SUGISAKA MASANORI

Journal of Robotics, Networking and Artificial Life
Vol. 10(1); June (2023), pp. 84–90
ISSN (Online): 2352-6386; ISSN (Print): 2405-9021
https://alife-robotics.org/jrnal.html

Research Article

Experimental Study of Underwater RF Communication for Live Video Transmission for AUVs Application

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ARTICLE INFO

Article History

Received 05 December 2022
Accepted 14 September 2023

Keywords

AUV
Rf communication
Network
Frame rate
Underwater video streaming

ABSTRACT

Autonomous Underwater Vehicles (AUVs) require long-distance communication, especially in the deep sea. Acoustics communication and wireless optical communication have limitations of low latency and water conditions effects respectively. Radiofrequency (RF) communication provides a high data rate with free orientation of the transmitter/receiver antennas. However, electromagnetic waves are highly restricted by high attenuation over short distances in the underwater medium. In this study, we investigated the RF communication in a tank full of seawater. A loop antenna and rectangular antenna were used for the base station and AUV respectively. The experiments were conducted to measure the transmission rate with different distances between the base station and the AUV using both User Datagram Protocol (UDP) and Transmission Control Protocol (TCP). Live video streaming with framerate analysis was considered. The results show the effect of the distance between the transmitter and receiver on the transmission rate, in addition, to the antenna's stability has huge effects on the connection stability. We successfully achieved a High-Definition (HD) video streaming with 25fps for over 1 meter.

1. Introduction

Over 70% of the earth's surface is covered by water [1]. and most of these area are not discovered yet. Due to the harsh environment, developing Underwater Autonomous Vehicles (AUVs) is an essential issue. AUVs play a very important role in many applications such as oceanography, marine biology, and underwater exploration [2].

Communication issue is considered the most significant challenge and difficulty that faces researchers in this field [3]. The unique characteristic of the underwater environment raises the difficulty of designing the communication systems. In underwater, three communication technologies could be used:

(i) Acoustics communication: This is the most commonly employed method for underwater communication. We can reach a long-range propagation up to several tens of kilometers using acoustic communication. However, the transmission baud rate is very low which can be several kilobits per second (kbps) [4], this can be considered as the most disadvantage of acoustic communication.

(ii) Wireless optical communication: This technology can provide a data rate of hundreds of Megabits per second (Mbps). Wireless optical is considered the most effective technology for a high data rate. However, the difficulty in achieving the Line of Sight (LOS) which needs aligning both transmitter and receiver, and the huge effect of the water turbidity on the light scattering are the main drawbacks of this technology [5].

(iii) Radio Frequency (RF) communication: RF communication provides a high data rate in a few Mbps [6], with free orientation of the transmitter/receiver antennas. This degree of freedom

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can allow the AUV to hover freely in the water. However, the electromagnetic waves are very restricted by the high attenuation over a short distance.

In this study, we investigate the transmission rate of RF communication in salty water, and analyze the underwater video live streaming over wireless UDP.

The rest of this article is organized as follows: the experiment setup and design are described in Section 2. Section 3 provides the results and discussion. The conclusion is given in section 4.

2. Experiment Setup and Design

2.1. *Experimental setup*

In these experiments, a regular octagonal-shaped stationary antenna with a diameter of 2m was used. A rectangular antenna of 0.8 m by 0.5 m is attached to the bottom of the AUV. All experiments were conducted in a tank with a size (length of 5m, width of 5m, and depth of 4.8m).

This tank was full of seawater to experiment with the same salinity as a real sea environment. The stationary antenna was fixed in the center of the tank using additional weights and ropes. Figure 1 illustrates the concept of the experiment design.

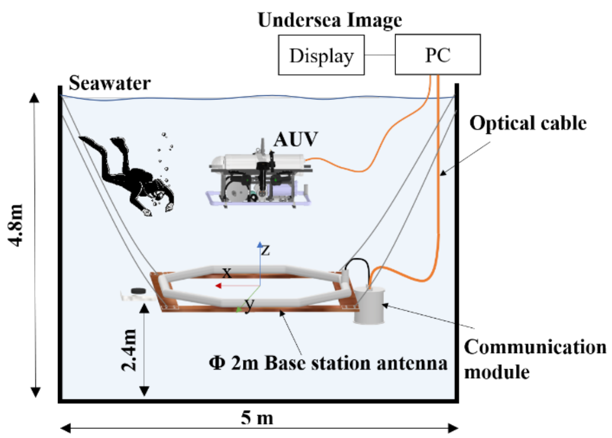

Fig. 1. Experimental design concept. The tank is filled with salty water, and the base antenna is an octagon shape with a size of 2m and floating. The AUV antenna is attached to the bottom of the AUV and the shape is a rectangle of the same size as the AUV. Both antennas are connected by fiber optic cables to isolate the AUV and the host computer. The underwater images are transmitted from the AUV antenna to the base station antenna and measured in the host computer. As the reference, the images are directly transmitted to the host computer by fiber optic cable.

