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소스 추적 기법에 기반한 수중통신 Potential 방법 연구

(Potential Method for Underwater Communication based upon Source Tracking Techniques)

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요 약

수중 환경의 복잡성 때문에 수중통신은 대기중에서의 통신과는 그 차이가 상당한 여러 가지 어려움들을 가지고 있다. 신호는 수중에서 많은 불규칙 소음들에 의해 저하된다. 뿐만 아니라 대역폭의 한계는 수중 통신에서 매우 큰 이슈이다. 그러므로 배열신호 처리 기법은 SNR을 개선에 적당하다. 이 논문에서 소스 추적기법에 기반한 수중 통신을 목적으로 하는 potential 기법을 제안하고자 한다. 또한 다중배열 소나를 이용한 새 추적 모델과 동 소나의 세부 구성을 제시했다. 실험들에서는 샘플 모델과 본 모델상에서 추적 결과의 차이점을 도출해 냈다. 실험 결과, 특히 수중환경에서 통신 문제들을 해결할 가능성이 수신기 구성이라는 것을 시연하였다.

Abstract

Because of the complexity of the underwater environment, the communication has difficulties that can differ significantly from those in air. The signal is degraded by many random noises. Furthermore, the limit of the bandwidth is a big issue in underwater communication. Therefore, the array signal processing can be adapted to improve the signal-to-noise ratio. In this paper, we propose a potential method for underwater communication based upon source tracking techniques. Also, a new tracking model by using a multi-array sonar and detail of the multi-array sonar configuration are shown in this paper. The experiment results demonstrated the receiver configuration is very potential to solve communication problems, especially in the underwater environment

Keywords: underwater communication, underwater random noises, underwater target tracking, passive sonar, array sonar.

I. Introduction

In underwater communication, it is important to recognize the direction and location of transmitter[1~2]. This is especially true in complex conditions that lead to difficulties in tracking problem, such as the degrading signal by random noise sources in underwater environment[2]. As shown in the Figure 1, there is a lot of complex noise background in the sea. In deep water, the sources of noise can be tides, seismic disturbances, oceanic turbulence, nonlinear wave interactions, ship traffic, surface waves and thermal noise[3]. Therefore, the ambient noise of the sea usually made measurement or estimation difficult.

Passive sonar receives the signal that the target emits, then detects and determines the location of the target[3]. There are many advantages in the array processing such as an increase of the signal-to-noise ratio(SNR)[4~5], defining the number of sources, estimating the waveforms of the propagating energy, and the locations of these sources[6]. Hence, it is

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effective to track the source using the sonar array in order to increase SNR for better underwater communication. By using two linear sonar arrays perpendicular to each other, source detection can be performed with the least target ghosts[7~8].

In communication, we try to extract as much information of the transmitter as possible such as direction of arrival (DOA). In this paper, a new source finding model by using a multi-array sonar and configuration of the array are proposed.

This paper is organized as follows. Section Ⅱ addresses the modeling for source tracking. It will present the related knowledge of our approach. Then, a detailed description of a configuration for using a multi-array sonar is defined in sections Ⅲ. In sections Ⅳ and Ⅵ the experimental results and summary are presented to demonstrate the capability of the proposed configuration.

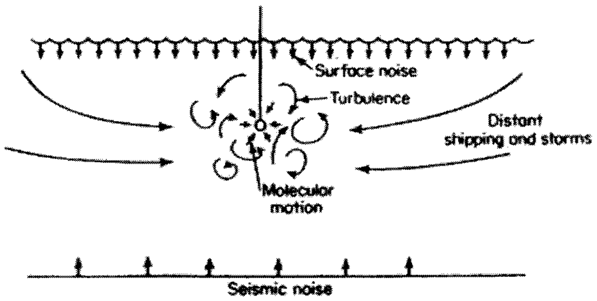

그림 1. 심해에서의 주변소음
Fig. 1. The noises background of the deep sea.

