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DESIGN AND DEVELOPMENT OF AN AUTOMATIC AND MAINTENANCE-FREE EBB AND FLOW HYDROPONICS SYSTEM

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Abstract: This study designed an automatic and maintenance-free Ebb and Flow Hydroponics System. It also assessed the quality of the developed hydroponics system using ISO 25010 Software Product Quality Standards. Five (5) IT experts were utilized to determine the quality of the developed Ebb and Flow Hydroponics System, whereas they assessed the device in terms of functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability. Similarly, twenty (20) end-users specifically fifteen (15) agriculture students and five (5) agriculture teachers, assessed the were functional suitability, usability, and portability of the device. The study made use of Robotic Process Automation (RPA) which is the method that highlights construction, development, and improvement of the product. RPA also have an emphasis on discovery, analysis, design, implementation, and support. The researcher therefore recommended to schools with limited land area to use Automatic and Maintenance-Free Ebb and Flow Hydroponics System to expose their students in planting crops.

Keywords: hydroponic system, maintenance-free Ebb, ISO 25010, Robotics Process Automation

I. INTRODUCTION

Agriculture plays an important role in any county's economy. The Philippines is an agricultural country where most citizens still live-in rural areas and support themselves through agriculture. However, the government has recognized the declining contribution of the agricultural sector in the country's GDP, and this drop in its performance is attributed to its vulnerability towards extreme weather events such as drought and typhoons, infestations, and poor adoption of high-yielding varieties at the end of the farmers (Guzman, 2018). For the Department of Agriculture (DA), the stigma of farming being a poor man's job does not make it easier to fulfil its mandate of reaching food security or attracting more people to join the sector.

Agriculture in the Philippines has always been associated with manual labor and backward traditional farming methods where plants are directly planted to the soils. This is called traditional soil farming. Traditional soil farming, typically plants get most of their water from their roots, where waterfalls above ground and water consumption is much higher. In fact, when packing density is concern, plants grow large root structure to access water and due to these large root structures, soil-based farmers need to plant crops far from each other. When it comes to grow time of plants, soil farming crops rely on natural rainfall or consistent watering, manually added fertilizer and constant competition happen for these limited and fluctuating resources like nutrients, water and oxygen that are essentially needed for the plants to grow healthy.

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This is where hydroponics comes in. Hydroponics, by definition, is a method of growing plants in water based nutrient rich solution. Hydroponics does not use soil. The basic premise behind hydroponics is to allow the plants roots to come in direct contact with the nutrient solution, while also having access to oxygen, which is essential for proper growth (Griffiths, 2014).

The significance of hydroponics is in providing a way for the average person to grow their own food without the need of soil. This is beneficial most particularly to people who do not have much space for planting crops, like for example, for people living in flats and inner-city areas.
The researcher who is also as an educator teaching Tech Voc and IT in Talavera Senior High School has found teaching agriculture in a school without farmland a very big challenge. It was then that he realized the beauty of hydroponics. He put up one in an open space in the school and the students were able to practice growing crops for their agriculture subjects. It was in the process that he realized the need to have controlled water and nutrient supply. With this realization coupled with his knowledge in information technology, he ventured in this research, hoping not just to address the need for a well-managed water and nutrients distribution in the farm, but likewise to make the young learners realize that with modern technology, agriculture does not have to be difficult and backward.

Statement of the Problem

This study sought to develop an automatic and maintenance free ebb and flow hydroponic system. It also assessed the quality of the developed system using ISO 25010 software product quality standards.

Specifically, this study aims to answer the following questions:

1. How may the system be developed in terms of:
   - 1.1 gathering data;
   - 1.2 analysis of the data;
   - 1.3 design;
     - 1.3.1 hardware
     - 1.3.2 software
   - 1.4 execution; and
   - 1.5 improvisation?

II. METHODOLOGY

Research Design

This research used developmental research design as it aimed to develop an automatic and maintenance free Ebb and Flow hydroponic system. As defined by Richey (1994), developmental research, as opposed to simple instructional development, is the systematic study of designing, developing, and evaluating instructional programs, processes, and products that must meet criteria of internal consistency and effectiveness. Developmental research is particularly important in the field of instructional technology. The most common type of developmental research involves situations in which the product-development process is analyzed and described, and the final product is evaluated.

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Locale of the Study

The study was conducted at Talavera Senior High School where the researcher is currently teaching. The said school which is located in Pag-asa District, Talavera, Nueva Ecija was founded in 2016 through the implementation of the K-12 Basic Education Curriculum which was a landmark legislation of the former President Benigno Aquino III. Now it has 46 teachers and is a home for more than 1300 students from Grade 11 to Grade 12.

One of the tracks in Talavera Senior High School is the Technical-Vocational (Tech-Voc), which consists of different strands such as Agriculture, Information and Communications Technology (ICT), Cookery, and Shielded Metal Arc Welding (SMAW). Since the Talavera Senior High School has only two (2) buildings built on a limited space within the space for the Junior High School in Talavera National High School, it has no space for the students' taking strands in agriculture to practice actual plant growing. Thus, the researcher who is a teacher under Tech-Voc track and an IT teacher at the same time pursued the conduct of this research to enable Talavera Senior High School agriculture students and teachers to practice their specialization even with the limited space and resources they have.

Figure 2. Picture of Talavera Senior High School, Talavera, Nueva Ecija

Respondents of the Study

This study utilized 25 respondents in order to evaluate the developed hydroponic system in terms of functionality, usability, efficiency, reliability, portability, and maintainability. Five (5) of these respondents were IT experts, while 20 of them were the end-users consisting of 15 agriculture students, and five (5) agriculture teachers. The evaluation of these respondents served as basis in ensuring that the developed hydroponic system possesses the qualities prescribed by the ISO 25010 Software product quality standards.

Sample and Sampling Procedure

In order for the researcher to select the respondents utilized in this study, the researcher used expert sampling which is a type of purposive sampling. Expert sampling is where samples are drawn from experts in the field being studied. It is used when one needs the opinions or

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assessment of people with high degree of knowledge in a particular area such as information technology

On the other hand, the twenty end-users namely: fifteen (15) agriculture students, and five (5) agriculture teachers were also chosen purposively on the basis of their being the direct users of the system.

Research Instrument

In order for the developed automatic and maintenance free ebb and flow hydroponic system to be assessed, the researcher used ISO/IEC 25010. The ISO/IEC 25010 standard was developed in 2011 to replace the ISO/IEC 9126 standard. The ISO/IEC 25010 is composed of two parts: the quality in use model and the product quality model. The quality in use model composed of five characteristics that relate to the outcome of interaction when a product is used in a particular context of use. This system model is applicable to the complete human-computer system, including both computer systems in use and software products in use. Conversely, a product quality model composed of eight characteristics that relate to static properties of software and dynamic properties of the computer system. The model is applicable to both computer systems and software products. In general, the developed system in this study was assessed using the ISO/IEC 25010 product quality model as shown below.