The transmission speed was measured in several AUV positions in the water tank with different distances vertically and horizontally between the AUV and the base antenna considering the origin point is the center of the base antenna.

The AUV used in these experiments is called Darya Bird. It was developed by several researchers and graduate students at Kyushu Institute of Technology [7]. The Robot consists of several high-pressure resistance hulls. This AUV is designed to operate in shallow water within a depth of 50 m. Figure 2 illustrates the AUV used in this study.

As shown in the Figure 6 thrusters are attached to the robot, 2 thrusters for controlling the heave, and 4 thrusters to control the surge and sway moving.

We added the communication module and the antenna to the main AUV. Table 1 illustrates the technical specifications of the AUV.

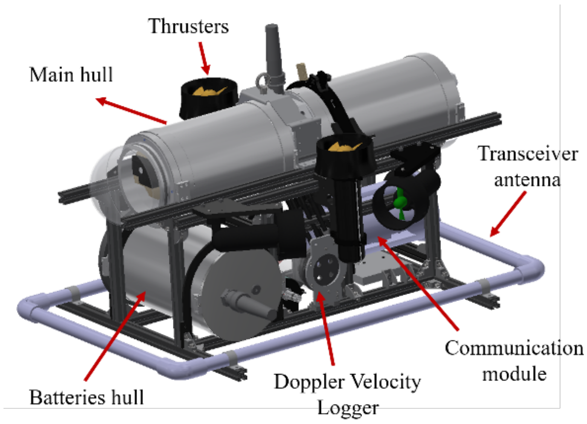

Fig. 2. The AUV used in the experiment (Darya Bird). The robot is 0.83 m long and 30kg weights.

Table 1. The technical specifications of the AUV (Darya Bird)

Attribute	Value
Structure	4 x Aluminum Pressure Hull Aluminum T-slotted Frame
Dimensions (mm)	558 × 548 × 830 (H×W×L)
Thrusters	4 × SeaBotix Thruster BTD150 2 × RoboPlus Hibikino Thruster
Controller Board	PC (Intel core i7)
Sensors	Network IP Camera (Front) Bar30 Depth sensor Cerulean Sonar DVL-75
Batteries	1 × LifoPo4 14Ah 2 × LifoPO4 9Ah

IP network camera used for video capturing with a resolution of 1028 × 720 and framerate of 25 fps. To minimize the number of cables, a Power over Ethernet (PoE) ejector and splitter were used to provide a 12 V PoE for the communication model and the camera. The camera, communication module, and all other devices are connected to the robot's PC by a Local Area Network (LAN) hub. A wired optical connection was used in both terminals (The AUV and the base antenna), for the AUV, the wired optical was important to capture the same streaming video for reference comparison.

The layout connection is shown in Figure 3.

The Wavelet OFDM System is used in this experiment. The standard frequencies used are 2 to 28 Mhz. However, because the underwater characteristic is frequency-dependent attenuation, a band compress function is used [8]. Two modes were used in this study, 1/16 mode and 1/32 mode which compress the standard frequencies. Table 2 shows the symbol length, start frequency, and end frequency for the two different used modes.

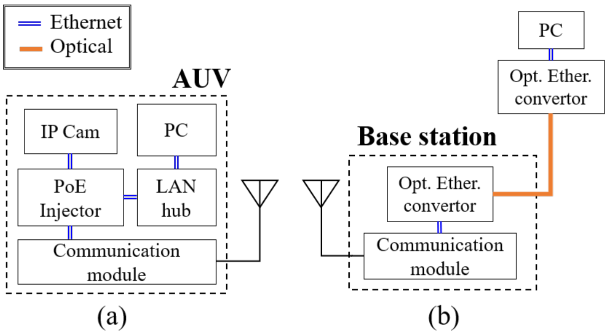

Fig. 3. The connection layout: (a) the connection inside the AUV, (b) the connection between the host computer and the base station antenna. The obtained images in the IP camera are transmitted to the communication module in (a) and encoded with a wavelet OFDM system, then decoded in (b).

Table 2. Wavelet OFDM parameter.

