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A Self Continuous Lake Water Quality Monitoring System for Early Pollution Detection

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Abstract-Water pollution is rapidly increasing throughout the world due to a skyrocketing demand for the consumption of water due the rapid urbanization and growing population. To withstand the demand of safe drinking water, the quality of the water has to be monitored day in day out. This paper is based on a research to develop a low cost real-time water quality monitoring system using IOT (internet of the thing). The system will be utilizing a different kind of sensors to measure both physical and chemical parameters of the water. There are four main parameters that have to be monitored, temperature, pH, dissolved oxygen and lastly turbidity. All he sensors will be controlled using a microprocessor, the data collected by the sensors will be transferred to the internet using a Wi-Fi module to have a real-time monitoring.

Keywords: Lake; water pollution; IOT; Arduino; autonomous;

1. Introduction

With the World Water Assessment program reporting that every day staggering two million tons of human waste is disposed into water courses, keeping tabs on quality is critical. At its core, the practice serves five major purposes [1]. Results are used to pinpoint any changes or trends that appear in water bodies over a period. These can be short of long-term developments. Regularly monitoring water quality is a crucial part of identifying any existing problems or any issues that could emerge in the future. For example, data has been used to reveal that over the past few years, increases in fertilisers used for food production had increased global nitrogen pollution in rivers by up to 20%. When designing and developing pollution prevention and management strategies data collected from water quality monitoring efforts is hugely helpful. With 70% of untreated industrial waste dumped straight into water systems, pollution management is a must. Today governments, communities and businesses are required to meet a range of water quality goals. Monitoring data is used to determine whether pollution regulations are being complied with. From oil spills and radiation leaks to floods and mass erosion, water quality monitoring data is a must when developing emergency strategies.

Water quality monitoring data is incredibly useful however it's not always easy to gather. Specialists use a range of different techniques to put together results, including taking samples of chemical conditions, analysing sediments and using fish tissue extracts to find traces of metals, oils, pesticides, dissolved oxygen and nutrients. Physical conditions such as temperature, erosion and flow offer valuable insight while biological measurements regarding plant and animal life indicate the health of aquatic ecosystems [2].

At the end of the day, water quality monitoring is an essential part of keeping the planet healthy and sustainable. As we continue to build cities, clear land for farming and make other man-made changes to the natural environment, water quality monitoring becomes increasingly important [1]. Land-based activities can have a huge impact on water systems and it's critical that we realise how these affect waterbodies, both above and below ground.

In 2008 clean water council in Minnesota announced on how the tax money is used to clean up and protect the water in their country. The total budget to protect the water is estimated to be around $220.514 million out of that budget $ 41 million was allocated for monitoring mapping and data analysis of the water quality this is around 18% of the total allocated budget [3].

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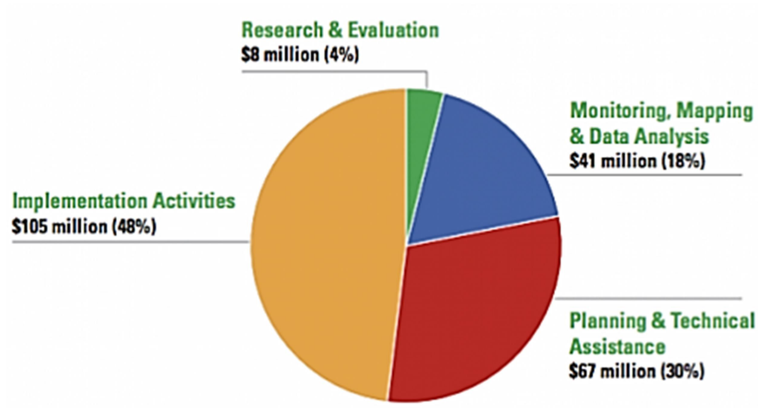

Figure 1. Tax money that is used to clean up and protect the water in their country [3]

A study done Water Environment Partnership in Asai WEPA in 2006 shows that out of 1,064 rivers that were analyzed only 619 rivers turn out to be clean this is only 58% of total rivers the rest of then falls under polluted category [4].

In 2005 National Institute Research Institute of Malaysia (NAHRIM) has reviewed 90 lakes around Malaysia, according to their report more than 60% of the lake that was reviewed are experiencing eutrophication. [5] In another study based on the three biggest lakes in Malaysia (Tasik Bunut, Tasik Chini and Tasik Bera) the report shows that all this three lakes water quality are deteriorating. The water reduction quality is caused mainly by overusing fertilizers by nearby plantations, sewage waste from the nearby rural area [6], logging activities around the lake and lastly oil discharge from motor boats which used on the lake. All this contribution leads to a reduction of marine life in the lake.

To save the marine life from deteriorating, a well maintains a system to monitor the quality of the lake has to be established. A precise and accurate measurement of the water quality has to be obtained in order to properly monitor and maintain the quality of the lake. One of the best approach to monitoring the quality of the water is by using a real-time water monitoring system, this type of system will help to continuously monitor some individual parameters of the water that can be used to monitor the quality of the lake, this will help to manually control each parameter of the water to best suit the marine life in the lake.

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2. Materials and Methodology

2.1. Design.

Figure 2 and Figure 3 represent the overall design of the boat all the sensors for the data collection will be fitted through the hole which are placed at the bottom of the boat and the electronics components for data collection will be placed in the right compartment of the boat. Where else in the left compartment of the boat the solar charger converter and the LiPo battery will be placed, this is to increase the ease of the maintenance. Three ultrasonic sensors placed on the front, left and right of the boat, the reason behind the placement of the ultrasonic sensor is further explained in the flowchart. 6 solar panels 3 each side will be connected in parallel and will be placed on top of the compartment to cover the compartment.

