http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (24): 8370-8376, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.8370.8376

Numerical Method for Simulating Ocean Ambient Noise Field

Shi Jie
School of Marine Science and Technology, Northwestern Polytechnical University,
Xi'an, 710072, China

Abstract: A numerical method for simulating ocean ambient noise field is proposed here. Cron and Sherman (1962) mentioned that noise in the ocean was a superposition of an isotropic noise field and an anisotropic noise field originating at the surface. In this study, by reasonable choosing the way noise sources distributed and reasonable design of time-delay filter, the broadband time series of noise data received at any point in ocean can be generated by running the numerical simulating method. The operation steps of the method are described in detail. The simulation results show that the spatial-correlation functions of isotropic noise field and surface noise field simulated by the simulation method are consistent with the theoretical analysis.

Key words: Ocean noise field, isotropic noise field, surface noise field, numerical simulation

INTRODUCTION

The ocean ambient noise which is considered as an interruption must be known firstly before we process the received underwater signal by sonar. Especially for target detection and localization in low signal to noise ratio environment it is very important to know the characteristics of the ocean ambient noise and the difference between the noise background and the signal. Although data derived from in-situ experiments can efficiently test the performance of sonar, simulated data provides the opportunity to examine sonar's performance for well-defined fields in laboratory. The traditional simulating method of the noise field nowadays is just to produce white noise data sequences independent. This method can give an approximate noise field when the distance between array hydrophones is larger than half-wavelength of signal but it is not correct when the distance between array hydrophones is smaller, just like vector-sensor array (Hawkes, 2001) or small-aperture array (Lo, 2004). In these situations, noise sequences received by sonar hydrophones cannot be just considered independent because they have correlation and the correlation will seriously affect the processing results. So it is necessary to simulate the ambient noise field with theoretical cross-correlation coefficient rather than simply assuming the noise sequences are independent white noise.

There are many reference articles (Cron and Sherman, 1962; Kuperman and Ingenito, 1980; Chapman,1987; Carey *et al*., 1990; Plaisant, 1992; Perkins *et al*., 1993; Harrison, 1996) talked about the theory of ambient noise model. For all these theoretical ambient noise models, the most basic theory is the model established by Cron and Sherman (1962). They proposed that noise in the ocean is a superposition of an isotropic noise field and an anisotropic noise field originating at the surface. They established noise models of the two noise fields and deduced the cross-correlation function of two arbitrary hydrophones in the two noise fields separately. The noise model mentioned by Cron and Sherman (1962) was used widely in underwater acoustic signal processing because it is suitable to describe the deep-sea environment and simple shallow-sea environment.

However the numerical simulating method of ambient noise field is mentioned rarely. Walker *et al.* (1981) presented method to generate a set of time series with given cross-correlation coefficient. However, the procedure is quite involved and limited to linear or planar arrays in its present form. Rosenfeld *et al.* (2000) proposed a frequency domain approach to simulating ambient noise fields. This approach can yield narrow-band frequency-domain ambient noise inputs for sonar processing scheme rather than broadband time series. These methods considered the spatial distribution of the ocean ambient noise but they did not give a general simulation method to simulate noise field mentioned by theoretical ocean ambient noise models.

In this study, firstly, we proposed a numerical method to produce the noise field and we described operation steps in detail. Then the cross-correlation function of noise sequence received by two arbitrary hydrophones in noise field was calculated. Finally we compared the cross-correlation function simulated and the theory function to prove the simulation method is correct.

OCEAN AMBIENT NOISE MODEL MENTIONED BY CRON AND SHERMAN

Experimental work suggested that noise in the ocean is a superposition of an anisotropic noise field due to the ocean surface and an isotropic noise field which is also ‘present in the absence of radiation from the surface. Cron and Sherman calculated the spatial-correlation function for a volume-noise model which produces an isotropic noise field and for a surface-noise model which produces an anisotropic noise field.

