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Study of Pattern Time Delay Coding Underwater Acoustic Communication Technique Based on a Single Vector Hydrophone

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Abstract: The study aims at improving the SNR at receiver during the long distance underwater acoustic communication. Pattern time delay shift coding underwater acoustic communication technique has been combined with single vector signal processing technique using prior code pattern knowledge to estimate communication transmitting node's position based on the active acoustic intensity average. And then linearly combines the sound pressure and the vibration velocity signals to form a combined directivity according to the estimated transmitting node's position. Theoretical analysis and the simulation study show the combined directivity can improve the SNR at the receiver. The robustness and practicality of the system are verified.

Key words: Single vector, combined directivity, pattern time delay coding, underwater acoustic communication

INTRODUCTION

Introduction With the increase of people's activities in oceans a large number of AUV and UUV have been employed which creates a great demand for underwater acoustic communication. Wherefore the development of effectiveness and robustness underwater acoustic communication technique is full of significance. Literature 1 proposed a communication system named Pattern time delay shift coding system which adapts to the underwater acoustic environment (Yin *et al*., 2006). The system applies to the requirements of medium-range and medium-communication rate environment. Nevertheless, with communication distance increases the SNR at the receiver decreases gradually. While the SNR at the receiver reached a certain small amount the decoding BER of the communication technology is rising sharply. Literature 2 proposed an active acoustic intensity average which could estimates the target azimuth using a single vector hydrophone. A directional communication can be realized through a combined directivity cooperating with a pseudo-random sequence which can achieved SDMA and improved certain order of magnitude of the SNR (Jing-Wei *et al*., 2012). A underwater acoustic communication system composed of single vector signal processing technique and Pattern time delay shift coding system has been proposed. A single vector hydrophone is used to estimate target azimuth and form a combined directivity which improved the decoding performance of the Pattern time delay shift coding system. Meanwhile, communication transmitting node's time-bearing display can be obtained using a single vector hydrophone and then the receiver adjusts feedback sending and receiving directivity according to the time-bearing display in real time to improve communication performance.

DOA ESTIMATION PRINCIPLE BASED ON SINGLE VECTOR HYDROPHONE

Vector sensor vibration velocity sensor has a dipole directivity which brings an inhibitory effect on the isotropic noise and gets a certain spatial processing gain compared to the traditional sound pressure hydrophone. The study aims to improve the robustness of the Pattern time delay shift coding underwater communication technique in the case of communication distance increases using the processing gain.

Foundation of vector signal processing: The main concern in this section is DOA estimation in the two-dimensional level. The outputs of vector hydrophone are the sound pressure channel and two-dimensional vibration velocity channels (Junying and Juan, 2009):

$$\begin{cases} p(t) = x(t) \\ v_x = x(t)\cos(\theta) \\ v_y = x(t)\sin(\theta) \end{cases} \tag{1}$$

where, x(t) is the sound pressure waveform and θ is the target azimuth. Two orthogonal vibration velocity signals can be obtained after a reasonable combination:

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$$\begin{cases} v_c = v_x\cos(\varphi) + v_y\sin(\varphi) \\ v_s = -v_x\sin(\varphi) + v_y\cos(\varphi) \end{cases} \tag{2}$$

where, φ is the assumed orientation, substituting Eq. 1 into 2:

$$\begin{cases} v_c = x(t)\cos(\theta - \varphi) \\ v_s = x(t)\sin(\theta - \varphi) \end{cases} \tag{3}$$

The Eq. 3 shows the two combined vibration velocity signal are still orthogonal. Changing the assumed orientation can realize electronic rotary of directivity simply and effectively at the time of DOA estimation using the single vector hydrophone.

DOA estimation based on active acoustic intensity average: The common DOA estimation methods using a single vector sensor are the acoustic intensity average and the complex acoustic intensity average. Literature 2 proposed a multi-user DOA estimation method for multi-user SDMA based on spread spectrum communication system using different pseudo-random sequences. Analysis and studies have shown that: the acoustic intensity average and the active acoustic intensity average have the same processing gain, but acoustic intensity average needs a integrator while the active acoustic intensity average needs to carry out a matched filtering. Pattern time delay shift coding system itself needs to carry out a matched filtering during the frame synchronization, the use of the active acoustic intensity average can save the computation of an integrator. Therefore, the study estimates communication transmitting node's DOA employing the active acoustic intensity average. The estimation principle based on the LFM signal and the active acoustic intensity average will be briefly described.

