AN INVESTIGATION OF THE EFFECTS OF FACTORS ON UNDERWATER LOCALIZATION WITH LOW SOURCE LEVEL IN SHALLOW WATER

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ABSTRACT

This paper investigates and observes matched field processing method (MFP) for underwater source localization. The article simulates and evaluates the factors that influence source localization errors in a shallow underwater region; such as emitted signal waveforms, season-varying environmental parameters, minimum accurracy of sound speed evaluation and the noise effects in the case of using one hydrophone. Moreover, MFP, using two hydrophones, is also investigated under the influence of Gaussian and Weibull noise model. Beside, the depth adjustment of the two hydrophones is adjusted for localization quality improvement. The obtained results demonstrate that localization results errors are affected by source charactersitics and oceanic environmental parameters in the case of using one hydrophone. The simulation also shows that the depth adjustments yield localization result improvement and the localization errors is more considerably influenced by Weibull noise than by the Gaussian one.

Keywords: *Matching Field Processing, Localization, Hydrophone, Shallow water.*

I. INTRODUCTION

The source detection and localization in shallow underwater based on MFP using one hydrophone**,** is studied in [3-5]. But, the disadvantage of this method is that it is sensitive to mismatched environmental problems. Therefore, this paper specifically presents the levels of the effects of the environmetal parameters on the localization results. Apart from the environmental factors, the effects of noise are also considered in target localization. However, for the purpose of localizing the underwater target under the noise effect, two hydrophones are used. Previous studies have observed the transmission model under the gaussian model, [7] while the weibull model is considered in this study. Moreover, the depth of the two hydrophones is considered when evaluating the localization results.

The rest of the paper is organized as follows. In section II, we discuss MFP algorithm and environment environmental effects on source localization result. The ocean environment model is stuided in section III. In section IV, the simulation results of localization performance under the affects of related factor are given. The conclusions and the future work can be found in section V.

II. MFP ALGORITHM AND ENVIRONMENT ENVIRONMENTAL EFFECT ON SOURCE LOCALIZATION RESULT

2.1. MFP using one hydrophone

The Broadband MFP algorithm, using one hydrophone based on the principle of dividing, observed space into the grid following the range r_i and the depth z_j. After that, the replica field signal at the hydrophone is calculated with the assumption that the source at each of the grid locations corresponds to the measured data of the hydrophone [5]. The best correlation result between the replica signal and the measured data at the hydrophone will determine the source position. The correlation between the replica signal and the measured data at the hydrophone will be the best result in determining the source location.

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$$\|e\|^2 = \left\| r - \hat{r}_{ij} \right\|^2 \quad (1)$$

Where r is the received signal at the hydrophone, and $\hat{r}_{ij}$ is the replica signal.

The least mean square (LMS) method is used for the localization algorithm in this paper. In equation (1), the best correlation corresponding with the miminum value of $\|e\|^2$ or with the maximum value of $1/\|e\|^2$ will determine the source location. The replica signal at the hydrophone corressponding with the source-emitted signal at each grid position $\hat{r}_{ij}$, is expressed by:

$$\hat{\boldsymbol{r}}_{ij} = \boldsymbol{G}_{ij}.\hat{\boldsymbol{s}} + \boldsymbol{n} \quad (2)$$

Where $\hat{\boldsymbol{G}}_{ij}$ is convolution matrix of Green function at a fixed transmiter and receiver position that corresponds to the grid cordinate (r_i, z_i), then $\hat{s}$ is a discrete-time singal vector and n is the noise of the environment. The value of Green function can be caculated indirectly, based on the frequency-domain green function that will be changed to the time-domain one through Inverse Fast Fourier Transform - IFFT.

When the signal source waveform is unknown, an estimated signal can be written as follows[7]:

$$\hat{\boldsymbol{s}} = \boldsymbol{G}^{+}\boldsymbol{r} \quad (3)$$

Where $\hat{\boldsymbol{G}}^{+}$ is a pseudoinverse matrix of $\hat{G}$.

