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ANALYSIS OF BODY-CONDUCTED SOUND TO IDENTIFY INFECTED PIGS

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Abstract. *Early detection of infected pigs is vital to reduce economic loss. In this study, we propose a wireless system to record body-conducted sounds of pigs individually and a method of analysis for the early detection of respiratory diseases in infected pigs. We conducted two experiments. In the first experiment, we measured the differences in the acoustic features of the recorded sound before and after infection with the porcine reproductive and respiratory syndrome. Significant differences were observed in the zero crossing and Mel-frequency cepstram coefficients before and after inoculation. This confirms that respiratory diseases can be detected by measuring the acoustic features of sound. The second experiment involved the extraction of the respiratory and heart rates by wavelet analysis of body-conducted sound. Additionally, these rates could be used to count the peaks at specific frequencies by wavelet analysis.*
Keywords: Pig, Body-conducted sound, Diseases, Respiratory rate, Heart rate

1. **Introduction.** Livestock such as pigs are raised intensively. The current trends in pig breeding in Japan demonstrate that the number of pigs per farm has been increasing since the 1990s [1]. In this situation, it is difficult to identify infected livestock. In particular, porcine reproductive respiratory syndrome (PRRS) causes mass infection and economic loss in intensive pig farming. To minimize these, it is vital to identify pigs infected by this disease at an early stage. Therefore, we investigate approaches to measure vital signs and detect infected pigs. In the past, analysis of respiratory sounds has been proposed as a method for the diagnosis of respiratory diseases [2-6]. Researchers focused on respiratory sounds to detect signs of disease [2,3] because sounds are one of the important indicators to detect infections [7,8]. Respiratory diseases are usually caused by lung infection. However, with the advancement in computer technology, especially in digital signal processing, the analysis of the sound of breath and body-conducted sound has attracted increasing attention because of its diagnostic capabilities [9]. Therefore, acoustic analysis of the respiratory system has been used in research for different diagnostic purposes.

Recent studies investigating the diagnosis of respiratory diseases focused on monitoring sound to assess the presence of cough using a microphone installed in a pig farm [2,5].

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Using this system, it is easy to detect the behavior caused by respiratory diseases in pigs. However, it becomes difficult to identify infected pigs when the number of breeding pigs is high. The monitoring system has high construction costs and is susceptible to environmental noise. In a noisy environment such as a pig farm, it is necessary to collect biological signals individually by attaching a sensor to each subject. In this context, we focused on body-conducted sound, using an extraction method that proved noise-resistant, in comparison with the use of a microphone [10].

In this study, we first proposed a system for recording body-conducted sound in livestock by using an FM transmitter. We also measured the difference in acoustic features before and after infection by a respiratory disease. However, this system was limited in that it could not measure accurately at low frequencies. Hence, to measure low-frequency sounds satisfactorily, we modified the recording method. Additionally, using wavelet analysis, the respiratory and heart rates were extracted from the body-conducted sound recorded using the newly proposed system.

2. **Recording System Using an FM Transmitter for Body-Conducted Sound.** To monitor pigs in real time, we developed a wireless recording system using an FM transmitter. Figure 1 illustrates the system for recording body-conducted sounds. This system uses a piezoelectric sensor and a microphone based on a micro electro mechanical system (MEMS) as transducers for simultaneously recording respiratory and body-conducted sounds.