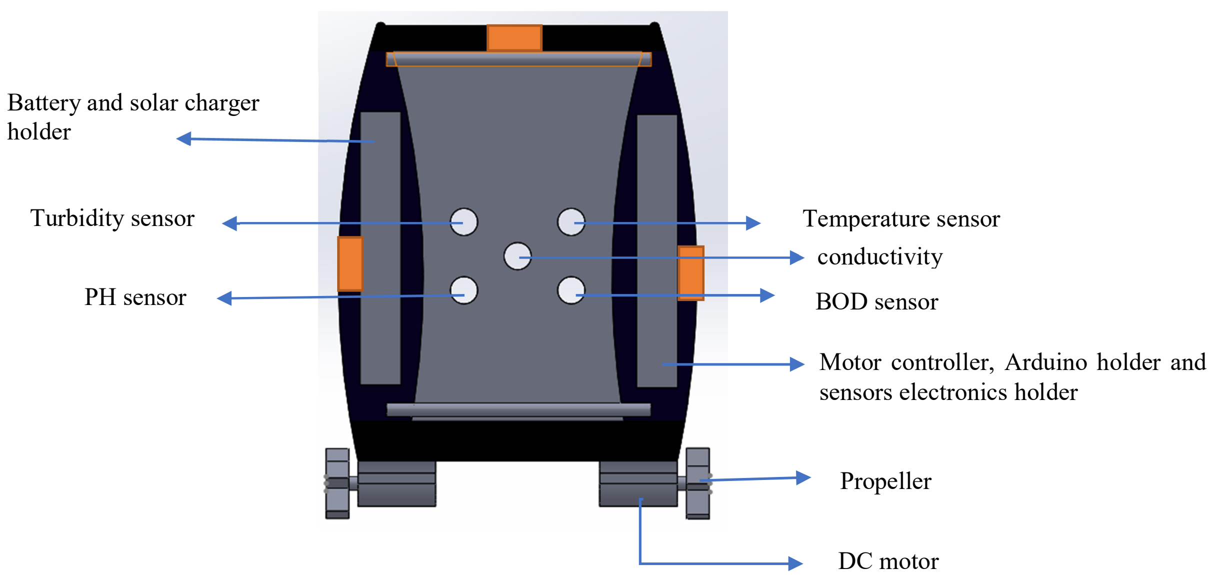

Figure 2. Overall Design of the Boat

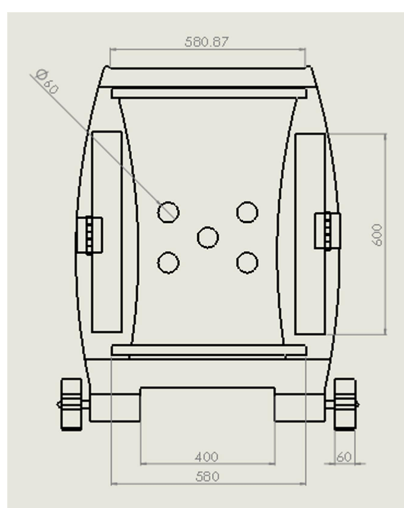

Figure 3. 1.1 Scale drawing (mm)

2.2. The overall design for data transmission

The overall design of the data collection consists of 5 different sensors and one microcontroller (Arduino) to obtain data. The gateway system for transmitting data to the cloud will be further discussed below.

2.2.1 Microcontroller

Arduino Mega 2560 which is illustrated in Figure 4 [7] has been chosen to be used as a microcontroller in this paper. For the data transfer, it acts as a sensor node to extract the data from the sensors to it. The main reason for choosing Arduino is due to its cost, it is an inexpensive open source product. The main processor is Atmel's ATmega 2560 microcontroller with a clock speed of 16MHz and also a 256kB of storage, the chip has enough clock speed and memory to process the data to the cloud.

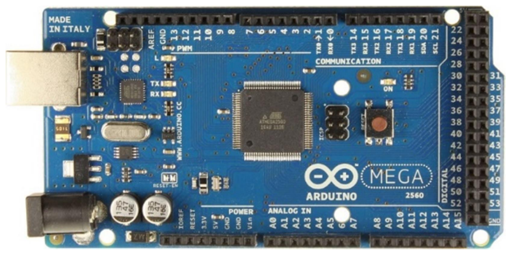

Figure 4. Arduino mega

2.2.2 pH sensor

To record the pH of the water pH sensor from phidgets is used. It can read the pH value from 0 to 14 and can be operated from a temperature range of 0 to 80 ℃. The sensor uses a BNC connection to transmit data. The signal from the sensor has to be converted to an analogue voltage signal in order for the Arduino to store the data. Figure 5 illustrates the pH sensor used in the system.

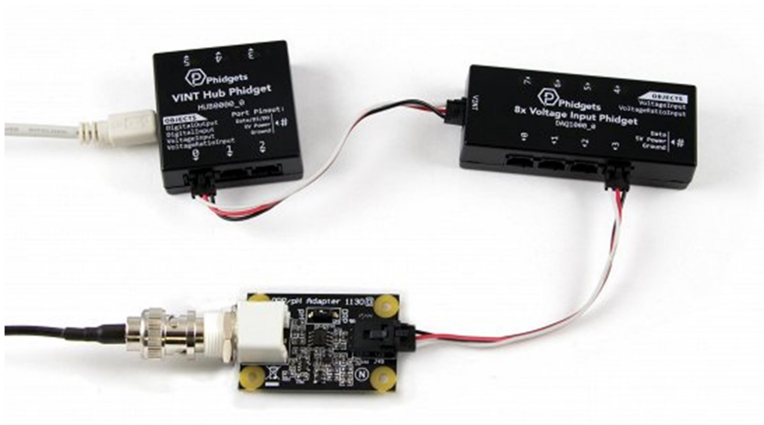

Figure 5. Phidgets pH sensor [8]

2.2.3 Temperature

The temperature sensor used to detect the temperature of the water is a standard LM35 which illustrated in Figure 6 [9]. This sensor can read a temperature range from -55 ℃ to 150 ℃, the main reason for choosing the temperature is due to its accuracy at a normal condition and the temperature in the lake would rarely go to an extreme range. The accuracy of the sensor at a normal condition is at 0.5 ℃. Since the sensor is directly calibrated in Celsius, the Arduino can easily collect the data from the sensor using a pulse-width modulation (PWM).