A frequency-domain green function based on standard mode approach is caculated by [8]:

$$G_{ij}(r_i, z_j, f) = \frac{i}{\rho(z)\sqrt{8\pi r_i}} e^{-i\frac{\pi}{4}} \sum_{m=1}^{\infty} \Psi_m(z_j)\Psi_m(z) \frac{e^{ik_m r_i}}{\sqrt{k_m}} \quad (4)$$

Where r_i is the range of the source, z_j is the depth of the source, z is the depth of the hydrophone, ρ is the environmental density factor, Ψ_m is the normal mode and k_m is the wave factor.

2.2. Cross-Correlation MFP (CMFP)

In [7] it is shown that two hydrophones are used to locate an underwater source in the case of having noise effect occuring in the environment. The purpose of the method is to caculate the cross-correlation of the received signal at the two hydrophones and also the cross-correlation signals of the corresponding replica field.

In this case, the sum of the squared error between the cross-correlation of the measured signal and of the replica signal is given by [7]:

$$\|e_\rho\|^2 = \left\| \rho - \rho_{ij} \right\|^2 \quad (5)$$

Where ρ is the correlation value of the measured signal at the hydrophone; and $\hat{\rho}_{ij}$ is the correlation value of the corresponding replica signal. In this case, the best correlation corresponds to the minimum $\|e\|_{\rho}^{2}$ value or to the maximum $1/\|e\|_{\rho}^{2}$ value. This will determine the source position.

