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Mini Aquaponics System using IoT Technology for Teaching and Learning

Nur Syuhada Mohamad[1]*, Muhammad Luqman Danial Zulazwi[1], Muhammad Aiman Mohd Razali[1], Muhammad Izzat Ismet[1]

[1] *Jabatan Teknologi Maklumat dan Komunikasi, Politeknik Ungku Omar (PUO), Jalan Raja Musa Mahadi, 31400 Ipoh, Perak, MALAYSIA*

*Corresponding Author: nursyuhada@puo.edu.my
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Internet of Things (IoT), physical hardware, web-based application, sensors, input values, monitors, real time, dashboard, Artificial Intelligence, maintenance.

Abstract

Aquaponics is a farming method that integrates two elements namely aquaculture and hydroponics, which helps in growing healthy organic food with low use of chemical fertilizers. The Mini Aquaponics System using IoT Technology for Teaching and Learning is a project developed specifically for secondary school students for Form 2 in the subject Reka Bentuk dan Teknologi (RBT). This project offers a more effective learning system to help students understand more about what aquaponics is and how it works compared to traditional learning methods using textbooks and lectures. This project focuses on helping teachers and students learn interactively to make them more interested in aquaponics learning with the integration of Internet of Things (IoT) technology. In this project, there are two methods implemented which are the integration physical hardware of the aquaponics unit with IoT technology and the development of the web-based application for the e- Learning Management System (e-LMS). This Aquaponics System provides several courses in the e-LMS. Several sensors are involved to get input values from the aquaponics unit to monitors and display the aquaponics condition. The integration between IoT devices and the aquaponics system shows remarkable results to the ecosystem that can be monitored in real time from a monitoring dashboard. The collection of raw data from the monitoring results is very useful in implementing Artificial Intelligence (AI) to suggest maintenance required by Aquaponics System. On the other hand, this project is very helpful for students, teachers and all interested parties in understanding how aquaponics works, the monitoring process and the benefits of this cultivation method.

1. Introduction

STEM education is derived from the abbreviation SMET which is Science, Mathematics, Engineering and Technology. This practical approach is not only intended to prescribe a set of activities or practices, but it is rather meant to start an extended dialogue regarding opportunities for innovation and encouraging research and development. Academics argue that this approach can help students build a stronger foundation that can be successful in a variety of contexts where it can encourage students to achieve transformative [1]. In the context of our country, STEM refers to education policy and school curriculum choices to increase competitiveness in the field of science and technology for students. STEM education puts a lot of emphasis on the aspect of high-level thinking skills (KBAT) where this component is seen to be able to produce a young generation who have high skills in solving various complex problems through knowledge in the field of communication, teamwork, creativity and critical thinking [2][3].

Reka Bentuk dan Teknologi (RBT) is a subject introduced to produce students who have thinking skills as contained in the *Pelan Pembangunan Pendidikan Malaysia 2013-2025 (PPPM)* [4]. RBT is taught to students about design criteria using technology in the construction and manufacturing of products so that they become individuals who have a global mindset and understand the latest technology that can solve future problems. In the Form 2 RBT subject syllabus, there is a learning topic of technology application in aquaponics design. Students need to know how aquaponics is built, what are the benefits of aquaponics, why aquaponics is better for the future and how aquaponics can replace conventional cultivation and aquaculture methods [5]. The current learning method used is using traditional methods through references in textbooks or visualization through reference sources such as videos and animations through open websites. The students do not have any experience in handling or performing aquaponics practically. Feedback on current teaching and learning methods has been obtained through survey questions to students and teachers at Sekolah Menengah Kebangsaan Raja Chulan, Ipoh, Perak.

This Paper is about the development of project Mini Aquaponics System using IoT Technology for Teaching and Learning. This project can help teachers and Form 2 students who take RBT subjects especially in understanding the concept of aquaponics design. This mini aquaponics is also suitable for a small industry such as modern farmers who are new to the farming industry and live at urban area. This Mini Aquaponics System will help to monitor crops and fish farming using Internet of Things (IoT) technology. This Mini Aquaponics System will monitor the water pH level, water temperature, water level in the aquarium and environmental humidity reading. It also helps to manage the feeding time of the fish to ensure that the fish always get enough food. Users can view and monitor all these functions through the user screen. This also helps improve the user's understanding of what needs to be taken and the process that occurs in the Aquaponics System.

