DEVELOPMENT OF AN AERATION SYSTEM FOR SMART AQUACULTURE FARMING

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

Lee Kong Chian Faculty of Engineering and Science
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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

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ABSTRACT

Aquaculture has seen much development in recent years but is still lagging in terms of smart technology when compared to that of other agriculture sectors. However, there are certain inefficiencies in current aquaculture technology, mainly the slow reaction time to changes in water quality in traditional farms and the unnecessary wastage of resources such as electricity. The purpose of this project was to develop a smart aeration system for aquaculture farming as dissolved oxygen (DO) is one of the most crucial factors in an aquaculture environment. The aims of this project were to develop an aerator prototype, the algorithms for real-time monitoring, autonomous response, integration with an Internet of Things (IoT) cloud platform and to conduct a feasibility study on the smart aeration system for controlling the DO level within an aquaculture system. In the development of the smart aeration system, SolidWorks was used for the 3D CAD designing of the mechanical components, the Arduino IDE was used for the software development aspects and Proteus was used to design the circuit for the electrical components of the system. The main components of the smart aeration system were NodeMCU, sensors, power supply, motor and impeller. The system could connect to the Blynk IoT cloud platform to both transmit data from the sensors to be displayed on the web interface or mobile application and receive instructions from the user wirelessly. Three impeller prototypes were designed and tested to determine the characteristics of the best impeller for the application, the best impeller was capable of increasing the DO percent saturation of the test environment by 15 % over 2 hours. The smart aeration system developed successfully demonstrated the capabilities to increase the DO percent saturation of water and maintain it autonomously at a targeted value of +5 % the initial value even when fish feed was added to act as a DO remover.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

BOD	Biochemical Oxygen Demand
CAD	Computer-Aided Design
CBOD	Carbonaceous Biochemical Oxygen Demand
DO	Dissolved Oxygen
GDP	Growth Domestic Product
GSM	Global System for Mobile Communication
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IR 4.0	Fourth Industrial Revolution
NBOD	Nitrogenous Biochemical Oxygen Demand
PLA	Polylactic Acid
PTS	Power Transmission System
RAS	Recirculating Aquaculture System
SoC	System on a Chip
TDS	Total Dissolved Solids

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Aquaculture also sometimes referred to as fish farming, is the cultivation of aquatic organisms in a controlled environment mainly for human consumption. Fish is an important source of protein in many parts of the world including Malaysia as fish food comprises approximately one-third of animal protein intake in Malaysia. With the catch fishing resources in Malaysia already reaching their maximum capacity and the ever-increasing demand for fisheries products as a healthy source of protein and fatty acids, aquaculture farming has the potential to fill the gap between the supply and demand of fish food serving as an important industry in providing for the food needs of the country in a sustainable fashion while also solving the current environmental issue of the overexploitation of marine resources in Malaysia.

Although aquaculture has seen much development in recent years it is still lagging in terms of smart technology when compared to that of agriculture. The modernisation of traditional aquaculture begins with the digitisation of the cultivation processes and transitioning the processes from manual to automatic. The digitisation driven Fourth Industrial Revolution (IR 4.0) has the potential to increase the sustainability and productivity of the aquaculture sector through Internet of Things (IoT) enabled water quality monitoring systems, smart aeration systems, automatic feeders, recirculating and filtration systems equipped with sensors, real-time data processing, monitoring and control (Yue and Shen, 2022).

The most important parameter of an aquaculture system is the water quality of the culture environment. Water quality directly affects the health and growth of the aquatic species and the most important parameter in water quality is dissolved oxygen (DO). DO is the amount of oxygen present in water, it is crucial for the survivability of fish as oxygen is required for aerobic respiration. The amount of DO in the culture water is normally controlled by aerators installed within the culture environment, be it a tank, open pond, lake or other establishments, therefore a good aeration system is crucial for optimum water management and production from an aquaculture system.

1.2 Importance of the Study

This study was undertaken to investigate the importance of aeration in an aquaculture system. On top of that, an affordable smart aeration solution connected to an IoT platform was developed to enable traditional farms to ride the IR 4.0 that trends towards automation. This project attempted to increase the efficiency of the farms by reducing the amount of wasted power (electricity) used to power the aerators within the farm in addition to providing the farmers with remote real-time monitoring and control of their aquaculture system's parameters.

1.3 Problem Statement

Aquaculture activities in controlled environments such as manmade ponds or indoor culture tanks are gaining in popularity and have gained much attention in recent years (Food and Agriculture Organization of the United Nations, 2020). However, there are certain inefficiencies in current aquaculture technology, mainly the slow reaction time to changes in water quality in traditional farms and the unnecessary wastage of resources such as electricity or feed. In many of these farms, there is not a concrete objective method of controlling water quality, one of which being the aforementioned DO within the aquaculture system. Farmers mostly gauge the water quality of their farms through experience and from observing the response of the fish to their living conditions. For example, an indicator that farmers may use to tell if the DO levels in the water are low is when fishes are swimming to the surface of the water to gasp for air, there are most likely already casualties within the farm and the production of fish has already been negatively affected.

A proposed solution to this problem is to modernise traditional aquaculture practices by moving the industry from an experience-based system that depends on the experience of the farmer to a smart evidence-based system that incorporates sensors and autonomous control in an IoT network to increase sustainability and productivity.

1.4 Aim and Objectives

The aim of this project was to develop an affordable IoT-enabled smart aeration system which would autonomously maintain the DO level of the aquaculture farm at an optimum range. The objectives of this project are as follows:

i. To design and develop the mechanical components of an aerator system for aquaculture purposes.
ii. To develop algorithms for an IoT smart aeration system that enables real-time monitoring and response.
iii. To conduct a feasibility study on the prototypes to evaluate the performance of the smart aeration system.

1.5 Scope and Limitation of the Study

The scope of this study was to study the role of aeration in aquaculture mainly by taking a deep dive into the importance of DO as a water quality parameter, its importance to the aquatic organisms within the culture environment and how DO interacts with other water quality parameters of the culture environment. The study also included the development of a system that is focused on IoT integration and autonomous control, an accompanying simple aerator system was designed alongside to demonstrate the functioning of the overall system.

The aerator system was of lab scale using miniature paddlewheel aerators. The study focused on the IoT platform and accompanying algorithms to run the aerators based on real-time DO levels. DO levels within the test environment were also manually input based on values from a hand-held sensor as one that could be connected directly to the circuit could not be obtained. These limitations of the study were mainly due to budget constraints.

1.6 Contribution of the Study

An aeration system for smart aquaculture farming to provide farmers with real-time monitoring and control to enable them to monitor their aquaculture environment and respond to changes remotely at any time was successfully developed.

The aeration system developed also showed to reduce the power consumed by the aerator through autonomous control of the aerator to allow the aeration system to idle the aerator when the DO saturation within the aquaculture environment had reached a user-defined target value and only running the aerator again when the DO saturation fell below that target value.

The smart aeration system could also be reconfigured to include additional sensors into the circuit and display that sensor data in the cloud IoT platform.

1.7 Outline of the Report

This report contains five chapters in total. Chapter 1 provides a general introduction to aquaculture, its role and the importance of aeration in an aquaculture environment. This chapter also states the problem statement, aims, objectives and scope of the report.

Chapter 2 serves to provide the reader with an in-depth literature review of the state of aquaculture in Malaysia, water quality considerations in an aquaculture environment especially those related to DO, an overview of currently available commercial aerators in the market as well as smart aquaculture services and technology currently being used in the aquaculture sector.

Chapter 3 describes the methodology for this study, outlining the design of the aeration system and the experimental procedure to evaluate the performance of the aeration system. This chapter goes through the tools used in the design of the aerator, the methods for fabricating the prototype and also the component selection process for the aeration system.

Chapter 4 displays the end product of the fabrication and the results of the feasibility study on the aeration system. The data collected is also discussed in this chapter.

Chapter 5 concludes the study by reiterating the key results obtained in relation to the aims of the study and evaluates its significance. Limitations of this study and also recommendations for future works are also elaborated in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Smart aquaculture systems are a complex network of many components monitoring parameters such as fish feed, water quality including DO, pH, ammonia, salinity, alkalinity, temperature, etc. However, as this study is focused on the smart aeration system, literature review will be focused on water quality considerations that affect or relate to DO, smart technologies that are or could be used in smart aquaculture, the different methods of achieving proper aeration of water and survey on commercially available aerators and smart aquaculture solutions while also touching on the importance of aquaculture in Malaysia.

2.2 Current State of Aquaculture in Malaysia

The latest statistics released by the Department of Fisheries Malaysia (2021) show that the fisheries sector recorded a production of 1.79 million tonnes of food fish valuing a total of RM 13.84 billion and contributing to 0.8 % of the national growth domestic product (GDP), further breakdown by subsector is shown in Table 2.1.

Table 2.1: Breakdown of Fishery Production by Subsector (Department of Fisheries Malaysia, 2021).

Fishery Sub-sector	Percentage of total production (%)	Quantity (tonnes)	Value (RM'000)
Capture Fisheries	77.3	1,383,299	10,098,000
Aquaculture	22.4	400,017	3,600,000
Inland Fisheries	0.3	5,625	83,000

According to the Department of Fisheries Malaysia (2021), the catch fishing resources of the country have already reached a maximum and further overexploitation of marine resources will bring a devastating reduction to fisheries landing in the country. As fish food comprises of approximately one-third of animal protein intake in Malaysia, further development in the aquaculture subsector is seen to have a great potential to increase the sustainable production and supply of fish in the country (Department of Fisheries Malaysia, 2021; Goh, et al., 2021).

Aquaculture in Malaysia can be split into 2 types, freshwater aquaculture and brackish water aquaculture. Aquaculture in Malaysia employs many different systems of production including ponds, ex-mining ponds, cages, cement tanks, canvas tanks, rafts, pen culture, bottom culture for cockle and long line for seaweed with tank systems gaining popularity especially for indoor fish production (Department of Fisheries Malaysia, 2021; Yusoff, 2015). The production systems employed in freshwater environments are ponds, ex-mining ponds, tanks, cage and pen culture systems while the production systems employed in brackish water environments are ponds, cages, rafts, bottom culture and long lines (Yusoff, 2015).

Freshwater aquaculture in Malaysia mainly produces freshwater catfish, red tilapia, river catfish, black tilapia and giant freshwater prawns while Brackish water aquaculture in Malaysia mainly produces marine fish, marine prawn cockles, mussels, crabs and seaweed. (Department of Fisheries Malaysia, 2021).

2.3 Water Quality Considerations in Aquaculture

Water quality is the combination of physical, chemical and biological parameters that affect the wellbeing and growth of organisms in a water body, thus directly affecting the production of a culture environment. Multiple papers in literature have outlined the importance of controlling water quality considerations in providing the optimum environment to culture fish within an aquaculture system (Bhatnagar and Devi, 2013; Saha, Rajib and Kabir, 2018). There are many factors that affect the water quality of a water body such as DO, pH, temperature, carbon dioxide, salinity, ammonia concentration, turbidity, hardness, etc (Bhatnagar and Devi, 2013; Raju and Varma, 2017; Saha, Rajib and Kabir, 2018). Although the environment of a water body is a complex system with an overwhelming amount of water quality variables, only DO and critical factors that affect it or are directly correlated to DO including biochemical oxygen demand, ammonia, temperature, pH and salinity are reviewed in this study as those are the focus of this project.

2.3.1 Dissolved Oxygen

One of the most important factors of water quality to ensure healthy fish growth is dissolved oxygen (DO). All aerobic aquatic organisms require a constant supply of DO for aerobic respiration and require molecular oxygen dissolved into the water as they are unable to utilise the oxygen from water molecules (Boyd, 2020). There are two main sources of oxygen in water, diffusion of oxygen from the atmosphere or the release of oxygen through photosynthesis from phytoplankton or aquatic plants (Bhatnagar and Devi, 2013; Boyd, 2020; Roy, et al., 2015). However, in farms especially aquaculture farms that are built indoors, the main source of oxygen is atmospheric oxygen as the atmosphere is composed of 21% oxygen. Atmospheric oxygen enters the water through diffusion and turbulence due to the physical agitation of the surface of the water (United States Department of Agriculture, 2011).

DO concentration in water can be expressed in milligrams per litre (mg/L) or alternatively as a percentage of saturation at the measured temperature and pressure. At optimum temperatures, it is agreed upon that to achieve good fish production, a DO concentration of more than 5 mg/L is necessary as fish begin to feel stressed at levels less than 5 mg/L (Bhatnagar and Devi, 2013; Summerfelt, 1998).

Low DO concentrations are a limiting factor for the production of aquatic organisms as it affects the growth, physiology and survivability of aquatic organisms (Bhatnagar and Devi, 2013; Summerfelt, 1998). Often, when the fishes are stressed, they will start to swim sluggishly and appear weakened while also swimming to the surface of the water to grasp for air (Bhatnagar and Devi, 2013). This phenomenon is one of the indicators used in traditional farms to indicate that the DO concentrations are low signalling farmers to engage in emergency aeration in an effort to save their fish.

Other than directly affecting the health of the fish in the water, the levels of oxygen in the water have also shown to be directly correlated with the amount of fish feed they consume especially in hypoxia (Subramanian, 2013). According to a study by Subramanian (2013), over the duration of a 6-week experiment, the feed intake of trout under hypoxia reduced by 29% as compared to the trout kept under normoxia and the trout kept under normoxia had higher growth and around 1.3 times greater body weights as compared to the trout kept under hypoxia at the end of the experiment.

2.3.2 Ammonia

Ammonia, NH_3 is toxic to fish as it tends to cause damage to the gills of the fish, destroy their mucous-producing membranes and other detrimental side effects such as reduced growth, poor feed conversion and lower disease resistance. The main sources of ammonia in an aquaculture system are from the excretion of fish as a by-product of the metabolism of protein (Summerfelt, 1998). Ammonia is also the by-product of the decomposition of organic matter by bacteria and other saprophytes (Bhatnagar and Devi, 2013; Boyd, 2020). This decomposition of organic material to produce ammonia requires the use of DO within the water, the amount or demand of DO required by the organisms that decompose the organic material in a water body is known as the Carbonaceous Biochemical Oxygen Demand (CBOD) (Ajayi, et al., 2016; Shmeis, 2018).

Ammonia is converted to nitrate (NO_3^-), a harmless substance to fish (except in high concentrations) in the process of nitrification, an important step in the nitrogen cycle. Nitrification is a two-step process where ammonia is converted to nitrite (NO_2^-) then to nitrate as follows:

$$\text{Nitritation:}\ 3NH3 + 3O_2 \rightarrow 2NO_2^- + 2H^+ + 2H_2O \qquad (2.1)$$

$$\text{Nitration:}\ 2NO_2^- + O_2 \rightarrow 2NO_3^- \qquad (2.2)$$

Ammonia is first converted to nitrite by the autotrophic Nitrosomonas bacteria combining oxygen with ammonia then to nitrate by the autotrophic Nitrobacter bacteria again combining oxygen with nitrite (Bhatnagar and Devi, 2013; Shmeis, 2018). This consumption of oxygen in the nitrification process is known as the Nitrogenous Biochemical Oxygen Demand (NBOD) (Ajayi, et al., 2016; Shmeis, 2018).

The sum of NBOD and CBOD is the Biochemical Oxygen Demand (BOD) is the sum of CBOD and NBOD. According to Boyd (2020), the BOD of bacteria and saprophytes in a water body may cause oxygen depletion in said water body if there isn't sufficient DO content to sustain their activity. Aeration holds an important role in not only ensuring that the BOD of the water body is met to prevent oxygen depletion of the fish but also in reducing the concentration of toxic ammonia (Bhatnagar and Devi, 2013; Boyd, 2020; Omofunmi, et al., 2016).