2.3. Depth - Adeaptive Cross Correlation MFP (ACMFP)

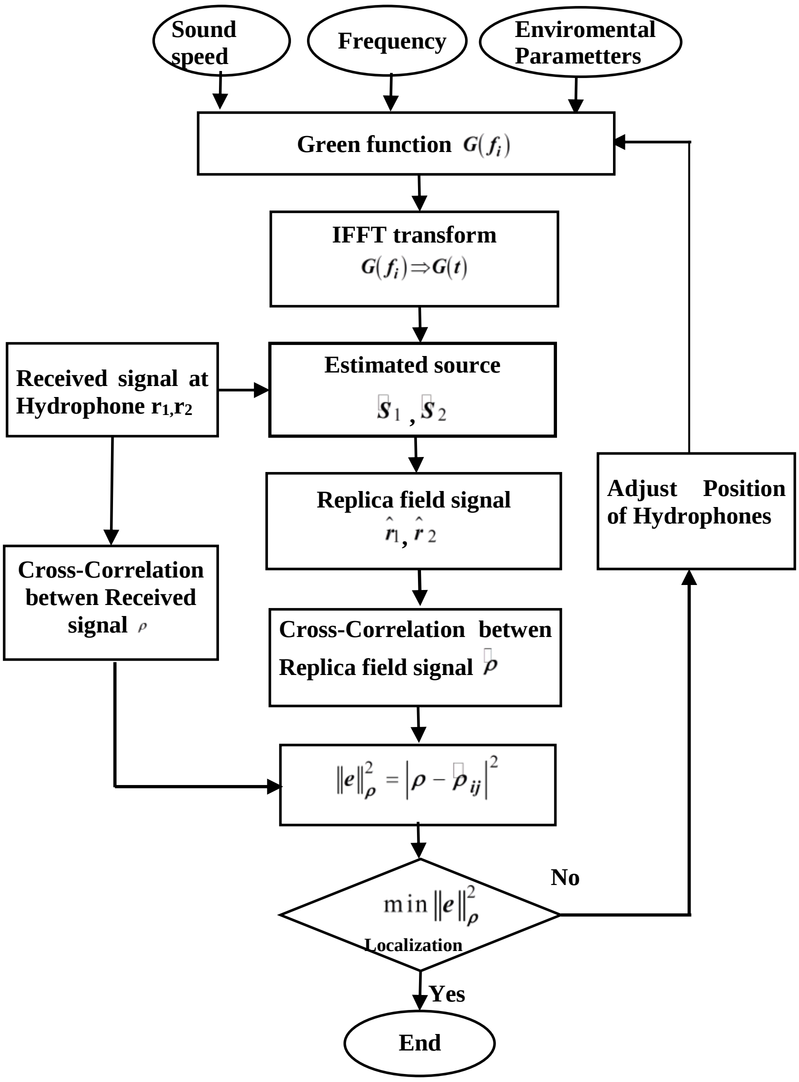

Figure 1. ACMFP Algorithm

The depth-adaptive algorithm s is employed to find the best suitable position to locate the hydrophones**.** This helps to improve the source localization result in the shallow water area. This is planned to settle underwater equipmments. The algorithm flow chart is drawn in figure 1.

III. OCEAN ENVIRONMENT MODEL

To evaluate the environmental effect, this paper uses a typical shallow water area model in Vietnam with environmental parameters as in figure 2.

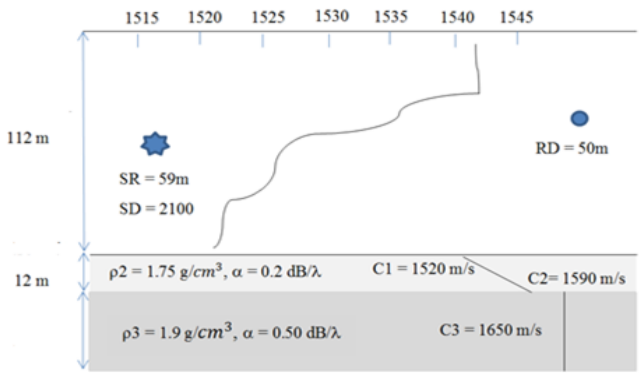

Figure 2. Ocean environment at the settlement model

IV. Simulation Result

4.1. Localization result observation with different signal waveforms

Two kinds of source signal waveforms are considered for the observation:

- Linear Frequency modulation signal LMF ranging from 50Hz to 150 Hz.
- Random amplitude signal ranging from 50Hz to 150 Hz:

$$s(t) = \sum_{i=50}^{150} a_i e^{j\pi f_i t} \qquad (6)$$

Where a_i is the random value that follows Gaussian distribution, f_i = 50÷150Hz.

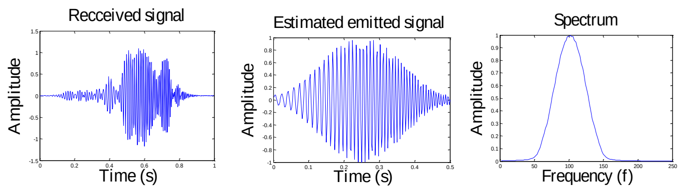

Figure 3. Received signal and estimated emitted signal for LMF waveform

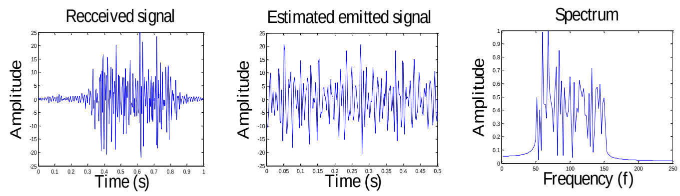

Figure 4. Received signal and estimated emitted signal for random waveform

The localization result is demonstrated corresponds to two kinds of signal above, in figure 5 and 6 and in table 1.

