Journal of Current Science and Technology, May-August 2021 Vol. 11 No. 2, 269-276

ISSN 2630-0656 (Online)

Cite this article: Puntsri, K., Khansalee, E., & Suttisopapan, P. (2021, May). Underwater environment sensors with visible light communication systems. *Journal of Current Science and Technology, 11*(2), 269-276.
DOI: 10.14456/jcst.2021.27

Journal of Current Science and Technology

Journal homepage: https://jcst.rsu.ac.th

Underwater environment sensors with visible light communication systems

Kidsanapong Puntsri[1,] *, Ekkaphol Khansalee[1], and Puripong Suttisopapan[2]

[1]Department of Electronics and Telecommunication Engineering, Faculty of Engineering, Rajamangala University of Technology Isan, Khonkhaen Campus, Khonkhaen 40000, Thailand
[2]Department of Electrical Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen 40000, Thailand

*Corresponding author; E-mail: kidsanapong.pu@rmuti.ac.th

Received 18 January 2021; Revised 16 April 2021; Accepted 2 May 2021;
Published online 27 May 2021

Abstract

This work presents a design and experiment of a new expectation for fresh underwater exploration, where the visible light communication (VLC) is employed as communication systems. The overall system is designed for a simple circuit and low-cost. The transmitter, which is located in the underwater, is responsible for transmitting the temperature and pH sensors information data. The LEDs (Light emitting diode) array with 10W power is used, where only one transistor driver circuit is proposed. The baud rate is 9,600 b/s (baud per second). At the receiver, 4 APDs (Avalanche Photodiodes) are utilized to receive and that converts the light signal to electrical signal. Since the input voltage of ESP8266 requires 5V, the summed 4-APD outputs by using equal gain combining (EGC) is needed. As a result, the amplitude between 3.3 V and 5 V is achieved. In this work, ua741 is used for the amplification IC, while ESP8266 is adopted for data processing and that sends the sensor data value to the internet. Netpie is used to store the data. To verify the system performance, the result was recorded for one hour with the communication distance of 125 cm (1.25 meters). It is shown that the system works very well and improves a lot, when compared with only 1- or 2-APDs receiver. Especially, this work can be used in the industry for replacing the traditional underwater exploration and provide greater safety in exploration in the future.

Keywords: *internet of things*; *light communication*; *realtime monitoring*; *underwater environment*; *visible light communication*.

1. Introduction

In the past, the water resources from the nature, such as rivers and swamps, can be used immediately. However, nowadays, the water is dirty and cannot be directly used anymore. It is contaminated by the wastes from the industries, communities and even their nature itself. Therefore, the water is not fresh any longer. Additionally, the contaminations effect to the water, which the oxygen, temperature and pH would be changed and it is not optimal to the aquatic animal (Kordach, Chardwattananon, Wongin, Chayaput, & Wongpat, 2018). The water exploration is very essential, which is normally tested by human directly. This would be risk of an accident. Therefore, to save the human and also the time, the new technology of water survey with real-time monitoring using internet of things (IoT) would be needed. In this case, real-time alarm would be also possible.

For the underwater communication systems, a high attenuation and low speed in underwater are the issues for radio frequency (RF) communication systems (Saini, Singh, & Sinha, 2017). As a result, the communication speed and capacity are very low, only in kilobits per second (kb/s) can be achieved (about 3 kb/s) (Kaushal & Kaddoum, 2016). Unlike the visible light communication (VLC) systems, it has low attenuation and very huge of bandwidth, which is up to THz. Therefore, VLC would be a candidate to be employed in underwear communication, as shown in (Chen, Zou, Zhang, & Chi, 2020).

