MOVABLE WATER QUALITY MONITORING SYSTEMS FOR AQUACULTURE TANK (INDOOR)

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechatronics Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"MOVABLE WATER QUALITY MONITORING SYSTEMS FOR AQUACULTURE TANK (INDOOR)"** was prepared by **MAH WAI PENG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechatronics Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Water quality parameters such as pH, temperature, water level, dissolved oxygen, ammonia, dissolved carbon dioxide, total soluble solid and etc, need to be monitored constantly in recirculating aquaculture system (RAS). RAS is a technique used in fish production by reusing the water. Conventional water quality monitoring systems are static and sinking type. Current innovative design allows sensors to be floating and moving around the culture tank. A microcontroller-based movable water quality monitoring system was built to measure water quality at every corner of the tank and send the results measured to user. pH and temperature sensors were connected with Arduino Uno to measure water quality every minute. 1Sheeld+, a “Bluetooth LE Tethered” shield for Arduino was used to transmit data between Arduino and smartphone. By pairing 1Sheeld board with 1Sheeld app over Bluetooth, data collected was logged into memory of smartphone as CSV format and sent to users via e-mail. Users will receive e-mail alert if data measured is out of range. This battery-powered system is automatically driven by a mini boat or also can be remotely controlled by user to move around the culture tank. Water quality parameters at different points of culture tank were measured. Users were able to obtain updated results from time to time and perform data analysis. A movable water quality monitoring system was successfully developed. The system was able to move all over the tank and measure pH value and temperature. Updated results are sent to users through email.

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LIST OF SYMBOLS / ABBREVIATIONS

°C	temperature
A	current
Ah	ampere hour
CO_2	carbon dioxide
I^2C	inter integrated circuit
NH_3	ammonia
ppm	concentration
µ	micro
m	milli
c	centi
k	kilo
M	mega
G	giga
Ω	ohm
V	voltage
m	meter
s	second
%	percentage
bps	data rate unit
mg/L	concentration
Hz	frequency

3D	three dimensional
ABS	acrylonitrile butadiene styrene
AC	alternating current
BNC	Bayonet Neill–Concelman
CMOS	Complementary metal–oxide–semiconductor
CSV	comma separated values
DC	direct current
DO	dissolved oxygen
EC	electric conductivity
EPS	expanded polystyrene

FS	full scale
I/O	input/output
IDE	integrated development environment
IPMC	ionic polymer-metal composite
IR	infrared
IP	internet protocol
GPRS	general packet radio service
GPS	global positioning system
GUI	graphical user interface
ISE	ion-selective electrode
LAN	local area network
NTU	Nephelometric turbidity units
pH	potential of hydrogen
PIC	peripheral interface controller
PING	computer network
PLA	polylactide acid
PVC	polyvinyl chloride
RAS	recirculating aquaculture system
RC	remote control
ROV	remotely operated underwater vehicle
SMS	short message service
UART	universal asynchronous receiver-transmitter
USB	universal Serial Bus
USCG	United States coast guard
XPS	extruded polystyrene

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CHAPTER 1

INTRODUCTION

1.1 Introduction to Mobile Monitoring System for Aquaculture

Recirculating aquaculture system (RAS) is an essential technology for fish farmers by reusing the water in fish production. It is commonly found in the aquaculture field. This system is an indoor and tank-based system where biological filters are used. Generally, this method allows fish to grow at high density under controlled environmental conditions (Business Queensland, 2016).

As the usage of water in RAS is less and the system is space saving, it is environmental friendly to use at producing fish commercially. Traditional fish farming was used in the last few decades; the growth of fish is fully dependent on external environment factors such as river's temperature, cleanliness of water, oxygen levels and other factors. On the other hand, RAS is able to eliminate some of these external factors depending on the design of the system. The growth of fish is greatly dependent on the water quality factors. The parameters that affects the growth of a fish include temperature, light, water flow rate, dissolved oxygen, dissolved carbon dioxide, salinity, organic material, pH and feeding rate. Water quality parameters must be fully monitored or controlled as water quality ensures fish's health and performance in aquaculture production system.

The data collection of water parameters and observation is essential in aquaculture. Therefore, effects have been geared towards utilising modern technology to improve aquaculture field. A low cost, efficient water quality monitoring system is needed to serve multiple applications when necessary. Water quality monitoring system allows users to record water quality parameters and observe the behaviour of fish with fully integrated, user friendly and automated system. This high efficiency system is capable of collecting data consistently and constantly which helps to reduce human labour.

In recent years, many researchers developed different types of water quality monitoring and surveillance systems for aquaculture. The development in modelling and simulation of the system are important during the design and analysis process of maneuverability. Based on specific requirements, monitoring system can be used to measure water quality parameters such as pH, temperature, salinity, water level, turbidity, ammonia level, and others. Various types of sensors are used to detect water parameters in the system.

Up to now, most of the water quality monitoring systems are mounted to a stationary or specific point. The system can be placed in a large tank and data collected as the parameters may vary at different location. Therefore, movable water quality monitoring system is needed in aquaculture tanks. The use of this system is to be able to fully monitor water quality at different points by moving around the tank.

This study attempt to design and build an affordable movable microcontroller-based water quality monitoring system. In this proposed design, the pH sensor, temperature sensor, and Arduino board were placed into a housing and it was attached on top of a toy boat. The system will be moving around the tank continuously when the power is turned on. The water quality parameters collected were saved into smartphone's memory as Comma-separated values (CSV) file and sent to users through email. When users are away from site, they can retrieve updated data from email and view the data as table format in Excel sheet.

1.2 Importance of the Study

The findings of this study will benefit the fish farmers considering that RAS is an important technology in aquaculture industries today. Movable water quality monitoring systems are needed for better monitoring and control. The greater demand of high efficiency in fish farming justifies the need for more advanced RAS integrated with movable monitoring system. Thus, improvement and modification is approached to enhance the performance of existing technology.

Information was gathered from different aspects such as existing RAS technology and robotic fish to have better understanding. Further study from journals and websites allows comparison of current technology from different authors, thus, modification and improvement can be done on current technology.

1.3 Problem Statement

The RAS should aim to make sure every water quality parameter is under control at every corner of the tank. Equally distributed optimum range of these parameters allows fish to grow at best state. The system should make sure that the fish is free of stress and other diseases.

Until today, there are still many fish farmers using river for fish farming. Fixed production rate cannot be created as it is dependent on environment and water quality factors. Even though RAS is used, there are still some drawbacks in this system. The sensors of current RAS are fixed at certain spots. The parameters can only be detected at that particular area. Some fish may experience insufficiency of oxygen at area undetected by the sensors and affect the growth of fish. Besides, in order to obtain water parameters results, farmers have to be on site to check and measure the data.

By attaching the sensors on a movable water quality monitoring system, it is believed that this can make sure all the parameters are fully monitored at every part of the tank and minimize possible stress in fish. On top of that, the Internet of Things (IoT) allows farmers to receive updated results, anytime, anywhere.

1.4 Aims and Objectives

This project was initiated to create an innovative floating movable water quality monitoring system to monitor the overall conditions of the culture tank and collect data at different points and depth of the culture tank.

The objectives of the project are to:

i. Design and develop a floating and movable water quality monitoring system

ii. Develop an algorithm to measure water quality parameters at different points of aquaculture tank

iii. Integrate the sensor system with the Internet of Things (IoT)

1.5 Scope and Limitation of the Study

The scope of this project was to design a movable monitoring system. The first part was to create a microcontroller-based water quality monitoring system while the second part was to design and construct the housing for the system.

Cost of sensors was one of the limitation of the study. Due to limited budget for this project, some of the accurate and precise sensors such as dissolved oxygen sensor, salinity sensor and turbidity sensor are not affordable. Therefore, they were not included in this project.

The size of the whole system was another limitation. Due to the wire connection of sensors and the size of Arduino board, mini movable monitoring system was not achievable. Another limitation was that a smartphone must be located somewhere near the system in order to transmit data between Arduino and the smartphone via Bluetooth.

1.6 Contribution of the Study

Sensors in traditional aquaculture monitoring system are fixed at specific location and require farmers to be on site to monitor the water parameters every interval of time. This process is time consuming and data acquired may not represents the overall condition of the whole culture tank. Manual monitoring also requires manpower which there and then increase the production cost.

This study allows water parameters to be collected at every corner of the aquaculture tank without any manpower. Moreover, IoT enables farmers to receive updated data from email which reduces workload of fish farmers by not purposely going on site for monitoring.

1.7 Outline of the Report

Chapter 1 outlined the background of monitoring system for aquaculture. Problem statements together with aim and objectives were clearly stated in this report to keep the project focused. Scope and limitation of study were also written to help further improvement in the future.

Chapter 2 presented the literature review of the whole monitoring system. Existing water quality monitoring systems were briefly described and water quality parameters were stated. Hardware and components that were used by researchers were identified to provide a better planning in developing own prototype.

Chapter 3 described the methodology used and components used in achieving the aim of this project and also finishing of the whole prototype. Gantt chart for part 1 and part 2 were attached to keep the project on track.

Chapter 4 showed the development and improvement of the system in both hardware and software. The flow of Arduino code algorithms were discussed to indicate how the system works. Testing of system in aquaculture tanks was done to ensure the system can be operated properly.

Chapter 5 concluded the overall functions of the system and recommendations for future work were proposed.

CHAPTER 2

LITERATURE REVIEW

2.1 Water Quality Monitoring System

Many water quality monitoring systems have been developed. Each of the systems were designed to meet different applications or requirements. These systems can be installed indoor or outdoor. In this section, mainly indoor monitoring systems were discussed.

Ryuh et al. (2015) developed a multi-robot system for monitoring mariculture in the sea coast. It was a three joints fish shape robot and it can mimic the swimming movements of a fish. Sensors such as infrared (IR) sensors, ultrasound range sensors, Global Positioning System (GPS) sensor and water pressure sensor were included for navigation and detection of water. This robot was designed to collect underwater marine information such as temperature, Electric Conductivity (EC) and pH value. The architecture of this system was controlling multi-agent robot (clients) with buoy robot (supervisor) as shown in Figure 2.1. With this method, a multi-agent system was formed to monitor and cover large scale of sea coast effectively. Buoy robot can either receive measurements from clients or distribute command to the clients. It can communicate with an off-shore control centre at the same time to receive mission and collect data.

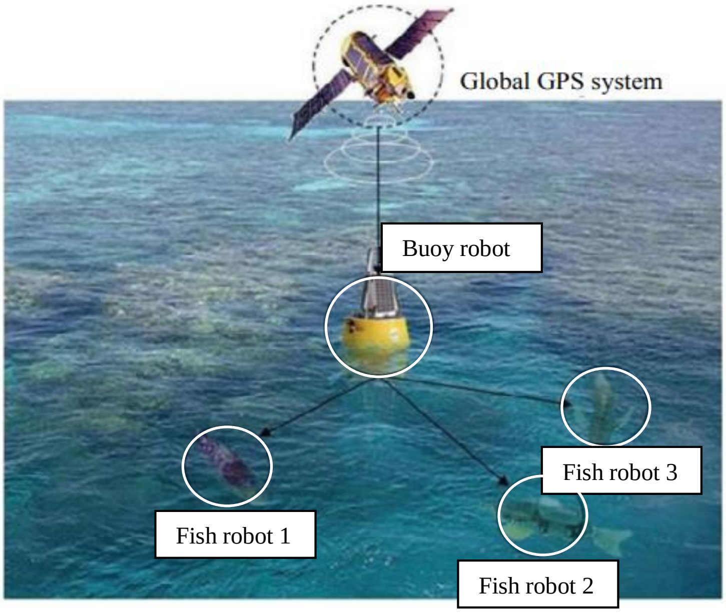

Figure 2.1: Control of multi-agent robot (client) with buoy robot (supervisor) (Ryuh et al., 2015)

A self-contained system was designed by Rillahan et al. (2009). The system's purpose was to observe and quantify the behaviour of Atlantic cod in an offshore aquaculture cage. The entire system including cameras, hydrophones and feeding tube were placed inside a modified U.S. Coast Guard (USCG) navigational buoy. Cameras were used to record movement of fish under water; hydrophones were used to detect swimming speed of fish; feeding tube was used to release fish food into the water. The objective of this system was to improve efficiency of aquaculture operations by gathering behavioural data of Atlantic cod. Figure 2.2 shows the structure of a net pen.

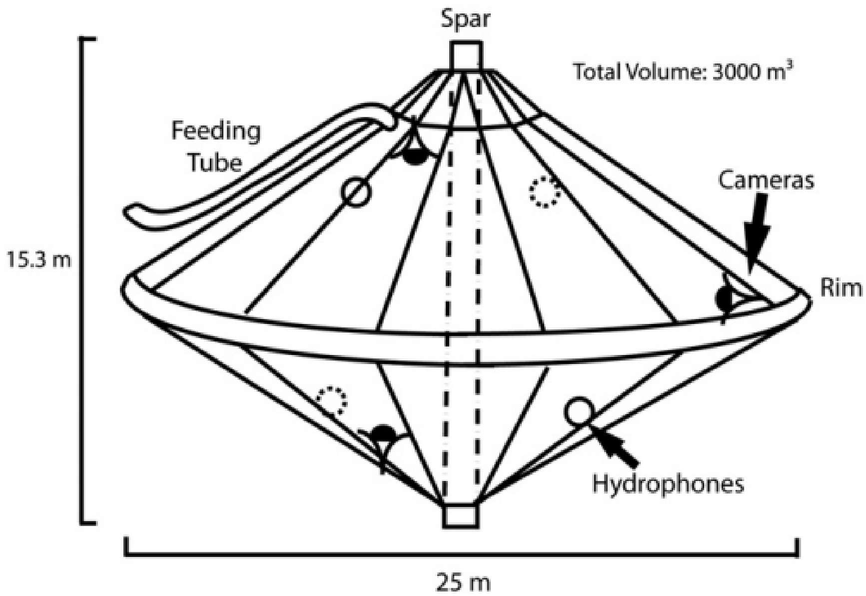

Figure 2.2: Placement of cameras, hydrophones and feeding tube on the Sea Station 3000 net pen (Rillahan et al., 2009)

Tan and his team members produced a robotic fish which can swim in the tank for mobile water quality sensing as shown in Figure 2.3. The robot was equipped with a GPS receiver for autonomous navigation, temperature sensor for sensing, microcontroller for controlling and ZigBee wireless communication module for communication. The circuit board was completely sealed off with silicone adhesive and placed into a toy fish. Ionic polymer-metal composite (IPMC) was used to generate swimming motion of the robotic fish and it can be navigated to specific location through a computer (Tan et al. 2006).

Figure 2.3: Robotic fish swimming in the tank (Tan et al., 2006)

Priya and Harish (2015) presented a raspberry pi-based underwater vehicle for measuring water quality parameters. It was a submersible vehicle which consists of temperature sensor, pressure sensor, magnetometer, power supply, thrusters, accelerometer, display, camera and motor drivers. Raspberry pi was used to measure analog data such as temperature and pressure. It can also control the movement of the system by driving the DC motors. As Raspberry pi has capability for image processing and video streaming, it can display the parameter values to any display unit. The driving system was sealed with silicon glue to prevent water from entering. The system was then put into the vehicle assembly as shown in Figure 2.4.

Figure 2.4: Vehicle assembly (Priya and Harish, 2015)

Chiu (2010) established a multi-functional aquarium for the purpose of remotely manipulating the automatic system using network remote control system. The sensors were attached and fixed to the sides of the water tank as shown in Figure 2.5. Visual basic interfaces were used to control the aquatic temperature, water quality and breeding via a network. A command will be emitted from computer server and sent to designated modulus. Users can monitor current temperature, status of fish and pH online.

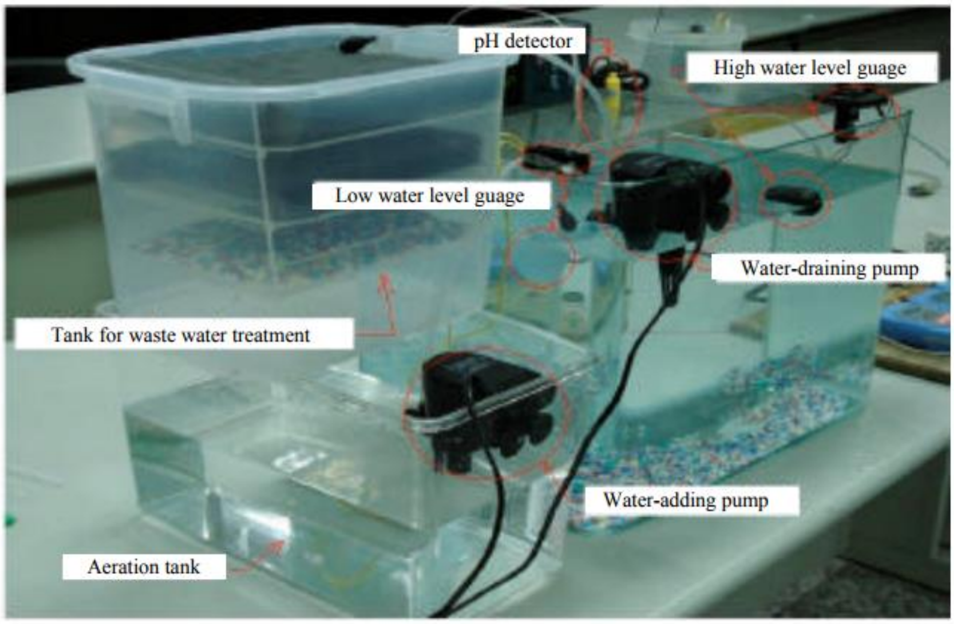

Figure 2.5: The inner water circulation/treatment system (Chiu, 2010)

Figure 2.6 shows an AquaMesh in fish pond which was developed by two researchers, Odey and Li. It was a smart wireless mesh sensor networks with the purpose of continuous monitoring of water quality parameters in the fish ponds. Odey and Li employed Waspmote embedded systems platform and smart sensors to use in water quality management applications. Aqua-environmental parameters were continuously monitored through multiple gateways of technologies such as Zigbee, GPRS and Wi-Fi. Alert or early warning is initiated to user whenever the threshold is exceeded. The system will generate data and store locally on the gateway or send to a remote web server and the data can be accessed with smart phones or computers (Odey and Li, 2013).

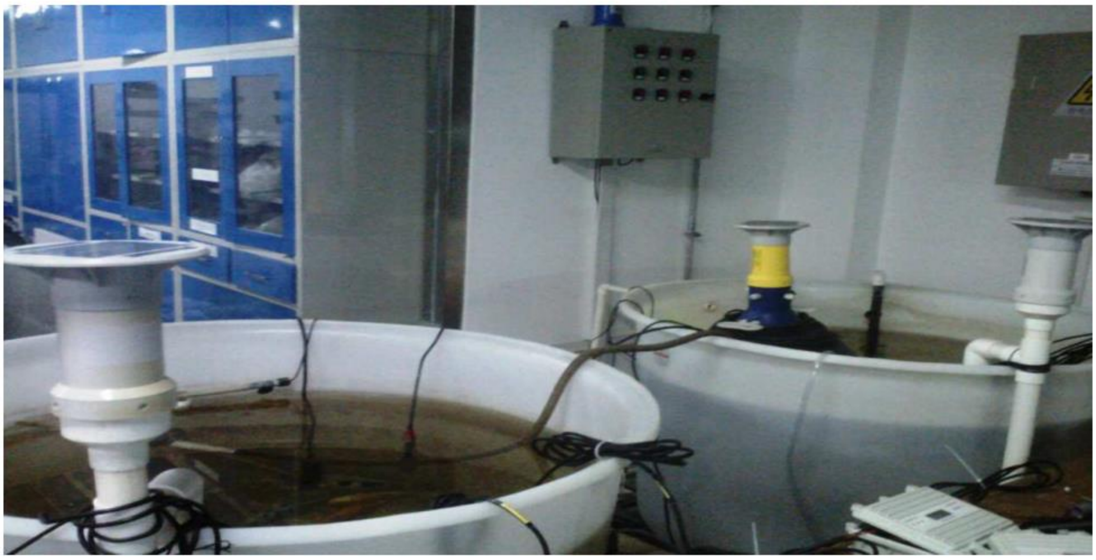

Figure 2.6: Experimental deployment of AquaMesh in fish pond (Odey and Li, 2013)

The common features for each of the systems mentioned earlier are temperature sensing, pH sensing and wirelessly controllable. Basic components include microcontroller, sensors, graphical user interface (GUI), power supply and wireless network. Some extra features such as global positioning system (GPS), dissolved oxygen sensing, light sensing, pressure sensing, electrical conductivity sensing, surveillance system, fixed positioned system or mobile system were included in some of the systems.

