Investigation of sea wave countermeasures in underwater position estimating system using electromagnetic waves

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Abstract: When divers rescue people in accidents at sea, they are exposed to dangers such as injuries by obstacles, and so on. If the divers can confirm their position, their rescue activities will become safer. In the previous study, assuming that we specify the positions of the divers performing rescue operations to support their work, we developed a 3D undersea position estimation algorithm communicating between the undersea and the sea surface. However, we did not yet consider the effects and countermeasures of sea waves. In this paper, we indicate the effects of sea waves on the algorithm and investigate wave countermeasures.

Keywords: undersea position estimating, RSS, received signal strength, lateral wave

Classification: Antennas and propagation

References

[1] E.Jimenez, S.Zazo, E.Quevedo, "Investigation on Radio Wave Propagation in Shallow Seawater: Simulations and Measurements", 2016 IEEE Third Underwater Communications and Networking Conference (UComms), Aug.2016.

[2] D.Pompili, and I.F.Akyildiz, "Overview of Networking Protocols for Underwater Wireless Communications", IEEE Commun.Mag., pp.97-102, Jan.2009.

[3] Marine Industry Research Group, "The research report of the development of ocean businesses and the effects of new business creation by the advanced underwater acoustic communication" [Translated from Japanese.], Japan Federation of Machinery Manufacturers, Ocean Industry Research Group, Tokyo, 2005.

[4] R.Otnes et al., "A Roadmap to Ubiquitous Underwater Acoustic Communications and Networking", Proc. 3rd Int’l. Conf. Underwater
Acoustic Measurements : Tech. & Results, Jun.2009.
[5] M.Chitre, S.Shahabudeen, and M.Stojanovic, " Underwater Acoustic Communications and Networking : Recent Advances and Future Challenges ", Marine Tech. Soc. J., Vol.42, pp.103-116, 2008.
[6] R.K.Moore, " Radio communication in the Sea ", IEEE Spectr., Vol.4, No.11, pp.42-51, Nov.1967.
[7] National Police Agency Community Safety Bureau Community Safety Planning Division, " The overview of water accidents in 2019 " [Translate from Japanese], https://www.npa.go.jp/publications/statistics/safetylife/chiiki/R01suinan_gaikyou.pdf, Jun.2020.
[8] R. Kato, M. Takahashi, N. Ishii, Q. Chen and H. Yoshida, " Investigation of a 3D undersea positioning system using electromagnetic waves " in IEEE Transactions on Antennas and Propagation, Aug.2020.
[9] A.Hales, G.Quarini, G.Hilton, L.Jones, E.Lucas, D.McBryde and X.Yun, " The effect of salinity and temperature on electromagnetic wave attenuation in brine ", Int. J. Refrigeration, Vol.51, pp.161-168, 2015.
[10] Q.Chen, M.Takahashi, N.Ishii, " Exploring EM Wave Applications under Sea Water - Concept of Positioning System Using Amplitude Decay - ", IEICE Technical Report, pp.25-28, Sep.2016.

1 Introduction

In recent years, various ways of using the ocean have begun to be explored, and many technologies have been developed to support the generation of new ocean businesses [1, 2, 3]. To date, acoustic waves have been commonly utilized for undersea wireless communications. This is because the attenuation of acoustic waves is smaller than that of electromagnetic waves and light waves, and it is suitable for remote communication at sea [4, 5]. However, it propagates at 1.5 km/s in the ocean, which is considerably slow, approximately one-fiftieth as fast as electromagnetic waves. Regarding light waves, the scattering attenuation with the muddiness of seawater is large. Reference [2] mentioned that light-wave telecommunication in seawater is unsuitable due to communication instability and capability. Regarding electromagnetic waves, because of a large attenuation, it is considered that undersea communication with electromagnetic waves is challenging [6]. However, we can ignore the reflection and diffraction of electromagnetic waves because of their large attenuation. Thus, we wish to consider using electromagnetic waves in the sea, especially in shallow seas.

We consider supporting technologies for water rescues as a way of using electromagnetic waves in seawater. According to [7], more than 1,000 water accidents have occurred annually. Accidents in the water are mainly caused by natural disasters and sinking accidents involving ships. When divers rescue people, the view of divers is sometimes interrupted by some obstacles floating in the sea; if divers know their current positions during the rescue, rescue activities will become much safer. Divers are constantly moving during the rescue, so the system must possess real-time positioning. In addition, the environment for rescue is not constant and needs to be adapted on a case-by-case basis. Thus, a simple algorithm
and less calculation time are required.

In the previous study, we developed an undersea positioning system that utilizes 10 kHz bands [8]. We assumed that receive antennas are fixed on the sea surface by installed on a raft in this system. However, in the actual environment, sea waves are often generated on the sea surface. This paper will follow this system and propose a system that is unaffected by sea waves by floating the receiving antenna above the sea surface.

2 Assumed position estimating system

In this study, for the position estimation in the sea, we assume two ideal environments. One is shallow and has a calm sea surface, and the other represents sea waves on the sea surface. We employed one-axis dipole antennas for our simulations as an introductory study. The simulation model is shown in Fig. 1. The model has a free space with a height of 8 m and seawater with a depth of 9 m ($\varepsilon_r = 80$, $\sigma = 4.0$ S/m). In the model with sea waves, sine waves were used to represent the sea waves. The amplitude and wavelength of this sine wave were set to 1.2 m and 4 m, respectively, as shown in Fig. 1(c). These parameters are the maximum size that a diver can rescue. Receiving antennas (Rxs) were installed at the height of 3 m above the sea surface, with sufficient margin from this wave. Nine 2 m Rxs are dipole antennas installed horizontally above the sea surface at intervals of 20 m. We assume that all Rxs are mounted on the drone, and the distance between each Rx is constant. A 0.7 m transmitting antenna (Tx) is a dipole antenna installed at any point in the sea. This state does not receive direct waves from the underwater but receives only lateral waves. Electric constants of seawater are based on Reference [9].

