Characterization of Underwater Optical Data Transmission Parameters under Varying Conditions of Turbidity and Water Movement

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Abstract— **Optical communication is one of the primary sought alternative techniques used in underwater transmission, as it is utilized in many applications such as military, seismic and oceanographic activities. Although there are already existing technologies in underwater communication, it still has a lot of concern regarding its parameters and improvement in every aspect possible. Currently, Underwater Optical Communication (UWOC) is one of the principal interests for underwater related studies, but these researches mainly focus on transmission of signal on still and clear water. Hence, this study aimed to characterize multiple different parameters, such as luminous flux, and bit error rate, which are important in analysing optical data transmission at varying levels of turbidity and under the condition of controlled water movement by using a River flow simulator/ Hydro-kinetic Turbine Testing Platform (RS/HTTP). High bit error rate (BER) and minimal luminous efficiency are the general effects of increasing turbidity, distance and speed of water movement.**

Keywords – Underwater communication, optical communication underwater, Effects of Turbidity and Movement

I. Introduction

Wireless communications should be fast, safe, reliable and error-free. As time passes by, a new era of communication takes place [1]. One of the emerging branches of communications is underwater communications. Underwater communications are being utilized to explore the activity of the ocean, especially how they respond during any seismic activity, like tsunamis, seaquakes, and earthquakes, for disaster prevention [2]. Several research works regarding underwater communication has already been done, but studies are still being done to improve and characterize every aspect possible [3].

Three methods prevalent in underwater communications are acoustic, optical and electromagnetic. Although acoustic means is advantageous compared to electromagnetic means in terms of range, it has limited bandwidth and high latency [4]. This specified problem is solved by the optical transmission method because of its higher bandwidth and lower latency. Underwater Optical Communication (UWOC) systems; or Visible Light Communication (VLC) networks utilized underwater are also known for their high data rate [5].

Current researches being undertaken mostly focus on optical communications transmission on still and clear water, despite the fact that the general objective of underwater communications research is to implement these in big bodies of water, where its water is not still and clear [2]. Parameters of data transmission are still needed to be further characterized under turbid and moving conditions of the test water [6].

In this paper, several parameters are considered such as bit error rate and luminous efficiency/lux. Bit error rate is considered as an important factor for data integrity. A low bit error rate means good data integrity [7]. Luminous efficiency, on the other hand measures the total radiant power of a specific transmitting device (e.g. LED). The received power is relevant to show if the amount of light/power received is still prevalent in different conditions [8].

As a reiteration, various underwater optical communications researches are already conducted considering distinct relevant parameters such as attenuation coefficients, bit error rate, signal-to-noise ratio, and others. A condition such as turbidity has been also considered. Tests were also usually done in still and clear water. However, no in-depth study of characterizing optical data transmission underwater has been conducted in moving and turbid waters with different levels of turbidity.

Overall, the proposed study aims to be a stepping stone to future studies, such as making an adaptive optical communication system which can adjust to varying levels of turbidity and unstable water movement.

II. Material Selection and General Setup

The characterization of parameters was accomplished employing the main setup: River Flow Simulator/Hydrokinetic Turbine Testing Platform (RS/HTTP) as shown in Figure 1. The dimension of the simulator is referenced to previous testing tanks from standard papers. The behavior of the machine exhibits a real-life river flow [9].

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The depth used in testing was 0.25 m above the higher ground. The volume of water utilized was calculated to be 0.4549 m^3. The total volume of the tank is 0.8389 m^3.

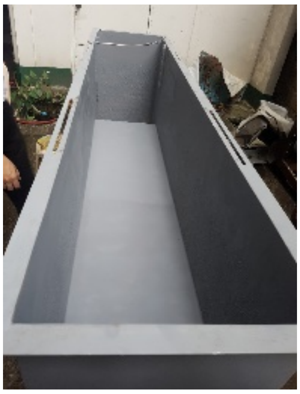

Fig. 1 River Flow Simulator

Figure 2 shows the general setup used in the study. The transmitter and receiver were placed inside waterproof transparent containers, which were positioned on top of a 2m base. The base was to stabilize the positions of the components especially when there is water flow/current. The transmitter and receiver were placed as close as possible to the façade of their respective container to minimize the dispersion of light.