In my proposed designed, it will be a floatable and movable monitoring system which contains of pH sensor, temperature sensor, Arduino microcontroller, mini boat and data logger. It was a simpler version of all other current systems mentioned earlier with similar functions.

2.2 Water Quality Parameters

The growth of fish is greatly dependent on the water quality factors. Good water quality must be maintained in RAS for the fish to grow under most suitable environment and for optimum effectiveness of bacteria in the biofilter (Masser et al., 1992). Water quality factors must be fully monitored or controlled. The factors include water temperature, dissolved oxygen (DO), carbon dioxide, pH, ammonia and nitrite.

Water temperature has great effect on fish, metabolic rates, biological filter activity and oxygenation. Fish are cold-blooded living creatures they have approximately the same temperature as their surroundings. Therefore, the temperature must be retained within a certain range in order for the cultured species to reach optimum growth. Generally, freshwater fish are classified into warmwater, coolwater and coldwater species. Temperature ranges for these three species are shown in Table 2.1.

Table 2.1: General temperature ranges for different species of fish (Swann, 1997)

Species	Temperature Range (°C)
Coldwater	12.77 - 18.33
Coolwater	18.33 – 23.88
Warmwater	23.88 – 32.22

Examples of warmwater fish include channel catfish and tilapia. The optimum temperature for catfish and tilapia is 29.44 °C and 30.55 °C respectively. The optimum growth for walleye and yellow perch fall between 15.55 °C and 29.44 °C as they fall under coolwater species. Coolwater fish will perform maximum growth at upper end of this range. All species of salmon and trout are coldwater fish. One of the examples if rainbow trout, its optimal temperature range for growth is 8.88 °C – 18.33 °C. Fish grow rapidly at optimum temperatures and eventually lower the possibilities of fish affected by diseases. Heaters, chillers or heat exchangers are often used to control the temperature. Adjustment of temperature to most suitable level helps the fish to reduce stress and control certain diseases (Swann, 1997).

Appropriate amount of DO must continuously supplied in RAS as fish require oxygen to for metabolization and growing. For optimum fish growth in warmwater systems, DO concentrations should be maintained above 5 ppm. The amount of DO decreases when temperature increases at sea level atmospheric pressure as shown in Table 2.2.

Fish and bacteria produce carbon dioxide (CO_2) during respiration. When DO concentrations are high, fish can tolerate approximately 10 ppm of CO_2 concentrations. Normally, there is less than 5 ppm of free CO_2 in water which support good fish populations. However, in recirculating aquaculture systems, CO_2 may exceed 20 ppm easily and fish will begin to feel stress. Excessed CO_2 can be removed from water by using packed column aerators or other aeration devices (Masser et al., 1992).

Generally, fish can accept a pH range from 6 to 9.5 for fresh water systems while for biofilter bacteria, the range is from 7 to 8.   A low pH will lead to inhabitation of nitrifying bacteria and toxic nitrogen wastes are not able to be removed. pH can be controlled by addition of alkaline buffers (Masser et al., 1992).

Ammonia is the main nitrogen waste excreted by fish and it eventually become toxic at high concentration. Un-ionized ammonia (NH_3) is extremely toxic which can cause tissue damage to fish. Each types of species has its own toxicity levels of NH_3, levels below 0.02 ppm are considered safe for every species. The amount of NH_3 is very sensitive to pH and temperature, when pH and temperature increase, NH_3 level will rise as shown in Table 2.3 (Masser et al., 1992).

Table 2.2: Oxygen saturation levels in fresh water at sea level atmospheric pressure (Masser et al., 1992)

Temperature of fresh water (°C)	**DO mg/L (ppm)**	**Temperature of fresh water (°C)**	**DO mg/L (ppm)**
10	10.92	24	8.25
12	10.43	26	7.99
14	9.98	28	7.75
16	9.56	30	7.53
18	9.18	32	7.32
20	8.84	34	7.13
22	8.53	36	6.95

Table 2.3: Percentage of total ammonia in the un-ionizes form at differing pH value and temperatures (Masser et al., 1992)

pH	**Temperature (°C)**								
	16	18	20	22	24	26	28	30	32
5.0	99.3	99.2	99.2	99.1	99.1	99.0	98.9	98.9	98.9
5.5	97.7	97.6	97.4	97.3	97.1	96.9	96.7	96.5	96.3
6.0	93.2	92.8	92.3	92.0	91.4	90.8	90.3	89.7	89.1
6.5	81.2	80.2	79.2	78.1	77.0	75.8	74.6	73.4	72.1
7.0	57.7	56.2	54.6	53.0	51.4	49.7	48.2	46.6	45.0
7.5	30.1	28.9	27.5	26.3	25.0	23.8	22.7	21.6	20.6
8.0	12.0	11.4	10.7	10.1	9.6	9.0	8.5	8.0	7.6
8.5	4.1	3.9	3.7	3.4	3.2	3.0	2.9	2.7	2.5

As ammonia sensor and DO sensor are not available and they are expensive to purchase, the parameters of pH and temperature were only measured in my proposed design. Other water parameters were not be included in this system.

2.3 Hardware and Components

2.3.1 pH Sensor

Rao et al. (2013) used pH sensor from Phidgets to measure the pH value. The model is 3550_0 – ASP200-2-1M-BNC pH Lab Electrode which is able to measure full pH range from 0-14 and able to function properly under temperature of 0 °C – 80 °C. The sensor is executed via BNC converter. Phidgets pH/ORP adaptor is required to convert BNC to analog voltage after sensing and obtain pH sensor data at Arduino analog input.

PH450 series which is able to measure pH range from -2 to 16 was used by Simbeye, Zhao and Yang and display at provided pH display controller. Negative pH value exists when the molarity of hydrogen ions in an acid solution is greater than one. Only special electrodes such as the PH450 is able to assess extremely low pH values. This device has pH resolution of 0.01 pH and accuracy of ±0.01 pH which comes with temperature compensation function, preloaded calibration standards and stability checks (Simbeye, Zhao and Yang, 2014).

Fowler et al. (1994) stated that pH value can be measured chemically or electronically. Add a reagent to a sample and observing the resulting colour change corresponds to the pH value is called the chemical method. Electronic method is to use an electrode placed in the water and has an output voltage correlated to pH. The electronic method was applied in Zhu’s and her teammates’ water quality online monitoring system (Zhu et al., 2009).

A water environment monitoring system using pH electrode LE-438 was created by Jiang and his team. It can measure pH range from 0-14 and the accuracy is ±0.05. Besides pH measurement, LE-438 is integrated with temperature sensor. It features with unbreakable and chemically resistant POM shaft (Jiang et al., 2009).

From the thesis of Spiten (2015), pH probe provided by Atlas Scientific was used for underwater monitoring Micro-ROVs. It is 15 cm long and 1.2 cm wide. It weighs only 100 grams. The probe can measure pH range from 0-14 and function under maximum pressure of 100 psi. The sensor was connected to Arduino Uno, communicated through BeagleBone and then transfer data to personal computer via tether to the top side adapter.

Most of the researchers use pH sensor probe to measure acidity of water. As the sensor cannot be connected directly to Arduino controller, BNC connector was needed to allow pH sensor to communicate with the Arduino. pH sensor probe and BNC connector were used in this project together with Arduino controller.

2.3.2 Temperature Sensor

According to Tan's and his team's report, the temperature sensor model used to show the mobile sensing application of the autonomous robotic fish was the National Semiconductor LM335 AZ. It has accuracy of 1 °C and wide operating temperature range. This device can operate from 400µA to 5*m*A with less than 1-Ω dynamic impedance (Tan et al., 2006). Vanmore et al. (2017) used LM35 temperature sensor which is the same type of sensor as LM335. These type of sensors are integrated circuit temperature sensors; they are not water proof. Even if it is sealed with silicon adhesive, the accuracy of results will be affected.

Rao and his team adopted the temperature probe from Atlas Scientific in the system to check the temperature of water. It can function up to 5 V and the full temperature sensing range is between -20 °C and 133 °C, with accuracy of ±1 °C. This temperature probe was attached with BNC connector, thus, it was able to connect to Arduino controller via adapter. It is also nonreactive to salt water and can be fully submerged in water, up to the BNC connector (Rao et al., 2013).

DS18B20 thermometer was used by Simbeye, Zhao and Yang (2014) as a temperature sensor. Its operating voltage range is between 3 V and 5.5 V, detect temperature range from -55 °C to +125 °C, with accuracy of ±0.5 °C. The DS18B20 digital thermometer supports 9-bit to 12-bit temperature measurements and the information collected is sent to central microprocessor via 1-Wire interface.

From the report of Priya and Harish (2015), they used TMP102 digital temperature sensor to detect temperature. It used inter integrated circuits (I^2C) bus of the Arduino for communication. TMP102 can measure temperature range from -55 °C to 150 °C with accuracy of ±1 °C. However, this type of sensor is also not waterproofed.

Jiang and his team used waterproofed LE-438 3-in-1 pH electrode to measure temperature. It is a combination of pH electrode and temperature probe. It can measure temperature from 0 °C to 80 °C, with accuracy of ±0.5 °C. It is suitable for field use and for samples with fluctuating temperatures (Jiang et al., 2009).

Based on the report of Zhu et al. (2009), Zhu and her team used thermistor thermometer to measure water temperature. It is a thermometer which measures temperature with a resistor and can be used indoors or outdoors. The signal from the sensor is transmitted to the Web-based monitoring chip with the objective of converting analog signal into digital signal.

In the proposed design, the sensors must be contacted with water in order to take measurement under water. Thus, the temperature sensor must be waterproofed and can be connected to Arduino controller. The DS18B20 temperature probe was the best choice for this proposed system.

2.3.3 Water Level Sensor

Simbeye, Zhao and Yang (2014) used UXI-LY pressure type level transmitter as water level sensor to measure the depth of water. Water level range can be detected from 1 m to 70 m, with accuracy of 0.3 % FS and can operate under temperature range from -10 °C to 70 °C. The shell of this transmitter was encapsulated in stainless steel and the cables were sealed with water proof ventilation pinout. This device is mainly used to measure big range of depth. Unfortunately, it is an expensive transmitter. Due to budget issue, this device cannot be applied in my prototype design.

A wireless sensor network to collect real time water quality measurements in northern Australia's tropical area was designed by Dinh and his team. They used Tyco PS100 pressure sensor for monitoring the water level. It can be fully submerged into the water and is corrosion resistance. The variation of the capacitive element and applied pressure was measured by an electronic circuit and then convert into analog output (Dinh et al., 2007).

Fisher and Sui (2013) used an ultrasonic sensing system to monitor liquid levels. The model chosen is the PING ultrasonic module which comprises of two transducers. Distance can be measured by determining the time interval of sending the pulse and receiving the reflection and distance can be converted based on the speed of sound.

An internet poultry farm was designed by Goud and Sudharson. They used ultrasonic sensor (HC-SR04) to measure and control water level. Its non-contact measurement range is from 2 cm to 400 cm, with precision of 0.3 cm (Goud and

Sudharson, 2015). HC-SR04 ultrasonic sensor was also used in the research of renewable energy system from Marfi, Padial and Lauret (2016). The sensor can measure water tank level continuously by connecting to two digital pins of the Arduino board. Kato, Sinde and Kaijage (2015) also used an ultrasonic sensor as non-contact sensor to measure the distance between the sensor and water surfaces.

Ultrasonic sensors are commonly used for water level measurements. However, the sensor cannot be submerged into the water, it must be mounted above water. The ideal water level sensor should be able to submerge into the water and measure the water depth. Therefore, the sensor chosen should be able to be sealed with waterproof material or use other waterproofed water level sensor such as submersible IP68 waterproof water level sensor. However, the IP68 is very expensive, it was not suitable to be used in this project due to limited budget. Hence, water level sensor was not installed in this system.

2.3.4 Dissolved Oxygen Sensor

Fowler et al. (1994) stated that dissolved oxygen (DO) can be measured by using electronic and chemical method. The electronic method is simply placing a DO probe in the water. A gold or platinum element where it is surrounded by a reagent solution is called the DO probe. A membrane separates the reagent solution from water where the oxygen along the passage will react with the gold or platinum element, DO can be measured by taking the measurement of voltage generated. However, the probe is expensive and the maintenance cost is relatively high.

Rao et al. (2013) used galvanic dissolved oxygen sensor to measure the DO level. The galvanic sensor consists of two electrodes; the negative electrode (cathode) can be silver or platinum, the positive electrode (anode) can be lead, zinc or iron. The sensor can be self-polarized as the reduction of oxygen is spontaneous (Hargreaves and Tucker, 2002). This DO sensor can measure DO content from 0 mg/L to 20 mg/L and operate properly below temperature of 50 °C. Moreover, it can be interfaced with Arduino Mega controller.

In Simbeye, Zhao and Yang (2014), the dissolved oxygen level in the water is measured by using DO3000 dissolved oxygen sensor. The DO3000 can measure range from 0 mg/L to 20 mg/L with automatic range switching. Besides, it allows temperature compensation from 0 °C to 60 °C and has resolution of 0.1%. This sensor employ data logging system for long term unattended data collection. The body design of the sensor is water proof and protected against harsh environment. The DO3000 is user friendly as it is easy to be configured and easy to collected data using personal computer.

The dissolved oxygen sensors mentioned earlier is very expensive and needs high maintenance cost, due to limited resources and budget, the dissolved oxygen parameter was not included in the proposed design.

2.3.5 Turbidity Sensor

Turbidity is the degree of cloudiness or haziness of a liquid that is caused by huge amount of suspended solids which normally invisible to human's naked eye (LaMotte, 2017). Presence of clay, fine inorganic and organic matter, algae, and other microscopic organisms in the water is also one of the causes that makes the water cloudy (Perlman, 2016). There are many different sizes of suspended solids in the water. In a sample of stationary liquid, the heavy and large particles will sink to the bottom while the smaller and lighter particles that suspended in the water will cause the water to turn turbid. Level of turbidity can be determined by measuring the amount of light scattered by suspended solids. As the intensity of scattered light increases, the higher the turbidity level. High level of turbidity blocks light penetration into the lower depth of water. This gives opportunities for the growth of pollutants and bacteria and harm the habitat areas for aquatic life such as fish. High concentrations of suspended solid decrease dissolved oxygen level and hinder fish to absorb oxygen. Therefore, turbidity is one of the important factors that must be measured in culture tank.

Turbidity can be measured in the Nephelometric Turbidity Units (NTU). When a light source is passed through a water sample, by measuring the attenuation or reduction in strength of the light source, turbidity level in the water can be checked. The turbidity sensor measures the amount of light transmitted through water sample to measure the turbidity level of water.

Even though it is important to measure the turbidity when determining the water quality in culture tank, due to limited resources and tight budget, turbidity sensor was not used in this project.

2.3.6 Ammonia Test Method

The ammonia level in water can be measured as total ammonia in the unit of mg/L. Ammonia can be measured by using ammonia probe or colorimeter. Ion-selective electrode (ISE) is a type of ammonia probe which consists of a thin membrane between two electrodes. The level of ammonia in the solution is determined by measuring the potential difference between the two electrodes.

The second method to measure the ammonia concentration is using colorimeter. The sample is added with one or more reagents and ammonia will react with the reagent to produce different colour intensity of the solution. The colour absorbance is then measure with colorimeter. A standard curve is generated from the sample absorbance reading and convert to ammonia concentration (EPA, 2016).

It is shown that ammonia level is easier to be measured using ISE compared to colorimeter method. The probe can be submerged into the water and record the data continuously in the culture tank. However, ammonia sensor is very expensive and due to limited budget, ammonia was not measured in this project.

2.3.7 Microcontroller

Nasirudin, Za'bah and Sidek (2011) designed a real-time monitoring system of fresh water quality by using PIC16F886 microcontroller. It can drive logical tasks including EUSART serial data, convert analog signal to digital signal and logical processing. The PIC16F886 provides input voltage from 2 V to 5 V and 20 mA standby current. Besides, it has low power consumption packaged with 28-pin CMOS 8-bits.

Reza, Tariq and Reza (2010) developed a microcontroller based water level sensing and controlling. The model of microcontroller used was the PIC16F84A made by Microchip Technology. The function was to collect input signals combination and decide an output to send signal to the output pin.

Microchip PIC16F688 to control an autonomous robotic fish was used by Tan and his team. The PIC16F688 acted as the brain of the robot which different modules handles coordination on the robot. It interfaced with sensors, GPS and digital compass to send and receive data measurements (Tan et al., 2006).

The programming languages for PIC microcontroller are assembly language and C language. It is a simple microcontroller, cheap and small in size. The integrated development environment (IDE) for the PIC can be either MPLAB or MPLABX.

Rao et al. (2013) used Arduino Mega 2560 as a sensor node in the autonomous water quality monitoring system. The Arduino was used to acquire and process data. It was chosen of its advantages of inexpensive, open-source product and provide enough analog or digital inputs for many sensors application.

A monitoring system for aquaculture in rural India was designed by Jadhav et al. (2017). Arduino board was used for the system communication. The water parameters sensors were connected to the Arduino, data is transmitted and the Arduino will create an output according to the condition set.

Two research scientists from Greece, Tatsiopoulos and Ktena developed a wireless sensor system to monitor indoor and outdoor environmental conditions. Arduino microprocessor acted as the heart of the system. It can receive inputs from variety of sensors and control the output actuators (Tatsiopoulos and Ktena, 2009). Arduino microcontroller uses Arduino language which is based on C/C++. It functions as microcontroller which is inexpensive and medium in size. It uses Arduino as IDE.

Priya and Harish (2015) designed an underwater vehicle using raspberry Pi as microcontroller. Raspberry Pi is able to measure analog parameters from temperature sensor, pressure sensor and display the values on a display unit. Raspberry Pi acts like a mini computer and can be programmed with different types of code such as Python, C/C++, Java and Ruby. It is larger than PIC and Arduino and is the most expensive among these three microcontroller. The IDE for raspberry Pi is the Raspbian.

It showed that these three types of microcontroller are commonly used for monitoring and controlling systems. Among PIC, Arduino and raspberry Pi, Arduino was most suitable in my proposed design as it is user friendly, easy to be programmed and medium in size. Arduino Uno was chosen as the size is smaller compared to Arduino Mega.

2.3.8 Data Acquisition and Transmission

Mendez, Yunus and Mukhopadhyay (2012) formed a wireless sensor network by using WSN802G WiFi / 802.11 module. Signal gating was formed by connecting the module with analog output sensors via multiplexer. The signals will be collected, transferred and logged to the server on the network. By using Wireless-G router, server can connect to the network wirelessly or through a wired Ethernet connection.

The wireless LAN architecture consists of three components including access point, client and bridge. These components establish local area network between different operating system. Access points are routers that used to transmit data across wired and wireless networking device; clients can be end device such as personal computer or other mobile devices such as smartphones which are linked with wireless network area; bridge is a type of connector used to establish connections between Ethernet and wireless LAN.

Simbeye, Zhao and Yang (2014) used ZigBee IEEE 802.15.4 as wireless sensor network for communication. The ZigBee protocol supports point-to-point, peer-to-peer, point-to-multipoint and mesh networking transparent data transfer between devices. Data can be transferred by way of broadcast or target address. The wireless communication module consists of three nodes in the network such as central coordinator, router and end device. Central coordinator stores information of the network; router links network together, transmit data to end devices.

A comparison was done on ZigBee protocol and Wi-Fi protocol based respective specifications and shown in Table 2.4.