Figure 3. ISO25010Software Product Quality Standards

A different set of research questionnaire was given to IT experts and end-users. IT experts were given a complete set of ISO 25010 Software Product Quality Standards specifically: functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability. However, end-users were only given a questionnaire which includes only the three main characteristics provided by ISO 25010 Software Product Quality Standards namely: functional suitability, usability, and portability. This was due to the technicality of other ISO 25010 Software Product Quality Standards. Other characteristics such as performance efficiency, compatibility, reliability, security, and maintainability could only be correctly assessed by IT experts.

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Data Gathering Procedure

There were two stages in this study, the development stage and the assessment stage, and the researcher gathered the data needed for each stage.

Data for the development stage were obtained through interview with expert agriculturists from the Central Luzon State University who were using hydroponics system. The researcher also made online research on how to develop automatic and maintenance free Ebb and Flow hydroponics system that can be controlled by android phones. The development phase took place only after the researcher had been equipped with all the necessary information he needed. Development began with the sequence planning, followed by the analysis of the system in order to understand its nature and to determine its essential features. Next was the construction of the system and program design, coding of the software program, testing and implementing the output and lastly, the maintenance requirements and considerations of the system.

After the development phase, the automatic and maintenance free Ebb and Flow hydroponic system was sent to IT experts for assessment in terms of the following ISO 25010 Software Product Quality Standards: functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, portability. On the other hand, the acceptability of the system was determined by the end-users based on the functional suitability, usability, and portability standards of ISO 25010.

Data Analysis Technique

Data for the development stage of the Automatic and Maintenance-free Ebb and Flow Hydroponics System was analyzed critically and presented textually as there were no statistical data involved in the process.

On the other hand, the data gathered in the evaluation of the end-users regarding the technical quality of the developed hydroponic system were analyzed statistically using weighted mean.

Moreover, data during the assessment stage pertaining to the expert evaluation were calculated using weighted scores and weighted mean of the responses and analyzed with regards to the different software criteria based on ISO 25010 Software Product Quality Standards.

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III. RESULTS AND DISCUSSIONS

1. Development of the Automatic and Maintenance-Free Ebb and Flow Hydroponic System

The automatic and maintenance-free Ebb and Flow Hydroponic System adopted the Robotic Process Automation (RPA) method which involves five stages specifically: Gather, Analyze, Design, Execute and Improvise.

1.1 Gathering Data

For this stage, the data from different design of automatic and maintenance-free Ebb and Flow hydroponic system were gathered and analyzed. Uncommon information regarding automatic and maintenance-free Ebb and Flow hydroponic system in the local hardware stores in the Philippines obliged the researcher to use the internet search approach. He then visited websites which focused on the development of different hydroponic system and came across the study conducted by Sihombing, Karina, Tarigan and Syarif (2018) where an automatic and maintenance-free system was developed. The researcher used the same study as his guide in the development of the system.

Aside from internet search, the researcher also watched different videos from youtube.com in order to follow the different steps on developing the Ebb and Flow hydroponic system. Youtube.com also provided the researcher not only with the idea on how to develop an automatic and maintenance-free hydroponic system but also with significant inputs from viewers comments and suggestions for improvement which contributed so much to his conceptualizations of his own work.

Brochures, catalogs and presentations provided on the internet were also gathered and analyzed by the researcher.

1.2 Analysis of data

Information gathered about automatic and maintenance-free Ebb and Flow hydroponics system were organized and collected in order to assess the functions, strengths and limitations of the existing designs. This allowed the researcher to create a new design that would best suit in the locale of the study.

As assessed by the researcher, most of the existing automatic and maintenance-free hydroponics system was built for wider scale system. There were also no locally written articles or studies about development of maintenance-free hydroponics system. Thus, in order for the researcher to help schools, specifically Talavera Senior High School where he was teaching, he decided to setup a low-cost automatic and maintenance-free system which would allow schools to reproduce the system without spending too much.

After the researcher interviewed some experts in using and developing hydroponics, he immediately thought about the kind of hydroponics system to develop and settled for the kind that would benefit the students and teachers of Talavera Senior High School - an automatic and maintenance-free Ebb and Flow hydroponics system they can use in the practical teaching and learning of agriculture in a limited space with soil quality that is not conducive for farming.

1.3 Designing of the Ebb and Flow hydroponic system

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Soon after he decided on the hydroponics system to develop, the researcher prepared the materials that he needed to construct the device. The following were the components used by the researcher to develop the Ebb and Flow hydroponics system: first was the arduino mega which gives instruction to the components connected to it; next was the relay, where the sensors are connected;, 20 centimeter female to female DuPont wires, and 20 centimeters male to female wires; DHT sensor to monitor the temperature and humidity of the bed; pH sensor for the very important role of determining the correct pH level of the water; solenoid valve that controls the flow of water; float switch sensor which will tell if the device still has the right amount of water on its tank and if the bed is already filled with water; diaphragm pump which is in charge of the pumping and siphoning of the water and nutrient needed by the crops; 12v fan which is needed for the maintenance of the temperature set on the device; Bluetooth device to connect the mobile application in the arduino; SD card; and SD card module for data logging and buck converter source of DC to DC.

Upon careful considerations of all the requirements for the design and development of the system, development ensued until the design was fully implemented and transformed into a prototype. The prototype was further analyzed, and the researcher concluded that the hydroponics system must be monitored on a daily basis to avoid the danger of committing even simple failures like a pump failure as such can kill off the plants within hours.

1.3.1 Hardware

The following are the different parts of the hardware used to develop the automatic and maintenance-free Ebb and Flow hydroponics system.

Figure 4: 12v fan

This 12v fan is used to dissipate the heat coming from the environment of the hydroponics system.

Figure 5: Buzzer

Buzzer is used to alert the user that the device has low water level and also helps the user to know the settings is activated

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Figure 6: Micro SD

Micro SD was used for data logging. This is where the data is saved.

Figure 7: 300 watts Buck converter dc to dc

Is an electronic circuit or electromechanical device that converts a source of direct current (DC) from

Figure 8: Floatswitch

A *float switch* is a type of level sensor, a device used to detect the level of water within a tank and bed of hydroponic system.

Figure 9: LCD

LCD is used to display the actual reading of temperature humidity of the environment and pH level of water. It also gives information to the user what is happening to his/her hydroponics.

Figure 10: SD Card module

Micro *SD Card Module* used for data storing or data logging application, includes an on-board voltage level conversion for easy interface with 3V or 5V devices.

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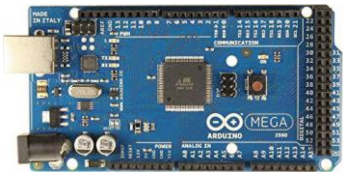

Figure 11: Arduino Mega 2560

Arduino Mega 2560 is a microcontroller that sends instruction to the devices connected to it.

Figure 12: Bluetooth module

Bluetooth module design for wireless connection is used to connect mobile app to send commands to arduino device.

Figure 13: Solenoid

Solenoid valve is an electromechanical device in which the solenoid uses an electric current to generate a magnetic field and thereby operate a mechanism which regulates the opening of fluid flow in a valve.

Figure 14: Jumper wires

Jumper wires are used to connect the entire device within the system

Figure 15: Temperature sensor

Temperature sensor is used to collect temperature and humidity coming from the environment of hydroponics systems and monitor it.