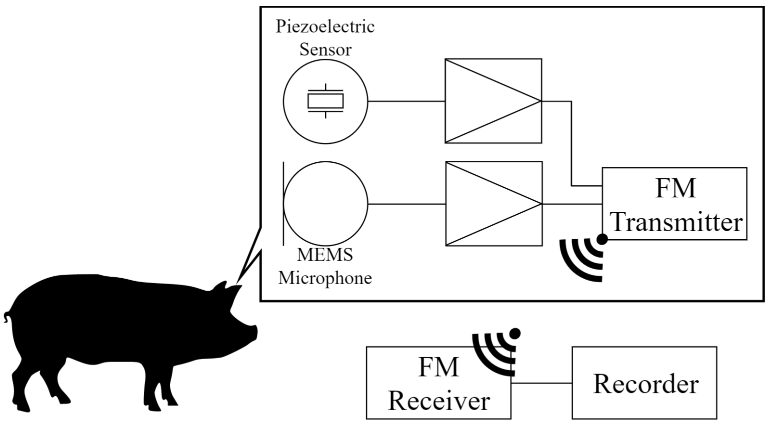
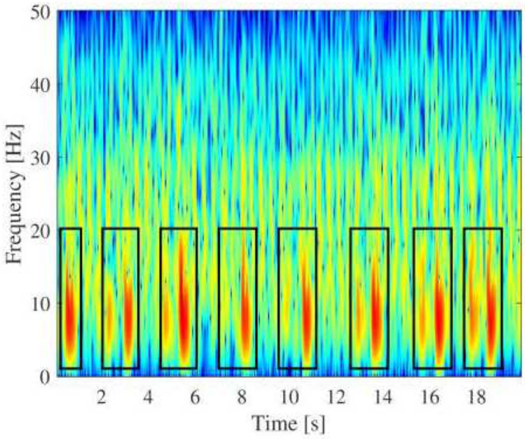


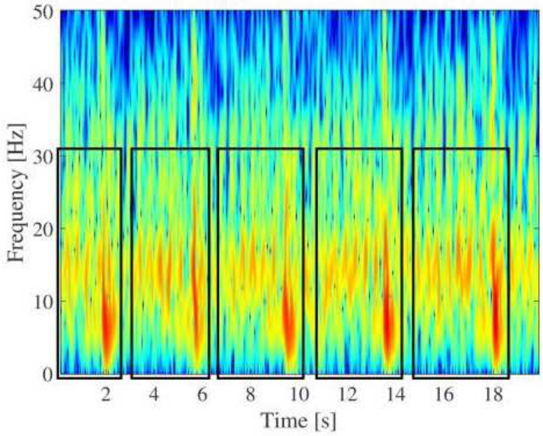
Figure 1. Overview of the wireless recording system using an FM transmitter

We recorded body-conducted sounds of pigs infected with PRRS to measure different acoustic features before and after infection. The subjects of this experiment were four specific pathogen-free (SPF) piglets of age 5 weeks at the time of inoculation. Each pig was inoculated with 2 mL of the PRRS virus (PRRSV) in Kagoshima isolate ($10^5 TCID_{50}$/mL). The sounds were recorded without sedation and anesthesia before and at 3, 5, 7, and 10 days after inoculation. According to clinical symptoms and autopsy, we confirmed that infection was established in all subjects. The airborne sound was recorded using the MEMS microphone, which was fixed on the nose of the pigs. Body-conducted sounds were recorded by the piezoelectric sensor, which was fixed on their ear. Both sounds were recorded at 44.1 kHz and 16 bits.

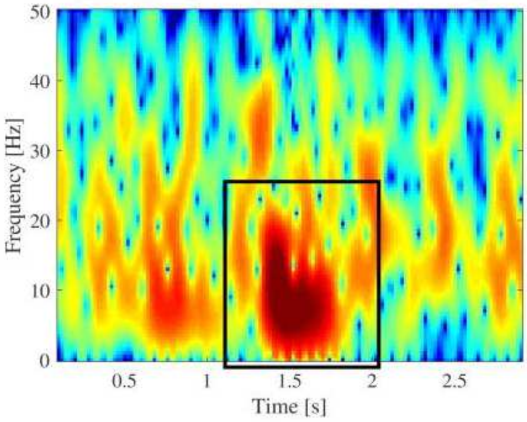
3. **Identification of Infected Pigs by Body-Conducted Sound.** We analyzed the body-conducted sounds recorded before and at 3, 5, 7, and 10 days after the virus inoculation. Figures 2(a)-2(d) display the corresponding spectrograms, recorded from the pigs' ear. The respiratory peaks were observed 8 times in 20 seconds before inoculation, and 5 times in 20 seconds 7 days after it. The breath timings are represented by black