Volume-noise model: The volume-noise model consists of an ensemble of identical noise sources uniformly distributed throughout a sphere of radius R_v as shown in Fig. 1. In this model a homogeneous, isotropic noise field exists in a region near the center of the sphere. Cron and Sherman deduced that as R_v, the correlation function of two receivers with the midpoint of the line joining them located at the center of the sphere and with the distance d can be expressed as:

$$\rho(d)=\frac{\sin kd}{kd} \tag{1}$$

Surface-noise model: The noise model to be considered now consists of noise sources uniformly distributed over a circular area of radius R_s on a plane surface as shown in Fig.1. In this model a homogeneous, anisotropic noise field exists in a region below the center of the circular area of noise sources. Each surface-noise source is a directional radiator with directionality of amplitude given by the function $g(\theta) = \cos^m(\theta)$, where m is an integer and θ is the angle between the line perpendicular to the surface at the noise source and line joining the noise source to the center of the receivers. Assuming that the radius of the circular area of noise sources is much larger than any other dimensions and let $R_s \to \infty$, Cron and Sherman (1962) deduced the spatial correlation functions of two separated receivers with parameter m = 0, 1, 2, 3:

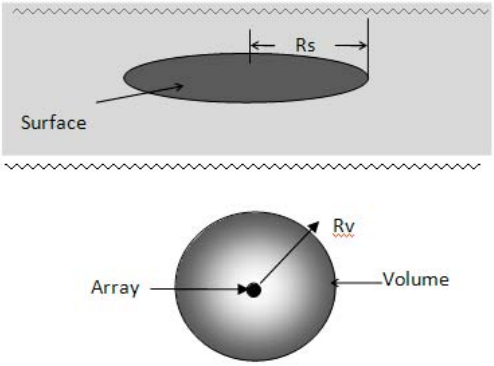

Fig. 1: Corn and Sherman’s noise model

$$\rho(d,\gamma,m)=\frac{\int_0^{\frac{\pi}{2}} g^m(\theta)\tan\theta\cos(kd\sin\gamma\ \text{cso}\theta)\,j_o(kd\cos\gamma\sin\theta)d\theta}{\int_0^{\frac{\pi}{2}} g^m(\theta)\tan\theta\,d\theta} \tag{2}$$

For conveniently validating the simulated noise field, the theoretical spatial correlation functions of two hydrophones which are placed horizontally and vertically with various m values are shown here.

m = 0,γ = 0,that is the two hydrophones are placed horizontally:

$$\rho(d, 0, 0) = J_0(kd) \tag{3}$$

m = 0,γ = π/2, that is the two hydrophones are placed vertically:

$$\rho\left(d,\frac{\pi}{2},0\right)=\frac{\sin(kd)}{kd} \tag{4}$$

m = 1,γ = 0:

$$\rho(d,0,1)=2\frac{J_1(kd)}{kd} \tag{5}$$

m = 1, γ = π/2

$$\rho\left(d,\frac{\pi}{2},1\right)=2\left[\frac{\sin(kd)}{kd}+\frac{\sin(kd-1)}{(kd)^2}\right] \tag{6}$$

m = 2, γ = 0:

$$\rho(d,0,2)=8\frac{J_2(kd)}{(kd)^2} \tag{7}$$

m = 2, γ = π/2:

$$\rho\left(d,\frac{\pi}{2},2\right)=\frac{12\left[(kd)^2-2\right]\text{cso}\,kd}{(kd)^2} \tag{8}$$

m = 3, γ = 0:

$$\rho(d,0,3)=48\frac{J_8(kd)}{(kd)^2} \tag{9}$$

m = 3, γ = π/2:

$$\begin{aligned}&\rho(d,\frac{\pi}{2},3)=\\&\frac{6\sin kd}{kd}+\frac{30\cos kd}{(kd)^2}-\frac{120\sin kd\left[(kd)^2-6\right]}{(kd)^5}-\\&\frac{30\cos kd\left[(kd)^2-2\right]}{(kd)^6}-\frac{720}{(kd)^6}\end{aligned} \tag{10}$$

NUMERICAL METHOD FOR SIMULATING OCEAN AMBIENT NOISE

Volume-noise model: A physical simulation approach can work with a generally defined array/noise field combination and can yield time-domain ambient noise inputs for a sonar processing scheme. It is straightforward to implement and can be simply modified to include a variety of desired physical parameters.