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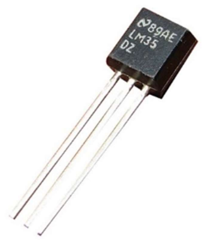

Figure 6. LM35 temperature sensor [9]

2.2.4 Electrical Conductivity

To measure the conductivity of the lake a conductivity sensor is used [10]. The sensor has a range of conductance of -2000 to 1300 µS/cm. The sensor uses the same BNC connector as the pH sensor that was previously discussed, therefore the signal from the sensor has to be converted to an analogue voltage signal in order for the Arduino to store the data. The sensor can go as deep as 343 meters before it malfunctions. The conductivity sensor used in the system is illustrated in Figure 7.

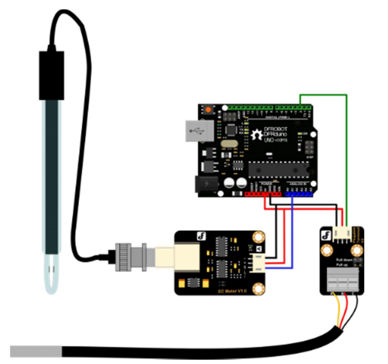

Figure 7. DF robot conductivity sensor [10]

2.2.5 Dissolved Oxygen

To measure the oxygen content of the water a dissolved oxygen is used. The sensor has a range of 0 – 20 mg/l [11]. The maximum operating temperature of the sensor is 50 °C and also the maximum operating depth of 343 meters. Figure 8 illustrated the DO sensor used in the system. The oxygen measure sensor used in the system is illustrated in Figure 8.

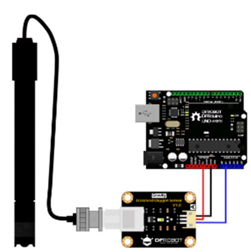

Figure 8. DF robot DO sensor [11]

2.2.6 Decision matrix to choose the best option for data transfer

The decision matrix Table shown in Table 1 helps to choose the most suiTable option for data transfer. The criteria rating is given based on the priorities for the system, since it has to cover the whole surface area of the lake the coverage area is the most important criteria for the system followed by the data transfer speed of the data since it has to send signals from six sensors continuously to the internet, the faster the data is transferred the more accurate the quality analysis will be, this will give an accurate value of the index at the precise place. Other than coverage area and transfer speed the third most important criteria is the amount of power consumption since the whole system will be autonomous the total power consumption of the whole system has to be very minimal as possible to last longer on a single charge. To increase the time taken for it to last on a single charge self-sustainable energy such as solar panels will be used.

From the decision matrix Table 1, it can be seen that data transfer through Wi-Fi is more suitable, this is due to Wi-Fi having a promising coverage area and high data transfer rate, higher speed and longer direct transmission range correlate with higher power usage and thus shorter battery life this is where it contributes fewer points. To overcome this issue the system will be equipped with solar panels so that it won't run out of power.

Table 1. Decision matrix Table for a gateway system

Factors	Criteria rating	Bluetooth	Zigbee	Wi-Fi	LoRaWan
Coverage area	4	2	1	3	4
Transfer rate	3	3	1	4	2
Power consumption	2	3	4	2	1
Cost	1	4	2	3	1
Total		27	17	31	25

As mentioned earlier the all the collected data will be transfer to the internet via Wi-Fi, the most reliable Wi-Fi module for this project is ESP8266 Wi-Fi serial module, this is due to its cost-effectiveness, reliabilities and lastly its low power consumptions. The Wi-Fi module used in this experiment is illustrated in Figure 9.

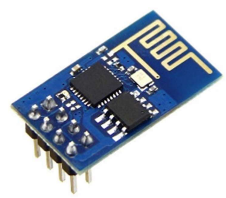

Figure 9. ESP 8266 Wi-Fi [12]

Figure 10 shows the electrical schematic of the overall data collection, the Arduino will be powered using a Li-Po battery.

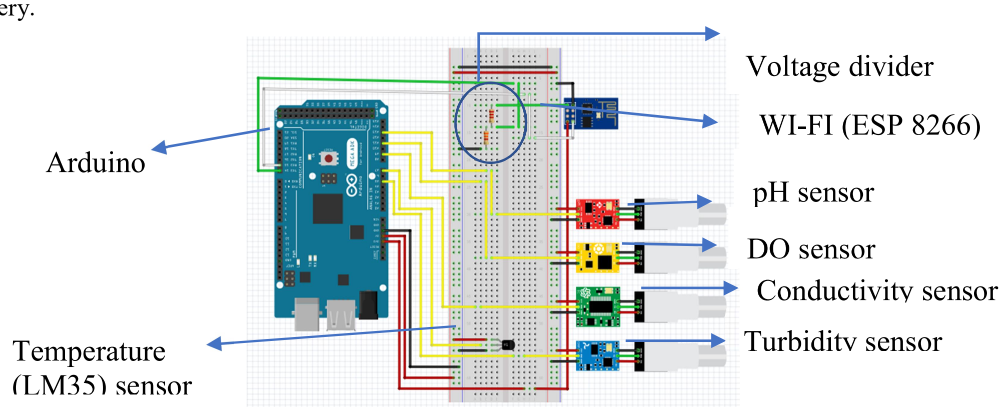

Figure 10. The Electrical Schematic for Data Collection

2.3 Autonomous

The system consists of four main components an Arduino mega, a GPS sensor for navigation, motor controller to control the DC motor and lastly an ultrasonic sensor to detect obstacles.

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2.3.1 GPS

This Grove - GPS module is a cost-efficient and field-programmable gadget armed with a SIM28 and serial communication configuration. It features 22 tracks / 66 acquisition channel GPS receiver. The sensitivity of tracking and acquisition both reach up to -160dBm, making it a great choice for personal navigation projects and location services, as well as an outstanding one among products of the same price class. Apart from that the GPS sensor only requires a voltage between 3.3 to 5 V, this will reduce the overall power consumption of the system. Lastly, the GPS has a baud rate range from 9600 to 115200 this will let the GPS and the Wi-Fi module to communicate if it is needed. The GPS module used in the system is illustrated in Figure 11.

