

A Conversion System Based on Acoustic Communication for Using Bluetooth Low Energy Sensors Underwater

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Abstract—In this paper, we propose a system for using a commercially available Bluetooth Low Energy (BLE) sensor underwater. Our system comprises a mounting device located close to the BLE sensor and a part located on the water surface. In the water, the mounting device receives the BLE signals from the sensor and converts them into acoustic waves that are emitted from a speaker. The part on the water surface receives those acoustic waves via a microphone and demodulates the data transmitted by the BLE sensor. The proposed system enables existing BLE sensors to be used underwater. Some of the functions of our proposed system are developed and evaluated using commercially available products, and the basic performance of the system is confirmed.

Index Terms—Bluetooth Low Energy, acoustic communication, underwater, sensor.

I. INTRODUCTION

Bluetooth Low Energy (BLE) [1] is used widely. Compared to conventional Bluetooth, BLE is focused on saving power, and many sensors with BLE communication have been developed. Normally, radio waves are attenuated greatly in water, so wireless communication devices such as BLE sensors cannot be used underwater. However, a wireless sensor that could be used underwater would be useful in various scenarios.

For example, Abe *et al.* [2] imagined installing a commercially available waterproof camera under a cage of a fish farm to measure the number of fish therein. In that case, it would be useful if the data acquired by the underwater camera could be seen in real time above the water. Alternatively, using inexpensive commercially available BLE sensors to assess in real time the water temperature and how the shape of the cage was changing would help to make aquaculture more efficient. In addition, if the smartwatches or smartphones worn by divers could connect to the Internet while underwater, the divers could use various services while underwater.

One way to use would-be wireless communication devices underwater is via underwater communication cables. The signal from the device propagates through the cable instead, thereby facilitating data communication between the underwater device and a terrestrial device. For example, the Lumica

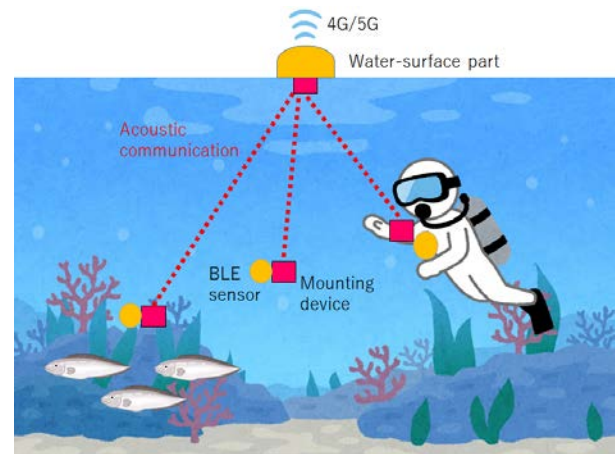


Fig. 1. Overview of proposed system

Wireless Line [3] is for use with a submerged waterproof Wi-Fi camera when fishing to view the underwater situation from above the water. However, the use of cables is limited because they reduce the extent to which the underwater devices can be moved.

In this paper, as shown in Fig. 1, we propose a system for using a commercially available BLE sensor underwater. Our system comprises a mounting device and a part located on the water surface. In the water, the mounting device is close to the BLE sensor and receives its BLE signals and converts them into acoustic waves that are emitted from a speaker. The water-surface part receives those acoustic waves via a microphone and demodulates the data transmitted by the BLE sensor. Our system enables existing BLE sensors to be used underwater. In this study, we developed and evaluated some of the functions of our proposed system using a Raspberry Pi and a commercially available microphone, speaker, and software audio modem (minimodem [4]).

The rest of this paper is organized as follows. We discuss related work in Section II and the proposed conversion system in Section III. Having implemented the proposed system in

Section IV, we evaluate it through experiments in Section V. Finally, in Section VI, we conclude the paper with an outlook on future work.

II. RELATED WORK

A. Underwater communication

Because radio waves generally cannot be used underwater, visible-light and acoustic communication technologies are used instead [5]–[7]. Short-range underwater visible-light communication using light-emitting diodes has attracted attention in recent years, but the mainstream products for underwater communication use acoustic means. There are various general-purpose underwater acoustic communication modems on the market [8], [9], but most are for use in relatively deep areas (e.g., for exploring seafloor topography) and are expensive. Several inexpensive underwater communication modems have been proposed [10], [11], but it is difficult to obtain those that have not been commercialized.

Some products assume underwater communication in relatively shallow areas; for example, Logosease [12] is an underwater transceiver for communication between divers. In addition, there are underwater communication devices for use in aquaculture farms [13] and consumer underwater drones that can be controlled by underwater communication [14]. However, none of these devices are intended to use existing wireless communication devices, and they are expensive. There is also the aforementioned underwater communication cable [3], whose uses and drawbacks were discussed in Section I.

