Measurement of an undersea positioning system using radio waves

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Abstract: In Japan, the number of water accidents is approximately 1,300 per year, which is almost constant in recent years. Although divers rescue people in the case of water accidents, there are various obstacles in the sea. Then, divers are always surrounded by a lot of dangers in the rescue activities. Therefore, assuming that identifying the locations of divers supports their rescue operations, we investigate an undersea positioning system using radio waves in the VLF band (10-kHz). According to previous research, radio waves of 10-kHz are theoretically attenuated at 3.5 dB/m, and can be transmitted in the distance of 30 m and more. In addition, a numerical simulation of a three-dimensional undersea position-estimation system has already been reported. In this study, we measured received signals at the real sea and showed the position-estimation results employing the algorithm for an undersea position estimation.

Keywords: Antenna, undersea radio waves, undersea position estimation, lateral wave

Classification: Antennas and propagation

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1 Introduction

Many technologies have been developed to support the generation of new ocean businesses in recent years [1]-[2]. To date, acoustic waves have been commonly utilized for underwater wireless communications. This is because the attenuation of acoustic waves is smaller than that of radio waves and visible light waves, and it is suitable for underwater remote communication [3]-[4]. However, acoustic waves in the sea have an attenuation of almost zero, all reflections and diffractions are received in the shallow sea and around the seabed. In addition, sounds from ships can be noise. According to [5], the diffraction depending on the depth of the sea may also be of concern. Regarding visible light waves, the scattering attenuation with the muddiness of the sea water is large. Reference [2] proposed that visible light-wave telecommunication in seawater is unsuitable owing to the instability and capability of communication. Because radio waves have a large attenuation, it is considered that underwater communication with radio waves is very difficult [6]. However, the reflection and diffraction of radio waves can be ignored because of their large attenuation. Thus, the use of radio frequency (RF) signals has been expected to be utilized as wireless communications in seawater.

We consider the development of supporting technologies for water rescues as a way of using radio waves in seawater. Several accidents occur in water worldwide. For example, water accidents in Japan occur approximately 1,300 per year [7]. Accidents in the water are predominantly because of natural disasters and sinking accidents involving ships. However, the view of divers in the sea during rescue is sometimes obscured, and there are various obstacles...
floating in the water. Therefore, consideration of the safety of the divers during rescue is required. Rescue activities will become much safer if divers know their own current positions during rescue. Hence, it is essential to establish an undersea positioning system based on wireless communication technologies.

Since divers are constantly moving during rescue, the system must possess real-time positioning. However, the environment in which they work has various factors to be considered for undersea positioning systems. Thus, a simple algorithm and a processing with little calculation are needed. In this study, we consider an underwater positioning system that utilizes the frequency in kHz bands to establish technologies that divers can employ easily in sea accidents. As a positioning system currently used in the ocean, the global positioning system (GPS) is widely used. However, we cannot use GPS in places where radio waves cannot reach, such as the sea. In such places, there are positioning technologies that match patterns to data collected in advance and utilize the attenuation of electric power through propagation \[8\]. In the positioning technique using the propagation loss, we estimated the propagation distances using the Received Signal Strength (RSS), drawing the sphere with the radius of the estimated distance whose center is each receiver, and calculating the cross point of the spheres.

A numerical simulation of the three-dimensional underwater position-estimation system has already been reported \[9\]. In this study, we measured the received signals in the real sea, and show the position-estimation results employing the algorithm for an underwater positioning system.

2 Condition for measurement

2.1 Measuring environment

An overview of the measuring environment is shown in Fig. 1(a), and the half-sheath dipole antenna employed for both a transmitting antenna (Tx) and the receiving antennas (Rxs) is shown in Fig. 1(b) \[10\]. In this measurement, we obtained the data of receiving signals from the Tx in the frame fixed at the seabed. The Rxs are installed around the sea surface by a crane car. Next, we indicate the frame of a Tx in Fig. 1(c) and (d). A Tx is set in the upper part of the frame made of fiber-reinforced plastic (FRP) shown in Fig. 1(c). We can change the distance between a Tx and the seabed by extending the two poles of FRP fixed the Tx in Fig. (c). A Tx is empowered from a battery in pressure-resistant vessel on the frame of the Tx. Fig.1(d) indicates the view of the frame of a Tx from above. We also indicate the frame of Rxs in Fig. 1(e) and (f) \[11\]. Four Rxs and a GPS antenna were mounted at the frame shown in Fig. 1(e).