According to Cron and Sherman ocean ambient noise model, for producing an isotropic noise field, we must place lots of noise sources uniformly-distributed in the whole spherical volume of radius R_v. And the radius R_v is assumed to tend to infinite. To this end, firstly, we divide the sphere volume into several spheres with various radiuses R_i (R_i is from 0 to R_v). If the maximum separation between array hydrophones put at the center of the sphere volume is d, considering the simulating complexity and the performance of simulating noise field, we can set R_i from d to 100 d with the separation step 5d.

The next stage is to place noise sources on each sphere surface in order to simulate the isotropic noise field for the sonar array. For each sphere with radius R_i we cut the spherical surface into several curved surfaces by equally divided solid angle and then put a wide-band noise source at the center of each curved surface. Note that the small sphere surface must cut into less curved surfaces than the larger sphere because the area of all curved surface must be equal in order to uniformly distribute the noise sources in the whole sphere volume. Following the lead of Cron and Sherman, the amplitudes of a given frequency component produced by the various noise sources are distributed about an ensemble average which is equal to the time average over a long time and the phases are random. Then the noise sources can simply have same amplitudes but their phases are random because the propagation distances from noise sources and array hydrophones are different.

Then the next stage is to determine the phase delay ô which is the propagation delay time from noise source to receiver. For example, the time delay of a noise source traveling from point S with coordinate (x_s, y_s, z_s) to a hydrophone point A with coordinate (x_A, y_A, z_A) can be expressed as:

$$\tau = \frac{\left|\overrightarrow{OS} - \overrightarrow{OA}\right|}{c} \qquad (11)$$

where, k is wave number and $k = 2\pi f/c$ and O is the origin.

Note that the delay τ can be generated by the non-integer time-delay FIR linear filter mentioned by Ma *et al*. (1995). For example, a noise source $S_i(t)$ which travels from its location to array sensor A with time delay τ_i defined by eq. 15 passes through the non-integer time-delay FIR linear filter to achieve a received wave signal $S_i(t-\tau_i)$.

Finally we can obtain the overall response at point A $y_A(t)$ in the isotropic noise field by summing all the received wave signals and $y_A(t)$ can be expressed as:

$$y_A(t) = \sum_{i=1}^{\infty} s_i(t-\tau_i) \qquad (12)$$

Surface-noise model: The numerical method of simulating surface noise field is similar to the method of simulating volume noise field mentioned above. The key point is how to divide the infinite surface. With a lot of practical operations, circular area of radius R_s on the ocean surface. Theoretically, R_s is assumed to be here the principle of dividing method can be as follows:

- Firstly we set R_s is 1000 d if the maximum distance between array sensors is d. Then divide the circular area with radius from 0 to into R_s into N ring areas by dividing the elevation angle equally, then the ith ring area
- Can be divided into M_i parts by dividing the azimuth angle equally, where $M_i = M_0+2(i-1)$, i = 1…N and M_0 is the number which the first ring area divided into small parts
- Since the ith ring area can be divided into
- M_i small plane area, the elevation angles and azimuth angles of the center of the small plane area can be expressed as:

$$\theta_i = (2i-1)\pi/4N \quad i = 1,\ldots,N$$

$$\varphi_{ij} = (2j-1)\pi/M_i \quad j = 1,\ldots,M$$

So the whole circular area can be divided into P small plane areas, where P = N×M and $M = \Sigma M_i$. The Block diagram of noise field simulation is shown in Fig. 2.

