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Study on Feeding Activity of Litopenaeus Vannamei Based on Passive Acoustic Detection

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ABSTRACT Litopenaeus vannamei, as the main target of shrimp farming in China, has a great market prospect and high economic value. However, domestic Litopenaeus vannamei farming and feeding efficiency are low, mainly through the use of hand tools by farmers to complete the feed throwing work, and the feed cost is high. Therefore, in view of the high density and low visibility of culture ponds in Litopenaeus vannamei aquaculture industry, it is impossible to judge the quantity and time of feed feeding by visual way. In this study, based on the analysis of acoustic feeding signal characteristics of Litopenaeus vannamei, accurate and intelligent control of feed amount is proposed, so as to reduce the breeding cost and obtain environmental benefits. This study designed a system for collecting and analyzing the acoustic signals of the feeding motion of Litopenaeus vannamei. Based on passive acoustic technology, the motion acoustic signal of Litopenaeus vannamei is extracted when starving. Through time domain and frequency domain research, the characteristic parameters of the motion acoustic signal of the specific body type of Litopenaeus vannamei are determined. The signal duration range is 8-10ms, and the average range of the resonance band is 2-10KHz. Furthermore, the dual-threshold method is further used to detect the effective range of the feeding signals, and then the number of acoustic signals is obtained, and the corresponding magnitude relationship between the characteristic parameters and the starvation degree of Litopenaeus vannamei is established, which can be used as a basis for judging intelligent feeding on demand. The research provides theoretical support for the feasibility of studying the feeding patterns of Litopenaeus vannamei through underwater passive acoustic detection.

INDEX TERMS Passive acoustics, Litopenaeus vannamei, pulse signal, threshold detection.

I. INTRODUCTION

Passive acoustic technology uses the radiated noise of underwater targets in different environments to detect, locate, track and identify targets [1]. By studying the correlation between the behavioral information of different aquatic species and their sound signals, it is gradually applied in underwater Biological research. For underwater creatures, specific psychological and physiological behaviors are difficult to visually observe [2]. However, they can transmit intraspecific and interspecific by vocalization, that is, they will make different sounds according to specific behaviors. For example, when eating [3], when moving underwater [4], when spawning, the panic sound made to avoid predators [5], and the different vocalization patterns due to regional seasonal problems [6], etc. Therefore, the use of passive acoustic technology to study the characteristics of the acoustic signals of different underwater creatures' specific behaviors has important theoretical and engineering practical application values. Passive acoustic technology can realize long-term detection of marine life and marine environment because of its low damage and low destructiveness. In the field of fish biology and fisheries, this technology can be used to determine the habitat, distribution, spawning area and living habits of fish [2]. Hawkins *et al.* [7], by studying the correlation between the vocalization of gadoid fish and its vocal structure, described the calling signals of gadoid fish in different situations. In addition, Abileah *et al.* [8] used the US Navy Sound Monitoring System (SOSUS) to conduct passive acoustic monitoring experiments to study the sound spectrum characteristics of salmon in the North Pacific Ocean. In the northern part of the Gulf of Nicoya, Donald *et al.* [9] used hydrophones to capture the

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sound made by Cynoscion squamipinnis (Perciformes: Sciaenidae) during spawning, so as to determine the spawning place of Cynoscion squamipinnis. Nelson *et al.* [10] studied the relationship between the acoustic activity and behavior of red grouper Epinephelus morio on the West Florida Shelf and found that the detected acoustic signals were related to spawning activities.

Relatively, passive acoustic technology also plays an effective observation role in the acoustic detection of underwater shrimp. Using passive acoustic technology, Au *et al.* [4] used hydrophones to collect and characterize the "click" noise signal emitted by snapping shrimp in the Kaneohe Bay. However, Bohnenstiehl *et al.* [6] through the year-long sound monitoring of snapping shrimp in Sub-Tidal Oyster Reef Habitat, analyzed the seasonality and the regular changes within a day of snapping shrimp sound, which has certain significance for the study of ocean acoustic landscape. Daniel *et al.* [3] analyzed the feeding signal of tiger prawns and determined the characteristics of tiger prawns' feeding sound, which provided a reliable means for detecting feeding activity in commercial ponds with complex acoustics. In contrast, Litopenaeus vannamei represents approximately 80% of the world's shrimp production. It is also the main target of shrimp farming in China and has high economic value. Passive acoustic technology is used to study the characteristics of the acoustic signal state of Litopenaeus vannamei feeding movement, and then establish a feed management system that automatically feeds on demand, thereby saving labor and feed costs, and further improving the economic value of production of Litopenaeus vannamei aquaculture industry.