Table 2.4: Comparison of ZigBee protocol and WiFi protocol (EngineersGarage, 2012)

	ZigBee	**Wi-Fi**
Application Focus	Monitoring and Control	Web, Video, Email
IEEE Standard	802.15.4	802.11.x
Operating Frequency	900-928MHz, 2.4GHz	2.4GHz, 5GHz
Channel Bandwidth	1MHz	0.3MHz, 0.6MHz, 2MHz
Network Range	10m – 100 m	30 m – 100 m
Data Transfer Speed	250kbps	11mbps, 54mbps
Bit Time	4µs	0.00185µs
Power Consumption	Low	High

An automated system was designed by Kanwar, Bjorneberg and Baker (1999) for monitoring quality and quantity of subsurface drain flow. The team used data loggers to record the electronic outputs of the flowmeters. Data loggers were used to record the time when each pump started to pump and stopped pumping water. As data logger system is able to measure the changes over short time period, it was an effective method to be used for monitoring system.

Sri et al. (2017) developed a blind stick navigator to assist the people with blindness. It was consisted of Arduino Uno along with 1Sheeld to detect obstacles using vibration mechanism and also messaging system to alert others their location. When Bluetooth and Global Positioning System (GPS) function were turned on in the smartphone, 1Sheeld was able to detect the blind's location. With the Short Message Service (SMS) feature in 1Sheeld, the location of the blind can be sent to others in case of emergency. A smart home security system was developed by Rafa and his team by using Arduino Uno, 1Sheeld and other sensors. In their design, 1Sheeld was used to connect smartphone with Arduino to enable smartphone's network to send messages, E-mails and capture picture (Rafa et al., 2010). 1Sheeld is the combination of a microcontroller and a Bluetooth module which allows data to be transmitted between Arduino and smartphone. It also gives users capability to set up Internet of Things (IoT) application by just connecting 1Sheeld to a smartphone. There are over 40 shields available in the 1Sheeld including data logger shield, email shield, and etc.

From Table 2.4, it showed that ZigBee and Wi-Fi have respective advantages and disadvantages. All the data will be stored into cloud server which comes with security risk of data leakage. External threats such as malicious hacks may lead to data leakage. On the other hand, data logging system is more secure as the data collected will be directly stored into a memory card. However, data can only be accessed when the memory card is taken out, this denotes that user is not able to get real time results. 1Sheeld is chosen for data acquisition and transmission as data logger shield and the email shield can be utilised. Other users is able to obtain logged data in CSV format by receiving E-mail sent from the smartphone. Besides, 1Sheeld is easier to be programmed compared to ZigBee and Wi-Fi module.

2.4 Design of Sensor Housing

Ryuh et al. (2015) designed a multi-agent school of robotic fish "Ichthus V5.5" as shown in Figure 2.7 for mariculture monitoring. The moving motion of the robotic fish mimicked the swimming motion of a real fish. Thus, the robotic fish was adopted with multi-joint tail to generate the same swimming motion of a real fish. There were many types of swimming patterns in the robotic fish. The patterns were all according to the swimming morphologies including cruise straight, cruise in turning, sharp-turn, ascent-descent and others. The movement of each joint was controlled by servo motor attached on it.

Figure 2.7: Robotic fish “Ichthus V5.5” (Ryuh et al., 2015)

Tan’s and his team’s initial robotic fish design used latex rubber to mould a real fish appearance as the material is flexible and waterproof. The circuit board was placed inside the rubber fish. A new housing was developed because the latex rubber turned out is not waterproof. The second generation of fish was to place the circuit board with sensors into a toy fish as shown in Figure 2.8 (Tan et al., 2006).

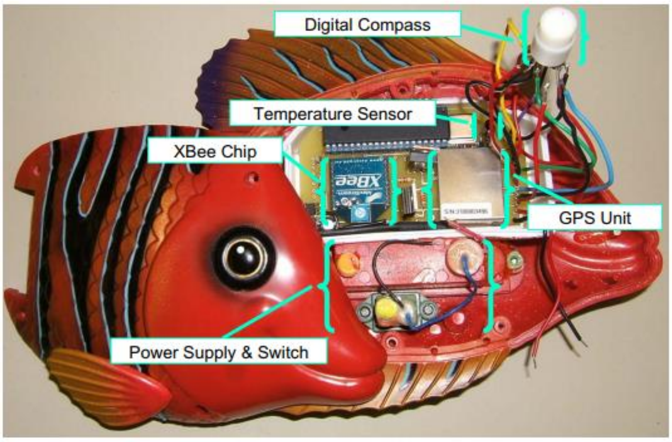

Figure 2.8: Assembled circuit board in a toy fish (Tan et al., 2006)

Priya and Harish (2015) designed an underwater vehicle by using PVC pipes. Figure 2.9 shows the mechanical design of the vehicle hull is assembled with T joints, U-joints and different lengths of pipes. The vehicle can go underwater as water is allowed to be filled inside the holes of PVC pipes to increase weight. DC motors were used to move the vehicle in different directions. Thrusters were connected to the motors and were used for forward, backward, left and right movements.

Figure 2.9: PVC assembly (Priya and Harish, 2015)

A designed stationary water quality monitoring system was created by Rao et al. (2013) and Chiu (2010). pH sensor, temperature sensor, water level sensor and other types of sensor were attached and fixed on the side of the tank. One of the disadvantages of stationary sensors was the water quality only can be measured at certain point. Areas where it is out of the sensor range cannot be detected which consequently affected the accuracy of results.

In the research of Rillahan et al. (2009), an offshore cage was designed to observe and quantify the behaviour of fish. Cameras, hydrophones and feeding tubes were placed on the submersible Sea Station 3000 net pen. Net pen is a net cage which enclose fish in coastal areas or in freshwater lakes. The behaviours of the fish in the net pen can be monitored by the sensors.

The water quality monitoring system was designed to be floating and moving around on the surface of water, while the features of a toy boat are corresponded to the criteria of this project. Therefore, a toy boat was used in this system to move the system all over the aquaculture tank.

2.4.1 Material for Housing Fabrication

There are many types of light and waterproof material that are suitable for the housing of movable water quality monitoring system. The choice of material is chosen based on their properties and characteristics. The types of materials include 3D printer filament, polypropylene and polystyrene are discussed.

Acrylonitrile Butadiene Styrene (ABS) and Polylactide Acid (PLA) are both commonly used in 3D printing. 3D-printing is a technology that is able to turn virtual 3D model into physical objects. It involves additive manufacturing process by fusing plastic filament with 3D printer to build three dimensional objects. ABS is often used in the industry for different applications due to its durability and strength, at the same time, flexible and heat resistance. It can be used in manufacturing of pipes, automotive components, toys, electronic assemblies and others. PLA is made of biodegradable thermoplastic which is a type of renewable resources. It is an environment friendly material as it is degradable. As PLA is able to degrade into harmless lactic acid in the body, it can be used in medical suturing and surgical implants. Besides, PLA is considered safe as it does not create toxic fume and awful smell, thus, this material also can be used in food packaging or hygiene products (Mich, 2013).

A transparent plastic container with lid as shown in Figure 2.10 was considered to use as the housing of the water quality monitoring system. It is rectangular in shape and made from material of clear polypropylene. Polypropylene is classified as “addition polymer” of thermoplastic which is made from the combination of propylene monomers (Creative Mechanism, 2016). It is widely used in many applications such as packaging for consumer products, plastics parts for automotive industry, special devices and textiles. One of the significant properties of polypropylene is chemical resistance. Water, detergents, diluted acids and bases do not react readily with polypropylene. Thus, it will not break down easily which makes polypropylene a good choice for containers of such liquids. Polypropylene is very popular due to its elasticity and toughness. It is a tough material because polypropylene will experience plastic deformation at the beginning of deformation process and then act with elasticity after a certain range of deflection. Polypropylene is considered tough since toughness in engineering term is defined as a material’s ability to deform plastically without breaking. Besides, polypropylene is fatigue resistance. Even it was bent or flexed, polypropylene will still retain its shape. So it is commonly used in making living hinges. Polypropylene is quite durable to withstand daily wear and tear. Most importantly, polypropylene has the property of insulation which is resistant to electricity. This is a crucial factor as the water quality monitoring system is placed on the surface of water. Polypropylene is also a soft material and light in weight which can be easily cut and float on the water (Professor, 2014).

Figure 2.10: Clear rectangular plastic container and lid

Expanded polystyrene (EPS) cube as shown in Figure 2.11 was one of the material options to use as the housing for the water quality monitoring system. Polystyrene is a versatile plastic which is hard and solid. When polystyrene is made into foam material, is it called expanded polystyrene (EPS) or extruded polystyrene (XPS). It has excellent cushioning properties where it is composed of watertight air-fill cells. More than 95% of its volume is air while the leftover percentage is the solid material (polystyrene), hence, polystyrene is extremely lightweight. Besides, it is durable and resistant to water damage due to its insulation is inert (Chemical Safety Facts, 2014).

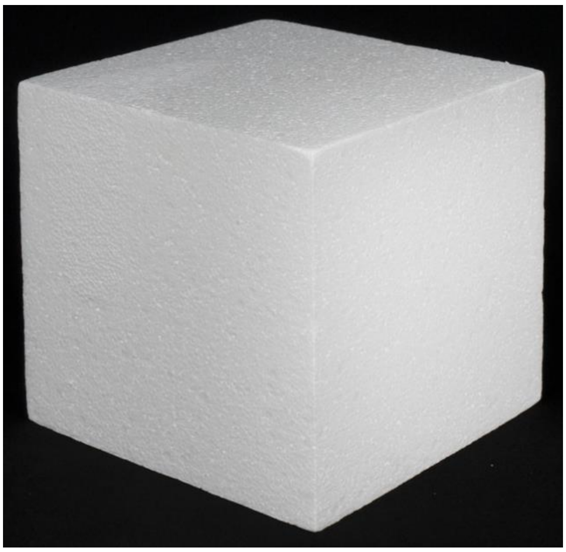

Figure 2.11: Expanded polystyrene (EPS) cube

In my proposed design, transparent rectangular plastic container was used to fabricate the housing for the water quality monitoring system. 3D printing technology was not suitable to print out the housing because a typical 3D printer that uses extrusion process tends to produce porous prints. It is possible that there are small gaps in between the layers. Gaps are more likely to appear in complex structures. Through these gaps, water may flow through, hence, it was not suitable to fabricate the housing. EPS cube was not preferable because it is difficult to hollow inside the cube in order to place all the sensors and Arduino in it. Clear rectangular plastic container was favourable as it is lightweight, water resistance and easy to cut.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Project Planning and Milestones

The overall flow of the project was summarized in Figure 3.1. After the final year project title was chosen, further background research was done for better understanding. The scope of study was determined to have an overall idea of conducting the project. Journals and articles were screened and compiled from other researchers to improve and modify from current monitoring systems' technology.

Conceptual design was proposed after referring to the features and components used by other researchers. After all the components and materials were purchased, circuit design was drawn to make sure electricity flows through every wire for the components to work accordingly. Arduino Uno was programmed using Arduino Software to control the electronic components including pH sensor, temperature sensor, ultrasonic sensor, 1Sheeld+ and mini boat. The sensors were used to measure the water quality parameters; ultrasonic sensor was used to measure distance between the aquaculture tank and the system; 1Sheeld+ was used to log data into smartphone in CSV format and send it to users via Email; mini boat acted as a floating platform to move the whole system around the culture tank. After all the coding was written, testing and debugging were done to make sure all the sensors were able to obtain accurate results; 1Sheeld+ was able to email users the logged data and ensure the floating platform was movable.

Once the software parts were finished, the system's housing was fabricated. A hole was cut at the bottom of plastic container according to the shape of mini boat. The mini boat was then fitted into the hole while the boat's propellers were allowed to be exposed to the water. Hot glue was applied on wherever there were gaps between the hole and boat to prevent water seeping in. Battery pack, Arduino Uno, 1Sheeld+, sensors and other electronic components were placed inside the plastic container after ensuring the housing was watertight and no water can be entered. Polystyrene was added on the housing to increase buoyancy of the whole system.

After the prototype was constructed, trial run was carried out to ensure the whole system can operate and function accordingly. Calibration and improvement were done to achieve better performance. Full performance testing was conducted in rectangular and round shape tanks. The prototype was tested for 2 hours continuously in each tank by allowing it to move around the tank and measure water quality at the same time. The coverage area of the moving system was observed to ensure the system was able to reach around the whole tank. In the final state, the data collected was processed using Microsoft Excel and discussion was made based on the overall project.

Gantt chart was used to illustrate how the project will run and keep track with the projects' progress. Figure 3.2 and Figure 3.3 showed the Gantt chart of the project for part 1 and part 2.

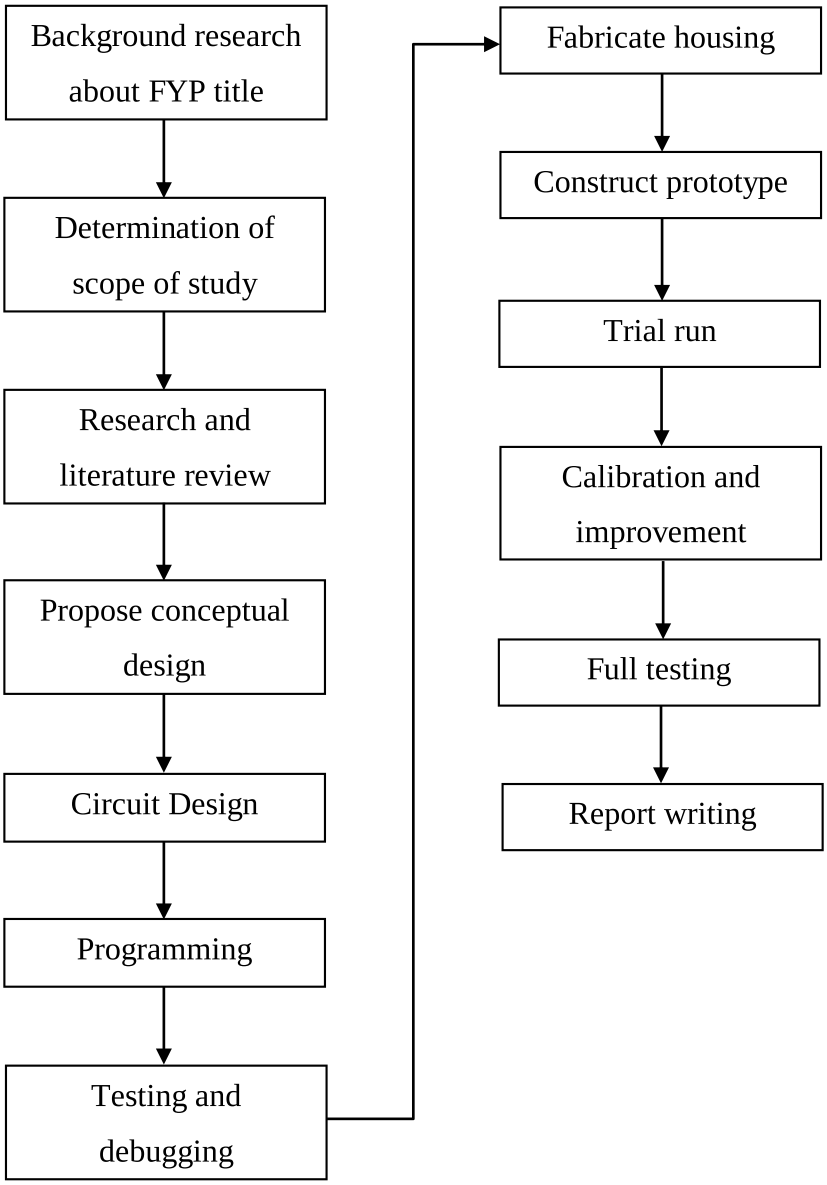

Figure 3.1: Overall flowchart of the project

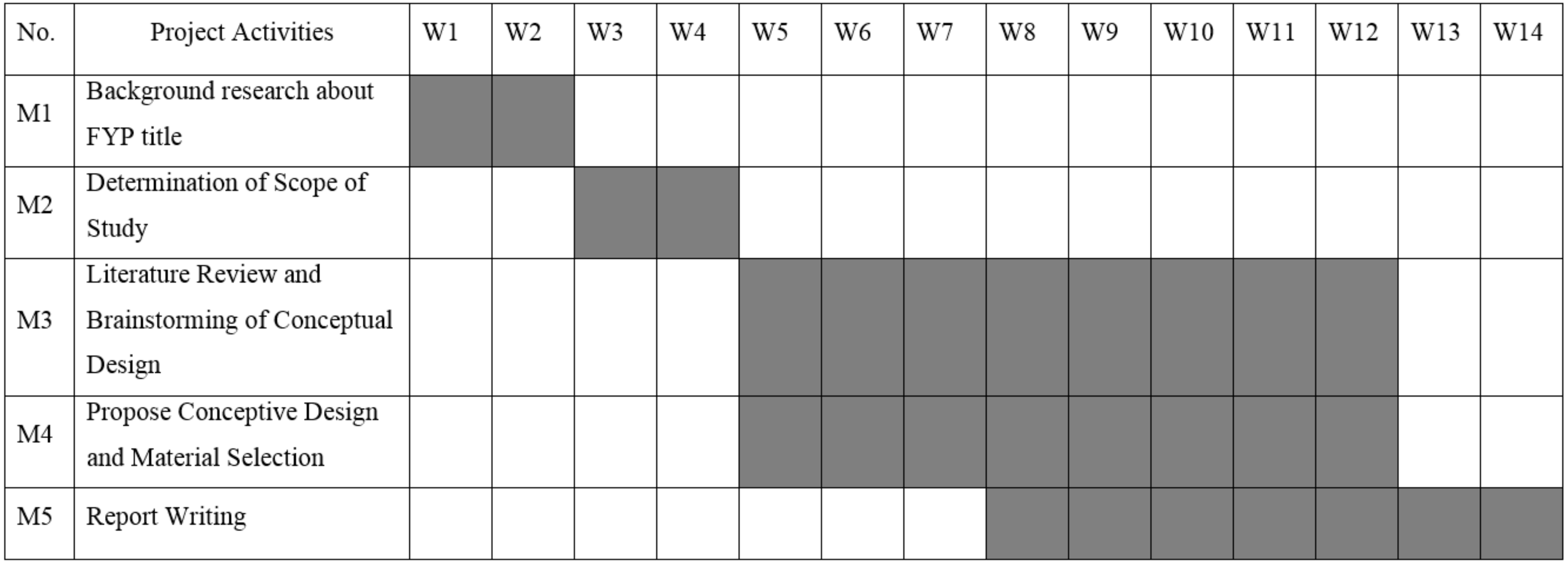

Figure 3.2: FYP Phase One Gantt Chart

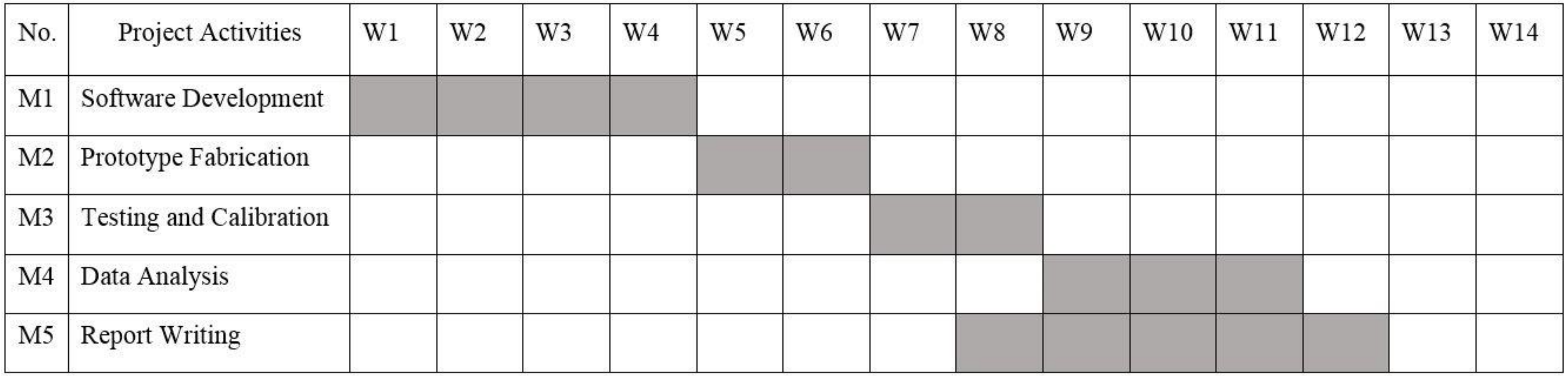

Figure 3.3: FYP Phase Two Gantt Chart

3.2 Block Diagram

The proposed system consisted temperature sensor, pH sensor and ultrasonic sensor which were used to measure the water temperature, pH value and the distance between the tank wall and the water quality monitoring system respectively. Arduino Uno acted as a microprocessor to collect data from the sensors. A 9V battery pack was used to operate the Arduino Uno as it allows external supply from 6V to 20V. 1Sheeld+ was sat on top of the Arduino board and communicates over Bluetooth to 1Sheeld app in order to transmit data between Arduino and the smartphone. 1Sheeld app was used to log data collected into smartphone's memory and then email to other users. The motors from the mini boat were attached with propellers to move the whole system within the tank. The DC motors were powered by 3V battery instead of sharing the 9V battery pack with the Arduino Uno as the board may damage.