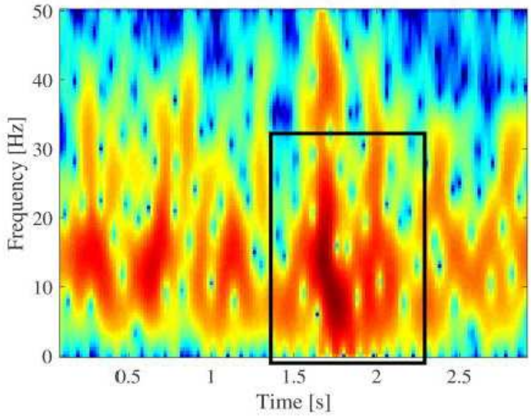
(a) Before inoculation (20 s)



(b) 7 days after inoculation (20 s)



(c) Before inoculation (magnification of the first 3 s of (a))



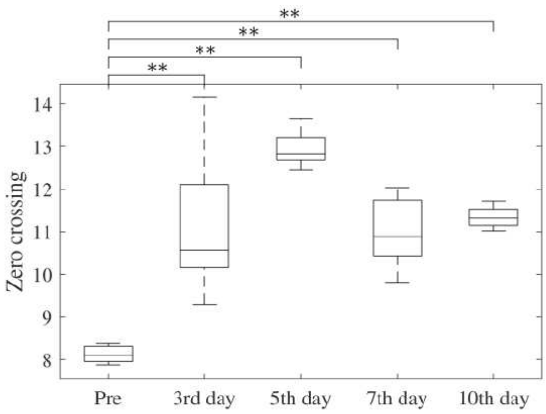
(d) 7 days after inoculation (magnification of the first 3 s of (b))

FIGURE 2. (color online) Comparison of body-conducted sounds before and after inoculation

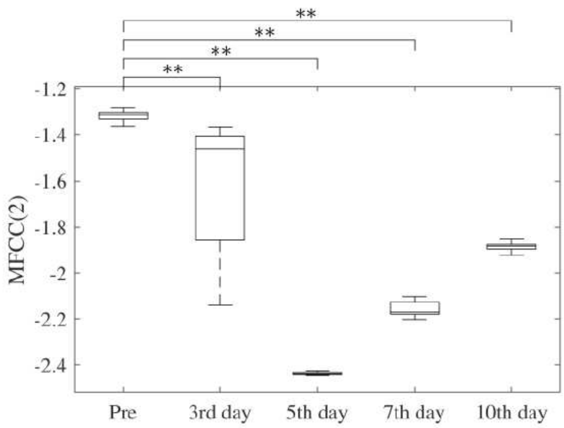
frames in Figures 2(a) and 2(b). As seen, in comparison with Figure 2(c), the breath intensity of Figure 2(d) (after infection) exhibited higher intensity and longer intervals. The respiratory rate decreased and the intensity increased with the PRRS infection.

Additionally, we analyzed the acoustic features to identify the difference in the body-conducted sounds of pigs infected with PRRS. The purpose of this was to confirm that the different acoustic features could reveal if the pigs were infected. Veterinary physicians and farmers diagnose diseases according to changes in respiratory sounds [8]. Therefore, we used the Tukey-Kramer's honest significant difference (HSD) test to measure zero crossing and Mel-frequency cepstram coefficients (MFCC) [11] for the recorded body-conducted sounds, and the coefficients found from acoustic analysis before and after inoculation. Ten acoustic samples were considered for analysis for each recording day, each sample being 5 seconds long. As depicted in Figures 3(a)-3(d), significant differences were observed before and after inoculation in the zero crossing and MFCC(1)-MFCC(3). Furthermore, the dispersion of MFCC(2) and MFCC(3) was lower after infection. This result was assumed to be caused by the decreased activity of the pigs infected. Therefore, PRRS can be diagnosed using zero crossing and MFCC.

