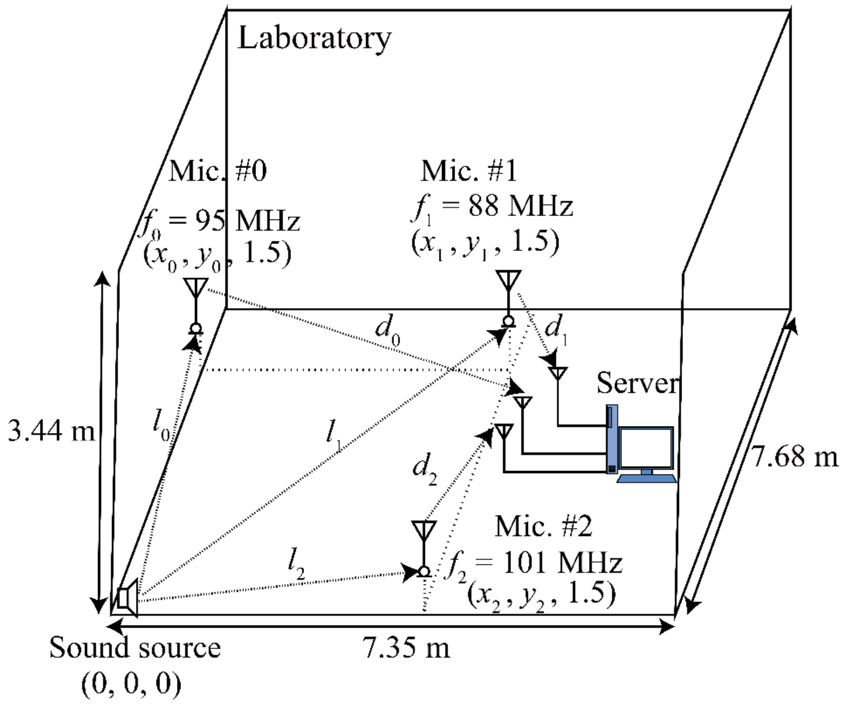


Figure 5. Experimental environment (laboratory).

Table I. Parameters of l_k and d_k used in experiment in laboratory.

<table>
<tr><th></th><th></th><th>l_0 (m)</th><th>l_1 (m)</th><th>l_2 (m)</th><th>d_0 (m)</th><th>d_1 (m)</th><th>d_2 (m)</th></tr>
<tr><td rowspan="5">Experiment I</td><td>(i)</td><td>1.0</td><td>1.4</td><td>1.0</td><td rowspan="5">2.0</td><td rowspan="5">2.0</td><td rowspan="5">2.0</td></tr>
<tr><td>(ii)</td><td>2.0</td><td>2.8</td><td>2.0</td></tr>
<tr><td>(iii)</td><td>3.0</td><td>4.2</td><td>3.0</td></tr>
<tr><td>(iv)</td><td>4.0</td><td>5.6</td><td>4.0</td></tr>
<tr><td>(v)</td><td>5.0</td><td>7.0</td><td>5.0</td></tr>
<tr><td rowspan="5">Experiment II</td><td>(i)</td><td rowspan="5">1.0</td><td rowspan="5">1.4</td><td rowspan="5">1.0</td><td>1.0</td><td>1.0</td><td>1.0</td></tr>
<tr><td>(ii)</td><td>2.0</td><td>2.0</td><td>2.0</td></tr>
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<tr><td>(v)</td><td>5.0</td><td>5.0</td><td>5.0</td></tr>
</table>

In this experiment, we evaluate the quality of the sound source localization of the proposed system by changing the source-microphone distance (l_k) and the microphone-server distance (d_k). At first, the sound source localization is performed by changing l_k with a specific value of d_k (Experiment I). Then the sound source localization is performed by changing d_k with a specific value of l_k (Experiment II). Table I shows the parameter combinations of l_k and d_k used in the experiment. During the experiment, we also measure the SNR of $r_k(t)$, as well as the quality of the sound source localization (localization error).