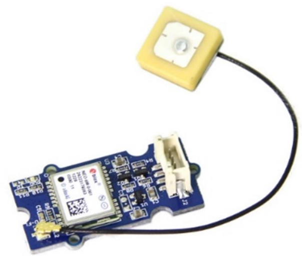

Figure 11. Grove GPS module [13]

2.3.2 Motor controller

To control the DC motor using the Arduino an L298N motor controller was used. L298N is equipped with a dual H bridge motor driver and can drive up to 2 bi-directional DC motor, this will help to control the 2 DC motor attached to the boat to be controlled individually. It requires a minimum voltage of 5 V to be operated, therefore it can be directly connected to the Arduino since Arduino only transmits signals in 5 V.

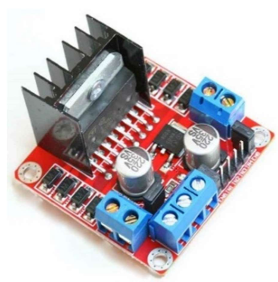

Figure 12. L298N motor controller [14]

2.3.3 Obstacle detection

To detect an obstacle continually the distance between the boat and the obstacle will be measured. To measure the distance of the obstacle an HC-SR04 ultrasonic sensor was used, the main reason this sensor has been chosen due to its accuracy and low power consumption, the sensor can be measured up to 1 meter with an accuracy of 0.3 cm, it can detect obstacle in a range of 45° angle and has a higher accuracy at 15° angle.

2.3.4 DC Motors

Figure 24 illustrated the electrical schematic diagram for the autonomous system two DC motor will be used to power the propellers in order to manure the system in the water, before determining the specification of the motor the total weight of the system has to be determined. A high torque and low-speed motor will be used propel the system in the water, once the weight is determined the torque of the motor will be determined using the calculation from Martenhoff's powerboat handbook [15]. The motor will be controlled using a motor controller, LN298 that will be controlled using an Arduino. The propellers will be 3d printed and it will connect to the shaft of the motor. Reviewing the design of the system it shows that the half of the boat will be submerged in the water therefore for the boat to properly paddle the boat the propeller of the boat must be placed at the middle part of the boat to partially submerge the propeller.

The boat will be equipped with two 12V DC motor with 111 rpm and 92 mA to propel, the motor will be attached to the rear end of the boat as illustrated in the design in Figure 9. It is estimated that the whole system will weigh around 5 Kg. The motor will provide a high torque of 3 Kg-cm and low speed, the specification of the motor is chosen based on from Martenhoff's powerboat handbook as mentioned earlier a power to weight ratio for an average 13ms^{-1} is calculated below.

$$Power\ to\ weight\ ratio = \ Power/Kg$$

$$13\ \mathrm{ms}^{-1} = \frac{54.82}{Kg} = 1300\ cms^{-1}$$

The maximum desired speed is 15 cms^{-1}. Therefore, the power to weight ratio of a motor to drive 15 cms^{-1} is.

$$\frac{54.82\ W}{Kg}\ X\ \frac{15}{1300} = \frac{0.633\ W}{Kg}$$

The estimated weight of the boat is around 5 Kg, the power of a motor to drive 15 cms^{-1} including a factor of safety of 20% is;

$$0.633\ \ W\ /\ Kg\ \ X\ 5\ Kg\ X\ 120\% = 3.8\ W$$

From the technical specification of motor pra provided, the maximum power of the motor provided is,

12V x 1.2 A X 80% = 11.5 W

Figure 13 shows a complete electrical schematic diagram of the autonomous system. From the Figure it can be seen that there are 3 ultrasonic sensors which detect the obstacle from front, left and right. The LiPo battery is providing electrical power to the motor controller while Arduino is controlling the function of motor controller through PWM pins.

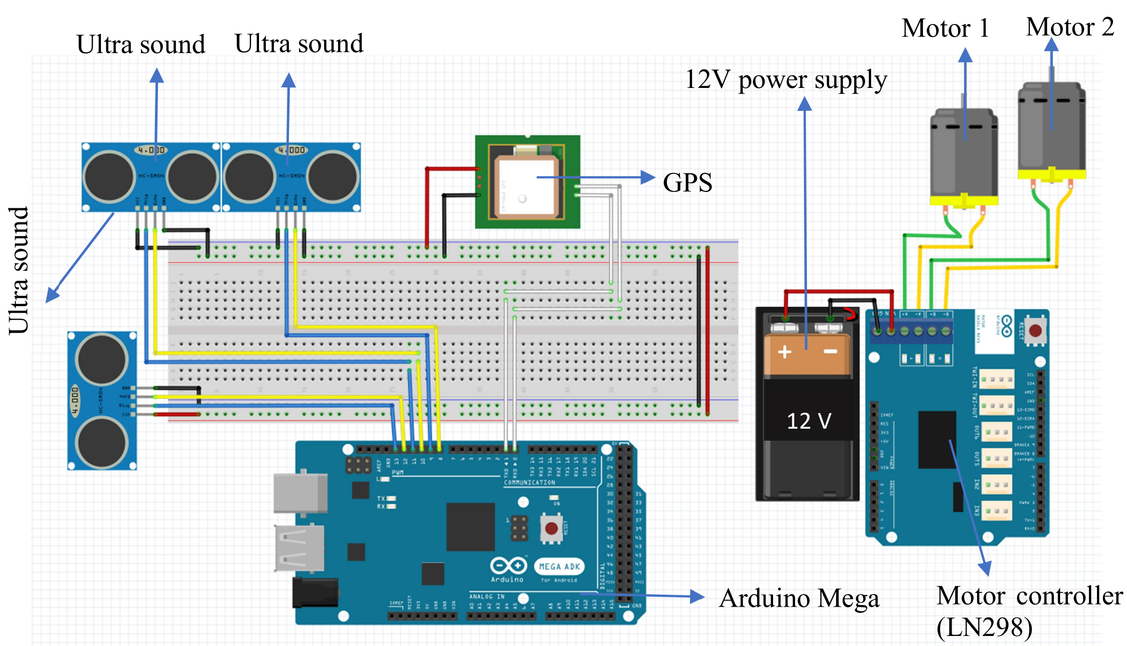

Figure 13. Electrical schematic design for the autonomous system

There are three stages to transmit the data from the Arduino to the cloud (Thingspeak), the first stage is to collect the data from the sensors to the Arduino, once all the data has been collected the second stage will be started which is to connect the Arduino to the internet, at the beginning the user has to manually key in the SSID

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name and the password of a Wi-Fi, this will let the Arduino connect to the internet, once the Arduino is connected to the internet the last stage will be started which is to transmit the data from the Arduino to the internet. Thingspeak was chosen due to its versatility of choosing different number channels and each channel will be given an IP address to send the data individually or in the group.