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Figure 16: pH meter

A *pH meter* is a scientific instrument that measures the hydrogen-ion activity in water-based solutions, indicating its acidity or alkalinity expressed as pH.

Figure 17: Diaphragm pump

Diaphragm pump 12v was used to flood and drain water as well as pump nutrients in the hydroponics system.

Figure 18: Relay

Relays are switches that open and close circuits electromechanically or electronically. Relays control one electrical circuit by opening and closing contacts in another circuit.

The researcher tested all the material components he classified as needed before he started to develop the system. Afterwards, these material components were connected in order to activate the developed system. The following figures are the electronic layout of the developed automatic and maintenance-free Ebb and Flow Hydroponics System.

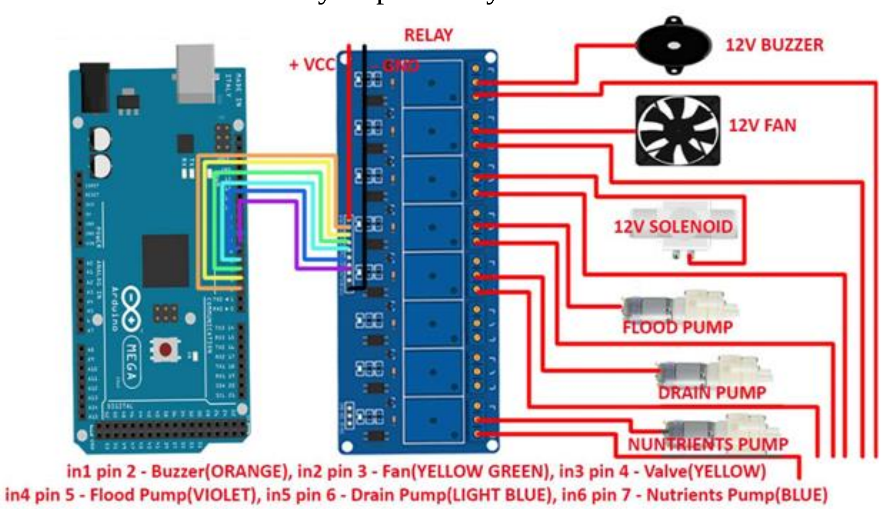

Figure 19. Arduino Mega to Relay

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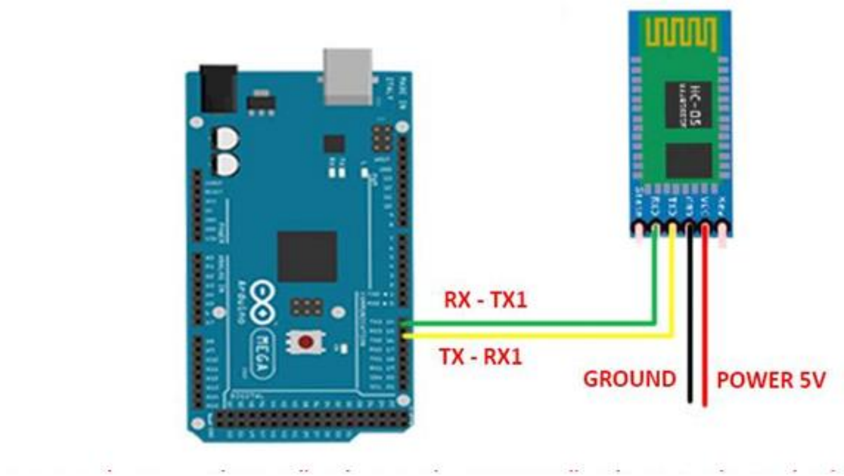

Figure 20. Arduino Mega to Bluetooth Module HC-05

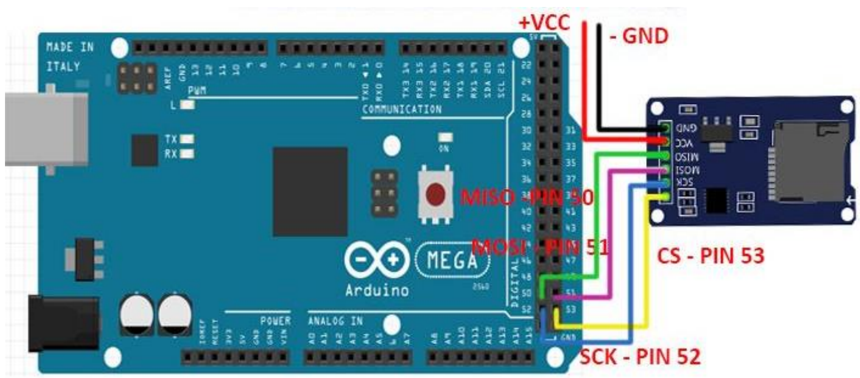

Figure 21. Arduino Mega to SD Card Module

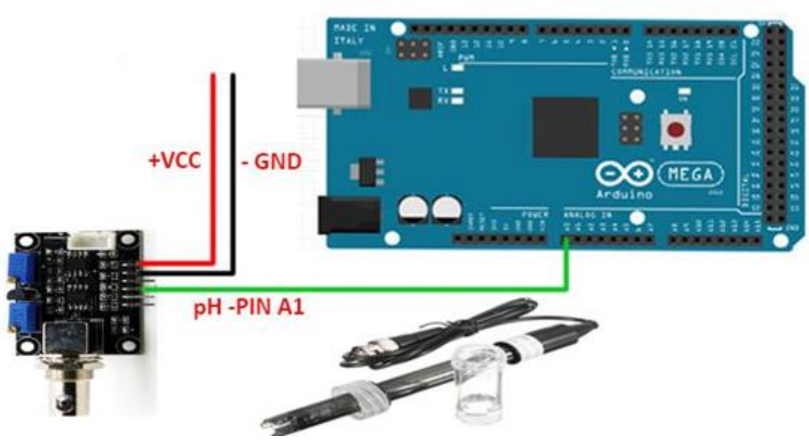

Figure 22. Arduino Mega to pH Sensor

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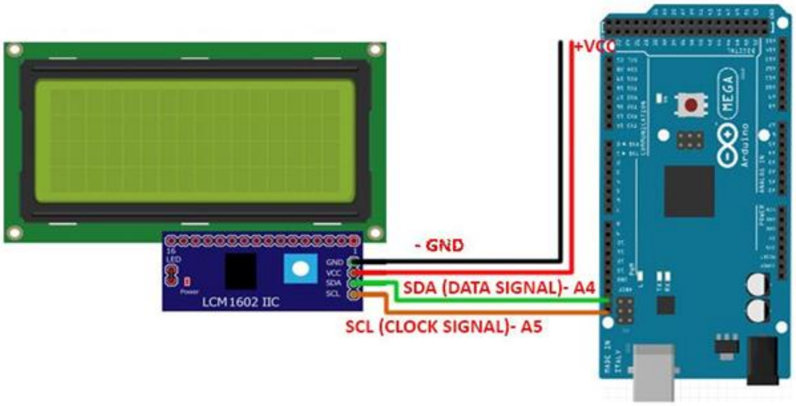

