

Ocean experiment result of Two Reference points Underwater Positioning System for Three AUVs Team Operation

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Abstract—This research presents a new underwater positioning system that does not rely on INS hence, a unique one is necessary. The purpose is to achieve a low-cost and compact AUV for swarm operation using the Long Base Line (LBL) method. This approach for the LBL underwater acoustic position system is ideal for the underwater AUV control system. The UEs and BS are positioned in a triangular shape as part of our targeting system configuration. The distance measurements between all nodes are performed by sending 2ms special sequences such as Chirp between the BS and the UEs as DL, and Zadoff-Chu (ZC) sequence between UEs as SL. The Ship and the Buoy towed by it alternates by sending the two DL signals every one to few seconds, whose positions are GNSS tracked. The proposed Two Reference Point Underwater Positioning System consists of three AUVs (UE1, UE2, and UE3), two reference points (BS1 and BS2), OFDM-based Down Link (DL) acoustic signals, Side Link (SL) acoustic signals and Up Link (UL) communication functions that delivers GNSS information, commands, etc. UE1 successfully calculated each of the UE positions utilizing the proposed Two Reference Point UW Positioning System.

Keywords—Underwater GPS, Underwater Positioning, Underwater communication, Underwater applications, Acoustic Communication, AUV, Swarming

I. INTRODUCTION

Because the Global Navigation Satellite System (GNSS) is ineffective underwater, there are vast parts of the deep-sea that have yet to be investigated [1]. The existing constellation of GPS satellites have insufficient availability and reliability underwater, therefore, such research captivates this study to further investigate GPS using the integrated GNSS advantage. The goal is to examine the use of drone-based surveillance, digital forensic environments, underwater and subterranean monitoring, and other defense-related applications. An autonomous robot can move and operate on the surface of the air and water is called an aerial or underwater drone [2].

The underwater positioning system for swarming multiple AUVs is described in this study. In order to create a low-cost and compact operation for swarming AUV, a new underwater positioning system that does not rely on INS is of interest. AUV-to-AUV information such as the distance and depth measurements can both be used because of the technology. Once the AUV has descended to the designated depth of reference point, the beacon signal can be utilized to identify its position. This high accuracy INS system will thereafter keep track of the AUV's position while performing intensive tracking calculations.

Drone technology has advanced to the point where they can be used in a wide range of applications such as underwater transporting, marine aqua-culture monitoring, and marine leisure

in which those drones are primarily used in unmanned aerial vehicles [3].

Underwater robots are designed to perform operations that humans aren't able due to the challenging and dangers of the underwater environment.

Our project's underwater drone is built by expanding the Raspberry Pi computing module, using a Xilinx Zynq ARM-embedded FPGA chip as our system board, and relying on an Oki Seatec OST2120 transducer for the transducer [4]. The designs are made available as open-source to support manufacturing innovation, particularly those involving drones [5]. They are based on an open-source hardware.

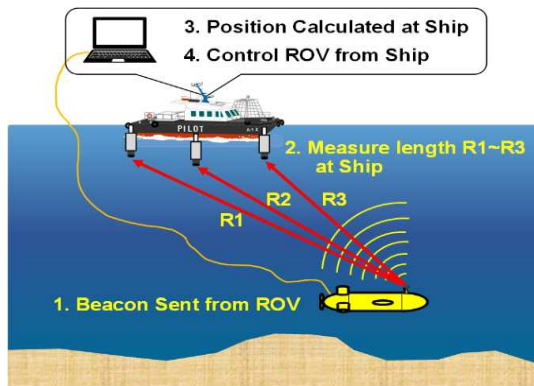


Figure 1: Conventional ROV Positioning where the lengths and depths are measured at and from the ship.

Figure 1 depicts the conventional ROV Positioning for our targeting system. 1. The beacon is sent from the ROV to the ship where 2. the lengths and depths are measured for R1, R2, and R3 at the ship. 3. At the ship, the positions are calculated, and 4. From the ship, the ROV can be controlled. Note that the ROV sends signal to the ship to calculate the ROV's position, but this time we do not have rolling compensation.

