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To cite this article: Meina Wang *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **310** 052062

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Analysis of seafloor reverberation related characteristics based on sea trial data

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Abstract. Ocean reverberation is one of the main factors affecting sonar performance. Studying the spatio-temporal correlation statistical characteristics of reverberation is of great significance for sonar detection and suppress reverberation, and is a problem that sonar designers have always been concerned about. This paper first gives an overview of the sea trial test; and analyzes the signal strength of the reverberation signals with different frequencies under different terrain conditions, which proves the reliability of the sea trial data. By processing the time-space correlation characteristics of the seabed reverberation data, the relationship between time-space correlation characteristics of the seabed reverberation data and the frequency and form of the transmitted signal and the seabed topography is obtained, which provides a theoretical reference for reverberation suppression and application.

1. Introduction

Ocean reverberation is the main disturbance of active sonar. For the “irregular sea area” where the horizontal boundary and the seabed boundary are irregular in shape and the boundary conditions are complex, reverberation has its special law. To study the active sonar detection problem in irregular sea areas, it is necessary to fully understand the time-space distribution characteristics of its reverberant field, so as to develop an effective underwater acoustic detection technology for the characteristics of the sound field and acoustic interference field in such sea areas. In particular, submarine reverberation is the main disturbance of active sonar detection of sinking mines. Therefore, studying the spatio-temporal correlation statistical characteristics of the reverberation sound field of the seabed has special significance for the anti-reverberation interference background during mine detection ^[1]. Through the processing of sea trial data, this paper focuses on the influence of seafloor topography and emission signals on the temporal and spatial correlation characteristics of seabed reverberation signals.

2. Overview of sea trials^[2]

The terrain of the test sea is inclined, and there are mountains on both sides, and the water quality is turbid. The acoustic emission system is located on the port side of the ship and the receiving system is located on the rear port side; the transmitting and receiving systems are spaced 32 m apart. The launch array is a wider beam launcher and is placed 6 meters underwater. The receiving array is a 40-element segmented unequal-space line array; during the experiment, the unequal-spaced 31-channel array element output and the other standard hydrophone output are sent to the 32-channel acquisition



memory via the multi-channel amplifier. The receiving array is placed in different poses to form a horizontal array and a vertical array. When these two poses are placed, the nearest array element from the water surface is 4.5m underwater.

In the test, the radiation direction of the transmitting transducer remains at an angle of 180 to the heading of the ship. The ship's heading is recorded every 3 minutes, and it changes with the wind and the flow. By combining the ship's heading with the seabed topographic map of the test sea area (see Figure 1), The position of the ship is indicated by \bullet , and the relative relationship between the incident direction of the sound wave and the seabed topography can be obtained. When the test ship has a compass value of 270, The direction of the incident sound wave drops rapidly and then rises slowly; When the test ship has a compass value of 330, the direction of the sound wave incidence is relatively flat; When the test ship's compass value is 160, the ground direction of the sound wave slowly decreases.

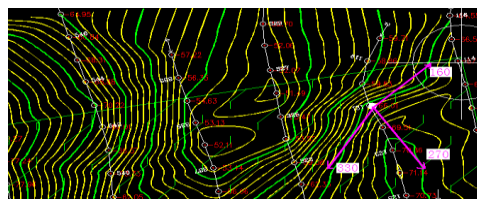


Fig. 1. Seabed topographic map of experimental sea area

The sea trial data processed in this paper are all calibrated (sensitivity calibration and phase calibration). Figure 2 shows the partial seafloor reverberation signal received by the standard hydrophone at the compass value of 330. As seen in the figure, the vast majority The data is ideal. In theory, the higher the frequency of the acoustic signal propagates in seawater, the faster the attenuation, so for the seabed reverberation signal, under the same conditions, the higher the frequency, the smaller the received reverberation signal. Because the intensity of the seabed reverberation is related to the seafloor scattering, the greater the seafloor undulation, the greater the scattering intensity, and the greater the reverberation received.