For generating an anisotropic noise field we can put P noise sources at each center of the small plane area, the location setting of receiver sensor and computation method of time delay are similar to simulating volume noise field mentioned above. Similarly, the total response received at arbitrary point A by summing all the received wave signals and it can be expressed as:

$$Y_A(t) = \sum_{i=1}^{N}\sum_{j=1}^{M} S_{ij}\,(t-\tau_{ij}) \qquad (13)$$

SIMULATION AND RESULTS

For testing the simulating noise field, we can compare the spatial correlation function of two arbitrary sensors in simulating noise field to the theoretical formulas.

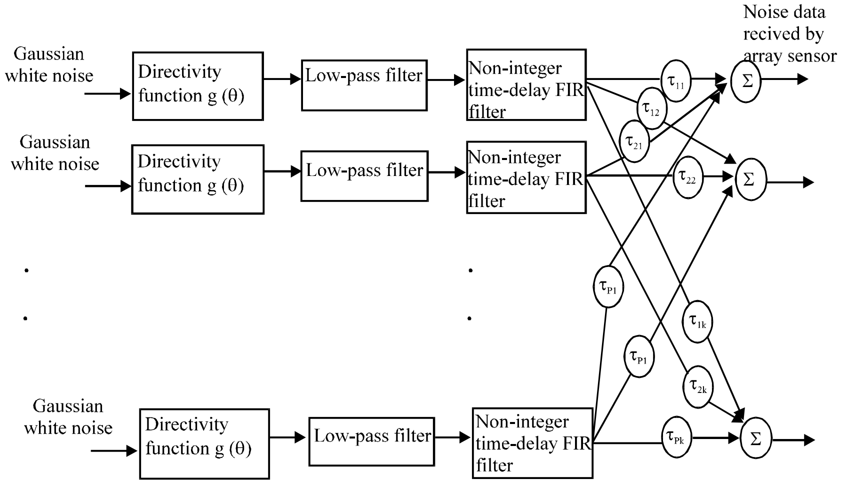

Fig. 2: Block diagram of noise field simulation

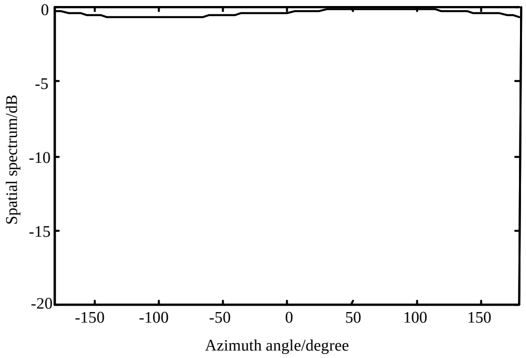

Fig. 3: Spatial spectrum of the simulating volume-noise field

Simulating for volume noise field: A circular array with radius 1.5 m and 24 sensors is put in the simulating noise field. We can analysis the performance of the simulating isotropic noise field by testing the spatial uniformity and spatial correlation of it.

The spatial spectrum of the simulating noise field is shown in Fig. 3. The result is achieved by conventional broadband beam scanning in the whole 360° horizontal space. As shown in the figure, the spatial uniformity of the simulating noise field is within 1dB and the result shows that the simulating noise field is basically isotropic. Fig. 4 shows the spatial correlation coefficient of a pair of hydrophones in the simulating isotropic noise field. From figure 4, we can see that the spatial correlation of a pair of hydrophones in the simulation isotropic noise field is basically similar with the theoretical result shown in eq. (1).

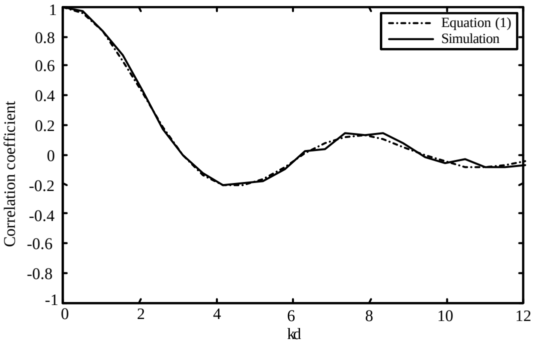

Fig. 4: Comparison of simulated correlation coefficient with theory in isotropic noise field