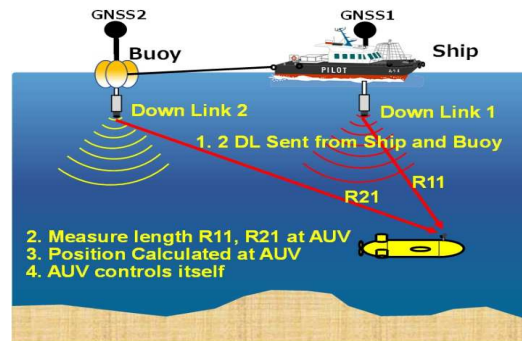


Figure 2: Proposed Positioning System for the AUV measured at the AUV.

Figure 2 depicts our Proposed Positioning System for the AUV. 1. 2 DL (DL 1 and DL 2) are sent from the Ship and the Buoy where 2. The lengths (R11 and R21) are measured at the AUV by the water pressure sensor. 3. At the AUV, the positions are calculated then 4. The AUV can control itself.

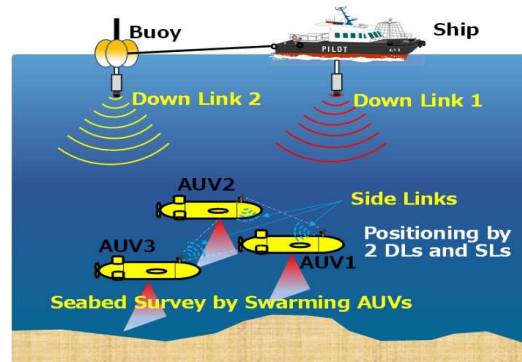


Figure 3: Proposed AUV Swarming for the Seabed Survey measured by the Down Links and Side Links.

Figure 3 depicts the Proposed AUV swarming. The AUV can survey and scan marine areas as deep as the seabed especially where humans aren't able to reach. With both the DLs (DL 1 and DL 2) and the SLs, each of the AUV can know each other's positions.

II. BRIEF EXPLANATION OF TWO REFERENCE POINTS UNDERWATER POSITIONING SYSTEM

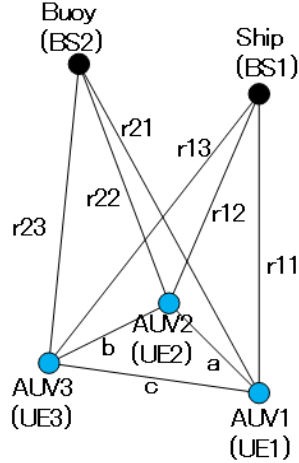


Figure 4: Distances Between All Nodes measured by the System

A topological relation of all nodes in the system which are measured by the DL and SL signals is shown in Figure 4. BS1 represents the Ship, BS2 represents the Buoy, and the AUVs

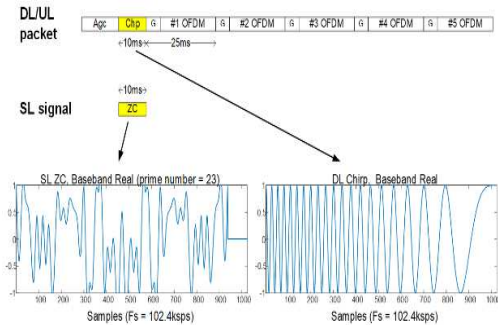


Figure 5: Signal Packet and Timing Detection

As time detection Reference Signals and signaling packets, the DL/UL and SL are shown in Figure 6. The Chirp Signal and the OFDM communication signals #1 through #5 of the DL/UL are both easily observable under Doppler Shift conditions[6-10]. The 10ms Zadoff-Chu (ZC) sequence makes up the SL Packet. The ZC sequence signals, each of which correlates to a different prime number, are utilized to identify those SL signals under conditions of overlap.

