Physics Extended Essay

'Saline Water & Light Fidelity Technology'

Research Question: What is the effect of different concentrations of saline water & the distance when transferring data using Light Fidelity technology?

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A. Introduction

Light Fidelity is a data transmission technology that can transfer data using wavelength from visible light spectrum. Light can transfer data at a speed of 1 Gbps. The term Li-Fi was coined by German scientist Harald Hass in year 2011 during one of his Ted Talks (TED). Currently, optical fibre is utilized to carry data at speeds ranging from 100mbps to 950mbps, which is significantly slower than Li-Fi.

While my Submarine Underwater Trip in Mauritius I learned a lot about the problems faced by the sailors underwater. One of the biggest problems according to me is that they cannot communicate with the outer world or the people who are on land. Radio waves cannot be used underwater because radio waves are absorbed by the water, but light waves are not absorbed by the water. Hence I researched & learned that we could use Li-Fi technology underwater.

LI-FI uses light-emitting diodes (LED) to transport data at breakneck speed. A huge number of files can be sent in parallel at a substantially faster transfer speed with LI-FI. Electromagnetic spectrum enables this simultaneous data transport. Instead of using typical radio frequencies, it uses a considerably more advanced method of communication, namely light, to successfully transport data. Advancement in Li-Fi was made possible by advancements in wireless communication. This suggests that LI-FI can be used for underwater communication, potentially altering how underwater vehicles & divers communicate. (Raghuvanshi and Singh)

LI-FI transmits data via light, which is far more secure; thus, scientists at the Kennedy Space Centre are working on LI-FI. Even the US Navy (Li-Fi Technology in the U.S. Navy) now uses a slow & obsolete underwater communication system that does not work well with the weak acoustics that exists underwater.

So, I designed a strategy to see if we could use Li-Fi technology to send data to a receiver on the opposite side of the saline water. To put this to test, I decided to create a saline water model

& send data from one end of the glass trays to other. The glass trays will be filled with varying concentrations of saline water. As a result, my research question is, **‘What is the effect of different concentrations of saline water & the distance when transferring data using Light Fidelity technology?’**.

B. Background Knowledge

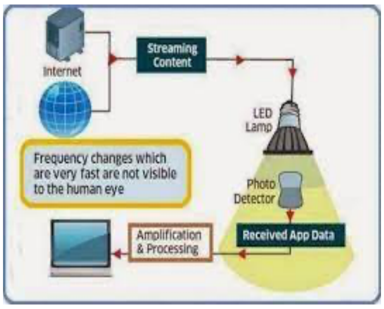

Figure 1 – Working of Li-Fi

The principle of LI-FI is based on data transmission using ("lifi study paper - approved - Tec") light frequencies from visible light spectrum, which is part of electromagnetic spectrum. Violet has a frequency of 7.9×10^{14} Hz & red has 4.0×10^{14} Hz. Wi-Fi, on the other hand, uses radio waves, which are also a part of the electromagnetic spectrum & have a frequency of which is less than 3×10^{6} Hz. (Electromagnetic Spectrum | COSMOS)

The Li-Fi system operates straightforwardly. On one end, there are light receivers, which are often solar cells, LED transmitters or Light sensors. On other end is a light source, which could be a regular tube light, an LED, a laser, or anything else. This light source is frequently coupled to an encoder, which translates the signals into 1's & 0's, with signal 1 being 'On' & signal 0 being 'Off'. LEDs are frequently switched so quickly that the changes are imperceptible to human vision. The changes are made in less than a microsecond. Binary codes are used to describe the unseen transport of data in the form of 1s & 0s. Data is often encoded inside the light in different combinations by altering the speed of light. An example of binary can be '01001000 01100101 01101100 01101100 01101111' which stands for 'Hello'. The light source is linked to the information network (Internet through a modem), & thus the receiving end receives information in the form of light signals & decodes the signal to a readble format which is then shown on a screen or device. (Nischay)

It is anticipated that Li-Fi is 80% more efficient than Wi-Fi. Thus, repeatedly flashing the LED or employing an array of LEDs will eventually provide data, that it can achieve speeds of up to 1Gbps or more. Li-Fi varies from fibre optic. All that is needed is a few of an array of LEDs, as well as a controller that controls/encodes data into those LEDs (ShivamKumar828) . The *Figure 1* represent the complete process in visual format.

Snell’s law can be used to explain how the change in density affrect the reflective index of water and how the angle of the light received changes. By observing the change in vertical height between the transmitter and the receiver end. We will also use Planks law to explain how different wavelength of light is absorbed by the water because of which the amount of energy per photon changes.

C. Experiment

a. Variables

Independent Variable	
The salinity of water (Salt Concentration / %) -	Using distilled water, we can change the concentration of salt in water. The salt percentage in distilled water will vary from 0% ±0.5 to 20% ±0.5. The ±0.5 is the uncertainty which is uncertainty of the measuring cylinder. The uncertainty of the weight machine is negligible.
Horizontal Distance (Horizontal Length / cm)-	Using a glass drying dish of different lengths we will change the distance. The glass drying dish will hold all the saline water. A centimetre ruler was used to measure the distance which has an uncertainty of ±0.05cm.
Dependent Variable	
Decibel of Sound (Decibel / dB) -	A Decibel meter we will measure the sound produce by the speaker at the receiver end. The uncertainty of the decibel meter is ±1.5dB for 1kHz sound.
Vertical height of laser dot (Vertical Length Output /cm) -	To measure we will use an centimetre ruler on the receiver end. We will measure the height at which we see the red laser dot from the bottom of the table. Ruler has an uncertainty ±0.05cm.
Voltage (Voltage / V) -	The receiver module will be connected to the digital voltmeter that will record voltage received from the solar panel. The voltmeter has an uncertainty of ±0.01V.
Control Variable	
Temperature (Celsius / °C) -	The temperature of the solution will be constant & the temperature of the dark room will be constant at 25°C; with the help of air conditioner.
Solar Panel -	The solar panel used will be the same in all the tests.
The vertical height of laser (Vertical Length Input /cm) -	The light source is placed at height of 15cm from the ground.
The intensity of Light -	The intensity of light will be the same as the same laser diode & the same LEDs will be used in all the tests.
Environmental Influence -	The experiment will be performed in the darkroom because of which there will be no external influence of light on the experiment.