2.3.3 Temperature

Temperature in the context of aquaculture is the measurement or degree of hotness or coldness of the body of water the fish are in. Fish have poor resistance to fluctuations in temperature and a sudden change of as little as 5 °C can often lead to stress or even the slaughter of fish (Saha, Rajib and Kabir, 2018). Temperature has a profound impact on water quality as it has a major influence on the rates of biological, physical and chemical processes that take place in the water body (Boyd, 2020; Saha, Rajib and Kabir, 2018). There is the general rule of thumb that the rate of biological and chemical responses double for every 10 °C increment in temperature. More importantly, temperature controls the solubility of gases in water, specifically the solubility of oxygen in water.

Figure 2.1 shows that at a given pressure, the solubility of oxygen in freshwater is inversely proportional to temperature (United States Geological Survey, 2018). For increasing temperatures, the solubility of oxygen decreases. Furthermore, increasing temperatures also increases the respiration rate and biochemical oxygen demand of organisms within a water body (United States Department of Agriculture, 2011).

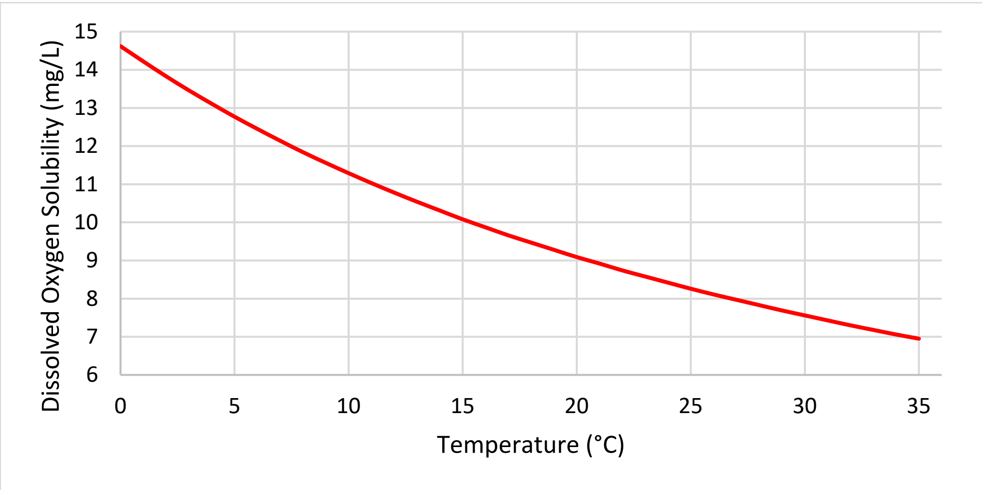

Figure 2.1: Solubility of Oxygen in Fresh Water at Various Temperatures (1 atm) (United States Geological Survey, 2018).

2.3.4 pH

The pH of water is an index of the hydrogen ion concentration in water. In the context of this study, it is important to note that a pH of 7 is neutral while lower pH represents acidic water, higher pH represents alkaline water and pH scale is logarithmic. A decrease or increase in integer value of the scale represents a concentration change of tenfold (e.g., pH of 6 is ten times more acidic than pH of 7). Factors that affect the pH of water include dissolved carbon dioxide in rainwater that falls in outdoor aquaculture environments, algal photosynthesis, respiration by bacteria, plants and fish (Boyd, 2020; Summerfelt, 1998). Carbon dioxide reacts in water when dissolved and produces carbonic acid, H_2CO_3 followed by bicarbonates ions, $HCO_3{}^-$ and hydrogen ions, H^+ as such:

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3{}^- + H^+ \qquad (2.3)$$

The production of these H^+ ions cause the pH of the water body to drop. During the day however, when sunlight is present for photosynthesis, carbon dioxide, CO_2 is consumed by plants or algae.

$$6CO_2 + 6H_2O \xrightarrow{Chlorophyll + Sunlight} C_6H_{12}O_6 + 6O_2 \qquad (2.4)$$

The above equation shows the process that takes place for photosynthesis. The conversion of carbon dioxide and water into oxygen and glucose through photosynthesis increases the pH of the water which is why the pH of water during the day is normally higher and drops during the night.

According to Bhatnagar and Devi (2013), fish mostly have a blood pH of around 7.4 and water bodies with pH ranging from 7.0 to 8.5 are generally conducive to fish production while water bodies with pH outside this range can induce stress in the fish or lead to death if the range is exceeded to drastically which is why it would be beneficial to be able to control and maintain the pH of the culture environment at that neutral to slightly alkaline range especially when sunlight is not available. According to Omofunmi, et al. (2016), other than increasing the DO levels, the aeration process also functions to reduce the concentration of carbon dioxide and increase the pH level of pond water. As carbon dioxide makes up only 0.04 % of the atmosphere while oxygen and nitrogen make up 21 % and 78 % respectively, the partial pressure of carbon dioxide is much lower in the atmosphere as compared to oxygen and nitrogen. Therefore, Aeration is able to establish the equilibrium between the atmosphere and water which will result in the saturation of water with nitrogen and oxygen while nearly completely eliminating dissolved carbon dioxide (Vakkilainen, 2017).

2.3.5 Salinity

Salinity is the total dissolved solids (TDS) concentration or aggregate concentration of electrically charged ions such as those shown in Table 2.2.

Table 2.2: Dissolved Solids Commonly Present in Culture Water (Saha, Rajib and Kabir, 2018).

Anions	**Cations**	**Other Constituents**
Bicarbonate, ${HCO_3}^-$	Calcium, Ca^{2+}	Ammonium, ${NH_4}^+$
Carbonate, ${CO_3}^{2-}$	Magnesium, Mg^{2+}	Nitrate, ${NO_3}^-$
Chloride, Cl^-	Potassium, K^+	Phosphate, ${PO_4}^-$
Sulphate, ${SO_4}^{2-}$	Sodium, Na^+	

Fish are adapted to specific salinity ranges and have evolved to maintain a constant osmotic (salt and water) balance in their bloodstream through the movement of water and salts across their gills (Bhatnagar and Devi, 2013). Which is why the main effect of salinity on aquatic organisms is related to osmotic pressure which increases with salinity. When the salinity of water increases beyond the specific range that the cultured organisms are adapted to, osmoregulatory difficulties arise and in excessive TDS concentration conditions, water can become unsuitable for fish production in its entirety (Boyd, 2020). Aeration plays a role in maintaining the salinity range in aquaculture as the aeration process is able to reduce the levels of salinity in the water. When water is mixed with air during aeration, the air oxidises the dissolved salts and makes them filterable by the filtration process within the aquaculture system (Vakkilainen. 2017).

2.4 Aeration in Aquaculture

As mentioned above, the main source of DO in farms is through diffusion from atmospheric oxygen. This diffusion naturally is rarely sufficient to sustain a productive farm especially in the case of dense aquaculture systems (Roy, et al., 2015). Therefore, aerators are used in such systems to increase the DO concentration within the water through a combination of increasing the surface area of water exposed to the atmosphere and mechanical agitation to facilitate the diffusion of atmospheric oxygen into the water. In open water or offshore aquaculture systems, aerators are rarely used as waves in open water provide rapid exchange with air while the water surfaces in ponds, small lakes and indoor aquaculture systems are rather calm impeding the oxygen transfer (Boyd, 2020). Aeration is not only crucial for directly increasing the DO levels of the culture environment but also provides for the BOD of the culture environment and regulates the levels of ammonia, temperature, pH and salinity within the culture environment.

To lower the costs of operating a farm, various aerators with varying impellers have been developed over the years such as paddlewheel, vertical pump, propeller-aspirator pump and others in an effort to improve the energy efficiency of aeration. According to the United States Department of Agriculture (2011), the paddlewheel type aerator is the most efficient among these aerators thus this study will focus on paddlewheel aerators both in terms of research and testing.

Most manufacturers of paddlewheel aerators originate from Taiwan as aquaculture holds great importance in Taiwan's economy both in terms of employment and food security (Chen and Qiu, 2014; Chen, Sung and Lin, 2015). These aerators are widely used due to their affordability and corrosion resistance (Bahri, et al., 2019). Most commercial paddlewheels have impeller speeds of roughly 100 RPM with the exception of some high-speed models from Tian Yuan International Co., Ltd. and also use 4 pole AC motors with standard synchronous speeds of 1500 RPM for 50 Hz AC supply or 1800 RPM for 60 Hz AC supply with gear reducers of ratios roughly 14:1 (50 Hz) or 17:1 (60 Hz) to achieve the final impeller speeds of ~100 RPM as shown in Table 2.3.

Table 2.3: Impeller Speeds of Aerators from Different Manufacturers (HCP Pump Manufacturer Co, Ltd., 2022; Hung Star Enterprise Corp., n.d.; Tian Yuan International Co., Ltd., 2010a; Tian Yuan International Co., Ltd., 2010b; Tian Yuan International Co., Ltd., 2010c; Zhejiang Fordy Machinery Co., Ltd., n.d.).

Manufacturer	**Model**	**Impeller speed (RPM)**
HCP Pump Manufacturer Co., Ltd	P-EP102	102.86
	P-EP204	102.86
	P-VP102	102.86
Hung Star Enterprise Corp.	HS-A120a	96 - 100
	HS-A240a	96 - 100
	HS-A120b	96 - 100
	HS-A240b	96 - 100
	HS-A140b	96 - 100
	HS-A120SS	96 - 100
	HS-A240	96 - 100
	H-260	96 - 100
	H-286	96 - 100
	H-3106	96 - 100
	H-36	96 - 100
	H-38	96 - 100
	H-310	96 - 100
	HS-H12	108 - 143
	HS-H24	108 - 143
Tian Yuan International Co., Ltd.	TA-55H	143
	TA-55HH	156
	TA-55H	121
	TA-66H	143
	TA-66HH	172
	TA-12CH	110 - 120
	TA-12C	80 - 90
Zhejiang Fordy Machinery Co., Ltd.	MSC-1.5	102.86
	CSC-816	102.86
	MSC-2.2	102.86

Where the commercial aerators differ is mainly in the impeller design. The most common impeller design is as illustrated in Figure 2.2. The impeller has 8 paddles, each paddle is flat from the centre up to the end where it curves slightly towards the direction that impacts the water. There are variations of this design from different manufacturers such as making the end angled similar to a triangular shape to decrease the forces on the paddle when it enters the water.

Figure 2.2: THK Paddlewheel Aerator TWC – 200 (THK Sales & Service (M) Sdn Bhd, 2020a).

Another common impeller design is where pipes with sharp or angled tips are inserted in a spiral pattern onto the shaft of the aerator as illustrated in Figure 2.3.

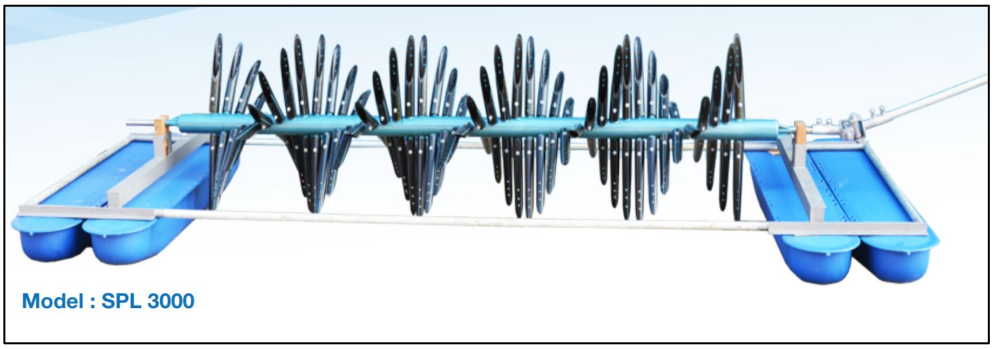

Figure 2.3: THK Spirol Aerator SPL 3000 (THK Sales & Service (M) Sdn Bhd, 2020b).

2.5 Smart Aquaculture Services in the Market

Smart aquaculture systems are already available in the market, especially smart monitoring, data capture and visualisation services. One such company in Asia is UMITRON Pte. Ltd. Based in Singapore and Japan, UMITRON is a company that provides services in the area of computerised aquaculture focusing on IoT integration, satellite remote sensing and machine learning. Their products include auto fish feeding, camera monitoring systems, real-time machine learning for fish appetite detection, fish body measurement systems powered by AI and others (UMITRON, 2019).

Another company in Asia that provides smart aquaculture systems is Qingdao Hishing Smart Equipment Co., Ltd., China. This company provides smart recirculating aquaculture systems (RAS) with smart control management that includes real-time monitoring, fault information and remote control over the internet. Another product by HISHING is a smart feeder specially designed for large-scale industrial RAS where a feeder attached to a rail that extends along multiple aquaculture tanks can feed the tanks and load itself when needed fully automatically (Qingdao Hishing Smart Equipment Co., Ltd., 2021a; Qingdao Hishing Smart Equipment Co., Ltd., 2021b).

2.6 Smart Technology in Aquaculture Development

The development of smart aquaculture systems has multiple components such as smart sensor modules, smart aeration system, local network systems and cloud platforms which are often interconnected in the Internet of Things (IoT) network. IoT refers to the interconnectivity and ability between devices and sensors or actuators to interact with each other on a public or private network (Atzori, Iera and Morabito, 2010; Giusto, et al., 2010). Review of the technology used in the smart aquaculture system including both software and hardware such as wireless transmission protocols, methods, cloud platforms, controllers and system on a chip (SoC) are the focus of this section.

2.6.1 Wireless Communication

The most apparent wireless communication protocol that is used in smart systems especially those with IoT integration is WiFi, a wireless network protocol based on standards by the Institute of Electrical and Electronics

Engineers (IEEE), commonly used for local area networking between devices. WiFi enables digital devices to exchange data through radio waves. Most smart systems have a central processing unit with a WiFi module to connect to the internet to transmit and receive data between the IoT network and the cloud platform.

The use of ZigBee has been established by Chen, Sung and Lin (2015) as a wireless data transmission protocol of choice between local devices for their automated aquaculture monitoring system. ZigBee is another IEEE standard for wireless data transmission that was designed to be used with low-cost and low power consumption devices making it suitable for battery powered devices. In their system, Microchips with ZigBee wireless transceivers were used to transmit data between different modules in their wireless sensor network where multiple slave modules send sensor data to a master module which was also equipped with a WIFI module to send the collected data to an IoT platform for the user to monitor. ZigBee compared to WiFi has much slower speeds and shorter range however it is preferred as a wireless communication protocol as it is extremely low power and uses a mesh networking standard instead of the star networking that is used by WiFi. Mesh networking means that each device in the network is connected to each other and can act as repeaters to pass signals from device to device, extending their effective range and work around obstacles that may block a direct line of sight signal. Star networks on the other hand required each device to communicate directly with the central hub and if a device is out of range of that central hub, that device will not be able to connect to the network.

2.6.2 Hardware Controllers

Individual components in an aquaculture culture system such as aeration system, water monitoring system and auto fish feed system often have their own processing units to control the functioning of the individual systems before transmitting and receiving data from a main processing unit. Some examples of the controllers used are microcontrollers or single-board computing units like the Arduino Uno, Raspberry Pi and NodeMCU.

The NodeMCU has been used by Dzulqornain, Rasyid and Sukaridhoto (2018) in their design and development of a smart aquaculture system as their main processing unit of choice. NodeMCU is an open-source development kit based on the ESP8266 module, a WIFI enabled microchip with microcontroller capabilities. The NodeMCU is very suitable for IoT applications as it is a low-cost board that already has a WIFI module integrated. NodeMCU boards can often be found in the price range of RM 15 to 20 (Cytron, 2021b). NodeMCU has 10 general-purpose input/output (GPIO) pins which are able to handle incoming and outgoing digital signals (NodeMCU Team, 2018). In their project, the NodeMCU was selected as the main processing unit due to the aforementioned reasons that are low-cost and has a built-in WiFi module. The NodeMCU was connected to multiple sensors including DO sensor, temperature sensor, pH sensor and water level ultrasonic sensor.