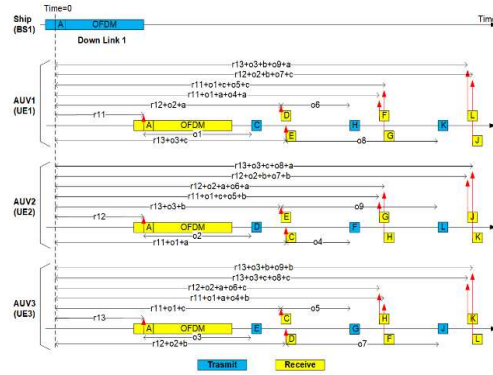


Figure 6: Down Link and Side Link Timing Diagram

With a delay of α_1 , α_2 , or α_3 , each AUV detects signal "A" and transmits signal C, D, or E to other AUVs. The C, D, and E signals from nearby AUVs can be used to approximate the timeframes as shown by the red arrow in Figure 5. By performing the aforementioned SL twice more while using the signals F, G, H, J, K, and L, all red-arrow timings can be determined. After all, seven timings for each AUV have been measured. Each AUV may separately solve six distances (delay times), including r_{11} , r_{12} , r_{13} , a , b , and c , using those seven timings. Another Down Link from the opposite BS will carry out the identical procedure, enabling the calculation of the r_{21} , r_{22} , r_{23} , a , b , and c distances. On the other hand, only calculating these distances is insufficient to identify the position of the AUV. The depth of each UE can be used to solve three sets of UE triangle placements.

The fixed-triangle position sequence of the UE can be categorized as either clockwise (CW) or counterclockwise (CCW) using the two sets [11]. One position solution can be reached if the rotation sequence is known since each UE contains a function that detects the direction of other UEs in order to set the CC or CCW placement.

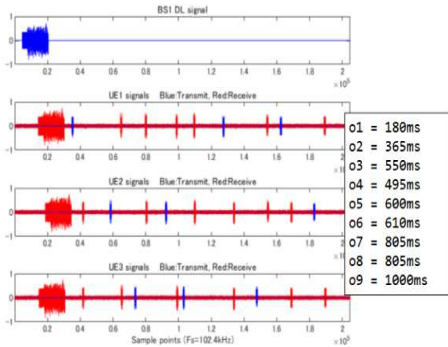


Figure 7: Simulated Timing Diagram and Detection

The simulated signal waveforms are shown in Figure 7, which has a time axis that varies from 0 to 4 seconds for all of the BS/UE placement. A propagation delay of around 2 seconds is necessary due to the free depth. For each example, control delays of o1 to o9 are best set. TX signals are represented by blue waves, whereas RX signals are represented by red waves. The Down Link and its activities are not depicted in the diagrams. However, in the simulation, the time between the BS is 2.0 seconds.

III. OCEAN EXPERIMENT SETUP

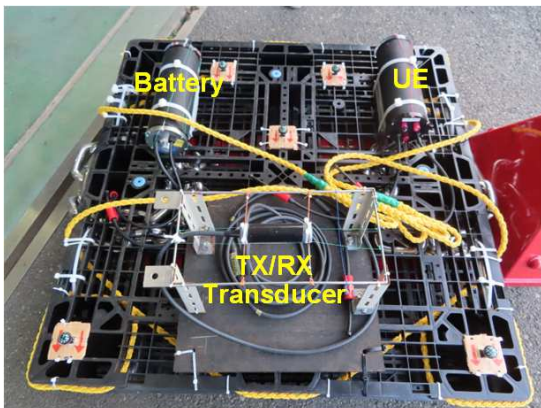


Figure 8: Photo of UE

There are three UEs at the seabed. One UL frame can send 3790 bytes for 16QAM modulation with code rate $R=1/2$ and 1895 bytes for QPSK

modulation with code rate $R=1/2$. A screenshot of the modem H/W system is displayed in Figure 8. A Zynq7000 ARM-embedded FPGA is used for digital signal processing, and a transformer-powered TX transducer is powered by an OST7010 Power Amplifier.