Figure 23. Arduino Mega to 20x4 LCD

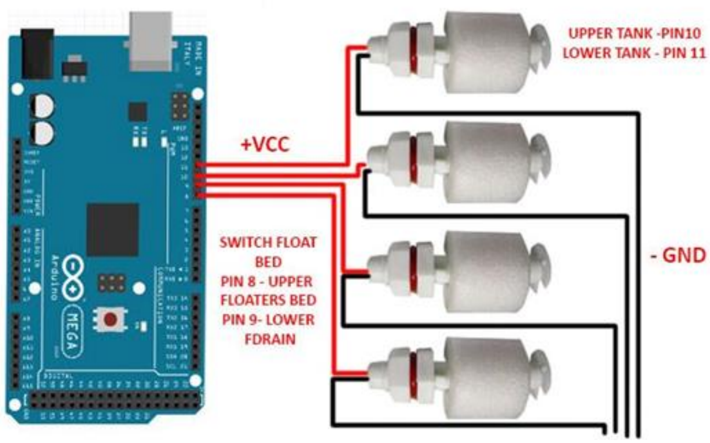

Figure 24. Arduino Megato Float switch

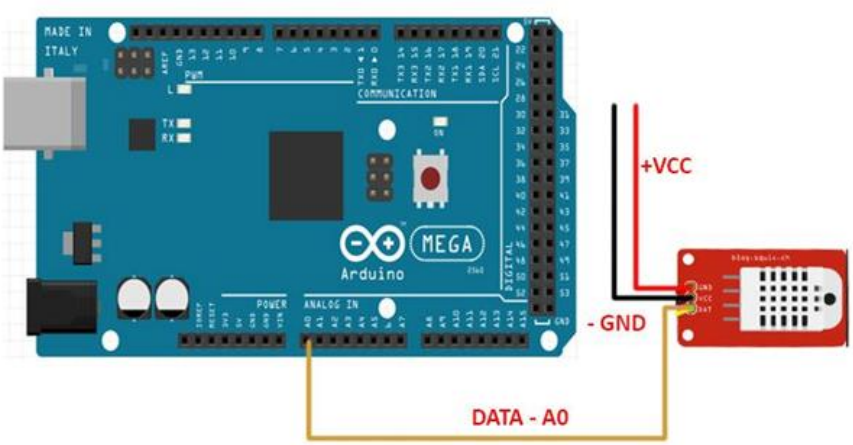

Figure 25. Arduino Mega to Temperature & Humidity (DHT)

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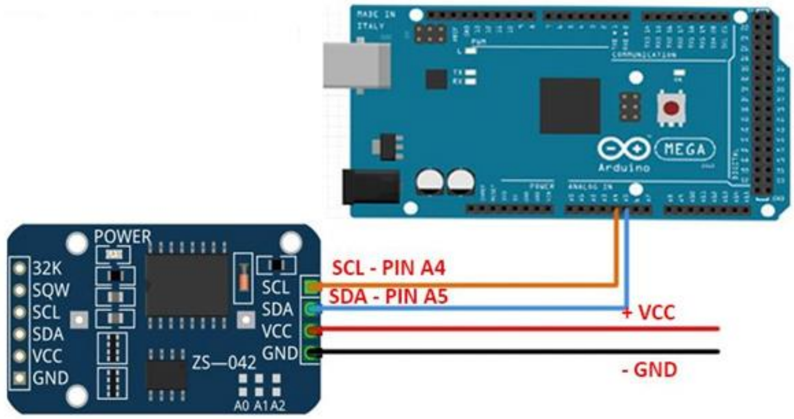

Figure 26. Arduino Mega to Real Time Clock

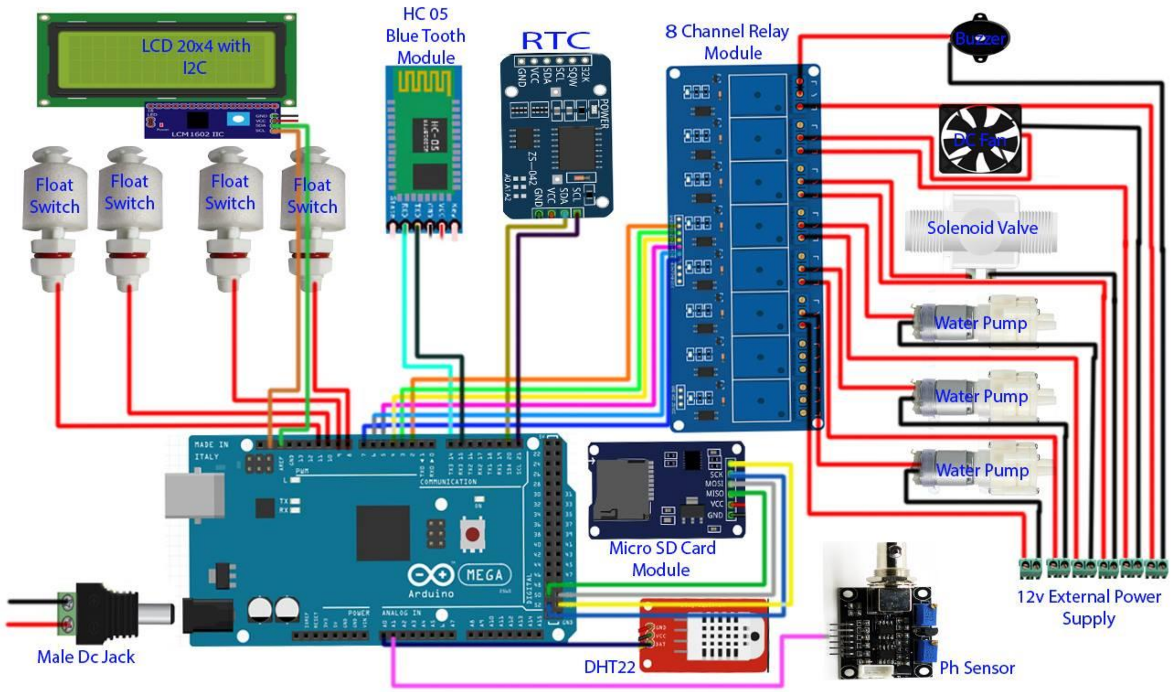

Figure 27. Internal Components Diagram

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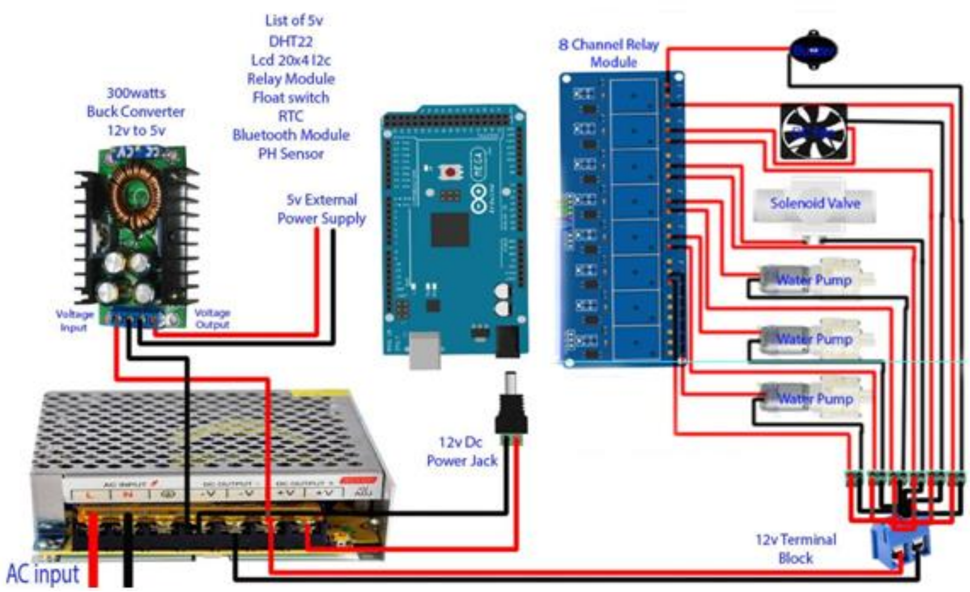