Ⅱ. Theoretical background of the modeling for source tracking

In the continuous-time domain, a sound source (hereafter moving target) should be defined via its position, velocity, and acceleration. For simplicity, in this model, the array sonar is fixed and the moving source is discussed in two dimensions: the x and y axes. The position $X(t)$ and velocity $X'(t)$ vector of the target are denoted by

$$X(t)=\left(X_x(t),X_y(t)\right) \tag{1}$$

$$X'(t)=\left(X'_x(t),X'_y(t)\right) \tag{2}$$

In addition, by choosing a fixed coordinate system, the center of the sonar array is located at the origin of this fixed coordinate system at t=0. The position vector of the array is defined by

$$Y(t)=\left(Y_x(t),Y_y(t)\right) \tag{3}$$

The position state vector is defined by the following matrix

$$V(t)=col\left[X_x(t)-Y_x(t),X'_x(t),X_y(t)-Y_y(t),X'_y(t)\right] \tag{4}$$

The motion equation of the target which describes the relationship of the velocity, position, and acceleration, can be found as

$$V'(t)=\begin{bmatrix}0100\\0000\\0001\\0000\end{bmatrix}V(t)+\begin{bmatrix}0\\a_x(t)\\0\\a_y(t)\end{bmatrix} \tag{5}$$

where $a_x(t)$ and $a_y(t)$ are the acceleration along an x and y axes, respectively. This equation can be succinctly expressed by the following equation

$$V'(t)=AV(t)+u(t) \tag{6}$$

where $u(t)$ is the acceleration along the x and y axes, and. A is the matrix.

As analyzed, this equation is expressed in a continuous-time model, so it must be converted into a discrete-time model by using the following equation

$$\begin{aligned}V(t)&=\int_0^t e^{A(t-\tau)}u(\tau)d\tau\\&=e^{AT}\int_0^{t-T}e^{A(t-T-\tau)}u(\tau)d\tau\\&\quad+\int_{t-T}^{t}e^{A(t-\tau)}u(\tau)d\tau\end{aligned} \tag{7}$$

Besides, in the discrete-time domain, to express the relationship between the velocity and position of the target at t=lT, the state vector V(l) is defined as the following discrete-time state equation

$$V(l)=\begin{bmatrix}1\,T\,0\,0\\0\,1\,0\,0\\0\,0\,1\,T\\0\,0\,0\,1\end{bmatrix}V(l-1)+\int_{(l-1)T}^{lT}\begin{bmatrix}(lT-\tau)a_x(\tau)\\a_x(\tau)\\(lT-\tau)a_y(\tau)\\a_y(\tau)\end{bmatrix} \quad (8)$$

This state equation presents the relativity of the array. The source's movement is succinctly expressed by

$$V(l)=BV(l-1)+u(l) \quad (9)$$

Also, an observation vector can be estimated and expressed as a relationship of distance and angle from the source to the target

$$z=col\left[\tan^{-1}\left(\frac{X_x-Y_x}{X_y-Y_y}\right),\sqrt{(X_x-Y_x)^2+(X_y-Y_y)^2}\right]+n \quad (10)$$

where n is the noise that represents the errors in measuring. The observation vector is succinctly expressed by

$$z(l)=\Re[V(l)]+n(l) \quad (11)$$

where $\Re[.]$ is the non-linear transformation that relates the observation location measurements to the target location.

Normally, the tracking system has two steps. First, by using the dynamic state equation (9) based on the incorporation of past measurements, a target's position state vector V can be predicted. Second, the state vector's estimate $\hat{V}$ is updated by correcting the prediction with current measurement. Assume that the estimate $\hat{V}(l-1|l-1)$ of the state target at snapshot $l-1$ is derived based on the set z_{l-1} of the observations. The state of the target at snapshot l can be directly predicted from the dynamic equation when the velocity motion is constant, so that $u=0$. The target's state is defined by

$$\hat{V}(l|l-1)=B[\hat{V}(l-1|l-1)] \quad (12)$$

The observation equation is expressed by $z(l)=\Re[V(l)]+n(l)$. Assuming that the predicted state is $\hat{V}(l|l-1)$, this measurement can be forecasted using this equation

$$\hat{z}(l|l-1)=\Re[\hat{V}(l|l-1)] \quad (13)$$

By comparing the estimation value with the actual value in measuring the location $z(l)$ at a snapshot, the state estimate at snapshot l has the following form