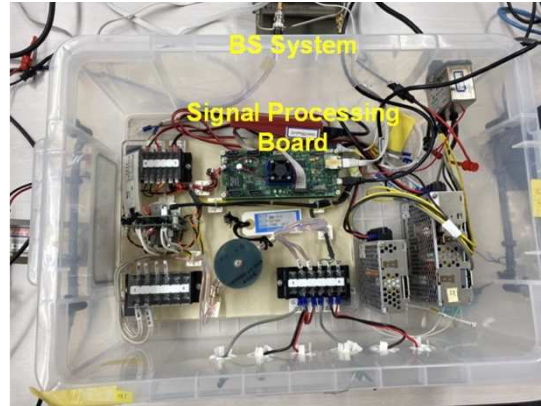


Figure 9: Photo BS

The two-element transducer picture for UEs is displayed in Figure 9. There are 2 BS System. The transducer is based on an Oki Seatec OST2120 transducer with Ha/Hb two branches merged into one body. The System board for UEs employing the Xilinx Zynq ARM-embedded FPGA chip.



Figure 10: Photo of BS (BS1 and BS2) Ships

There are two Ships for BS1 and BS2. Figure 10 displays the signal processing diagram on the UE side. Recently, a two-element transducer was developed. To further elaborate, the Ha branch is utilized for RX and TX in OFDM transmission. The Ha and Hb branches are both used to find SL signals. In addition to precise timings for measuring distance, phase differences between incoming SL signals that have been received are also recorded in order to determine orientation. UEs such as CCW or CW will have their triangular placement determined using this direction detection function. The Ha and Hb receivers have matching filters (cross correlator) with 11 templates, including "A" (BS1 chirp), "B" (BS2 chirp), and "C to L" (9 ZC sequences).

One transducer is for the BS's RX/TX, and the other is for the System seabed for the UEs. This overall concept of the positioning system has multiple base stations. BS1 and BS2 can be synced by GNSS so that both swarming AUVs and divers can determine the system's reference points.



Figure 11: Photo of BS Transducer

Figure 11 displays BS signal processing. Both the transmitting (TX) and receiving (RX) functions are available on the BS1 side. UE to BS1 signal transmission consumes relatively high power in comparison to SL power, so the receiver must continuously monitor the UE's condition. BS2 only generates DL2 signals with embedded GNSS information. Due to the high power required for signal transmission from the UE to the BS1, the receiver must monitor the UE's condition at extended intervals.

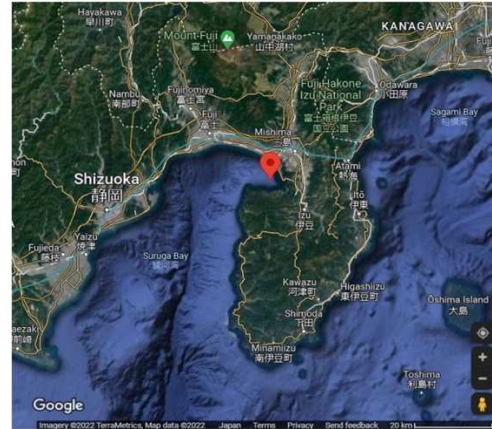


Figure 12: Experiment Site

As displayed in Figure 12 the ocean experiment was carried out in Shizuoka Prefecture at Suruga-bay, Japan, at a depth of 100 meters.