The Arduino Uno is also a board that has been used widely in IoT applications. Yadav, et al. (2022) have established the use of Arduino Uno board as the computing module of their aerator system while using a NodeMCU only as a WiFi module to communicate with the cloud. As their system had multiple analogue inputs, the Arduino Uno board was more preferable having 6 analogue pins that utilise Analog to Digital converter (ADC) while the NodeMCU has only 1 analogue pin. There are also Arduino Uno boards that have built-in WiFi however it is more cost effective to use an Arduino Uno board without WiFi paired with a NodeMCU for WiFi communication as an Arduino Uno board without WiFi can be obtained for RM 109 to 179 while Arduino Uno boards with built-in WiFi are around RM 259 to purchase (Cytron, 2021a).

2.7 Summary

Aquaculture is an important industry in the country, producing food fish worth RM 13.84 billion in the year 2021 and contributing to 0.8 % of the national GDP. There are many factors that affect the aquaculture environment mainly the quality of the water body, these factors are a combination of physical, chemical, and biological parameters that affect the wellbeing and growth of organisms in the aquaculture environment. The key factors that affect the water quality are DO, ammonia, pH and salinity. The most important factor of water quality is likely DO as all aerobic aquatic organisms require a constant supply of DO for respiration.

The main source of DO in a water body is through the diffusion of atmospheric oxygen into the water. However, natural diffusion is rarely sufficient to sustain a dense farm which is why aerators are used to increase the DO within the farm. Most paddlewheel aerators originate from Taiwan and are imported through distributors as these aerators are affordable and corrosion resistant.

Components such as smart sensor modules, smart aeration systems, cloud technology and IoT integration are being developed for the aquaculture industry with certain services already being used in the sector. Such services include remote sensing, auto fish feeding systems, camera monitoring systems, smart RAS among others.

There are many types of controllers and processing units that are used to control such technology. An example of these controllers is the NodeMCU board which is a development kit with built-in WIFI capabilities. The further advantage of being an affordable kit makes the NodeMCU a very suitable kit for development of IoT applications.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The aim of this study was to develop an aerator system that is integrated into an IoT platform. The overall system was split into 2 parts for design: the aerator system alongside the IoT system. A work plan was developed to outline steps taken to achieve the goals of the study along with a Gantt Chart highlighting the timeline and milestones of this project.

3.1.1 Work Plan

Figure 3.1 shows the overall work plan for this project.

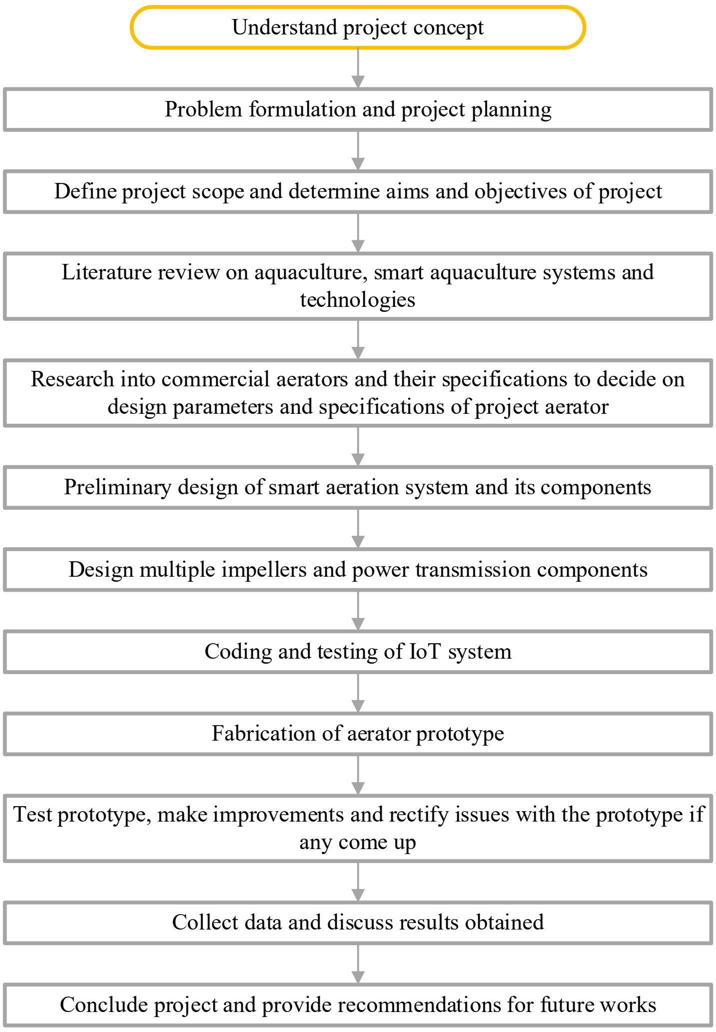

Figure 3.1: Work Plan Flow.

3.1.2 Gantt Chart

Figures 3.2 and 3.3 show the Gantt chart for FYP parts one and two respectively.

No.	**Project Activities**	**Planned Completion Date**	**W 1**	**W 2**	**W 3**	**W 4**	**W 5**	**W 6**	**W 7**	**W 8**	**W 9**	**W 10**	**W 11**	**W 12**	**W 13**	**W 14**
1	Problem formulation & project planning	06/02/2022	■	■												
2	Progress report - Introduction - Problem statement - Limitations and scope - Aims and objectives	05/03/2022		■	■	■	■	■								
3	Progress Report - Literature review	01/04/2022		■	■	■	■	■	■	■	■	■				
4	Designing prototype aeration system - Conceptual design of overall system - Drafted aerator design	04/03/2022				■	■	■								
5	Design of Aeration system - Finish propeller design - Produce detailed CAD design of whole system - Code algorithm for aerator control and IoT integration	01/04/2022						■	■	■	■	■				
6	Finalise Progress report	22/04/2022											■	■	■	
7	Prepared presentation slides	22/04/2022													■	

Figure 3.2: FYP Part One Gantt Chart.

No.	Project Activities	Planned Completion Date	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14
1	Aerator prototype hardware - Successfully 3D print impellers. - Fabricate other components of prototype including base plate, brackets, shaft spacers and covers.	15/07/2022	■	■	■	■	■									
2	Develop aerator prototype software - Algorithm to control aerator on/off automatically - Enable manual control of aerator	22/07/2022			■	■	■	■								
3	Evaluate aerator performance - Validate the sensor readings of sensors used against benchtop measurement equipment - Experiments on aerator with varying speeds, impellers and fish feed present in water - Evaluate the effectiveness of the smart system	05/08/2022						■	■	■						
4	Final report - Complete final report - Check spelling, grammar and format of the report	02/09/2022								■	■	■	■	■		
5	Prepare for final presentation	16/09/2022												■	■	■

Figure 3.3: FYP Part Two Gantt Chart.

3.2 Design of Aeration System

The aeration system would have two components, the aerator component including mechanical design and the smart system including IoT integration and control. Figure 3.4 shows the block diagram for the overall system.

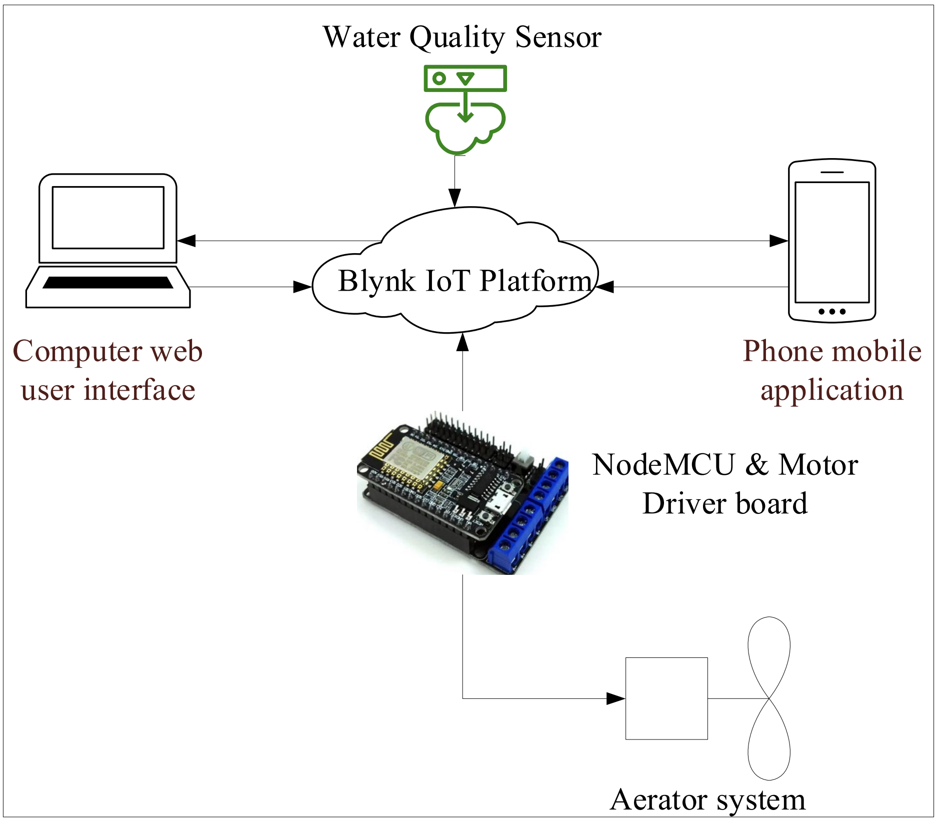

Figure 3.4: Overall Aeration System Block Diagram.

3.2.1 Aerator and Power Transmission System

The aerator system was tested in a lab environment, thus the aerator designed was of miniature scale. As discussed in Chapter 2, common commercially available paddlewheel aerators use 4 pole AC motors running at speeds well above 1,000 RPM with gear reducers to reduce the speed of the impeller to roughly 100 RPM. To achieve this similar impeller speed in the power transmission system (PTS), a 12 V 150 RPM (no-load) DC motor was used alongside a belt pulley with a ratio of 2:1. The belt pulley was used to separate the motor from the impeller so it could be protected from damage due to water splashing and corrosion, the ratio of 2:1 was used to ensure that the aerator would spin at over 100 RPM when under load.

Even though the aerator was of miniature scale and may not directly reflect real-world conditions, the best achievable aeration was still determined and compared. Therefore, three different impeller designs based on commercially available designs and literature review were proposed. The impeller prototypes and aerator PTS were designed using the CAD software SolidWorks. The technical drawings for each impeller prototype and aerator are available in Appendix A. The first two designs were similar to the common paddlewheels from aforementioned Taiwanese manufacturers while the last was a spiral fork-like aerator based on the study done by (Ahmad and Boyd, 1988). Figure 3.5 illustrates the CAD for the first design which was based on the most commonly found paddlewheel aerator in the market. The overall diameter of this impeller is 220 mm, the inner ring diameter is 30 mm, the outer ring diameter is 90 mm, the diameter of the holes on the paddles are 12 mm and the paddles are 4 mm thick.

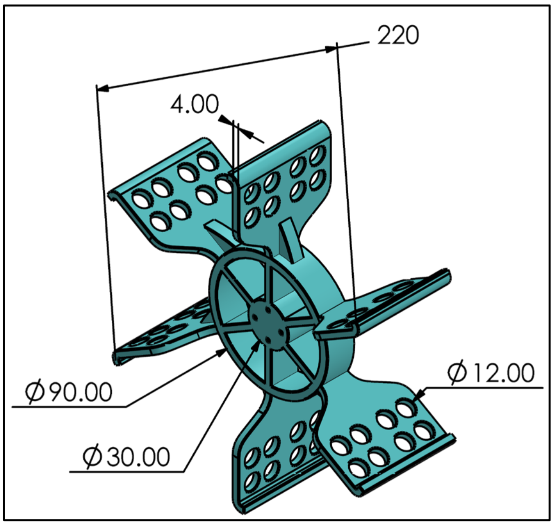

Figure 3.5: Impeller 1 CAD.

The second design was based on findings from Ahmad and Boyd (1988) and a slightly less common commercial design of triangular paddles. It incorporated findings from Ahmad and Boyd (1988) who found that paddles made with angled plates and a triangular profile at the end had the highest standard aeration efficiency. The study was very old therefore, modern design parameters such as holes on the paddles and a divider at the middle of the paddle to increase the splashing were added to the design. Figure 3.6 illustrates the

CAD design for impeller 2. The overall diameter of this impeller is 220 mm, the inner ring diameter is 30 mm, the outer ring diameter is 90 mm, the diameter of the holes on the paddles are 12 mm and the paddles are 4 mm thick.

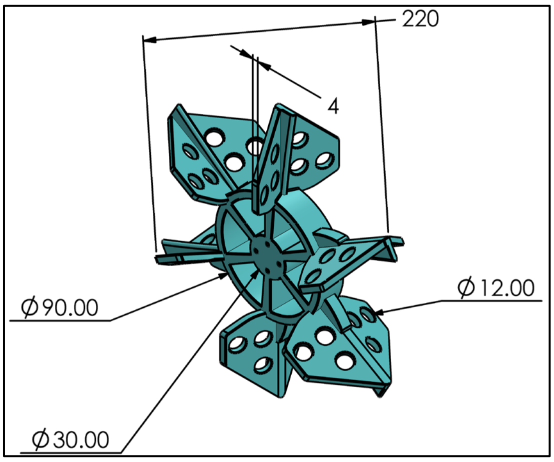

Figure 3.6: Impeller 2 CAD.

Lastly, the third design was based on the optimum aerator design from Ahmad and Boyd (1988) where angled paddles with triangular profiles are placed in a spiral formation. Figure 3.7 illustrates the CAD design for impeller 3. The overall diameter of this impeller is 200 mm, the shaft diameter is 60 mm, the paddles are 70 mm long and 2.2 mm thick. The paddles are arranged 22.5° apart from each other in a spiral pattern.

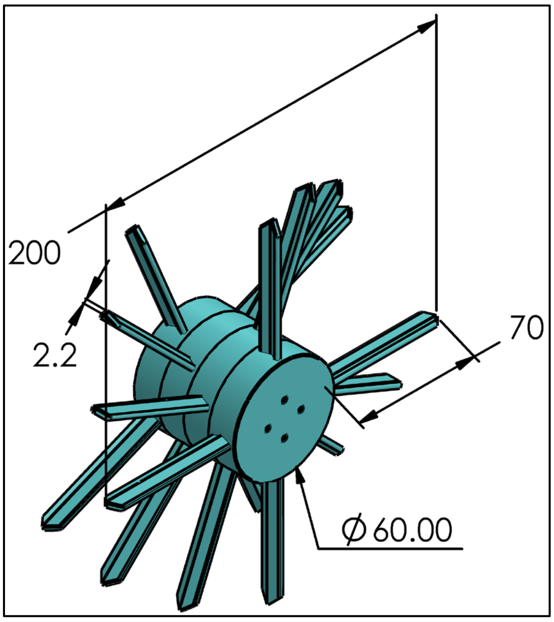

Figure 3.7: Impeller 3 CAD.

A PTS to move and control the paddlewheel aerators was designed to test the three different paddlewheel designs. The CAD of the overall system is shown in Figure 3.8.