Figure 1 shows the structure of the active acoustic intensity average based on the combined vibration velocity:

v_c, v_s are two combined vibration velocity output of vector hydrophone. Each channel's signal was carried out a matched filtering with the local reference LFM signal and then select the peak by search the matched filtering results:

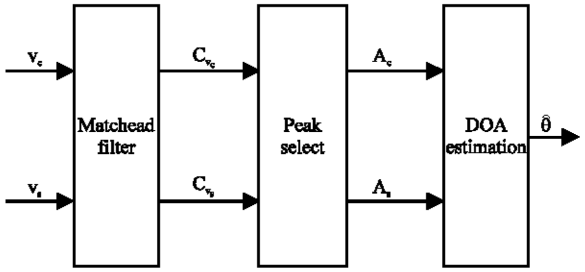

Fig. 1: Structure schematic diagram of active acoustic intensity average

$$\begin{aligned} A_c &= \max[\overline{x(t)v_c(t-\tau)}] \\ &= \max[c_{v_c}(\tau)] \\ &= A\cos(\theta+\tau) + \Delta_c \end{aligned} \tag{4}$$

$$\begin{aligned} A_s &= \max[\overline{x(t)v_s(t-\tau)}] \\ &= \max[c_{v_s}(\tau)] \\ &= A\sin(\theta+\tau) + \Delta_s \end{aligned} \tag{5}$$

where, A is the correlation peak value Δ_c and Δ_s is small interference amount. Equation 5 divided by Eq. 4 and then taking the arctangent:

$$\hat{\theta} + \varphi = \arctan\frac{A_s}{A_c} \tag{6}$$

where, $\hat{\theta}$ is the estimated DOA and φ is the assumed target orientation.

COMBINED DIRECTIVITY OF SINGLE VECTOR HYDROPHONE

Vector hydrophone vibration velocity channels have dipole directivity. The vector hydrophone can form a variety of directivities by combine the three outputs and the different applications can take different combined directivities. The combined directivities of a single vector hydrophone were analyzed in this session in order to find out which is suitable for underwater acoustic communication to obtain a better communication performance.

Literature 4 mainly studied the following five combined directivities: $(p+v_x)^2$, $(p+v_c p)$, $(p+v_x)v_c$ $(p+v_x)p$ and $p+v_x$ (Zhixiang, 2004) (Fig. 2). Consider of the computational overhead during the underwater acoustic communication at the receiver, the linear combined directivity are mainly studied and the processing gain will been analyzed in this session (Fig. 3).

For a single vector sensor, marked the sound pressure signal power, σ_s^2 the noise power, σ_n^2 the vibration velocity signal power and then noise power of the vibration velocity channel is $\sigma_s^2/2$ (Qihu, 2000; Jingwei, 2011). The power of the linear combined signal is while noise power is, at this point the SNR is:

$$(S/N)_{pv} = \frac{(1+k)^2\sigma_s^2}{(1+k^2/2)\sigma_n^2} \tag{7}$$

The output signal to noise ratio is max when $(1+k)/(1+k^2/2)$ reached the maximum when its derivation is equal to zero and $k = 2$. In other words the vector sensor output SNR is the highest in case of $k = 2$ and