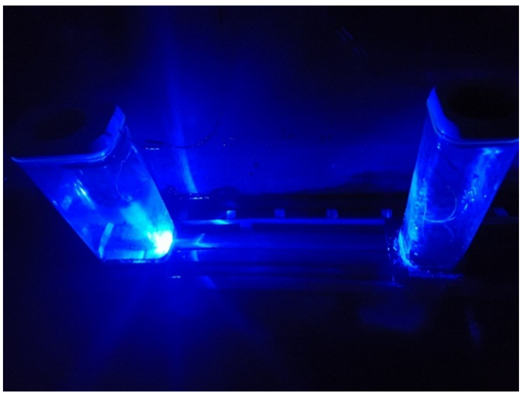

Fig. 2 General Setup: Transmitter (Left) and Receiver (Right)

High powered blue LED was utilized in this study as the transmitter; a photodiode, as the receiver. Both the LED and the photodiode were connected to different Arduino UNO microcontrollers; these devices controlled the data transmitted, and interpreted the received data. The data transmitted is in ASCII form.

III. Varying Water Movement and Turbidity Level

The motor used for this study is a Honda GX390 13 hp motor. The rotating speed of the motor was varied by rotating the throttle lever clockwise and counter-clockwise to increase and decrease the speed respectively. The throttle lever is connected to the throttle valve, which limits the amount of gas-air mixture that enters the engine.

To measure the turbidity for each set up, a turbidity meter was used. The turbidity meter digitally measured the turbidity of the samples in Nephelometric Turbidity Unit (NTU) [10]. Each turbidity level is an addition of quarter of a medicine cup with ten milliliter mark of ferric oxide. Three trials were made as to observe the range of the turbidity level for each setup.

TABLE I. Character Received Rate in Still Water

Set up	Trial 1	Trial 2	Trial 3
Clear Water	0 NTU	0 NTU	1.07 NTU
Turbid Water Level 1	34.96 NTU	35.74 NTU	34.57 NTU
Turbid Water Level 2	56 NTU	55 NTU	51 NTU
Turbid Water Level 3	120 NTU	121 NTU	120 NTU
Turbid Water Level 4	238 NTU	232 NTU	229 NTU
Turbid Water Level 5	301 NTU	297 NTU	290 NTU

As a summary, the study was conducted in both air and underwater. For each underwater configuration, there are 5 turbidity levels excluding clear water, 2 speed levels excluding still and 32 distances (from 0.5 cm to 165 cm with an increment of 0.5 cm).

IV. Quantifying Luminous Efficiency and Bit Error Rate

The formula in (1) computes for the luminous efficiency of the LED. Where η is the luminous efficiency of the LED, ϕ is the luminous flux measured using a photometer and P is the power of the LED. Hence, it is emitted flux (lumens) divided by the power (watts).

$$\eta = \frac{\phi}{P} \tag{1}$$

ϕ, luminous flux is computed using (2); wherein, lux is denoted by lx; while the area covered by the light is A.

$$\phi = lx * A \tag{2}$$

The lux was directly measured using a photometer; the area is approximately the circular surface that is struck by light on the photometer. The area of the light sensor of the photometer was computed to be 0.1256637 m^2.

In determining Bit-Error Rate, it is the calculation of erroneously detected bits ($Nerr$) over the total received bits ($Ntotal$).

$$BER = \frac{Nerr}{Ntotal} \quad (3)$$

In the experiment proper, the BER is attained by using the XOR function in MATLAB. Apparently, the input data is "XORed" with the output data.

In order to further give information about the integrity of data, character receive/success rate is also computed. It is the measure of the successful characters received by the detector.

From the data gathered, focusing on the bits, the error could be classified as single, multiple or burst error for each test.