Mode	1/16	1/32
Symbol length	131.072 μs	262.144 μs
Start frequency	125 kHz	62.5 kHz
Stop frequency	1.75 MHz	0.87 MHz

2.2. *Experiment design*

The transmission rates were measured in several placements of the AUV. The origin of the coordinate is in the center of the base station antenna, the x-axis is in the horizontal plane and the z-axis is in the gravity direction.

We used a crane to fix the AUV in a very stable position in the water. All devices inside the AUV were turned on to get its noise on the signal.

The crane was supported with a scale to precise the exact position of the AUV.

First, align the center of the AUV antenna and stationary antenna to the center of the tank.

Second, moving the AUV along the positive direction of the z-axis.

Third, moving horizontally on the x-axis, we repeat the translation along the z-axis. These steps were applied to measure 8 different positions of the AUV.

3. Results and Discussion

The results of this study are divided into two sections:

3.1. *Transmission rate*

Tables 3 and 4 illustrate the transmission rate of UDP and TCP for both 1/16 mode and 1/32 mode of the wavelet OFDM system respectively.

For the 8 positions of the AUV, we found that the transmission rate is higher when x=z=0, and goes lower when the AUV is moving along the positive direction of the z-axis

Table 3. The transmission rate of UDP and TCP in 1/16 mode. The origin is in the center of the base station antenna. The x-axis is in the vertical plane and the z-axis is in the gravity direction.

x [m]	z [m]	UDP [Mbps]	TCP [Mbps]
0	0	6.8	4.7
0	1	4.8	3.3
0	1.65	0	0
1	0	6.8	4.5
1	1	0.4	1.7
1	1.2	0	0
2	0	6.5	4.6
2	1	0	0

Table 4. The transmission rate of UDP and TCP in 1/32 mode.

x [m]	z [m]	UDP [Mbps]	TCP [Mbps]
0	0	2.7	2.4
0	1	2.3	2
0	1.1	2.9	1.7
1	0	3.3	2.4
1	0.6	2.6	1.9
2	0	3.3	1.9
2	0.8	0	0

In 1/16 mode, the maximum transmission rate was 6.8 Mbps for UDP at the center (x=z=0). While the maximum rate was 4.7 Mbps for TCP.
In 1/32 mode the maximum transmission rate was 2.7 Mbps for UDP at the position (x=z=0). While it was 2.4 Mbps for TCP. Figures 4 and 5 illustrate the graphical representation of the transmission rate shown in Tables 3 and 4 respectively.
The transmission rate was drastically decreased when the AUV was moving far from the base antenna along the z-axis Furthermore, in the case of 1/16 mode, we achieved a long distance between the two antennas compared with the 1/32 mode.

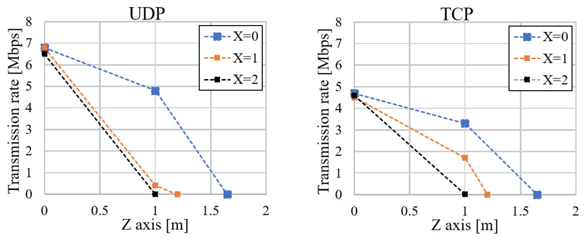

Fig. 4. The transmission rate of UDP and TCP in 1/16 mode.

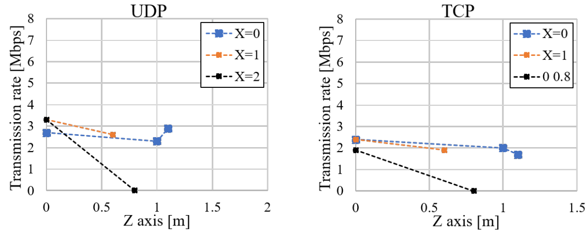

Fig. 5. The transmission rate of UDP and TCP in 1/32 mode.

3.2. *Video streaming framerate*

For live video streaming, three scenarios were considered:

3.2.1. Case 1: The AUV is placed in x=0m, and z=0.5m

When the AUV is placed in the x=0m and z=0.5m, the live video streaming was obtained in both links, the wireless over UDP and the wired optical. While the video was captured, a diver jumped into the water and dived in front of the AUV camera. The frame rates of the two captured videos from different links were compared.
Figure 6 illustrates the framerate of the received videos when z=0.5m.
In the figure, it is noticed a drastic decrease in the framerate when the diver jumped into the water. The framerate at the time of jumping was 25 fps on average and decreased to 0 fps for the next 15 sec. Then the framerate was stable for the rest of this scenario.