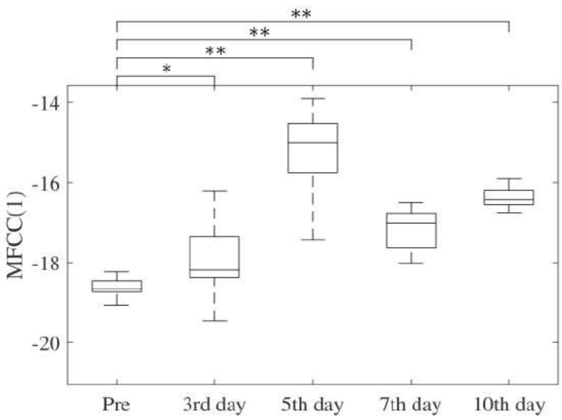
4. **System Improvement for Long-Time Monitoring.** The proposed system, shown in Figure 1, transmits sounds using the FM transmitter. Respiratory sounds lay in the low-frequency region of body-conducted sounds. However, in the first experiment, it was



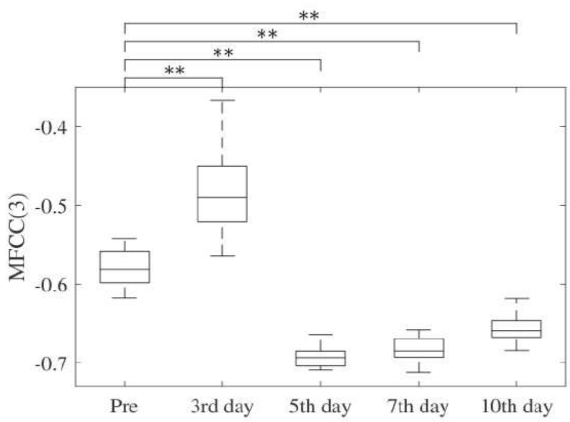
(a) Zero cross



(b) MFCC(1)



(c) MFCC(2)



(d) MFCC(3)

Significance level *: 5%, **: 1%

FIGURE 3. Descriptive statistical values for zero crossing and MFCC(1)-MFCC(3). Tukey-Kramer's HSD test was performed on each recording day.

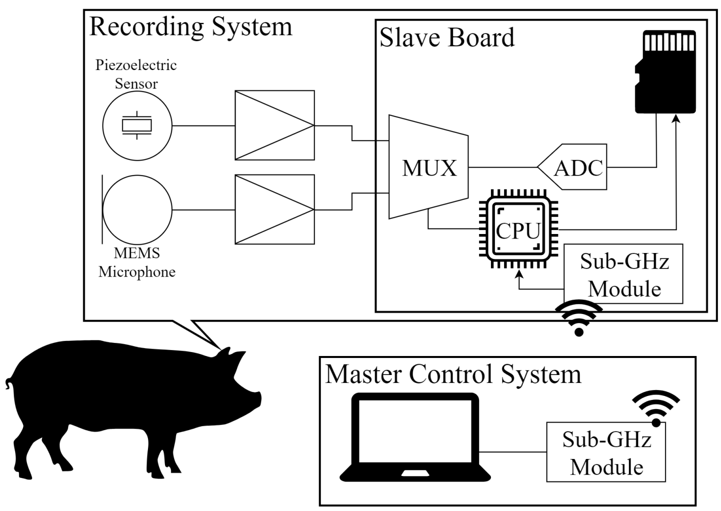


FIGURE 4. Overview of the new recording system in the sub-GHz band

difficult to record respiratory sounds satisfactorily using this system because of FM cross-talk. In fact, low-frequency sounds (under 10 Hz, approximately) decreased in intensity when transmitting recorded sounds in the FM band. Therefore, we propose a new system to record body-conducted sounds, controlled in the sub-GHz band and transmitting sounds in the absence of a transmitter. Figure 4 shows an overview of the proposed system. Sub-GHz communications propagate at long distances while consuming low power. Furthermore, the new system can record sounds irrespective of their frequency band and stores them directly on microSD cards. Therefore, pig infection can be monitored for a long time using the method previously introduced.

