An effective detection method based on the biological acoustic characteristics of the outlet of nuclear power plant

Jianfei Zhang¹, Shisong Zhang², Chong An³, Yuanling Luan⁴ and Wenzhi Li⁵

¹,²,³,⁴,⁵ Dalian measurement and Control Technology Research Institute, NO. 16, BinhaiStreet, Zhongshan District, Dalian, Liaoning, 116013, P. R. China

Jianfei_zhang760@163.com

Abstract. In order to improve the reliability of nuclear power plant cold source, it is necessary to establish a defense system in depth of marine biology, identification, detection, early warning and hierarchical response. Among them, detection and early warning is a front-end disposal measure, which can provide accurate and timely marine biological information for the follow-up hierarchical response. At the same time, it can replace the underwater inspection of divers and reduce the risk of industrial safety. In this paper, the underwater acoustic high-resolution multi beam detection method is used to detect marine creatures such as jellyfish, and its echo characteristics are obtained. The distribution density and body scattering intensity characteristics of jellyfish in sensitive sea areas are analyzed. The results show that the high-resolution multi beam acoustic method is effective for detecting marine creatures at the outlet of nuclear power plant.

1. Introduction
Since 2011, many nuclear power generating units at home and abroad have had incidents that affect the safe and reliable operation of the circulating water system due to jellyfish, brown algae, sediment, small fish and shrimp, blocking the cooling water pipe introduced into the turbine of the power station, resulting in the power station having to shut down the reactor and seriously affecting the safety of the unit. In July 2014, a large number of Aurelia aurita blocked the CFI intake, resulting in a short-term power reduction operation reactor of unit 1 / 2; in July 2015, a large number of Aurelia aurita blocked the CFI intake, resulting in the shutdown of unit 2; in August 7, 2016, Ningde nuclear power plant, was due to a large number of Haitian melons pouring into the intake, resulting in the reactor shutdown. These events have a serious impact on the safety and economy of the base power plant operation. Most of the coastal nuclear power plants have realized the severity of the water intake blockage event. In this paper, in order to meet the early-warning needs of the nuclear power plant water intake area for the invasion of jellyfish, fish and other marine organisms, the echo characteristics of jellyfish groups in the sea water are studied by using the underwater acoustic high-resolution multi beam detection method. The obtained image information of marine creatures is analyzed, processed and identified by using the feature analysis and statistics module, and the density of the monitored sea jellyfish groups is obtained. The results provide a basis for the early warning and disposal of marine organisms in the cold source waters of nuclear power plants.

2. Principle
The high frequency multi beam acoustic imaging technology is based on the acoustic plane array. The detection results are output in the form of acoustic image through the plane array beamforming, and the
detection of weak targets is realized by using its high signal-to-noise ratio gain. Beamforming technology comes from the principle that the array has directivity. Set a receiving transducer array composed of N non directional elements (as shown in Figure 1). Each array element is located at a space point \((x_n, y_n, z_n)\). The natural directivity of the array is formed by adding the signals of all the array elements to get the output. At this time, if a far-field plane wave is incident on the array, its output amplitude will change with the change of plane incident angle. When the signal source is in different directions, because the phase difference between the received signal and the reference signal of each array element is different, the amplitude of the formed and output is different, which is, the response of the array is different.

Taking N-element linear array as an example, the array spacing is d. The receiving sensitivity of each array element is the same, and the incident direction of plane wave is \(\theta\) (as shown in Figure 2). The output signals of each array element are:

\[
F_0(t) = A \cos(\omega t) \\
F_1(t) = A \cos(\omega t + \phi) = \text{Re}[e^{j\omega t} \cdot e^{j\phi}] \\
F_n(t) = A \cos(\omega t + n\phi) = \text{Re}[e^{j\omega t} \cdot e^{jn\phi}]
\]

Where A is the signal amplitude, \(\omega\) is the signal angular frequency, \(\phi\) is the phase difference between the received signals of adjacent array elements, Re is the real part, including:

\[
\phi = 2\pi f\tau = \frac{2\pi d}{\lambda} \sin \theta
\]

Therefore, the output of the array is:

\[
s(\theta, t) = \sum_{n=0}^{N-1} F_n(t) = A \cdot \text{Re}[e^{j\omega t} \sum_{n=0}^{N-1} e^{jn\phi}]
\]

Because:

\[
s = 1 + a + a^2 + \ldots + a^{N-1} = \frac{1-a^N}{1-a}
\]

\[
\sum_{n=0}^{N-1} e^{jn\phi} = \frac{1-e^{jN\phi}}{1-e^{j\phi}} = e^{j[(N-1)\phi/2]} \frac{\sin (N\phi/2)}{\sin (\phi/2)}
\]

Therefore:

\[
s(\theta, t) = A \frac{\sin (N\phi/2)}{\sin (\phi/2)} \cos \left( \omega t + \frac{(N-1)\phi}{2} \right)
\]

Divide the two sides of the above formula by Na at the same time to normalize, then the output amplitude is:
\[ R(\theta) = \frac{\sin\left(\frac{N\theta}{2}\right)}{N\sin\left(\frac{\theta}{2}\right)} = \frac{\sin\left(\frac{N\pi d}{2}\sin\theta\right)}{N\sin\left(\frac{\pi d}{2}\sin\theta\right)} \] (9)

\( R(\theta) \) shows that the output amplitude of a multiple array varies with the incident angle of the signal. Generally speaking, for an arbitrary array, no matter which direction the sound wave is incident from, it is impossible to form in-phase addition or get the maximum output. Only linear array or space plane array can form in-phase addition in the normal direction of the array and get the maximum output. However, if the array of any array is processed properly, it can form in-phase addition in a predetermined direction and get the maximum output.