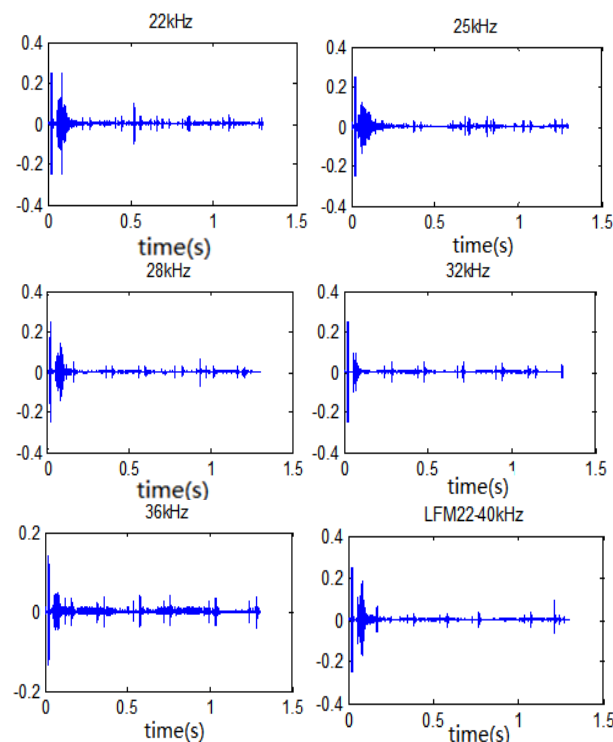


Fig. 2. Seafloor reverberation signal received by standard hydrophones when transmitting different frequency signals

Below we analyze whether the sea trial reverberation data satisfies the above theory. Tables 1 and 2 show the signal strengths of the seabed reverberation signals at different frequencies in different terrains.

As can be seen from the above table, the signal strength of the seafloor reverberation decreases with increasing frequency, and the flatter the ground, the lower the signal strength of the seafloor reverberation. Consistent with the theory, it proves that the following results of the sea trial data processing also have certain reliability.

3. Analysis of Spatial Correlation Characteristics of Sea Test Data

The spatial correlation characteristic of the seafloor reverberation signal is a curve in which the cross-correlation coefficient of the seabed reverberation signal changes as the spacing of the elements increases. Its theoretical expression is^[3]

$$R_{\text{ss}} = \int_{-\Theta/2}^{\Theta/2} \cos(kl\theta) d\theta = \frac{\sin \frac{\pi l}{\lambda} \Theta}{\frac{\pi l}{\lambda} \Theta} \quad (1)$$

The Horizontal directional opening angle of hydrophone is $\Theta = 2\arctan(\frac{r}{h})$, the depth of the receiving element to the seabed is h , the working distance is r , and the spacing of the elements is l .

The spatial correlation of the reverberation sought in this paper is described by the cross-correlation coefficient of the reverberation signals of different array elements. If the reverberation signal received by the two array elements is $X(t)$ and $Y(t)$, then the spatial correlation coefficient is expressed as:

$$r = \frac{K_{xy}(0)}{\sqrt{K_x(0)K_y(0)}} = \frac{R_{xy}(0) - m_x m_y}{\sigma_x \sigma_y} \quad (2)$$

Since the receiving array is divided into two horizontal and vertical deployment forms, when the spatial correlation processing is performed on the receiving arrays of the two poses, the horizontal spatial correlation and the vertical spatial correlation are obtained.

3.1 Horizontal space correlation

The horizontal spatial correlation of seabed reverberation is discussed in terms of the seabed topography and emission signals. Figure 3 shows the horizontal spatial correlation of the CW pulse signal with a frequency of 36 kHz and the LFM22k-40k signal at a compass value of 270, 330, and 160, respectively. Figure 4 is a horizontal spatial correlation of CW pulse signals and LFM signals with frequencies of 25 kHz and 36 kHz, respectively, under the same terrain. The results show that whether the transmitted signal is CW pulse signal or LFM signal, the flatter the ground, the larger the horizontal spatial correlation coefficient of reverberation; and in the same terrain, as the spacing of the array elements increases, the horizontal spatial correlation coefficient of LFM signals is smaller than the CW pulse signal.