This Mini Aquaponics System also provides an e-Learning Management System (e-LMS) to attract students' interest and improve students' understanding of the topic of aquaponics design for RBT students in form 2. This e-LMS offers a lot of information to all students along with their teachers to make learning methods more interactive while helping teachers to be used as teaching materials that can be used during teaching and learning sessions. In addition, this e-LMS is also able to help anyone, especially small entrepreneurs who want to learn aquaponics techniques. All material such as learning modules, tutorials and quizzes are available in this e-LMS. Solar panels are one of the functions used in the development of Mini Aquaponics System using IoT technology to help plant growth through UV lighting that has been generated through solar panels. In addition, this agricultural technology will offer an incredible way to grow organic vegetables, fruits and herbs that are free from harmful chemicals yet have fresh and safe protein for people to get a nutritious diet for their bodies.

1. Materials and Methods

1.1 Materials

The development of the Mini Aquaponics System using IoT Technology for Teaching and Learning project is an IoT-based system consisting of two main parts which are hardware and software. Mini Aquaponics refers to hardware while the operation of Aquaponics System and the e-LMS system refers to software. The integration between hardware and software systems produces a complete system using IoT technology. In the Form 2 RBT Textbook Syllabus, students need to learn aquaponics design as well as sketch an informative Aquaponics System using electronic equipment. Students were exposed to 3 models of Aquaponics Systems, namely the Raft system, the Ebb & Flow system and the Nutrient Film Technique (NFT) system. In this study, the Mini Aquaponics produced is using the NFT model [5].

i. Hardware

To produce the development of a Mini Aquaponics using NFT model, the electronic components hardware used shows in Table 1.

Table 1 *Hardware requirement*

Hardware	Description
Arduino Uno R4	Acts as a central processing unit to process input data from the sensors and upload to the cloud.
NodeMCU ESP8266	Acts as a central processing unit to process output data from the input user.
Waterproof Temperature Sensor	This sensor can be submerged into the water to get the temperature value of water to make sure the water temperature is good for fish.
DHT11	Used to measure the temperature and humidity of the environment to ensure the condition is appropriate for both fish and plants.
Ultrasonic sensor	Used to monitor the water level of the fishtanks to make sure the water level is appropriate for the fish.
PH sensor	Used to monitor the alkalinity and acidity of the water to maintain the optimal pH level for fish and plants to grow healthily
RFID sensor	To control the electricity of the aquaponic system. Act as a security purpose during maintenance process.
Water Pump	Used to circulate the water through the aquaponic system, providing the water rich in nutrient to all plant beds.
LED Grow light	Act as natural sunlight for the indoor aquaponic system, providing light energy for plants photosynthesis
Solar Panel	Provide renewable energy to power the IoT components involves in aquaponic system.
Servo Motor	Used to dispensing the fish food on certain time, ensuring the fish are fed consistently.
Solar controller	Used to manage the charging and discharging of batteries connected to solar panels. The primary function is to prevent from overcharging the battery.
Lcd I2C	Used to display the time for next fish feeding session.
Step up boost converter	Used to increase (step up) the voltage from a lower input level to a higher output level.
Sealed lead acid battery	Used to store the excess energy from the solar panel to be use during low power source.
USB module	Provide electricity to all microcontrollers in aquaponic system.
Relay	Electrically controlled switches that provide isolation between control and load circuits.

ii. Software

The operation of the aquaponics system is based on the integration between electronics components configured in Arduino Integrated Development Environment (IDE) software. The programming code from the Arduino IDE is uploaded into the main hardware components of the Arduino is the microcontroller. There are 4 microcontrollers involved in this project, one Arduino Uno R4 and three NodeMCU ESP8266. The Arduino Uno R4 is configured to allow all the input data from the sensors to be uploaded into the cloud which is a public broker. The public broker used MQTT protocol to allow all the data kept into the cloud. The data will be transferred to the dashboard of Node-Red. The data keeps on updated after one minute. The NodeMCU ESP8266 act as an output controller. User able to control the switch for grow light and water pump. MQTT will send the input to the ESP8266 and trigger the pin connected to the actuators [6]. The IoT diagram in Fig. 1 shows how the data from the microcontroller is sent to the cloud, which is MQTT Broker. The data will be published to the MQTT topic called AquaData. AquaData was an intermediary party before the data was passed to the consumer.

Fig. 1 *IoT Diagram (MQTT Broker)*

To produce the development of this Mini Aquaponics System using IoT Technology for Teaching and Learning, Table 2 shows the list of software needed.