Figure 28. External Power Supply Diagram

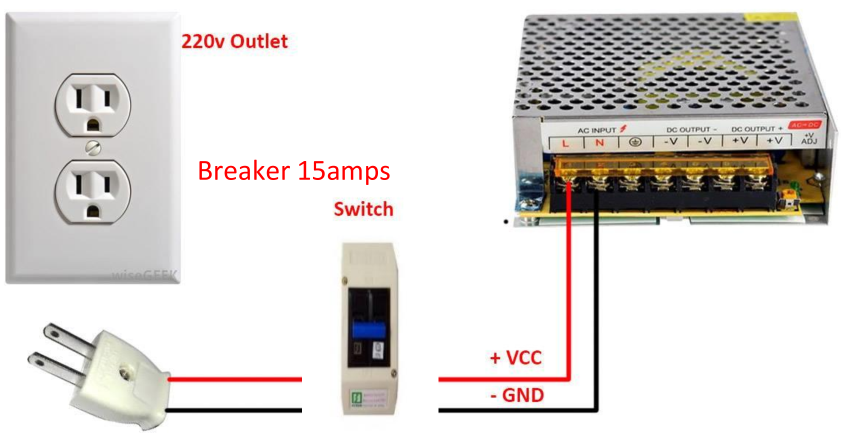

Figure 29. 10 amps Power Supply with 15 amps breaker connected to 220v outlet

Once the materials were tested working, the researcher assembled and connected all the components one by one. Shown on the next pages was an illustration on how each component was connected in order to develop the automatic and maintenance-free Ebb and Flow hydroponics system.

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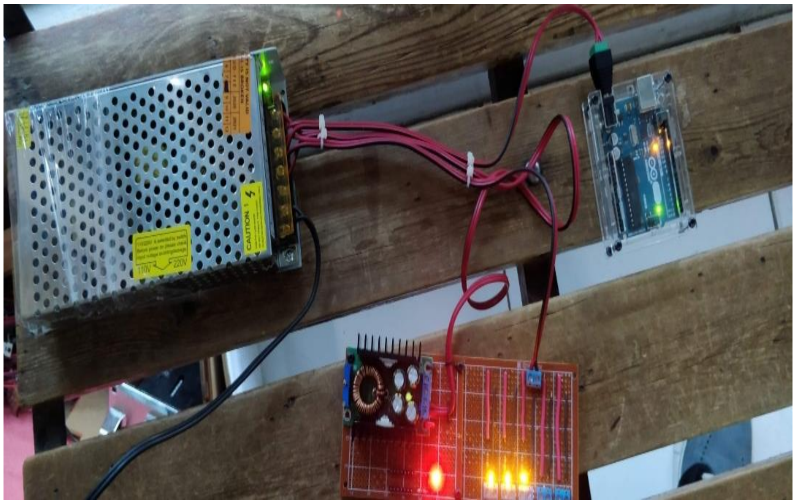

Figure 30. Testing of new power supply with buck converter

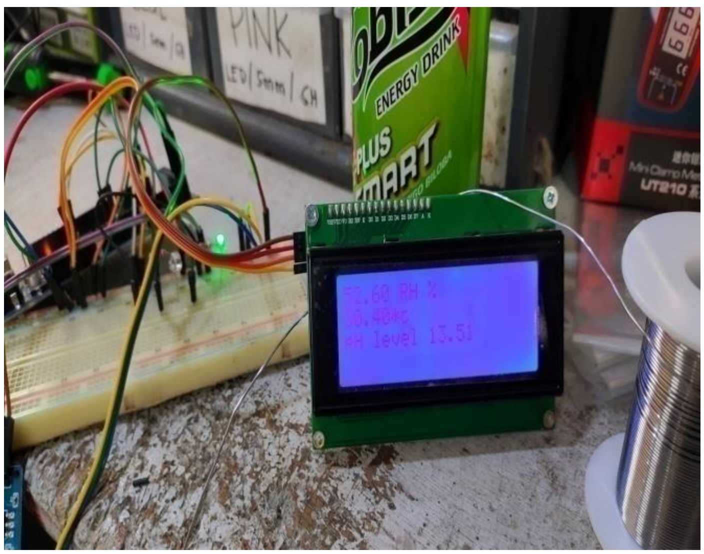

Figure 31. Testing of DHT, pH sensor and LCD

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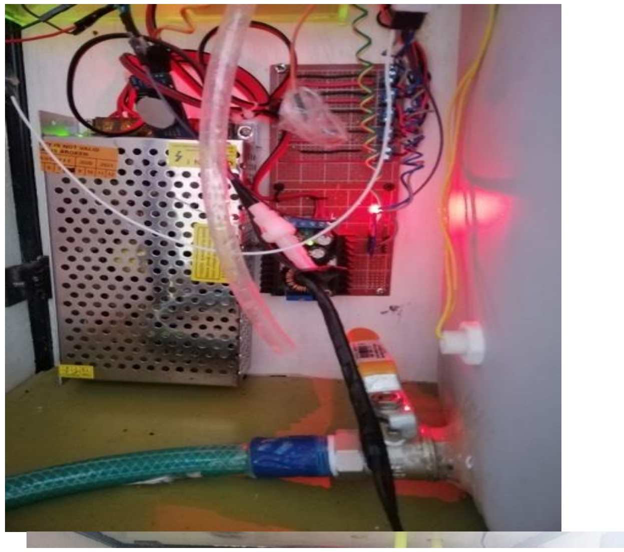

Figure 32. Installing the new power supply and testing with other components

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Figure 34. Diaphragm pump and solenoid

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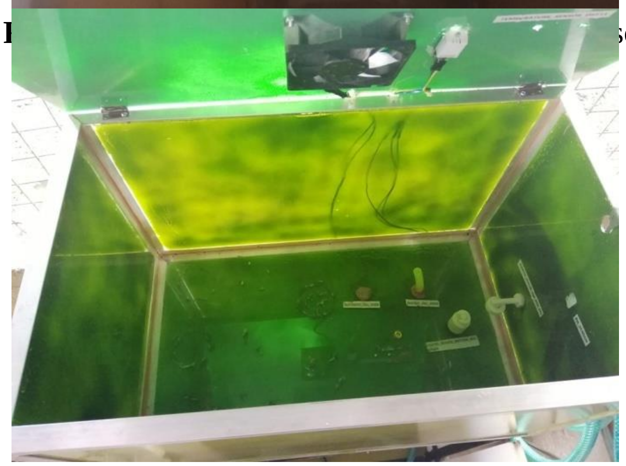