The block diagram of the proposed design is shown in Figure 3.4. The block consists of temperature sensor, pH sensor, ultrasonic sensor, Arduino Uno, 1Sheeld+ and two DC motors.

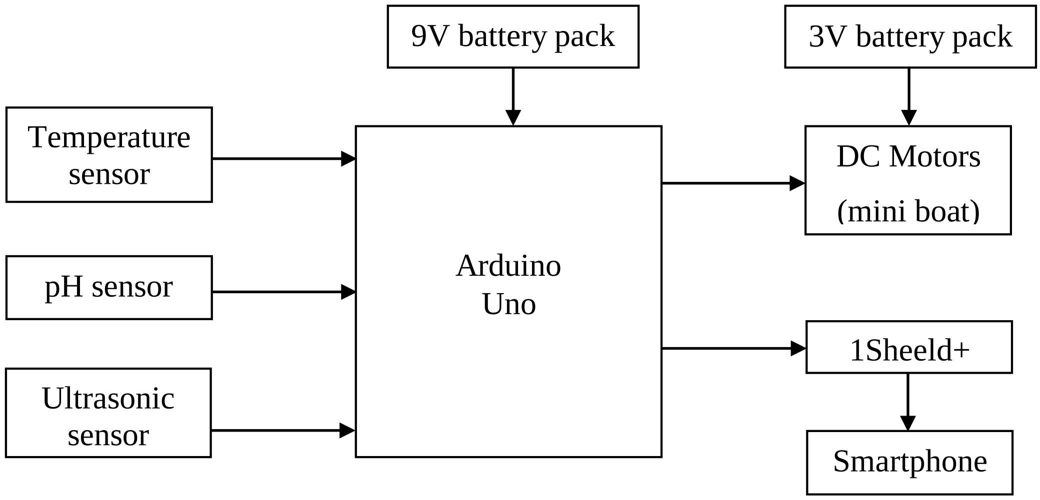

Figure 3.4: Block diagram of Arduino-based water quality monitoring system

3.3 Overall water quality monitoring system

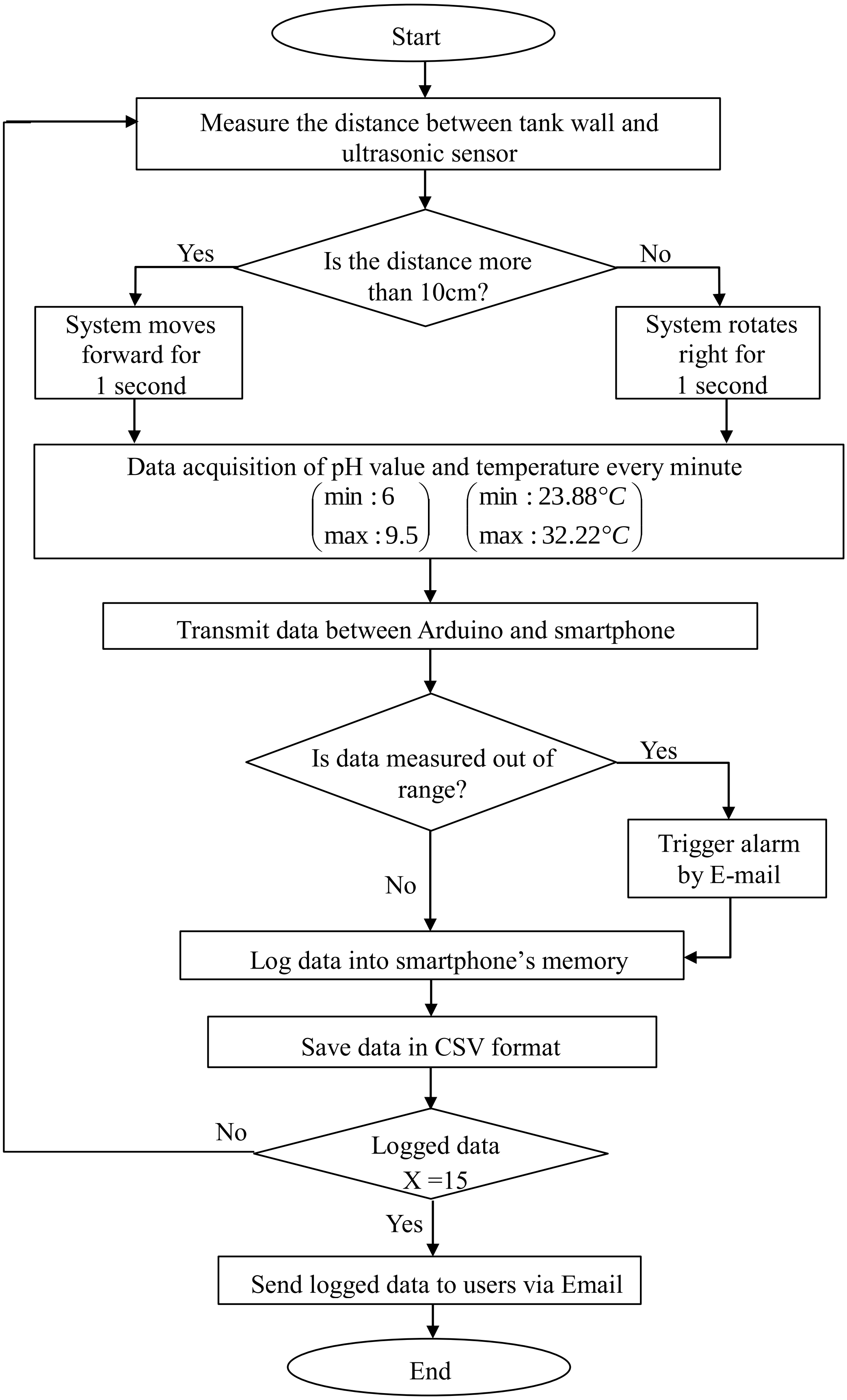

Figure 3.5: Overall flow of the water quality monitoring system

The overall flow of movable water quality monitoring system for aquaculture tank is shown in Figure 3.5. Flowchart explains a process clearly from the start to the end by using symbols and text. It is a graphical description of decisions and the results made based on those decisions. The flowchart is drawn before writing any code to the Arduino. Programming becomes easier by following the procedure of the flowchart. The flow of whole system process is explained below.

Arduino Uno was operated by a 9V battery pack. After the Arduino board was switched on, the distance between the tank wall and the system was determined by the ultrasonic sensor. This was to prevent the system from colliding with the wall of tank. Even if the system has bumped into the wall, the boat propellers help to rotate the system and move it away from the wall. In order to avoid any wall clashing or stuck at one position, the system was set that the minimum distance between the ultrasonic sensor and the wall is 10 cm. When the distance measured is more than 10 cm, this indicated that the system is still far away from the wall, the system will be moved forward for 1 second. If the distance is less than 10 cm, this signified that the system is very close to the wall, hence, the system will rotate right for 1 second to avoid colliding with the wall.

Data acquisition of pH value and temperature was performed right after the system has moved. The pH value and temperature were measured every minute to have more accurate results. Data measured was then transmitted between Arduino and smartphone. Once the parameters were measured, the system will check if the data measured is out of range. According to the research found in literature review, the minimum and maximum pH value is 6 and 9.5 respectively for any freshwater fish. On the other hand, warmwater fish can withstand within temperature range between 23.88 °C and 32.22 °C. If either pH value or temperature was above or below the ideal range, alarm was triggered by sending a warning email to users. After the data was measured, the measurements are logged into smartphone’s memory as CSV format. When every 15 data was logged, it will be sent to users via email, if not, the data will keep logging until it reached 15 data. This means that users will receive updated results every 15 minutes.

3.4 Conceptual Design of Housing

Figure 3.6 shows the conceptual sketch design of the movable water quality monitoring system. The dimension of the housing must be able to place all the components including the Arduino board and sensors into the housing. The initial plan was to use 3D printing technology to print an ellipsoid shape housing with dimension of length 15 cm, width 10 cm and height 20 cm. The purpose to print in ellipsoid shape is to allow the housing to move around even if it hits the edge of the tank. The housing will be floating on the water surface and the circuit board and sensors will be placed inside. Two holes should be created at the bottom of the housing to place the probe of pH sensor and temperature sensor. This is to allow the sensors to measure water quality directly from the water. Ultrasonic sensor can be placed on top of the housing to measure the distance between the wall and system without getting splashed by the water. Two DC motors were intended to be attached with propellers and placed under the container for the system to move around the tank.

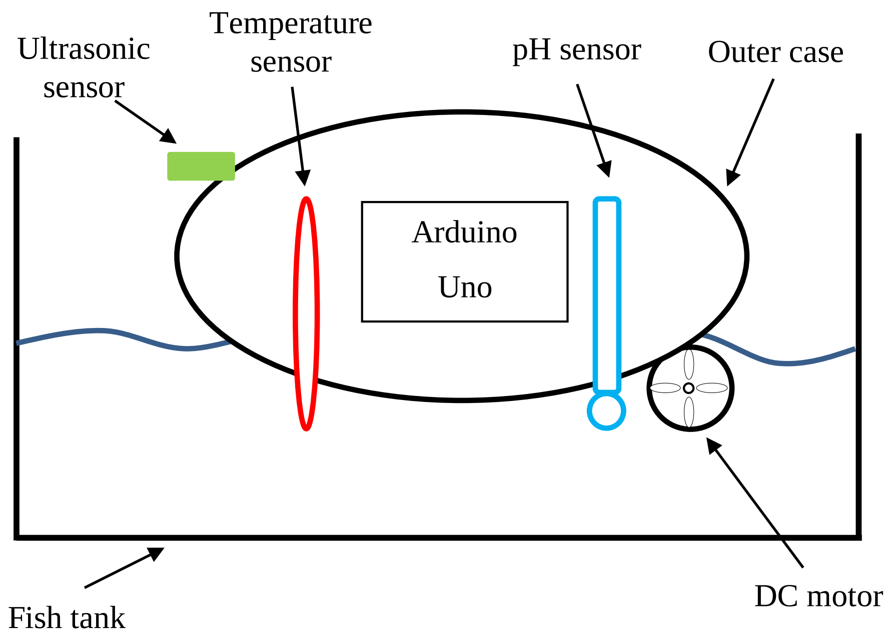

Figure 3.6: Sketch design of the system housing

3.5 Hardware and components

3.5.1 Arduino Uno

Arduino Uno as shown in Figure 3.7 is a microcontroller with 14 digital I/O pins and 6 analog inputs. It can be powered with a computer via USB connection or external power source such as battery or AC-to-DC adapter. The suitable range of voltage supply to operate the board is from 7 V to 12 V.

The Arduino Uno can be programmed with Arduino software. The core programming language for Arduino software is C++ language which is user friendly. This user friendly software can be used in Mac, Windows and Linux.

The reasons of choosing Arduino Uno was because it is less expensive compared to Raspberry Pi. The Arduino Software is more user friendly compared to Raspbian and MPLABX. Besides, the software is published as open source tools which allows users to understand the technical details easily. The open source of code from experienced programmers helps users to shorten their development time and debugging time.

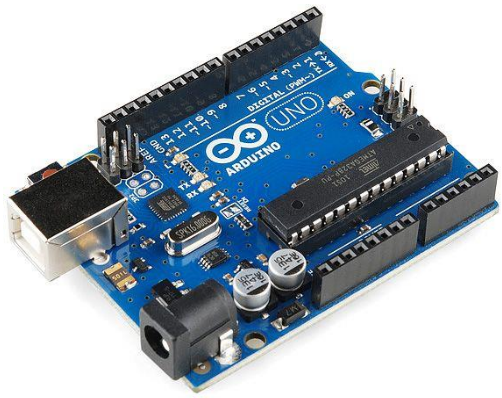

Figure 3.7: Arduino Uno

3.5.2 Temperature Sensor

Waterproof DS18B20 temperature sensor as shown in Figure 3.8 was used in the proposed design. It is a sealed digital temperature probe which is able to submerge into the water. The DS18B20 has 1-Wire interface so it only one wire needs to be connected from the Arduino. The probe can measure temperature from -55 °C to +125 °C with accuracy of ±0.5 °C. In order to get the temperature from the sensor, the output voltage will be measured. Since the sensor outputs an analog voltage, the wire will be connected to the analog input pin of the Arduino.

Figure 3.8: DS18B20 Temperature Sensor

3.5.3 pH Sensor

The device that was used to measure the pH value of water is the aquarium hydroponic spare laboratory pH electrode probe BNC connector as shown in Figure 3.9. It can measure pH range of 0-14 pH between 0 °C to 60 °C of water temperature with accuracy of ±0.1 pH. As the electrode probe is attached with BNC connector, a pH sensor circuit board is needed to connect to the Arduino board. The pH sensor provides analog output signal, hence, it will be connected to Arduino's analog input pin.

Figure 3.9: pH Electrode Probe

3.5.4 Ultrasonic Sensor

The HC-SR04 ultrasonic sensor as shown in Figure 3.10 was used to measure the distance between tank wall and the system. 40,000 Hz of ultrasound which travels through the air is emitted from the sensor and bounce it back if an object or obstacle is detected on its path. By measuring the travel time and the speed of the sound, the distance of object from the sensor can be calculated.

Figure 3.10: HC-SR04 Ultrasonic Sensor

3.5.5 1Sheeld+

1Sheeld+ as shown in Figure 3.11 was a platform for Arduino to utilise smartphone's sensors and capabilities to use them in many different Arduino projects. The difference between 1Sheeld and 1Sheeld+ is that 1Sheeld+ is compatible with both Android and iOS devices while the first generation 1Sheeld only compatible with Android devices.

Basically, 1Sheeld+ consists of two parts. The first part is the physical board that consists of a microcontroller and a Bluetooth module to transmit data between Arduino and smartphone. It is stacked on top of the Arduino board and can be operated by using the same power source supplied to the Arduino Uno. The second part is the mobile app on smartphone and the software platform. It communicated between 1Sheeld+ and smartphone used as virtual shields for Arduino.

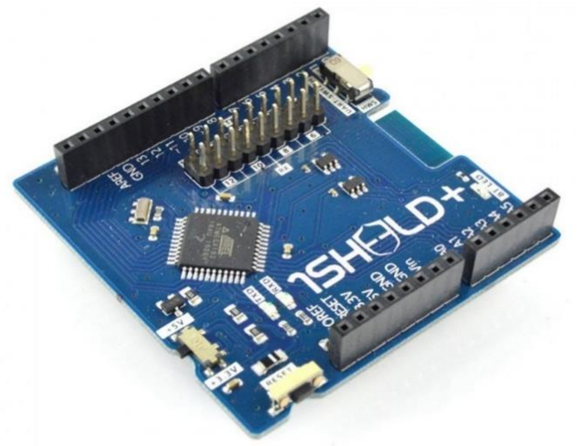

Figure 3.11: 1Sheeld+

1Sheeld+ uses a standard HM-10 Bluetooth low energy adapter (BLE 4.0) which can support both iOS and Android smartphones. The communication range is up to 30 feet. Smartphone communicates with Arduino using UART with 7.37 MHz operating frequency. Since the communication range is not more than 30 feet, a smartphone must be placed near the system in order to utilise the features of the 1Sheeld+.

3.5.6 Mini Boat

A super mini dual motor remote control (RC) speed boat as shown in Figure 3.12 was used in this project. The function of the boat was to act as a floating platform to support and move the whole system around the culture tank. Modification was done to the boat to accommodate all the components of the system including pH sensor, temperature sensor and Arduino board. This mini boat can move forward, backward, left, right and reverse. The dimension of the mini boat is 13.5 cm (length) x 4.5 cm (width) x 5 cm (height). Plastic is the main material of the boat. The motors are driven by the RX2C ATS302R decoder. It has an internal and selectable DC-DC converter that allow the motor to operate steadily and reliably under lower supply voltage. The input voltage range of RX2C is from 0.8 V to 3.0 V.

Figure 3.12: RC mini speed boat

3.6 Software

3.6.1 Arduino Software (IDE)

The Arduino Software as shown in Figure 3.13 is an open source Integrated Development Environment (IDE) which can be used to write code and upload it to Arduino board. As this Arduino IDE is an open source and extensible software, several tutorials are available for users to understand technical details about the software.

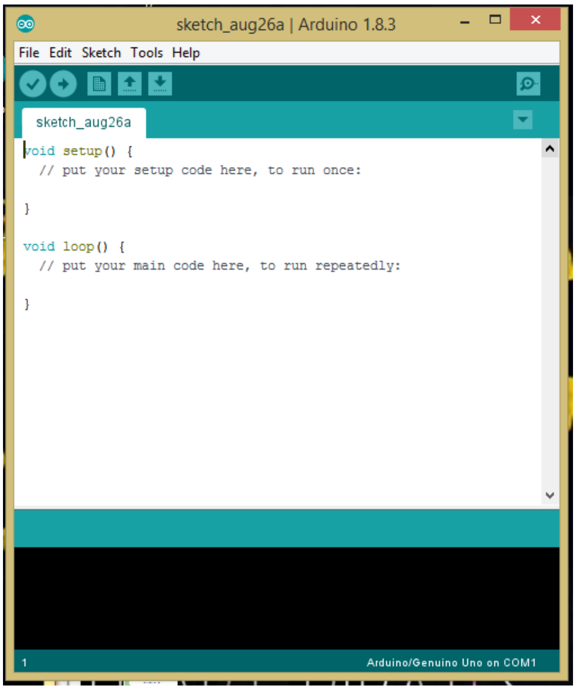

Figure 3.13: Snapshot of Arduino Software IDE

3.6.2 1Sheeld App

The 1Sheeld application is shown in Figure 3.14. The software platform helps 1Sheeld+ to connect the Arduino to 1Sheeld's own apps on smartphones over Bluetooth. There are over 40 shields available in 1Sheeld+. For this system, several shields were used, they are the 'Data Logger Shield', 'Email Shield', 'Game Pad Shield' and 'Push Button Shield'. 'Data Logger Shield' is used to log data in CSV format into smartphone's memory; 'Email Shield' is used to email other users the logged data; 'Game Pad Shield' is used to remote control the mini boat; 'Push Button Shield' allows user to decide when to start logging the data.

Figure 3.14: 1Sheeld app

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Design of Movable Water Quality Monitoring System

4.1.1 First Design of Prototype

Figure 4.1 and Figure 4.2 show the side view and top view of the first prototype design respectively. Initially, the system was consisted of pH sensor, temperature sensor, proximity sensor, data logging shield, Arduino board and a 9V battery.

The three sensors were fitted into the holes at the bottom of the plastic container as shown in Figure 4.1. Proximity sensor was intended to act as water level sensor to measure the depth of the water. As the proximity sensor is not water resistant, it was wrapped by a plastic sheet. However, due to refraction of water, the proximity sensor was not able to measure water level accurately.

In Figure 4.2, it is shown that a data logging shield was stacked on top of the Arduino board and a memory card was inserted in the data logging shield. Before 1Sheeld+ was introduced, the data logging shield was used to log measured data into a memory card. Unfortunately, implementing data logging shield in this system did not allow users to obtain updated results. Users have to go onsite and take out the memory card to retrieve measured water parameters. Hence, the application of data logging shield was reconsidered and a better replacement was looked into.

A 9V battery was initially chosen to operate the Arduino board and data logging shield. It was selected due to its tiny size which will not occupy much space of the container. Despite of the high voltage of battery, the 9V battery has low current supply which is only about 400-600 mAh of capacity. After test running the system, it was found that the battery could only last for less than 2 hours. Hence, alternative power source was searched to extend the operation time of the system.