Table 2 *Software requirement*

Hardware	Description
Node-Red	It provides a browser-based editor that makes it easy to wire together flows using the wide range of nodes in the palette that can be deployed to its runtime in a single-click.
XAMPP	It provides an easy-to-install environment for developing and testing web applications on a local machine.
PhpMyAdmin	Open-source web application written in PHP that provides a graphical interface for managing MySQL or MariaDB databases. Designed to simplify complex database operations, allows users to perform a wide range of tasks such as creating, modifying, and deleting databases, tables, fields, and rows, running in SQL queries.
Arduino IDE	A user-friendly software platform designed for programming and uploading code to Arduino microcontroller boards
Visual Studio Code	A code editor developed by Microsoft, designed to provide developers with a highly customizable and efficient environment for writing code across various programming languages and platforms.
Web Hosting	A web hosting service provider offering a range of hosting solutions tailored to the needs of individuals, businesses, and organizations.
SVG Editor	A software tool designed specifically for creating, editing, and manipulating Scalable Vector Graphics (SVG) files, which are XML-based vector image formats widely used for web graphics, icons, logos, illustrations, and more.

2.2 Methods

The methodology used for this project is Agile methodology. With Agile, this project will quickly incorporate feedback from educators and learners, ensuring that the system matches their changing needs and promotes productive learning experiences.

2.2.1 Requirement

This project manages to collect all the important information and requirements from the relevant parties, including teachers and Form 2 *Reka Bentuk dan Teknologi* (RBT) students.

2.2.2 Design

Design the overall system architecture including hardware and software components. Create schematic diagram details how sensors integrated to microcontrollers and design the user interface for e-Learning Management System (e-LMS),

2.2.3 Develop

The development phase was divided into two primary components which are sensor integration and IoT devices control and the other one focuses on mechanical components.

2.2.4 Test

Before the product was released or available for user used, this project conducted the phase of testing to verify that hardware and software components work together and function well.

2.2.5 Deploy

In this phase, this project ready to launch the final product, documented the user manual and provided training to end users.

2. Results and Discussion

2.1 Result

The thorough process conducted using Agile methodology has contributed to the successful development of the Mini Aquaponics System using IoT Technology for Teaching and Learning. To achieve this project objectives, three (3) major categories have been implemented in an integrated manner using the latest technology. The categories are as follows:

2.1.1 IoT Infrastructure

Fig. 3 and Fig. 4 show the physical diagram between electronics components including sensors, actuators and microcontrollers. All the sensors connected to the required pin to make sure all the input readings can be processed by the microcontrollers. The solar panel is connected to the solar converter to make sure all the electrical energy is stored to the solar battery. Fig. 5 shows the complete physical design of the project prototype.