Figure 36. Insi ith 12v fan, DHT

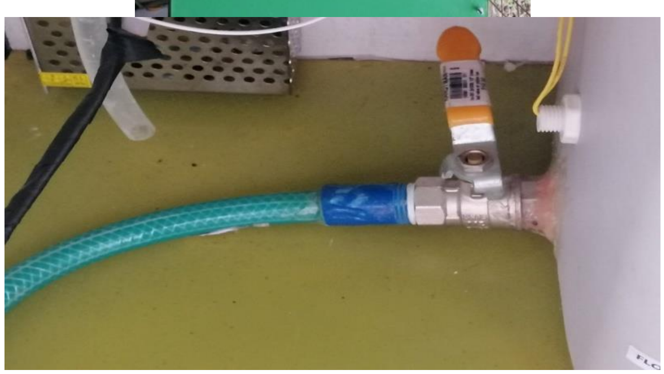

Figure 38. Drain plug of water tank

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Figure 39. Overall view of working Ebb and Flow Hydroponics System

When the Ebb and Flow hydroponics system is opened, it would only display the current status acquired by the temperature and pH sensor through the LCD. However, the mobile application is needed in order to run the device. Using mobile application, the user needs to connect to Bluetooth to send command and data from arduino. Once the user connects the device, he will choose the setting that he wants for his crop.

Once the sensor detected that the tank does not have enough water, the buzzer will buzz and the solenoid water inlet will automatically fill the tank. The buzzer will not stop until the water reached the minimum water level. On the other hand, the solenoid will only stop once the tank has reached its maximum level. Afterwards, the pump will automatically eject nutrients in the tank for 5 seconds. Once this is done, the arduino will pump water in the bed where the crops are planted. This is to ensure that the nutrients is already scattered in the tank before flooding the bed. Once the bed already reached its desired water level, the water pump will automatically stop. The water will stay on the bed according to the time set on the device. Once the time set up by the user is done, the drain pump will automatically start. This function will be repeated until the user shall have set up another setting on the device. The sensor would check the water pH level every 8 in the evening. If the pH of water is below the point set in the mobile app the system will automatically pump nutrients in the tank. This is used due to the unstable pH reading in the morning.

Figure 40 below shows how mobile application and the developed device interact with one another. It has two levels. It gives the user an insight on how mobile application and developed device integrates with one another. It only has one administrator/user.

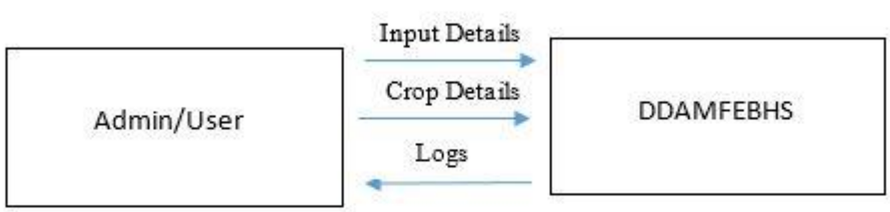

Figure 40. Context diagram

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DFD level 0 shows in figure 41, the overall functions of the systems using mobile app integrated in hydroponic system.

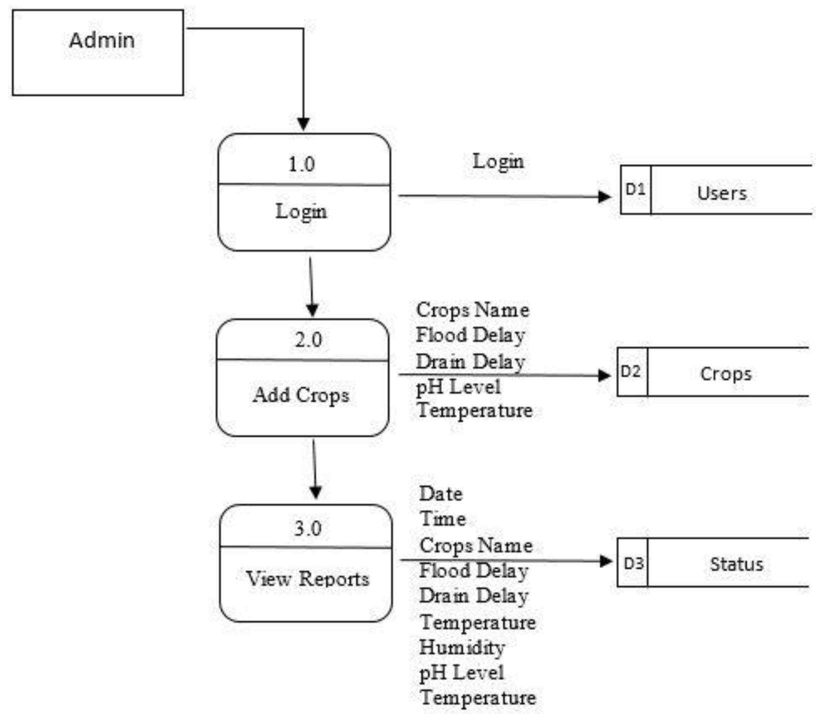

Figure 41. DFD Level 0

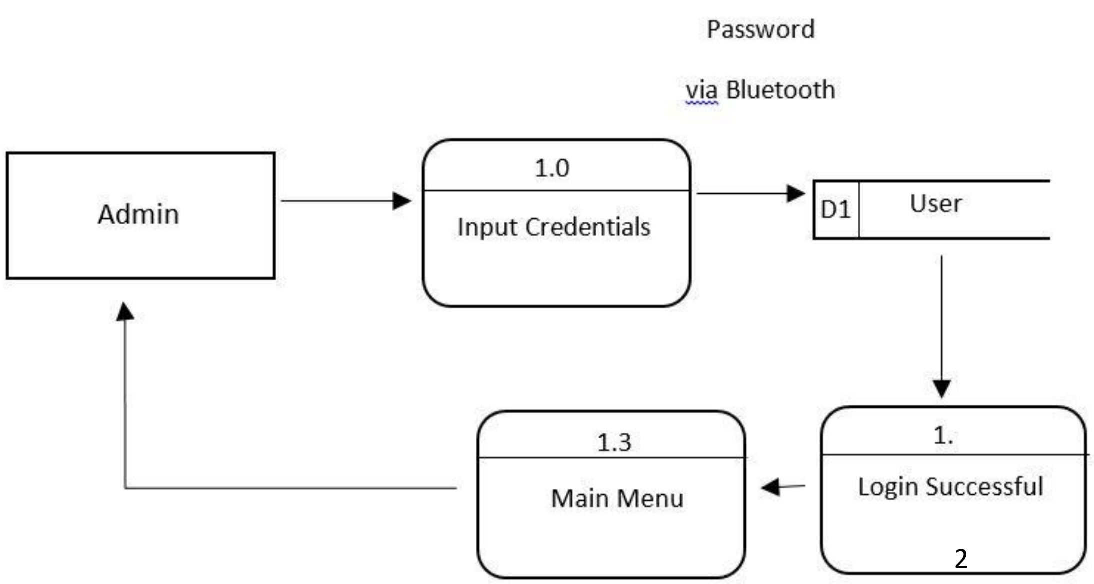

Figure 42. DFD Level 1 of user.