V. LUMINOUS EFFICIENCY

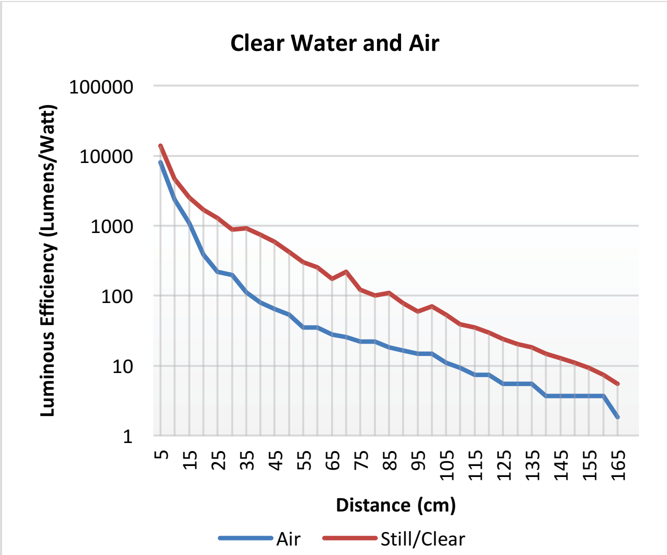

Fig. 3 Comparison between Air and Clear/Still Water Transmission

Figure 3 shows that the luminous efficiency for still and clear water transmission yielded higher values than the air transmission. Hence, the clear and still water condition is decided to be the basis for luminous efficiency.

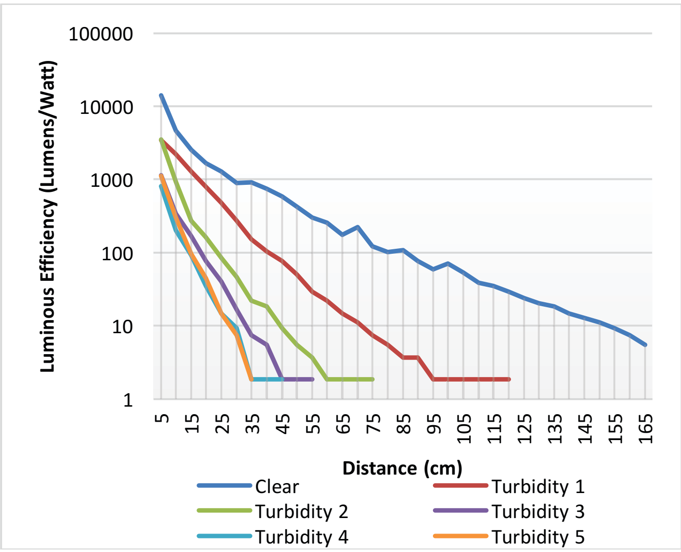

Fig. 4 Luminous Efficiency at Various Turbidity Levels on Still Condition

Figure 4 displays tests done at still condition. The various lines represent turbidity levels. This graph is to show the trend of luminous efficiency at a certain movement/speed of water; in this case, still. A sudden addition of turbidity led to an abrupt and significant decrease in the luminous efficiency. For high levels of turbidity; as observed in turbidity levels 3, 4, and 5. The decrease becomes smaller in value.

Increasing the speed of the simulator yields to same interpretations as in figure 4, with minimal discrepancies. The effects are implied to be negligible as the trend of values is very similar. Figure 5 shows the graph for luminous efficiency on Speed 2 condition.

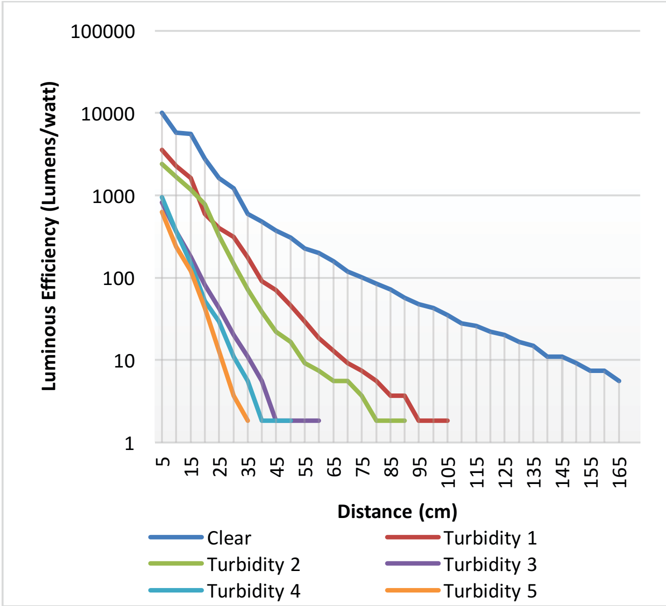

Fig. 5 Luminous Efficiency at Various Turbidity Levels on Speed 2 Condition

Clear water transmission is better in light efficiency compared to air transmission. In general, the still and speed 2 environments display the highest luminous efficiency; while speed 1 shows a decreased amount in initial luminous efficiency (at 5 cm). Luminous efficiency reaches a value of 0 lm/W at almost same distances (differences of only 5 to 10 cm) at different speeds. It is also observed that increasing turbidity has a great change/decrease in luminous efficiency. An initial addition of turbidity exhibits a large decrease in efficiency while at turbidity levels 3 to 5 exhibits a lower decrease value.

