Experimental Evaluation of Effect of Turbidity on the Performance of Visible Light Communication in an Underwater Environment

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***Abstract*— In tuna farming, turbidity measurement is highly important since one of the cause of death of tuna is a choking death due to muddy water. In this paper, we consider to use visible light communication modules for estimation of turbidity in underwater environments. If these modules can be used as turbidity meters, additional introduction of dedicated turbidity meters is not necessary. In this paper, through experimental evaluations using off-the-shelf visible light communication modules, we investigate the effect of turbidity on the performance of visible light communication in an underwater environment.**

Keywords-visible light communication; underwater sensor networks; turbidity; fish farm monitoring;

I. INTRODUCTION

In recent years, tuna farming has attracted a lot of attentions since the amount of natural tuna has been decreasing. In our university, we have developed technologies for farming bluefin tuna [1]. One of the cause of death of tuna in our fish farm is a choking death due to muddy water. Therefore, it is very important to measure or estimate turbidity in the fish farm and to take an appropriate action depending on the measurement result. Currently, the turbidity in a fish farm is measured by visual judgment of a diver in our university. If the measurement can be conducted automatically, low cost and continuous turbidity monitoring can be accomplished in the fish farm.

Our research group has proposed a fish farm monitoring system [2], [3] as shown in Fig. 1. In our system, sensor nodes are assumed to be attached at variety of places such as fish, preserves, and remotely operated vehicles (ROVs). Sensor information is gathered at a remote server through sink nodes for efficient fish farming. Since fish or remotely operated vehicles have mobility, we assume wireless communication among sensor nodes and sink nodes. Here, in underwater environments, decay of radio is high and its transmission distance is too short (e.g. 10 cm) [2]. Therefore, we assume acoustic communication or visible light communication among nodes in our system.

Here, when the turbidity in an underwater environment changes, it may affect to the performance of communication such as error rate. If communication modules used for underwater sensor networking can be used for estimation of turbidity, additional introduction of dedicated turbidity meters is not necessary. Therefore, in this paper, we evaluate the performance of a communication module in an underwater environment through experiments to confirm whether it can be used for estimating turbidity.

In this paper, we focus on visible light communication among underwater communication technologies. We evaluate the effect of turbidity on the performance of visible light communication through experiments using off-the-shelf modules. In the experiments, we put visible light communication modules to both sides of an aquarium. The turbidity of water is controlled by adding bath powder, and the distance between modules is varied by changing aquariums.

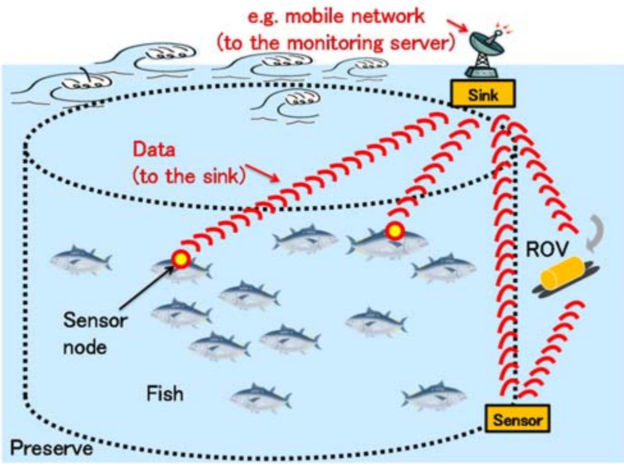

Figure 1. A fish farm monitoring system

The rest of this paper is organized as follows. In Section 2, we introduce related work. After we explain experimental environment in Section 3, we describe evaluation results and discussions in Section 4. Finally, we conclude this paper with an outlook on future work in Section 5.

II. RELATED WORK

Currently, various turbidity meters are commercially available. However, these meters are expensive and can only measure turbidity in a specific point. To automatically measure turbidity in a wide area, a lot of meters should be placed or meters should be moved by using vehicles for example.

There are some researches on estimation of turbidity using cameras [4], hyperspectral cameras [5], LEDs [6], communication modules [7], and so on. In [4], the authors proposed a method for estimating turbidity using images obtained by a camera in underwater environments. In this approach, a dedicated camera is necessity for estimation of turbidity.

In [7], the authors considered to use a visible light communication module for estimation of water velocity and turbidity. They considered a physical layer approach where the water velocity and turbidity are estimated by signal processing of received signals. On the other hand, in this paper, we use higher layer information for estimation of turbidity. In addition, we do not assume specific modules but assume visible light communication modules compliant with a specification [8].

III. Experimental Environment

In this section, we explain the experimental environment in this paper.