The measured electric conductivity \(\sigma\) is about 4.7 S/m. It is assumed that relative permittivity of the seawater \(\varepsilon_r\) is about 80. The length of axis of the half-sheath dipole antennas is 810 mm. The operating frequency is 10 kHz, and the input power is 200 mW. Combining the data obtained from receiving signals, we estimate a location of an undersea Tx. This measurement has
been conducted with the licence of the experimental test station.

2.2 Process of measurement
The process of the measurement is shown in Fig. 1 (g). A Tx is fixed at one point in the sea. In addition, the Tx and Rxs are installed in parallel. Shown as Fig. 1(g), we moved the frame of Rx meanderingly; at the interval of 2 m in the direction of x, and 2 and 8 m alternately in the direction of y. We obtained the data of a receiving signal at each point of 36 points employing a spectrum analyzer: N9913A Fieldfox RF Analyzer of Keysight. The setup for the experiment in seawater is connected by an optical fiber with the PC on the land through E/O and O/E converters.

(a) Overview of measurement.  
(b) Half-theath dipole antenna.  
(c) Side view of frame of Tx.  
(d) Top view of frame of Tx.  
(e) Side view of frame of Rxs.  
(f) Top view of frame of Rxs.  
(g) Process of measurement.

Fig. 1: Sea model for the undersea antenna position estimation.
3 Overview of position estimation

In this chapter, we show the overview of the employed algorithm in this study and the main process, angle correction. The position-estimation flow is shown in Fig. 2 (a), and the points where we estimated the positions are shown in Fig. 2 (b). Among the four received signals at 10 m distances, we selected the three signals with the largest powers. Then, the distances between antennas are calculated from the RSSs of the selected signals. The estimated position of a Tx is the intersection of the three spheres with the radiiuses of the calculated distances. However, the received signals are affected from the directivity of the antenna and the lateral wave propagating over the sea surface [9]. Therefore, received signals do not always have the values corresponding to the distances between antennas. In the algorithm of [9], we correct the distances between antennas according to the incident angle at which an Rx receives radio waves transmitted from the Tx at the estimated position. In this measurement, we conducted the position estimations of Tx at 16 points in the area of 10 m × 10 m, shown as Fig. 2 (b). Since it is difficult to obtain the received signals in the layout shown as Fig. 2 (b), we estimated the position of each Tx employing the relative positions between an Rx and a Tx. The depth at which Tx is fixed is 6.5 and 7.3 m.

![Flow of position estimation](image)

(a) Flow of position estimation (b) Points of position estimation

Fig. 2: Sea model for the undersea antenna position estimation.

4 Measuring result

In this study, we estimated the positions of a Tx that exists at a depth of 6.5 m and 7.3 m in the sea, based on the data of the received signals and the estimation algorithm.

4.1 Target error of position estimation

As the target of the position estimation, we describe the target error against the factual position of a Tx. We evaluated the estimation accuracy based on the distance between the positions acquired from a GPS antenna and estimated positions. Since we are considering the real-time location of a diver in the sea in this study, we establish a maximum of 2.0 m as the target error, considering an adult male expanding his arms and legs.
4.2 Position-estimation result

Figure 3 shows the position-estimation results in the case that a Tx exists at two depths, 6.5 m and 7.3 m. As shown in Fig. 3 (a) and (b), we achieved the error within 2.0 m at 88% in both planes. The worst error in two planes at the depth of 6.5 m and 7.3 m is approximately 4.5 m. In Fig. 3 (a) and (b), we consider that the errors in the area at almost same distances from four RxS can be large, because the effect of position estimation from lateral waves are superior. We assume that large errors at these positions results from the infinitesimal RSSs owing to the angular characteristics of the Tx in the numerical analysis as shown in Fig. 3 (c).

5 Conclusion

In this study, we measured the received signals at the real sea, and estimated the position of an undersea Tx using the algorithm with the correction based on incident angles of radio waves. Errors within 2.0 m, which is the target error considering an adult male expanding his/her arms and legs, were achieved at 88% of the 6.5 m and 7.3 m planes. Therefore, the proposed system is sufficiently effective in a real environment. As a future study, we investigate the cause of the position-estimation error of more 2.0 m in this actual measurement. We also examine external factors such as environmental noise and the effect on the positioning system in the presence of the human bodies such as diver’s.

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