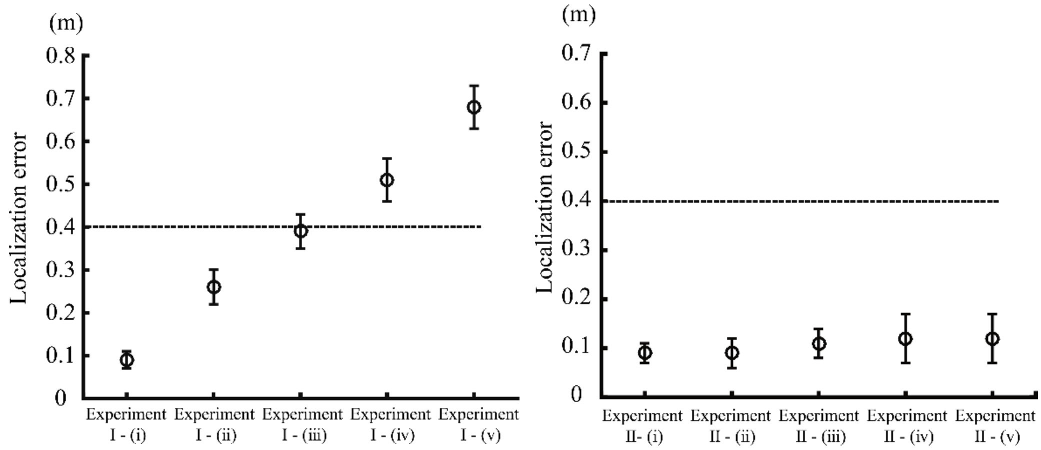
3.2 Experimental results and discussions

Figure 6 and Table II show the experimental results. Figures 6(a) shows a relationship between sound source localization error and source-microphone distance (l_k). Figures 6(b) shows a relationship between sound source localization error and microphone-server distance (d_k). Table II shows a relationship between SNR and source-microphone distance (l_k) and microphone-server distance (d_k).

From this experiment, we found that the distance between sound source and microphone is a main factor that affects the quality of the sound source localization. Specifically, the localization error increases as the source-microphone distance (l_k) increases, while the localization error does not change much even if the microphone-server distance (d_k) increases [Fig. 6(a)]. Furthermore, the SNR decreases as the source-microphone distance (l_k) increases, while that does not change much even if the microphone-server distance (d_k) increases [Table II].

Next, we focus on the value of the localization error. In previous studies, it was found that the localization error should be less than 0.4 m to detect a sneezing swine individual from a group of pigs in a pig pen (Kawagishi *et al.*, 2014). From Fig. 6, we found that the source-microphone distance (l_k) should not over 3 m while the microphone-server distance (d_k) can be set flexible within 5 m.

Consequently, we found that the quality of the sound source localization would not be affected by the quality of wireless radio transmission.



(a) (b)

Figure 6. Experimental results obtained in laboratory; sound source localization error obtained in (a) Experiment I and (b) Experiment II.

Table II. SNR of $r_k(t)$ obtained in Experiment I and II.

	Experiment I					Experiment II				
	(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)	(v)
SNR (dB)	28.1	26.0	23.8	23.1	22.27	28.1	28.0	28.3	28.5	29.3

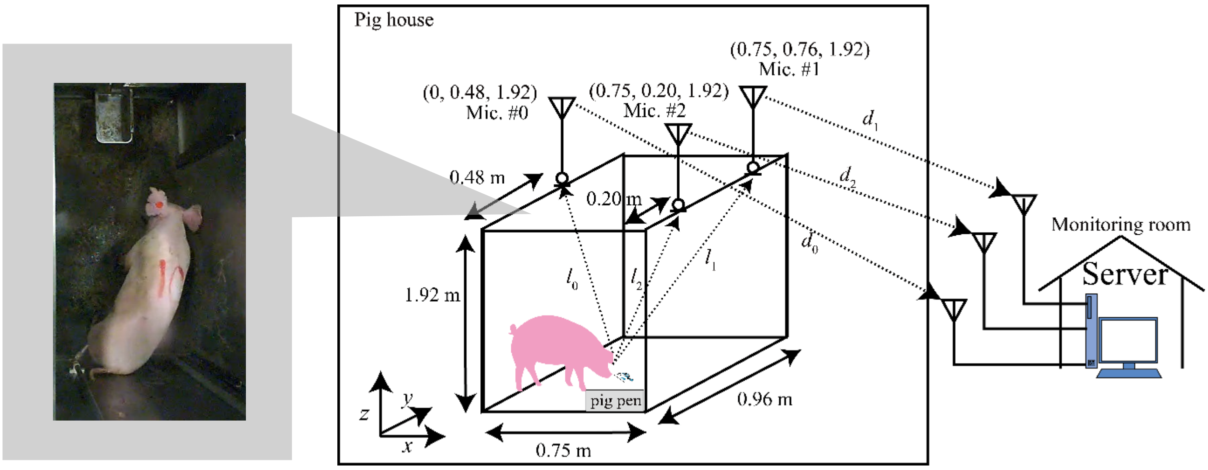


Figure 7. Experimental environment (pig house).