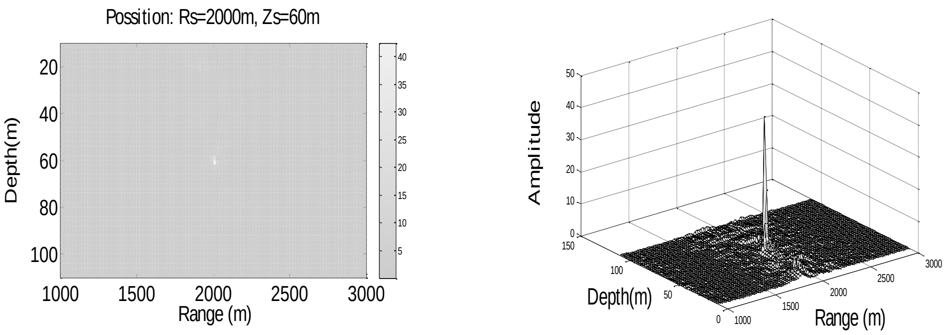

Figure 5. Ambiguity Surface localization function with LMF waveforms

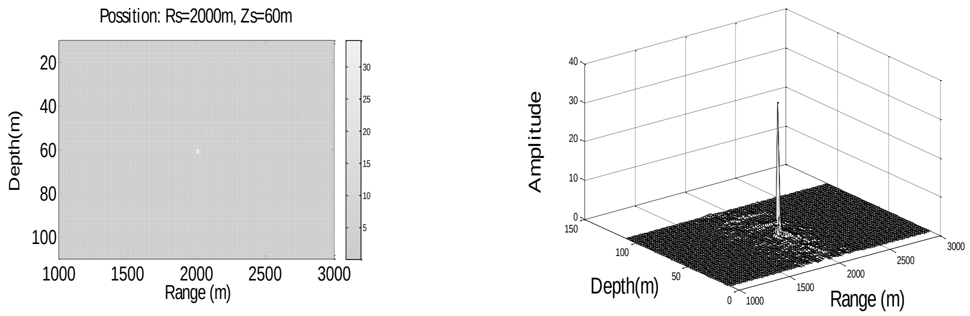

Figure 6. Ambiguity surface for random waveforms

Table 1. The localization result corresponding to different signal waveforms

Signal Waveforms	Source position		Estimated position		Localization Error		Peak	Back-ground	Peak/ Back-ground
	$r_{s0}(m)$	$z_{s0}(m)$	$\hat{r}\,(m)$	$\hat{z}\,(m)$	$\Delta r(m)$	$\Delta z(m)$	U_P	U_B	*PBR*
LFM	2000	59	2000	60	0	1	42.41	0.19	215.77
Random	2000	59	2000	60	0	1	34.14	0.07	438.68

Table 1 shows that the localization result is good in both the cases of the linear frequency modulation signal LFM and in the random signal because the localization error is small. The ratio peak/background PBR is larger than 215, which points out that the signal waveforms do not remarkably influence the localization results.

4.2. Season-varying environmental parameters observation

Here we consider the season-varying environmental parameters. In fact, the depth and bottom parameters have not been changed according to the seasons, while the temperature parameters have been changed. Hence, the variant of the temperature will can be analysed in detail. We can assume that the temperature parameter change Δt of $2{,}5^0$ will lead to the value of sound speed error Δc to be approximately 10m/s.

Table 2. The localization results with season-varying environmental parameters

Enviromental Condition	Source position		Estimated position		Localization Error		Peak	Back-ground	Peak/ Back-ground
	$r_{s0}(m)$	$z_{s0}(m)$	$\hat{r}\,(m)$	$\hat{z}\,(m)$	$\Delta r(m)$	$\Delta z(m)$	U_P	U_B	*PBR*
Constant	2000	59	2000	60	0	1	42.4	0.2	215.7
ΔC=10, Update Data	2000	59	2000	60	0	1	37.5	0.2	204.2
ΔC=10, Not Update Data	2000	59	2100	110	100	41	0.93	0.07	13.12

Based on the result with the season-varying temperature it can be shown that if updated environmental parameters have small errors, then the ratio PBR is larger than 200 and the localization results are not greatly different. If the parameters are not updated, the results will have big errors. Therefore, when the temperature varies according to the seasons and is larger than a given value, it needs to be updated to ensure the accuracy of the results.