In this simulation, we employed the Finite Difference Time Domain (FDTD) method. All cells are 0.1 m × 0.1 m × 0.1 m, and the time step is $1.92 \times 10^{-10}$ sec, which satisfies the Courant limit. This calculation is iterated 1.75 million times. As a boundary condition, 14 layers of PML were deployed. Moreover, we feed a 1-V sinusoidal wave into a Tx constantly.

**Fig. 1.** Sea model for the undersea antenna position estimation system
3 Sea wave countermeasures and estimating algorithm

In this section, we describe the sea wave countermeasures and the flow of underwater position estimating. In the previous study, we assumed that all Rxs are floated on the sea surface by fixed on something like a raft. In this system, when sea waves occur, changes in the posture of Rx and the distance between antennas will affect the Receiving Signal Strength (RSS) values. Therefore, since this underwater position estimation system uses RSS, sea waves have no small effect on position estimation accuracy. Thus, we proposed a system that avoids posture changes of Rxs caused by sea waves by installing the Rxs above the sea surface.

Fig. 2(a) shows the relationship between RSS and the antenna distance with Rxs floating in the air numerically. For example, the parameters are shown for Tx depths of 2m, 3m, and 7m. These parameters were calculated using two dipole antennas deployed in parallel, as shown in Fig. 1(c). Note that this RSS does not take into account the antenna matching. RSS is a logarithm of the ratio of the received power to the input power and is calculated as Eq. (1).

\[ \text{RSS} \ [\text{dB}] = 10 \log_{10} \frac{\text{Received Power} [\text{W}]}{\text{Input Power} [\text{W}]} \]  

(1)

RSS is well attenuated relative to the distance between the antennas. Furthermore, at a depth of 3 m and under two sea surface conditions, calm and wavy, the difference in RSS is at most 0.3 dB. Therefore, we thought that using a receiving antenna floating in the air would be a sufficient countermeasure for sea waves.

Subsequently, we will describe the angle correction employed in this position estimation. The dipole antenna does not have a perfectly isotropic directivity, so the value of RSS changes depending on the angle of incidence of the electromagnetic wave to Rx. Due to the boundary conditions at the sea surface, electromagnetic waves radiated from Tx will propagate radially through the air from the sea surface point directly above. Therefore, the RSS is corrected using the two angle variables \( \theta \) and \( \phi \) formed by Rx and the point on the surface directly above Tx, as shown in Fig. 1(a). Fig. 2(b) shows the quadratic surface for angle correction when a depth at Rx is 3 m. This surface is created in advance before the position estimation. The amount of RSS correction, \( \Delta \text{RSS} \), is calculated based on the approximate surface.

At the end of this section, we describe the flow of underwater position estimation. Fig. 2(c) shows the simplified estimation flow. First, we select three Rxs with large RSS and calculate the distance between antennas from RSS. Then, we draw three spheres with the radius of the distance between the antennas around Rx and calculate cross point as tentatively estimated positions. And then determine \( \Delta \text{RSS} \) from the two angles \( \theta \) and \( \phi \) between Rxs and this tentative position using the angle correction surface. The final estimated position is recalculated using the corrected RSS based on Eq. (2).

\[ \text{RSS}_{\text{corrected}} = \text{RSS} + \Delta \text{RSS}. \]  

(2)

As a note in position estimating, the water depth at Tx is assumed to be known.
Position estimating result

In this study, we simulated the position estimation of a Tx that exists at a depth of 2 - 7 m in the sea with sea waves. In this section, we present the results of the positioning simulation. We evaluated the estimation accuracy based on the distance between the factual and estimated positions. We establish a maximum of 2.0 m as the target error, considering an adult male expanding his/her arms and legs. We indicate the results at depths of 2 - 7 m with sea waves as the error frequency rates in Fig. 3(a-b). In this simulation, we used the model shown in Fig. 1(a-b) with the addition of sea waves. And Tx was placed at 225 points on 15 x 15 grid points at 3 m intervals. As shown in Fig. 3(a-b), although there were several points where we did not achieve the target error at depth 2 m, we achieved the target error at integer depths from 3 m to 7 m. Overall, most of the errors are widely distributed in the range of 0.2 m to 1.4 m. Therefore, even under the environment of sea waves, we can estimate the position with some accuracy. Furthermore, we show the detailed results in calm or with sea waves when Tx is at a depth of 3 m in Fig. 2(c). Although the overall accuracy decreases in the presence of sea waves,
we achieved the target error. Therefore, the method is sufficiently effective as a countermeasure against sea waves. For more accurate position estimation, we can consider multiple angle corrections or introduce a new angle correction algorithm.

Fig. 3. The result of undersea position estimating

5 Conclusion

We investigated sea wave countermeasures in an undersea position estimating system using electromagnetic waves. This study proposed the undersea positioning system, which uses Rxs floating above the sea surface. Then, we showed that it is possible to obtain RSS attenuation corresponding to the distance between antennas, even for Rx above the sea surface. In addition, we introduced a correction method of RSS for the directivity of antennas, taking into account the propagation path of electromagnetic waves. As a simulation result, even in the situation where sea waves are existing, we almost achieved a target error within 2.0 m at 225 points at depths of 2 - 7 m in our proposed system. Therefore, the proposed countermeasures against sea waves are sufficiently effective.

As a subject in the future, we need to consider other factors that may occur in real environments, such as the appearance of obstacles. Also, in order to improve the accuracy of position estimation, we need to develop antennas with more uniform directivity and introduce multiple angle corrections or a new angle correction algorithm.