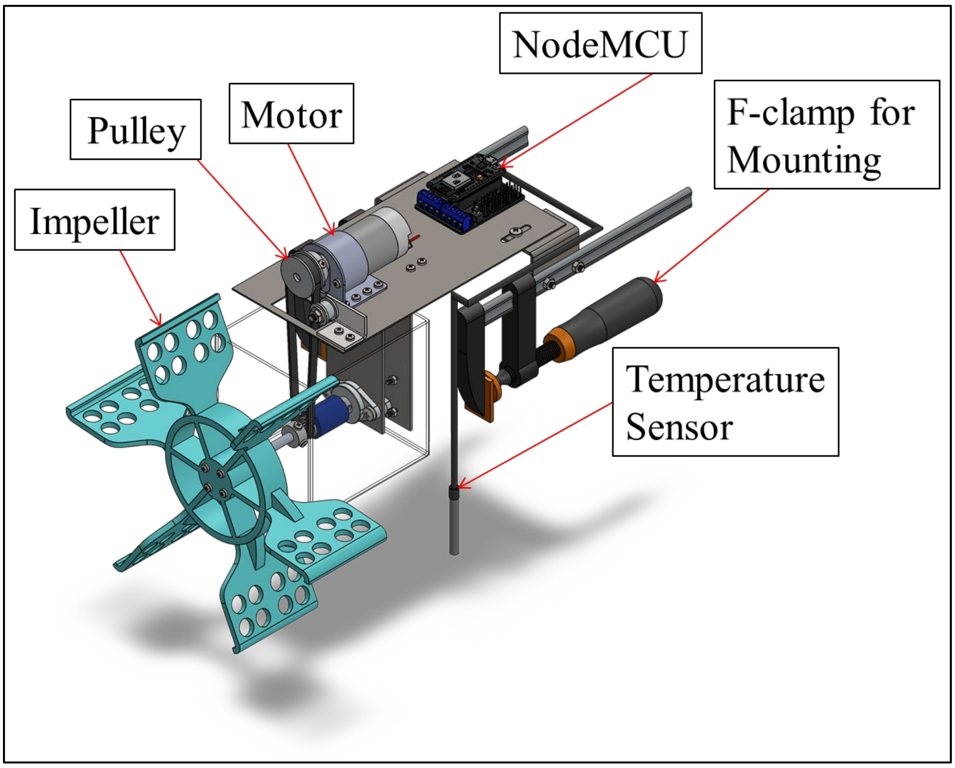

Figure 3.8: Overall Aerator CAD (Impeller 1).

The impellers were 3D printed using polylactic acid (PLA). PLA is common plastic filament material used in 3D printing, it is a non-toxic, odourless bioplastic and can be produced from renewable and sustainable sources such as polysaccharides (starch) from corn. (Pakkanen, et al., 2017; Roman-Ramirex, et al., 2020). PLA also produces fewer fumes as compared to common oil-based 3D printing filaments such as ABS (Pakkanen, et al., 2017). PLA is also biodegradable and recyclable by the hydrolysis process back into its monomer lactic acid to be reused (Piemonte, Sabatini and Gironi, 2013).

The base along with other L-brackets were fabricated with sheet metal. The DC motor and the electrical components were mounted on the top, 2 L-brackets were used to hold the flanges that would be used to support the shaft and to mount a plastic container. A simple belt tensioner made up of sheet metal and a free spinning pulley was fabricated and mounted to a slotted hole to be able to properly tension the pulley system. A plastic container with a drainage hole was mounted to cover both the flanges and the belt pulley to minimise degradation of the parts from water splashing.

3.2.2 Electrical Circuit

The components of the circuit included the NodeMCU which acted as the "brains" of the aerator, sending data and receiving instructions to and from the IoT platform while controlling the motor. Other components were the motor driver, which is a L293D chip, the 12 V motor, the DS18B20 digital temperature sensor, resistors, power and ground lines. The circuit was designed in Proteus and the schematic of the circuit is shown in Figure 3.9.

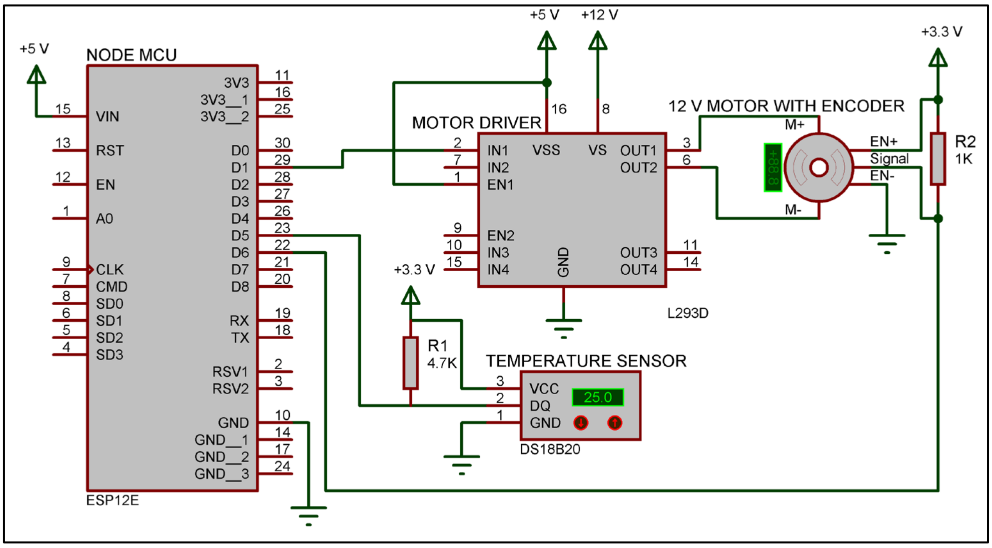

Figure 3.9: Schematic Circuit Diagram.

3.2.3 IoT System

During the selection process for the controller, multiple options such as Arduino Uno boards, knock off boards based on the Arduino Uno and NodeMCU development kits were considered. Ultimately, the NodeMCU platform was selected as the controller of choice for the system as the NodeMCU is a low-cost, low power single board development kit that has built-in WiFi capabilities and sufficient GPIO pins for the system requirements. Furthermore, the NodeMCU is also supported in the Arduino integrated development environment (IDE).

The IoT platform chosen to be used for this project is the Blynk IoT platform which has support for the NodeMCU development kit. The Blynk IoT platform allows the user to customise and design the web and mobile dashboard according to the requirements of the project. The dashboard designed for this project served three main functions:

i. To show current conditions of the aerator including motor status and speed, current DO level and temperature in the water.
ii. To allow for manual control of the aerator by allowing the user to manually override the system to turn the aerator on or off and to input the DO level from an external sensor.
iii. To show past trends of DO level and Temperature of the water from different intervals of time such as from the past hour or days

3.2.4 Program

The program for the NodeMCU was coded in the Arduino IDE. The program was responsible for controlling the operations of the smart aeration system which included. This included sending data from the digital temperature sensor and the speed encoder of the motor to the Blynk IoT platform, autonomously controlling the aerator by determining whether the aerator should be running or idle depending on the DO levels, receiving input and instructions sent through the IoT platform by the user which included the manually input DO level and the manual override controls for the aerator. The program flowchart is shown in Figure 3.10.

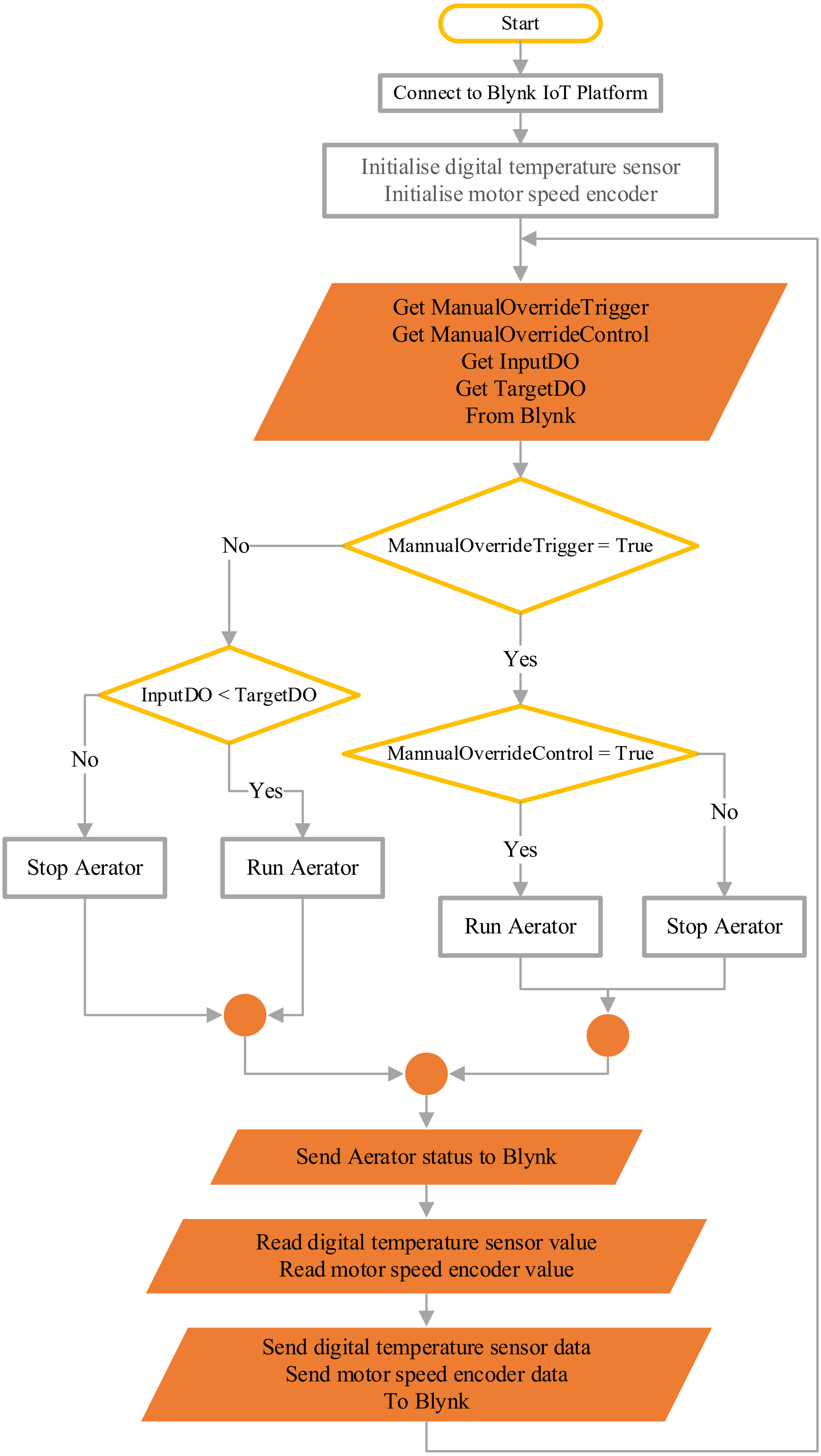

Figure 3.10: Program Flowchart.

3.3 Experiments for Performance Evaluation

The experiments were initially planned and conducted with a 150-gallon (~568 litres) PE water tank outside the workshops of UTAR with water sourced from a tap nearby while travelling to a lab on the fifth floor each time to use a handheld DO sensor to obtain the DO of a water sample from the tank. The handheld DO sensor available in the lab was a Eutech DO 450 from Thermo Scientific, the sensor is shown in Figure 3.11.

Figure 3.11: Eutech DO 450.

However, after a few runs of the experiments that were conducted with the initial setup, it was decided that the experiments would need to be re-run with a different setup as there were too many uncontrollable variables with the setup such as the incapability to travel up to the lab, collect a reading and travel back down before the next reading was required to be taken, the different time it took to wait for an available lift and the uncontrollable environment of which the tank was located, leaving the tank exposed to the birds that would poop into the water, introducing unwanted ammonia and contaminant into the water. The experiments were reconducted indoors with a 70-litre tank and a new handheld DO sensor that could be directly dipped into the tank when a reading was required to overcome the previously mentioned issues. The new handheld DO sensor used was a D09100 dissolved oxygen meter from Yieryi, the sensor is shown in Figure 3.12.

Figure 3.12: D09100 dissolved oxygen meter.

Effects of different speeds on the performance of the three impellers were experimentally studied in the presence of fish feed acting as a DO remover to simulate a more realistic aquaculture environment. The accuracy of the digital thermometer module was also tested by comparing the temperature output to that of a mercury thermometer from the lab.

The handheld DO sensor used displayed the DO level in the water in terms of mg/L, this value can then be converted to DO saturation (%) using Table B-7 in Appendix B, by taking the solubility of oxygen for the temperature of water at the time of recording from the DO sensor and using equation 3.1 where $DO_{measured}$ is the recorded value and DO_{max} is the value obtained from Table B-7 at the respective temperature at the time of reading.

$$DO\ saturation = \frac{DO_{measured}}{DO_{max}} \times 100\ \% \tag{3.1}$$

3.3.1 Evaluation of Different Impellers for Design Selection

The performance of the three impeller designs were experimentally studied. The experiments were conducted with a fixed amount of fish feed (40 g) in the tank and the aerator running continuously with the motor running at full speed. The DO levels were measured by analysing a sample of water from the middle of the tank every 20 minutes for a duration of two hours, this experiment was conducted for all three impellers. The DO levels of a tank with 40 g of fish feed without any aeration was also recorded as a control study to compare the data against and to confirm the effects of fish feed in the water. The impeller with the best performance was selected as the final aerator design.

3.3.2 Evaluation of Smart Aeration Component

As a DO sensor that could be connected directly to the NodeMCU platform could not be obtained due to the limited budget, the test of the smart component of the aerator was conducted through manual input of DO level.

The procedure for testing the aerator was similar to that in section 3.3.1. However, instead of running the aerator constantly, autonomous control was added. The DO sensor was simulated through manual input of the multiparameter digital water quality meter output into the Blynk platform.

The performance of the system was evaluated based on if the system could maintain the DO percentage saturation at +5 % the initial saturation autonomously over a period of 2 hours. The system was allowed to run without manual control other than the input of the reading of the DO sensor into the Blynk platform at regular intervals of 10 minutes throughout a 2-hour period.

3.4 Summary

This study began with project planning and definition of the scope and goals. After research was complete, the design process of the smart aeration system began followed by the feasibility study on the prototype including analysing the data and providing recommendations for future work. The smart aeration system was split into two parts for design – the mechanical components and the software components.

The aerator was first designed in SolidWorks to better visualise the individual parts and the system as a whole. The design of the 3 impeller prototypes took ideas from reviewing commercially available aerators and literature on paddlewheel aerator designs. The electrical circuit was designed in Proteus, the components of the circuit included the NodeMCU, digital temperature sensor, motor and motor driver. The impellers were 3D printed using PLA while other components were fabricated in the workshop using sheet metal.

The software aspects of the smart aeration system included the program for the NodeMCU and IoT integration. The NodeMCU program would be responsible for controlling the operations of the smart aeration system which included, sending data from the sensors to the IoT platform, autonomously controlling the aerator, and receiving input and instructions sent through the IoT platform by the user

The experiments on the aeration system were conducted using a 70-litre tank containing 40 g of fish feed. A handheld DO sensor was used to take readings from the water to be manually input into the IoT dashboard over the duration of 2 hours. For the experiments evaluating the 3 impeller prototypes, a DO reading was taken every 20 minutes. 2 control runs were also conducted without the aerator to verify the effects of 40 g of fish feed dissolved in the water. For evaluation of the smart aeration system a DO reading was taken every 10 minutes to increase the responsiveness of the system.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The overall aeration system including power transmission, component selection and three different impeller designs were successfully fabricated. The results and discussion of the experiments ran on the fabricated prototype system are compiled in this chapter.

4.2 3D Printed Impellers

Figure 4.1 shows the first 3D printed impeller prototype where the impeller was designed based on the most common commercially available paddlewheel aerator.