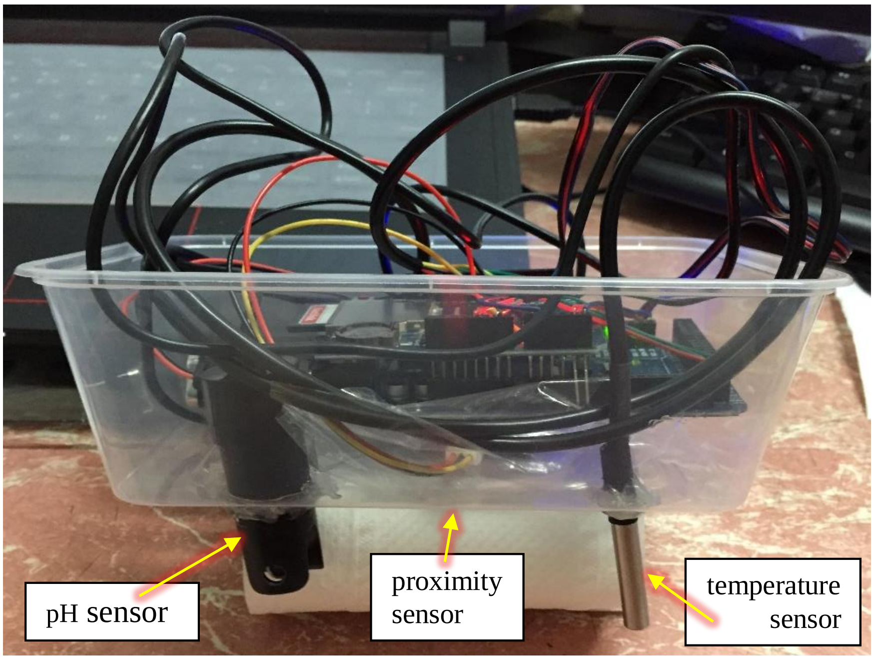

Figure 4.1: Side view of first prototype

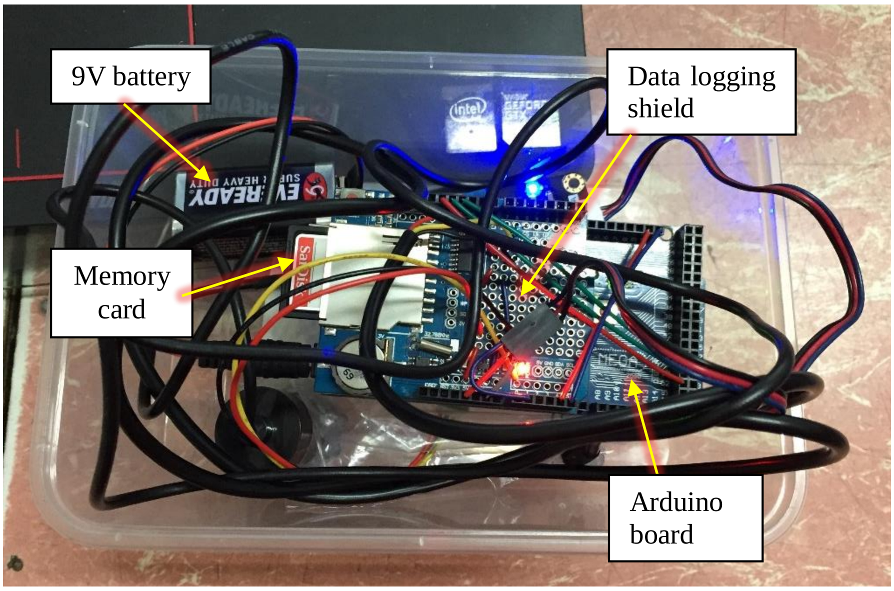

Figure 4.2: Top view of first prototype

4.1.2 Final Design of Prototype

The top view, side view and back view of the improved system's housing are shown in Figures 4.3 to 4.5 respectively. A transparent plastic container was used to insert all the components including the Arduino board, battery packs, pH sensor, temperature sensor and wires into it.

As for improvements from the first prototype, the 9V battery was replaced by 6 AA batteries as an AA battery has capacity rating of over 2500 mAh. The only drawback of using 6 AA batteries is that they are very heavy and occupied a lot of space in the container. Water level was not included in the water parameters measurements as the proximity sensor had been abandoned. The ideal replacement for the proximity sensor was the submersible IP68 waterproof water level sensor. However, it is too expensive hence it was not used in this project. Data logging shield was replaced by 1Sheeld+ as it allows users to create IoT applications by just connecting the Arduino to smartphone via Bluetooth. This means that users is able to obtain updated results from time to time no matter where the users are.

From Figure 4.3, it can be seen that the battery pack and Arduino Uno which was attached with 1Sheeld+ were placed perfectly inside the plastic container. By referring to Figure 4.4, an ultrasonic sensor was added to the system and located at the opposite end of the boat propellers to measure the distance between tank wall and the system. It was placed at the side of the housing to obtain more accurate result.

Polystyrene was added to the housing as shown in Figure 4.5. This was to increase the buoyancy so that the system will not easily sink into the water. The polystyrene was cut into circular shape so that the system can rotate back even it hits the tank wall or went into the corner of tank. pH sensor and temperature sensor were placed at the polystyrene part as it is easier to be cut and there was no more available space inside the plastic container. The boat propellers were placed until they were exposed to the water. The system only can be moved by spinning the propellers under the water. Since the plastic container, polystyrene and mini boat are all separate components, they were assembled together using hot glue gun. Any existing gaps were sealed with hot glue as it is water resistance.

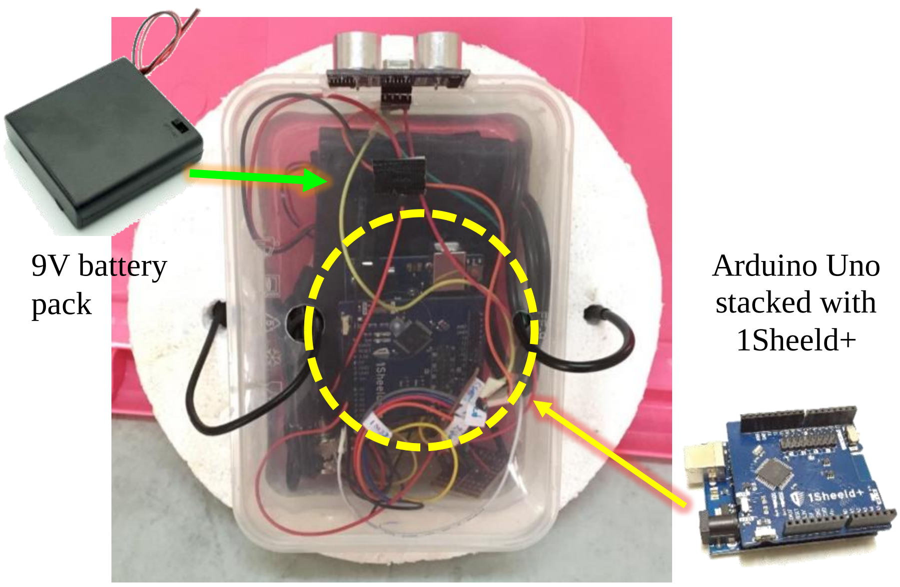

Figure 4.3: Top view of the housing

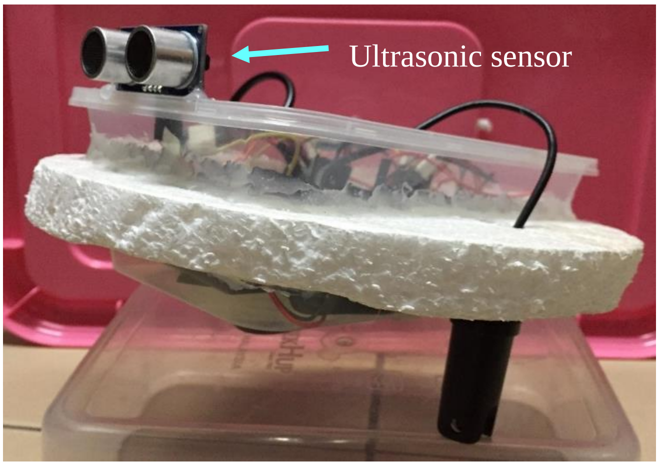

Figure 4.4: Side view of the housing

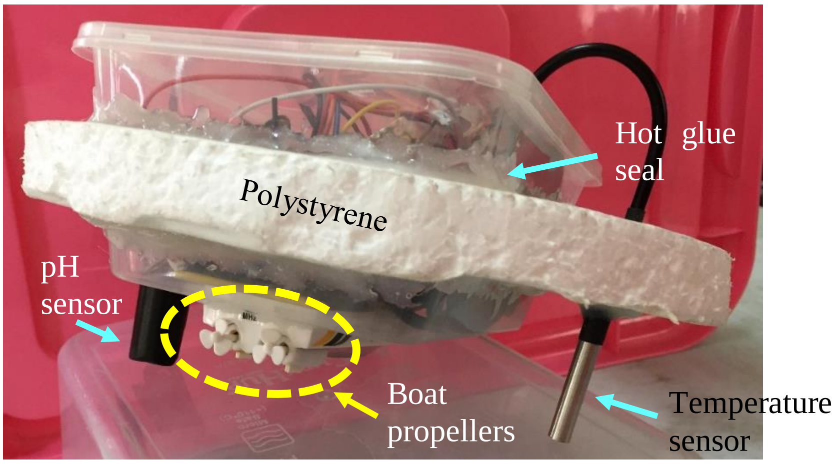

Figure 4.5: Back view of the housing

4.1.3 Main Circuit Diagram

Figure 4.6 shows the circuit diagram for the movable water quality monitoring system. It was drawn using Proteus PCB Design & Simulation software. However, the circuit was not complete as 1Sheeld+ cannot be found in the software's library. The sensors connection were still the same even 1Sheeld+ was not available in the software as the 1Sheeld+ was physically attached on top of the Arduino Uno as shown in Figure 4.7.

The wire connection between each sensor and the Arduino Uno is shown in Table 4.1. Temperature sensor, pH sensor and ultrasonic sensor shared the same Vcc pin (5V power pin) and GND pin (Ground) so that they have a common reference voltage. The input pins of pH sensor (A) and temperature sensor (DQ) were connected to Arduino's analog pins as the value received from the sensors will kept fluctuating.

As for the ultrasonic sensor, Trig (signal output pin) and Echo (signal input pin) only receive or send out '0' or '1' signal, they were both connected to the digital pins of Arduino. The same goes to the RX2X AT302R decoder. Pin 6, 7, 10 and 11 of the decoder are only allowed to receive binary signal, hence, they were also connected to digital pins of the Arduino Uno.

The 5 kΩ resistor which was connected between DQ and Vcc of the temperature sensor acted as a pull-up resistor. It was needed as the input pin of temperature sensor has high impedance. Without some load at the end of the line, the interconnecting wire will create noise and hence giving inaccurate readings.

Table 4.1: Wire connection between Arduino board and sensors

Sensors Pin	Arduino Pin
Ultrasonic sensor	
5V	VCC (5V power pin)
Trigger	8 (Digital pin 8)
Echo	9 (Digital pin 9)
Gnd	GND (Ground Pin)
pH sensor	
Vcc	VCC (5V power pin)
A	A1 (Analog pin 1)
Gnd	GND (Ground Pin)
Temperature sensor (DS18B20)	
VCC	VCC (5V power pin)
DQ	A0 (Analog pin 0)
GND	GND (Ground Pin)
RX2X ARS302R Decoder	
6 (Right)	4 (Digital pin 4)
7 (Left)	5 (Digital pin 5)
10 (Backward)	6 (Digital pin 6)
11 (Forward)	7 (Digital pin 7)

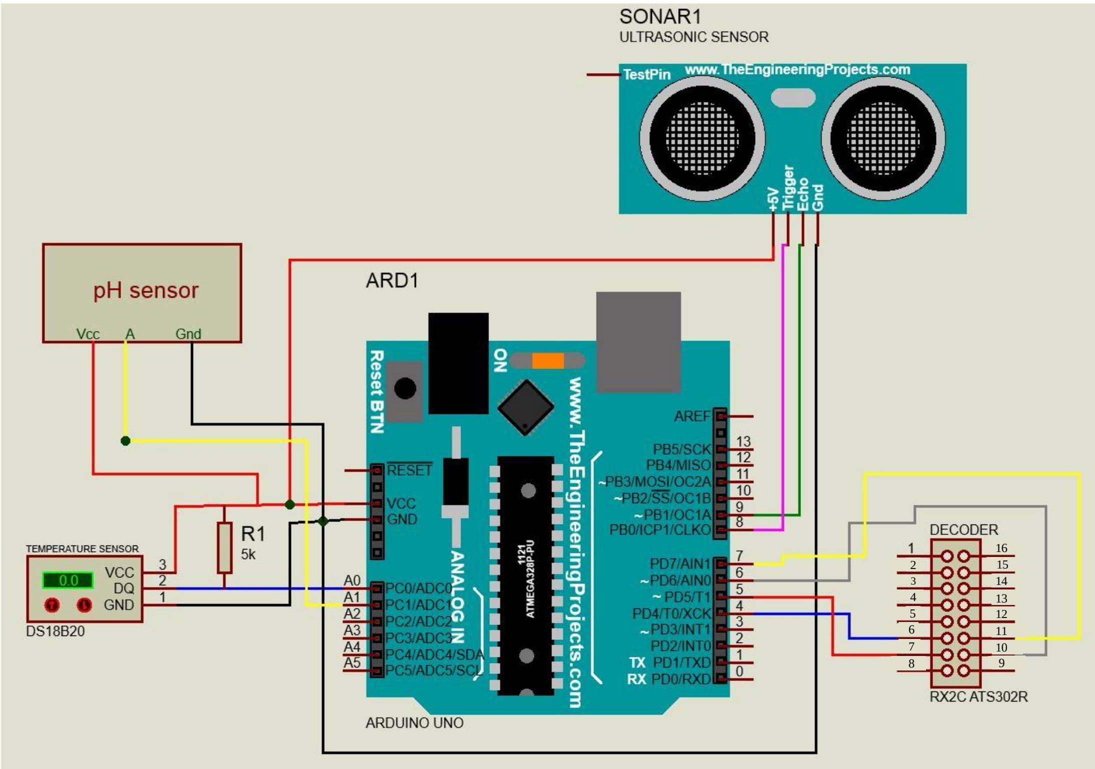

Figure 4.6: Circuit diagram of movable water quality monitoring system

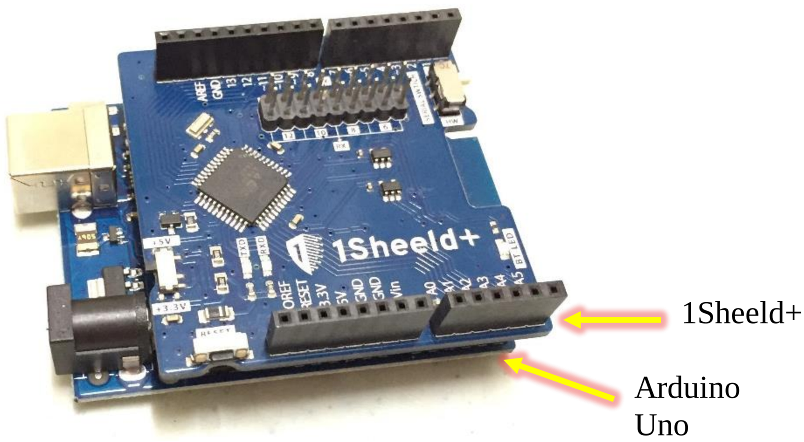

Figure 4.7: Stacking of 1Sheeld+ on top of Arduino Uno

4.2 Floating Platform

The original package of the mini boat consisted of components as shown in Figure 4.8. Initially, the mini boat was operated by a 2.4 V rechargeable battery with capacity of 70 mAh. It can be charged by a remote control but it will only last for 5 minutes. This was not desirable for a long term running system. Therefore, the mini boat was modified so that it can operate as long as possible. As the mini boat was originally a remote controlled speedboat, the movement of the boat only can be controlled by using a remote control. In this system, the boat was supposed to move automatically by itself without the presence of remote control. Hence, the circuit board was modified to allow Arduino to control the motors.

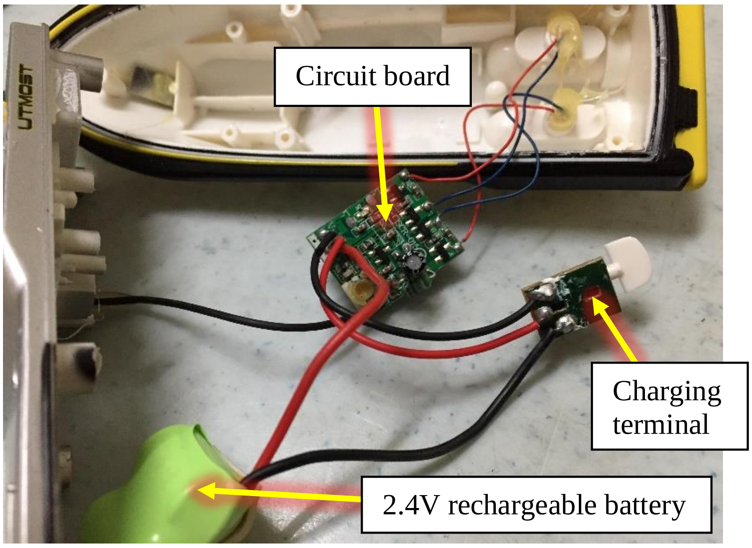

Figure 4.8: Components from original mini boat

4.2.1 Circuit Diagram

Since the 2.4V rechargeable battery and charging terminal were not suitable in running long term, they were not employed in this system, hence, they had been removed from the circuit board as shown in Figure 4.9. Under the circuit board, it was connected to a RX2C ATS302R receiver. At the beginning, the RX2C ATS302R receiver was paired with TX2C ATS302T from the remote control. TX2C ATS302T is the encoder while RX2C ATS302R is the decoder. Both of these provide function keys of controlling forward, backward, rightward, leftward and turbo motions. Without the TX2C ATS302T, RX2C ATS302R will not receive any command and hence, the mini boat will not function. Modification was made based on the RX2C ATS302R so that it can be controlled by the Arduino.

Figure 4.10 shows the pin assignment of a RX2C ATS302R from data sheet. There were 4 wires extending from the motors according to Figure 4.9. The wires were connected to pin 6, 7, 10 and 11 of the RX2C ATS302R. From this, it is known that the motors were controlled by these 4 pins. Additional wires were soldered on each pin as shown in Figure 4.11 and the other end of the wires were connected to the Arduino's digital pins. This is to allow Arduino to turn the motor by sending HIGH or LOW signal to pin 6, 7, 10 and 11.