VLC is very attractive to investigate for both indoor and underwater communication channel, which are shown in (Lee & Park, 2011; Pathak, Feng, Hu, & Mohapatra, 2015; Puntsri & Suttisopapan, 2019). Light emitting diode (LED) is mostly used to transmit information data, where the lambda is in visible region. Therefore, LED can be lighting the room while transmitting data. Theoretical of underwater communication system using LED has studied, where the line of sight (LoS) is considered, such as (Ali & Khalid Rahi, 2018). The performance is measured by bit error rate (BER). The 32-pulse position modulation (PPM) modulation format was employed. A design circuit of underwater communication system using VLC, where the low power blue-green LEDs was adapted, as presented in (Wen, Cai, & Pan, 2016). The MOSFET drive circuit was used. The result showed that the communication distance of 10 m with the speed of 115.2kbps can be achieved. Additionally, a mathematical model of diversity gain of 2 × 2, 3 × 3 and 4 × 4 VCL–MIMO, where 4 × 4 MIMO has the lowest bit error rate (BER) was proposed. Equal gain combining (EGC) with on-off keying is used in (Yilmaz, Elamassie, & Uysal, 2019). Additionally, the long distance communication was also invested in (Nakamura, Mizukoshi, & Hanawa, 2015; Celik, Saeed, Shihada, Al-Naffouri, & Alouini, 2020). However, only numerical simulation was employed.

2. Objectives

In this work, a prototype of real-time underwater exploration using VLC as a communication system is proposed. The new communication system likes VLC is the main contribution. Additionally, there are many factors to define the water quality. However, the measurement of temperature and pH are used as an example. The modulation format of intensity modulation direct detection (IM/DD) (Chen, Zou, Zhang, & Chi, 2020) with OOK is used. At the transmitter part, only one transistor is used to drive the 10W blue light LED. Please note that the blue light has the lowest attenuation as reported in (Nakamura, Mizukoshi, Hanawa, 2015). The maximum communication speed is 9,600 b/s with 1.25 m long. At the receiver part, four avalanche photodiodes (APDs) are employed to convert the light signal to electrical signal. The signal power is much improved when compared to only one APD. The outputs are fed to the amplifier and ESP8266 in the following. The measurement value is uploaded to the Netpie. As a result, the measurement data can be easily shown on website or smartphone using application. Additionally, this is an extended work form (Puntsri, Yindeemak, & Bubpawan, 2020).

3. Materials and methods

3.1 Transmitter and receiver design methods

The overall system diagram of underwater environment sensors using VLC as a communication system is shown in Figure 1, where the temperature and pH monitoring are used as the examples for testing the communication system. The communication distance is 125 cm, where the light travels from the transmitter to the receiver in the water is 50 cm and the air is 75 cm. Next, the details of the transmitter and receiver circuit design are followed.

At the transmitter part, only one transistor is used to drive the 10W LED. NSS1C201LT1G is employed, where the maximum voltage is 100V and maximum current is 3A. The driver circuit diagram is shown in Figure 2A. The input to the driver is from the Arduino with 5V; there for the $V_I = 5V$ is set. In this case, $I_C = P_{LED}/V_{LED} = 10W/10V = 1A$. Additionally, from the data sheet $\beta = 80$; therefore, $I_B = I_C/\beta \quad (= 1A/80 = 0.0125A)$. Next, R_B and R_C are simple given by (Mahatanakul, 2003)

$$R_B = \frac{V_I - V_{BE}}{I_B} = \frac{5-0.95}{0.0125} = 324\Omega \approx 300\Omega, \quad (1)$$

and

$$R_C = \frac{V_{CC} - V_{LED}}{I_C} = \frac{12-11.5}{1} = 0.5\Omega \approx 1\Omega, \quad (2)$$

respectively. LED SMD ship with blue light with the lambda of 465-460 nm is applied. The Vcc is 11V and the current is 900 mA.

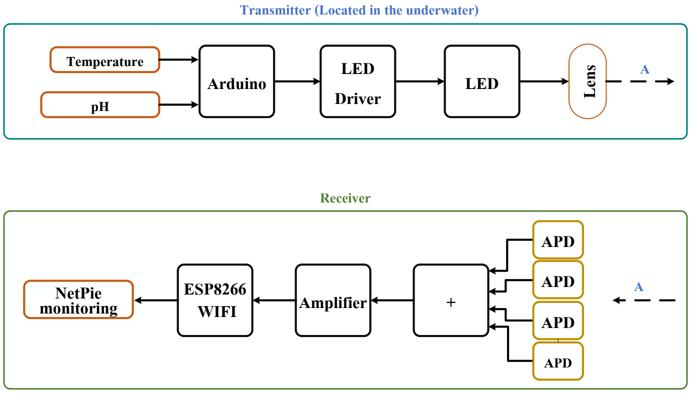

Figure 1 Proposed underwater exploration using VLC.