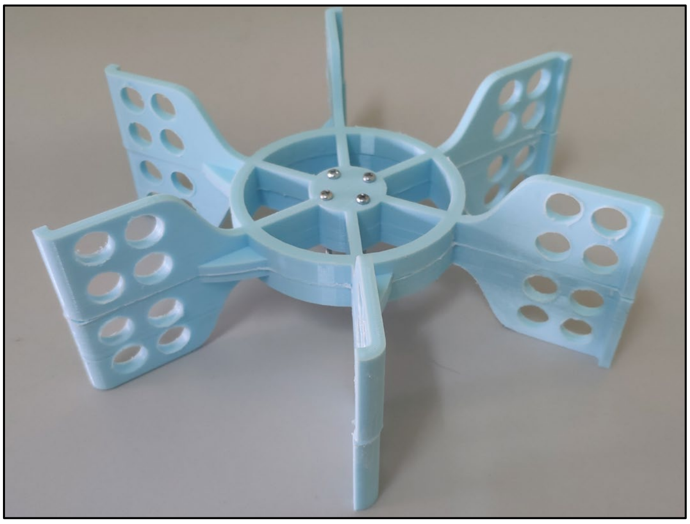

Figure 4.1: Impeller 1 Prototype.

The perforations on each paddle served to break up the water upon impact and create more bubbles and splashing thus increasing the surface area of the water to facilitate the diffusion of oxygen into the water.

Figure 4.2 shows the second 3D printed impeller design where the impeller was designed based on commercial impellers that have triangular tips and angled paddles.

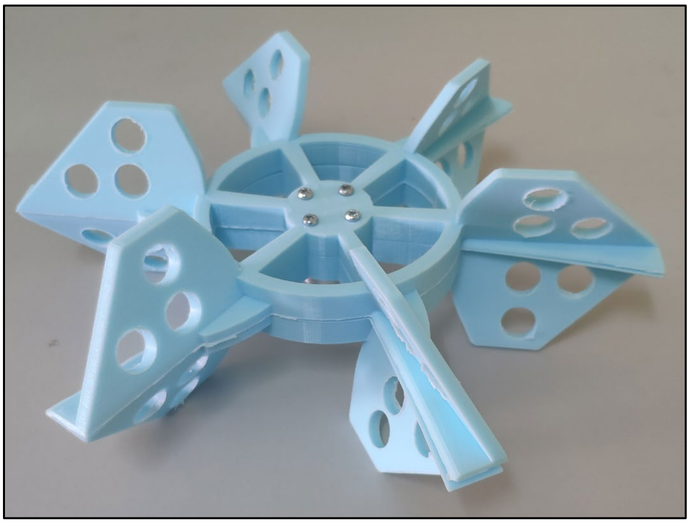

Figure 4.2: Impeller 2 Prototype.

The perforations served the same purpose as the first prototype. The angular profile of the impeller was to reduce the total contact area impacting the water at an instance to reduce the load on the motor. The divider in the centre of each paddle also served the same purpose of reducing the load on the motor by splitting the water upon impact.

Figure 4.3 shows the third 3D printed impeller design where the impeller was designed based on the commercial impellers that have pipes inserted in the shaft with angled paddles and triangular tips.

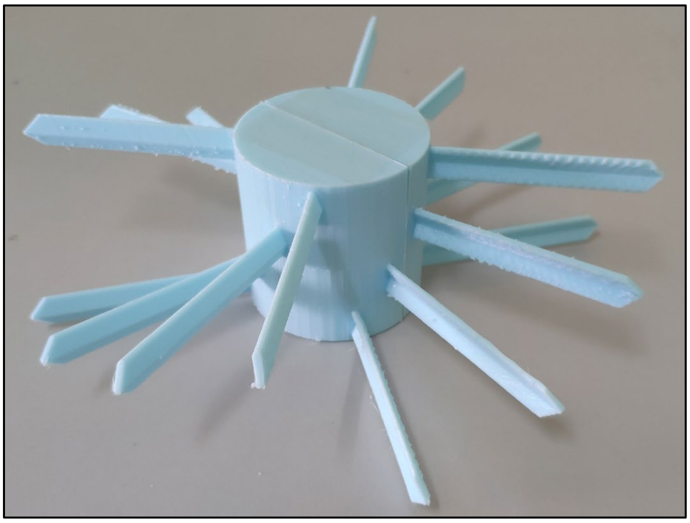

Figure 4.3: Impeller 3 Prototype.

Impeller 3 prototype had more, smaller paddles that were arranged 22.5 ° apart from each other to reduce the load on the motor from a higher sporadic load to a more continuous lower load.

During the printing process, complications arose when the impellers were printed in one whole piece leading to low structural integrity of the part. This problem was overcome when the impellers were printed in separate pieces then combined later with bolts to result in stronger impellers.

4.3 Aerator and Power Transmission System

Figure 4.4 shows the general setup of the experiment to evaluate the performance of the aeration system with the main components labelled.

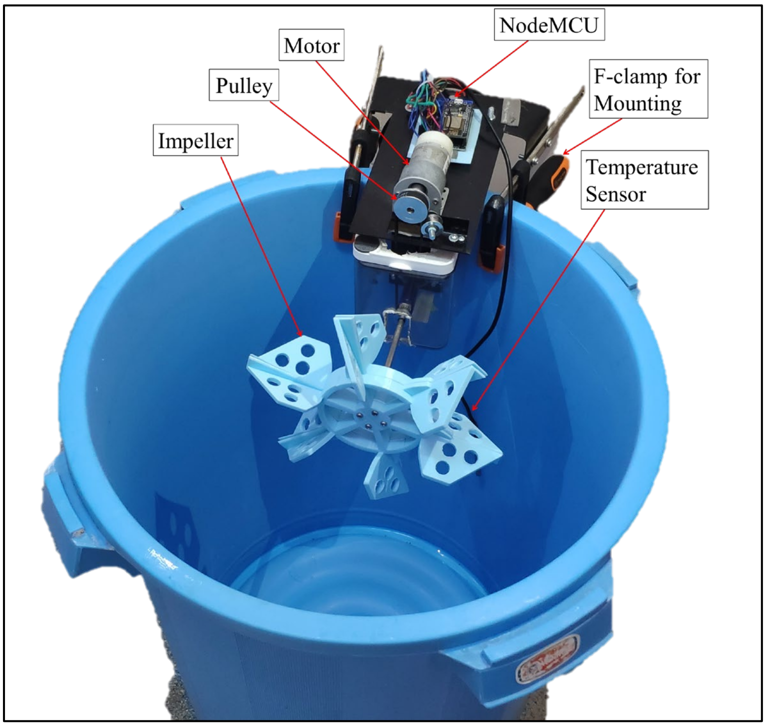

Figure 4.4: Experimental Setup (Impeller 2).

Figures 4.5, 4.6 and 4.7 show the aerator system during the experiment for impellers 1, 2 and 3 respectively.

Figure 4.5: Aerator with Impeller 1.

Figure 4.6: Aerator with Impeller 2.

Figure 4.7: Aerator with Impeller 3.

4.4 Mobile and Web Dashboards

Snapshots of the mobile dashboard and PC web dashboard which shows all modules of the system running are shown in Figures 4.8 and 4.9. The mobile dashboard has the full functionality of the web dashboard with a layout that is more suited for interacting with on a mobile screen.

The dashboard includes 9 modules: DO input, motor status, Aerator RPM, DO level, manual override switch, manual motor control, DO chart and temperature chart. The DO input was made to allow the user to key in readings from the handheld DO sensor, the manual override switch and manual motor control switch are to select if the aerator is in manual control mode and to control if the aerator is running or not if in manual override mode. The other modules are to display info on the system including the current motor status, aerator speed, temperature, DO level and past DO levels and temperature.

The dashboard on the IoT platform could be further customised when necessary to include data from additional sensors present in different systems by reconfiguring the dashboard to include more display modules after the sensors have been integrated into the physical circuit of the aeration system.

The differences between the mobile dashboard and web dashboard were that the mobile dashboard is limited to viewing past data only from 3 days ago while the web dashboard can view data from up to 3 months in the past.

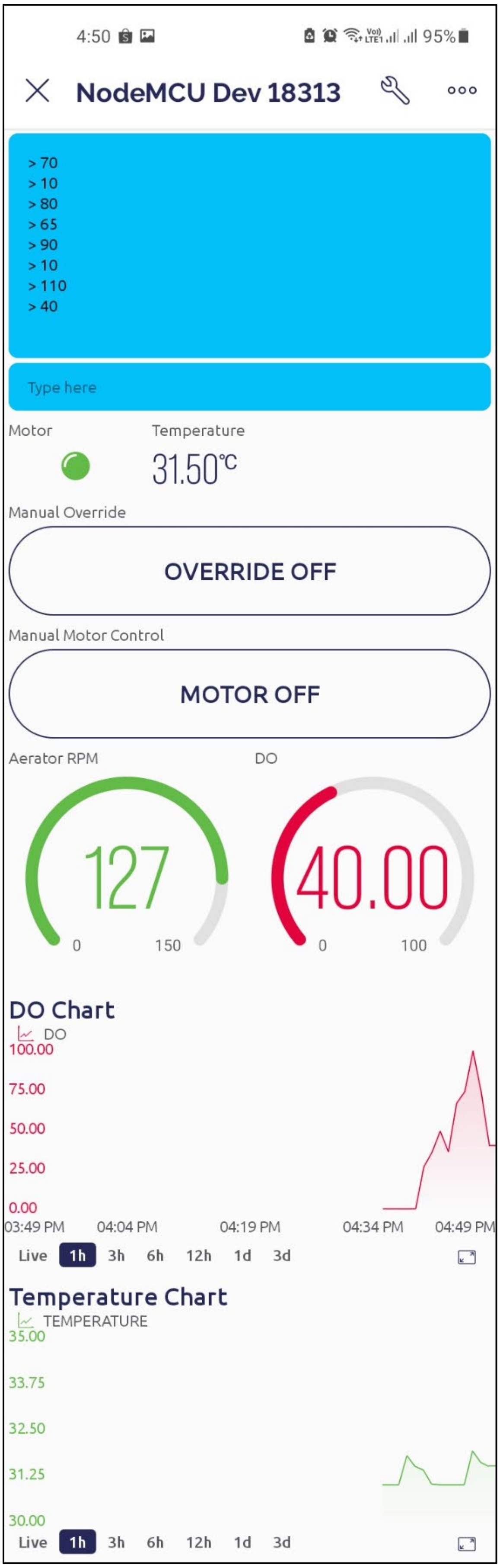

Figure 4.8: Mobile Dashboard.

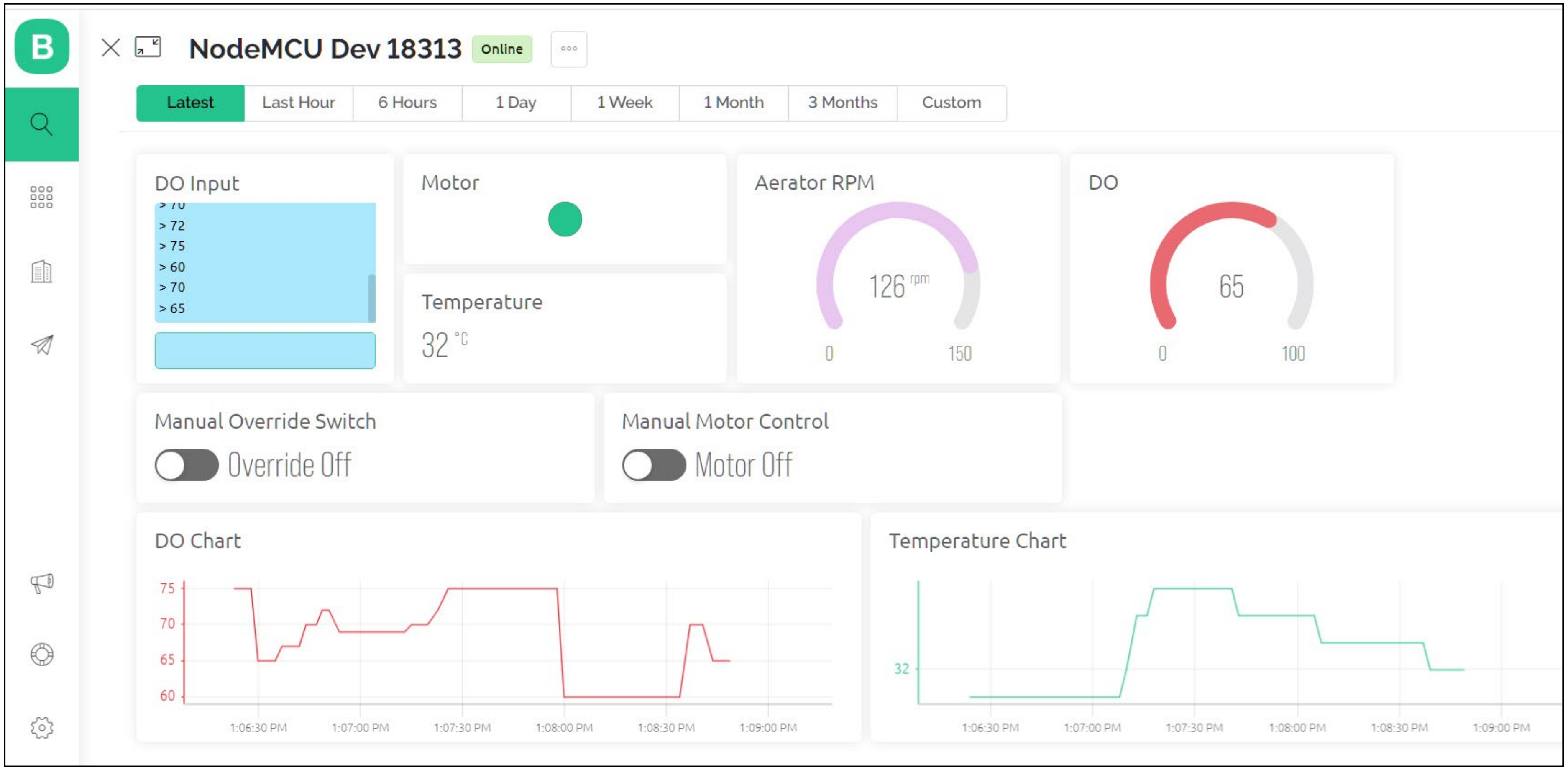

Figure 4.9: Web Dashboard for Smart Aeration System.

4.5 Validation of Digital Temperature Sensor

The results of comparing the output of the digital temperature sensor module against a handheld digital thermocouple are shown in Table 4.1. The maximum percent error in readings were no greater than 3 %, the percent error also decreased when reading larger values.

Table 4.1: Reading from Digital Temperature Sensor and Handheld Thermocouple.

No.	Digital temperature sensor reading (°C)	Handheld thermocouple reading (°C)	Percent Error (%)
1	4.0	4.1	2.4390
2	18.5	19.0	2.6316
3	27.0	27.8	2.8777
4	27.5	28.2	2.4823
5	30.0	29.9	0.3344
6	31.0	30.8	0.6494
7	32.5	32.3	0.6192

4.6 Results of Varying Impeller Designs Experiment

Experiments were conducted for each of the impellers, with the impellers running at full speed for the duration of 120 minutes. The time interval, DO concentration (mg/L) and temperature (°C) were recorded throughout the duration of the experiments with the DO percentage saturation being calculated from the temperature and DO concentration with the assumption that the pressure stayed at 1 atm throughout the experiments. Control runs where the same readings were recorded but without any aerator running were conducted concurrently to study the effect of the dissolved fish feed on water. The DO percentage saturation was then plotted against time for each experiment. The results of these experiments are shown in Table 4.2 and Figures 4.10 to 4.14.