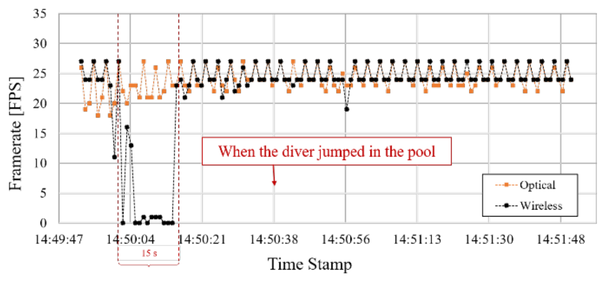

Fig. 6. The framerate of the received videos when z=0.5m. Case 1. When the diver jumped in the tank, the base station antenna swayed and the video framerate decreased.

3.2.2. Case 2: The AUV is placed in x=0m, and z=1m

In this scenario, the AUV was placed in x=0 m and z=1 m from the center of the base antenna. As same as the first scenario, the diver jumped into the water and kept swimming in front of the AUV camera. Figure 7 illustrates the framerate of the received video when z=1m. When the diver jumped into the water, the framerate

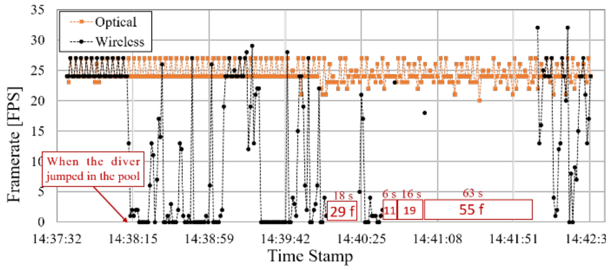

Fig. 7. The framerate of the received videos when z=1m.

decreased excessively to 0 fps. However, in contrast with case 1, for the rest of the video time, we received a bad and unstable frame rate. A very bad connection was noticed; 29 frames within 18 seconds and only 85 frames within 85 seconds. Figure 8 shows snapshots from the received videos from the second scenario when the AUV was placed at a 1-meter distance from the base antenna. Randomly obtained frames from both videos (wireless and wired optical) were compared.

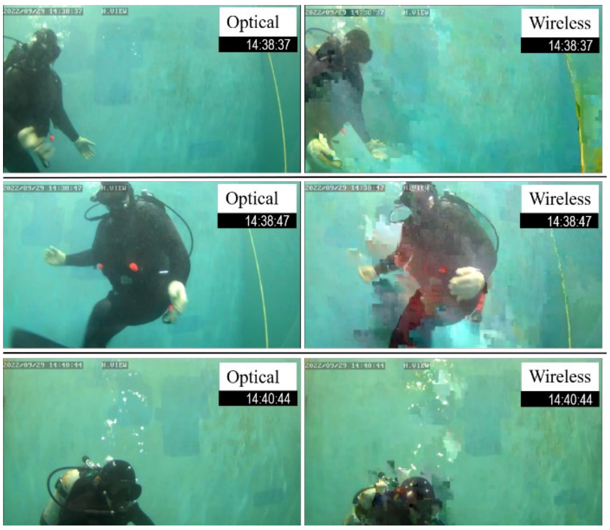

Fig. 8. Snapshots from the received videos when z=1m. (Same frames at the same timestamps).

We noticed that the snapshots with the same timestamp provided the same frame (the diver's position and his gesture were the same). When the quality of the received video was bad, the overlapped frames were received. However, two snapshots showed different timestamps for the same frame as shown in Figure 9.

Fig. 9. Snapshots from the received videos when z=1m, (Mismatch timestamp when the same frames).

The reasons for these obtained results can be attributed to two points:

(i) The instability of the antenna: When the diver jumped into the water, the base antenna and the AUV swayed and got some vibration. In case 1, when (z=0.5), the vibration time was about 15 seconds, while in case 2, the slight swaying and vibration of the base antenna had more effect since the distance between the two antennas was longer than in the first case. That made the bad connection continue longer for all video time. On the other hand, the diver hit the ropes which fixed the base antenna. this caused more vibration of the base antenna and affected the received signal.

(ii) The bubbles: When the diver jumped into the water, a huge amount of bubbles were generated. These bubbles added additional attenuation to the main attenuation.

3.2.3. Case 3: The AUV is moving up and down the base antenna

In this scenario, the AUV was hovering in the tank, it started from up, crossed the antenna, and hovered down. The hovering speed was 0.02 meters per second on average. Figure 10 illustrates the framerate of the received video over the wireless link.
We can notice the sudden loss of the signal without any bad signal. The reason is the coverage area of the base antenna, and the AUV movement did not make any vibration to the antenna. The wireless signal was lost at 0.94 m as a depth difference between the two antennas as shown in Figure 11.