At the receiver part, the overall circuit is shown in Figure 2B. The incoming light from the transmitter is converted to electrical signal by 4 APDs. As a result, the received power is 4 times in total. Next, the APDs output are fed to the mom-inverting amplifier using741 op-amp. The output of the amplifier should be more than 3.3V to make the ESP8622 works properly. In this work, the amplifier gain is set to be 221, where the $R_1 = 11k\Omega$ and $R_2 = 50\Omega$ are selected. Therefore, the amplifier gain, denoted by A_v, is calculated by

$$A_v = \frac{R_1}{R_2} + 1 = \frac{11\times 10^3}{50} + 1 = 221, \qquad (3)$$

and $R_3 = R_4 = R_5 = R_6 = 100\Omega$, respectively. The received light is explanted by Beer's law (Celik, Saeed, Shihada, Al-Naffouri, & Alouini, 2020), which is given by

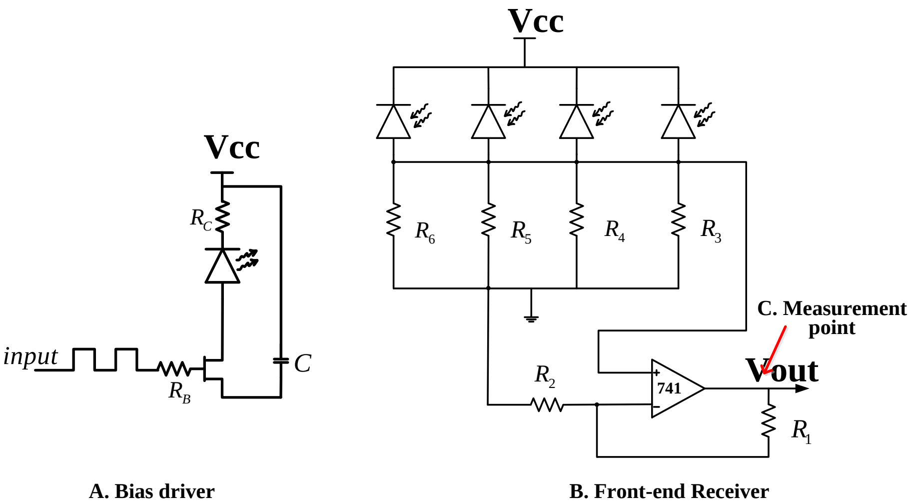

Figure 2 Design circuit: A. Bias diver, B. Front-end Receiver.

$$I = R \cdot I_0 \exp(-e(\lambda) \cdot d), \quad (4)$$

where, I is the revived light intensity, I_0 it the transmitted light intensity and R (A/W) is APD responsibility. The attenuation coefficient is expressed by

$$e(\lambda) = a(\lambda) + b(\lambda), \quad (5)$$

hence, $a(\lambda)$ is absorption coefficient and $b(\lambda)$ is scattering coefficient. d is communication distance. As a result, the received signal, denoted by $y(t)$, is given by

$$y(t) = R \cdot I \cdot x(t) + n(t), \quad (6)$$

where, $x(t)$ is the transmitted signal and $n(t)$ is noise, which is modeled by additive white Gaussian noise (AWGN) with zero mean and the variant is σ_n.