B. Remote control of Bluetooth devices

Several previous studies have considered communication with remote Bluetooth devices [15], [16]. Okada and Suzuki [15] proposed a system with good usability for controlling Bluetooth devices remotely in the home. Their system treats remote Bluetooth devices as if they are nearby by transmitting Bluetooth control messages through an encrypted tunnel using Datagram Transport Layer Security. In addition, experiments using mobile Internet showed that communication is possible within the timeout time specified by Bluetooth. Also, Albert *et al.* [16] proposed a method called UbiPAN for handling remote Bluetooth devices. In UbiPAN, gateways are installed in each remote Bluetooth device and the user's environment, and information is exchanged between the gateways by using the Session Initiation Protocol. By contrast, in this paper we consider controlling underwater BLE sensors using acoustic communication technology.

III. PROPOSED SYSTEM

As shown in Fig. 1, the system proposed in this paper comprises a mounting device connected to the underwater BLE sensor and a part installed on the water surface. We assume a simple BLE sensor that broadcasts its data periodically and whose configuration is easily changed by sending control packets. The BLE sensor and the mounting device are either pre-waterproofed or put in waterproof cases for use. As with

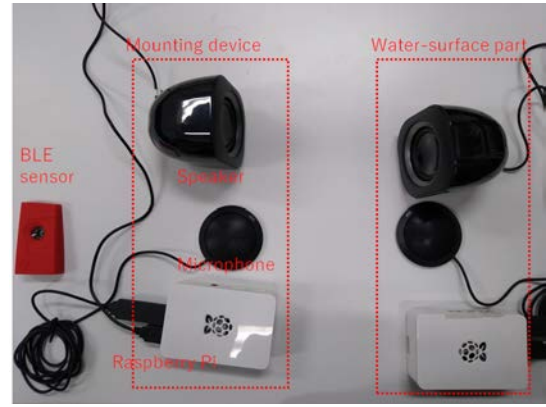
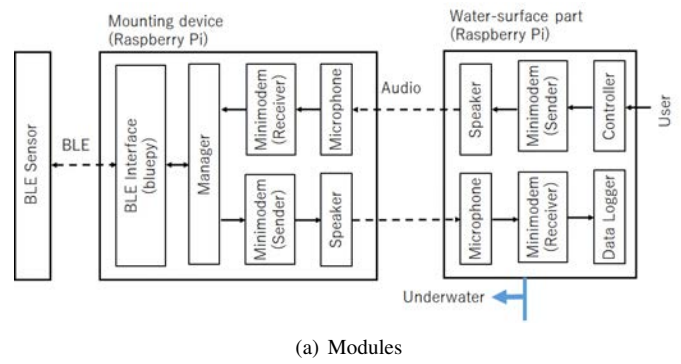


Fig. 2. Implementation of proposed system

the underwater communication cable [3], it is assumed that the mounting device and the BLE sensor can communicate wirelessly. The water-surface part is connected to an existing network via a mobile network and can be controlled by a remote user.

In our system, a general-purpose terminal equipped with a BLE module, a microphone, and a speaker is used for both the mounting device and the water-surface part. First, the wireless frame transmitted by the underwater BLE sensor is received by the BLE module mounted on the mounting device. The mounting device then converts the data received from the BLE sensor into acoustic waves and transmits them from the speaker. Finally, the water-surface part demodulates the acoustic waves received via its microphone and obtains the data transmitted by the BLE sensor, and a user located remotely acquires those data.

Meanwhile, if a remote user wants to control the underwater BLE sensor, then the user operates the water-surface part to send control data to the mounting device using acoustic communication. When the mounting device receives the acoustic waves, it demodulates the control data and send them to the BLE sensor. Our system enables existing BLE equipment to be used underwater.

IV. IMPLEMENTATION

In this section, we report on part of our proposed system being implemented using commercially available equipment.

For simplicity, we assume only one mounting device in this paper; expansion to multiple mounting devices is a future issue.

The configuration and a photograph of our implemented system are shown in Fig. 2. As the main part of the mounting device and water-surface part, we used a Raspberry Pi 3 Model B+ with the Raspbian operating system (version 2018-4-18). The speaker was an ELECOM MS-P08USBBK, and the microphone was a Sanwa Supply MM-MCU06BK. We used two BLE sensors: a Texas Instruments SensorTag (CC2541) and an Omron environmental sensor (2JCIE-BL01). The SensorTag has multiple sensors for temperature, humidity, barometric pressure, acceleration, angular velocity, and magnet field, and its specifications are in the public domain. The environmental sensor also has multiple sensors for temperature, humidity, light, ultraviolet, pressure, noise, and acceleration. In this study, to communicate with the BLE sensor at the mounting device, we developed a code based on the Python library bluepy [17]. We also used a software frequency-shift-keyed audio modem (minimodem 0.24 [4]) to perform acoustic-wave modulation and demodulation at both the mounting device and water-surface part, as shown in Fig. 2.