We recorded body-conducted sounds in healthy pigs using the proposed system to extract vital information, such as heart and respiratory rate, from them. The subject of this experiment was a three-way cross pig (Landrace, Large White, and Duroc: LWD) of age 5 weeks. In this experiment, the pig inhaled anesthesia, and a piezoelectric sensor was placed on its ear, while we recorded body-conducted sounds at 1,638 Hz and 16 bits.

5. **Measurement of Respiratory and Heart Rate from Body-Conducted Sound by Wavelet Analysis.** To detect diseases, vital information such as respiratory and heart rate should be measured. Figure 5 shows a waveform of the recorded sound, resampled at 200 Hz. Resampling was used to measure the respiratory and heart rate easily, as shown in Figures 2(a) and 2(b). We recognized features of respiratory and heartbeat sounds in the body-conducted sounds, as shown in the waveform of Figure 5. The wavelet analysis helps correlate these sounds with each frequency extracted from the waveform and displays time-widths adapted to these frequencies. It is typically used to analyze non-stationary signals [12]. We extracted data of respiratory and heart rate by using wavelet analysis and the new transmission system. Figure 6 shows the scalogram, i.e., a

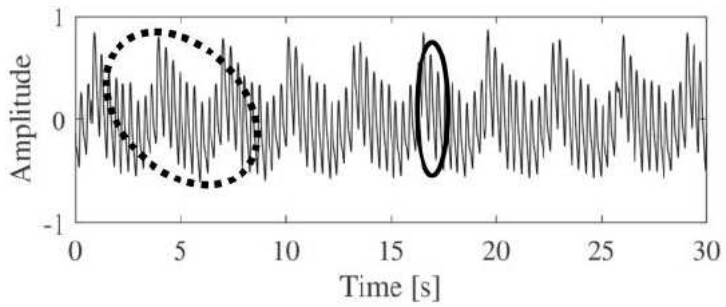


FIGURE 5. Waveform of the recorded data

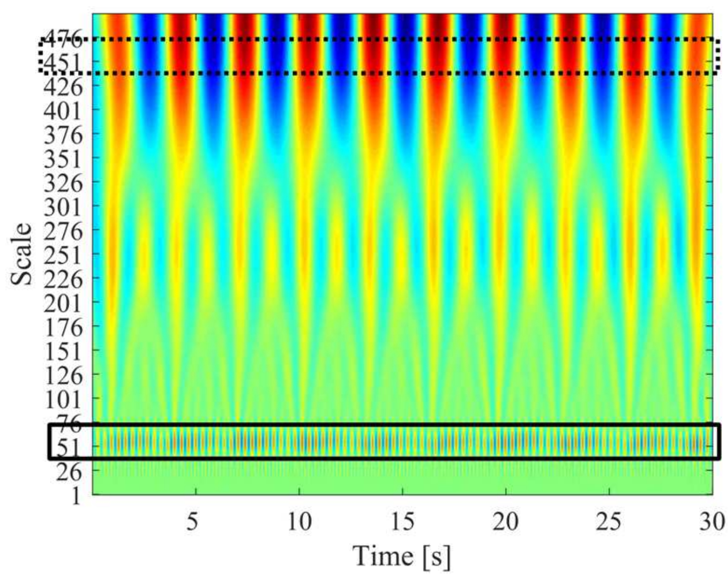


FIGURE 6. (color online) Scalogram of the wavelet analysis

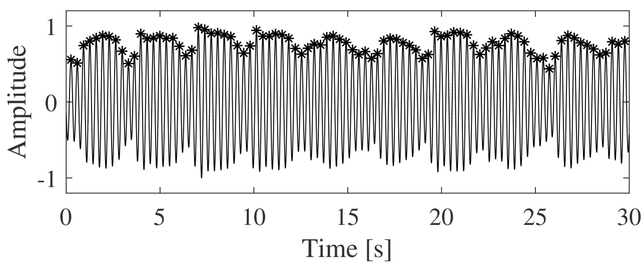


Figure 7. Waveform at scale 60 of the scalogram (heartbeat: 176 beats/min)