In the currently published literature, there are few studies on the acoustic signals related to the feeding activities of Litopenaeus vannamei, and it is difficult to judge whether the shrimp are eating or not based on the acoustic signals. Existing studies generally believe that when Litopenaeus vannamei eats, the food is crushed by the collision and friction of the jaws of the shrimp to produce acoustic signals, and the feeding sound is a continuous "click" sound [11]. However, this study has found through many experiments that the acoustic signals emitted by Litopenaeus vannamei when feeding are mainly produced by the behavior of the shrimps swimming and grabbing food when they are hungry. It is also similar to the continuous single pulse signal, which can be used as a representative of shrimp feeding activities. With the decrease of starvation degree, the intensity of shrimp movement gradually decreases, and the number of signals generated gradually decreases. The study mainly used time domain and frequency domain analysis to discuss the main acoustic parameters produced during the feeding process of adult Litopenaeus vannamei in the experimental water tank. Perform signal detection of the effective range on the confirmed shrimp feeding signals and calculate the number of feeding sound signals, which will help future follow-up study.

The rest of the paper is organized as: In Section II, the collection and analysis system, experimental scenes and methods will be elaborated. In Section III, in the time domain and frequency domain, the characteristics of the collected eating sound signals are analyzed to indicate that the feeding activities of shrimp are related to their behavior of swimming and grabbing food when they are hungry. In Section IV, dual-threshold method is used to detect the effective range and calculate the number of feeding signals. In Section V, analyze the characteristics of the noise signal generated by the oxygen generator that affects the collection of the target feeding signal. The final conclusion is discussed in Section VI.

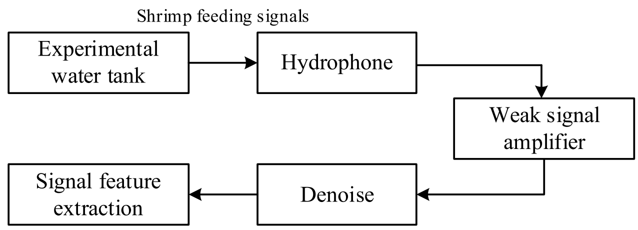

FIGURE 1. **Feature extraction system for acoustic feeding signal of Litopenaeus vannamei.**

II. SYSTEM DESCRIPTION

A. ACOUSTIC FEATURE EXTRACTION

The real-time acquisition and analysis system of feeding sound signal of Litopenaeus vannamei based on passive acoustic technology is shown in Fig. 1. According to the needs of the experiment, the required number of shrimp in the water tank is caged. After feeding, the shrimp feeding signals are generated. The high-performance hydrophone is used to convert the underwater sound signals of the shrimp into electrical signals. After the weak signal amplifier, the electrical signals are converted into digital signals through the data acquisition card. During the experiment, the camera equipment is responsible for recording the various motion states of Litopenaeus vannamei when feeding, and cooperate with hydrophone to extract the shrimp feeding signals to be studied. Using digital filtering technology to remove underwater environmental noise and electrical noise from the collected acoustic signal data, complete the collection and detection of shrimp feeding signals. In order to simulate the difference of shrimp feeding signals under different environmental conditions, it is necessary to change the feeding times and the number of shrimp to realize the passive acoustic signal detection of Litopenaeus vannamei under different conditions. After statistical analysis, the degree of shrimp starvation can be obtained, and then the shrimp feed can be controlled on demand.

B. EXPERIMENTAL SCENE

The experimental site is located in the Xiaxinglong breeding base, Haicang District, Xiamen City, Fujian Province. The experimental time is late June 2020. Before the experiment, 5 and 10 adult Litopenaeus vannamei were placed in two water tanks (40 × 20cm in length and width) with fresh water and continuous oxygen supply, which was conducive to the shrimp to be familiar with the environment of the

FIGURE 2. The experimental water tank.

experimental water tank, as shown in Fig. 2. Before the experiment started, the shrimp were fasted. Since the sound signal is directly related to the start of feeding, this delay may be related to the time required for the shrimp to detect and reach the food, as well as the satiety and attractiveness of the food provided. Therefore, make sure that the shrimp are hungry before the start of the experiment, thus maintaining an interest in food. In this experiment, the fasting time for the shrimp was 24 hours. Placing the shrimp in a small-volume water tank helps the shrimp detect and grab food faster.