Table 1. Signal strength of standard hydrophones when receiving horizontally (dB)

compass	22kHz	25kHz	28kHz	32kHz	36kHz	40kHz	FM22-40
270	172.1236	169.7484	168.8415	169.2926	157.3892	150.1604	163.8316
330	166.6983	162.8233	157.7807	157.5207	147.9301	138.9182	159.1877
160	188.345	183.9046	180.5179	177.1917	172.8863	172.1137	181.5852

Table 2. Signal strength of standard hydrophones during vertical reception (dB)

compass	22kHz	25kHz	28kHz	32kHz	36kHz	40kHz	FM22-40
350	164.9202	159.2048	154.5613	151.0953	147.5037	138.1983	151.3786

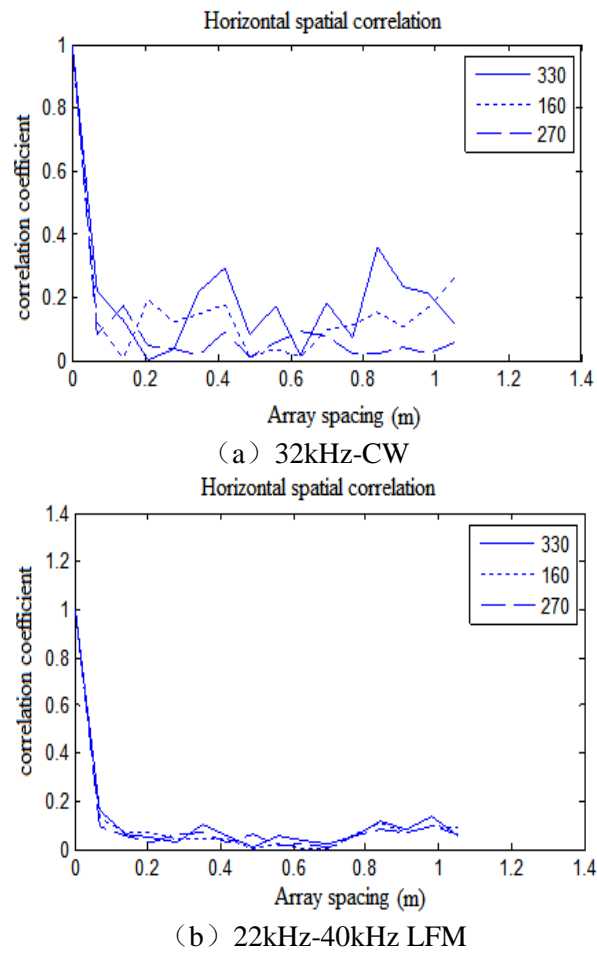


Fig. 3. Horizontal spatial correlation of the same signal in different terrain conditions

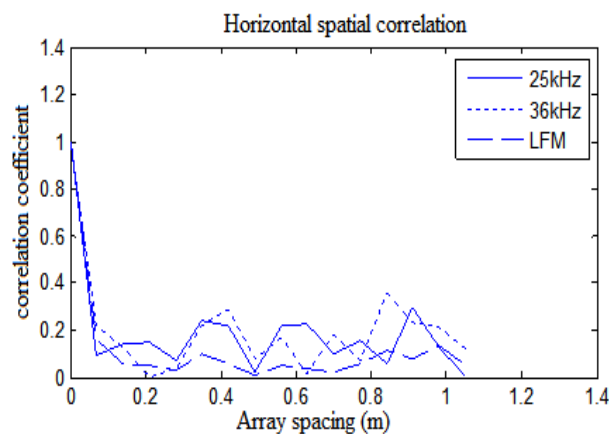
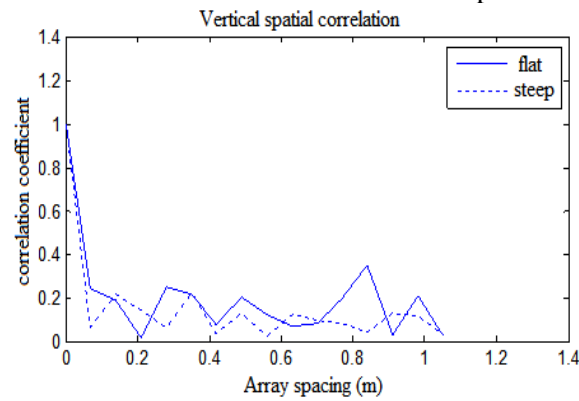