A. Visible Light Communication Modules

In the experiments, we used off-the-shelf visible light communication (VLC) modules as shown in Fig. 2. The receiver module is Naito Densei VL-100-USB-3RA [9] and the sender module is Naito Densei VL-100-3T [10]. In these modules, the pulse position modulation is employed and the data rate is 4.8 kbps. These modules are compliant with JEITA CP-1223 [8] which is a Japanese specification of visible light communication.

The sender module is powered by a battery and it transmits same frames continuously through its LED. The total length of a frame is 24 bytes which is composed of a header field (6 bytes), a payload field (16 bytes) and a footer field (2 bytes). The receiver module is connected to a PC though USB cable, and it is powered through USB. The receiver module receives frames when its illuminance sensor receives sufficient amount of signals. The version of firmware of the receiver module used in the experiments is version 4.0.0.0.

B. Communication Performance Index

By using a software provided by the vendor, payload data of received frames and the performance of communication in a certain measurement duration T as listed in the following can be measured.

- The number of lost frames n_{loss}.
- The number of received frames with an error n_{err}.
- The number of received frames with no error n_{suc}.

Here, the total number of frames n is calculated as

$$n = n_{loss} + n_{err} + n_{suc}.$$

We define the rate of successful frame reception r_{suc} and the rate of frame reception r_{rec} as follows.

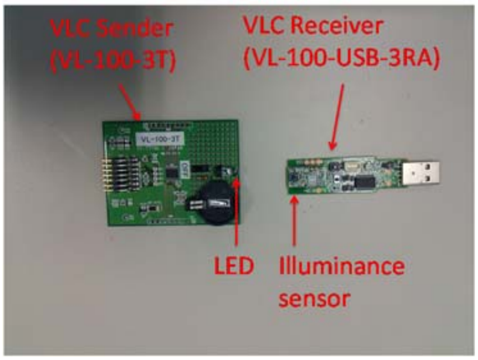

Figure 2. Visible light communication modules used in the experiments

TABLE I. LIST OF MODULES FOR THE EXPERIMENTS

Name	Specification
VLC receiver module	Naito Densei VL-100-USB-3RA
VLC sender module	Naito Densei VL-100-3T
Aquarium A (40.6 cm)	W 10.2 x D 40.6 x H 7.6 cm
Aquarium B (30.5 cm)	W 10.2 x D 30.5 x H 7.6 cm
Aquarium C (20.3 cm)	W 10.2 x D 20.3 x H 7.6 cm
Bath powder	Hakugen Nigoriyu-Kikou (Kurokawa)
Turbidity meter	Optex TD-M500

$$r_{suc} = \frac{n_{suc}}{n},$$

$$r_{rec} = \frac{n_{suc}+n_{err}}{n}.$$

In addition, by comparing payload of received frame with payload of transmitted frame, we can measure an error rate of received frames e in the measurement duration as follows.

$$e = \frac{1}{n_{err}+n_{suc}} \frac{1}{L} \sum_{i=1}^{n_{err}+n_{suc}} \sum_{j=1}^{L} unmatch(d_{i,j}^{recv}, d_j^{send}),$$

where $d^{recv}{}_{i,j}$ is the j-th byte in the payload of the i-th received frame in the measurement duration and $d^{send}{}_j$ is the j-th byte in the payload of the transmitted frame. L is the length of payload (L=16 in this experiment). The function *unmatch()* returns one if two data is not same. Here, we note that we used e as error rate since bit error rate cannot be obtained by the software used in the experiments.

C. Overview of Experimental Environment

Figure 3 shows the overview of experimental environment. Table I summarizes the list of modules for the experiment. In the experiment, we put the sender and receiver modules in both sides of an aquarium as shown in Fig. 3. The receiver module is connected to a laptop PC to report the status of communication performance.

To change the distance between modules d, we prepared three kinds of aquarium as listed in Table I. Therefore, the distance d in this paper is varied among 40.6 cm, 30.5 cm, and 20.3 cm. To change the turbidity of water in an aquarium, we added bath powder bit by bit. To measure the turbidity of water, we used a turbidity meter TD-M500 [11] made by Optex, Inc. In this meter, turbidity can be measured in the range from 0 to 500 in the Formazin turbidity unit (FTU).

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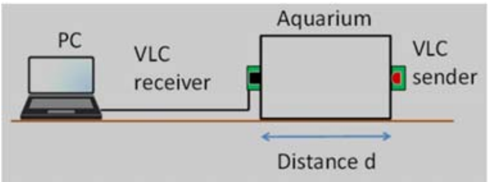
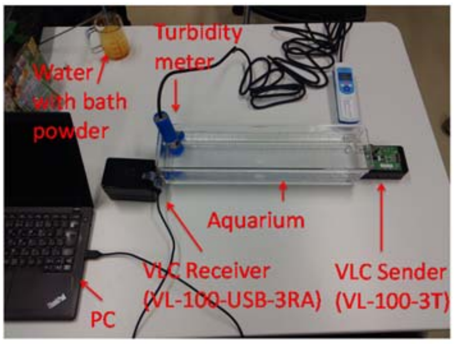


(a) Overview



(b) Snapshot

Figure 3. Experimental environment

IV. Experimental Results and Discussion

In this section, we show experimental results and discussion.