The experiment uses WBT22-1107 hydrophone to collect the shrimp feeding sound signal. The receiving sensitivity response of the hydrophone is −193dB ± 3dB @22KHz (re 1 $V/\mu Pa$ @1m, 20m cable), and the experimental sampling rate is 100KHz. Because after feeding, the shrimp mainly eat at the bottom of tank. Therefore, during the experiment, the hydrophone was placed in the center of the water tank down close to the shrimp, as shown in Fig. 3. The whole process of the experiment was recorded synchronously using camera equipment.

FIGURE 3. Location of hydrophone.

Because the sound signals generated by the shrimp feeding motion is very weak, when the oxygen generator is turned on, the noise generated by it is too loud, which affects the acquisition of the target signals. Therefore, the signal collection in this experiment was performed with the oxygen generator turned off, and there was no interference from other acoustic signals.

C. EXPERIMENTAL DATA COLLECTION AND ANALYSIS

In order to observe the feeding situation of different numbers of shrimp under the continuous feeding times, in the experimental water tanks with 5 and 10 shrimps respectively, signal data were collected for three consecutive feedings, and the shrimp feeding situation was recorded by camera equipment. After the hydrophone was placed successfully, it did not affect the normal activity of the shrimp. In the experimental water tanks with different numbers of shrimp, the data collection time of the three feedings was 8 minutes. Before the start of each feeding signal collection, the shrimp were supplied with oxygen for 1 minute to maintain the normal state.

After the signals are collected, all the signals are denoised to filter out the influence of low-frequency electrical noise on the target signals. Based on the time domain, frequency domain and time-frequency analysis of feeding signals of Litopenaeus vannamei, the acoustic characteristics of feeding signals are analyzed and discussed. In the spectrum analysis, the Welch method is used to calculate the power spectrum of the signal, and the Blackman window weighting function is applied, and the frequency resolution is 390 Hz. With a window length of 0.1s, the short-time Fourier transform of the signal is calculated, which is defined as:

$$S_n(e^{j\omega}) = \sum_{m=-\infty}^{\infty} s(m)\omega(n-m)e^{-j\omega m} \tag{1}$$

where $s(m)$ is the shrimp feeding signal sequence; $\omega(n)$ is the real window sequence. With different values of n, the window $\omega(n-m)$ slides along the time axis, and different window signals are taken out for Fourier transform to obtain the time-frequency distribution of the feeding signals.

III. ANALYSIS OF FEEDING SIGNALS

A. GENERATION OF FEEDING SIGNALS

During the signal collection process, it can be observed through real-time photographic recording that before the first feeding, most of the shrimp were not moving at the bottom of the tank, and some of them were swimming. 30 seconds after the signal collection, the required feed was put into the tank, and most of the shrimp began to swim and grab food. With the increase of collection time, most of the shrimp gradually stopped swimming and ate at the bottom of the tank. Before the second feeding, the situation in the tank was the same as that in the first feeding signal collection. After feeding, only a small number of shrimp were moving to grab food. Until the third feeding signal collection, almost no shrimp was moving after feeding.

Through the time-domain observation of the three collected signals, before feeding in the experimental tank of 5 shrimp, almost no signal was generated and then be collected. After 30 seconds, signals are detected and collected, as shown in Fig. 4(a), (b), and (c). After 30 seconds

