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Underwater Acoustic Positioning Using Time-of-flight Signal Blocks
直達波到達時間群を用いる水中音響測位

Tohru Yoshihara[†1], Tadashi Ebihara[2], Koichi Mizutani[2] and Yuma Sato[1]
([1]Aomi Construction; [2]Univ. Tsukuba)
吉原 到 [1], 海老原 格 [2†], 水谷 孝一 [2], 佐藤 優磨 [1] ([1]あおみ建設, [2]筑波大・シス情系)

1. Introduction

Acoustic positioning is a fundamental technology for the efficient operation of mobile vehicles in the sea, where visibility is generally poor. In underwater acoustic positioning, the position of the transmitter (Tx) is often assumed by measuring the time-of-flight (ToF) of the sound wave from the Tx to the receiver (Rx), and combining this with the baseline length between the Tx and Rx and the known Rx coordinates [1,2]. However, most of them are designed to operate in environments where the effect of multiple reflections is small, and acoustic positioning techniques for environments where the effect of multiple reflections is significant, such as in harbours, are not well established. The reason for this is that in a multiple reflection environment, it is challenging to separate the direct wave from the reflected wave, and the baseline length between transmitter and receiver cannot be measured correctly.

To address this issue, in this paper, we propose an underwater positioning technique that can accurately separate direct and reflected waves by constructing a database of ToF signal blocks in advance and comparing the database with the impulse response of the communication channel. We also demonstrate the effectiveness of the proposed method by experiments in a test tank.

2. Proposed method

Figure 1 shows a block diagram of the proposed technique. A Tx located at unknown coordinates (x_s, y_s, z_s) outputs a modulated pulse stretching signal (e.g., M-sequence) from the emitter to the underwater channel. A Rx with N hydrophones computes the impulse response of the communication channel between emitter and hydrophone #n (n = 0, 1, …, N-1), $r_n(t)$, by performing pulse compression on the received signal, applies time-window blocks $\tilde{r}_n(t)$ on $r_n(t)$ to separate the direct wave from the reflected wave, and performs positioning by solving

$$\begin{cases} (x_s - x_0)^2 + (y_s - y_0)^2 + (z_s - z_0)^2 = l_0^2 \\ (x_s - x_1)^2 + (y_s - y_1)^2 + (z_s - z_1)^2 = l_1^2 \\ \vdots \\ (x_s - x_{N-1})^2 + (y_s - y_{N-1})^2 + (z_s - z_{N-1})^2 = l_{N-1}^2 \end{cases}, \quad (1)$$

where l_n is the baseline length between emitter to hydrophone #n.

In a multipath environment, $r_n(t)$ has multiple peaks at the ToF of the direct and reflected waves, and the peaks sometimes interfere with each other. Therefore, the Tx-Rx distance may not be measured correctly if the peak position of $r_n(t)$ is assumed to be the ToF of direct wave. To address this issue, the proposed method precomputes the ToF of the direct wave between emitter and hydrophone #n for each

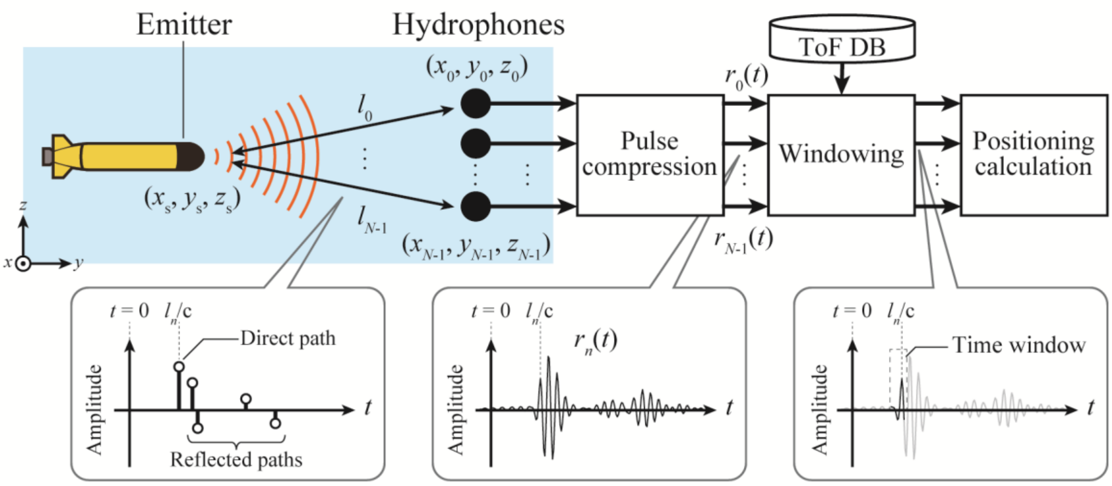

Fig. 1 Block diagram of underwater acoustic positioning system using ToF signal blocks.