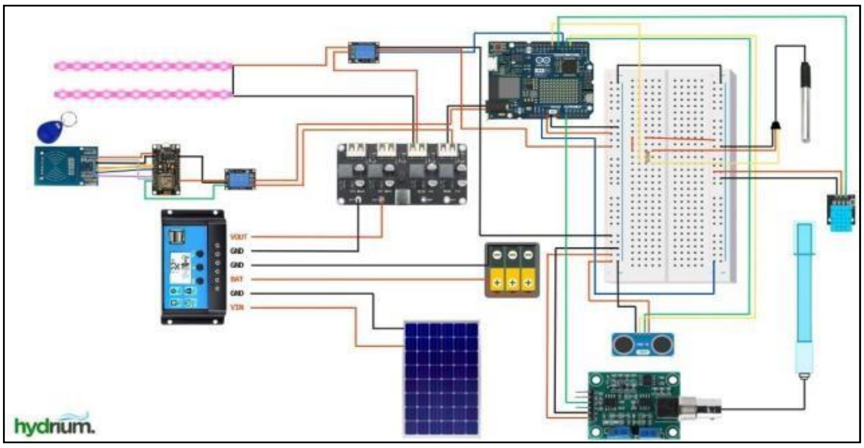

Fig. 3 *Physical Diagram using Arduino Uno R4 Microcontroller*

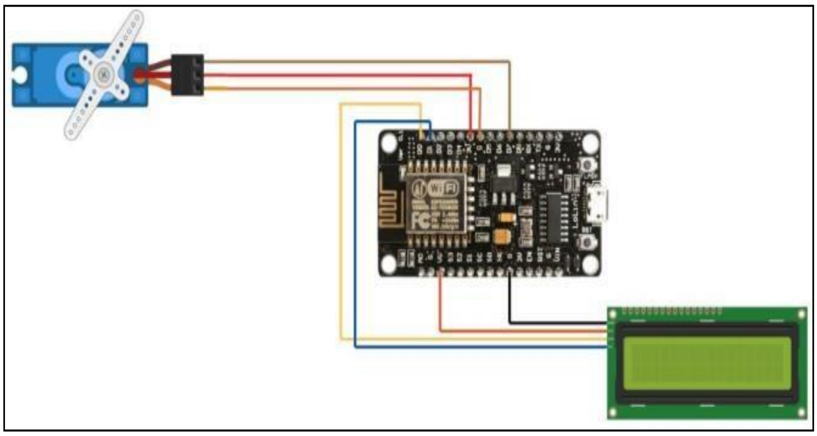

Fig. 4 *Physical Diagram using NodeMCU ESP8266 Microcontroller*

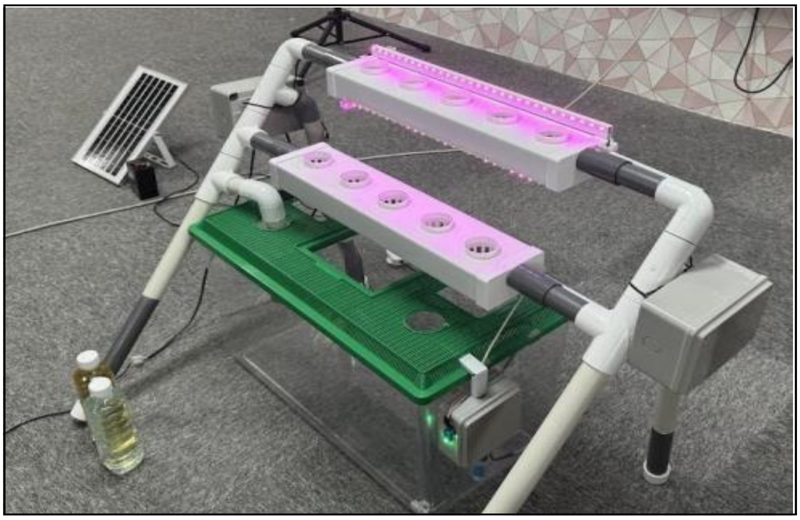

Fig. 5 *Physical Design of Project Prototype*

Fig. 6 shows Node-red monitoring dashboard. In the monitoring dashboard, the user can read the current values of environmental temperature, PH level, humidity, water level and water temperature. User provided with the indicator to show the conditions of the aquaponic system.

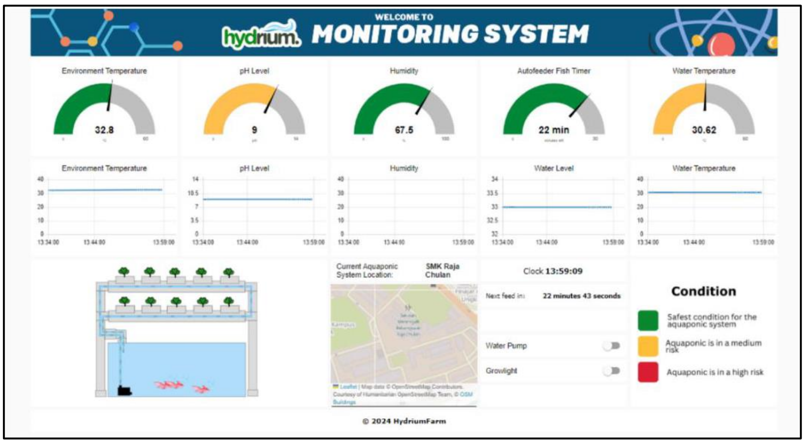

Fig. 6 *Node-red Monitoring Dashboard*

2.1.2 Web-based Application

The e-Learning Management System (e-LMS) developed using web-based application to attract students' interest and improve students' understanding of the topic of aquaponics design for RBT students in form 2. Examples of the interface contained in the e-LMS as shown in Fig. 7.