Simulating for surface noise field: For testing the numerical simulating method of generating anisotropic noise field, we compare the calculating correlation coefficients of sensor pairs put on (d/2,0,0), (-d/2,0,0) and (0, 0,d/2), (0,0,-d/2) separately with the theoretic spatial correlation expressed by the eq. (7)-(14). The parameters set in simulating experiments are d = 0.4 m, c = 1500 m sec^{-1}, N = 100, M_0 = 4. Fig. 5-8 show the spatial correlation of hydrophones in the simulating surface noise field.

Figures 5-8 show that the spatial correlation of pairs of hydrophones in simulating surface noise field is basically similar with the theoretical ones. And the results show that the numerical simulation method proposed here is effective.

Note that the distribution of noise sources affects the performance of the simulating method. Theoretically, to produce realistic noise field there must be infinite noise sources uniformly distributed on the surface of ocean.

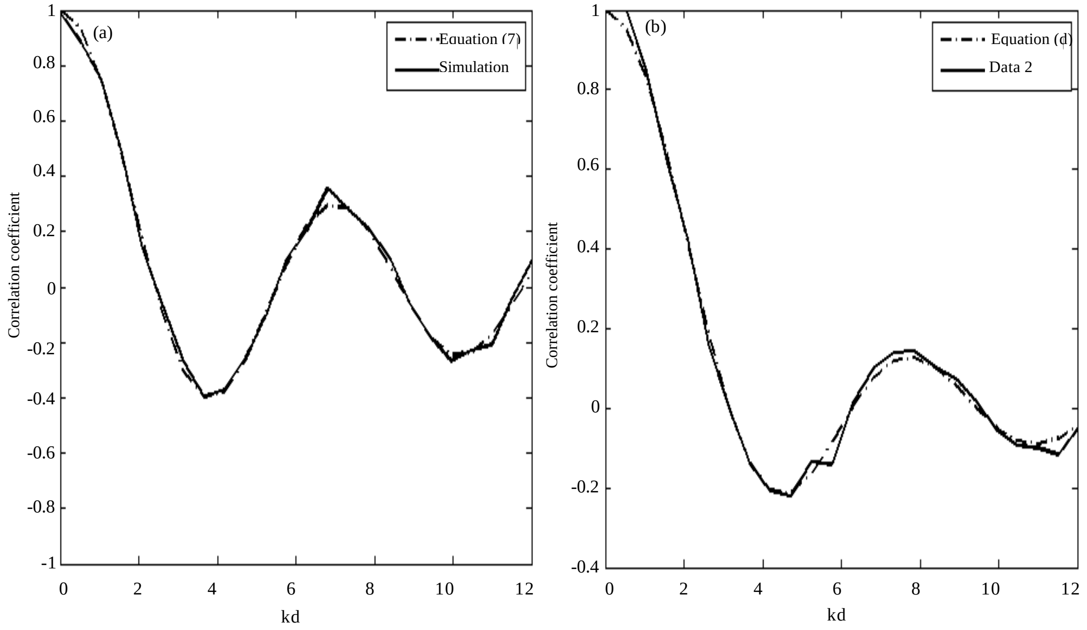

Fig. 5(a-b): Comparison of simulated correlation coefficient with theory in surface noise field when m = 0 (a) hydrophone pairs placed horizontally and (b) placed vertically