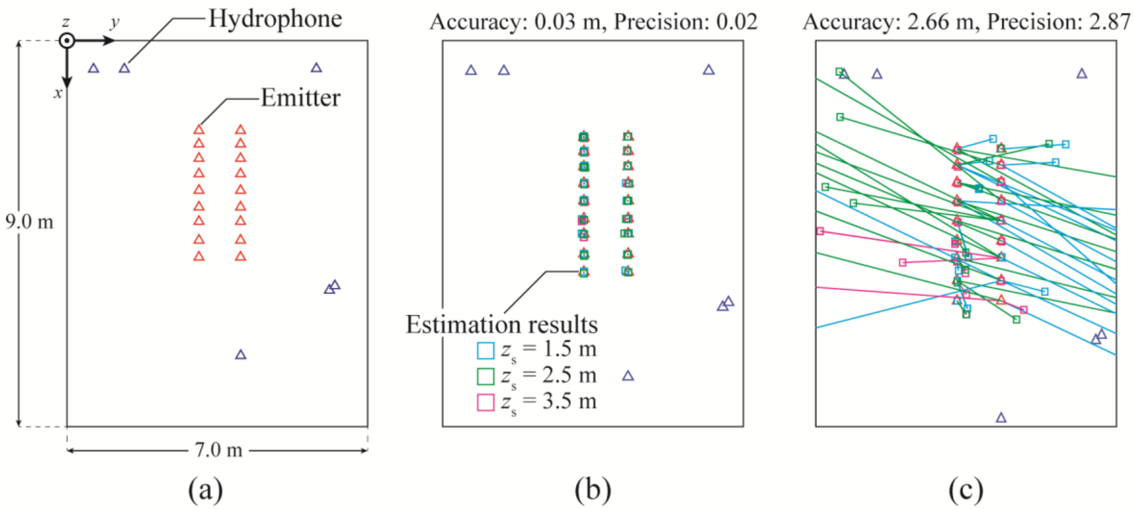

Fig. 2 Experimental environment and results; (a) experimental environment, (b) experimental result using proposed method, and (c) conventional method.

region where the emitter exists, and stores them in a database as time-window blocks, $\tilde{r}_n(t)$. By carefully designing the time window, it is possible to select only the direct wave peaks in the impulse response, and thus achieve accurate positioning in multipath environments.

3. Experimental results and discussions

The effectiveness of the proposed method was tested in a large experimental water tank. **Fig. 2(a)** shows the experimental environment. Six hydrophones (BII-7523, Benthowave) were installed in a test tank of size 7.0×9.0×4.6 (m^3) at the locations indicated by the blue-colored triangles in the figure. Emitter (OST-2120, OKI Seatec) was also installed at the locations indicated by the red-colored triangles in the figure. In such environment, positioning experiments were conducted by changing the depth of the emitter [z_s = 1.5, 2.5 and 3.5 (m)]. Since the depth can be measured with a bathymetric meter, z_s was assumed to be known. The signal used in the experiment was a phase-shift keying (PSK) modulated M-sequence of length 127 (carrier frequency: 35 kHz and signal bandwidth: 25 kHz). At each position, 10 experiments were conducted and accuracy (difference between the measured average value and the true value) and precision (standard deviation of measured values) were calculated.

Figures 2(b) and **2(c)** show the experimental results. Fig. 2(a) shows the positioning results of the proposed method, where the estimated position is indicated by colored squares. Fig. 2(b) shows the positioning results of the conventional method, which measures the baseline length from the peak of the impulse response of the communication channel without using a time window. The accuracy and precision of the proposed method are 0.03 m and 0.02, respectively. On the other hand, the accuracy and precision of the conventional method are 2.66 m and 2.87, respectively. These results suggest that it is difficult to assume that the peak time of the impulse response of the underwater channel is the ToF of the direct wave in a severe multipath environment such as the experimental water tank, and on the other hand, it is possible to achieve accurate positioning by extracting only the ToF of the direct wave using a time window.

4. Conclusions

An underwater positioning technique that can accurately separate direct and reflected waves by constructing a database of ToF signal blocks in advance and comparing the database with the impulse response of the communication channel is proposed. The effectiveness of the proposed method was evaluated by experiments in a test tank. The obtained results suggest that accurate positioning can be achieved by extracting only the ToF of the direct wave using a time window.

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References

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