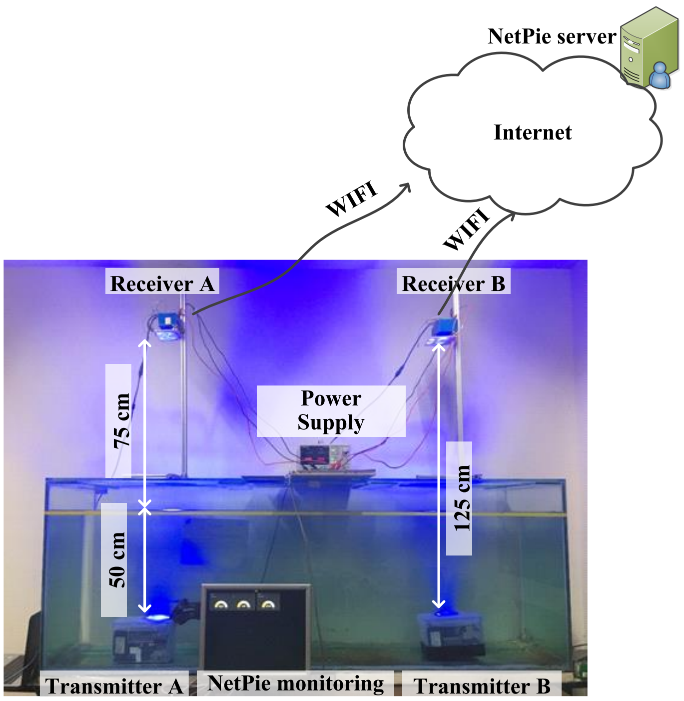

Figure 3 Experimental setup for underwater environment sensors with visible light communication systems.

3.2 Experimental setup

This section details about experimental setup of the proposed underwater exploration using VLC. The setup is shown in Figure 3. The temperature and pH are used as an example. The pH Sensor (PH Sensor E-2-1-C) from e-Gizmo Mechatronix Central, 2017), where the range of measurement is 0 – 14 pH and the accuracy is ± 0.1pH at room temperature (25 degree). The temperature meter from Waterproof DS18B20 Sensor Kit (DFRobot, 2017) is used, and the accuracy is ±0.5 degree with the range of measurement is -55 to 125 degree. At the transmitter part, the Aruino, LED driver circuit, blue light LED, battery and everything are packed in a box and located in underwater. The freshwater in the tank size of 60 × 200 × 120 cm is used. In this work, the communication distance in the underwater is 50 cm and 75 cm in air; as a result, 125 cm in total. The on-off keying modulation format is applied.

At the receiver part, the four APDs from Hamamatsu (Hamamatsu, 2006), with the bandwidth of 10 MHz is used. The outputs of the

APDs are amplified by op-amp 741 and its output is fed into the ESP8266. The ESP8266 sent the measured temperature and pH to Netpie using WIFI. The Netpie stores the information data. As a result, we can retrieve the data to show on the website or application on smartphone any time.

Table 1 The results of voltage bias with the baud rate 9,600 b/s.

Scheme								Unit
LED bias voltage	12	11.5	11	10.5	10	9.5	9	V
LED bias current	1.18	1.02	0.85	0.70	0.56	0.45	0.32	A
sum 4 APDs output	39.30	32.90	27.40	24.83	20.81	15.42	12.69	V (milli)
Amplifier output (at point c in figure 2B)	3.516	2.958	2.560	1.970	1.681	1.435	0.965	V
NetPie showing	yes	yes	yes	no	no	no	no	-
Bit error rate of the system	no	no	no	3.93×10^{-4}	2.00×10^{-3}	3.35×10^{-3}	1.13×10^{-2}	-

4. Results and discussion

In this section, the experimental results of underwater exploration using VLC are described. First, the optimum LED bias voltage is investigated. The voltage bias is varies from 9 V to 12V, where the communication distance is set to be 125 cm. Please note that, the distance can be extended; however our tank is limited. The baud rate is 9,600 b/s. The result is shown in Table I. As can be seen, the optimum bias voltage is 11V and the current is 0.85A. The bias can be increased up to 12V; however, heat inside the box will too much and it will become a problem to the system.