Table 1 – Independent, Dependent & Control Variable

b. Apparatus

Items	Quantity	Use in experiment
1. DC Power Supply	1	To power the light source
2. Laser Diode	1	As light source
3. LED	4	As light source
4. AUX Cable	2	In the receiver circuit
5. Solar Panel	1	In the receiver circuit
6. Speaker	1	In the receiver circuit
7. Retort Stand	4	In both receiver & transmitter circuit.
8. Decibel Meter	1	In the receiver circuit
9. Distilled Water	1000 Litre	Prepare saline solution
10. Table Salt	1kg	Prepare saline solution
11. Glass Drying Tray	2	To hold the saline solution between both the circuits
12. 1-meter Ruler	1	In both receiver & transmitter circuit.
13. Common Lab Apparatus	1	Thought out the experiment.

Table 2 – Apparatus list

c. Methodology

i. Transmitter Module

It converts the digital signal to an analogue signal & transmits data utilising the electromagnetic light spectrum.

1. In a parallel circuit connect four LEDs & a Laser Diode.
2. A crocodile clip is used to connect the positive end of the circuit to the positive end of the Aux cable.
3. Using crocodile clips, connect the negative end of the circuit to the negative end of the DC power supply.

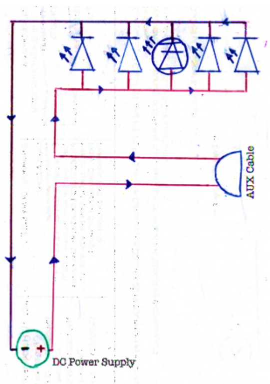

Figure 2 – Transmitter Module

4. A crocodile clip is used to connect the negative end of the Aux wire to the DC power supply.
5. Connect the Aux cable to the gadget that has an Aux socket.

ii. Receiver Module

It is responsible for converting the analogue signals received into digital signals. Analogue signal is received on a solar panel.

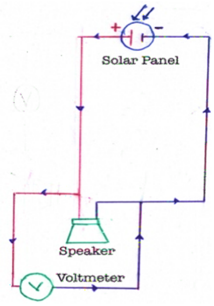

Figure 3 – Receiver Module

1. Connect positive end of the solar panel to positive end of the Aux wire.
2. Connect negative end of the solar panel to negative end of the Aux cable.
3. The Aux wire is connected to a speaker, which produces the sound received.
4. A voltage meter is connected parallelly across the speaker.

iii. Saline Water

1. For 5% of salt concentration, we need to measure out 1liter of distilled water using measuring cylinder, then measure out 50gms of salt using weight machine.
2. Add 50gms of salt to distilled water & stir it vigorously.
3. To increase the concentration to 10% - 100gms, 15% - 150gms or 20% - 200gms add the amount of salt mentioned for different concentration to 1liter of distilled water.

iv. Experiment Setup

1. Place transmitter module at one end of the table. Use clamps to fix light source at a height of 15 cm from the base of the table.
2. Receiver module is placed at the other end of the table. The solar panels are attached at a height of 2 cm from the bottom of the table.
3. Difference between the transmitter module & the receiver module is 18 cm & 25 cm.

4. With two supports at each horizontal end of the table, position the glass drying tray at the same height as the transmitter module.