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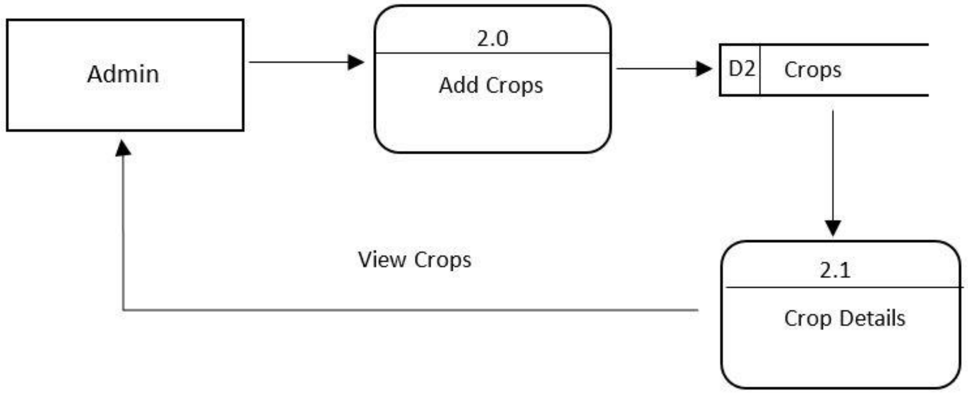

Figure 43. DFD Level 1, adding crops.

Figure 44 shows the DFD Level 1 of report logs of the developed system.

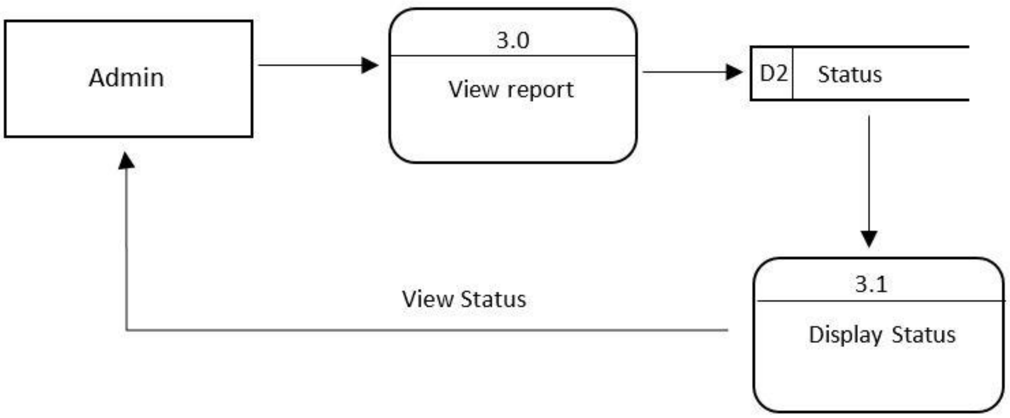

Figure 44. DFD Level 1 of report logs.

Table 4 shows the Database Normalization. This was used to avoid redundancy in the database and to ensure that all data were stored accordingly. The first normal form contains attributes which have repeating values for every single entry. It should only have one attribute.

Table 4.
Database Normalization

Unnormalized Form	1st Normal Form	2nd Normal Form	3rd Normal
Crops_name	Cropsname	Crops_id	Crops_id (PK)
Flooddelay	Flooddelay	Flooddelay	Flooddelay
Draindelay	Draindelay	Draindelay	Draindelay
Temperature	Temperture	Temperature	Temperature

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pHLevel	pHLevel	pHlevel	pHlevel
Date			
Time	Date	Report_id	Report_id (PK)
Humidity	Time	Date	Date
	Humidity	Time	Time
		Humidity	Humidity
			Crops_id (FK)

Figure 45 shows the relationship between entities in the database structure.

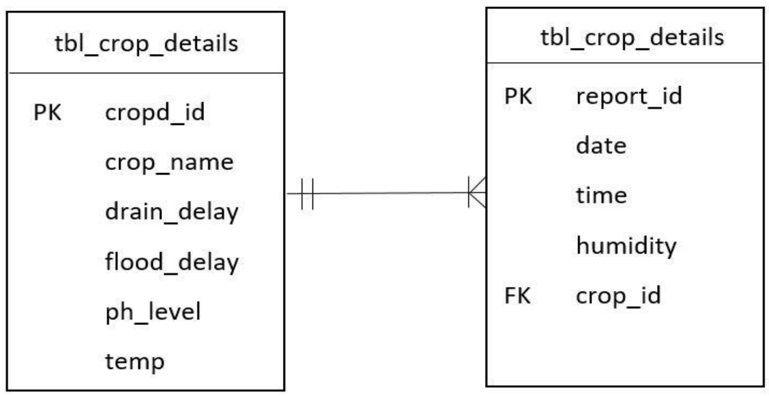

Figure 45. Entity Relationship Diagram

Table 5 and 6 shows the Data Dictionary. This is a file that contains the database's metadata. It also contains records about other objects in the database. It is a crucial and an important component of any relational database.

Table 5.
Data Dictionary for crop details

FIELD NAME Tbl_status	TYPE(SIZE)	FIELD DESCRIPTION
Cropid (PK)	int(2)	Unique crop id
Cropname	varchar(30)	Refers to crops name
Flooddelay	int(3)	Stores flood delay time
Draindelay	int(3)	Stores drain delay time
Phlevel	int(3)	Store the level of acidity of water
Temp	int(3)	Stores the temperature of the environment

Table 6.
Data dictionary for status

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Figure 46 shows the admin/user's capability in performing everything in the app without

FIELD NAME Tbl_status	TYPE(SIZE)	FIELD DESCRIPTION
Reported (PK)	int(3)	Unique report id
Cropid (FK)	int(3)	Refers to crop id
date	Datetime	Refers to date of updates
Time	Datetime	Refers to time of update
Humidity	Float(5)	Refers to the relative humidity of the bed

restrictions. It can connect, add crops, updates the status of the device and disconnect from the connections

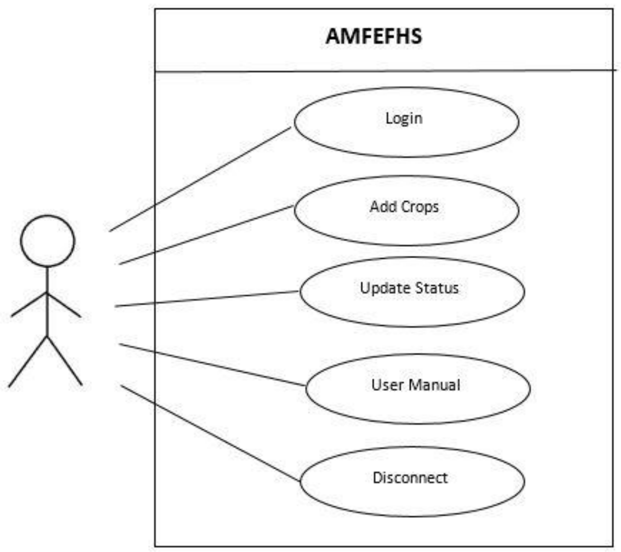

Figure 46. Use Case Diagram

1.1.1 Software

To control the Automatic and Maintenance-free Ebb and Flow hydroponics system, three software models were used namely: Arduino integrated development environment (IDE), TinyDB, and MIT App Inventor.