When collecting data from an underwater BLE sensor, the user first accesses the water-surface part and specifies the media access control (MAC) address of the target BLE sensor, the universally unique identifier (UUID) corresponding to the sensor data to be acquired, and the data collection interval. The water-surface part then transmits a control message to the mounting device using acoustic communication. Upon receiving the control message, the mounting device sends a request message to the sensor corresponding to the specified MAC address and UUID at a predetermined frequency. After the mounting device receives the response message from the BLE sensor, it transfers the information about the UUID and sensor data included in the message to the water-surface part using acoustic communication. As described above, the user can acquire the desired data from the underwater BLE sensor.

V. EVALUATION

In this study, to evaluate the basic characteristics of our implemented system, we subjected it to indoor experimental evaluation. We used a Texas Instruments SensorTag (CC2541) as the BLE sensor, and we used the minimodem default settings for simplicity.

A. Evaluation of communication distance

First, as shown in Fig. 3, we assessed the communicable distance between the mounting device and water-surface part. We measured the bit error rate for different values of the distance between the speaker and the microphone and the baud rate. In each experiment, 100 kB of sensor information were transmitted and received, and the results are shown in Fig. 4. As can be seen, for each baud rate, the bit error rate increased with increasing distance. Also, for each distance, the bit error rate increased with increasing baud rate.

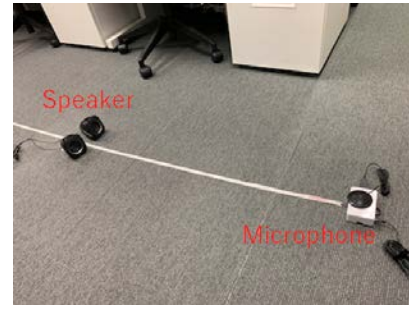


Fig. 3. Experiment to evaluate communication distance

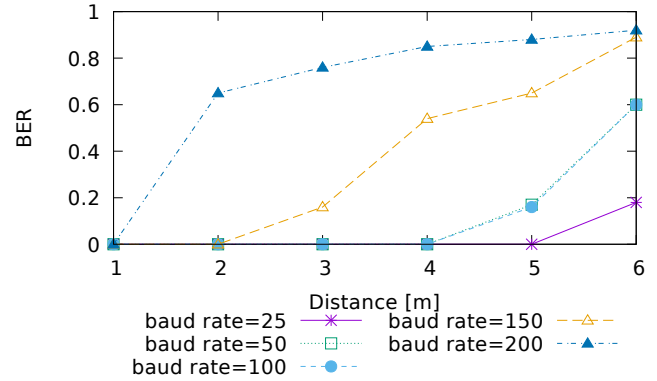


Fig. 4. Evaluation of communication distance

Here, at each baud rate, no communication was possible beyond 6 m. To increase the communication distance, we must consider improvements such as increasing the speaker volume, using a microphone with better performance, and using a frequency with less noise. These improvements are for future work. Also, to carry out future experiments underwater, we must use either waterproof cases or a waterproof microphone and speaker. Experiments in water constitute a future topic.

B. Evaluation of communication delay

Next, we evaluate the communication delay by investigating the initial and transfer delays. The initial delay is the time from when the water-surface part transmits the control message to when it receives the first item of sensor data. The transfer delay is the time from when the mounting device receives the data from the BLE sensor to when the water-surface part receives the data. Experiments were conducted with various data-collection intervals.

The results given in Table I are the averages of 10 measurements. It was confirmed that the initial delay was around 18 s and the transfer delay was around 3.5 s regardless of the interval settings. Therefore, the data-collection interval should be set to 3.5 s or more.

VI. CONCLUSION AND FUTURE WORK

In this paper, we proposed a conversion system for using BLE sensors underwater. In the reported study, we developed

TABLE I
EVALUATION OF COMMUNICATION DELAY

Interval setting [s]	Initial delay [s]	Transfer delay [s]
0	21.59	3.64
1	18.35	3.44
5	17.95	3.54
10	17.95	3.60
30	17.67	3.46
60	17.93	3.63

part of the proposed system, verified its operation in the laboratory, and evaluated its basic communication performance.

As future work, it is necessary to evaluate our proposed system underwater. We also plan to extend the developed system so that not only BLE but also other wireless communication methods such as Wi-Fi can be used underwater. Furthermore, our system needs to be expanded to work with multiple mounting devices.

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