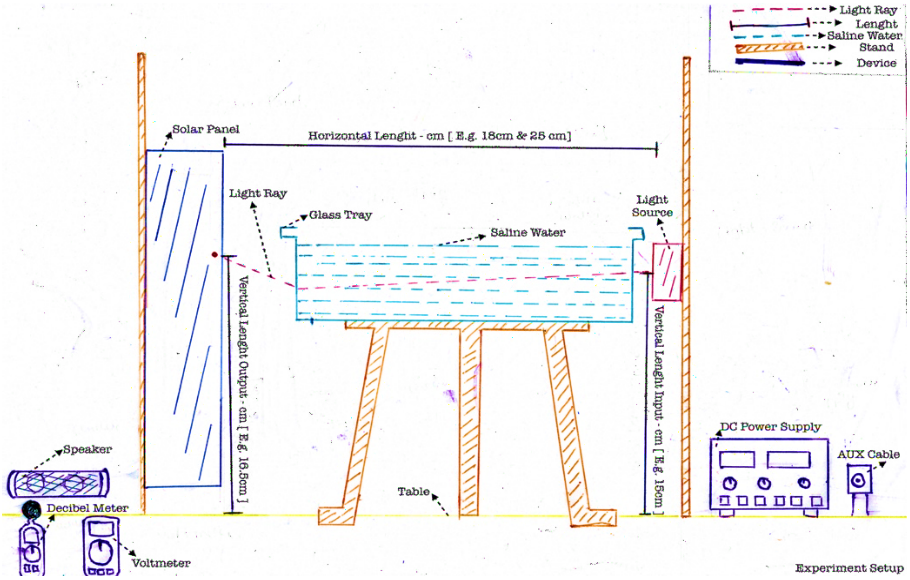

Figure 4 – Setup Diagram

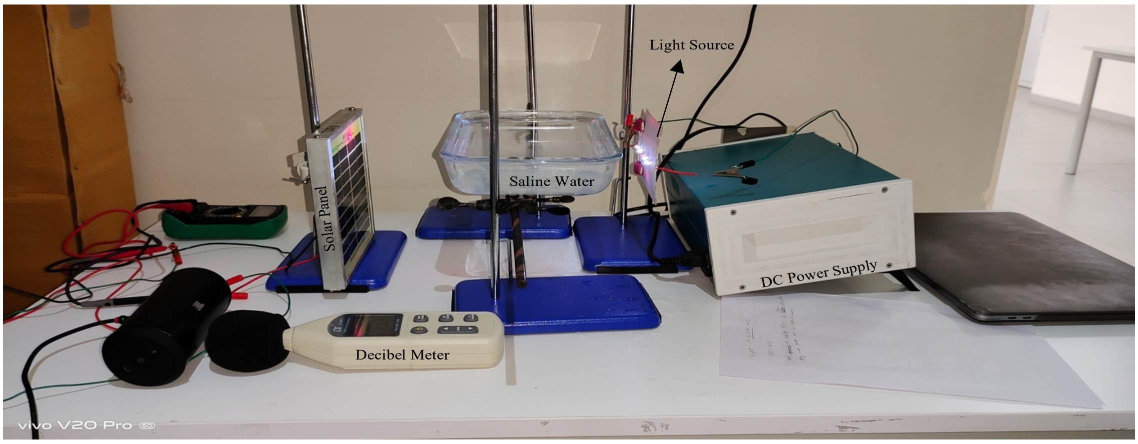

Figure 5 – Setup Image – Setup Image – Front View

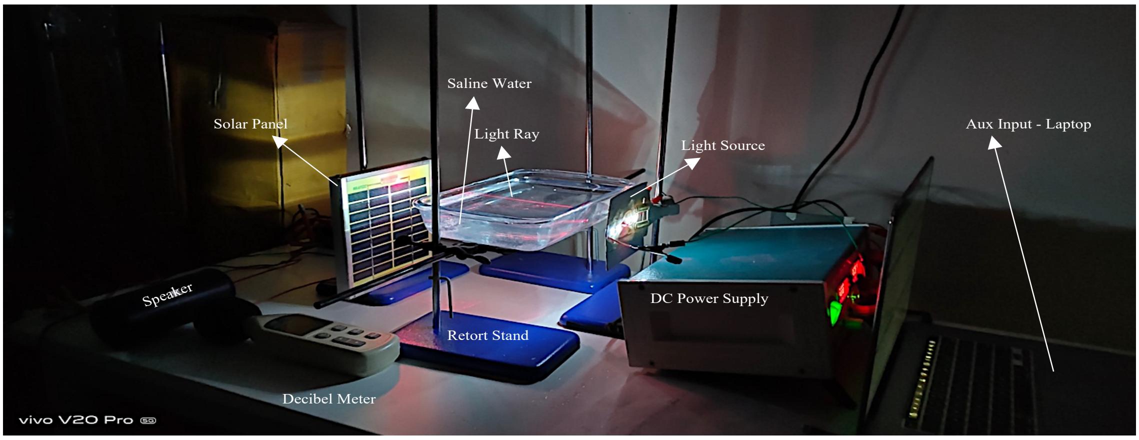

Figure 6 – Side View – Dark Room

d. Raw Data

I. Horizontal Length – 18cm ± 0.05cm

Salt Concentration / % ±0.5	Trials	Voltage / V ± (0.01)V		Vertical Length ± (0.05cm)		Decibel ± (1.5 dB)	
	Types	Input	Output	Input	Output	Input	Output
0%	*1*	3.00	1.61	15.00	16.51	51.0	102.1
	2	3.00	1.60	15.00	16.51	51.0	101.7
	3	3.00	1.59	15.00	16.50	52.0	102.0
	Average Trial	3.00	1.60	15.00	16.51	51.3	101.9
5%	*1*	3.01	1.57	15.00	16.31	51.0	102.1
	2	2.99	1.57	15.00	16.32	51.0	102.1
	3	2.99	1.58	15.00	16.30	51.2	102.0
	Average Trial	3.00	1.57	15.00	16.31	51.1	102.1
10%	*1*	3.00	1.55	15.00	16.02	51.0	102.6
	2	3.00	1.55	15.00	16.00	50.0	102.6
	3	3.00	1.55	15.00	16.01	50.2	102.7
	Average Trial	3.00	1.55	15.00	16.01	50.4	102.6
15%	*1*	2.99	1.53	15.00	15.70	52.7	103.0
	2	3.00	1.53	15.00	15.70	53.8	103.1
	3	3.00	1.53	15.00	15.70	53.8	103.1
	Average Trial	3.00	1.53	15.00	15.70	53.4	103.1
20%	*1*	3.00	1.50	15.00	15.53	56.5	104.1
	2	2.99	1.50	15.00	15.51	57.1	103.8
	3	3.00	1.50	15.00	15.50	55.7	104.1
	Average Trial	3.00	1.50	15.00	15.51	56.4	104.0

Table 3 - Salt Concentration from 0% + 0.5 to 20% ± 0.5 at 18cm – Raw Data

1. *Table 3* consists of data for horizontal length of 18cm ± 0.05cm. It has value for 0%, 5%, 10%, 15% & 20% salt concentration. The uncertainty in salt concentration is ±0.5 but for 0% it is only +0.5. The double line in the table is used to divide the data of different salt concentration, each salt concentration is known as a part. The table is divided into 5 main parts and each part has four rows. The table also has five main column.
2. The first row of part 0% has the data for Trial 1, the second for Trial 2 and the third for Trial 3. The mean value of all the trial is write in the fourth row named Average Trial. This is the same for every part ranging from 5% to 20% of the table.
3. The First column has the heading *Salt Concentration*.
4. Second Column has the heading *Trials,* it holds the data for Trial 1, Trail 2 and Trail 3.
5. Third Column is named *Voltage*; it holds the data for voltage recorded in all the experiment. The voltage is recorded using a multimeter with an uncertainty of ±0.01V.
    a. It is divided into two sub-column named '*Input*' & '*Output*'.
        i. The *Input* consists of the voltage provided by the DC power supply to the light source. During this time no data is transferred only the light is being transferred. This is taking place in the transmitter module.
        ii. The *Output* consists of the voltage received by the solar panel when light hits the solar panel. During this time data is being transferred with the light. This is taking place in the receiver module.
6. Fourth Column is named *Vertical Height Decibel*; it holds the data for the vertical height recorded in all the experiment. The vertical angle is recorded using the centimetre ruler with an uncertainty of ±0.05cm.
    a. It is divided into two sub-columns named '*Input*' & '*Output*'.
        i. The *Input* consists of the Vertical Length at which the light source is fixed using a retort stand.

ii. The *Output* consists of the Vertical Length received at the point where the red laser dot strikes the solar cell.