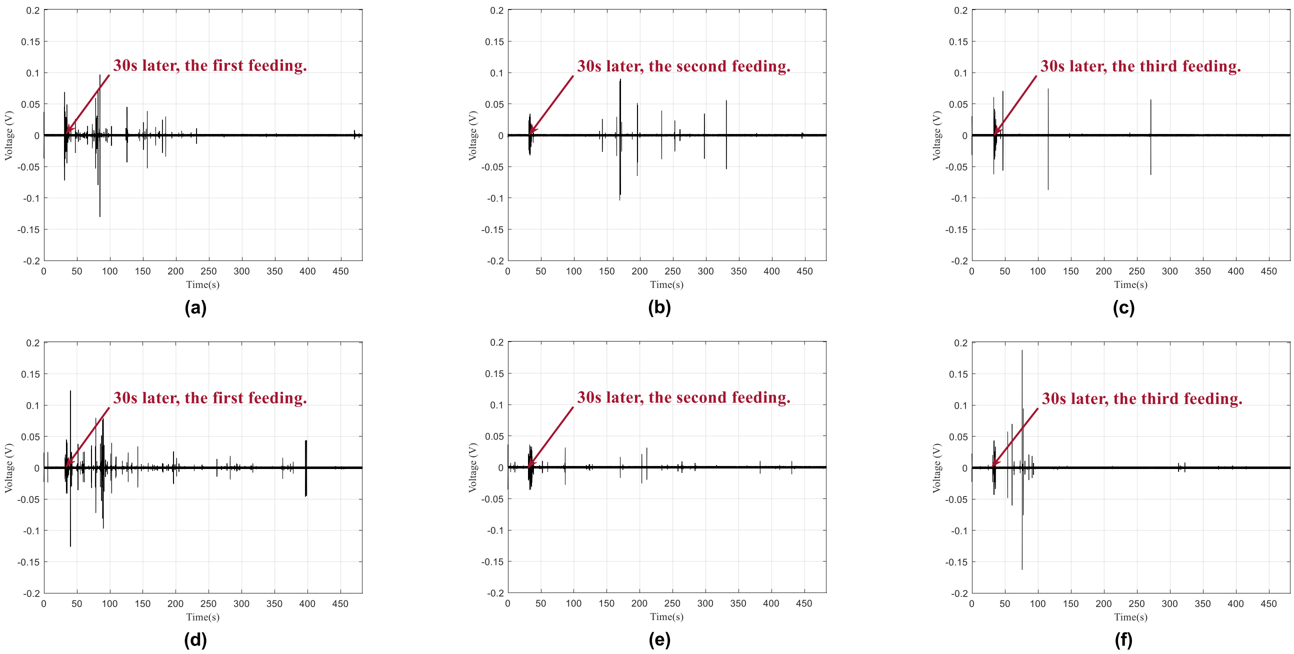

FIGURE 4. Time domain of signal acquisition for 3 different feedings. (a, b, c) 5-shrimp, (d, e, f) 10-shrimp.

of signal acquisition, the food was fed. By comparing with the photographic record, the shrimp began to move to grab food and eat, and the acoustic signal generated during the movement of the shrimp was collected. As the number of feedings increased, most of the shrimp stopped moving to grab the food. This phenomenon indicates that the movement of shrimp to grab food represents the feeding activity. When the shrimp was fed for the first time, the degree of starvation was high, and the number of collected signals was dense and large. Signals were generated during the entire collection time, indicating the progress of the feeding activities. With the increase of feeding times, the starvation degree of shrimp decreased. They gradually stopped moving, and the number of acoustic signals collected decreased. Until the end of the third feeding signal collection period, no signal was collected. The three feeding signals collected in the 10-shrimp experiment tank are roughly the same as those in the 5-shrimp experiment tank, as shown in Fig. 4(d), (e), and (f).

The signal is analyzed by short-time Fourier transform, and the window length is 0.1s. In the case of different numbers of shrimp, 30 seconds after the first feeding, the energy of 15-25dB in the frequency range of 2-10KHz increased significantly, and it lasted for 10 seconds after the feeding started, as shown in the red box of Fig. 5. In the latter period of time, energy intermittently increased significantly, indicating the progress of feeding activities of shrimp.

B. ANALYSIS OF TIME DOMAIN WAVEFORM AND FREQUENCY SPECTRUM OF FEEDING SIGNALS

The feeding acoustic signal generated by the movement of Litopenaeus vannamei collected in the experiment is in the

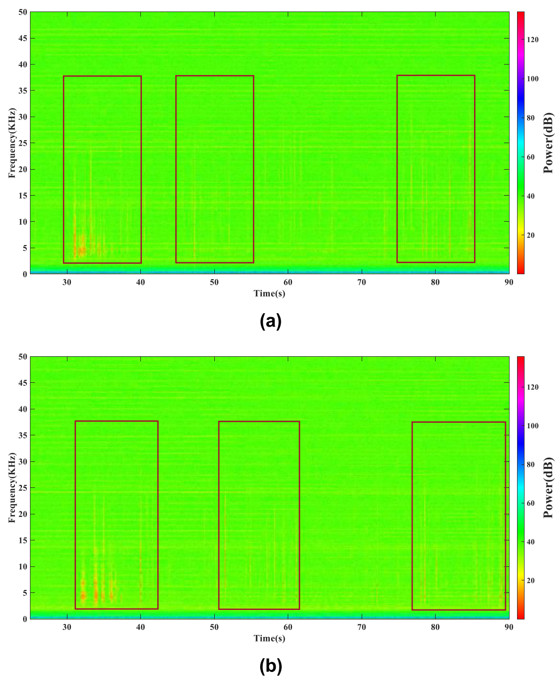

FIGURE 5. Time-frequency distribution of signal collected for the first feeding. (a) 5-shrimp, (b) 10-shrimp.