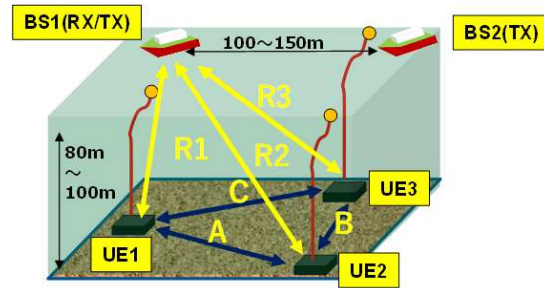


Figure 13: Experiment Setup

Figure 13 displays the experiment setup. The AUVs (UE1, UE2, and UE3) can detect the signal "A" and determine the distances R1, R2, and R3. The distances between BS1 and BS2, which represent the RX and TX, are approximately 100 to 150 meters, whereas the depth between the ships' BSs and the seabed UEs is 80 to 100 meters. After detecting signal, A, each AUV (UE1, UE2, or UE3) delays sending a signal to the other AUV by 0.2 seconds. By identifying the B and C signals from the nearby AUVs, one can approximate the timings that are indicated. In the end, six timings for each AUV have been measured. Each AUV may separately solve the R1, R2, R3, A, B, and C distances (delay times) using those timings. On the other hand, merely measuring these distances does not reveal the AUV's location. The three AUVs' respective depth information as well as their orientation can also be used to determine the position.

IV. MEASURED RESULTS

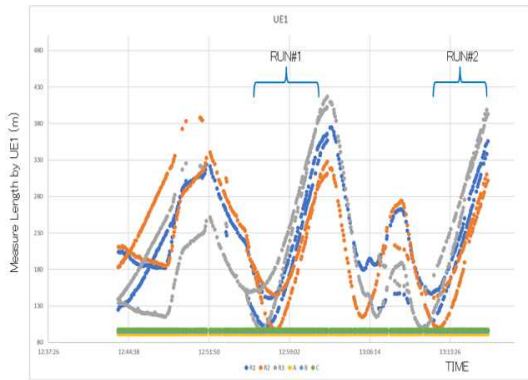


Figure 14: Measured Length at UE1

In the proposed system, the positions of the 3 AUVs are estimated in each AUV. The positioning errors of the three UEs are computed by UE1. The position UE1 can be estimated by combining the lengths of R2 and R3 with the depth of UE1. Because the positioning error of UE1 is independent, all measured lengths can be determined by the UE2 and UE3. The blue represents R1, the orange represents R2, and the

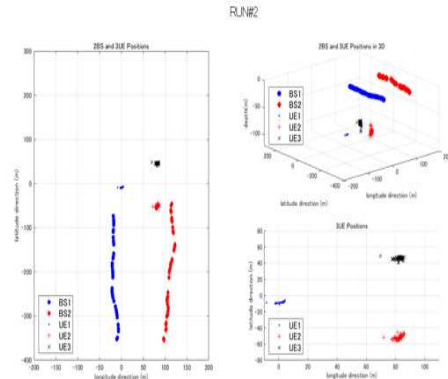


Figure 16: Position Plot Run 2

Figure 16 illustrates the Positions Plot Run 2. The transducer's position is not accurate because there is no rolling compensation which resulted in a bad deviation. The color Blue represents the RTK GPS: Blue; while the color Red represents the low accurate GPS.