$$V(l|l)=V(l|l-1)+G[z(l)-\hat{z}(l|l-1)] \quad (14)$$

To get this equation, the predicted location can be corrected with a function of the difference between the predicted and the observed values. $G[.]$ represents the gain function. In addition when the noise is absent (n=0) the gain function $G[.]$ of the state update equation equals to $\Re[.]$, which is invertible. The state vector can be predicted by

$$V(l)=\Re^{-1}[z(l)] \quad (15)$$

Obviously, during the prediction, a deviation may appear as the difference between the actual state V and the estimate state $\hat{V}(l|l)$. An error vector is defined as $\mathrm{E}(l|l)=V(l)-\hat{V}(l|l)$, and expanded by using the state estimate equation, the measurement equation, and the state dynamics equation, as the following

$$\begin{aligned}\mathrm{E}(l|l)=&B[V(l-1)]-B[\hat{V}(l-1|l-1)]+u(l)\\&-G\begin{Bmatrix}\Re[B[V(l-1)]+u(l)]+n(l)\\-\Re[B[\hat{V}(l-1|l-1)]]\end{Bmatrix}\end{aligned} \quad (16)$$

From this equation, an attempt can be made to analytically obtain the squared error which has the form as $\varepsilon[E^{2}] = \varepsilon[E'E]$, and it will be minimized by varying the gain function $G[\cdot]$.

III. Configuration of the two-array sonar for source tracking

The sonar $array_1$ is chosen to overlap with the x axis of the coordinate system. As shown in Figure 2, a target belongs to the left side of $array_2$. The linear equation O_1S has the form $y = Px + Q$ and crosses $O_1(x_1, y_1)$. The P, Q parameters can be calculated by

$$P = \tan\left(\frac{\pi}{2} + \alpha\right) \tag{17}$$

$$Q = y_1 - x_1 \tan\left(\frac{\pi}{2} + \alpha\right) \tag{18}$$

where α is the angle propagation from the target to the center of $array_1$.

Thus, the linear equation for O_1S can be expressed as

$$y = \tan\left(\frac{\pi}{2} + \alpha\right)x + \left[y_1 - \tan\left(\frac{\pi}{2} + \alpha\right)x_1\right] \tag{19}$$

Similarly, the linear equation O_2S can be obtained as the following form

$$y = \tan(\beta)x + [y_2 - \tan(\beta)x_2] \tag{20}$$

where the position of O_2 is (x_2, y_2) and β is the angle propagation from the target to the center of $array_2$.

In other case, the target belongs to the right side of $array_2$ can be shown as in Figure 3. The linear equation O_1S has the follow form

$$y = \cot(\alpha)x + [y_1 - \cot(\alpha)x_1] \tag{21}$$

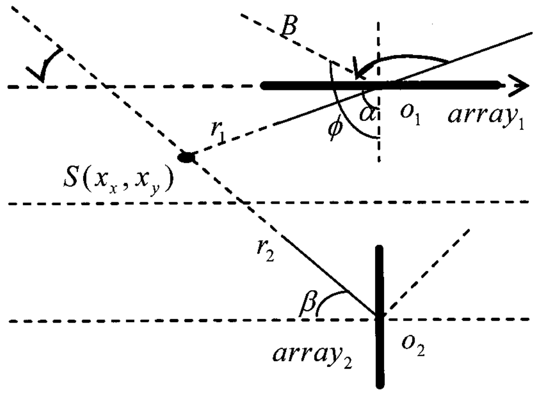

그림 2. 2개의 어레이 소나의 왼쪽 배치
Fig. 2. The left side configuration of the two-array sonar.

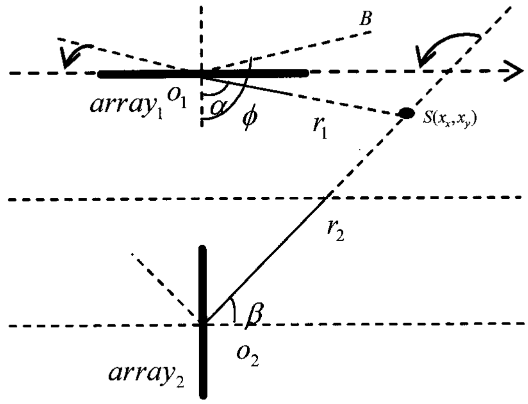

그림 3. 2개의 어레이 소나의 오른쪽 배치
Fig. 3. The right side configuration of the two-array sonar.