form of a single pulse, as indicated by magnified graph in red box in Fig. 6. The signal duration range is 8-10ms, and the frequency range is 2-10 KHz. There is a maximum spectral peak near the frequency of 5KHz, and the intensity is about - 78dB, as shown in Fig. 7(a). Comparing the frequency domain waveform of the shrimp feeding interval with the frequency

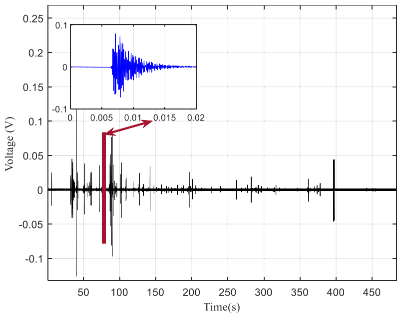

FIGURE 6. Feeding signals.

domain waveform of the shrimp not feeding interval, it can be found that in the range of 2-10KHz, the signal energy of the former is higher than that of the latter, indicating that new acoustic signals is generated during feeding, as shown in the Fig. 7(b).

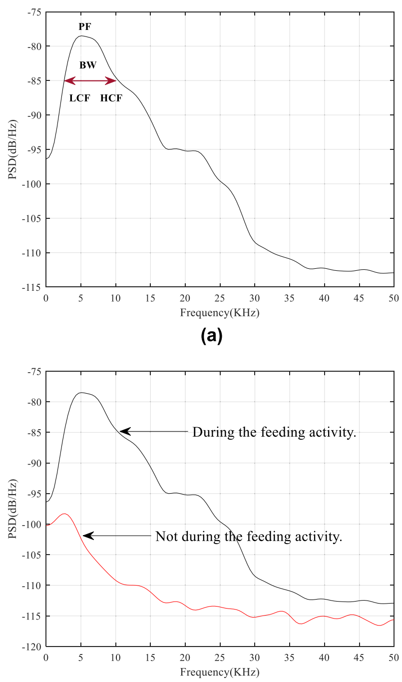

FIGURE 7. Frequency domain waveform of shrimp feeding signals.

Compared with the Penaeus monodon (giant tiger prawn) feeding sound signal studied by Daniel *et al.* [3], most of the signal energy of the tiger prawn feeding sound signal is concentrated in the resonance frequency band between 3KHz and 7.6KHz on average, the signal duration is between 0.48ms and 0.72ms, and the maximum peak appears in the range of 5-10KHZ.

C. CORRELATION BETWEEN FEEDING SOUND SIGNALS AND SWIMMING MOVEMENT

Litopenaeus vannamei is in a state of restlessness during hypoxia, and most of the shrimp are swimming quickly in

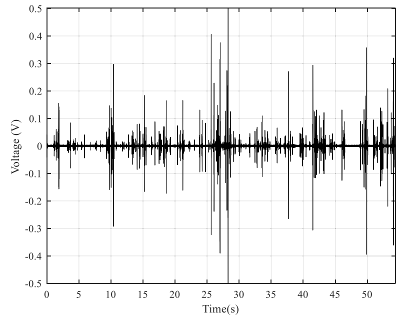

FIGURE 8. Motion signals of shrimp in hypoxic state-time domain.

the tank. The experiment carried out 1-minute data signal acquisition for this situation, as shown in Fig. 8. Correlation calculation is carried out between the shrimp feeding signal $d(t)$ and the complete shrimp hypoxic agitation signal $s(t)$ [6], so as to obtain the detected value, which represents the correlation value D at each time step t.

$$D(t) = \sum_{n=-\infty}^{\infty} d(n)s(n-t) \tag{2}$$

Through the correlation detection algorithm, the correlation value is higher than 0.05, indicating that the correlation between the signals is high, as shown by the red line in Fig. 9. This result also shows that shrimp move intensively when they are hungry, and then grab food and produce motion sound signals, which characterize the progress of feeding activities.

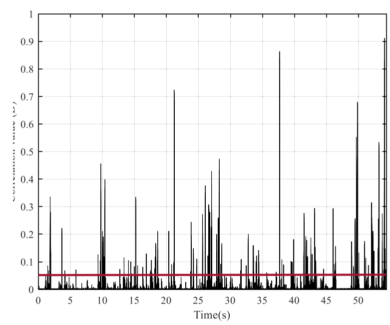

FIGURE 9. Correlation between motion signals of shrimp in hypoxic state and single feeding signal.