7. Fifth Column is named *Decibel*; it holds the data for decibel of sound recorded in all the experiment. The decibel of sound is recorded using a decibel meter with an uncertainty of ±1.5dB for 1kHz sound.
   a. It is divided into two sub-column named *Input* & *Output*.
      i. The *Input* consists of the decibel produced by the speaker when only light is transferred. During this time data is not transferred with the light. This is the decibel of sound that includes the disturbance produced by the speaker when the light strikes the solar panel.
      ii. The *Output* consists of the decibel produced by the speaker when both, data & light is being transferred. This is the decibel of sound that includes the disturbance produced by the speaker & also the sound of the data which is being transferred when the light strikes the solar panel.
8. The average of all the trails is calculated using the formula $Average\ Trial = \frac{[Trial\ 1]+[Trial\ 2]+[Trial\ 3]}{Total\ number\ of\ trials}$. [1]

[1] Sample Calculation in **Appendix 1 – Sample Raw Data calculation**

II. Horizontal length – 25cm ± 0.05cm

Salt Concentration / % ±0.5	Trials	Voltage / V ± (0.01)V		Vertical Length ± (0.05cm)		Decibel ± (1.5 dB)	
	Types	Input	Output	Input	Output	Input	Output
0%	*1*	3.01	1.36	15.00	17.71	52.6	103.5
	2	3.01	1.37	15.00	17.73	52.1	105.1
	3	3.01	1.37	15.00	17.72	53.0	103.0
	Average Trial	3.01	1.37	15.00	17.72	52.6	103.9
5%	*1*	3.00	1.33	15.00	17.51	53.0	104.3
	2	3.00	1.31	15.00	17.53	52.9	104.3
	3	3.01	1.32	15.00	17.51	53.0	103.8
	Average Trial	3.00	1.32	15.00	17.52	53.0	104.1
10%	*1*	3.00	1.27	15.00	17.21	53.2	105.8
	2	3.00	1.28	15.00	17.25	53.3	105.8
	3	3.00	1.27	15.00	17.23	53.2	106.0
	Average Trial	3.00	1.27	15.00	17.23	53.2	105.9
15%	*1*	3.01	1.24	15.00	16.90	60.0	106.5
	2	3.01	1.25	15.00	17.00	61.0	106.3
	3	3.01	1.23	15.00	16.90	60.5	106.2
	Average Trial	3.01	1.24	15.00	16.93	60.5	106.4
20%	*1*	3.00	1.20	15.00	16.59	70.0	107.1
	2	3.00	1.21	15.00	16.72	68.5	107.0
	3	3.01	1.19	15.00	16.73	69.5	107.1
	Average Trial	3.00	1.20	15.00	16.68	69.3	107.0

Table 4 - Salt Concentration 0% + 0.5 to 20% ± 0.5 at 25cm – Raw Data

Table 4 consists of data for the horizontal length of 25cm ± 0.05cm. It has the value for 0%, 5%, 10%, 15% & 20% *Salt Concentration*. All the data in *Table 4* is recorded & is calculated the same way as done for *Table 3*.

e. Computed Data

I. Horizontal length – 18cm ± 0.05cm

Salt Concentration / % ±0.5	Trials	Computed Voltage / V ± (0.02)V	Vertical Angle ± (0.02)°	Computed Decibel ± (3.0 dB)
0%	*Trial 1*	1.61	4.80	51.1
	Trial 2	1.60	4.80	50.7
	Trial 3	1.59	4.76	50.0
	Average Trial	1.60	4.78	50.6
5%	*Trial 1*	1.56	4.16	51.1
	Trial 2	1.58	4.19	51.1
	Trial 3	1.59	4.13	50.8
	Average Trial	1.58	4.16	51.0
10%	*Trial 1*	1.55	3.24	51.6
	Trial 2	1.55	3.18	52.6
	Trial 3	1.55	3.21	52.5
	Average Trial	1.55	3.21	52.2
15%	*Trial 1*	1.54	2.23	50.3
	Trial 2	1.53	2.23	49.3
	Trial 3	1.53	2.23	49.3
	Average Trial	1.53	2.23	49.6
20%	*Trial 1*	1.50	1.69	47.6
	Trial 2	1.51	1.62	46.7
	Trial 3	1.50	1.59	48.4
	Average Trial	1.50	1.63	47.6

Table 5 - Salt Concentration 0% + 0.5 to 20% ± 0.5 at 18cm – Computed Data

1. *Table 5* consists of computed data for the horizontal length of 18cm ± 0.05cm. The has the value for 0%, 5%, 10%, 15% & 20% *Salt concentration*. The uncertainty in salt concentration is ±0.5 but for 0% it is only +0.5. The double line in the table is used to divide the data of different salt concentration, each salt concentration is known as a part. The table is divided into five main parts and each part has four rows. The table also has five main column.
2. The first row of part 0% has the data for Trial 1, the second for Trial 2 and the third for Trial 3. The mean value of all the trial is write in the fourth row named Average Trial. This is the same for every part ranging from 5% to 20% of the table.
3. The First column has the heading *Salt Concentration*.
4. Second Column has the heading *Trials*.
5. Third Column is named *Computed Voltage*; it holds the data for the computed voltage for all the experiment.
    a. The voltage is calculated using the formula $Computed\ Voltage = \frac{[Output\ Voltage] \times 3}{[Input\ Voltage]}$. [2]
    b. The uncertainty is ±(0.01)V.[3]
6. Fourth Column is named *Vertical Angle*; it holds the data for the vertical angle for all the experiment.
    a. The voltage is calculated using the formula $Vertical\ Angle = \tan^{-1}(\frac{[Output\ Vertical\ length] - [Input\ Vertical\ length]}{[Horizontal\ length]})$ [4]
    b. The uncertainty is ±(0.02)°.[5]

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[2] Sample Calculation in **Appendix 2 – Sample Computed Data calculation**
[3] Calculation in **Appendix 3 – Computed Voltage Uncertainty Calculation**
[4] Sample Calculation in **Appendix 2 – Sample Computed Data calculation**
[5] Calculation in **Appendix 4 – Vertical Angle Uncertainty Calculation**

7. Fifth Column is named *Computed Decibel*; it holds the data for the computed decibel for all the experiment.
    a. The decibel of sound is calculate using the formula $Computed\ Decible = [Output\ Decible - Input\ Decible]$[6].
    b. The uncertainty is ±3dB.[7]
    c. This helps to remove the background sound & the disturbance produced by the speaker which only gives out sound produced by the data that the speaker plays.
8. The average of all the trails is calculated using the formula $Average\ Trial = \frac{[Trial\ 1]+[Trial\ 2]+[Trial\ 3]}{Total\ number\ of\ trials}$. [8]

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[6] Sample Calculation in **Appendix 2 – Sample Computed Data calculation**
[7] Calculation in **Appendix 5 – Computed Decibel Uncertainty Calculation**
[8] Sample Calculation in **Appendix 2 – Sample Computed Data calculation**