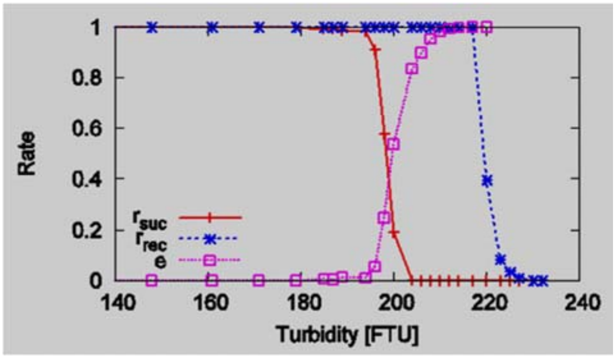
A. Experimental Scenario

We conducted experiments using the environment explained in the previous section. We started from an experiment using tap water without any bath powder. Then, we added bath powder bit by bit to the aquarium. After that, we measured the turbidity using the meter and started frame transmission / reception using visible light communication modules. For each experiment, we measured the communication performance during 60 seconds by using the vendor-provided software explained in Section III-B.

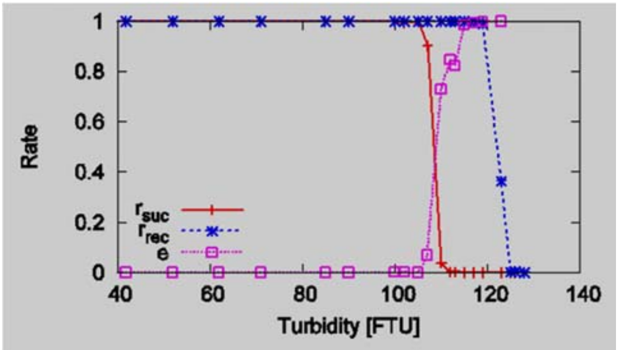
B. Effect of Turbidity on the Communication Performance

Figure 4 shows the rate of frame reception r_{rec}, the rate of successful frame reception r_{suc}, and error rate e against turbidity for each aquarium. As shown in the figure, the rate of successful frame reception is one and the error rate is zero until a certain value of turbidity. We call this threshold of turbidity T_{suc} in this paper. The threshold is varied depending on distance d. In this experiments, T_{suc} is around 56 for d = 40.6 cm, 100 for d = 30.5 cm and 185 for d = 20.3 cm.

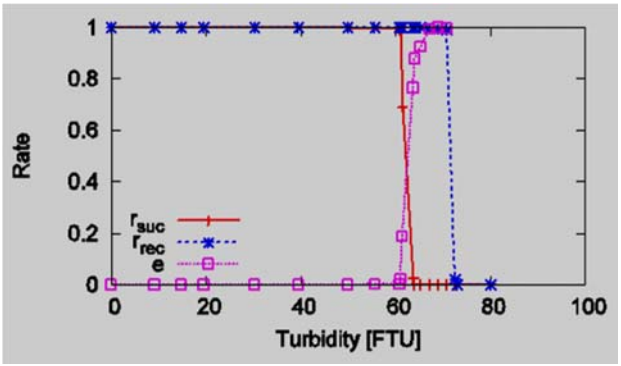
When the turbidity exceeds the threshold T_{suc}, the rate of successful frame reception rapidly down to zero and the error rate gradually up to one. Then, at a certain value of turbidity, the rate of frame reception rapidly down to zero and the error rate reaches to one. We call this threshold of turbidity T_{err} in this paper. The threshold is also varied depending on distance. In this experiments, T_{err} is around 73 for d = 40.6 cm, 128 for d = 30.5 cm and 232 for d = 20.3 cm.



(a) d = 20.3 cm



(b) d = 30.5 cm



(c) d = 40.6 cm

Figure 4. The rate of frame reception, the rate of successful frame reception, and error rate against turbidity

When the turbidity exceeds the threshold T_{err}, the rate of frame reception stays zero, which means that communication between modules is not possible. From these results, we confirm that the turbidity and the distance between modules influence the performance of visible light communication.