IV. DETECTION OF THE EFFECTIVE RANGE OF THE FEEDING SIGNALS

Before the detection of the effective range of the feeding signal, the measured initial signal is preprocessed, and a band-pass filter is applied to the signal, thereby suppressing the influence of environmental, man-made or biological noise on the target signal. Next, through threshold detection, the starting point and ending point of the signal are detected.

Because in the next shrimp feeding signal processing, only the signal segment is processed.

In this study, the dual-threshold method was used to detect the effective range of feeding signal. The algorithm is based

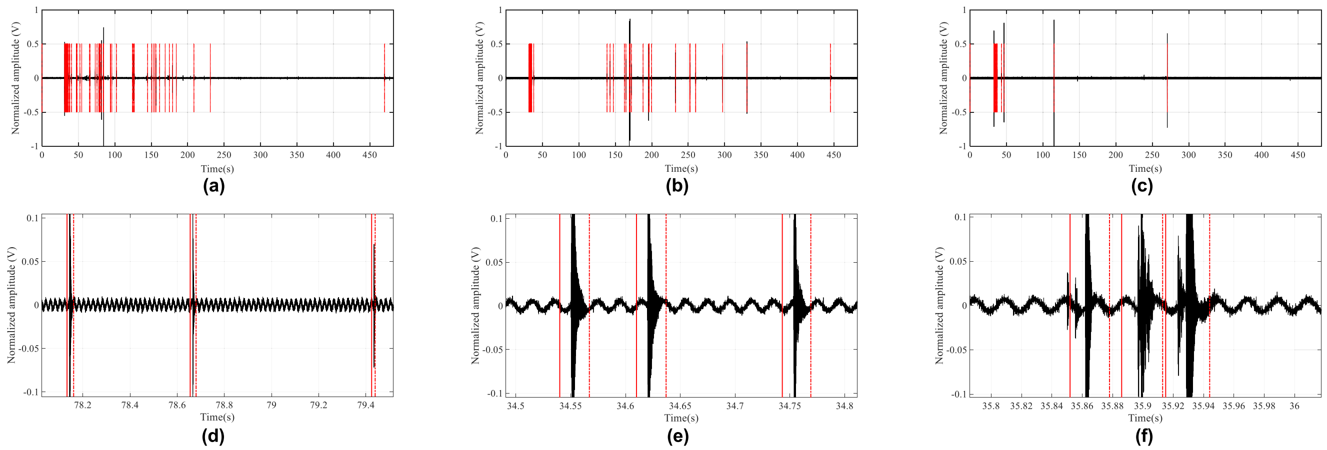

FIGURE 10. Detection of the effective range of the feeding signals (5-shrimp). (a, d) The first feeding, (b, e) The second feeding, (c, f) The third feeding.

on the short-term energy and the short-term average zero-crossing rate of the signal [12]. The effective shrimp feeding signal is determined by a two-level threshold judgment method. In the actual operation of the detection, after the normalization process, the collected signal is first processed by window division, with the window length of 0.01s. On the basis of the window division, the short-term average energy and short-time average zero crossing rate of the signal are obtained, and the comparison and judgment are made according to the threshold value.

Suppose the time domain of the collected signal is $s(n)$, and the i-th window signal obtained after windowing by the window function $w(n)$ is $y_i(n)$, then $y_i(n)$ satisfies:

$$y_i(n) = w(n) \times s((i-1) \times inc + n), \quad 1 \le n \le L, \; 1 \le i \le fn \tag{3}$$

In the equation, $w(n)$ is the Hamming window; $y_i(n)$ is the voltage amplitude collected by the i-th window signal, L is the window length; inc is the window shift length; fn is the total number of windows after the signal is windowed.

The short-term energy equation for calculating the i-th window signal is:

$$E(i) = \sum_{n=0}^{L-1} y_i^2(n) \quad 1 \le i \le fn \tag{4}$$

The short-term average zero-crossing rate indicates the number of times the signal waveform crosses the zero level in a window signal. For continuous signals, zero crossing means that the time-domain waveform passes through the time axis; for discrete signals, if adjacent sample values change signs, it is called zero crossing. The short-term average zero-crossing rate is the number of times the sample value changes sign.