The autonomous part can be divided into two parts, manoeuvring using GPS sensor to set a path and obstacle avoidance using ultrasonic sensors. The ultrasonic sensors and the GPS sensors will be working simultaneously to make the boat fully autonomous. the system starts with initialising the GPS sensor. Once the GPS has been initialised a connection between the sensors and the satellite has to be established. The user can key in multiple coordinate (longitude and latitude) to create a path for the boat, from the flowchart it can be seen that the boat will autocorrect its direction to follow the new coordinates. As the boat identify its new

2.4 Power Source

Since the intensity of the sunlight changes day in day out, a lithium polymer (LiPo) battery will be required to store the energy from the sunlight. One of the main factors in choosing the solar panels in this project is to ensure that the output voltage from the solar panels must be higher than the LiPo battery voltage. The output voltage of the solar panels has to be higher because when the output voltage of the solar panels is lower than the batter, charges from the battery will flow back to the solar panels. However, no matter how good the solar panels is as poor weather condition or at night time the output voltage from the solar panels will be low. Therefore, to overcome this issue a diode will be used to only allow the current to flow in one direction, this will prevent any backward flow.

Apart from backflow another important consideration to not let the LiPo battery from overcharging. Overcharging the battery will degrade the lifespan of the batter. To prevent the battery from overcharging a solar controller also known as the solar charger will be used to regulate the voltage the battery gets from the solar panels. The overall electrical schematic of the solar charger is illustrated in Figure 27.

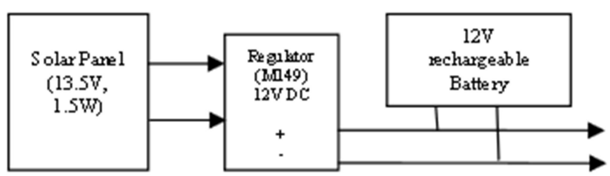

Figure 14. Solar power regulation and storage [16]

2.5 Water Sampling

The water sampling will be done at Taylor's university lake. The sampling will be done of different part of the lake to test the consistency and the accuracy of the data, the water sample will be taken to the lab to obtain the experimental result of the data the actual data from the sensor is then compared to the experimental data to determine the accuracy of the collected data. The procedure to measure the parameters is explained in detail in the appendix.

3. Results and Discussion

3.1 Functionality of Prototype

The overall design of the system is illustrated in appendix 1. The scale of the drawing is 1.1 in centimetres. It was found out that the overall weight of the system together with all the sensors, battery and solar panel was 6.2 Kg. The maximum speed at a 2 different throttle speed was measured, the speed at half throttle and the speed at full throttle. The throttle speed was controlled through the pulse width modulation (PWM) from the Arduino. The rage of PWM for a DC motor from an Arduino is 0 – 255 where 0 represent no throttle and 255 represent maximum throttle. The distance and the time at 2 different throttle speed are measured to calculate the speed. The sample calculation using equation 5 is shown below. According to the calculation, the speed at full throttle is 40.8 cm/s, by calculating the speed of the system the rate of area coverage can be computed, equation 6 shows the formula to compute the rate of an area the system can cover. Apart from that the angular displacement was also computed by estimating the time taken for the system to make full 360° rotation, the rotation is created by rotating on of the motor in a clockwise direction and the other motor in an anti-clockwise direction, this will create an opposite moment at each of the propeller to rotate the system. The results from the findings are shown in Table 2.

Speed.

$$V = \frac{D}{T} \quad (1)$$

Where;

V = Speed (cm/s)

D = Distance travelled (cm)

T = time (s)

$$V = \frac{7.5\ m}{18.4\ s} = 0.408\ m\ s^{-1} = 40.8\ cm\ s^{-1}$$

The rate of the area covered.

$$\mathrm{A = v\ X\ w}$$

Where;

A = rate of Area covered ($^{cm^2}/_{s}$)

V = speed (cm/s)

W = width of the boat (cm)

The rate of angular displacement.

$$\omega = \frac{360}{\mathrm{T}}$$

Where;

ω = Angular displacement (°/s)

T = Time

Table 2. Performance of the boat at different throttle speed

Throttle	Parameter	Set 1	Set 2	Set 3	Average
	Distance	100	100	100	100
Half Throttle	Time	43.5	42.5	45.6	43.9
	Speed	2.30	2.35	2.19	2.28
	Rate of area	133.4	136.3	127.0	132.2
	Time take for a full 360 rotations (Left)	32.6	35.8	35.8	34.7
	Time take for a full 360 rotations (Right)	39.7	40.1	40.9	40.2
	Angular displacement (Left)	11.04	10.0	10.1	10.4
	Angular displacement (Right)	9.1	9.0	9.0	9.0
	Distance	100	100	100	100
	Time	19.7	22.4	21.9	21.3

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Full Throttle	Speed	5.08	4.46	4.57	4.70
	Rate of area	294.64	258.68	265.1	272.8
	Time take for a full 360 rotations (Left)	19.3	22.0	20.8	20.7
	Time take for a full 360 rotations (Right)	23.6	24.5	23.4	23.8
	Angular displacement (Left)	18.7	16.4	17.6	17.6
	Angular displacement (Right)	15.3	14.7	15.4	15.1

From Table 2, it can be seen that the angular displacement when turning right is higher than the angular displacement when turning left. The difference between angular displacements might be due to 2 different reason, the first reason might be due to an improper weight distribution of the boat and secondly both the motors are not properly aligned where one is lower than the other one. This cause one of the motor to have a higher drag when rotating compared to the other this will cause of the motor to rotate slower than the other. The coding for the autonomous system can be further improved by taking in account of this error for a more proper manoeuvring