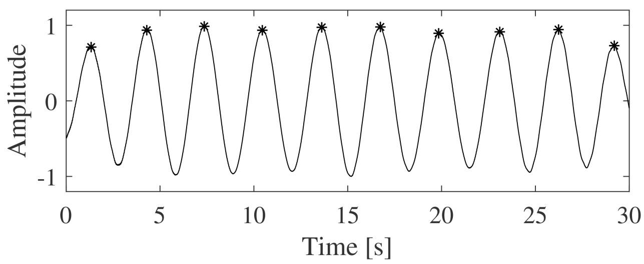


Figure 8. Waveform at scale 440 of the scalogram (breath: 20 breaths/min)

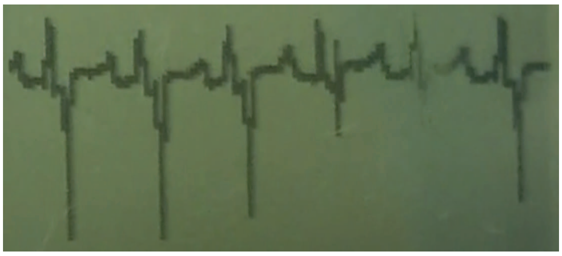


Figure 9. Electrocardiogram of a pig (timescale: 2 seconds)

visual representation similar to the spectrogram of the wavelet analysis, of these sounds. In wavelet analysis, there is a relationship between scale and frequency. A small scale implies high frequency, and a large scale, low frequency. Periodic signals were observed at approximately scale 60 (approximately 6.25 Hz) and 440 (approximately 0.37 Hz), as shown in Figure 6. These signals are inferred to be respiratory and heartbeat sounds, respectively. We extracted the amplitude related to these scales and counted the peaks found. Figure 7 shows the amplitude around scale 60, and Figure 8 around scale 440. The peaks shown in Figure 8 appeared simultaneous to the long period signal seen in the dotted rectangle of Figure 6. Pigs breathe at intervals of approximately 3 s, as seen in Figure 2(a). Therefore, we confirmed that the respiratory rate can be extracted by wavelet analysis. Furthermore, peaks shown in Figure 7 appeared simultaneous to the short period signal seen in the solid rectangle of Figure 6. The heart rates of pigs ranged between 170 and 190, as measured from the electrocardiogram of Figure 9. Thus, we verified that also the heart rate can be extracted through wavelet analysis, from body-conducted sounds of pigs. Therefore, monitoring the health of pigs using these methods is proved possible.

6. **Conclusions.** In this paper, we proposed a wireless recording system for body-conducted sounds. Using this system, the sounds of pigs before and after inoculation of PRRS were recorded. By comparing the spectrograms of sounds obtained before and after inoculation, it was confirmed that the respiration rate decreased and the respiratory intensity increased after PRRS infection. Additionally, the results of zero crossing

and MFCC analysis suggest that it is possible to diagnose diseases such as PRRS at an early stage. Therefore, the acoustic features of body-conducted sounds are analyzed and a system is developed to detect diseases that infect pigs. Furthermore, we improved an existing signal transmission method by transmitting in the sub-GHz band to record low-frequency sounds satisfactorily. As a result, the respiratory rate could be recorded clearly. The respiratory and heart rate were extracted in wavelet analysis by counting the peaks at a specific frequency of body-conducted sounds. Our results suggest that daily measurements of livestock's health and stress will be possible.

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