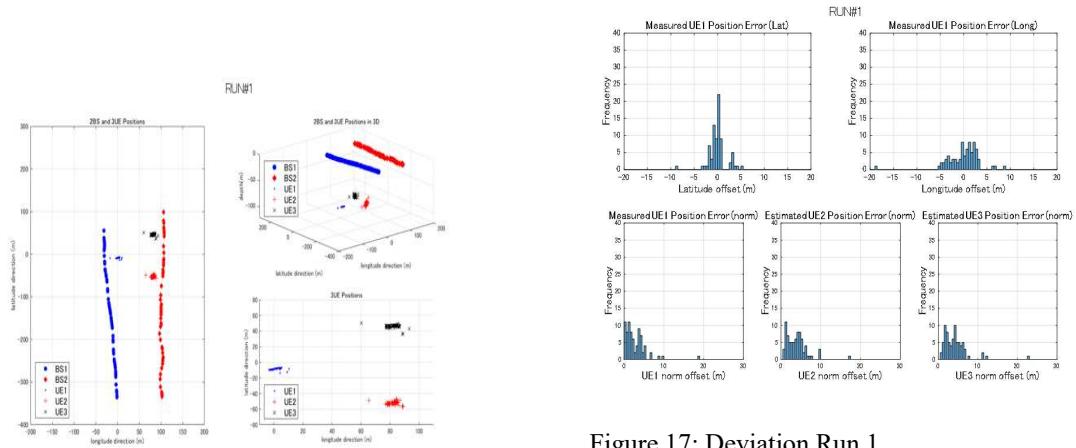


Figure 17: Deviation Run 1

Figure 15: Position Plot Run 1

Figure 15 illustrates the Position Plot Run 1. The two BSs and the three UEs Position plots were obtained at UE1 for three different views. Because UE1's depth is fixed; UE2&3's depth can be easily is calculated. The color Blue represents the RTK GPS: Blue; while the color Red represents the low accurate GPS.

Provided in Figure 17 is the Deviation Run 1. There are three UE Positioning error deviation that were obtained in UE1. The measured UE1 standard deviation for the UE1 sites at 1.87m (latitude) and 3.41m (longitude). The BS1/BS2 transducers' GPS positions exhibited significant errors because this experiment was unable to use a higher precision RTK GPS or ship rolling adjustment. In regard to the latitude and longitude for the UE2 and UE3, the larger distribution, the larger errors.

RUN#1	UE1 measured	UE2 estimated	UE3 estimated
lat sigma (m)	1.26	1.79	1.95
lon sigma (m)	3.44	3.30	3.95
depth sigma (m)	-	3.08	2.18

Figure 18: Sigma Data Run 1

In Figure 18, the Sigma Data Run 1 has been measured and estimated. The measured UE1 standard deviation for the UE1 sites at 1.26m (latitude), and 3.44m (longitude). UE2 sites at 1.79m (latitude), 3.30m (longitude), and 3.08m (depth). UE3 sites at 1.95m (latitude), 3.95m (longitude), and 2.18m (depth).

RUN#2	UE1 measured	UE2 estimated	UE3 estimated
lat sigma (m)	0.88	2.54	1.55
lon sigma (m)	2.24	2.47	2.51
depth sigma (m)	-	3.76	3.53

Figure 19: Sigma Data Run 2

In Figure 19, the Sigma Data Run 2 has been measured and estimated. The measured UE1 standard deviation for the UE1 sites at 0.88m (latitude), and 2.24m (longitude). UE2 sites at 2.54m (latitude), 2.47m (longitude), and 3.76m (depth). UE3 sites at 1.55m (latitude), 2.51m (longitude), and 3.53m (depth).

The measured Constellations are depicted in Figure 20 for BS1-DL at UE1 transducers at a depth of 100-150 meters and UE transducers are at a depth of 80-100 meters below it. Figure 20 indicates the DL OFDM configuration that was received at UE1. The ship and the buoy received the GNSS position data via DL OFDM communication signals. The signal is then periodically sent to the ship to inform it of the AUV's condition. With the QPSK modulation and the R=1/2 Convolutional Code forward error correction, the 5 OFDM symbols

packet carries 596 bit data [13]. BS1-DL at UE1 with a 50 QPSK has good constellation resulting in successfully communication.

The measured Constellations are depicted in Figure 21 for BS1-DL at UE3. The DL OFDM configuration that was received at UE3 and with a 50 QPSK, BS1-DL at UE3 has good constellation resulting in successfully communication.

The measured Constellations are depicted in Figure 22 for BS2-DL at UE3. The DL OFDM configuration that was received at UE1 and with a 50 QPSK, BS1-DL at UE1 has good constellation resulting in successfully communication.