Fig. 4. Horizontal spatial correlation of different signals in the same terrain conditions

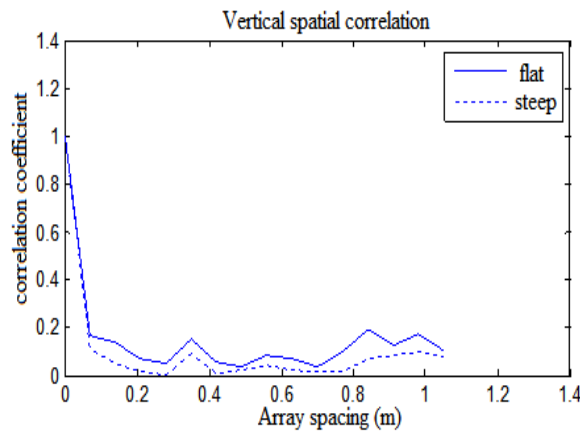
3.2 Vertical spatial correlation

The vertical spatial correlation of reverberation is discussed in view of the different seafloor topography and emission signals. Figure 5 shows the vertical spatial correlation of the 32 kHz CW pulse signal and the LFM22kHz -40 kHz signal when the sound waves are transmitted at steep terrain and flat terrain. Figure 6 shows the vertical spatial correlation of the cw pulse signal and the LFM signal with frequencies from 25kHz to 36 kHz, under the same terrain. The results show that whether

the transmitted signal is CW pulse signal or LFM signal, the flatter the terrain, the larger the vertical space correlation coefficient of reverberation. In the same terrain, as the spacing of the elements increases, the vertical spatial correlation coefficient of the reverberation of the LFM signal is smaller than the CW pulse signal; this result is the same of the horizontal space correlation.



(a) 32kHz-CW



(b) 22kHz-40kHz LFM

Fig. 5. Vertical spatial correlation of the same signal in different terrain conditions

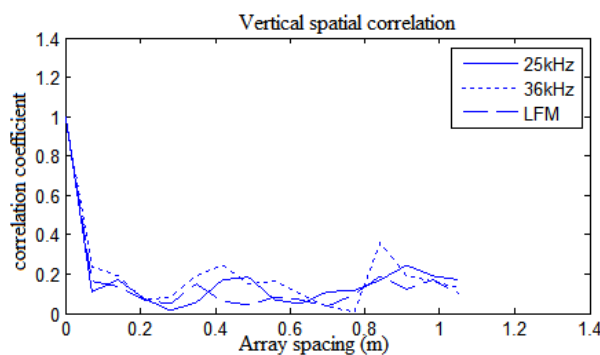


Fig. 6. Vertical spatial correlation of different signals in the same terrain conditions

4. Analysis of time correlation characteristics of sea test data

The time correlation of the reverberation is described by the autocorrelation function of a reverberation signal, if the reverberation is^[4]:

$$s(t) = s_0(t) \cos[\omega_0 t + \Phi(t)] \quad (3)$$

Where, $s_0(t)$ —signal envelope; ω_0 — center frequency of the signal spectrum; $\Phi(t)$ — FM function. Then the autocorrelation function is:

$$R(\tau) \approx (1/\delta) \left\{ \int_{-\infty}^{\infty} s_0(t) s_0(t+\tau) \cos[\Phi(t+\tau) - \Phi(t)] dt \right\} \cos \omega_0 \tau \quad (4)$$