4.3. Localization quality observation with environmental parameters errors in experimental conditions.

The sound speed is the parameter that we observe because it has more negative effects on the quality of the localization results than other environmental factors do. In this sesssion, we evaluate the influence of sound speed error ΔC on the localization result. In table 3, when $\Delta C \geq 0,4$ m/s the result brings high errors that do not meet the quality of the localization result. When $\Delta C < 0,4$ m/s the localization result is still accurate.

Table 3. The localization result corresponding to different sound speed errors.

Sound speed Error	Source position		Estimated position		Localization Error		Peak	Back-ground	Peak/ Back-ground
	r_{s0} *(m)*	z_{s0} *(m)*	$\hat{r}$ *(m)*	$\hat{z}$ *(m)*	*Δr(m)*	*Δz(m)*	U_P	U_B	*PBR*
$\Delta C = 0$	2000	59	2000	60	0	1	42.41	0.19	215.77
$\Delta C = 0.1$	2000	59	2000	60	0	1	37.35	0.18	199.89
$\Delta C = 0.2$	2000	59	2000	60	0	1	30.59	0.17	171.63
$\Delta C = 0.3$	2000	59	2000	60	0	1	23.34	0.17	134.34
$\Delta C = 0.4$	2000	59	2240	110	240	51	0.62	0.06	9.12
$\Delta C = 1$	2000	59	2220	110	220	51	0.46	0.03	15.49

4.4. Noise effect observation

In table 4, the source localization result**,** based on the broadband MFP algorithm which is used to cancel noise, is evaluated with noise levels from 10dB to -3dB. In the results in table 4, the effectiveness of noise cancellation in Gaussian case is better than in Weibull case. Clearly, when Gaussian noise is used for the observation, the localization quality is ensured with the low thresold level of signal to noise ratio equal -3dB. In the case of weibull noise effect, the low threshold level requirement is 0 dB.

Table 4. The localization result corresponding to Gausian and Weibull noise model

Signal noise rate - SNR (dB)	Gaussian Noise					Weibull Noise				
	Estimated position		Peak	Back-ground	Peak/ Back-ground	Estimated position		Peak	Back-ground	Peak/ Back-ground
	$\hat{r}$ *(m)*	$\hat{z}$ *(m)*	U_P	U_B	*PBR*	$\hat{r}$ *(m)*	$\hat{z}$ *(m)*	U_P	U_B	*PBR*
10	2000	59	9.06	0.02	516.02	2000	60	7.87	0.02	441.0
6	2000	58	2.61	0.02	158.28	2000	58	5.81	0.02	342.1
3	2000	62	0.48	0.01	35.20	2000	58	0.87	0.02	57.3
0	2000	58	0.19	0.02	10.74	2000	58	0.13	0.01	9.05
-3	2000	56	0.11	0.02	5.85	2000	56	0.02	0.01	2.08

4.5. Depth adaptive observation

In the table 5, the simulated source localization result based on adaptive broadband MFP is employed with the SNR equal to 6dB. The process of adaptively adjusting the hydrphone depth that is best suitable to the environmental condition at the pasive sonar settlement position has two cases, namely hydrophone 1: 20m and hydrophone 2: 22m. At this depth level, the error ΔR(m)=0m and ΔZ(m)=1m has a maximum peak per background ratio (PBR=216.32) with a detected pulse that has only one main peak.