Figure 5 summarizes the relationship between communication performance and conditions of turbidity and distance d. If communication performance is good which means that the rate of successful frame reception is mostly one, the turbidity is in the area below the solid red line in the figure. On the other hand, if the rate of successful frame

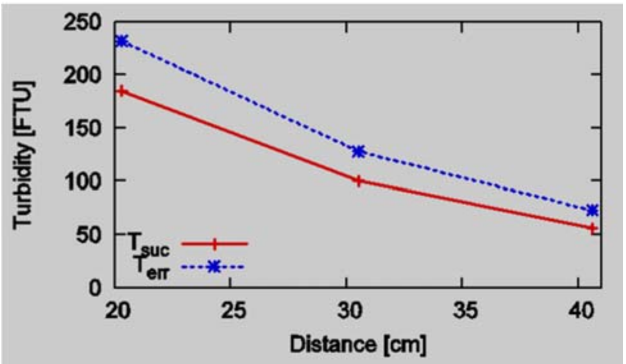


Figure 5. The relationship between communication performance and conditions of turbidity and distance *d*

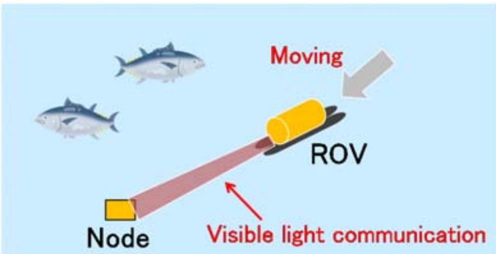


Figure 6. An example of turbidity estimation using a remotely operated vehicle and a sensor node

reception is less than one, however, frames can be received with an error rate, the turbidity is in the area between the solid red line and the dotted blue line. If no frame can be received, the turbidity is in the area above the dotted blue line.

C. Discussion on Turbidity Estimation

Now, we discuss whether the visible light communication module can be used as turbidity meter in underwater fish farm environments or not. Here, we assume that the distance among modules can be obtained by using a localization method and corresponding thresholds T_{err} and T_{suc} in the fish farm are preliminary known. In this case, if we obtain the performance of communication among visible light communication modules, we can roughly estimate the turbidity among the three areas in Fig 5. In addition, if a visible light communication module is attached at a remotely operated vehicle as shown in Fig. 6 and we obtain the performance of communication by changing the distance, we can narrow the range of estimation.

In this paper, we just show the preliminary experimental results and discussion for estimation of turbidity using visible light communication modules in underwater environments. As future work, we plan to conduct additional experiments and develop the method for estimating turbidity using visible light communication.

V. CONCLUSION AND FUTURE WORK

In this paper, through experiments using off-the-shelf modules, we evaluated the effect of turbidity on the performance of visible light communication in an underwater environment. We confirmed that the turbidity and the distance influence the performance of visible light communication.

As future work, we should conduct additional experiments under various environments by changing environmental light, muddy water, water flow velocity, and so on. In addition, we plan to develop a method for estimating the turbidity based on the performance of visible light communication. Furthermore, we plan to evaluate the estimation method under a real fish farm environment.

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REFERENCES

[1] D. Normile, ``Persevering researchers make a splash with farm-bredtuna," Science, vol. 324, pp. 1260–1261, Jun. 2009.

[2] Y. Taniguchi, ``Experimental evaluation of a WiFi device in an undersea environment," in Proceedings of AIMS 2015, Dec. 2015, pp. 408–411.

[3] Y. Taniguchi, ``Evaluation of acoustic data communication for fish farm monitoring," in Proceedings of DNCOCO 2015, Dec. 2015, pp. 195–199.

[4] K. Souma, K. Abe, H. Habe, and N. Iguchi, ``Evaluation of turbidity by image," Proceedings of 20th Student Convention of Kansai Section of IEICE, Mar. 2015, in Japanese.

[5] Z. Pan, C. Glennie, C. Legleiter, and B. Overstreet, ``Estimation of water depths and turbidity from hyperspectral imagery using support vector regression," IEEE Geoscience and Remote Sensing Letters, vol. 12, no. 10, pp. 2165–2169, Oct. 2015.

[6] S. Mylvaganaru and T. Jakobsen, ``Turbidity sensor for underwater applications," in Proceedings of IEEE OCEANS 1998, Sep. 1998, pp. 158–161.

[7] C.-C. Chang, C.-T. Wu, Y.-B. Lin, and M.-H. Gu, ``Water velocimeter and turbidity-meter using visible light communication modules," in Proceedings of IEEE SENSORS 2013, Nov. 2013, pp. 1–4.

[8] Standard of Japan Electronics and Information Technology Industries Association (JEITA), ``CP-1223 visble light beacon system," available at http://www.jeita.or.jp/japanese/standard/book/CP-1223/.

[9] ``VLC Receiver Module Evalution Kit," available at http://sys.ndk-m.com/products/?id=1397822228-338715.

[10] ``VLC Sender Module Evaluation Board," available at http://sys.ndk-m.com/products/?id=1413879271-321200.

[11] ``OPTEX TD-M500," available at http://www.optex.co.jp/env/products/tdm500/.