The short-term average zero-crossing rate equation for calculating the i-th window signal is:

$$Z(i) = \frac{1}{2}\sum_{n=0}^{L-1} |\mathrm{sgn}\,[y_i(n)] - \mathrm{sgn}\,[y_i(n-1)]| \quad 1 \le i \le fn \tag{5}$$

After calculating the short-term energy and the short-term average zero-crossing rate of the complete signal, the first decision is made. First, according to the short-term energy of the signal, a higher threshold H1 is selected for rough judgment. There are starting and ending points of the feeding signal in the range outside the time point corresponding to the intersection of this threshold and the short-term energy envelope. Then select a lower threshold H2, continue to search from the possible range of the last rough judgment, and find the two points A and B where the threshold H2 intersects the short-term energy envelope. These two points are the starting point and the ending point of the feeding signal determined by the short-term energy. After that, a secondary judgment is made on the basis of the first judgment. At this time, based on the short-term average zero-crossing rate, select the threshold H3, and continue searching from outside the range determined by points A and B, and find two points C and D where the threshold and the short-term average zero-crossing rate intersect respectively. Finally, the range between the time points corresponding to points C and D is the effective range of the shrimp feeding signal.

Fig. 10(a), (b), and (c) show the detection results of the effective range of the signals collected by three feedings in the 5-shrimp experimental tank. The red box is the detected signal. The partial enlarged view is shown in Fig. 10(d), (e), and (f). The red solid line is the starting point of the feeding signal, and the red dashed line is the ending point of the feeding signal. According to the figure, the number of signals detected during the first feeding is higher than the last two feedings. The motion sound signal produced by the shrimp during feeding will gradually decrease as the decrease of shrimp starvation and the increase of feeding times. The detection results of three feeding signals collected in the experimental tank where 10-shrimp are located are roughly the same as those in the experimental tank for 5-shrimp, as shown in Fig. 11.

According to the number of signals generated by different shrimp numbers and feeding times, as shown in Fig. 12. During the first feeding, the number of sound signals generated

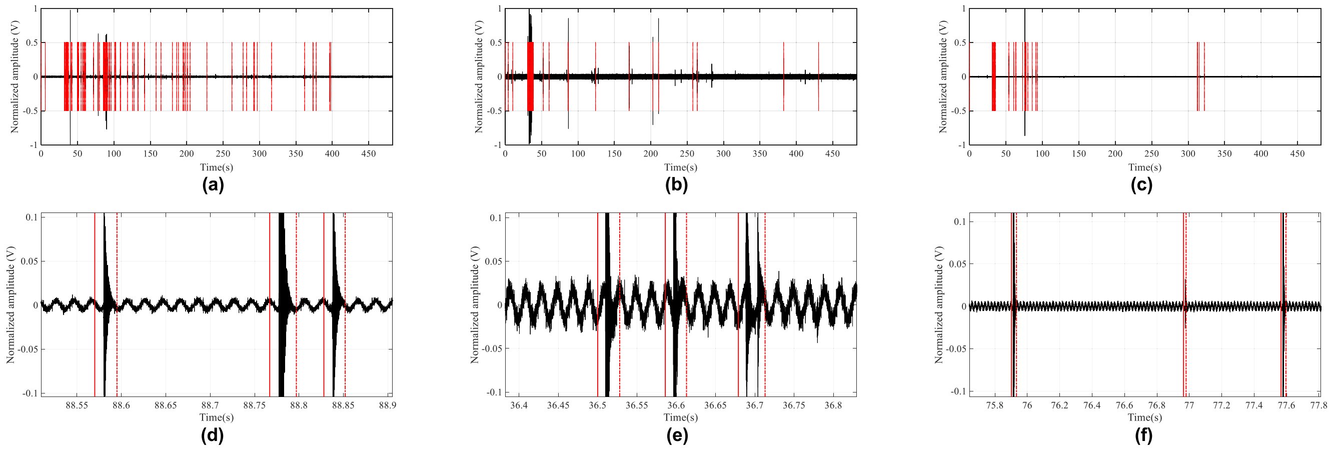

FIGURE 11. Detection of the effective range of the feeding signals (10-shrimp). (a, d) The first feeding, (b, e) The second feeding, (c, f) The third feeding.

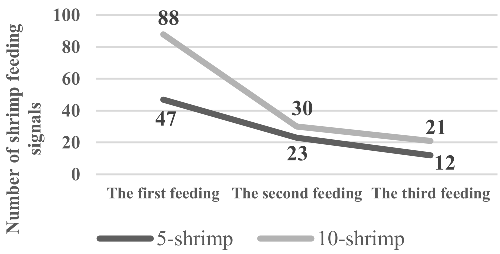

FIGURE 12. Statistics on the number of shrimp feeding signals.

by 10 shrimp within 8 minutes of data collection could reach 88, and in the same experimental scenario, the number of acoustic signals of 5 shrimp could reach 47. More than half of the signals were detected within 1 minute after feeding. With the increase of time, the number of signal detection gradually decreased. In the later stage of collection, almost no signal was detected. That is, with the increase of feeding times, the starvation degree of shrimp decreased, and the movement gradually stopped, and the number of acoustic signals collected decreased. At the same time, in the experimental tank of 10 shrimp, the number of shrimp feeding signals collected by three feedings was higher than that of 5 shrimp experimental tank. This phenomenon indicates that the number and the starvation degree of shrimp are directly proportional to the number of shrimp feeding signals. As the number of feeding times increases, the starvation degree of shrimp and the number of shrimp feeding signals decreases.