VI. BIT ERROR RATE

Bit Error Rate (BER) of the data transmitted in air medium was first obtained. The BER at shorter distances exhibit the same BER as that of the BER at 105 cm, 0.00% BER or in other words, perfect transmission is obtained. The BER beyond 105 cm shows a nearly proportional increase in BER as distance increases up to 130 cm. Beyond 130 cm, the BER remains relatively constant. When the transmitter and receiver was submerged in clear water, BER exhibits a closely proportional increase with respect to distance. The maximum

BER at still water is 30.71%. At varying speed, the BER displayed by the setup increases and becomes more erratic. Maximum BER of 40.00% and 40.71% for speeds 1 and 2 are measured respectively. The cause of the erratic behavior of the setup is due to the motion of the water. Even through the use of a river flow simulator, the water flow created is not entirely uniform, as it is supposed to simulate real life river flow.

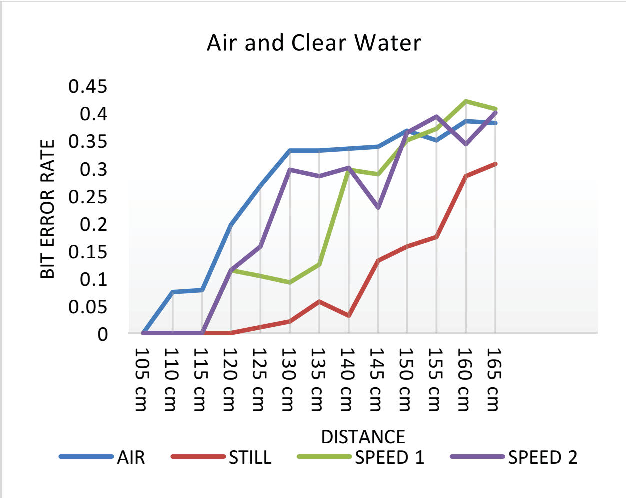

Fig. 6 Bit Error Rate on Air and Clear Water

Figure 7 presents data when a turbidity of approximately 34.96 NTU (Turbidity Level 1) is present in the water. Still water is consistent at a proportional increase in BER referenced to distance. Its maximum obtained BER is 37.14%. The maximum BER at speed level 1 is 36.07% and speed level 2 is 40.36%.

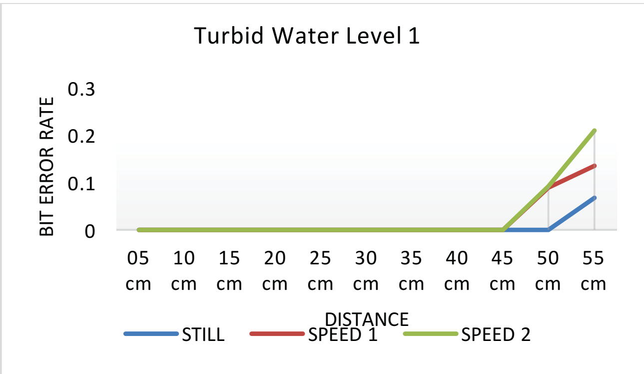

Fig. 7 Bit Error Rate Turbid Water Level 1

Figure 8 shows data when data is transmitted underwater with a turbidity of approximately 56 NTU (Turbidity Level 2). The data show a curved graph leading to relatively the same BER, approximately 40% BER.