And, the form of O_2S can be expressed as the following

$$y = -\tan(\beta)x + [y_2 + \tan(\beta)x_2] \tag{22}$$

To generalize, we define l and r as two new factors

$$l = \begin{cases} 1 & \text{if } target \text{ } in \text{ } the \text{ } left \text{ } side \text{ } of \text{ } array_2 \\ 0 & elsewhere \end{cases} \tag{23}$$

$$r = \begin{cases} 1 & if \text{ } target \text{ } in \text{ } the \text{ } right \text{ } side \text{ } of \text{ } array_2 \\ 0 & elsewhere \end{cases} \tag{24}$$

Finally, the position of S is the root of the following set of equations

$$
\begin{cases}
y = \left(\cot(\alpha) r + \tan\left(\frac{\pi}{2} + \alpha \right) l \right) x \\
\quad + \left[y_1 - \left(\cot(\alpha) r + \tan\left(\frac{\pi}{2} + \alpha \right) l \right) x_1 \right] \\
y = \left(\tan(\beta) l - \tan(\beta) r \right) x \\
\quad + \left[y_2 - \left(\tan(\beta) l - \tan(\beta) r \right) x_2 \right]
\end{cases} \tag{25}
$$

V. Simulation results and discussion

The model is denoted by a trajectory scenario and illustrated as the following

$$v(l) = Bv(l-1) + u(l) + n(l) \tag{26}$$

where u(l) is an acceleration matrix with u(l)=diag ([0.25ms^{-2}, 0.25ms^{-2}]) and n(l) is random noise. The target's initial estimate is (100m,300m) with velocities [10m/s, 6m/s] and the position of the center $array_1$ and $array_2$ are (100m,0m) and (100m,800m), respectively.

By using the random noise of 3dB with 40 samplings, the input and estimated locations for this scenario are shown in Figure 4. Similarly, a comparison between the input and estimated locations by using the random noise of 7dB and 20dB are presented in Figures 5 and 6, respectively.

As shown in Figure 4, the difference between the input and estimate states is less than 5m, proving that the perpendicular configuration is a good one for building the estimated location system.

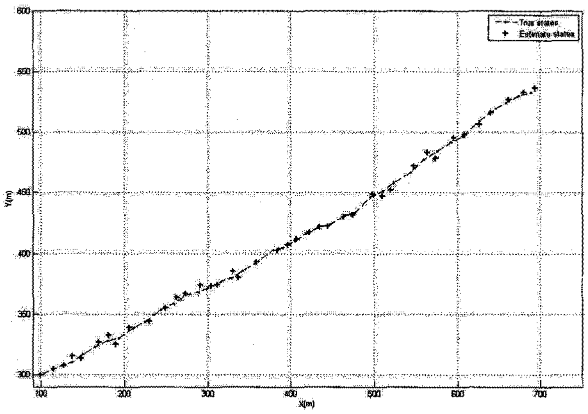

그림 4. 랜덤 소음이 3dB일때 입력위치와 추정위치
Fig. 4. The input and estimated location measurement with random noise 3dB.

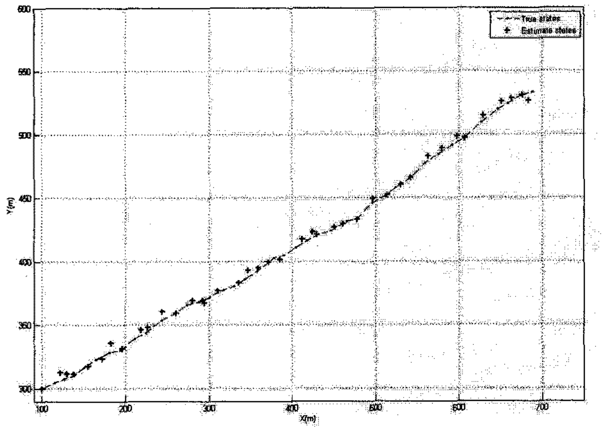

그림 5. 랜덤 소음이 7dB일때 입력위치와 추정위치
Fig. 5. The input and estimated location measurement with random noise 7dB.