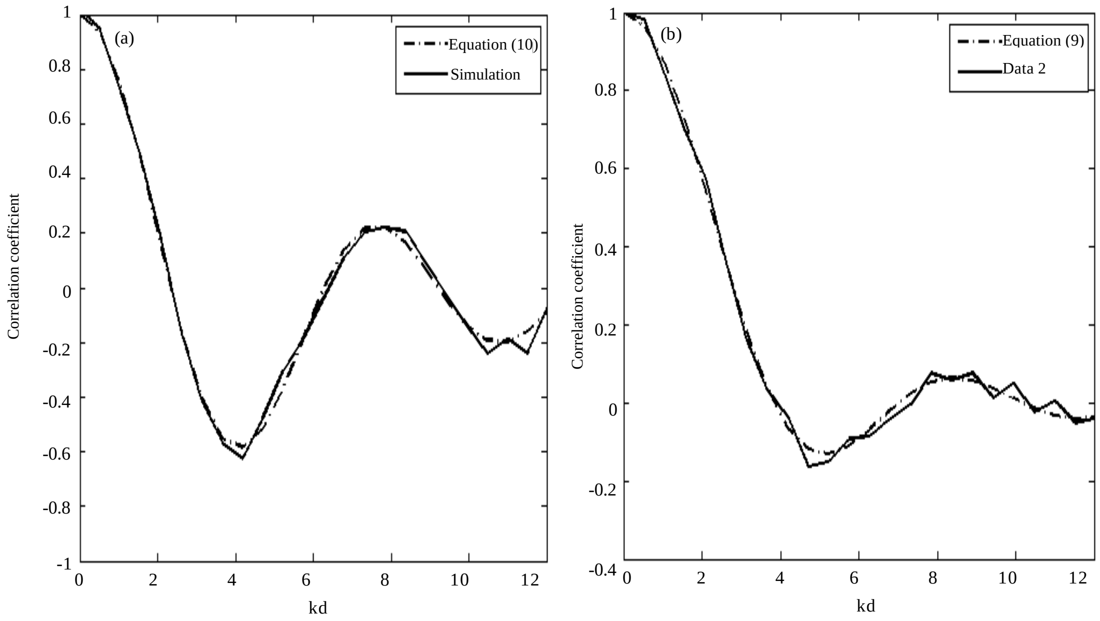

Fig. 6(a-b): Comparison of simulated correlation coefficient with theory in surface noise field when m = 1 (a)horizontally and (b)vertically

From fig. 5-8, we can see that the parameters we choose are reasonable set. But if we divide the circle area with radius R_s into fewer rings and place fewer points on each ring, that is to say, less

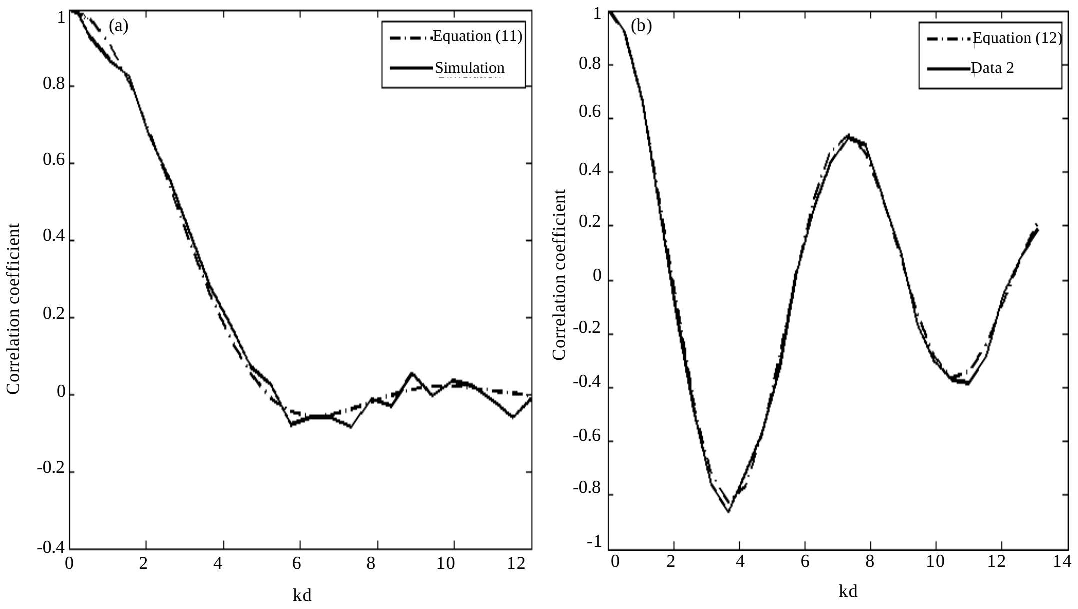

Fig. 7(a)-b: Comparison of simulated correlation coefficient with theory in surface noise field when m = 2 (a)horizontally and (b) vertically