3. Test device

Based on the high-resolution multi-beam acoustic method to detect marine biotechnology, a marine biological early warning system is constructed. The test device is shown in Figure 3. At a certain distance from the cold source water intake of the power station, a monitoring line is established, a data link is established between the monitoring sonar and the communication buoy, and the data of the monitoring sonar is transmitted back to the shore monitoring room by the communication buoy. Fixed monitoring stations are arranged at both sides and central points of the water intake to solve the monitoring capacity of the area covered by the emergency water. In the experiment pool and a certain sea area of Dalian, we have carried out the detection experiments of jellyfish and other sea creatures, and obtained the echo characteristic data of jellyfish. The layout of monitoring points of cold source water intake is shown in Figure 4.

4. Data processing method

4.1 Individual data processing of jellyfish

The echo data of jellyfish is processed by programming, and the acoustic image of individual target of jellyfish is obtained. The relative echo intensity \( \text{RES} \), diameter \( D_e \) and height \( H_e \) of jellyfish are calculated, and the echo characteristics of individual jellyfish are extracted. The calculation method of each parameter is as follows.

From the sonar equation:

\[ E_L = S_L - 2T_L + TS \] (10)

\[ T_L = 20 \log R \] (11)

Among them, \( E_L \) is the echo signal level of combined sonar parameters, \( S_L \) is the sound source level of sonar; \( T_L \) is the one-way sound propagation loss, taking spherical wave attenuation, ignoring the absorption loss of sea water; \( R \) is the target distance; \( TS \) is the target strength.
4.2 Data processing of jellyfish population

In the process of jellyfish detection, the scattering intensity of all jellyfish targets in the water is calculated as a group. The scattering intensity $S_{s, v}$ is defined as follows: the ratio of the scattering sound intensity per unit area or volume to the incident sound intensity at a distance of 1 meter from the scatterer (surface), and the ratio is expressed in decibels, i.e

$$S_{s, v} = 10 \log \frac{I_{\text{scat}}}{I_{\text{inc}}}(12)$$

$S_{s, v}$ represents the scattering intensity of volume scatterer or interface scatterer, $I_{\text{inc}}$ is the sound intensity of incident plane wave, $I_{\text{scat}}$ is the sound intensity scattered by unit volume or unit area (after being converted to unit distance).

5. Test result

The body wall structure of jellyfish is composed of two layers of epithelial cells sandwiched with mesothelium, which is thick. The gastric circulation cavity around the body wall is a simple capsule, or it is divided into four gastric sacs by the membrane (Figure 5). The echo image of individual jellyfish is composed of two parts: a larger background highlight and four smaller echo highlights, as shown in Figure 6, which are processed echo images in a certain detection (normalized). Through comparative analysis, it is found that the larger background bright spots in the picture are generated by the reflected sound waves of the umbrella body (middle glue layer) of jellyfish, and the four bright spots with higher brightness correspond to the four gastric sacs of jellyfish.

![Figure 5. Real image of sea moon jellyfish.](image1)
![Figure 6. Real image of sea moon jellyfish.](image2)

Figure 7 and Figure 8 show the time-varying characteristics of jellyfish distribution density and the time-varying characteristics of jellyfish population scattering intensity. It can be seen from the figure that the change trend of the two is relatively consistent, showing volatility, reflecting the uneven distribution of jellyfish distribution density in time and space in the sea water. The distribution density of jellyfish fluctuates with time, with the range of 100-400/m$^3$. There are four peaks in this period, with the distribution density of 310, 320, 400 and 260/m$^3$, as shown in Figure 9. In the results of jellyfish statistics on the distance slice, the distribution of jellyfish numbers on the distance slice at the same time presents a strip, and compared with other times, the number of jellyfish in this time increases significantly. It also shows that the distribution of jellyfish in the sea water is not uniform, which has the characteristics of changing with time. The average density of jellyfish in this period is 254/m$^3$. 
Figure 7. Characteristics of distribution density of jellyfish with time

Figure 8. Characteristics of scattering intensity of jellyfish population with time

Figure 9. Distribution density of jellyfish varies with distance

Figure 10 to Figure 12 show the change characteristics of the distribution density of another one-way jellyfish with time and the scattering intensity of jellyfish population with time. It can be seen from the figure that the distribution density of jellyfish fluctuates with time, with the range of $100-350/\text{m}^3$. There are four peaks in this period, and the distribution density is divided into 370, 350, 320 and 350 $/\text{m}^3$. In the results of jellyfish statistics on the distance slice, the distribution of jellyfish numbers on the distance slice at the same time presents a strip, and compared with other times, the number of jellyfish in this time increases significantly. It also shows that the distribution of jellyfish in the sea water is not uniform, which has the characteristics of changing with time. The average density of jellyfish in this period is $274/\text{m}^3$. 
6. conclusion
In this paper, the underwater acoustic high-resolution multi beam detection method is used to detect the jellyfish and other sea creatures, and the echo characteristics are obtained. In the detection results of individual jellyfish, the relative echo intensity and other characteristic parameters of jellyfish are extracted; the number of individuals in the jellyfish group is detected and counted by using the characteristic parameters of individual jellyfish, so as to evaluate the distribution density of jellyfish and other sea creatures in the water body. And the threat level provides the basis. In view of the detection of jellyfish population, the characteristic parameters of jellyfish distribution density and acoustic scattering intensity are proposed. The results show that the acoustic scattering intensity is approximately proportional to the distribution density of jellyfish. At the same time, it is feasible to use the high-resolution multi beam acoustic method to detect marine organisms at the outlet of nuclear power plant. The identification of jellyfish and other weak scatterer targets needs further study. In the future, we will continue to study the differences of acoustic emission characteristics between jellyfish, fish, shrimp, seaweed and other marine organisms.

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