From the Table, the rate of the area covered at different throttle speed was calculated, at full throttle, the average rate of the area covered is $272.8cm^2/s$. The time taken for the boat to map out Taylor's lake can be calculated by using equation 8. The area of the lake is measured using google map. From Google map it ,was known that the area of the lake is approximately $16{,}400m^2$. The calculation for the time takes is shown below. From the calculation it can be seen when the boat is moving at full throttle, it take approximately 1 week to cover the whole lake in Taylor's university.

$$\mathrm{T} = \frac{Area\ of\ lake}{r\text{ate of arae}} \tag{4}$$

$$\mathrm{T} = \frac{1.64 \text{ x } 10^8 \text{ cm}^2}{272.8 \text{ cm}^2/\text{s}}$$

$$\mathrm{T} = 6.958 \text{ days}$$

3.2 Taylor's Lakeside Water Quality

Table 3 shows the results obtained from Taylor's University Lake. The measurement is taken at 3 different throttle speed, measurement when the boat is static, measurement when the boat is moving at half throttle speed and lastly the measurement when the boat is moving at full throttle speed.

Table 3. Data collection at a different location of Taylor's lake

Water Quality	Throttle	Lake Water Samples				
		Location 1	**Location 2**	**Location 3**	**Location 4**	**Location 5**
Turbidity (V)	Static	4.2	4.2	3.8	4.2	4.2
	Half throttle	4.2	4.2	3.6	4.2	4.2
	Full throttle	4.2	4.2	3.6	4.2	4.2
DO (mg/L)	Static	5.73	6.11	6.14	5.81	6.27
	Half throttle	8.70	8.78	8.83	8.80	8.77
	Full throttle	8.79	8.87	8.90	8.88	8.86
Temperature (°C)	Static	28.30	28.55	28.30	28.55	28.05
	Half throttle	28.80	28.45	28.30	28.30	28.55
	Full throttle	28.55	28.30	28.25	28.55	28.55
pH	Static	8.6	8.8	8.5	8.4	8.4
	Half throttle	8.5	8.8	8.4	8.3	8.4

	Full throttle	8.5	8.8	8.6	8.6	8.3
Conductivity	Static	335.5	346.7	349.5	355.8	345.9
	Half throttle	225.6	235.9	269.7	244.6	255.8
	Full throttle	105.1	98.6	111.6	132.9	144.9

From the Table it can be seen that the turbidity value of the lake is at 4.2V, the voltage of the turbidity sensor can be calculated using the relationship equating between voltage and the turbidity given by the manufacturer, the equation relating voltage and turbidity is shown in equation 9. From the equation the turbidity of the lake is measured to be 27.9NTU, the turbidity value remains constant even though the speed varies. The turbidity at location 3 of the lake slightly varies, this can be due to some dirt or littering from people since location 3 is near to allocated area for people to smoke in Taylor's University.

$$\mathrm{Y} = -1120.4X^2 + 5742.3\mathrm{X} - 4352.9 \tag{5}$$

Where.

Y = Turbidity (NTU)

X = Voltage (X)

$$\mathrm{Y} = -1120.4(4.2)^2 + 5742.3(4.2) - 4352.9$$
$$\mathrm{Y} = 27.9\ NTU$$

As for DO, it can be seen that the data obtained when the boat is static and the when the boat is moving is different this shows that the sensitivity of the DO sensor is slightly lower. Moving on to the temperature and the pH sensor, the data collected at different scenarios are constant therefore it can be concluded that the temperature used in this system is responding well to the speed of the boat. Lastly, the data obtained from the conductivity sensor is slightly deviating in all kind of scenarios and at a different location, but the deviation is in the range of ± 20 at the same throttle speed. However, as the throttle speed increases the deviation changes drastically.

3.4 Experimental data vs actual data

Water sample from Taylor's lake was taken and test it in the lab to test the difference between the experimental data which is shown in Table 4 and the actual data obtained from the sensors, to test the actual data to the experimental data the actual data obtained from Table 22 will be average it out into Table 5 shows the data obtained from the actual lab test and the average data at difference speed. In the Table, the percentage difference is shown in Table and illustrated graphically in Figure 15.

Table 4. Experimental data

Parameters	Set 1	Set 2	Set 3
Turbidity / NTU	4.6	4.5	4.7
DO / mg/L	6.68	7.05	6.9
pH	8.3	8.9	8.5
Conductivity/ µS/cm	356.7	301.8	306.7

Table 5. Averaged experimental and actual data

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Parameters	Experimental data	Data from sensors		
		Static	Half throttle	Full throttle
Turbidity / NTU	25.6	27.9	27.9	27.9
DO / mg/L	6.6	6.0	8.8	8.9
Ph	8.3	8.5	8.5	8.6
Conductivity (µS/cm)	321.7	346.7	246.3	118.6