The time correlation of seafloor reverberation is discussed below based on the seabed topography and the emission signal. Figure 7 and Figure 8 shows the time correlation of the seafloor reverberation signal received by the CW pulse signal and the LFM signal when the sound waves are transmitted at steep terrain and flat terrain. Figure 9 is the time correlation of the seafloor reverberation which the LFM signal and the CW pulse signal in the same terrain. The results show that whether the transmitted signal is CW pulse signal or LFM signal, the flatter the terrain is, the smaller the time correlation radius of the reverberation is. The time correlation radius of the CW pulse signal decreases with increasing frequency, the time correlation radius of the LFM signal is smaller than The CW pulse signal.

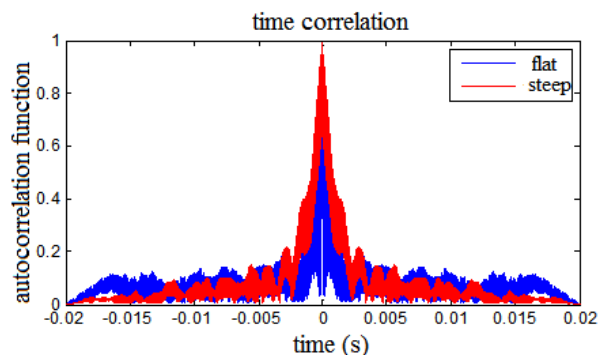


Fig.7. Time correlation of CW pulse signals in different terrains

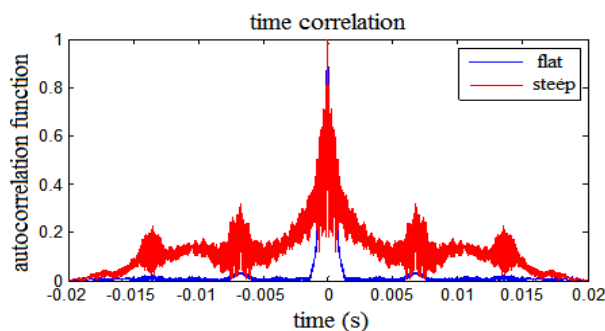


Fig. 8. Time correlation of LFM 22KHz-40KHz signals in different terrains

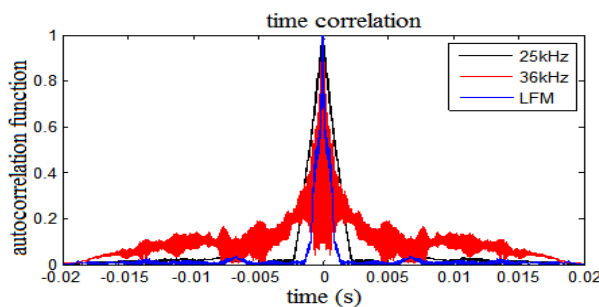


Fig. 9. Time correlation of different signals in the same terrains

5. Conclusion

In this paper, it mainly for factors affecting the correlation of reverberation - seafloor topography and emission signals, are processed and analyzed for the time-space correlation characteristics of the calibrated seabed reverberation data. The following conclusions are drawn:

(1) Regardless of whether the transmitted signal is the CW pulse signal or the LFM signal, the flatter the ground, the larger the spatial correlation coefficient of the reverberation; and in the same terrain, as the spacing of the array elements increases, the transmitted signal is the LFM signal. The spatial correlation coefficient is smaller than the CW pulse signal's.

(2) Regardless of whether the transmitted signal is the CW pulse signal or the LFM signal, the flatter the ground, the smaller the time-dependent radius of the reverberation; and the smaller the time-dependent radius of the CW pulse signal with increasing frequency, the time-dependent radius ratio of the LFM signal is smaller than the CW pulse signal's.

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