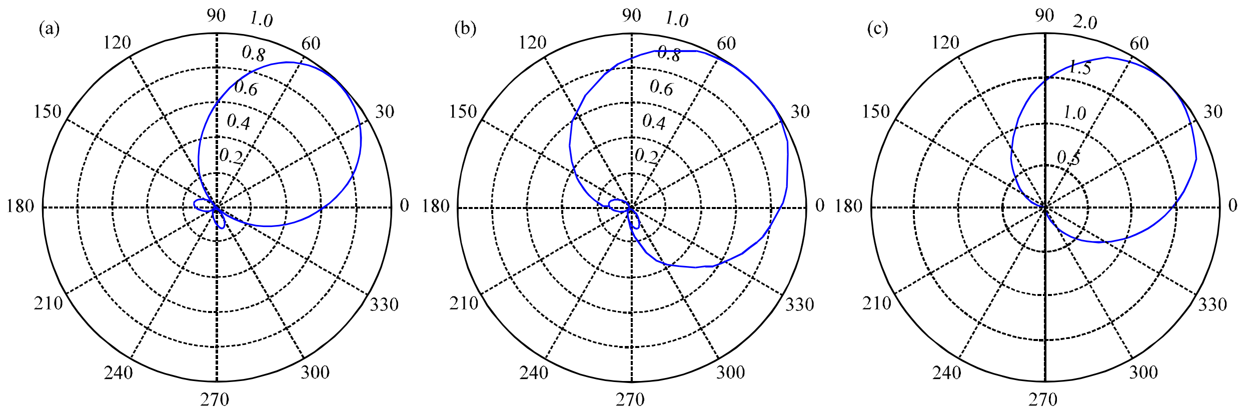

Fig. 2(a-c): Directivity of (a) $(p+v_c)v_c$, (b) $(p+v_c)p$ and (c) $(p+v_c)^2$

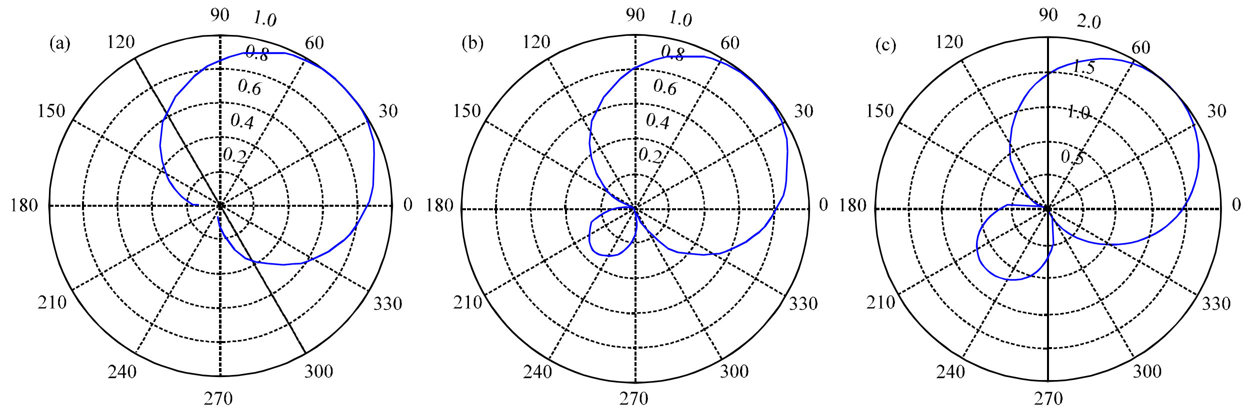

Fig. 3(a-c): Directivity of $p+kv_c$ when (a) $k = 1$, (b) $k = 2$ and (c) $k = 3$

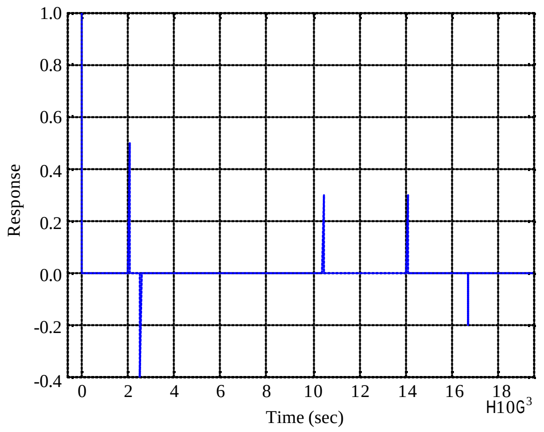

Fig. 4: Multi-path channel

two-dimensional situation. Considerable space gain can be obtained using the vector sensor's directivity particularly when combining the sound pressure channel and vibration velocity channel. For the phase shift keying communication systems using the linear combination $p+kv_c$ to obtain the space directivity gain is appropriate. While similar combined forms of p•v will distort the PSK signal's phase information and then the system decoder will complicate and the communication quality will reduce.