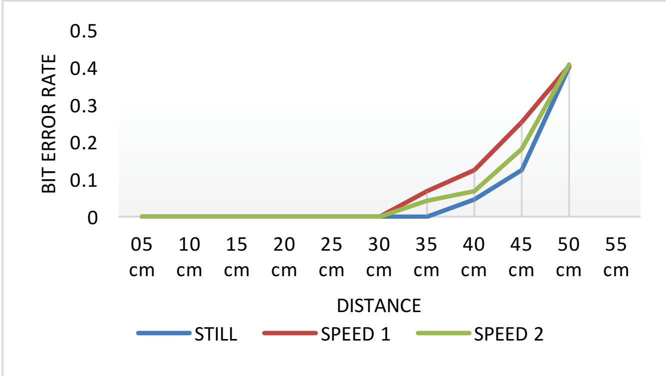

Fig. 8 Bit Error Rate Turbid Water Level 2

Figure 9 is the BER at data transmission at water of 120 NTU (Turbidity Level 3). At still water, the BER suddenly increased from 5.00% at 30 cm to 36.43% at 35cm. An explanation of this is that as the water becomes more turbid, the BER increases faster with changing distance. At moving water, the data varies only slightly to that of still water.

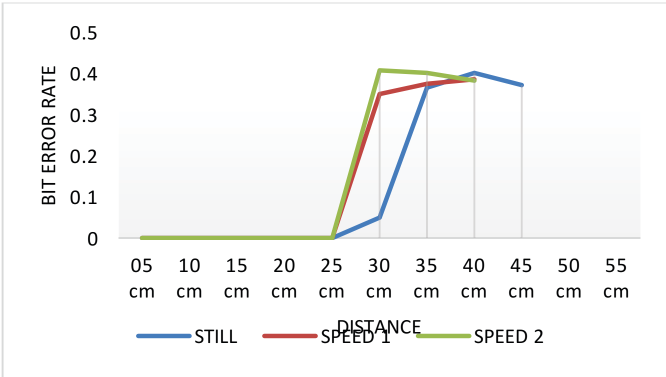

Fig. 9 Bit Error Rate Turbid Water Level 3

Figure 10 shows the BER when the setup is submerged in water of turbidity level 238 NTU (Turbidity Level 4). At still water, a sudden increase in BER is seen in the figure. Moving the water makes the BER limited, having 100% BER at distances greater than 30 cm. The maximum BER of speed 1 and speed 2 are 36.43% and 37.14%, respectively. The figure displays closer BER values between still and moving water.

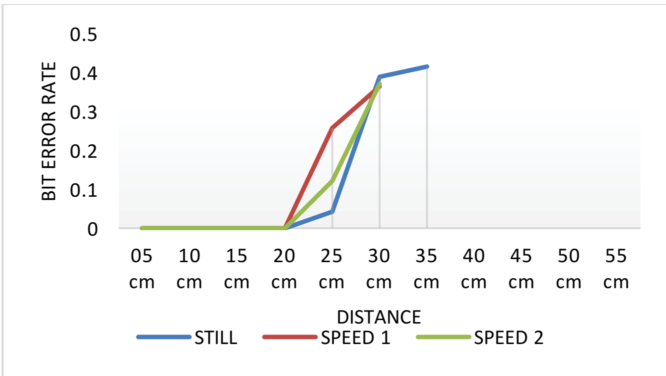

Fig. 10 Bit Error Rate Turbid Water Level 4

Figure 11 is the data when transmission is done at water with 301 NTU (Turbidity Level 5).The BER at 20 cm shows that still water has a BER of 6.79% and speed levels 1 and 2 both have BER of 0.00%, showing perfect transmission at that distance and distances below it.