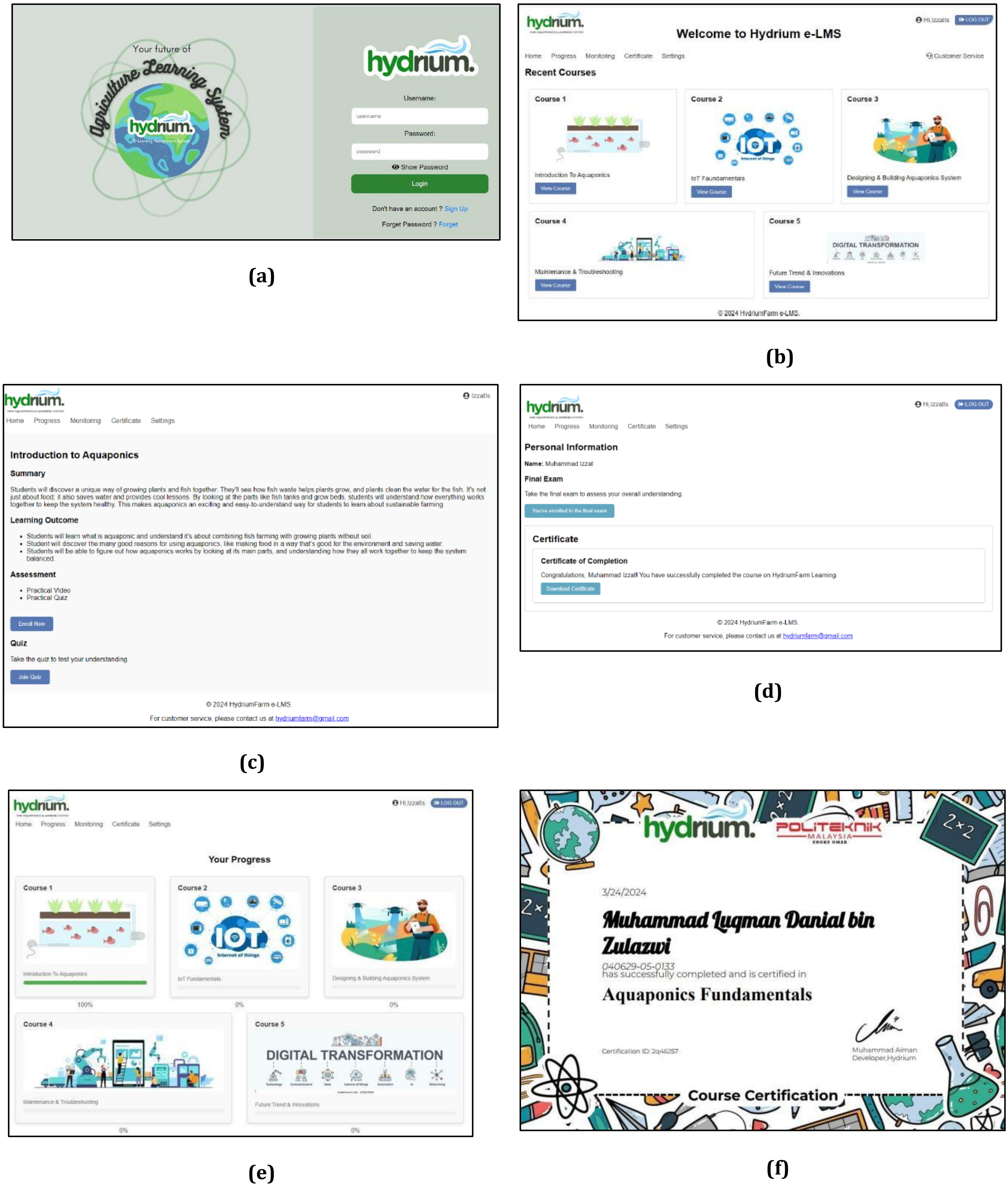

Fig. 7 *e- Learning Management System Interface (a) e-LMS Login Page (b) e-LMS Course Interface (c) e-LMS Course Enrolment (d) Interface for Final Exam to confirm Course Completion (e) e-LMS Progress Interface (f) e-Certificate*

2.1.3 Datasheet System and Weekly Report

The datasheet system generated from the raw database in googles sheets. The raw database summarized data every week to get the average values of environment temperature, water temperature, humidity, water pH and water level. Fig. 8 shows datasheet report system.

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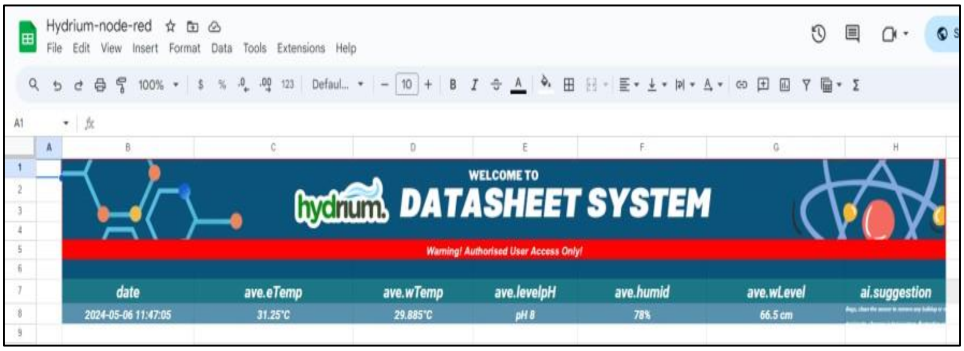