Second, the number of APDs used is considered. For only one APD and the LED bias at 11V, the output voltage of the APD is 16 mV, as shown in Figure 4. However, the signal after amplifier output is not good enough for the ESP8266, both voltage (only 2.8V) and shape, as shown in Figure 5. In this case, the communication is not possible. Therefore, 4 APDs are introduced, the output voltage of the 4 APDs is about 40 mV, and the communication can be improved significantly. The output of the amplifier gives 5 Vp-p, as shown in Figure 6.

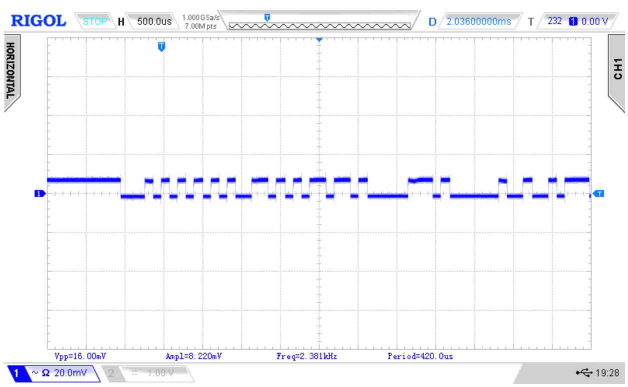

Figure 4 Output signal from only one APD with 11V of the LED bias voltage.

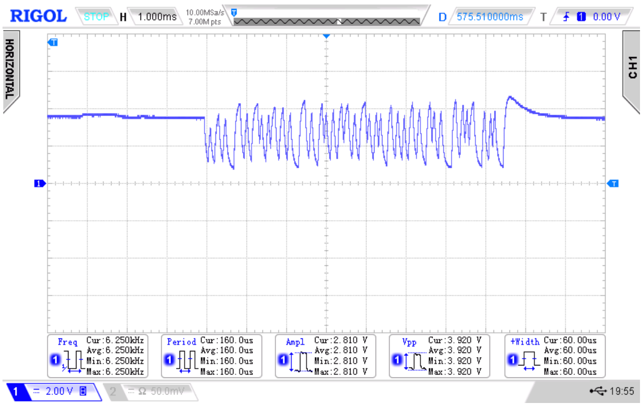

Figure 5 Output signal of the amplifier circuit (at the c point in Figure 2B, but only one APD) with the baud rate of 9,600 b/s.

Please see measurement point A in the Figure 1. Comparing with only one APD, it is much better. Please note that, we have also increased the baud rate for more than 9,600 b/s; but, as we know, the op-amp 741 cannot be handle, the frequency is too much. As a result, in this case, the ESP8266 does not understand the input signal and the information data on the NetPie is totally wrong. The 9,600 b/s is at best for this setup.

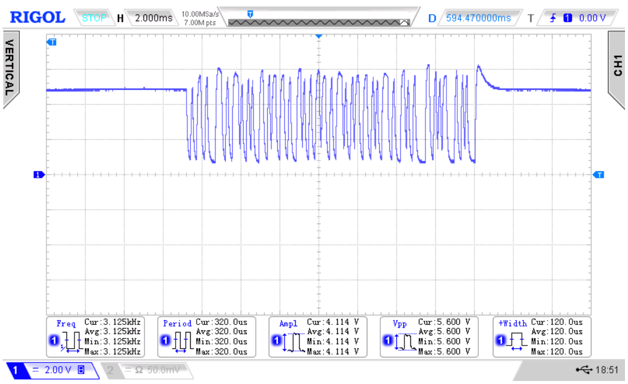

Figure 6 Output signal of the amplifier circuit (at the c point in Figure 2B) when 4 APDs are considered with the baud rate of 9,600 b/s.

For the last investigation, the measurement result of the NetPie, as shown in Figure 6, is shown. There are two measurement points, as can be seen in Figure 2. However, only temperature is shown for the transmitter A. To verify the system work well, we let the system runs in real-time for 1 hour, and the result is shown in Figure 7. Additionally, the bit error rate (BER) should be considered. However, it is already shown that the measurement value can be read in real-time without error, which means that there is no error.