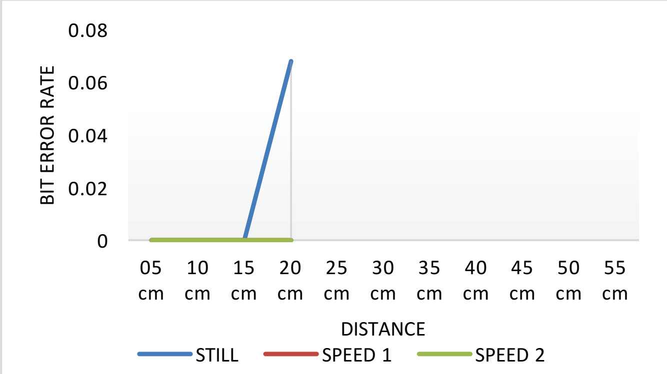

Fig. 11 Bit Error Rate Turbid Water Level 5

VII. Character Receive Rate

The analysis of data for character receive rate is with reference to distances from right to left. Figure 12 shows the character receive rate (success rate) of still water at varying turbidity levels. It can be seen that there is a generally uniform increase in the receive rate of transmission of characters. Still water starts increasing in character receive rate at 160 cm and continues to rise until it reaches 100% at 120 cm. Turbid level 1 shows increase in character receive rate starting from 70 cm to 55 cm. Turbid level 2 starts increasing at 50 cm and receives perfect transmission at 40 cm. Turbid level 3 starts rising at 35 cm and receives perfectly at 35 cm. Turbid levels 4 and 5 increases from 30 cm to 25 cm and 25 cm to 20 cm, respectively. The trend is that as turbidity level increases, there is a much steeper slope in the character receive rate.

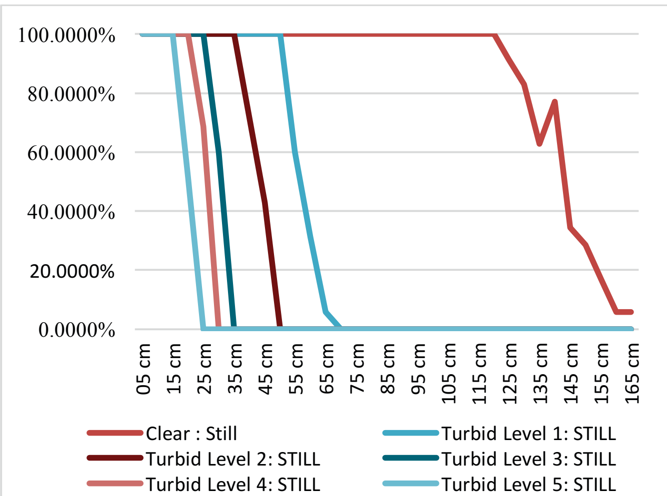

Fig. 12 Character Receive Rate on Still Water at Different Levels of Turbidity

Figure 13 shows character receive rate of varying turbidity levels at speed level 1 of moving water. At clear water, the character receive rate starts increasing at 150 cm and oscillates until it reaches 100% receive rate at 115 cm. Turbid level 1 starts rising at 70 cm and reaches 100% transmission at 50 cm. There is a noticeable gap in the slope of the two: turbid level 1 oscillates until 115 cm, while turbid level 5 rises from 25 cm to 20 cm.

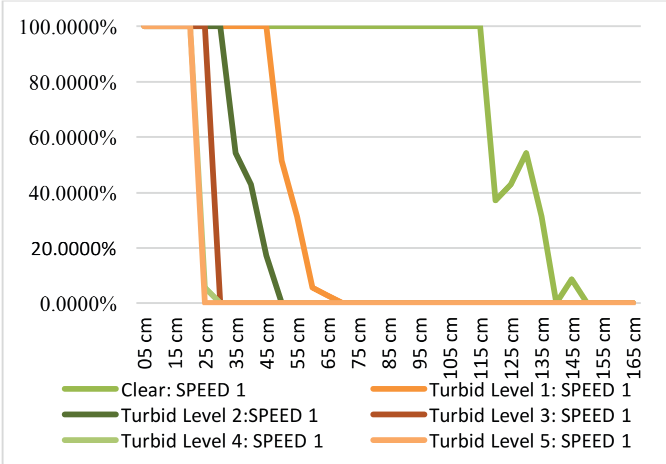

Fig. 13 Character Receive Rate on Moving water (speed 1) at Different Levels of Turbidity

Figure 14 presents character receive rate of varying turbidity level at speed level 2. At clear water, the receiver starts receiving at 150 cm but starts to rise at 130 cm until it reaches 100% transmission at 115 cm from the transmitter. Turbid level 1 starts rising and oscillating at 70 cm and achieves perfect transmission at 50 cm. Turbid level 2 shows signs of reception of data starting at a distance of 45 cm and ends its rise at 35 cm. The trend is still applicable at speed level 2, as seen in the figure. Turbid levels 3 and 5 have the same slope while turbid level 4 rises at 30 cm and ends at 25 cm.