II. Horizontal length 25 cm ± 0.05cm

Salt Concentration / % ±0.5	Trials	Computed Voltage / V ± (0.02)V	Vertical Angle ± (0.02)°	Computed Decibel ± (3.0 dB)
0%	*Trial 1*	1.36	8.56	50.9
	Trial 2	1.37	8.62	53.0
	Trial 3	1.37	8.59	50.0
	Average Trial	1.36	8.59	51.3
5%	*Trial 1*	1.33	7.94	51.3
	Trial 2	1.31	8.00	51.4
	Trial 3	1.32	7.94	50.8
	Average Trial	1.32	7.96	51.2
10%	*Trial 1*	1.27	7.00	52.6
	Trial 2	1.28	7.13	52.5
	Trial 3	1.27	7.06	52.8
	Average Trial	1.27	7.06	52.6
15%	*Trial 1*	1.24	6.03	46.5
	Trial 2	1.23	6.34	45.3
	Trial 3	1.25	6.03	45.7
	Average Trial	1.24	6.13	45.9
20%	*Trial 1*	1.20	5.05	37.1
	Trial 2	1.21	5.46	38.4
	Trial 3	1.19	5.49	37.6
	Average Trial	1.20	5.33	37.7

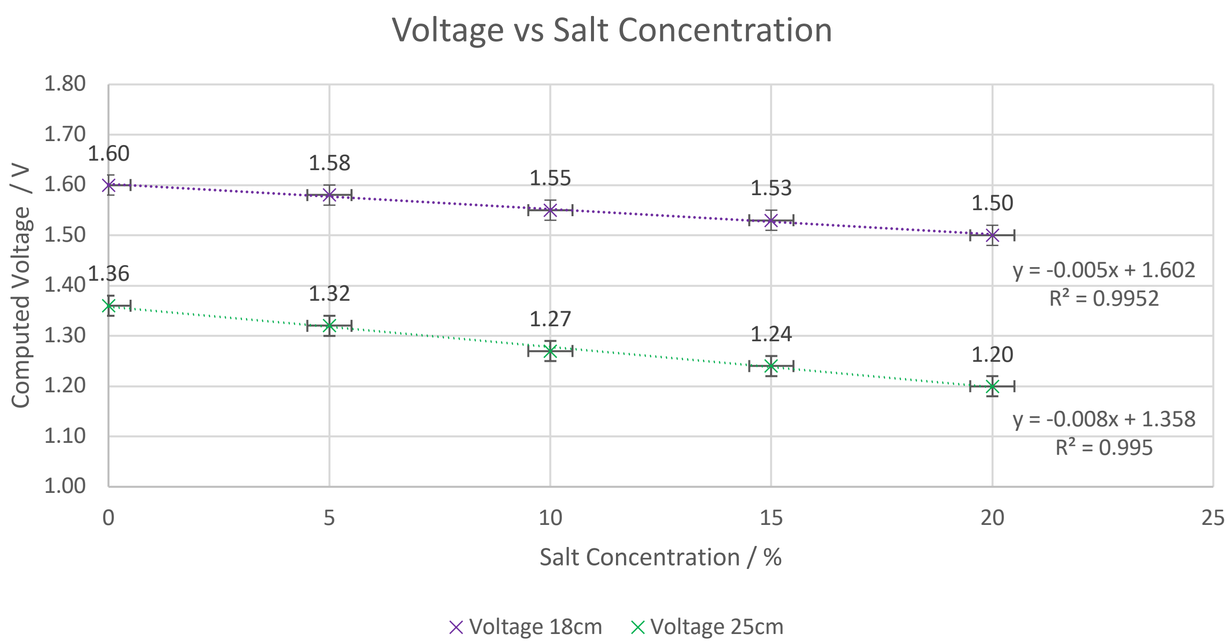
Table 6 - Salt Concentration 0% + 0.5 to 20% ± 0.5 at 25cm – Computed Data

Table 6 consists of data for the horizontal length of 25cm ± 0.05cm. It has the value for 0%, 5%, 10%, 15% & 20% salt concentration. All data in *Table 6* is recorded & calculated in the same way as done for *Table 5*.

D. Data Analysis

The *Graph 1, 2 & 3* are the plotted by taking the data of the Average trails from *Table 5* & *Table 6*.[9]