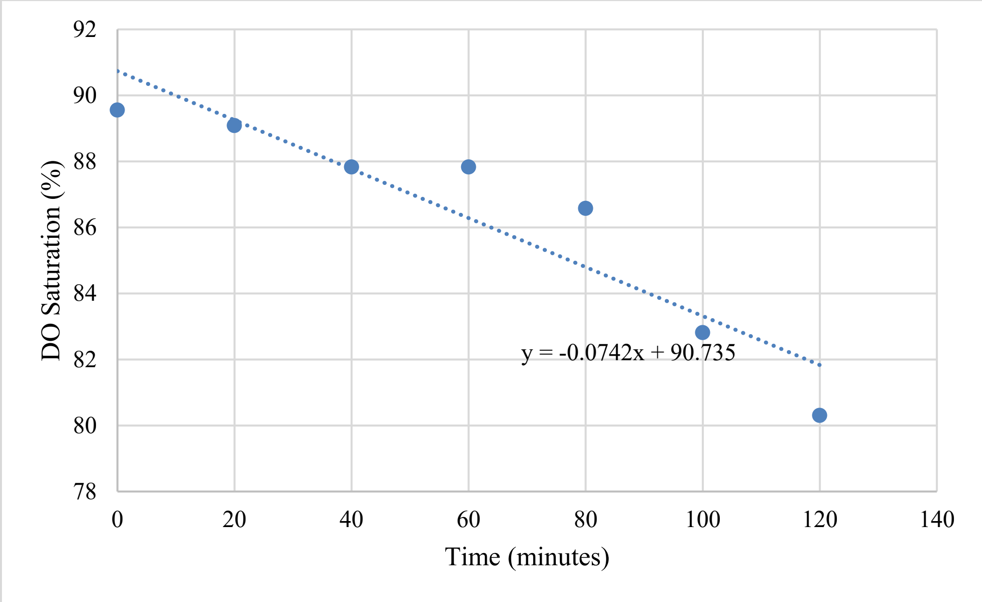

Figure 4.10: DO Saturation Against Time (Control 1).

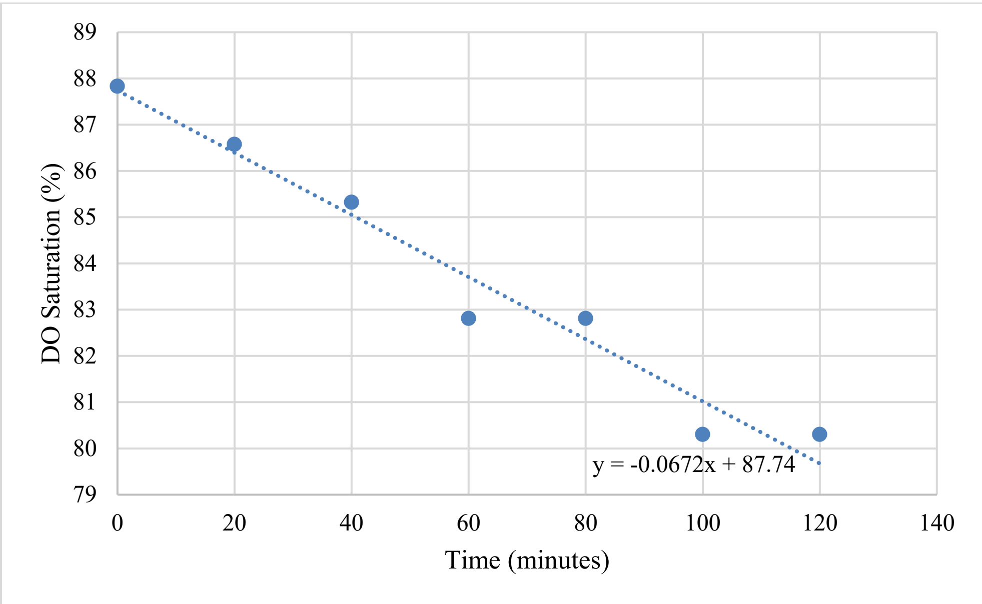

Figure 4.11: DO Saturation Against Time (Control 2).

Table 4.2: Aerator Speed During Experiment.

Impeller	**Aerator speed (RPM)**
1	145
2	170
3	180

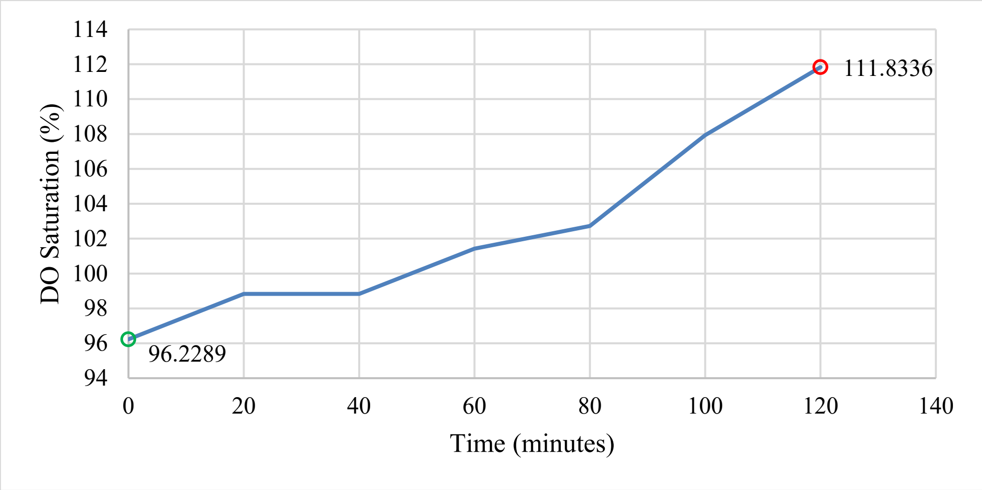

Figure 4.12: DO Saturation Against Time (Impeller 1).

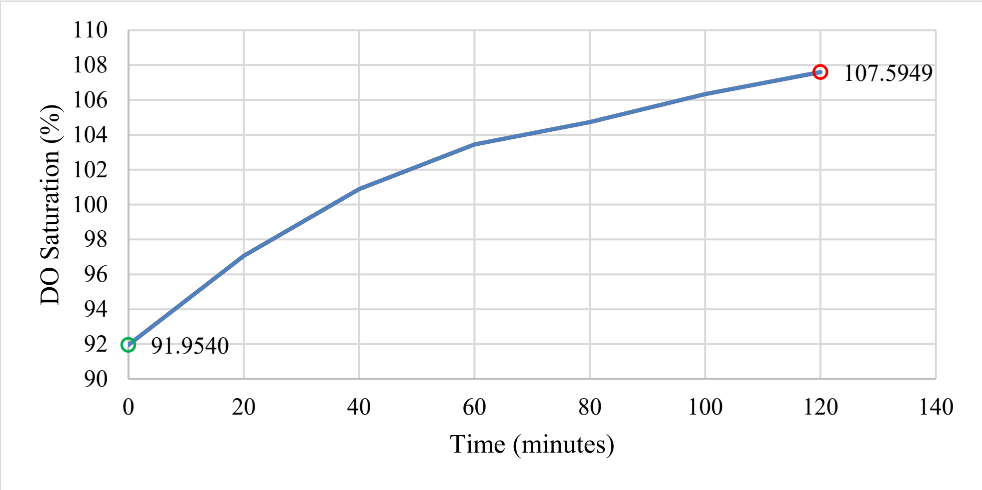

Figure 4.13: DO Saturation Against Time (Impeller 2).

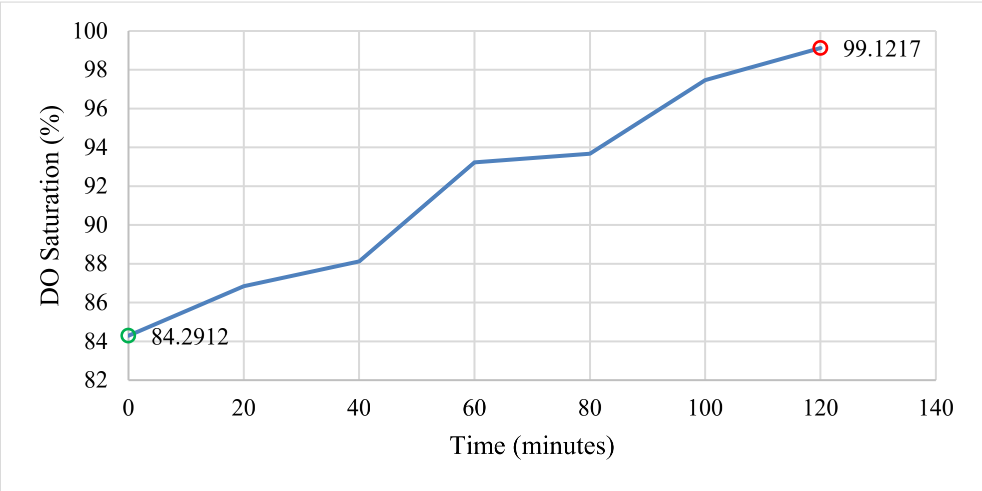

Figure 4.14: DO Saturation Against Time (Impeller 3).

Linear regression was used to show the effects of 40 g of fish feed on the DO saturation of the water. The data collected from the two control tanks resulted in a decrease in DO saturation of -4 to -4.5 % per hour based on the gradient of the trend lines plotted.

Based on the results, impeller 2 performed the best, having the highest overall increase in DO saturation of the water at + 15.6409 % over the two-hour experiment followed by impeller 1 with a + 15.6047 % and impeller 3 at + 14.8305 %. The motor of the aerator was running at full speed throughout all experiments and its speed was also observed for each impeller.

Although throughout all tests, the motor was running at full capacity, the speed varied with impeller as different impellers caused the load on the motor to vary. Impeller 3 had the fastest aerator speed of around 180 RPM followed by impeller 2 at 170 RPM and impeller 1 at 145 RPM.

The difference in speed was likely due to the varying shape of the contact area between the paddle of the impeller and the water surface. Impeller 3 had the smallest paddles with sharp contact areas coupled with the spiral arrangement of the 16 paddles along the shaft spaced at 22.5° apart, meaning that only one paddle was impacting the water surface at any instance resulting in a lower and more continuous load on the motor. Impellers 1 and 2 had 6 larger paddles that applied a more sporadic load on the motor as the paddles were evenly spaced 60 ° apart, resulting in higher load and thus lower speeds. Impeller 2 had a sharp divider at the centre of each paddle to split the water upon contact as highlighted in Figure 4.15 along with angled paddles to reduce the contact area with water at any time while spinning, impeller 1 had flat paddles that would all come in contact with the water at the same time, likely resulting in the highest load on the motor and the lowest speed.

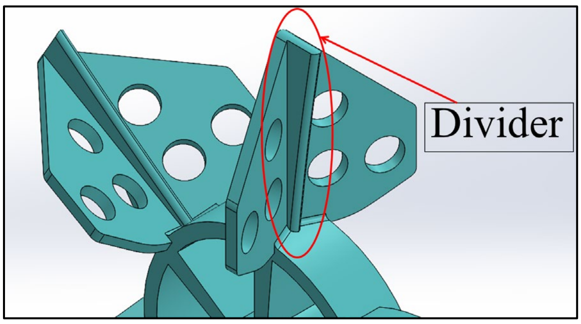

Figure 4.15: Impeller 2 CAD with Divider Circled.

4.7 Results of Smart System Evaluation Experiment

As impeller 2 performed the best, it was used in the subsequent experiment to evaluate the performance of the smart aeration system. Again, the time interval, DO concentration (mg/L) and temperature (°C) were recorded throughout the duration of the experiment with the DO percentage saturation being calculated from the temperature and DO concentration. The same amount (40 g) of fish feed was used as well. Figure 4.16 shows the graph of DO saturation against time for the experiment on the smart aeration system and Figure 4.17 shows the status of the aerator based on whether the aerator was running or idle.

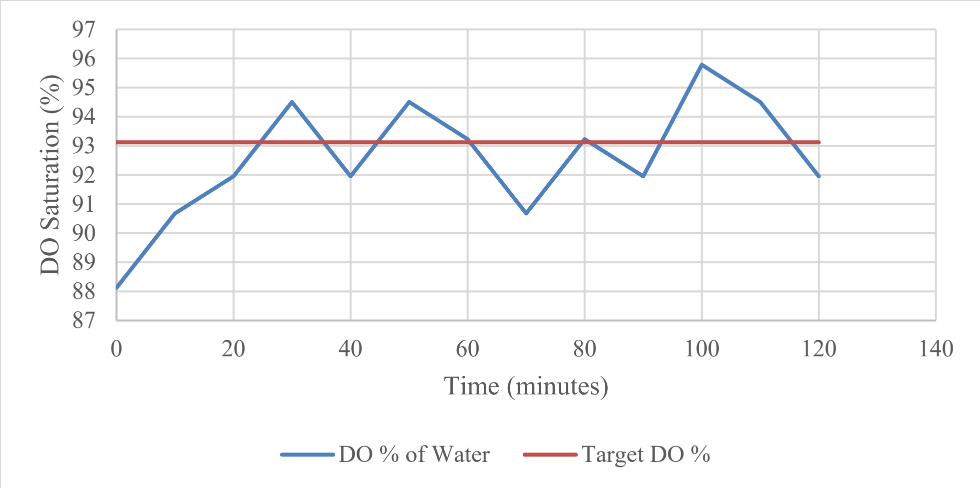

Figure 4.16: Evaluation of Smart Aeration System by Comparison of Real-time and Targeted DO Levels.

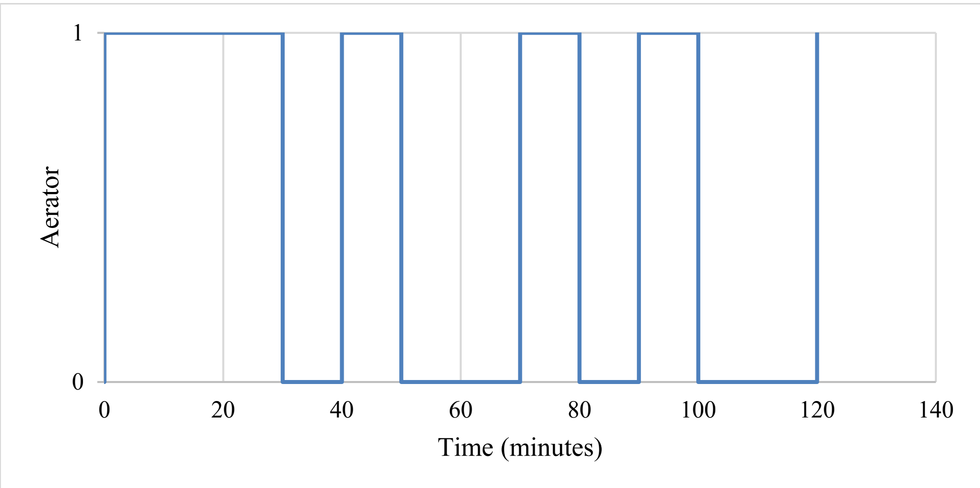

Figure 4.17: Aerator Status Against Time (1 = Running, 0 = Idle).

The graph in Figure 4.16 shows that the smart aeration system was able to maintain the DO saturation around the target DO saturation of 93 %. The target of 93 % was determined by adding five prevent to the initial reading which was 88 %. The aerator would run until the target DO saturation was achieved and stop running while the DO saturation was at or above the set target DO saturation percentage. The results showed that the DO saturation could be maintained around 93 % saturation with occasionally slight dips below the target value while the aerator only cumulatively ran for one hour or half the experiment period.

The power savings of the smart aeration system is estimated to be slightly less than half what would be consumed if the aerator ran continuously. As with the power supply used, the motor could draw a maximum of 1 A of current while under load but the NodeMCU and connected sensors are only rated to draw current in the range of milliamps, relatively much less compared to the running of the motor.

The period between measuring DO saturation readings with the handheld DO meter was shortened from 20 minutes in previous experiments to 10 minutes to reduce the time where the system did not have data. The system would likely perform better if a DO sensor was directly connected to the circuit so that the interval between readings could be set by the user to shorter or longer times depending on the application.

4.8 Summary

The 3 impeller prototypes were 3D printed successfully after the issue of low strength parts was solved by printing the parts in separate smaller pieces. The aerator was successfully fabricated and was able to be mounted onto the wall of the water tank with the attached F-clamps.