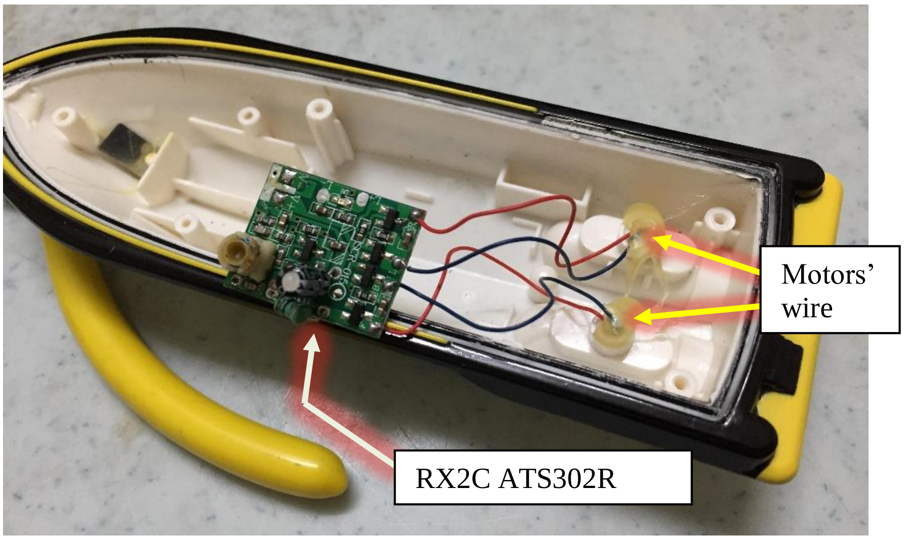

Figure 4.9: Circuit board with 2.4V rechargeable battery being removed

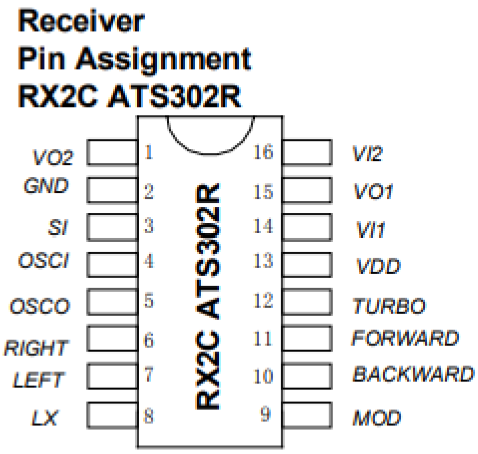

Figure 4.10: Pin assignment for RX2C ATS302R (Actions Semiconductor, 2004)

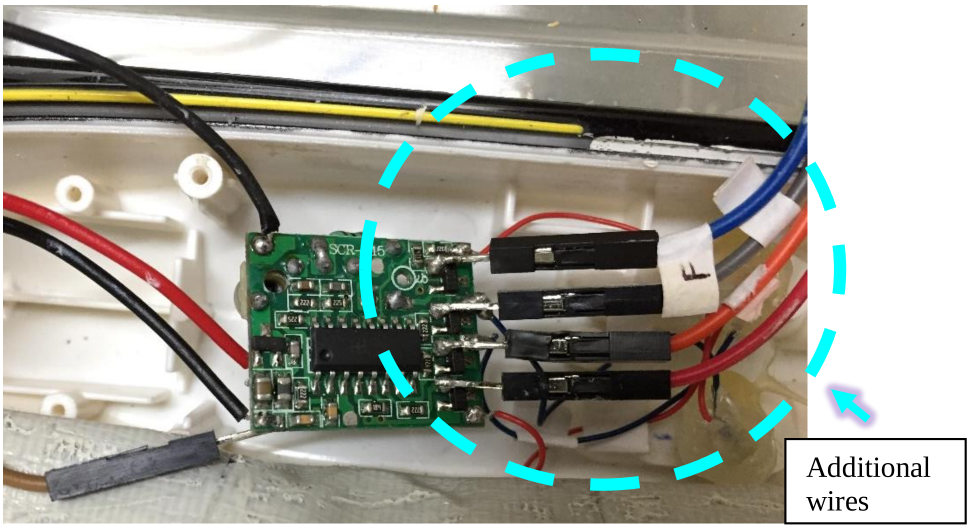

Figure 4.11: Modified circuit board

From Figure 4.12, it is shown that the 2.4V rechargeable battery was replaced by two AA batteries which added a total of 3V voltage supply (each AA battery delivers 1.5V). According to TX2C ATS302T/RX2C ATS302R data sheet, the input voltage range for RX2C AT302R is from 0.8V to 3.0V, hence, two AA batteries were used to power the motors. DC motors were not allowed to share the same power source with the Arduino as the board may get damaged. Due to this reason, external power was supplied to the two DC motors. On top of that, by replacing rechargeable battery with AA batteries solve the problem of short operating time. AA battery can operate longer than the rechargeable battery. Charging terminal was also removed as battery recharging is no more necessary.

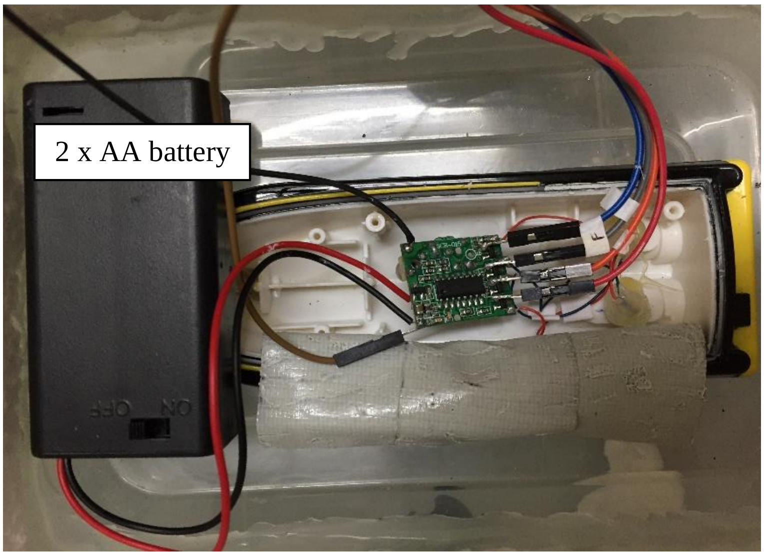

Figure 4.12: Replacement of 2.4V rechargeable battery with 2 x AA battery

4.2.2 Boat's Speed

The modified boat's run was tested in a rectangular shape tank and a round shape tank. In this system, the boat was programmed to be moved in forward, backward, right rotating and left rotating motions. The speed for forward and backward motion are calculated by using the Equation 1; speed for leftward and rightward motion are calculated using Equation 2. Table 4.2 shows the speed for all motions when they are measured without load.

Equation 1: $speed, s = \frac{distance, d}{time, t}$

Equation 2: $revolution\ per\ minute, rpm\ = \frac{number\ of\ rotation}{60\ s}$

By determining the speed of each motion, the Arduino was allowed to control the distance moved by the system. In Arduino coding, the distance can be decided by changing the time needed to run the motors.

Table 4.2: Motor speed for forward, backward, leftward and rightward motion

Motion	**Speed (cm/s)**
Forward	4.973
Backward	7.716
Motion	**Speed (rpm)**
Leftward	5.837
Rightward	5.682

4.3 Software Development

In this project, only software Arduino IDE was used to develop the mobile water quality monitoring system. It is a system that is able to utilize smartphone to log data into its memory via Bluetooth and email the data to users. Besides, users were also allowed to control the position of the system through 1Sheeld app.

The main loop of the Arduino coding is shown Figure 4.13. Algorithms of the code are shown in Appendix B. GamePad.setOnButtonChange() is a function that allows users to control the movement of boat using 'Game Pad Shield' in the 1Sheeld App. The movable water quality monitoring system will only start to operate when users push a virtual button in the 1Sheeld App. Once the button was pushed, the ultrasonic sensor started to measure the distance between the tank wall and the system. The boat moved forward if the distance was greater than 10 cm, or else it would rotate left.

After the boat had moved, Logger.start() will create a spreadsheet (CSV) file to log data into given file name. The system will read the pH value and temperature from the two sensors every minute. If the water parameters were out of range, the system will send an email alert to users to notify them the current condition of the aquaculture tank. The data was then saved into the spreadsheet created. When new data has been collected, Logger.add() function adds the data to a new row.

Counter was incremented by 1 every time a new data is added. When the counter reached 15, Logger.stop() stops logging data onto the spreadsheet and save the file into the smartphone's memory. Email.attachFile() attaches the last saved CSV file to sender’s email and use Email.send() function to send the email out to other users. This means that users will be receiving email that consisted of updated water parameters in CSV format every 15 minutes. By adjusting the Arduino code as shown in Figure 4.14, the time interval to read the water qualities and the number of data needed can be changed based on user’s requirement.

Figure 4.15 shows the “Game Pad” function to control the movement of the mini boat. User is able to control the boat using ‘Game Pad Shield’ as shown in Figure 4.16 through 1Sheeld App. When “Up” button is pressed in the ‘Game Pad Shield’, the boat will move forward; when “Down” button is pressed, boat moves backward; when “Left” button is pressed, boat rotates in anticlockwise direction; when “Right” button is pressed, boat rotates in clockwise direction.

The Arduino code for controlling the direction of motor was written based on the truth table shown in Table 4.3. The truth table indicates how the motor will function given the state of the logic pins. Pin 6 and Pin 7 were used to control one motor while pin 10 and pin 11 were used to control another motor. Therefore, pin 6 and pin 7 cannot be HIGH at the same time, this also apply to pin 10 and pin 11, or else, the motor will jam.

‘Game Pad Shield’ from the 1Sheeld app was utilized to replace the original remote control for the mini boat. User can easily control the movement of system by connecting the smartphone to Arduino over Bluetooth.

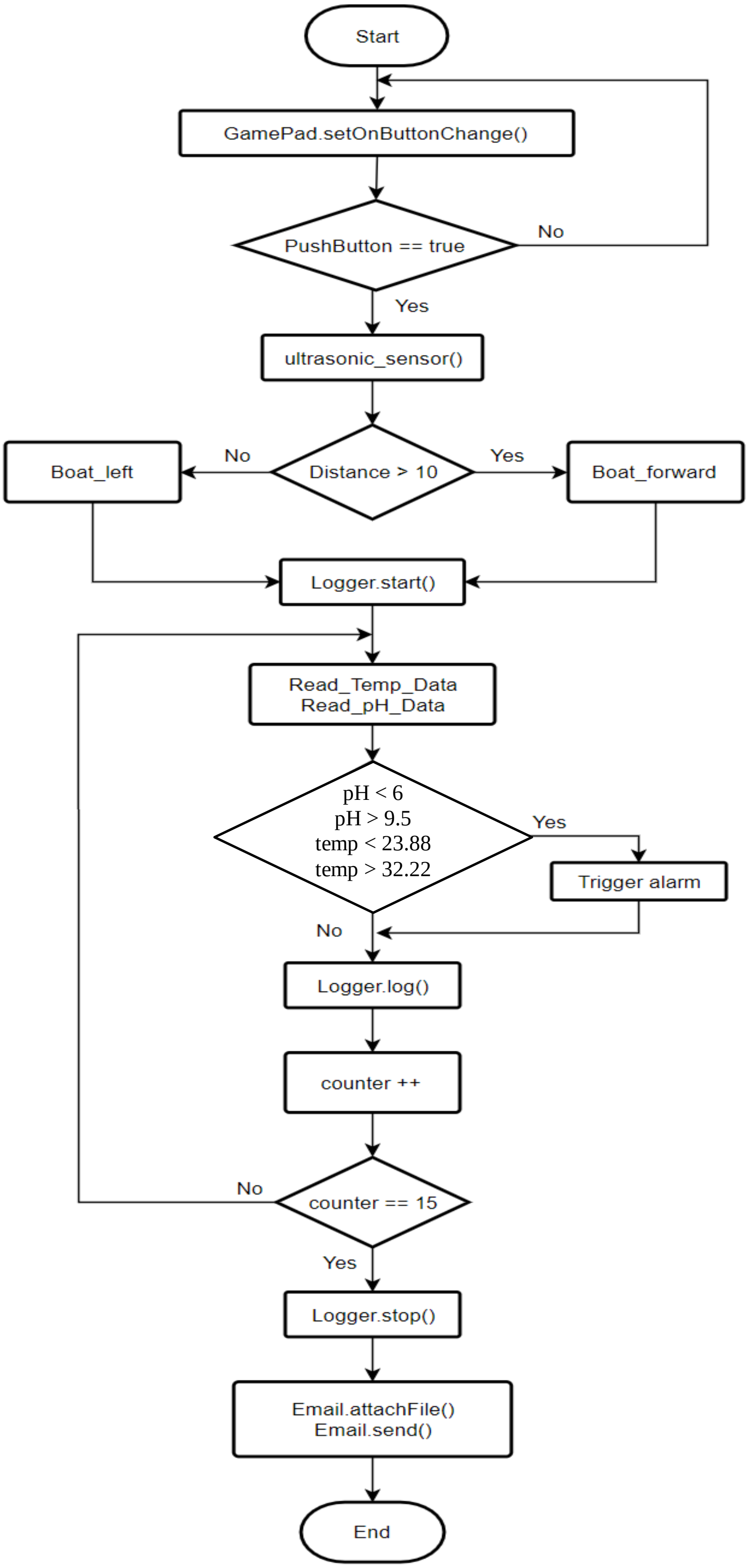

Figure 4.13: Main Program Flow Chart

```
/* data logging shield */
long interval = 60000;        //record data every 60000ms (1 min)
long previousTime = 0;
int counter = 0;
int NumData = 15;                //number of data in one file
String title = "Data logger";
```

Figure 4.14: Arduino code for changing the time interval and number of data needed

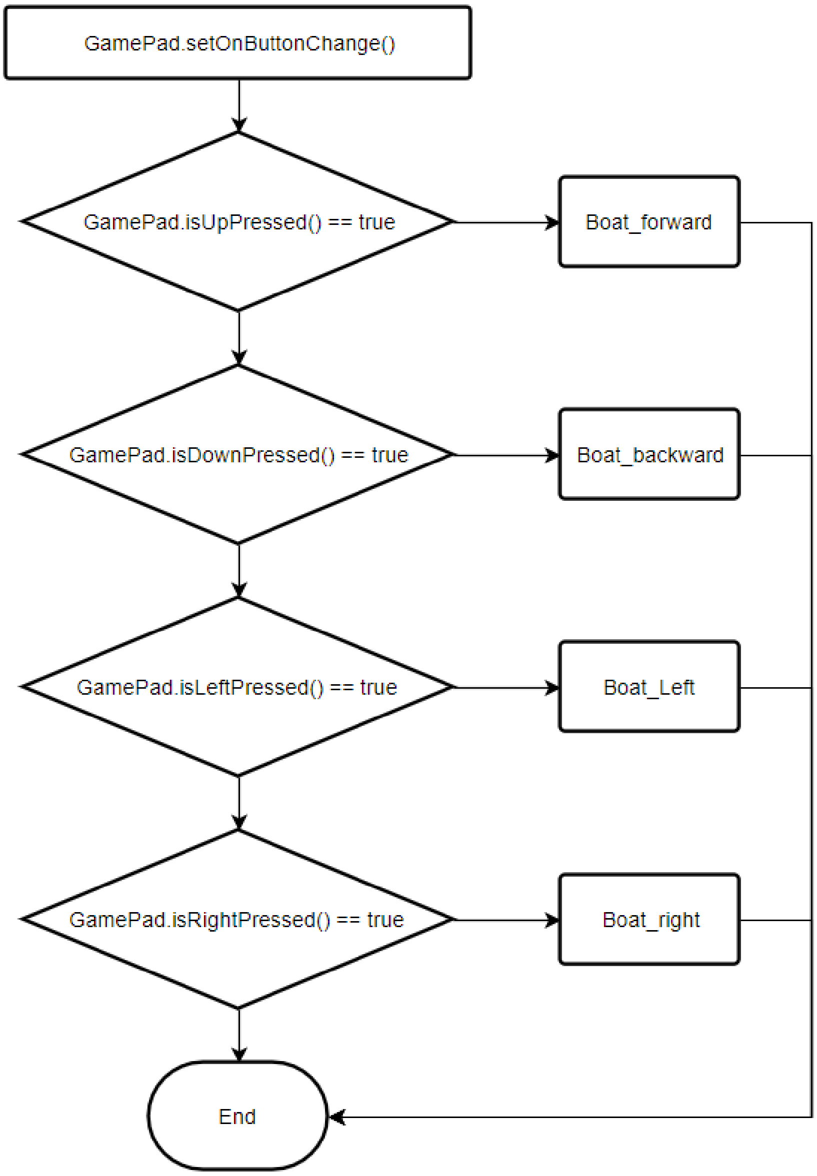

Figure 4.15: “Game Pad” Flow Chart

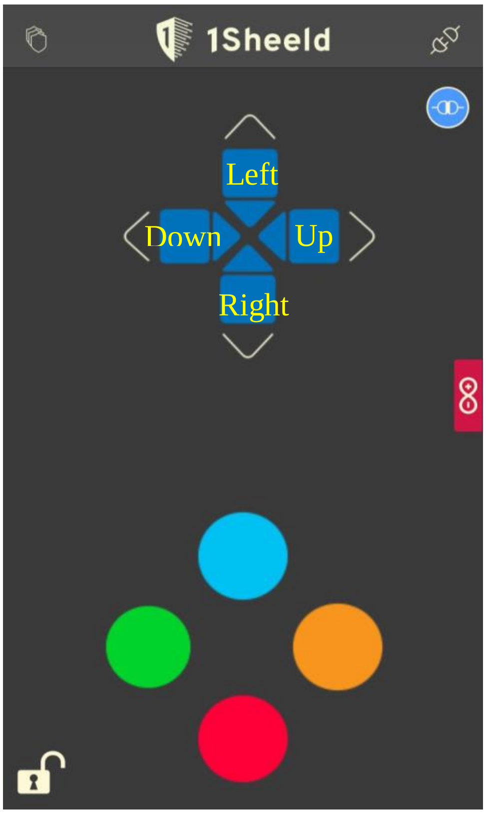

Figure 4.16: ‘Game Pad Shield’

Table 4.3: Logic to control the direction of motor

Boat Motion	Pin 6	Pin 7	Pin 10	Pin 11
Forward	LOW	HIGH	LOW	HIGH
Backward	HIGH	LOW	HIGH	LOW
Leftward	LOW	HIGH	HIGH	LOW
Rightward	HIGH	LOW	LOW	HIGH
Stop	LOW	LOW	LOW	LOW

4.4 Integration of Sensor System with the Internet of Things (IoT)

Developed movable water quality monitoring system was integrated with the Internet of Things (IoT). 1Sheeld+ allowed users to create IoT applications by connecting its IoT chip to a smartphone. 1Sheeld+ can be used by placing it onto the Arduino board. By using 1Sheeld library, code was written on the Arduino software before uploading to the Arduino Uno. The code was then used to control sensors that are connected to the board. 1Sheelp app can be downloaded from Play Store for Android devices or from App Store for iOS devices. 1Sheeld application can be opened from smartphone as shown in Figure 4.17 (a). The app will connect to 1Sheeld+ using

Bluetooth. Therefore, the smartphone must be close to the 1Sheeld+. Figure 4.17 (b) shows all of the shields that are available in 1Sheeld app.

(a) (b)

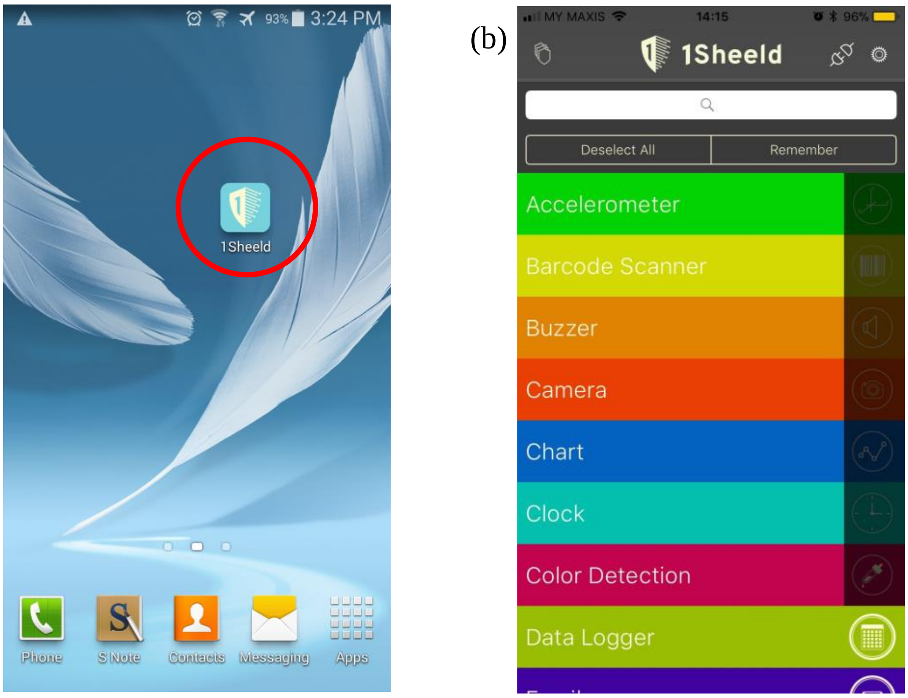

Figure 4.17: (a) 1Sheeld app (b) Available shields in 1Sheeld app

The shields used in this system were the ‘Email Shield’, ‘Game Pad Shield’, ‘Data Logger Shield’ and ‘Push Button Shield’ as shown in Figure 4.18 (a) to (d). ‘Game Pad Shield’ was optional for user to control the system manually. The system was moved once user has pushed the button in ‘Push Button Shield’. Water qualities were measured after the motors have stopped turning. The data will then be saved into smartphone’s memory in CSV format through the ‘Data Logger Shield’ shield. Once the smartphone has logged 15 data, ‘Email Shield’ emailed users the latest results in CSV format. Users will then receive an email that is attached with a CSV file as shown Figure 4.19. The results received are shown in Figure 4.20 after user has opened the file. Users will be kept updated by receiving email every 15 minutes. An email alert was sent to user as shown in Figure 4.21 once the pH value or temperature is detected out of range.