a. Computed Voltage



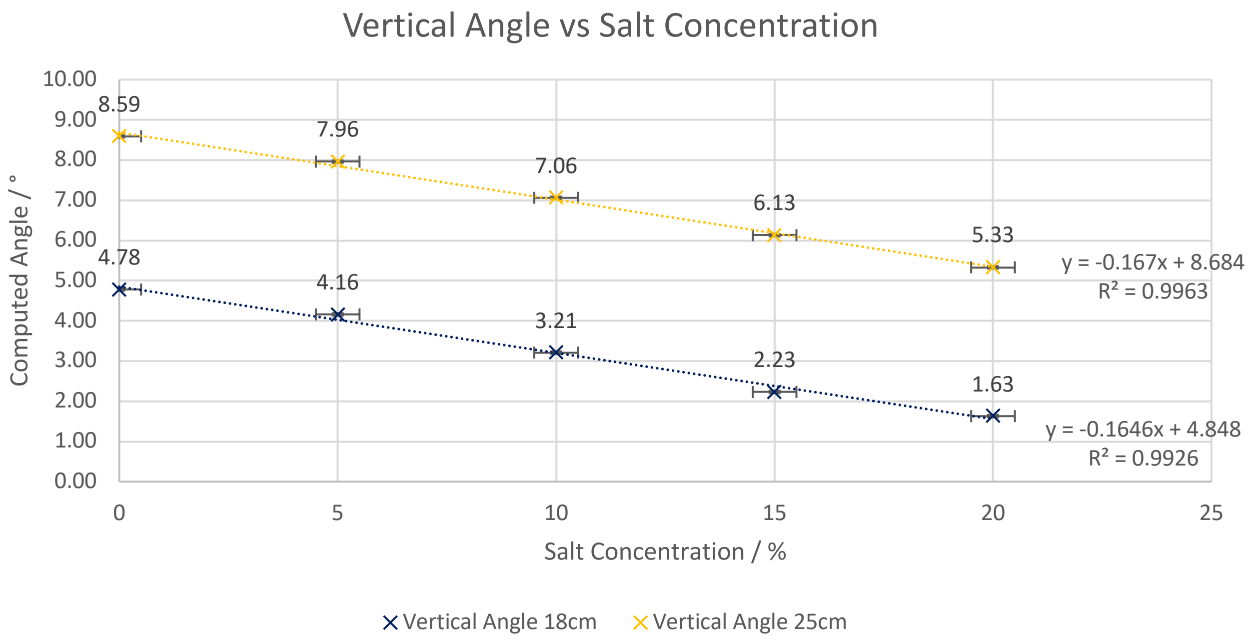
Graph 1 – Voltage vs Salt Concentration

In *Graph 1* we see that when the salt concentration decreases, and the Computed voltage increases. The equation for the line in the graph is $y = mx + c$, the m value in both equations is negative, demonstrating a linear decrease in the voltage. We know that increasing the salinity increase the density of the water. The attenuation of light refers to the reduction in light intensity as it travels through a medium due to the absorption and scattering of photons. (Physics) In this experiment we use white light as the light source hence the energy per photon is in the range of 1.77eV to 3.10eV (The visible spectrum) but because of attenuation of light the average energy per photon decreases. This can also be proved with the help of Plank's law

[9] Data table for the value in graph in **Appendix 6 – Data Table for Analysis**

that states the $E = \frac{hc}{\lambda}$ where h is the Planck's constant (6.626×10^{-34} Js), λ is the wavelength and c is the speed of light; when light travels through water its speed and wavelength decrease which lead to decrease in the photon energy. If the photons are powerful enough, they will knock out the electrons in the outermost shells of the conduction material to generate electricity. So, to conclude, the speed and wavelength of light decrease the energy of photons decreases because of which the amount of voltage decrease with the increase in the salt concentration. The increase in length increases the attenuation hence we can conclude that computed voltage is inversely proportional to salt concentration and horizontal length. (Seawater - Acoustic properties | Britannica)

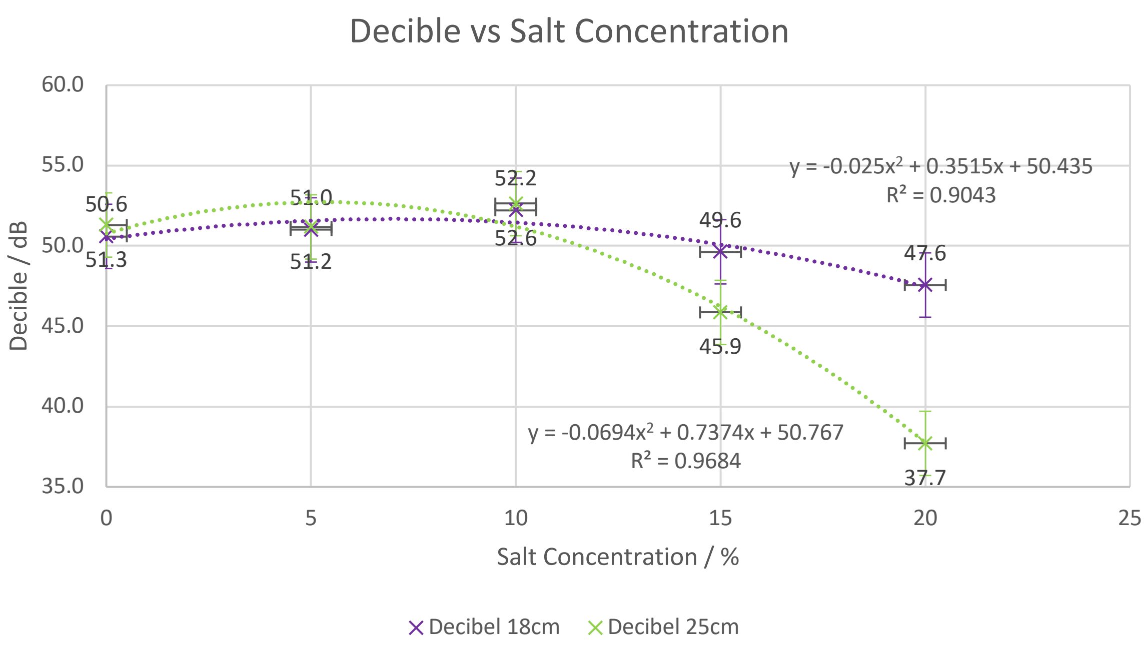
b. Vertical Angle



Graph 2 – Vertical Angle vs Salt Concentration

In *Graph 2* we see that when the salt concentration decreases, and the vertical angle increases. The equation for the line in the graph is $y = mx + c$, the m value in both equations is negative, demonstrating a linear decrease in the voltage. We know that increasing the salinity increase the density which further increases the reflective index. This causes a change in the speed of light which leads to bending or refraction. Also, when the reflective index increases, the red dot of the laser magnifies, demonstrating that light spreads out when it passes through different densities. This can also be proved with the help of Snell's law that states the ratio of the sine of the angles of incidence and transmission is equal to the ratio of the refractive index of the materials at the interface; hence we can state that when light moves from rarer to denser medium it moves towards the normal. Hence the vertical angle decreases. To summarise, the salt concentration is inversely proportional to the vertical angle, but the vertical angle is directly proportional to the horizontal length.

c. Computed Decibel



Graph 3 – Computed Decibel vs Salt Concentration

We can see that the graph peaks at 10% salt concentration. The equation for the line in the graph is $y = ax^2 + bx + c$; the value a is less than zero hence the graph is oriented downward demonstrating a second-order polynomial relation between the salt concentration and decibel. decrease in the voltage. There is an increase in decibel as we progress from 0% to 10% salt concentration. This is because the light spreads out evenly over the solar panel & there is the least attenuation. Because of the attenuation of light, most of the photos are spread or absorbed by the water due to which there is a gap between the data being transferred. this the speaker. So, when you look at Table 5 & Table 10, you can see that the input decibel is significantly greater decibel than in the other tables. As a result, we declare that the most efficient salt concentration of salt is 10% since it gives out the maximum efficient decibel. There is no direct relation between the horizontal length and the amount of sound produced.