(a)

water_temp	temp	water_level	ph	humid
29.94	31.8	34	9	81
30	31.7	34	9	77.6
29.94	31.7	33	9	77.9
30.06	31.7	34	9	77.6
30	31.7	34	9	77.6
30	31.7	33	9	77.6
30.06	31.7	34	9	77.6
30	31.7	34	9	77.6
30	31.7	34	9	77.6
30	31.7	34	9	77.6
30	31.7	34	9	77.6
30	31.7	34	9	77.3
29.94	31.6	34	9	81.1
30	31.6	34	9	80.8
30	31.6	34	9	79.8
29.94	31.6	33	9	79.8
29.94	31.6	34	9	79.4
29.94	31.6	34	9	79.8
29.94	31.6	34	9	79.8
29.94	31.6	34	9	80.4
29.94	31.6	34	9	81.1
30	31.6	34	9	80.4
29.56	31.7	33	8	65.1
29.69	31.8	33	8	66.2

(b)

Fig. 8: Datasheet Report System (a) *Average reading weekly (b) Data reading every 60 seconds*

After generating the report in the datasheet system, this project is also able to produce a Weekly Report that can be downloaded in pdf file and its summary content is easy to read and understand by the end user. The other advantages and capabilities in this project are also where the weekly report can give suggestion of prevention and maintenance recommendations that use Artificial Intelligence (AI) technology. The Weekly Report shows in Fig. 9.

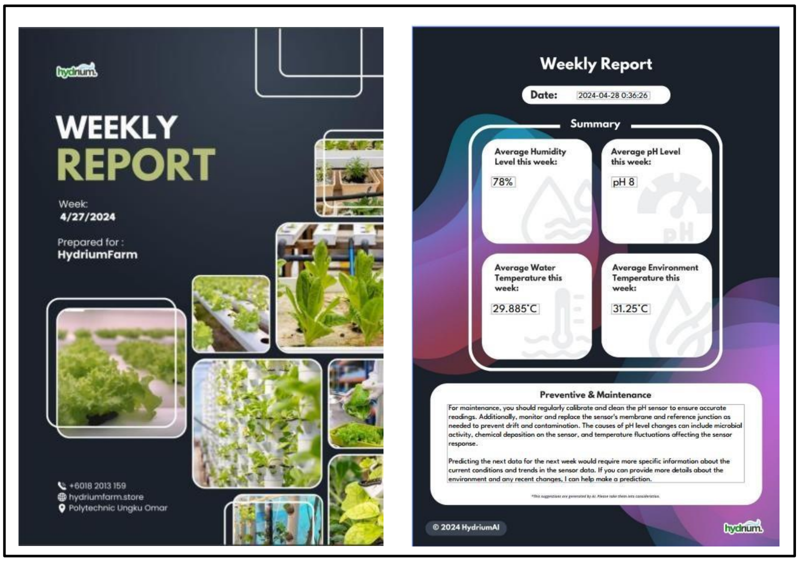

Fig. 9: *Weekly Report*

3. Conclusion

The integration of an IoT-enabled Aquaponics System and e-Learning Management System in secondary school education offers an innovative learning approach. This project successfully combines practical and hands-on experience with advanced digital educational tools to create a dynamic and engaging learning environment. Students get hands-on experience in sustainable agriculture, learning about the symbiotic relationships between fish and plants. The use of IoT technology enhances this experience by providing real-time data on water quality, temperature, and pH level, allowing students to effectively monitor and manage the system. This IoT integration fosters a deeper understanding of both scientific concepts and modern technological applications.

Combining IoT Technology and e-LMS Systems encourages multidisciplinary learning, critical thinking, and problem-solving skills. Students not only understand theoretical concepts but are also able to apply them in real-world scenarios. Be able to prepare them for future challenges in sustainability, technology and beyond. Overall, this project emphasizes the importance of innovative educational strategies in creating an interesting and effective learning environment. By integrating IoT technology into Aquaponics System and the use of the e-Learning Management System for students, especially for the Form 2 RBT syllabus, able to gain knowledge, skills and experience for the future.

Acknowledgement

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