The mobile dashboard and web dashboard for the Blynk IoT platform was successfully designed with all modules to meet the requirements set which were to provide real-time monitoring, allow for manual control and show past data for DO and temperature. The readings from the digital temperature sensor were compared to a handheld thermocouple and the percent error of the digital temperature sensor did not exceed 3 %.

The effect of 40 g of fish feed dissolved in the water was seen to decrease the DO saturation percent in the water by 4 to 4.5 % per hour. Each prototype impeller was capable of increasing the DO saturation percent of the water by roughly 15 % over a 2-hour duration. The speed of the impeller ranged from 145 to 180 RPM when the motor of the aerator was running at full capacity likely due to the different amount of load on the motor depending on the geometry of the impeller.

As impeller 2 performed the best, it was used in the subsequent evaluation of the smart aeration system where the system successfully maintained the DO saturation percent around 93 % which was an increase of 5 % from the initial 87 % even when the aerator was only running for half the 2-hour duration of the experiment.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A smart aeration system with IoT integration along with an accompanying mechanical aerator was successfully designed and fabricated. The IoT platform enabled real-time monitoring as well as a record of past data of the water environment and control of the aerator. The aerator displayed capabilities to significantly increase the DO saturation % in water by ≈ 15 % over 2 hours. After the feasibility study was conducted, the smart aeration system was able to maintain the DO saturation % at $\approx +5$ % the initial reading with the aerator only required to run half the duration of the experiment reducing power consumption by roughly half if compared to an aerator that would be running continuously.

The study showed that a smart aeration system is feasible for aquaculture purposes both to provide the user with real-time monitoring and control of the aeration system in an aquaculture environment remotely while also reducing the power consumed by aerators which could significantly reduce the overhead cost of aquaculture.

5.2 Recommendations For Future Work

The main problem faced during this project was the inability to obtain a DO sensor that could be directly integrated into the aeration system. The lack of such a DO sensor required the system to be tested by manually inputting the DO obtained from an external handheld sensor. A recommendation for this study is to obtain a DO sensor that can be directly connected to the system in future works to more properly design and test the smart aeration system. Currently, the system obtains a reading for the DO saturation % based on the frequency of which the user manually inputs the value after taking a reading from the handheld DO sensor. With a DO sensor integrated directly into the system, the system can respond in real-time or be configured to take readings at any interval set by the user.

Another recommendation is to attempt to work together with an industrial link for this project. The industrial link could be an aerator manufacturer that could lend an aerator to conduct experiments on the smart aeration system at full scale to validate the viability of the smart system. A full-scale feasibility study could then potentially be conducted at a lake at the Kampar campus.

The current system is also limited to only be deployed where WIFI is available, future works could integrate a Global System for Mobile Communication (GSM) module which will allow for a SIM card to be connected to the system to use enable connectivity to the cloud IoT platform through cellular data.

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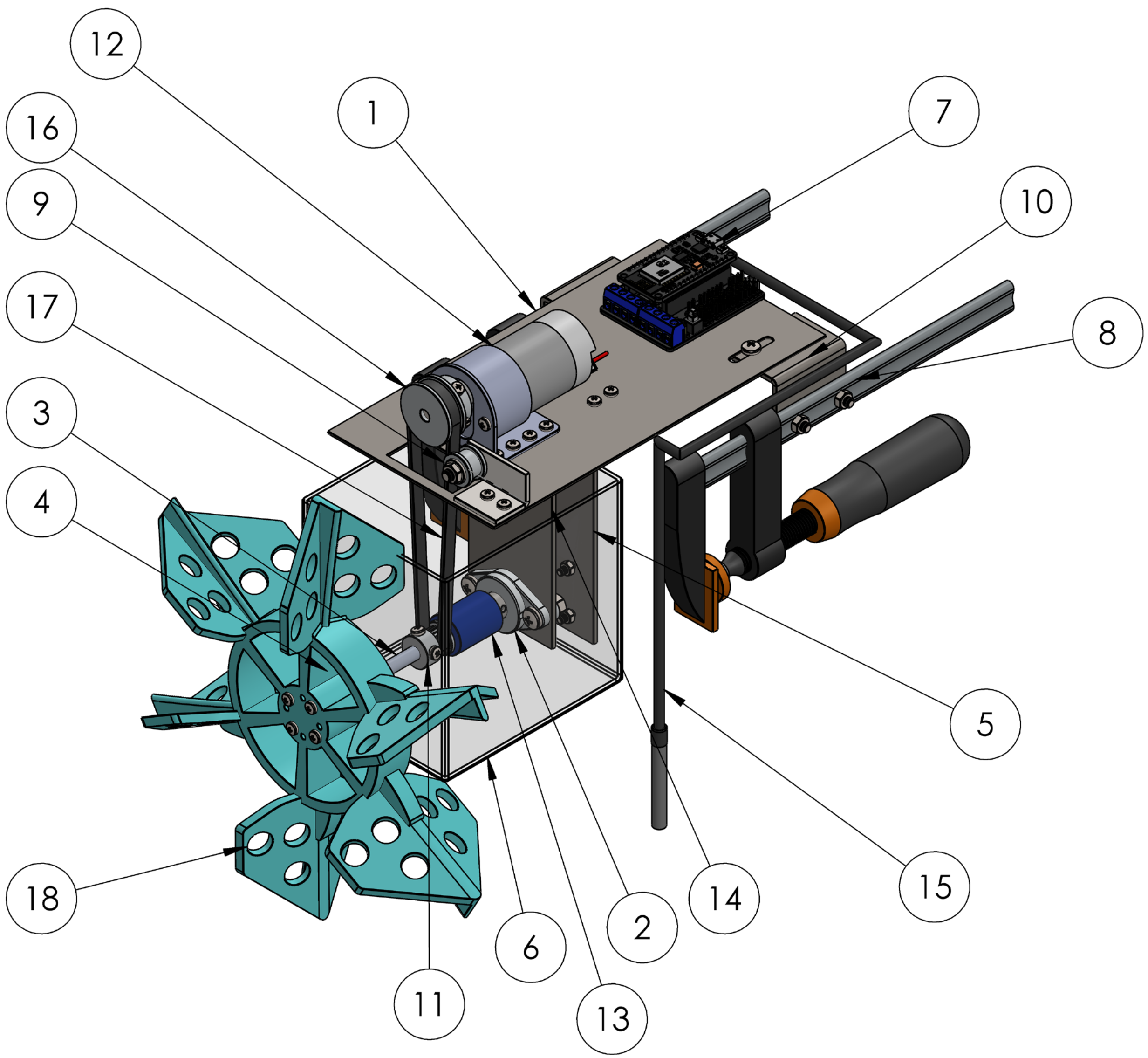
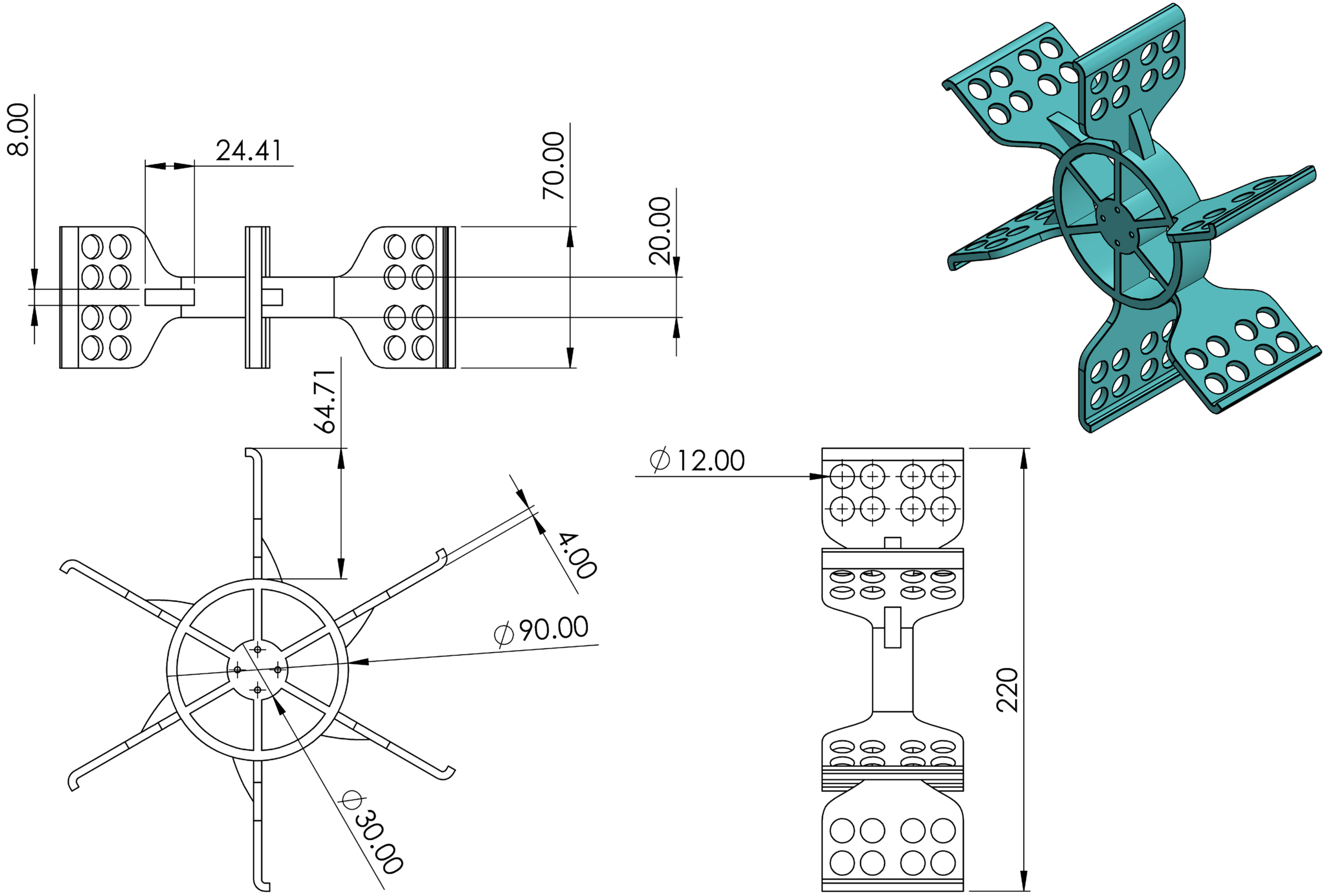
APPENDICES

Appendix A: Technical Drawing of Aerator and Impeller Prototypes

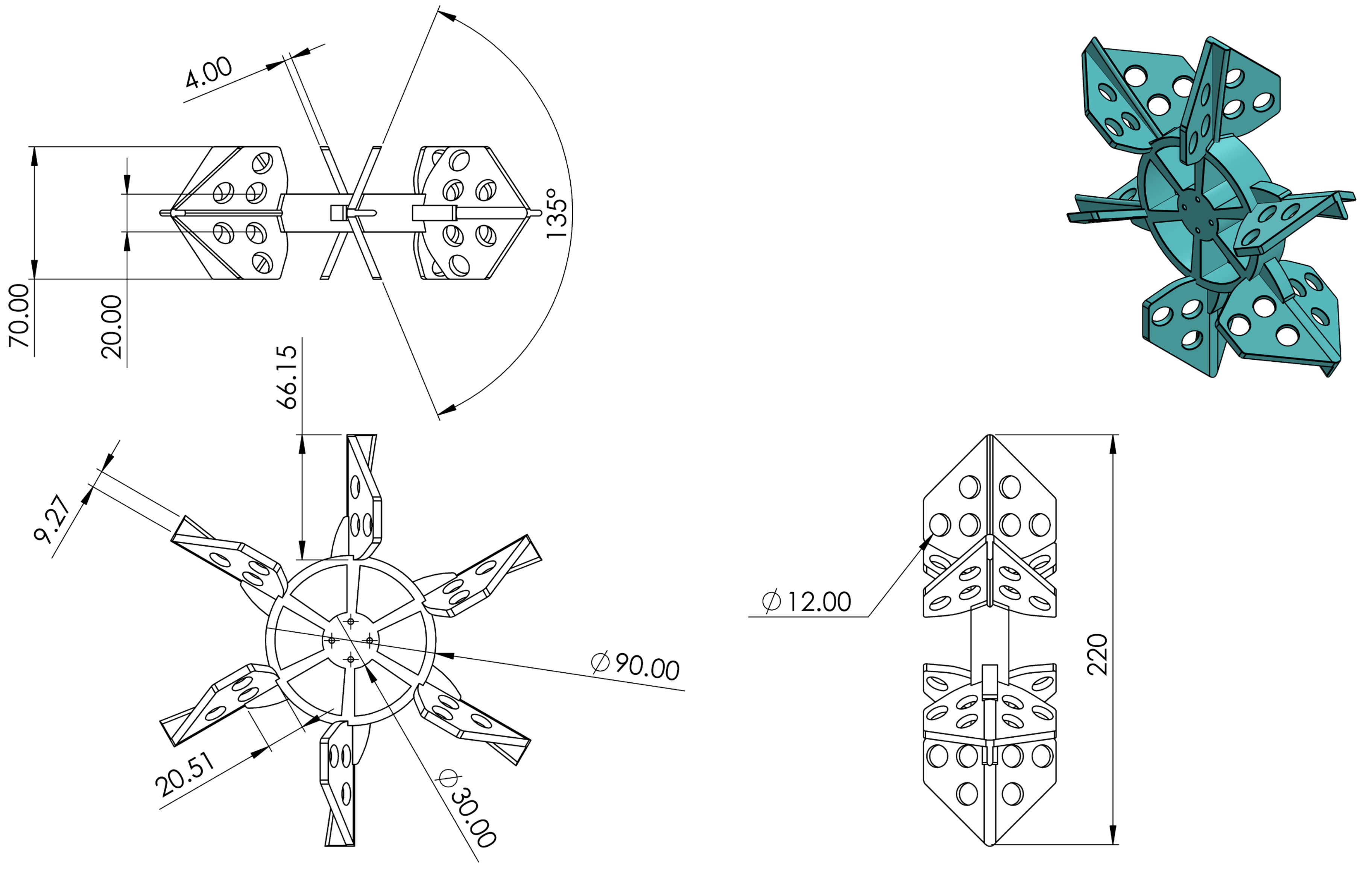
ITEM NO.	PART NUMBER	QTY.
1	Base	1
2	Flange	2
3	Propeller Shaft	1
4	Metal Hub	1
5	Cover Bracket	1
6	Flange Cover	1
7	NodeMCU ASM	1
8	F-clamp	2
9	Belt Tensioner	1
10	L Bracket	2
11	Pulley 20T	1
12	Motor	1
13	Coupling	1
14	Flange Bracket	1
15	Digital Temperature Sensor	1
16	Pulley 40T	1
17	Belt 40T	1
18	Impeller 2	1