E. Conclusion & evaluation

a. Conclusion

The primary goal of the experiment was to determine how different salt concentration of saline water affect the data transfer using light fidelity technology. The computed data presented above demonstrates how changes in salt concentration and horizontal distance affect voltage, vertical angle, and decibel. I used to believe that the voltage, vertical angle, decibel of sound would be a linear graph with a negative slope when plotted against salt concentration before conducting this experiment. However, after carrying out the experiment, I am able to see the pattern and assess how this change may have occurred. The findings show that there is no linear link between salt concentration and decibel of sound, he we can say that because of the attenuation of light it might create errors in data transfer. It is generally determined by the amount and intensity of light directed at the receiver module. The vertical angle and salt concentration have an inverse relation, which can be demonstrated using the help of Snell's law. The Planks law proves that the voltage produced by the solar panel will decrease because the speed and range of the wavelength decreases. Also after doing this experiment I got to know why we use only visible light section of the electromagnetic spectrum this is because it does not affect individuals since visible rays are safe to use when compared to other sections of electromagnetic spectrum like X-Rays, Gamma Rays and etc.

b. Evaluation

Some limitations of this experiment are the cost because some of the apparatus used in the actual world for research may be expensive, but in the lab, we utilised less expensive alternatives, such as white LEDs & laser diodes instead of high beam lights. Also instead of transferring the text message we transferred sound waved as our data but to be more precise we need to use microcontrollers that transfer text message so that we can determine which alphabets are missing in the transferred message.

The possible source of error in this experiment can be the draining of the speaker's battery as the speaker was charged once and was used for all the trials. Another limitation was that inserting the apparatus in water was not possible as they circuit was not waterproof because of which the were placed at the end of the glass tray which might create change in the angle of light received.

Even after all the source of error I created a real life model wherein each variable can be controlled individually or in various combinations to explore & evaluate if a potential outcome is viable. This gives you a huge advantage in terms of finding accurate results. The research is a model of the real world, where we eliminated real-world difficulties such as water pressure and pollution level of water. The experiment was carried out in a dark room, which eliminates all natural & artificial light in the room. In the actual world, this lights could cause a disturbance in data transit.

Some of the ethical issues related to this experiment at that about 3 to 4 litres of distilled water was used to create the saline solution which can instead be use in a place where it is required the most. There was a wastage of resources like salt & electricity. All the equipment brought for the experiment might have left carbon footprint behind. As there is no data available from the research in the actual world, we cannot identify the risks of this research in the real world scenario.

c. Extension

Future study could be conducted in a larger model, such as a swimming pool, using more precise equipment. Performing it in a swimming pool will allow us to learn about real-world issues such as sunlight interference, water pressure, and many more.

As a starting point, in the near future, we may integrate optical fibre technology with Li-Fi technology to transport data from the rovers to the surface command unit.

The disadvantage of Li-Fi is that this may limit the regions and situations in which Li-Fi can be used, such as causing problems for aquatic life that has been surviving without light for years. Transmitting data can be hampered by obstructive obstacles on paths. (Rao and C)

Despite all of the difficulties and issues surrounding this experiment, there is always the possibility that this technology will revolutionise the world and become beneficial to people.

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G. Appendix

a. Appendix 1 – Sample Raw Data calculation

The calculation is a sample calculation of the Step 8 of the *Table 3* under the heading *Raw Data - Horizontal Length – 18cm ± 0.05cm*. The Average Trail in the *Table 3* for input voltage of salt concentration 0% is calculated as

$$Average\ Trial = \frac{[3.00] + [2.99] + [3.00]}{3} = \frac{8.99}{3} = 2.999V \sim 3volts$$

b. Appendix 2 – Sample Computed Data calculation

- The calculation is a sample calculation of the Step 5.a of the *Table 5* under the heading *Computed Data - Horizontal Length – 18cm ± 0.05cm*. We can calculate the *Computed voltage* from the *Table 3*, the salt concentration 0%,

$$Computed\ Voltage = \frac{1.50\ \times\ 3}{3} = \frac{4.5}{3} = 1.5V \pm (0.02)\mathrm{V}$$

- The calculation is a sample calculation of the Step 6.a of the *Table 5* under the heading *Computed Data - Horizontal Length – 18cm ± 0.05cm*. We can calculate the Vertical Angle from the *Table 3*, the salt concentration 0%,

$$Vertical\ Angle = \tan^{-1}\frac{16.51 - 15.0}{18} = \tan^{-1}\frac{1.51}{18} = 4.80\ \pm (0.02)°.$$

- The calculation is a sample calculation of the Step 7.a of the *Table 5* under the heading *Computed Data - Horizontal Length – 18cm ± 0.05cm*. We can calculate the Computed Decibel from the *Table 3*, the salt concentration 0%,

$$Computed\ Decible = 102.1 - 51.0 = 51.1 \pm 3\mathrm{dB}.$$

- The calculation is a sample calculation of the Step 8 of the *Table 5* under the heading *Computed Data - Horizontal Length – 18cm ± 0.05cm*. We can calculate Average Trail in the table for the input voltage of salt concentration 0% is calculated as

$$Average\ Trial = \frac{[1.50] + [1.51] + [1.50]}{3} = \frac{4.51}{3} = 1.503\ V \sim 1.50volts$$

c. Appendix 3 – Computed Voltage Uncertainty Calculation

Salt Concentration / % ±0.5	Trials	Voltage / V				Computed Voltage / V	
	Types	Input Voltage	Input Voltage Uncertainty	Output Voltage	Output Voltage Uncertainty	Computed Voltage	Computed Voltage Uncertainty
0%	*1*	3.00	0.33	1.61	0.62	1.61	0.02
	2	2.99	0.33	1.60	0.63	1.60	0.02
	3	3.00	0.33	1.59	0.63	1.59	0.02
	Average Trial	3.00	0.33	1.60	0.63	1.60	0.02
5%	*1*	3.01	0.33	1.57	0.64	1.56	0.02
	2	2.99	0.33	1.57	0.64	1.58	0.02
	3	2.99	0.33	1.58	0.63	1.59	0.02
	Average Trial	3.00	0.33	1.57	0.64	1.58	0.02
10%	*1*	3.00	0.33	1.55	0.65	1.55	0.02
	2	3.00	0.33	1.55	0.65	1.55	0.02
	3	3.00	0.33	1.55	0.65	1.55	0.02
	Average Trial	3.00	0.33	1.55	0.65	1.55	0.02
15%	*1*	2.99	0.33	1.53	0.65	1.54	0.02
	2	3.00	0.33	1.53	0.65	1.53	0.02
	3	3.00	0.33	1.53	0.65	1.53	0.02
	Average Trial	3.00	0.33	1.53	0.65	1.53	0.02
20%	*1*	3.00	0.33	1.50	0.67	1.50	0.02
	2	2.99	0.33	1.50	0.67	1.51	0.02
	3	3.00	0.33	1.50	0.67	1.50	0.02
	Average Trial	3.00	0.33	1.50	0.67	1.50	0.02
Mean Uncertainty	-x-	-x-	0.33	-x-	0.65	-x-	0.02