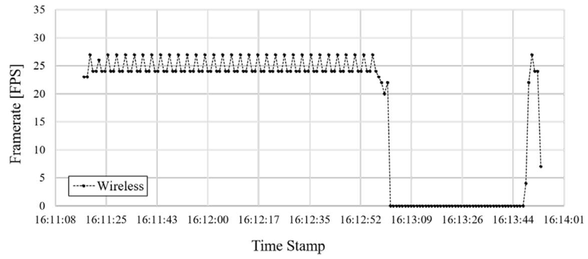

Fig. 10. The framerate of the received videos over wireless UDP when the AUV is hovering in the water tank.

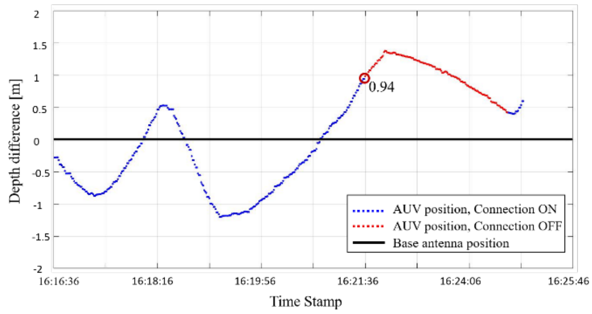

Fig. 11. The depth difference position of the AUV and the base antenna. The blue dots refer the the depth position when we can communicate with the AUV, the red dots refer to the AUV's depth when we could not be able to revive the wireless signal. The black line refers to the base antenna depth.

Compared to the results obtained in Figures 4 and 5 when the AUV is under the base antenna, we could not reach a long distance of communication. Due to the disturbance of the AUV body on the signal.

4. Conclusion

This article presented an experimental study of underwater transmission rate and video streaming using Radio frequency communication for AUVs applications. All experiments were conducted in a tank full of seawater to experiment with the salinity of the real environment. Loop antennas were used, diameter of 2 m for the base antenna and a rectangular-shaped one attached to the bottom of the AUV. We achieved a transmission rate of 4.8 Mbps for UDP and 3.3 Mbps within 1 meter. Furthermore, we successfully achieved HD video streaming with an average of 25fps over a 1 m distance. The results showed the huge effect of antenna stabilization on the signal. Furthermore, the disturbance of the AUV body when it is in between the transmitter and receiver antennas shorted the communication distance. Further experiments are necessary to confirm the bubbles effect. Furthermore, the multipath signals which reflected from the tank wall have effects on the received signal, therefore, confirming the maximum distance to obtain stable streaming in a real environment is necessary.

Acknowledgments

This study was part of commissioned research (No.02301) "Beyond 5G R&D promotion project" by the National Institute of Information and Communications Technology (NICT), Japan.
We acknowledge all who supported us during the experiencements.

References

1. Baker, Beth & Aldridge, Caleb & Omer, Austin. (2016). Water: Availability and use. Mississippi State University Extension. 2016. p3011.
2. Chen P, Li Y, Su Y, Chen X, Jiang Y. Review of AUV Underwater Terrain Matching Navigation. J Navig. 2015;68(6):1155-1172.
3. Heidemann J, Stojanovic M, Zorzi M. Underwater sensor networks: Applications, advances and challenges. *Philos Trans R Soc A Math Phys Eng Sci*. 2012;370(1958):158-175. doi:10.1098/rsta.2011.0214
4. Jiang W, Yang X, Tong F, Yang Y, Zhou T. A Low-Complexity Underwater Acoustic Coherent Communication System for Small AUV. *Remote Sens*. 2022;14(14):1-15. doi:10.3390/rs14143405
5. Al-Zhrani S, Bedaiwi NM, El-Ramli IF, et al. Underwater Optical Communications: A Brief Overview and Recent Developments. *Eng Sci*. 2021;16:146-186. doi:10.30919/es8d574
6. Ali MF, Jayakody DNK, Chursin YA, Affes S, Dmitry S. *Recent Advances and Future Directions on Underwater Wireless Communications*. Vol 27. Springer Netherlands; 2020. doi:10.1007/s11831-019-09354-8
7. Tanaka Y, Alhamad R, Fujinaga T, et al. Multi Robot Strategy and Software Development of Robots for Underwater Survey. *Robonation's Annu 21th RoboSub Compet J*. Published online 2018:1-5.
8. Hasaba, Ryosuke, et al. "Experimental Study of Wavelet-OFDM Radio Communication System for AUVs Under Seawater." 2023 17th European Conference on Antennas and Propagation (EuCAP). IEEE, 2023.

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