4. PERFORMANCE EVALUATION OF THE PROPOSED SYTEM IN PIG HOUSE

4.1 Experimental environment

We evaluate the performance of the proposed system in a pig house. Figure 7 shows the experimental environment. As shown in the figure, the experiment is performed in a pig house of National Institute of Animal Health, National Agriculture and Food Research Organization whose size is 1.35×3.45×2.05 (m^3). As well as Section 3, we set three microphones with a radio transmitter at a height of 1.92 m from the floor. The microphone-server distance (d_0, d_1, d_2) was set to 2–3 m, the source-microphone distance (l_0, l_1, l_2) is set as 2.1–2.2 m. Note that l_k and d_k satisfy the values that achieve localization error of less than 0.4 m in Section 3. The carrier frequency of each transmitter is the same to that used in preliminary experiment. We also put three radio receivers (RAD-P088S, AudioComn) that are connected to the analog-to-digital converter (USB-6221, National Instruments) on an adjacent monitoring room. The signal processing is performed on a server (i5-4690 CPU, RAM 16GB). Different from the preliminary experiment, the sound source is a weaned piglet (8 week old) (Takemae *et al.*, 2018).

In this experiment, we deploy the proposed system and existing (wired) system, while measuring the length of time for system deployment. Furthermore, we evaluate the quality of the sound source localization of the proposed system for two weeks. We also evaluate the quality of the sound source localization of the existing system as reference.

4.2 Experimental results and discussions

The length of time for proposed system deployment was approximately 30. Min. by one worker, while that for existing system deployment was approximately 120 min. by three workers. We found that the proposed wireless system is much easier than the existing system, since there is no need to install long cables in a pig house.

During the experiment, both the proposed system and existing system work successfully for two weeks. During the experiment, both system detected the swine sneezing 10 times. Figure 8 shows an example of sound source localization result by the proposed system [Fig. 8(a)] and existing system [Fig. 8(b)]. From this figure, we found that the proposed system and existing system achieve localization error of 0.2 and 0.25 m, respectively. This means that the sound source localization system using wireless microphones achieves almost the same quality of that using wired microphones, while ensuring the system flexibility.

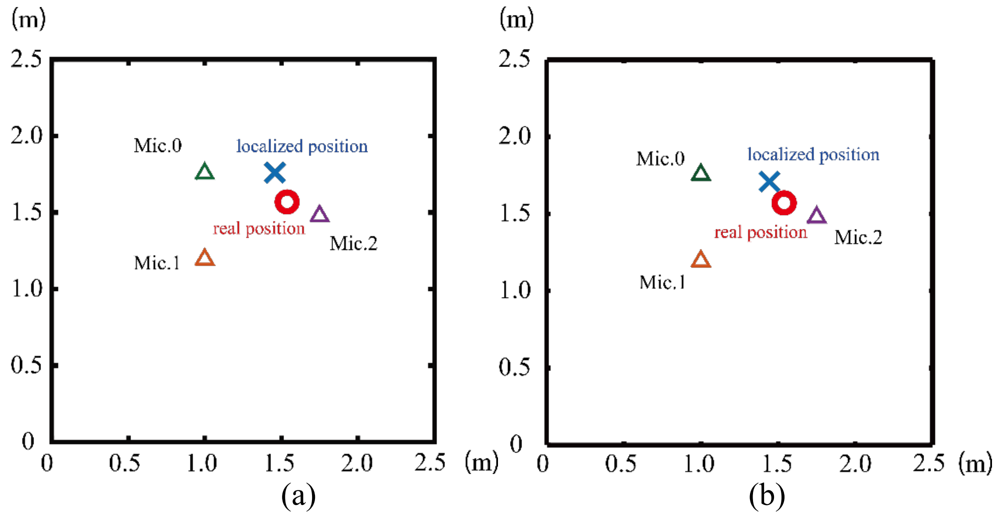


Figure 8. Example of sound source localization result obtained in pig house; localization error of (a) proposed system (wired) and (b) existing system (wireless).

5. CONCLUSIONS

In this paper, we develop a monitoring system using wireless microphones to make the system deployment more flexible. When deploying the wireless monitoring system to a large space, the degradation of the communication quality affects detection of sneezing sound and sound source localization. Therefore, we analyzed a relationship between an installation position of the wireless microphones and the localization accuracy. To evaluate the proposed system, we experiment both in laboratory and pig house. In the experiment in the laboratory, we evaluate the quality of the sound source localization of the proposed system by changing the source-microphone distance (l_k) and the microphone-server distance (d_k). From the result of the experiment, we found that the distance between sound source and microphone is a main factor that affects the quality of the sound source localization. In the experiment in a pig house, we deploy the proposed system and existing (wired) system, while measuring the length of time for system deployment. We also evaluate the quality of the sound source localization of the existing system as reference. The length of time for proposed system deployment was approximately 30. min. by one worker, while that for existing system deployment was approximately 120 min. by three workers. We found that the proposed wireless system is much easier than the existing system, since there is no need to install long cables in a pig house. From figure 8, we found that the proposed system and existing system achieve localization error of 0.2 and 0.25 m, respectively. This means that the sound source localization system using wireless microphones achieves almost the same quality of that using wired microphones, while ensuring the system flexibility.

ACKNOWLEDGMENT

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