(a) (b)

(c) (d)

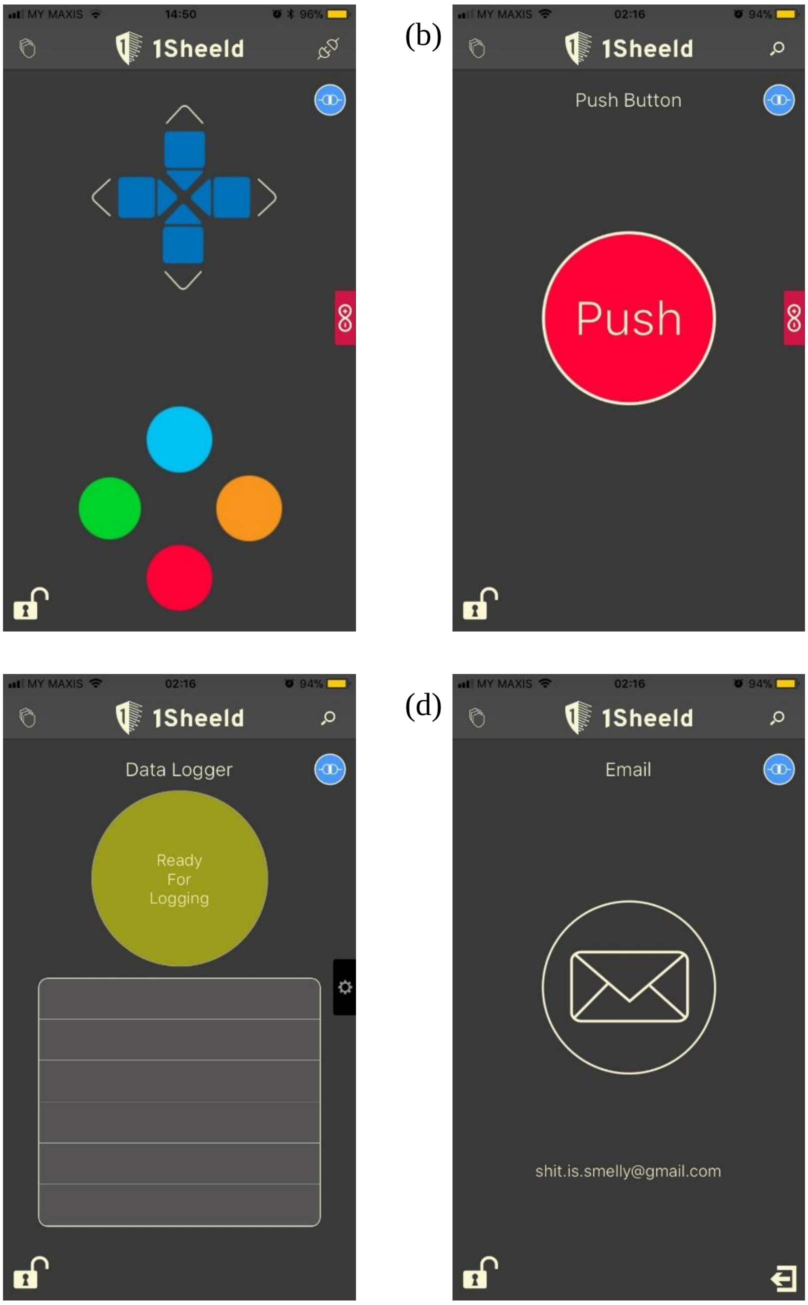

Figure 4.18: (a) ‘Game Pad Shield’ (b) ‘Push Button Shield’

(c) ‘Data Logger Shield’ (d) ‘Email Shield’

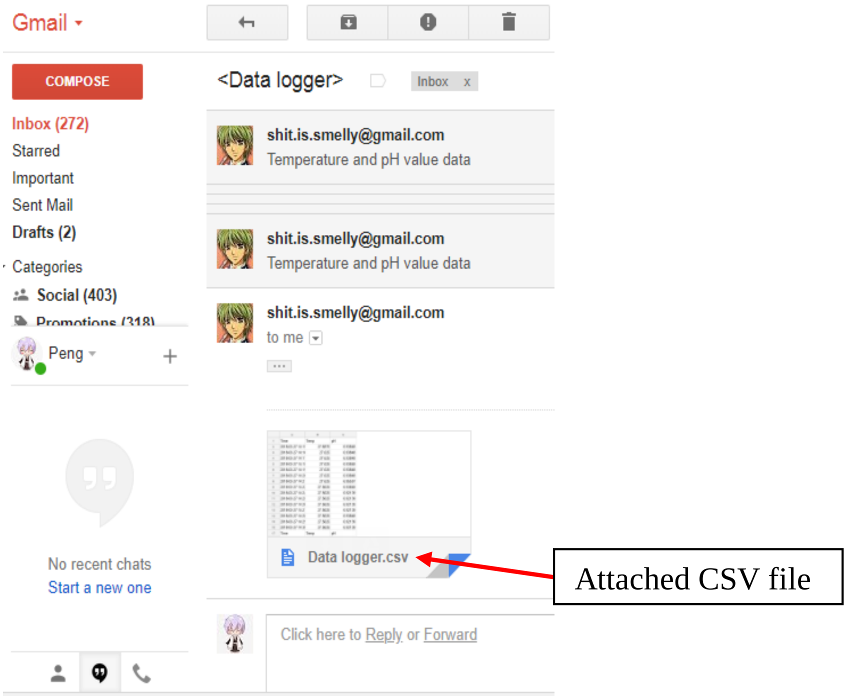

Figure 4.19: Email interface

	A	B	C
1	Time	Temp	pH
2	2018-03-27 14:15:39	27.6875	6.93848
3	2018-03-27 14:16:44	27.625	6.93848
4	2018-03-27 14:17:47	27.625	6.93848
5	2018-03-27 14:18:49	27.625	6.93848
6	2018-03-27 14:19:51	27.625	6.93848
7	2018-03-27 14:20:53	27.625	6.93848
8	2018-03-27 14:21:55	27.625	6.95557
9	2018-03-27 14:22:57	27.5625	6.93848
10	2018-03-27 14:24:00	27.5625	6.92139
11	2018-03-27 14:25:02	27.5625	6.92139
12	2018-03-27 14:26:04	27.5625	6.92139
13	2018-03-27 14:27:06	27.5625	6.92139
14	2018-03-27 14:28:08	27.5625	6.93848
15	2018-03-27 14:29:10	27.5625	6.92139
16	2018-03-27 14:30:12	27.5625	6.92139
17	Time	Temp	pH
18	2018-03-27 14:31:15	27.5625	6.9043
19	2018-03-27 14:32:18	27.5625	6.92139
20	2018-03-27 14:33:20	27.5	6.92139
21	2018-03-27 14:34:22	27.5	6.93848
22	2018-03-27 14:35:24	27.5	6.93848
23	2018-03-27 14:36:26	27.5	6.9043
24	2018-03-27 14:37:28	27.5	6.9043
25	2018-03-27 14:38:31	27.5	6.88721
26	2018-03-27 14:39:33	27.5	6.9043

Figure 4.20: Example of data collected

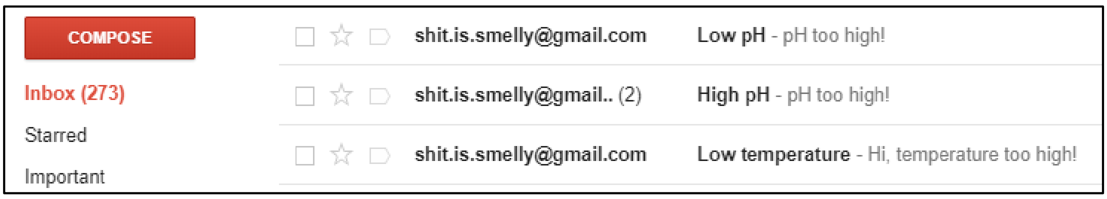

Figure 4.21: Email alert

4.5 Performance of the System

The system was tested on rectangular shape tank and round shape tank. Figure 4.22 shows the path moved and area covered by the system in rectangular tank while Figure 4.23 shows the round tank.

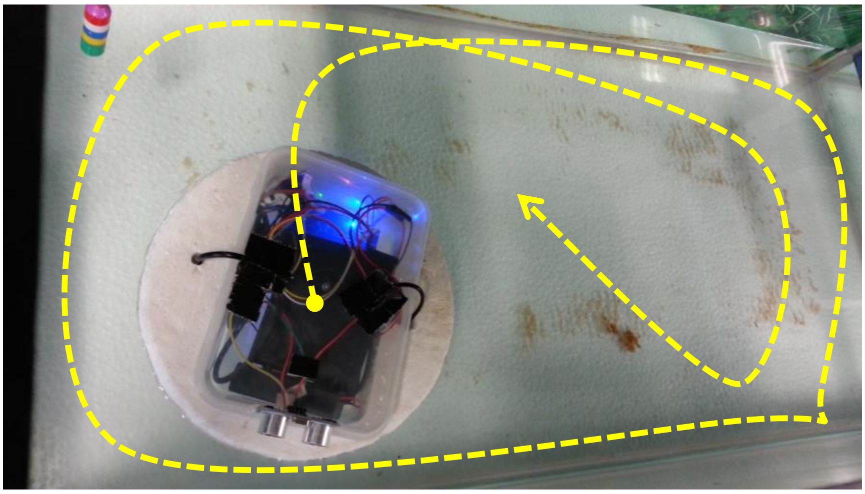

Figure 4.22: Area coverage of the system in rectangular tank

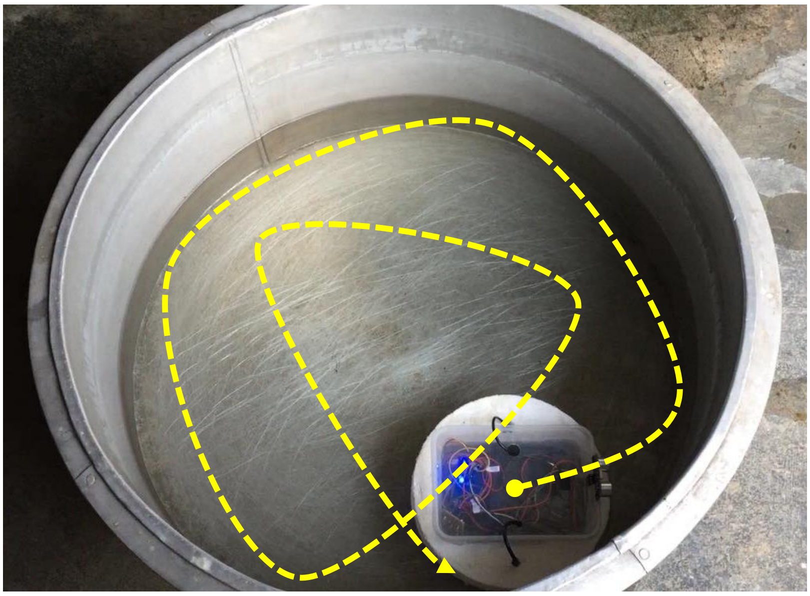

Figure 4.23: Area coverage of the system in round tank

From Figure 4.22 and Figure 4.23, it shows that the system is able to move around the tank. Due to the round shape design of the polystyrene, the system was able to move away from the tank wall or turn around when it went into the corners. This shows that the movable water quality monitoring system was able to cover all the whole area in any shape of tank.

After the prototype was done, it was tested for continuous two hours in a rectangular aquaculture tank which is located at UTAR KB614. Figure 4.24 and Figure 4.25 show the temperature graph and pH graph respectively. The time interval shown in the graphs was not 1 minute due to the time was compressed as hundreds of data were collected within the two hours of trial run.

Both temperature and pH value dropped gradually as time passed. The temperature dropped from 24.625 °C to 24.1875 °C while the pH value dropped from 7.675 to 4.769 in two hours. The acceptable range for temperature is between 23.88 °C and 32.22 °C. pH value with less than 6 or more than 9.5 is considered out of the acceptable range. The temperature only decreased slightly, there was no email alert regarding temperature as it was within the desirable range. However, the pH value has fallen significantly, when the pH value has dropped below 6, an email alert is sent to user as shown in Figure 4.26. Practically, the pH value in the water will not deviate from the actual value too much. A drop of nearly 3 pH value within 2 hours was abnormal where water with 4.7 pH value is considered acidic in the culture tank. Therefore, pH value was tested using the lab's pH meter, it was found out that the real pH value of the water is 7.69. Hence, it was concluded that the issue was within the system's coding. The code was modified to solve this problem.

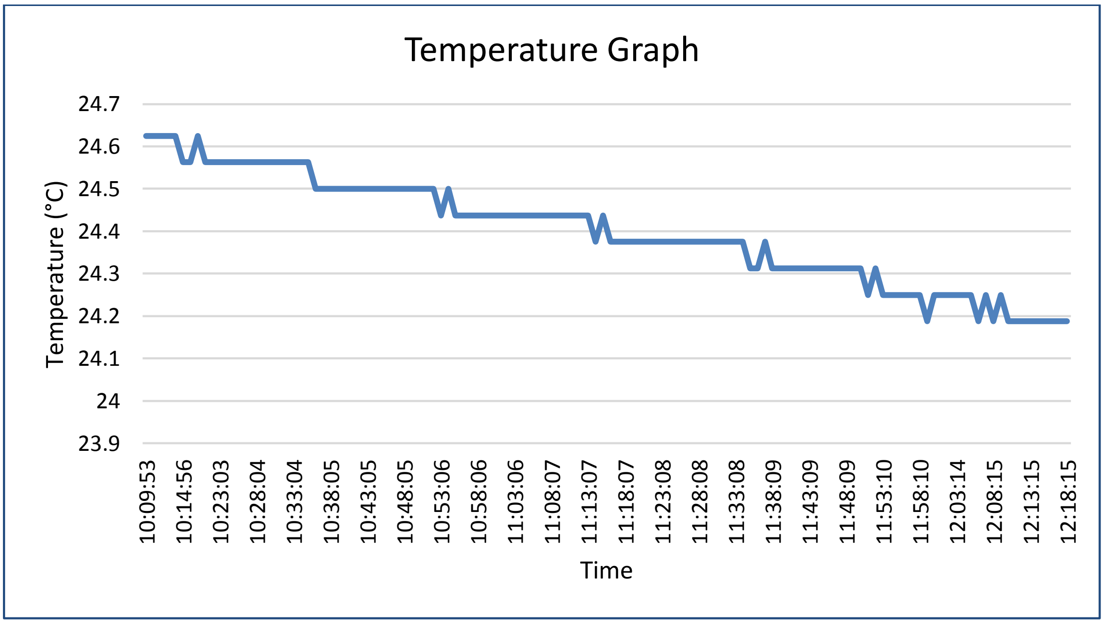

Figure 4.24: Temperature graph

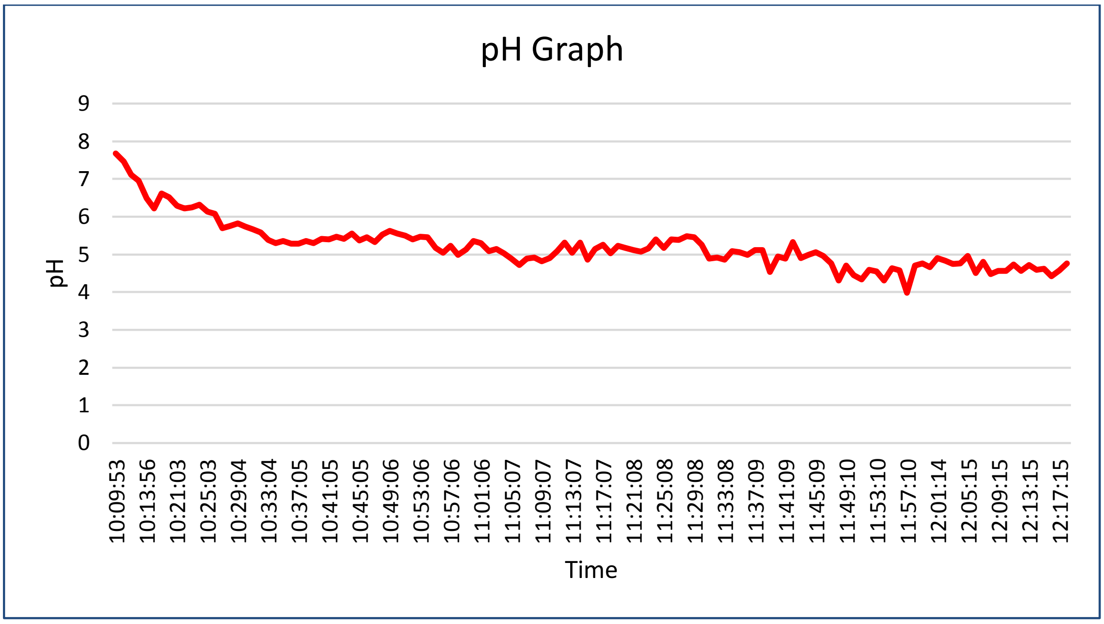

Figure 4.25: pH graph

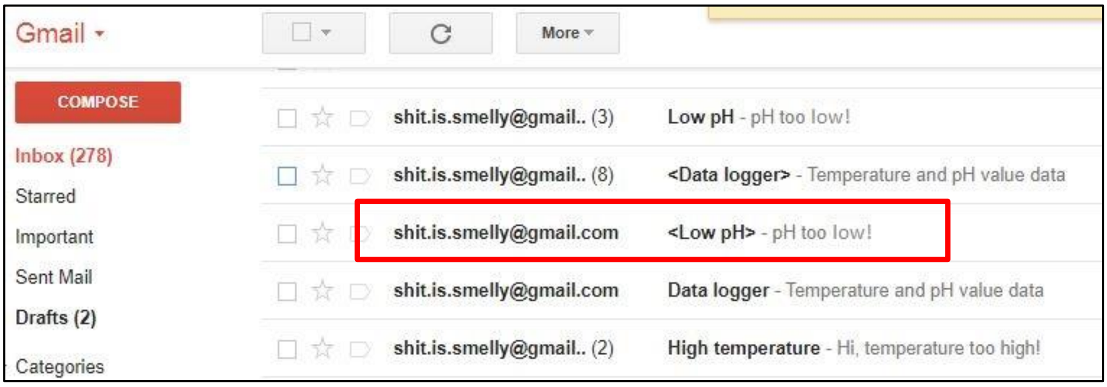

Figure 4.26: Email alert when pH value less than 6

4.6 Improvement of the System

During the trial run of the system, none of the two readings from both sensors were accurate. The huge change in pH value during continuous measurement was due to two analog inputs were read at the same time. Therefore, research and study were done to find a solution.

The problem was solved by reading each analog sensor twice and then add a small delay (100ms) in the Arduino code after every analog reading. The reason of causing the sensor to give inaccurate results is because the analog-to-digital converter (ADC) multiplexer needs switching time, time is needed to stabilize the voltage after switching. Basically, the multiplexer will switch after the first analogRead() is called, therefore, with addition of time delay, the voltage is allowed to stabilize. The second analogRead() call will be more accurate with less jitter. Figure 4.27 and Figure 4.28 show the first version and modified version of code respectively. Read_Temp_Data() function was used to read temperature value from Arduino analog pin A0 while Read_pH_Data() function was used to read pH value from Arduino analog pin A1.

```
void Read_Temp_Data(){
  sensors.requestTemperatures();
  temperature = sensors.getTempCByIndex(0);
}

void Read_pH_Data(){
  sensorValue = analogRead(pH_sensor);
  pHVol = sensorValue*5.0/1024;
  pHValue = 3.50*pHVol;
}
```

Figure 4.27: First version of Arduino code

```
void Read_Temp_Data(){
  sensors.requestTemperatures();
  temperature = sensors.getTempCByIndex(0);
  delay(100);
  sensors.requestTemperatures();
  temperature = sensors.getTempCByIndex(0);
  delay(100);
}

void Read_pH_Data(){
  sensorValue = analogRead(pH_sensor);
  delay(100);
  sensorValue = analogRead(pH_sensor);
  delay(100);
  pHVol = sensorValue*5.0/1024;
  pHValue = 3.50*pHVol;
}
```

Figure 4.28: Modified version of Arduino code

After the Arduino code had been modified, the system was tested in a round tank. Figure 4.29 and Figure 4.30 show the collected data after the modification of system. From Figure 4.30, it can be seen that the temperature only fluctuates slightly with less than 0.3 of deviation from the initial value. The initial and final temperature were 31.4375 °C and 31.3125 °C respectively. On the other hand, the deviation of pH value seen from Figure 4.30 was also minimal. There was only an increase of 0.07 pH value within the two hours. This can be concluded that the system has been improved.