Simulation study: In order to verify the effectiveness and robustness of the underwater acoustic communication system, simulation studies of the single vector Pattern time delay shift coding underwater acoustic communication system were taken in this section.

Simulation conductions: System simulation parameters: sampling frequency 48 kHz, system bandwidth 4~8 kHz, the Pattern code width 10 msec, the information code width 20 msec, number of coded bits 4 bit, synchronization code width 40 msec, guard interval 50 msec, the DOA range: 30~40°.

The multi-path channel taken during the simulation is shown in Fig. 4.

SIMULATION RESULTS

The DOA estimation was obtained by the active acoustic intensity average using each frame synchronous communication signal. With the passage of communication time communication transmitting node's time-bearing display can be obtained.

Figure 5 shows the time-bearing display of the simulation when spectrum level SNR is 5dB. The accurate DOA estimation given by the active acoustic intensity average. Using the estimated communication transmitting node's position, the combined directivity main peak of vector sensor could been adjusted to the communication transmitting note's position by electronic rotary at the receiver. The space gain can improve the SNR at the receiver. Consider of the DOA estimation error of the active acoustic intensity average: because of the main lobe wide of the combined directivity is wider and the loss of space gain is small in the range of DOA estimation error. Therefore the estimation error will not been considered here. In addition, once the transmitting node's position was estimated at the receiver, a directive transducer can been used to send feedback information and then the directivity space gain is obtained to improve the communication system's performance.

Table 1: Statistics of simulation results

BER (%)	SNR-5 (db)	0	5	10
P	4.8412	0.1458	0	0
P+Vc	0.2125	0	0	0
P+2Vc	0.1307	0	0	0
P+3Vc	0.1875	0	0	0
P+4Vc	0.2219	0	0	0
P+5Vc	0.2313	0	0	0

0 means there are not any error bit in the range of statistics means not BER = 0

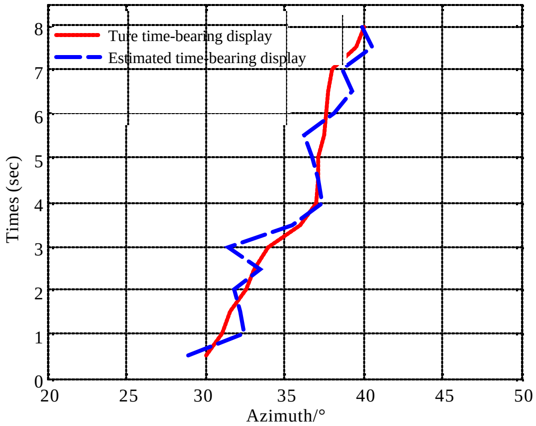

Fig. 5: Time-bearing display

Table 1 shows the BER statistical results of single vector Pattern time delay shift coding underwater acoustic communication system. The noise used in simulation is band-limited white Gaussian noise and the SNR is calculation of the sound pressure signal.

It can be seen from Table 1, that decoding BER employing a combined directivity of single vector hydrophone is lower than the decoding BER using only sound pressure signals especially in low SNR conditions at the same SNR level. In addition, the decoding BER employing different linear combined directivity ($p+kv_c$) have been studied. The statistics results shows: The decoding BER employing combined directivity is $p+2v_c$ lowest, once k is greater than 2 the decoding BER will increase gradually with the increase of k. In summary: the single vector Pattern time delay shift coding system employing linear combined directivity has effectiveness and robustness. The system has obvious advantages than the system which only employs the sound pressure channel or other linear combined directivity.

CONCLUSION

Pattern time delay shift coding underwater acoustic communication technique has been combined with single vector signal processing technique. Single vector sensor has been used to estimate communication transmitting node's position based on the active acoustic intensity average. And then linearly combines the sound pressure and the vibration velocity signals to form a combined directivity according to the estimated transmitting node's position. The SNR at the receiver improved by linearly combines the sound pressure and vibration velocity signals. And the bit error rate declines compared with the literature (Yin *et al*., 2006) with the same input SNR. The robustness and practicality of the system are verified by the theoretical analysis and simulation study.

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