- The uncertainty calculation is of the Step 5.b of the *Table 5* under the heading *Computed Data - Horizontal Length – 18cm ± 0.05cm*
- The equation to calculate Computed Volage follows $y = \frac{a}{c}$ we use $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b}$ to calculate uncertainty.

- The Input Voltage uncertainty is calculated using the formula $Input\ Voltage\ Uncertainty = \frac{[Voltmeter\ uncertainty]}{[Input\ Voltage]} \times 100$. This give the percentage uncertainty of all the data.
- The Output Voltage uncertainty is calculated using the formula $Output\ Voltage\ Uncertainty = \frac{[Voltmeter\ uncertainty]}{[Output\ Voltage]} \times 100$. This give the percentage uncertainty of all the data.
- The Computed Voltage Uncertainty is calculated using the formula $Computed\ Voltage\ Uncertainty = \frac{[Input\ Uncertanity]+[Output\ Uncertanity]}{100} \times [Computed\ Voltage]$. Here we add the percentage uncertainty of the data and after dividing it by 100 we get the relative uncertainty which we later multiple to the data and we get the absolute uncertainty.
- The mean uncertainty is calculated the taking the average of the above uncertainty. The final absolute uncertainty of the computed voltage is ±0.02V.

d. Appendix 4 – Vertical Angle Uncertainty Calculation

Salt Concentration / % ±0.5	Trials	Vertical Length / cm				Vertical Angle / cm	
	Types	Input Vertical Length	Input Vertical Length Uncertainty	Output Vertical Length	Output Vertical Length Uncertainty	Vertical Angle	Vertical Angle Uncertainty
0%	*1*	15.00	0.33	16.51	0.30	4.80	0.03
	2	15.00	0.33	16.51	0.30	4.80	0.03
	3	15.00	0.33	16.50	0.30	4.76	0.03
	Average Trial	15.00	0.33	16.51	0.30	4.78	0.03
5%	*1*	15.00	0.33	16.31	0.31	4.16	0.03
	2	15.00	0.33	16.32	0.31	4.19	0.03
	3	15.00	0.33	16.30	0.31	4.13	0.03
	Average Trial	15.00	0.33	16.31	0.31	4.16	0.03
10%	*1*	15.00	0.33	16.02	0.31	3.24	0.02
	2	15.00	0.33	16.00	0.31	3.18	0.02
	3	15.00	0.33	16.01	0.31	3.21	0.02
	Average Trial	15.00	0.33	16.01	0.31	3.21	0.02
15%	*1*	15.00	0.33	15.70	0.32	2.23	0.01
	2	15.00	0.33	15.70	0.32	2.23	0.01
	3	15.00	0.33	15.70	0.32	2.23	0.01
	Average Trial	15.00	0.33	15.70	0.32	2.23	0.01
20%	*1*	15.00	0.33	15.53	0.32	8.56	0.01
	2	15.00	0.33	15.51	0.32	8.62	0.01
	3	15.00	0.33	15.50	0.32	8.59	0.01
	Average Trial	15.00	0.33	15.51	0.32	8.59	0.01
Mean Uncertainty	-x-	-x-	0.33	-x-	0.31	-x-	0.02

- The uncertainty calculation is of the Step 6.b of the *Table 5* under the heading *Computed Data - Horizontal Length – 18cm ± 0.05cm*

- The equation to calculate Vertical Angle follows $y = \frac{a}{c}$ we use $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b}$ to calculate uncertainty.
- The Input Vertical Length uncertainty is calculated using the formula $Input\ Voltage\ Uncertainty = \frac{[Decibel\ Meter\ uncertainty]}{[Input\ Vertical\ Length]} \times 100$. This give the percentage uncertainty of all the data.
- The Output Vertical Length uncertainty is calculated using the formula $Output\ Voltage\ Uncertainty = \frac{[Decibel\ Meter\ uncertainty]}{[Output\ Vertical\ Length]} \times 100$. This give the percentage uncertainty of all the data.
- The Vertical Angle Uncertainty is calculated using the formula $Vertical\ Angle\ Uncertainty =$ $\frac{[Input\ Vertical\ Length\ Uncertanity]+[Output\ Vertical\ Length\ Uncertanity]}{100} \times [Vertical\ Angle]$.

  Here we add the percentage uncertainty of the data and after dividing it by 100 we get the relative uncertainty which we later multiple to the data and we get the absolute uncertainty.
- The mean uncertainty is calculated the taking the average of the above uncertainty. The final absolute uncertainty of the vertical angle is ±0.02°.

e. Appendix 5 – Computed Decibel Uncertainty Calculation

- The uncertainty calculation is of the Step 7.b of the *Table 5* under the heading *Computed Data - Horizontal Length – 18cm ± 0.05cm*
- The equation to calculate Computed Decibel follows $y = a + b$ we use $y = \Delta a + \Delta b$ to calculate uncertainty.
- Hence we will add ±1.5dB with ±1.5dB and we will get ±3dB.

f. Appendix 6 – Data Table for Analysis - D

Salt Concentration / % ±(0.5)	Horizontal Length/ cm ±(0.05)cm	Computed Voltage / V ± (0.02)V	Vertical Angle ± (0.02)°	Computed Decibel ± (3.0 dB)
0	18	1.60	4.78	50.6
5	18	1.58	4.16	51.0
10	18	1.55	3.21	52.2
15	18	1.53	2.23	49.6
20	18	1.50	1.63	47.6
0	25	1.36	8.59	51.3
5	25	1.32	7.96	51.2
10	25	1.27	7.06	52.6
15	25	1.24	6.13	45.9
20	25	1.20	5.33	37.7