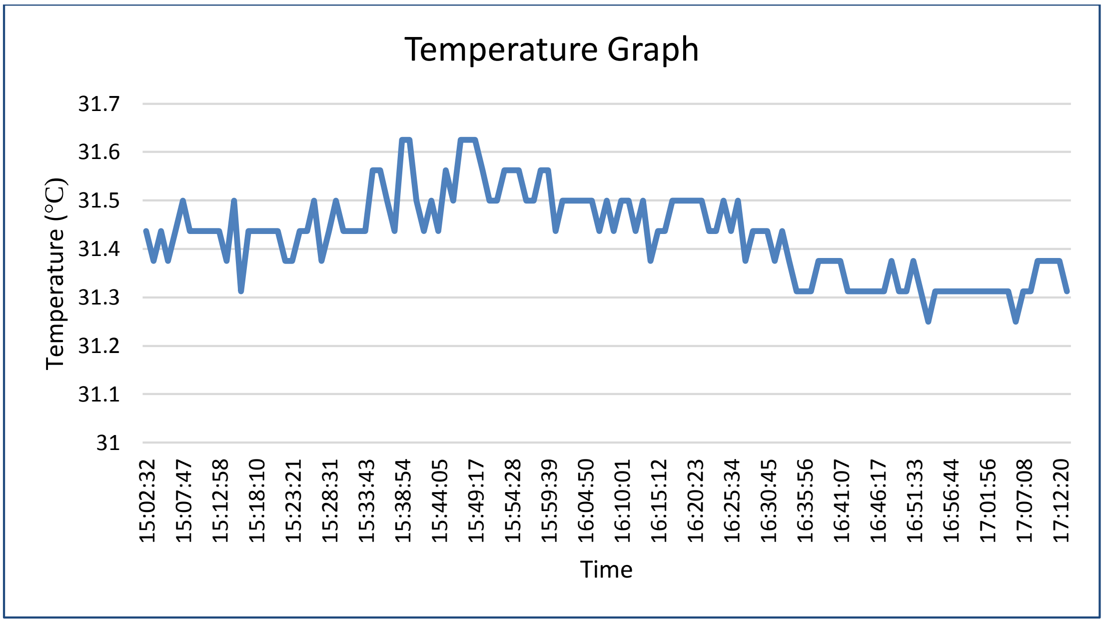

Figure 4.29: Temperature graph after code modification

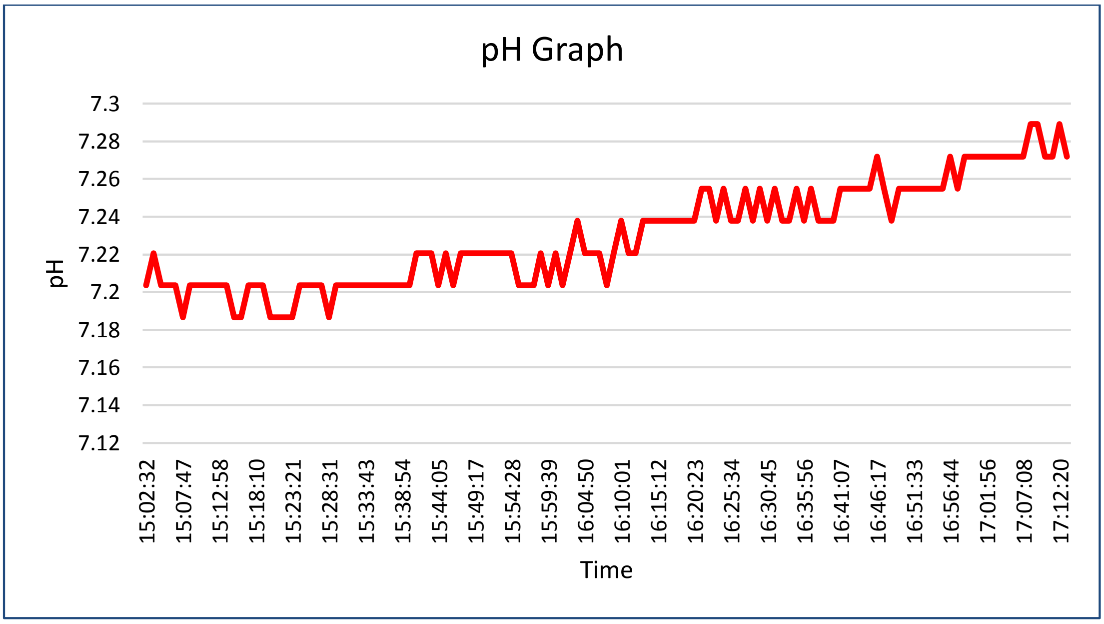

Figure 4.30: pH graph after code modification

4.7 Discussion

Conventional water quality monitoring system is sinking and static type. The sensors are all stationary at the wall of aquaculture tank. This developed movable water quality monitoring system enabled the water qualities to be measured at every corner of the aquaculture tank as the system was floating and moving around the tank. Even if it has collided with the wall or stuck at the corner of tank, the system was able to move away from it due to its round shape design. The system was tested in rectangular shape tank and round shape tank, results shown that the path of the system moved was able to cover the whole area of the tank.

Arduino Uno and 1Sheeld+ were implemented in the system to control the pH sensor, temperature sensor and motors. Users were allowed to control the movement of system using their smartphones. When the system was placed in the aquaculture tank, it started to move automatically after user has pressed the virtual push button in 1Sheeld app. Arduino started to measure water qualities through the sensors. Data collected were saved into smartphone’s memory and then were sent to users via email, hence, users may receive updated results anytime anywhere.

This movable water quality monitoring system was powered by a 9V battery pack which is placed together with the Arduino board inside the system’s container. The system was powered by battery instead of power supply is to avoid any long wiring connection. When wire cable is exposed to water, it creates risks of electrocution which is very dangerous. Hence, the battery pack was inserted into a water tight container to prevent the circuit board from getting wet. Besides, the dimension of the system was approximately 21 cm x 21 cm, it can be easily taken out from the tank and place it into another tank. Users do not have to be concerned about the trouble of installation or uninstallation.

However, there were also drawbacks in this system. As the system was operated by batteries, it has limited lifespan. Batteries have to be replaced regularly in order for the system to function continuously. Besides, since 1Sheeld+ communicates with smartphone via Bluetooth, the smartphone must not be too far from the system; it must be within the range of 30 feet which is approximately 9 metre. The function of a smartphone placing near the system was to access the 1Sheeld app over Bluetooth. The smartphone will email the data by connecting to Wi-Fi. Therefore, users still can receive email alert or data collected at any places by using different smartphone. Another downside of this system is the smartphone that placed near the system must be an iOS device. Based on 1Sheeld library, the Email.attachFile() function called in the Arduino code only support iOS app. This indicates that the CSV file only can be attached to an email and send it out through iOS device. Users still can receive the email with Android devices.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

A microcontroller-based movable water quality monitoring system was successfully developed. The system was able to float on the water surface without any water leaking into the housing. By operating the system continuously, it had the capability to cover the whole area of the aquaculture tank. Hence, measurements at any point of the tank can be taken.

The monitoring system was able to measure water qualities such as temperature and pH value of the aquaculture tank. It was capable to drive itself away from the tank wall when collision took place. The system will not be stranded at any point of the culture tank. Hence, water quality parameters at different points of aquaculture tank can be measured.

Arduino Uno was used as microcontroller to control the sensors and motor while 1Sheeld+ was used to transmit data between Arduino and smartphone over Bluetooth. By integrating the sensor system with the Internet of Things (IoT), users were able to obtain updated results through email.

5.2 Recommendations for future work

This movable water quality monitoring system can be improved if more time and budget are given for this project. One of the methods to improve the system is by adding more sensors such as ammonia sensor, dissolved oxygen sensor and water level transducer to the system. As ammonia level and dissolved oxygen value are equally important as the pH value and temperature in aquaculture tank, the parameters should be measured to have a better monitoring of the fish's condition.

Besides, Internet Protocol (IP) camera can be installed on the system for surveillance purpose. IP camera allows video recorded to be sent or received through computer network and the Internet. Users can perform real time monitoring on the fish movement and also the surrounding of the aquaculture tank by using a smartphone.

Another suggested improvement is to implement Wi-Fi module in the system to develop a real time water quality monitoring system. Users can monitor real time data through customized app without placing any smartphone near the system. Aside from that, wireless sensors are encouraged to be introduced to reduce the complexity of wire connection as much as possible.

The system can be improved by replacing the Arduino Uno with a PIC microcontroller as PIC is much smaller in size compared to the Arduino board. The dimension of the housing can be reduce. With a smaller size of moving object, the fish in the tank will be less easily to be frighten.

Green energy such as solar power can be used to operate the water quality monitoring system. As AA batteries are not reusable, the use of solar energy would help to reduce electronic waste. Besides, regular replacement of batteries are not required.

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APPENDICES

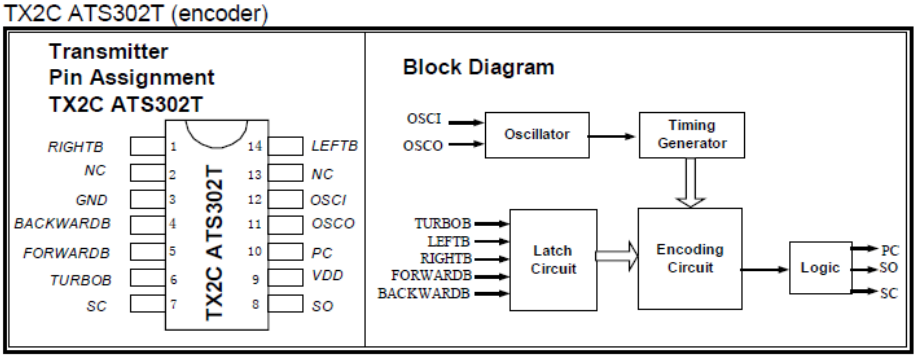
APPENDIX A: TX2C ATS302T/RX2C ATS302R Data Sheet

MOBICON Electronic Components

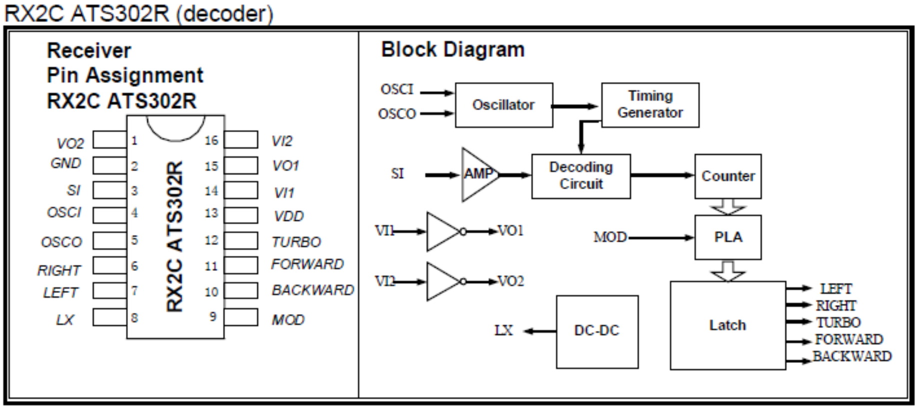
Actions Semiconductor Co., Ltd. 5-Function Remote Controller **TX2C ATS302T/RX2C ATS302R**

Pinouts and Block Diagrams

TX2C ATS302T (encoder)



RX2C ATS302R (decoder)



Absolute Maximum Ratings

DC Supply Voltage.................................. -0.3V to 6.0V
Input/Output Voltage.......... GND -0.2V to VDD + 0.2V
Operating temperature............................ -10°C to 60°C
Storage Temperature............................ -25°C to 125°C

Comments*

Never allow a stress to exceed the values listed under "Absolute Maximum Ratings", otherwise the device would suffer from a permanent damage. Nor is a stress at the listed value be allowed to persist over a period, since an extended exposure to the absolute maximum rating condition may also affect the reliability of the device, if not causing a damage thereof.

APPENDIX B: Arduino Coding

```
#define CUSTOM_SETTINGS    //To reduce the library compiled size and limit its memory usage
#define INCLUDE_EMAIL_SHIELD
#define INCLUDE_GAMEPAD_SHIELD
#define INCLUDE_DATA_LOGGER_SHIELD
#define INCLUDE_PUSH_BUTTON_SHIELD

#include <DallasTemperature.h>
#include <OneWire.h>

/* Include 1Sheeld library. */
#include <OneSheeld.h>

/* data logging shield */
long interval = 60000;     //record data every 60000ms (1 min)
long previousTime = 0;
int counter = 0;
int NumData = 15;          //number of data in one file
String title = "test battery life";

/* Boolean to start logging. */
bool startFlag = false;

/* Temperature sensor */
int temp_sensor = A0;
float temperature = 0;

/* pH sensor */
const int pH_sensor = A1;
int sensorValue;
float pHVol;
float pHValue;
```

```
/* Ultrasonic sensor */
const int trigPin = 8;    //sensor trigger pin is connected to pin 10
const int echoPin = 9;    //sensor echo pin is connected to pin 9
float duration;           //time for sound wave to travel through and fro
float distance;           //distance of object from sensor
float speedOfSound = 303.49;  //speed of sound in m/s (the speed varies depending on
atmospheric conditions: the temperature)

/* Boat */
int one_red = 7;    //ccw1
int one_blue = 6;   //cw1
int two_blue = 5;   //cw2
int two_red = 4;    //ccw2

/* Notification Shield */
boolean flag_1 = false;
boolean flag_2 = false;
boolean flag_3 = false;
boolean flag_4 = false;
String notify_1 = "High temperature" ;
String notify_2 = "High pH";
String notify_3 = "Low temperature";
String notify_4 = "Low pH";

OneWire oneWirePin(temp_sensor);
DallasTemperature sensors(&oneWirePin);

void setup() {

  OneSheeld.begin();      //Start communication with 1Sheeld

  pinMode(temp_sensor, INPUT);
  pinMode(pH_sensor, INPUT);
  /* Boat */
```

```
  pinMode(one_red, OUTPUT);
  pinMode(one_blue, OUTPUT);
  pinMode(two_red, OUTPUT);
  pinMode(two_blue, OUTPUT);
  /* Ultrasonic Sensor */
  pinMode(trigPin, OUTPUT);   //set trigger pin as output
  pinMode(echoPin, INPUT);    //set echo pin as input

  sensors.begin();      //begin temperature sensor

}

void loop() {

  unsigned long currentTime = millis();

  if(PushButton.isPressed() == true)
  {
    Logger.stop();
    OneSheeld.delay(500);
    Logger.start(title, true);
    startFlag = true;
  }

  if(startFlag)
  {
    if (currentTime - previousTime > interval){     //record data every given interval

    previousTime = currentTime;

    Read_Temp_Data();       //take data from temperature sensor
    Read_pH_Data();         //take dara from pH sensor
    ultrasonic_sensor();    //Measure distance
```

```
/* Notify with Email when is data out of range */
if(temperature >= 32.0){        //When temperature too high
  if(!flag_1)
  {
    Email.send("wpeng0317@gmail.com",notify_1,"Hi, temperature too high!");
    delay(300);
    flag_1 = true;
  }
}
  else{
    flag_1 = false;
    }

if(pHValue >= 8.0){       //When pH too high
  if(!flag_2)
  {
    Email.send("wpeng0317@gmail.com",notify_2,"pH too high!");
    delay(300);
    flag_2 = true;
  }
}
else{
  flag_2 = false;
}

if(temperature <= 26.0){        //When temperature too low
  if(!flag_3)
  {
    Email.send("wpeng0317@gmail.com",notify_3,"Hi, temperature too high!");
    delay(300);
    flag_3 = true;
  }
}
else{
```

```
flag_3 = false;
}

if(pHValue <= 4.0){       //When pH too low
  if(!flag_4)
  {
    Email.send("wpeng0317@gmail.com",notify_4,"pH too high!");
    delay(300);
    flag_4 = true;
  }
}
else{
  flag_4 = false;
}

/* Add temperature & pH values as column in the CSV file. */
Logger.add("Temp",temperature);
Logger.add("pH", pHValue);
/* Log the row in the file. */
Logger.log();
counter ++;

if(distance >= 10.0){
  Boat_forward ();
  delay(1000);
  Boat_stop ();
}
else if(distance < 10.0){
  rotate_left();
  delay(1000);
  Boat_stop ();
}

if (counter == NumData){
```

```
      Logger.stop();
      Email.attachFile(LAST_DATA_LOGGER_CSV);
      Email.send("wpeng0317@gmail.com", "Data logger","Temperature and pH value
data");
      counter = 0;
      startFlag = false;
      /* Start Logging again. */
      Logger.start(title, true);
      startFlag = true;
      }
   }
  }
  GamePad.setOnButtonChange(&myBoatFunction);
}

void Read_Temp_Data(){
  sensors.requestTemperatures();
  temperature = sensors.getTempCByIndex(0);
  delay(100);
  sensors.requestTemperatures();
  temperature = sensors.getTempCByIndex(0);
  delay(100);
}

void Read_pH_Data(){
  sensorValue = analogRead(pH_sensor);
  delay(100);
  sensorValue = analogRead(pH_sensor);
  delay(100);
  pHVol = sensorValue*5.0/1024;
  pHValue = 3.50*pHVol;
}

void ultrasonic_sensor(){
```

```
  digitalWrite(trigPin,LOW);    //set trigger pin LOW
  delayMicroseconds(2000);      //pause to let signal settle
  digitalWrite(trigPin,HIGH);   //set trigger pin HIGH
  delayMicroseconds(15);        //pause with trigger pin HIGH
  digitalWrite(trigPin,LOW);    //finish trigger pulse by bringing it LOW

  duration = pulseIn(echoPin,HIGH);        //measure sound wave travel time in
microseconds
  duration = duration/1000000.;       //convert duration to seconds

  distance = speedOfSound*100.*duration/2;    //calculate distance in cm
}

void Boat_forward (){
  digitalWrite(one_red, HIGH);
  digitalWrite(two_blue, HIGH);
  digitalWrite(one_blue, LOW);
  digitalWrite(two_red, LOW);
}

void Boat_stop (){
  digitalWrite(one_red, LOW);
  digitalWrite(two_blue, LOW);
  digitalWrite(one_blue, LOW);
  digitalWrite(two_red, LOW);
}

void rotate_left(){
  digitalWrite(one_red, LOW);
  digitalWrite(two_blue, HIGH);
  digitalWrite(one_blue, HIGH);
  digitalWrite(two_red, LOW);
}
```

```
void Boat_backward(){
  digitalWrite(one_red, LOW);
  digitalWrite(two_blue, LOW);
  digitalWrite(one_blue, HIGH);
  digitalWrite(two_red, HIGH);
}

void rotate_right(){
  digitalWrite(one_red, HIGH);
  digitalWrite(two_blue, LOW);
  digitalWrite(one_blue, LOW);
  digitalWrite(two_red, HIGH);
}

 void myBoatFunction ()
 {
  if (GamePad.isUpPressed()){
    Boat_forward();
    }
    else if (GamePad.isDownPressed()){
    Boat_backward();
    }
    else if (GamePad.isLeftPressed()){
    rotate_left();
    }
    else if (GamePad.isRightPressed()){
    rotate_right();
    }
    else {
    Boat_stop ();
   }
 }
```