V. NOISE SIGNAL ANALYSIS

When the oxygen generator is not turned off, the continuous background noise generated by the oxygen generator will affect the signal acquisition. In future detection algorithms, the key problem is how to detect shrimp feeding signals from the continuous background noise generated by the oxygen generator. The signal generated by the oxygen generator is similar to the shrimp feeding sound signal, and in the time domain, it is also a repetitive single pulse signal, as shown in Fig. 13.

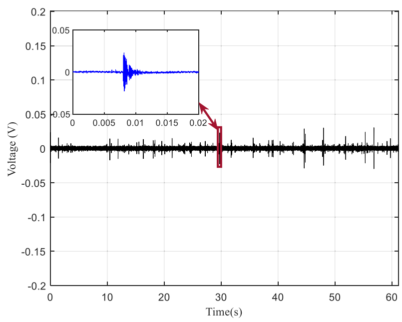

FIGURE 13. Time domain of oxygen generator noise.

When the signal is collected, it is superimposed on the feeding signal as a series of pulse signals. In the frequency domain, the frequency range of the noise signal is 7-13KHz. On average, the resonance band is higher than the feeding signal, and there is a partial overlap of frequency bands, as shown in Fig. 14.

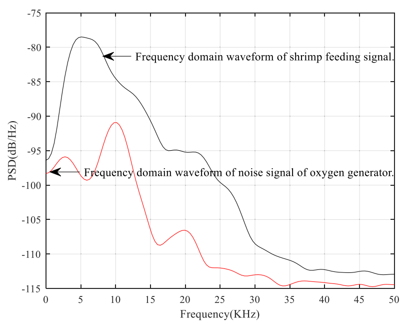

FIGURE 14. Frequency domain comparison of noise signal of oxygen generator and shrimp feeding signal.

In other experimental environments, there are other pulse interferences, coupled with the time similarity of feeding and interference events, which leads to misjudgments in signal detection, which illustrates the potential difficulty in distinguishing feeding activities from other types of pulse interference.

VI. CONCLUSION

Through the comparison of signal time domain analysis and real-time photographic records, in the case of different numbers of shrimp, no acoustic signals were collected when they were not fed, and after 30 seconds of signal acquisition, the food was fed, acoustic signals were collected. When the shrimp was first fed, the starvation level of the shrimp was high. The shrimp grabbed food and ate by swimming. As the number of feedings increased, the starvation of the shrimp decreased, and the intensity of exercise showed a downward trend. The shrimp gradually stopped exercising and then stopped eating. This phenomenon indicates that the start of shrimp feeding will generate the related signals and it is related to shrimp movement. By correlating the collected signal with the acoustic signal of the shrimp moving during hypoxia, the correlation value is high, which further shows that when the shrimp is hungry, it swims and grabs food to generate acoustic signals.

Based on the passive acoustic technology to collect the feeding motion sound signal of Litopenaeus vannamei, through time domain and frequency domain analysis, it is found that the signal is similar to single pulse signal, the duration is about 8-10ms, and the resonance band range in the frequency domain is 2-10KHz. The detection of the effective range of the shrimp feeding signal is carried out by the dual-threshold method, and then the number of shrimp feeding signals is calculated. Through statistical analysis, the number of signals generated during the first feeding of the 10-shrimp experimental tank is the largest. With the decrease of the number of shrimp, the increase of feeding times and the decrease of shrimp hunger degree, the number of feeding signals generated gradually decreases, which provided theoretical basis for further on-demand control of feeding amount.

At the same time, other impulse noises will have a greater impact on the collection and detection of shrimp feeding signals. The noise pulse signal generated by the oxygen generator partially overlaps the resonance frequency band of the target feeding signal. In the future research work, we will consider how to correctly detect the target feeding signal under the background noise generated by the oxygen generator, so as to realize the automatic and intelligent feeding of shrimp and improve economic benefits.

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