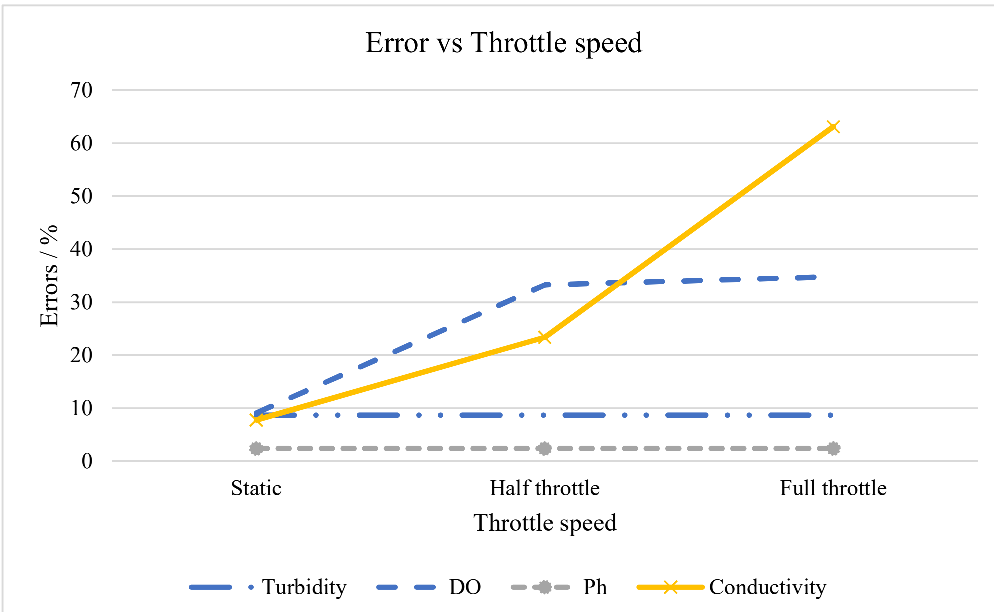

Figure 15. Graphical representation of errors and throttle speed

From Figure 15 it can be seen that the percentage difference of turbidity and pH is constant when the speed is changed where else for DO and conductivity the percentage difference is changing at different speed, the percentage difference of conductivity increases linearly with the speed where else for DO the increment is constant and slowly start to decrease. From the Figure, it can be concluded that the speed of the boat has to be below half throttle to obtain a more comparable data compared to a lab tested data. The data obtained from the lab test might not be accurate since the apparatus used in the experiment might not be fully calibrated and it might not be accurate compared to a real water quality testing. Apart from that parameter such as dissolved oxygen and turbidity uses a standard temperature to obtain the value, during the experiment the current temperature was assumed to be the standard temperature to match the result with the data collected from the sensors.

To justify the condition of the lake the data obtained from half throttle speed will be used. Table 6 shows a comparison between the data at half throttle speed and the optimum condition of the lake previously discussed in the literature review section.

Table 6. Summary of finding for collected data

Parameters	Taylor's Lake	Optimum condition
Turbidity / NTU	27.9	5 -55
DO / mg/L	8.8	More than 8
pH	8.5	6.5 – 8.5
Conductivity / uS/cm	246.3	150 - 500

Temperature / °C	28.4	25

From the Table 6, it can be seen that all the parameters obtained from the lake falls within the optimum range except the temperature of the lake. The optimum temperature of the lake was set with respect to the Dissolve oxygen as previously discussed, from the literature review the to obtain a dissolved oxygen of 8mg/L and above the temperature must be less than 25 °C, from the Table it can be seen that the even though the temperature of the lake was slightly higher the dissolve oxygen is still more than 8 mg/L. Apart from the temperature it can be seen that the pH of the lake is at the edge of the maximum requirement level, this increment can again reflect to the temperature where as previously discussed in the literature review as the temperature increases the hydrogen ions will also increase, therefore, the pH of the lake will shift to left but the acidity of the lake remains the same or vice versa. Therefore, comparing to the standard temperature of 25 °C the lake should have a higher pH than the optimum condition.

3.5 Charging and discharging rate

Figure 16 represents the charging rate of the LiP0o battery using 6 solar panels which are connected in parallel. From the Figure, it is shown that it takes roughly about 2 hours for the voltage to stabilise from 9.45 V to 11.25 V. The maximum voltage the 6 parallel solar panels can only produce around 11.74 V under an optimum condition.

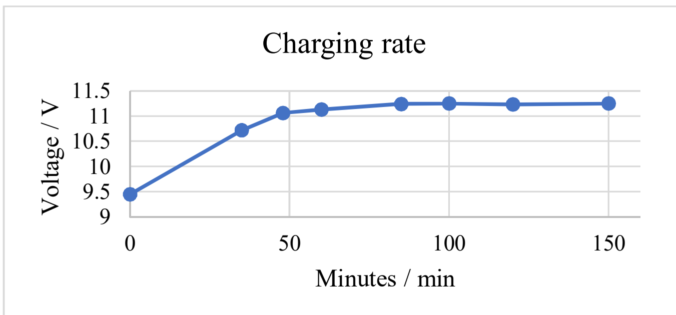

Figure 16. Battery voltage against time (Charging)

The solar panels did not achieve the maximum voltage due to lack of availability of sunlight during the test day. When connected to power socket it was measured that the maximum voltage the LiPo battery can take in was at 12.5 V. This show that the solar panels does not produce enough voltage to fully charge the LiPo battery. The value obtained is still acceptable since the system will not be running for the entire day and also as the battery is discharging the solar panels will be continuously charging the battery. Table 7 and Table 8 show the experimental data for charging and discharging rate using solar panels.

Table 7. Experimental data for charging rate using solar panels

Time / hr	0	35	48	60	85	100	120	150
Voltage / V	9.45	10.72	11.06	11.13	11.24	11.25	11.23	11.25

Table 8. Experimental data and discharging rate

Time / hr	0	1	2	3	4	5	6	7	8	9	10	11	12	12.4
Voltage / V	12.5	12.4	12.1	11.9	11.8	11.6	11.4	11.4	11.2	11.2	11.2	11.0	10.9	10.8

Figure 17 shows the discharge rate of the battery when the 2 DC motor is running, by referring to Figure 16 it can be concluded that it takes about 12 hours and 15 minutes to drop the voltage from 12.5 V to all the way to

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10.94 V. Once the battery reaches 10.94 V the DC motors stops operating, this is due to the requirement of the DC motors. A 12 V DC motors require a minimum of 10.94 V of the voltage supply to operate, where else at this point the data collection will be still operation since all the sensors and the Arduino requires a 5 V supply.

In addition, by referring to Figure 16 it can also be seen that the voltage drops range from0.23 V to 0.06 V per hour. The decrement of voltage slows down to a minimum between11.55 V and 11.22 V. Despite that, the voltage decreases tremendously from 10.94 V to 10.79V within 15 minutes. Other than that Figure 17 shows that there is some fluctuation on the discharging rate, this can be due to two factors, the battery might be faulty therefore it is not giving a steady discharge rate or there might be some unwanted internal friction when the motor is rotating.