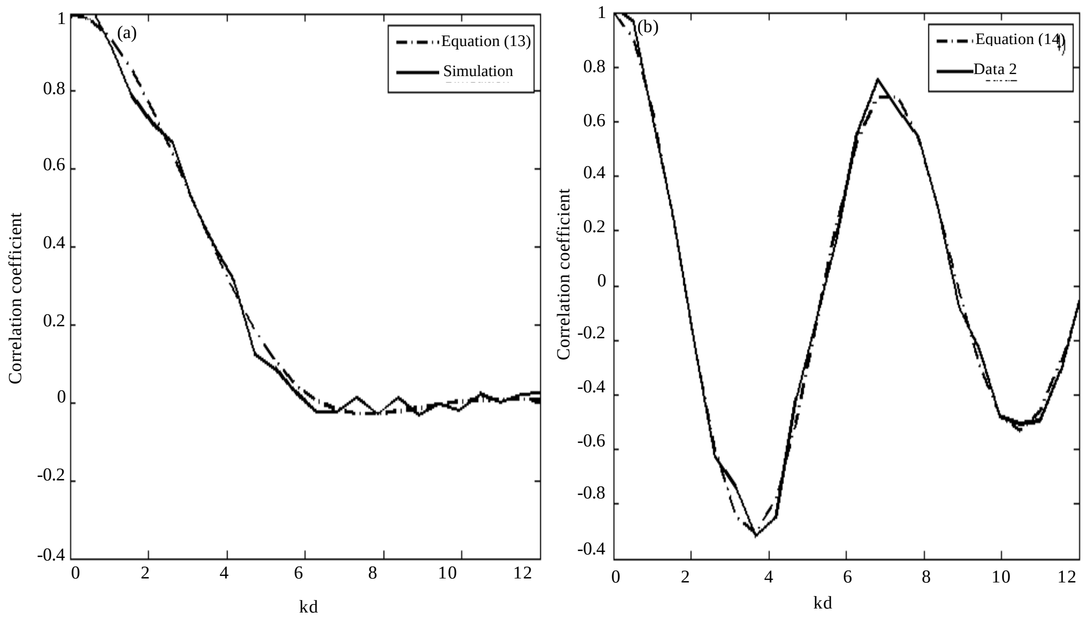

Fig. 8(a-b): Comparison of simulated correlation coefficient with theory in surface noise field when m = 3 (a)horizontally and (b) vertically

noise sources are placed on the ocean surface, the performance of the simulating noise field is not so good yet just like Fig. 9. For example, we set parameters as:

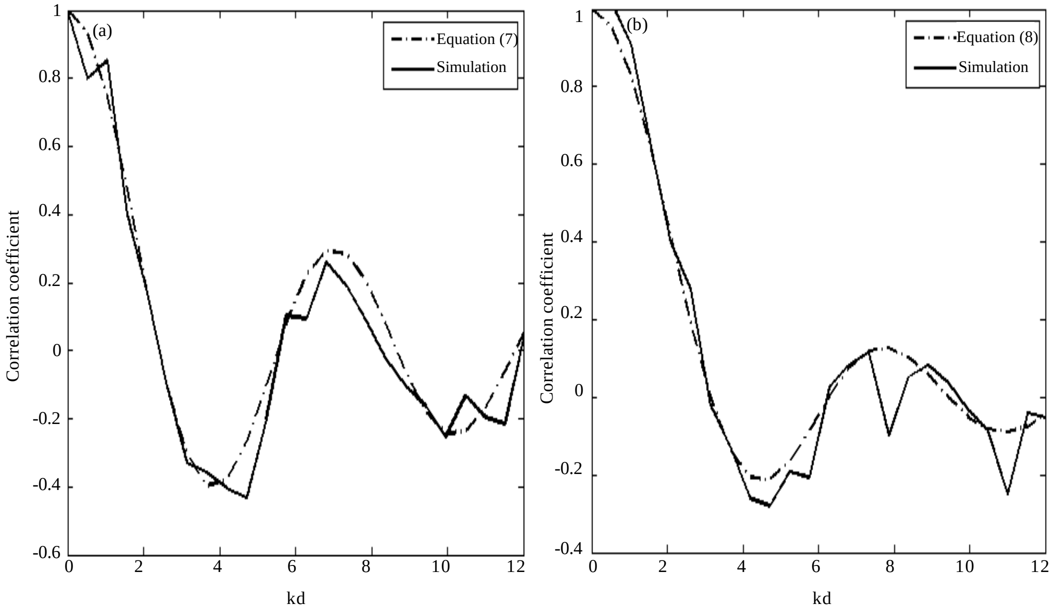

Fig. 9(a-b): Comparison of simulated correlation coefficient with theory in surface noise field when m = 0 (a) horizontally and (b) vertically

$d = 0.4$ m, $c = 1500$ m sec^{-1}, $N = 50$, $M_0 = 2$.

CONCLUSION

In this study, a simulating method for modeling ocean ambient noise was presented. It can generate broadband time series of ambient noise data received by sonar array sensors in an isotropic noise field and a surface noise field mentioned by Cron and Sherman. Computer simulation experiments show that the spatial correlation characteristics of the two noise fields are basically similar with the theoretical ones.

REFERENCES

Carey, W.M., R.B. Evans, J.A. Davis and G. Botseas, 1990. Deep-ocean vertical noise directionality. IEEE J. Oceanic Eng., 15: 324-334.

Chapman, D.M.F., 1987. Surface-generated noise in shallow water: A model. Proc. Inst. Acoust., 9: 1-11.

Cron, B.F. and C.H. Sherman, 1962. Spatial -correlation functions for various noise models. J. Acoustic Soc. Am., 34: 1732-1736.

Harrison, C.H., 1996. CANRAY: A model of ambient noise, coherence and array response. Applied Acoustics, 99: 2055-2066.

Hawkes, M., 2001. Acoustic vector-sensor correlations in ambient noise. J. Oceanic Eng., 26: 337-347.

Kuperman, W.A. and F. Ingenito, 1980. Spatial correlation of surface generated noise in a stratified ocean. J. Acoustical Soc. Am., 67: 1988-1996.

Lo, K.W., 2004. Adaptive array processing for wide-band active sonars. IEEE J. Oceanic Eng., 29: 837-846.

Ma, Y.L., J.W. Zhao and Q. Zhang, 1995. A method for high precision time delay implementation by a FIR degital filter. Acta Acoustica, 20: 121-126.

Perkins, J.S., W.A. Kuperman, F. Ingenito, L.T. Fialkowski and J. Glattetre, 1993. Modelling ambient noise in three-dimensinal ocean environments. J. Acoustical Soc. Am., 93: 739-752.

Plaisant, A., 1992. Spatial coherence of surface generated noise. Proceedings of Underwater Defence Technology, (UDT'92), Microware Exhibitions and Publishers Ltd., Kent, UK., pp: 515-522.

Rosenfeld, A.L., D.L. Hutt and P.C. Hines, 2000. A frequency-domain approach to simulating ambient noise fields. Oceans MTS/IEEE Conf. Exhibition, 1: 447-452.

Walker, R.S., D.V. Crowe and W.R. Mayo, 1981. Synthetic multichannel time series for simulating underwater acoustic noise. Proceedings of the IEEE International Conference on Acoustic, Speech and Signal Processing, Volume 6, March 30- April 1, 1981, IEEE Press, pp: 1042-1045.