Table 5. The localization result corresponding to different Depth of Hydrophones

Position of Hydrophones	Source position		Estimated position		Localization Error		Peak	Back-ground	Peak/ Back-ground
	r_{s0} *(m)*	z_{s0} *(m)*	$\hat{r}$ *(m)*	$\hat{z}$ *(m)*	*Δr (m)*	*Δz (m)*	U_P	U_B	*PBR*
10m and 12m	2000	59	2000	60	0	1	2.05	0.01	148.10
20m and 22m	**2000**	**59**	**2000**	**58**	**0**	**1**	**3.72**	**0.01**	**216.32**
30m and 32m	2000	59	2000	60	0	1	1.43	0.01	110.52
40m and 42m	2000	59	2000	58	0	1	0.50	0.01	45.32
50m and 52m	2000	59	2000	60	0	1	2.32	0.01	155.88
60m and 62m	2000	59	2000	58	0	1	1.14	0.01	83.77
70m and 72m	2000	59	2000	58	0	1	2.02	0.02	128.46
80m and 82m	2000	59	2000	60	0	1	1.24	0.01	97.98
90m and 92m	2000	59	2000	60	0	1	1.91	0.02	98.47

V. CONCLUSION

The paper simulates and evaluates the factors that influence the underwater localization errors including sound-speed, the season-varying environmental parameters; update version of the parameters and the required minimum accuracy of sound speed evaluation when using single hydrophone**.** The simulation demonstrates that the localization results are not affected by the waveform of the source signal in both two case of LFM and random signal. Moreover, when environmental parameters vary following the seasons, the update version of the parameters needs to be given to ensure the accuracy of the localization results. The requirement of the accuracy of sound speed evaluation with $\Delta C < 0{,}4$ m/s will give an accurate result. The paper also presents the depth adaptive algorithm to choose the best hydrophone position when using two hydrophones. Besides, when applying correlation algorithm for the case of using two hydrophones, the simulation shows that Gaussian noise does not considerably influence on the localziation results as the Weibull one do. More specific, the results are guaranteed in the case of Gaussian noise with SNR higher than -3dB, and in the case of Weibull with SNR higher than 0dB. In addition, with the depth adaptive adjustment of the two hydrophones, the results are also improved. In the future work, we will expands the results in environmental mismatch case and consider numerous adaptive MFP algorithms in an uncertain propagation environment.

REFERENCES

[1] Baggeroer, A.B., W.A. Kuperman, and P.N. Mikhalevsky (1993). "An Overview of Matched Field Methods in Ocean Acoustics". IEEE Journal of Oceanic Engineering 18 (4): 401-424.
[2] Xiao Z, Xu W, Gong Xianyi, (2009) "Robust Matched Field Processing for Source Localization Using Convex Optimization". IEEE Oceans' 2009, 1-5.
[3] Lee Y P, (1998). "Time-domain single hydrophone localization in a real shallow water environment". IEEE Oceans'98 Conference Proceedings, Nice, France, 1074-1077.
[4] Frazer LN, Pecholcs PI, (1990), "Single - hydrophone localization". J.Acoust.Soc.Am, 88(2): 995- 1002.
[5] Chapin S R, (2008), " Application of the method of least squares to a solution of the matched field localization problem with a single hydrophone ". Ph.D.dissertation, The University of New Orleans, 2008.
[6] Skarsoulis Shuai YAO, Kun LI, Shiliang FANG, (2014), "Cross correlation matched field localization for unknown emitted signal waveform using two-hydrophone", Inter-noise 2014, Melbourne, Nov. 16-19.
[7] Kalogerakis M A, (2006), "Two - hydrophone localization of a click source in the presence of refraction". Applied Acoustics, 67(11): 1202-1212.
[8] Jensen, F., W. Kuperman, M. Porter, and H. Schmidt, (1994), "Computational Ocean Acoustics". New York: AIP Press
[9] Paul C. Etter (2003), "Underwater Acoustic Modeling and Simulation", Published in the Taylor & Francis e-Library, Taylor & Francis Group.
[10] Yann Le Gall, Francois-Xavier Socheleau and Julien Bonnel, (2016), "Matched-Field Performance Prediction with Model Mismatch". IEEE Signal Processing Letters, Volume 23, Issue:4: 409-413.
[11] Kai Zhang and Wenxu, (2016) "Performance Robust Matched Field Processing with Convex Optimization", IEEE Oceans 2016-Shanghai.

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