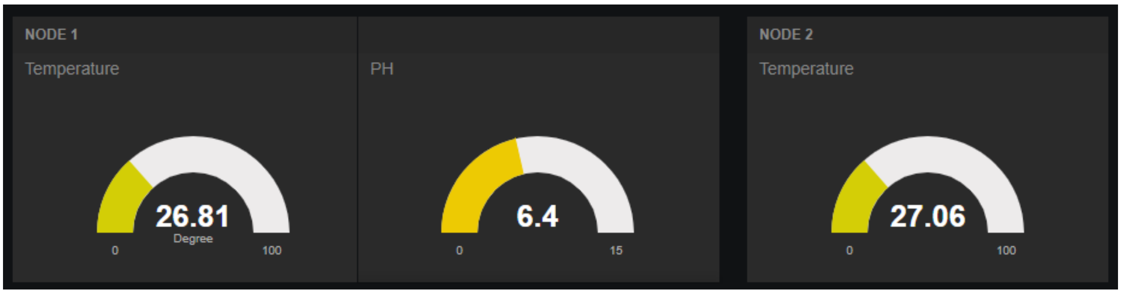

Figure 7 The measurement values is shown by Netpie.

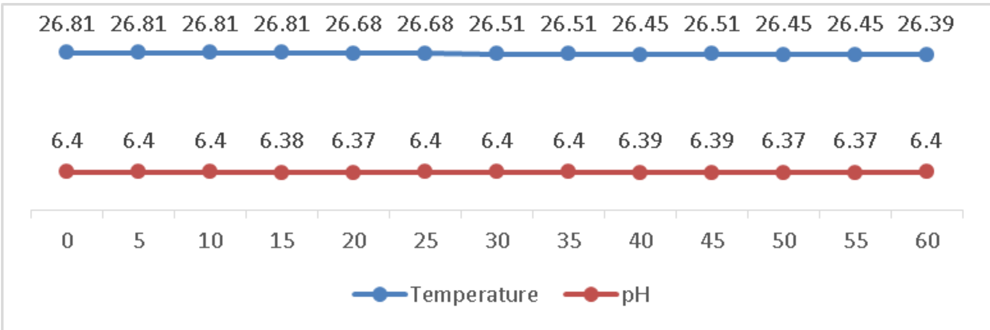

Figure 8 The measurement values is shown in real-time for 1 hour.

5. Conclusion

A prototype of temperature and pH monitoring using VLC as a communication system was proposed. A 10W blue light is employed at the transmitter, while 4 APDs was used at the received part. The communication distance of 125 cm can be achieved with the baud rate of 9,600 b/s. Additionally, we have tried higher than that; however, the 714 op-amp cannot be responsible fast enough. On-off keying is employed. The measured value was uploaded to the Netpie on the internet. As a result, the data can be retrieved and show on the website or smartphone using application any time. Additionally, the prototype was implemented in real-time, which can be applied to any industries. Especially, the human is no need to measure the water directly, and no risk occurs. In the future, the number of speed is considered, and it will be increased.

6. Acknowledgements

The authors would like to thank the anonymous reviewers for their valuable comments and suggestions to improve the quality of the paper. Additionally, this work is funding by Rajamagala University of Technology Isan, Khonkhaen Campus, under the contract on ENG 14/63.

7. References

Ali, M. A. A., & Khalid Rahi, S. (2018). Line of sight (LoS) underwater wireless optical communication based on LED. *9th International Symposium on Telecommunications (IST)*. pp. 270-274. DOI: 10.1109/ISTEL.2018.8660998

Celik, A., Saeed, N., Shihada, B., Al-Naffouri, T. Y., & Alouini, M. (2020). End-to-end performance analysis of underwater optical wireless relaying and routing techniques under location uncertainty. *IEEE Transactions on Wireless Communications, 19*(2), 1167-1181. DOI: 10.1109/TWC.2019.2951416

Chen, M., Zou, P., Zhang, L., & Chi, N. (2020). Demonstration of a 2.34 Gbit/s real-time single silicon-substrate blue LED-based underwater VLC system. *IEEE Photonics Journal*, *12*(1), 1-11. DOI: 10.1109/jphot.2019.2958969