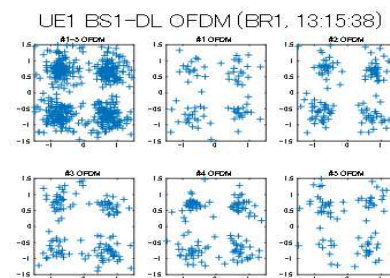


Figure 20: Constellation BS1-DL at UE1

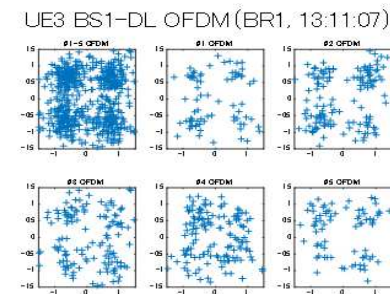


Figure 21: Constellation BS1-DL at UE3

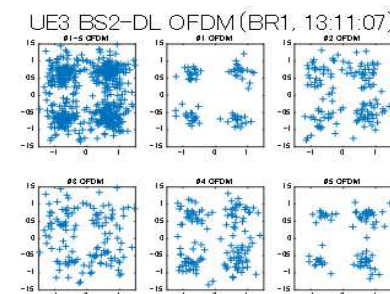


Figure 22: Constellation BS2-DL at UE1

In Figure 21, it exhibits the delay profile for the x-axis sampling points. There was no inter-symbol interference that happened for maximum delays.

In Figure 23, exhibits the delay profile in which all delay peaks are less than 512 Cyclic Prefix (CP) and with a Guard Interval (GI) of 5.0ms, the 2048-point OFDM symbol length is 20.0ms.

In Figure 25, it exhibits a poor delay. The reason for it being bad is because of the reflection by its own body. But despite the delays, the experiment was still a success.

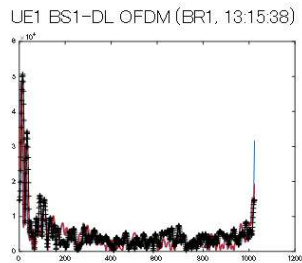


Figure 23: Delay Profile for BS1-DL at UE1

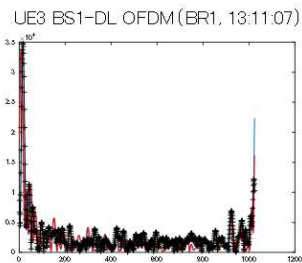


Figure 24: Delay Profile BS1=DL at UE3

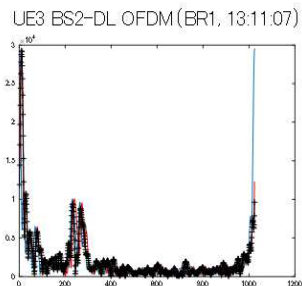


Figure 25: Delay Profile BS2-DL at UE3

V. CONCLUSION

This paper described a Two Reference Point Underwater Positioning System for swarming AUVs. Our targeting system is situated to structure to cover the triangle area. In addition to the work mentioned above, the LBL technique can require more than two known reference points for a more accurate positioning, but the suggested system only requires two GNSS-supported reference points and does not require high accuracy INS. The system's reference points can also be altered just by using one buoy being towed by one ship. An intensive computer-based simulation of signal processing has been performed for two experiments for BS1 and BS2 in which the three UEs can identify their own and the other's UE positions according to their simulation results, and all the BS can be synchronized by GNSS.

A comparison between BS1 and BS2 by using the computer-based signal processing: With the SL's Carrier to Noise to Ratio CNR=0dB and the DL's CNR 6dB=6dB and CNR=0dB and the DL's CNR dB=6dB, for several testing for BS1 and BS2 were simulated.

Since this experiment could not use a higher accuracy RTK GPS and the ship rolling compensation, the BS1/BS2 transducers GPS positions had errors. However, all the UE positions were successfully estimated by UE1 using the proposed Two Reference Point UW Positioning System.

Acknowledgment

This study has been supported by the Development of Seafloor Exploration Technology (DeSET) Project 2020-2022 of The Nippon Foundation, JASTO and Leave a Nest Co., Ltd.

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