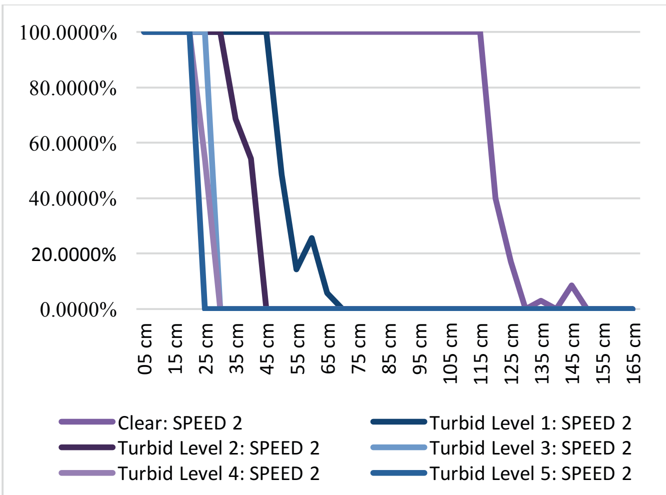

Fig. 14 Character Receive Rate on Moving water (speed 2) at different levels of turbidity

From the given figures, it is evident there is a trend in the character receive rate as turbidity increases. At all levels of speed, from still up to speed 2, the rate at which character is received is directly proportional to the increase in turbidity present in the water. Between each graph, the effect of moving water is evident at clear water and at turbid level 1, as seen in figures 12, 13, and 14. The distance in which the receiver starts to receive data decreases as speed level increases.

VIII. CONCLUSION

From the results obtained in this study, it can be said that the turbidity level, distance and water flow rate affect the bit error rate and luminous flux of the underwater optical communication system.

In terms of luminous efficiency, as the lux meter was moved away from the light source, abrupt decrease/change in luminous flux is observed. At turbid conditions, the reading of the lux meter is less than the readings in non-turbid or less turbid conditions of same distance. At increasing speeds, the luminous efficiency has minimal discrepancies or negligible differences with respect to the still water.

Based from the tests, single and multiple random erroneous bits are detected by the receiver. It was evident in the study that the bit error rate was not affected by the change in distance within the range of 0.1 m to 0.7 m given that the water has 0 NTU of turbidity. Increasing the turbidity level increases the bit error rate in still water conditions. A change in distance given that the turbidity level is greater than zero further increases the bit error rate in each turbidity level.

Adding turbidity to water indicates the addition of minute opaque particles in the medium, thus blocking the path of the light and affects transmission of data. This is proven by conducting tests in varying turbid water and comparing the data received at varying distances. The results indicate less light passes through the water into the receiver as the water becomes more turbid, showing that minute particles in the water prevents light from passing through to the receiver.

Adding flow into the water affects each test differently. In the clear water, flow decreases the reliability of the data at the same distance, proven at a distance of 135 centimeters, where the data of each level differs from one another. In turbid water, the flow shows less effect in the transmission of data, affecting only distances where data is already unreliable. At closer distances, the flow does not affect the transmission of data for both clear and turbid waters.

The research yielded different results depending on the environment, meaning that not only does the turbidity affect the transmission rate, but as well as the environment the setup is in. Conducting tests in air medium shows that the maximum distance that the receiver can properly detect the data being transmitted is 105 cm. Comparing the results of air medium transmission with the results of general clear water medium transmission, it is clear that the water medium is more reflective than air medium. This increased reflectivity of water medium is due to the surface of the water reflecting the light back into the water, resulting in a brighter light, thus making the light travel at a longer range for this particular setup.

IX. RECOMMENDATIONS FOR FUTURE WORK

The proponents recommend using more diverse light sources as transmitters such as a higher powered LED, a laser pointer or an LED array, and another receiver, preferably an avalanche photodiode to improve sensitivity. It is recommended to use varying colors of light sources to know the possible effects whether it has the same effect or not. Another type of particle is also recommended aside from Iron Oxide as there are various types of particles found in bodies of water. It is also suggested to either find or construct a larger flow simulator to increase the range and scope of the study. Adding more levels of speed, distance, and turbidity is highly advised in order to gather more data for research. A much rigid setup is advised so that the setup is more waterproof and there is less interference and erratic behavior on the transmitter and receiver.

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