DFRobot. (2017). Waterproof DS18B20 Sensor Kit. Retrieved from: https://media.digikey.com/pdf/Data%20Sheets/DFRobot%20PDFs/KIT0021_Web.pdf

e-Gizmo Mechatronix Central. (2017). PH Sensor E-2-1-C. Retrieved from: https://www.e-gizmo.net/oc/kits%20documents/PH%20Sensor%20E-201-C/PH%20Sensor%20E-201-C.pdf?fbclid=IwAR2QK9gcAg-rt2AVwbM8Acw7phpkNybou0aJa83VqTE0IXh9YxfSfrvUwPE

Hamamatsu. (2006). Cat. No. KPIN1050E01 Aug. 2006 DN. Retrieved from: https://docs.rs-online.com/ec2b/0900766b80d838f0.pdf

Ji, Y., Wu, G., & Wang, S. (2018). Modulation analysis for long distance underwater VLC systems under dead time limit. *IEEE 18th International Conference on Communication Technology (ICCT).* Corpus ID: 57378367, pp. 392-395. DOI: 10.1109/ICCT.2018.8600250 Corpus ID: 57378367

Kaushal, H., & Kaddoum, G. (2016). Underwater optical wireless communication. *IEEE Access*, *4*, 1518-1547. DOI: 10.1109/ACCESS.2016.2552538

Kordach, A., Chardwattananon, C., Wongin, K., Chayaput, B., & Wongpat, N. (2018). Evaluation on the quality of Bangkok tap water with other drinking purpose water. *In E3S Web of Conferences*, *30,* 01011 (2018). *Water, Wastewater and Energy in Smart Cities.* pp. 1-9. DOI: 10.1051/e3sconf/20183001011

Lee, K., & Park, H. (2011). Modulations for visible light communications with dimming control. *IEEE Photonics Technology Letters,* 23(16), 1136-1138. DOI: 10.1109/LPT.2011.2157676

Mahatanakul, J. (2003). *Electronics*. Bangkok, Thailand: Top Publishing (http://www.toptextbook.com/).

Nakamura, K., Mizukoshi, I., & Hanawa, M. (2015). Optical wireless transmission of 405 nm, 1.45 Gbit/s optical IM/DD-OFDM signals through a 4.8 m underwater channel. *Optics Express, 23*(2), 1558-1566. DOI: 10.1364/OE.23.001558

Pathak, P. H. Feng, X. Hu, P. Mohapatra, P. (2015). Visible light communication, networking, and sensing: A survey, potential and challenges. *IEEE Communications Surveys & Tutorials*, *17*(4), 2047-2077.

Puntsri, K., & Suttisopapan, P. (2019). High spectrum efficiency of MIMO-SC-FDMA for optical wireless communication systems. *RMUTI JOURNAL Science and Technology, 12*(3), 1-12.

Puntsri, K., Yindeemak, A., & Bubpawan, T. (2020). pH and temperature underwater monitoring with application using visible light communications. *Proc. SPIE 11331, Fourth International Conference on Photonics Solutions (ICPS2019), 113310B (11 March 2020).* DOI: https://doi.org/10.1117/12.2552971

Saini, P., Singh, R. P., & Sinha, A. (2017). Path loss analysis of RF waves for underwater wireless sensor networks. *International Conference on Computing and Communication Technologies for Smart Nation (IC3TSN).* Corpus ID: 46857725, pp. 104-108. DOI: 10.1109/IC3TSN.2017.8284460

Wen, D., Cai, W., & Pan, Y. (2016). Design of underwater optical communication system. *OCEANS 2016 – Shanghai*. Corpus ID: 5771161. pp. 1-4. DOI: 10.1109/OCEANSAP.2016.7485659

Yilmaz, A., Elamassie, M., & Uysal, M. (2019). Diversity Gain Analysis of Underwater Vertical MIMO VLC Links in the Presence of Turbulence. *IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom).* pp. 1-6. DOI: 10.1109/BlackSeaCom.2019.8812823