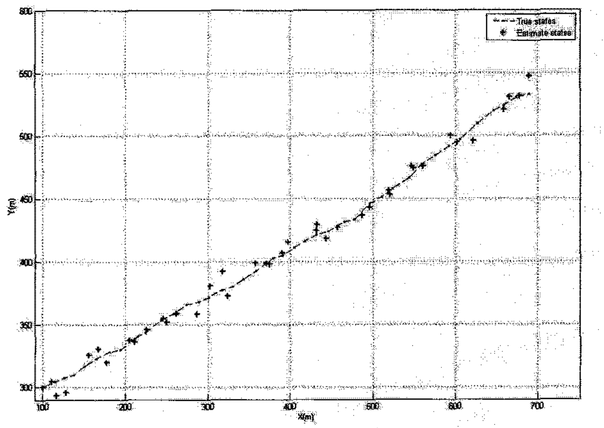

그림 6. 랜덤 소음이 7dB일때 입력위치와 추정위치
Fig. 6. The input and estimated location measurement with random noise 20dB.

The Root Mean Square Error (RMSE) of the estimated location results with random noises of 3dB, 7dB, and 20dB at the x and y axes are shown in Figures 7 and 8, respectively.

At both x and y axes, the random noises are added. As shown in Figure 7 and 8, the RMSE of 3dB noise value has minimum value and achieves better tracking result compared to the others. Also, the RMSE will be increased as the random noise increases.

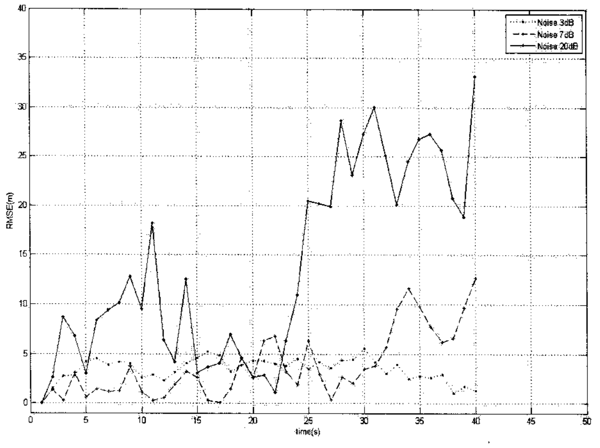

그림 7. x-축에서 추정 위치의 RMSE
Fig. 7. The RMSE of the estimated location on the x axis.

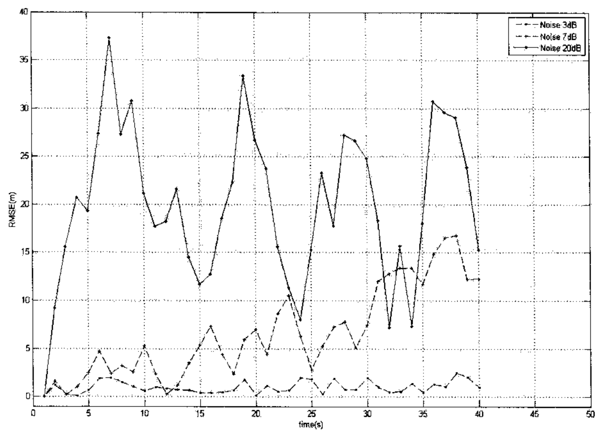

그림 8. y-축에서 추정 위치의 RMSE
Fig. 8. The RMSE of the estimated location on the y axis.

VI. Summary

By choosing suitable configuration, not only the number of image ghosts is minimized, but also the complexity of the communication is reduced. We proposed a potential method for underwater communication which increase the SNR by using the multi-array sonar. The experimental results exhibit the better and more competitive performance of the proposed model.

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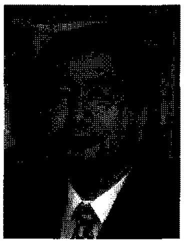

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