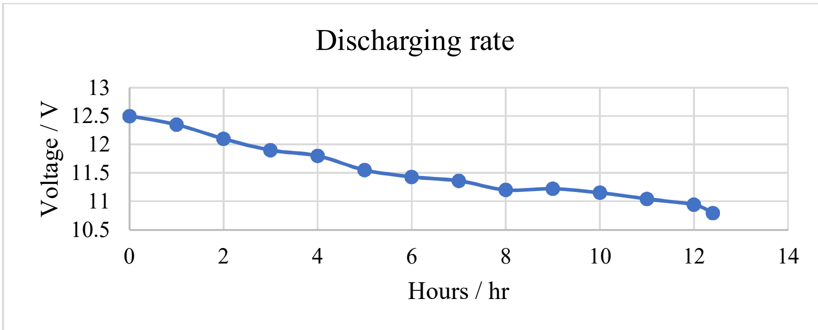

Figure 17. Battery voltage against time (Discharging)

In summary by comparing both Figure 16 and Figure 17 it can be conclude that the minimum voltage required to run the DC motors is 10.94 V and therefore the total operational hours of the system is around 12 hours The discharge test was done by running the DC motors on air, as in real life the operational hour will be less due to friction of the water and the thrust required to move the boat. On the bright side, the charging rate was about 2 hours using the solar panels, therefore, this will increase the operational hours of the system.

To predict the overall power consumption of the system the additional power consumption of the sensors, probes and microcontrollers as well as the additional force due to drag by the water must be included. Table 9 below summarizes the power consumption of all components.

Table 9. Power usage of each component except motor based on technical specifications

Components	Power usage (W)
GPS	0.1500 [13]
3 Ultrasonic sensors	0.2250 [17]
Temperature probe	0.0500 [9]
Dissolved Oxygen probe	0.0675 [11]
Turbidity probe	0.2000 [18]
Arduino Mega	0.2500 [7]
Motor Controller	0.1800 [14]
Total	**1.1225**

According to the previous calculation, each DC motor requires 4 W, using this information the total power consumption of the system can be calculated. The power consumption between all other components relative to the motors is calculated below. This shows that apart from the DC motors 14.03% of the total power is being used to power the sensors and the Arduino.

$$\frac{1.1225\ \text{W}}{8\ \text{W}} \times 100\% = 14.03\%$$

4. Summary of findings

There are 3 different finding in this project, design, data collection from the lake and lastly the data from the solar panels. The overall weight of the boat measured to be 6.5 Kg, the boat has an average speed of 4.7 cm/s, but to obtain an accurate data the boat must only have half throttle speed of 2.28 cm/s. as for the angular displacement at half throttle speed, the boat has an angular displacement of 10.4°/s to the left and 9°/s to the right.

To compute the accuracy of the sensors data from 5 different location and was obtained from the data obtained from Taylor's University lake. All the data from the sensors was directly uploaded to Thing Speak. From the findings it was known that the lake has an average temperature on 28.5 °C, on average the turbidity of was the lake was known to be 27.9 NTU where else there was a slight deviation at location 3 due to littering. The dissolved oxygen has the greatest number of percentage difference comparing to an actual lab tested data, the percentage varies from 9% all the way to 34% as the speed increases, on average the lake gives DO of 8.3 mg/L. the pH sensor and the conductivity sensor gave a small percentage difference, where the Ph sensor gave a difference of 2.4% and the conductivity sensor errors range from 2 to 7%. On average the lake has a Ph of 8.7 and have a conductivity of 4093.5 µS/cm.

Moving on to the data from the solar panels, the solar panels takes approximately 2 hours to cully charge the LiPo battery. It was found out that the minimum power required to run the DC motor was 10.94 V, therefore the battery takes approximately 12 hours and 15 minutes to discharge the battery from 12V to 10.94V, with respect to the power consumption of the DC motor the rest of the sensors including the Arduino and the motor controller consumes 14% of power compared to the DC motors.

5. Conclusion

In this study, the autonomous water quality monitoring system will be energy sustainable with the help of solar panels, this will increase the charge time compared to the discharge rate, therefore, it will keep the system powered on more longer compared to a system without solar panels. The system will move autonomously in a fixed coordinate pattern while avoiding any incoming obstacle automatically, all the data will be measured when the system comes to halt and it is uploaded to ThingSpeak through Wi-Fi data transfer with the help of ESP Wi-Fi module connected to the Arduino. From the data obtained it was slightly challenging to obtain real-time data due to the fluctuation of the temperature. To minimize the complexity of the technical part of the boat the data collection and the autonomous part of the boat will be working independently, both the data collection and the autonomous part will be using individual Arduino. The data collection and the autonomous part can be linked by the time of the data collection and the coordinate of the GPS at a given time. Separating both the system will increase the ease of maintenance of the boat since it is easy to identify the problem when there is a malfunction. Due to the fluctuation of the temperature in the lake, it is slightly harder to conclude the condition of the lake.

Looking back at the objective of the project, To produce a self-sustainable lake monitoring unit to measure lake water quality in real time, it can be concluded that in the end of the project it can be concluded that the self-sustainability was able to be achieved with the implementation of the solar panels which takes around only 2 hours to charge the batter and also by implementing obstacle avoidance system, with the aid of the low-powered Wi-Fi module a real-time monitoring system was able to be achieved. Moving on to the second objective, to develop a low-cost autonomous system for lake monitoring, it was also achieved by implementing all the cheap technology available in the market to produce a low-cost autonomous system. The autonomous system is able to map out Taylor's lake approximately in 1 week, but at a higher throttle speed, the errors of the data collected are on the high side. However, reducing the throttle speed of the system decrease the errors.

6. Future work

In order to have a more reliable and efficient data, future research can be conducted to determine a procedure of how to efficiently change these sensors in the field. Calibrating the EC sensor over a longer period seemed to have fixed.

The calibration issue with the EC sensor. However, further research needs to be conducted to ascertain if a longer calibration of the EC sensor truly fixed its ability to hold calibration. Future study is necessary to increase the system's reliability over time by finding out whether the probes ability to hold calibration varies depending on the water quality.

It will also be necessary to integrate the logs for power drawn from the solar charged battery to the file containing the sensor readings so that this can be used to troubleshoot the system when it malfunctions. The autonomous system could not detect obstacle underwater the sensor can only detect the obstacle on the surface of the water, further studies had to be done in order to implement an underwater obstacle detection.

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