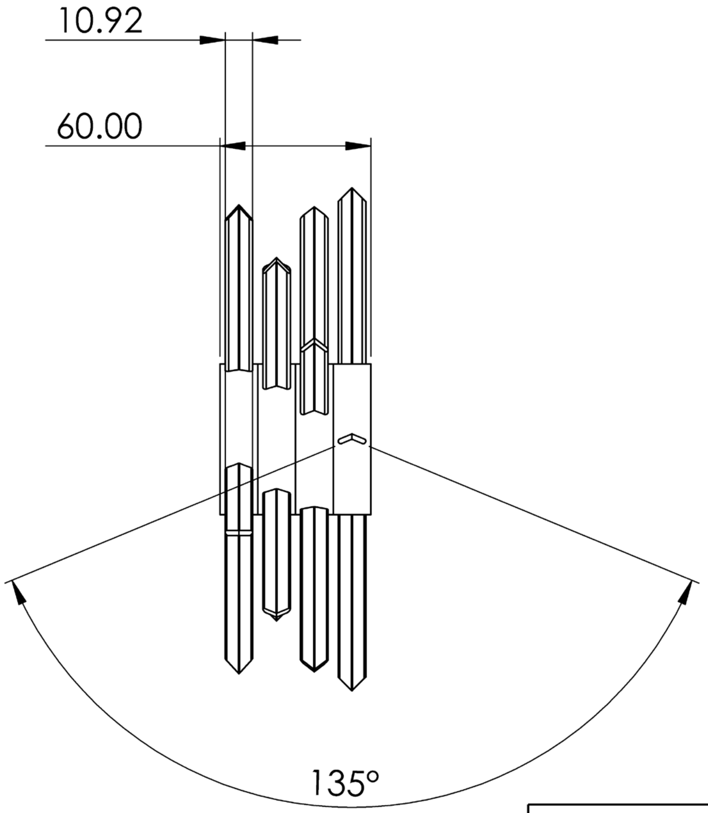
UNLESS STATED OTHERWISE ALL DIMENSIONS IN mm	MATERIAL - FINISH AS MACHINE	DRAWN BY MATTHEW CHAN YUN XIN 1800276 DATE: 07 SEPTEMBER 2022	UNIVERSITI TUNKU ABDUL RAHMAN Aerator ASM (Impeller 2) SCALE 1:3 · DWG NO 1 · SHEET 1 OF 1

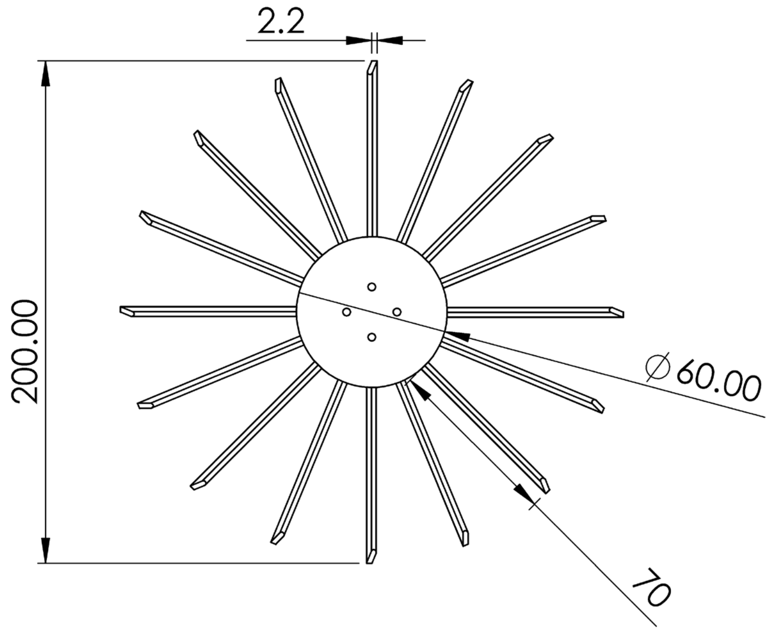


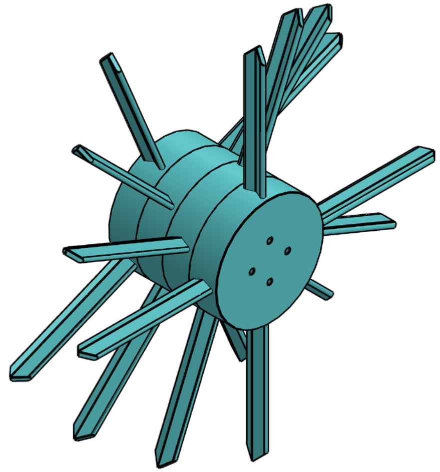
UNLESS STATED OTHERWISE ALL DIMENSIONS IN mm	MATERIAL PLA FINISH AS MACHINE	DRAWN BY MATTHEW CHAN YUN XIN 1800276 DATE: 07 SEPTEMBER 2022	UNIVERSITI TUNKU ABDUL RAHMAN Impeller 1 SCALE 1:3 · DWG NO 1 · SHEET 1 OF 1



UNLESS STATED OTHERWISE ALL DIMENSIONS IN mm	MATERIAL PLA FINISH AS MACHINE	DRAWN BY MATTHEW CHAN YUN XIN 1800276 DATE: 07 SEPTEMBER 2022	UNIVERSITI TUNKU ABDUL RAHMAN Impeller 2	
			SCALE 1:3	DWG NO 1 — SHEET 1 OF 1







UNLESS STATED OTHERWISE ALL DIMENSIONS IN mm	MATERIAL PLA FINISH AS MACHINE	DRAWN BY MATTHEW CHAN YUN XIN 1800276 DATE: 07 SEPTEMBER 2022	UNIVERSITI TUNKU ABDUL RAHMAN Impeller 3 SCALE 1:3 | DWG NO 1 | SHEET 1 OF 1

Appendix B: Tables

Table B-1: Data for Control 1.

Time (mins)	Temperature (°C)	DO (mg/L)	DO Saturation (%)
0	26.5	7.2	89.5522
20	27.0	7.1	89.0841
40	27.0	7.0	87.8294
60	27.0	7.0	87.8294
80	27.0	6.9	86.5747
100	27.0	6.6	82.8105
120	27.0	6.4	80.3011

Table B-2: Data for Control 2.

Time (mins)	Temperature (°C)	DO (mg/L)	DO Saturation (%)
0	27.0	7.0	87.8294
20	27.0	6.9	86.5747
40	27.0	6.8	85.3199
60	27.0	6.6	82.8105
80	27.0	6.6	82.8105
100	27.0	6.4	80.3011
120	27.5	6.4	80.3011

Table B-3: Data for Impeller 1 Prototype.

Time (mins)	Temperature (°C)	DO (mg/L)	DO Saturation (%)
0	30.0	7.4	96.2289
20	30.0	7.6	98.8296
40	30.0	7.6	98.8296
60	30.0	7.8	101.4304
80	30.0	7.9	102.7308
100	30.0	8.3	107.9324
120	30.0	8.6	111.8336

Table B-4: Data for Impeller 2 Prototype.

Time (mins)	Temperature (°C)	DO (mg/L)	DO Saturation (%)
0	28.0	7.2	91.9540
20	28.0	7.6	97.0626
40	28.0	7.9	100.8940
60	28.0	8.1	103.4483
80	28.0	8.2	104.7254
100	27.5	8.4	106.3291
120	27.5	8.5	107.5949

Table B-5: Data for Impeller 3 Prototype.

Time (mins)	Temperature (°C)	DO (mg/L)	DO Saturation (%)
0	28.0	6.6	84.2912
20	28.0	6.8	86.8455
40	28.0	6.9	88.1226
60	28.0	7.3	93.2312
80	27.5	7.4	93.6709
100	27.5	7.7	97.4684
120	27.0	7.9	99.1217

Table B-6: Data for Evaluation of Smart Aeration System.

Time (mins)	Temperature (°C)	DO (mg/L)	DO Saturation (%)
0	28.0	6.9	88.1226
20	28.0	7.1	90.6769
40	28.0	7.2	91.9540
60	28.0	7.4	94.5083
80	28.0	7.2	91.9540
100	28.0	7.4	94.5083
120	28.0	7.3	93.2312

Table B-7: Solubility of Oxygen in Fresh Water at Various Temperatures and Pressures (United States Geological Survey, 2018).

	Barometric Pressure (atm)						
Temperature (°C)	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**
20.0	4.44	5.37	6.30	7.23	8.16	9.09	10.02
20.5	4.39	5.32	6.24	7.16	8.08	9.00	9.92
21.0	4.35	5.26	6.17	7.09	8.00	8.92	9.83
21.5	4.30	5.21	6.11	7.02	7.92	8.83	9.73
22.0	4.26	5.15	6.05	6.95	7.85	8.74	9.64
22.5	4.21	5.10	5.99	6.88	7.77	8.66	9.55
23.0	4.17	5.05	5.93	6.81	7.70	8.58	9.46
23.5	4.13	5.00	5.87	6.75	7.62	8.50	9.37
24.0	4.08	4.95	5.82	6.68	7.55	8.42	9.28
24.5	4.04	4.90	5.76	6.62	7.48	8.34	9.20
25.0	4.00	4.85	5.71	6.56	7.41	8.26	9.12
25.5	3.96	4.81	5.65	6.50	7.34	8.19	9.03
26.0	3.92	4.76	5.60	6.44	7.27	8.11	8.95
26.5	3.88	4.71	5.54	6.38	7.21	8.04	8.87
27.0	3.84	4.67	5.49	6.32	7.14	7.97	8.79
27.5	3.80	4.62	5.44	6.26	7.08	7.90	8.72
28.0	3.76	4.58	5.39	6.20	7.02	7.83	8.64
28.5	3.73	4.53	5.34	6.15	6.95	7.76	8.57
29.0	3.69	4.49	5.29	6.09	6.89	7.69	8.49
29.5	3.65	4.45	5.24	6.04	6.83	7.62	8.42
30.0	3.62	4.40	5.19	5.98	6.77	7.56	8.35
30.5	3.58	4.36	5.15	5.93	6.71	7.49	8.28
31.0	3.54	4.32	5.10	5.88	6.65	7.43	8.21
31.5	3.51	4.28	5.05	5.82	6.60	7.37	8.14
32.0	3.47	4.24	5.01	5.77	6.54	7.30	8.07
32.5	3.44	4.20	4.96	5.72	6.48	7.24	8.00
33.0	3.40	4.16	4.92	5.67	6.43	7.18	7.94
33.5	3.37	4.12	4.87	5.62	6.37	7.12	7.87
34.0	3.34	4.08	4.83	5.57	6.32	7.06	7.81
34.5	3.30	4.04	4.79	5.53	6.27	7.01	7.75
35.0	3.27	4.01	4.74	5.48	6.21	6.95	7.68
35.5	3.24	3.97	4.70	5.43	6.16	6.89	7.62
36.0	3.21	3.93	4.66	5.38	6.11	6.84	7.56
36.5	3.17	3.90	4.62	5.34	6.06	6.78	7.50
37.0	3.14	3.86	4.58	5.29	6.01	6.73	7.44
37.5	3.11	3.82	4.54	5.25	5.96	6.67	7.39
38.0	3.08	3.79	4.50	5.20	5.91	6.62	7.33
38.5	3.05	3.75	4.46	5.16	5.86	6.57	7.27

Appendix C: Program Code for NodeMCU

```
// Include the libraries for temp sensor
#include <OneWire.h>
#include <DallasTemperature.h>
// Data wire for temperature sensor is plugged into port
14
#define ONE_WIRE_BUS 14
// Setup a oneWire instance to communicate with sensor
OneWire oneWire(ONE_WIRE_BUS);
// Pass our oneWire reference to Dallas Temperature.
DallasTemperature sensors(&oneWire);
// Arrays to hold device address
DeviceAddress insideThermometer;

// Blynk IoT dashboard information
#define BLYNK_TEMPLATE_ID "TMPLb9VXBrdr"
#define BLYNK_DEVICE_NAME "NodeMCU Dev"
#define BLYNK_FIRMWARE_VERSION        "0.1.0"
#define BLYNK_PRINT Serial
//#define BLYNK_DEBUG
#define APP_DEBUG
#include "BlynkEdgent.h"

//pin declaration for motor control
int PWMA = 5; //Right side
int DIRA = 0; //Right side
int PWMB = 4; //Right side
int DIRB = 2; //Right side
bool Motor_State = 0;

//declaring variables
float TempC;  //temperature variable
float InputDO; //input DO value
float TargetDO = 7; // target DO value (default is 7,
changes depending on user input in Blynk)

//declaring variables for manual control for aerator
bool ManualOverrideTrigger = 0; //Initialise Manual
Override Trigger variable
bool ManualOverrideControl = 0; //Initialise manual
Override motor control variable

//declaring variables for motor encoder and calculations
of speed
int EncoderInput = 12; // Pin where the encoder input is
fed.
// Variable for saving pulses count.
```

```
int EncoderPulses = 0;
int PreviousPulses = 0;
int CurrentPulses = 0;
int var = 0;
long PreviousMillis = 0;
long CurrentMillis = 0;
float RPM = 0; //variable to store RPM of motor


//Constantly synchronising control for ManualOverrideTrigger with the Blynk platform
BLYNK_WRITE(V2)
{
  if (param.asInt() == 1)
  {
    ManualOverrideTrigger = 1;
  }
  else
  {
    ManualOverrideTrigger = 0;
  }
}
//Constantly synchronising control for ManualOverrideControl with the Blynk platform
BLYNK_WRITE(V4)
{
  if (param.asInt() == 1)
  {
    ManualOverrideControl = 1;
  }
  else
  {
    ManualOverrideControl = 0;
  }
}
//Constantly synchronising control for InputDO with the Blynk platform
BLYNK_WRITE(V5)
{
  InputDO = param.asFloat();
}

BLYNK_WRITE(V7)
{
  TargetDO = param.asFloat();
}
```

```
//Subroutine to get temperature value from temperature sensor
void ReadTemp()
{
  sensors.requestTemperatures(); // Send the command to get temperatures
  TempC = sensors.getTempC(insideThermometer);
  Serial.print("Temperature (°C) = ");
  Serial.println(TempC);
  Blynk.virtualWrite(V0, TempC); //send Temperature value to be displayed in Blynk Platform
}

//Subroutine to get encoder pulses over 2 seconds and convert to RPM
void ReadEncoder()
{
  EncoderPulses = 0;
  PreviousMillis = millis();
  var = 0;
  while (millis() - PreviousMillis < 2000)
  {
    if (digitalRead(EncoderInput) > var)
    {
      var = 1;
      EncoderPulses++;
    }
    if (digitalRead(EncoderInput) == 0) {
      var = 0;
    }
    delay(1); // Delay for stability.
  }
  RPM = float(EncoderPulses * 2 * 30 / 210);
  Serial.print("Motor Speed (RPM) = ");
  Serial.println(RPM);
  Blynk.virtualWrite(V1, RPM); //send RPM value to be displayed in Blynk Platform
}

void setup()
{
  pinMode(EncoderInput, INPUT);  //initialising Encoder
  pinMode(PWMA, OUTPUT); // Initialise digital pin 5 as an output
  Serial.begin(9600); //initialising serial communication for debugging
  delay(100); //delay for stability
```

```
  sensors.begin(); //initialising temperature sensor
  if (!sensors.getAddress(insideThermometer, 0)) ;
  sensors.setResolution(insideThermometer, 9);

   BlynkEdgent.begin(); //initialising communication with
Blynk Platform
}

//main program
void loop()
{
  BlynkEdgent.run();

//synchronise motor controls with instructions from Blynk
Platform
  if (ManualOverrideTrigger == 1)
  {
    if (ManualOverrideControl == 1)
    {
      digitalWrite(PWMA, HIGH);
      Blynk.virtualWrite(V3, HIGH);
    }
    else
    {
      digitalWrite(PWMA, LOW);
      Blynk.virtualWrite(V3, LOW);
    }
  }
  //Run or Idle aerator depending on current DO level and
Target DO level
  else
  {
    if (InputDO < TargetDO)
    {
      digitalWrite(PWMA, HIGH);
      Motor_State = HIGH;
      Blynk.virtualWrite(V3, HIGH);
    }
    else
    {
      digitalWrite(PWMA, LOW);
      Motor_State = LOW;
      Blynk.virtualWrite(V3, LOW);
    }
  }

  ReadTemp(); //Update Temperature value in Blynk Platform
  ReadEncoder(); //Update Aerator speed in Blynk Platform
```

```
  Blynk.virtualWrite(V6, InputDO); //Display Current DO
level in Blynk Platform
}
```

Appendix D: Certificate of Award for Final Year Project Poster Competition (June Trimester) 2022

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