The Arduino integrated development environment (IDE) was used in the development of the device software. Arduino IDE is a cross-platform application for Windows, macOS, and Linux, that is written in the programming language Java. It is used to write and upload programs to Arduino compatible boards, but also, with the help of 3rd party cores, other vendor development boards. It is used to code the Arduino part of the system.

TinyDB was also used in the development of the device software. Tiny DB provides a simple way to store and retrieve data efficiently and to store the data in long-term storage. It is the database used in developing mobile app in MIT app inventor.

Lastly, to develop the mobile app used in Arduino MIT App Inventor was used. MIT App Inventor is a visual, blocks language for building Android Apps.

The table below shows the actual connection of the mobile application to the Bluetooth device of the Ebb and Flow hydroponics system.

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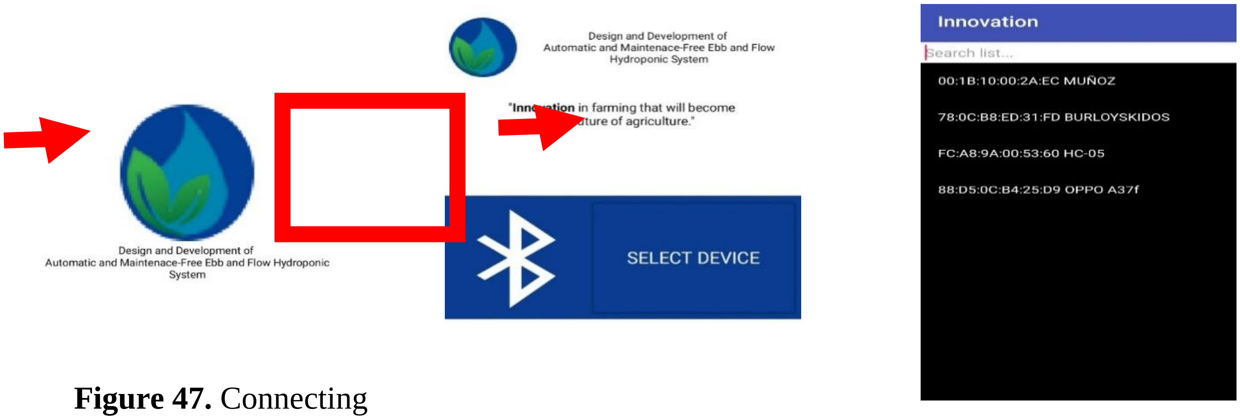
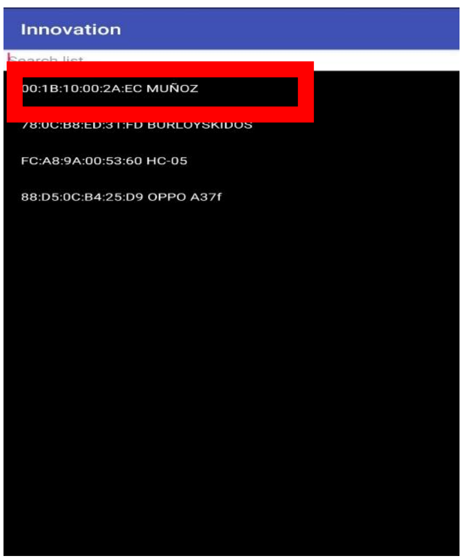


Figure 47. Connecting Mobile App to Bluetooth device



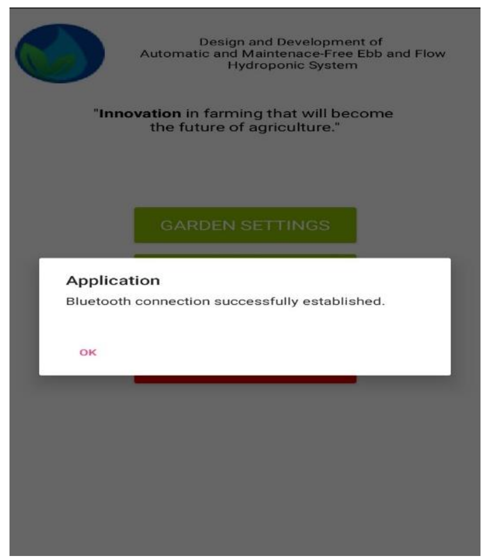


Figure 48. Bluetooth device successfully connected to arduino

Once the Bluetooth is already connected to the mobile application, the user can choose from different settings. Using the mobile application, the user can change the garden setting where the user can specifically program the flood delay, drain delay, pH level and level temperature of a specific crop planted on the hydroponics system.

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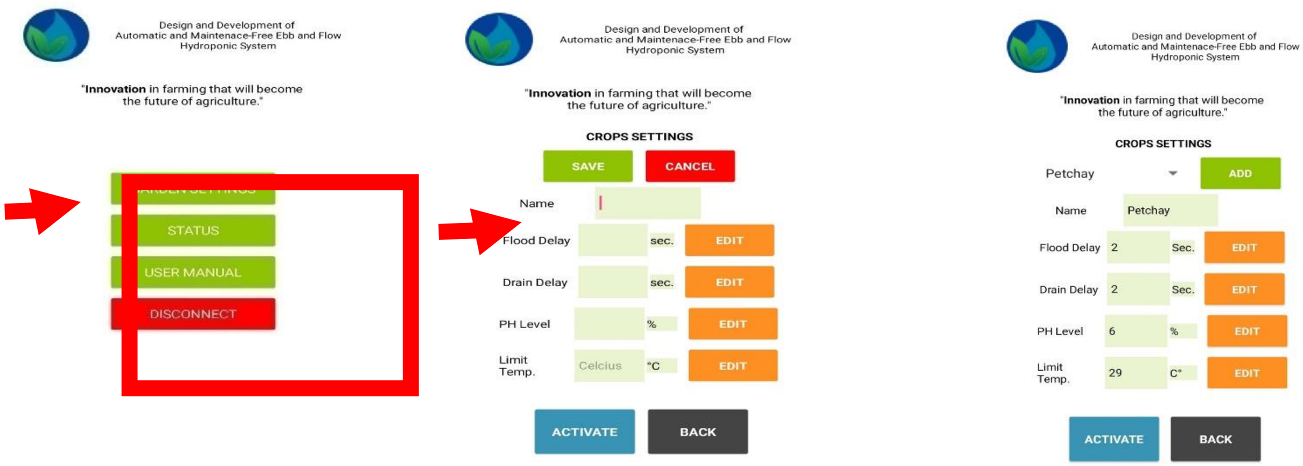

Figure 49. Adding Crops

The user can also monitor the crop's status in terms of the Ebb and Flow hydroponics system's temperature, humidity and pH level.

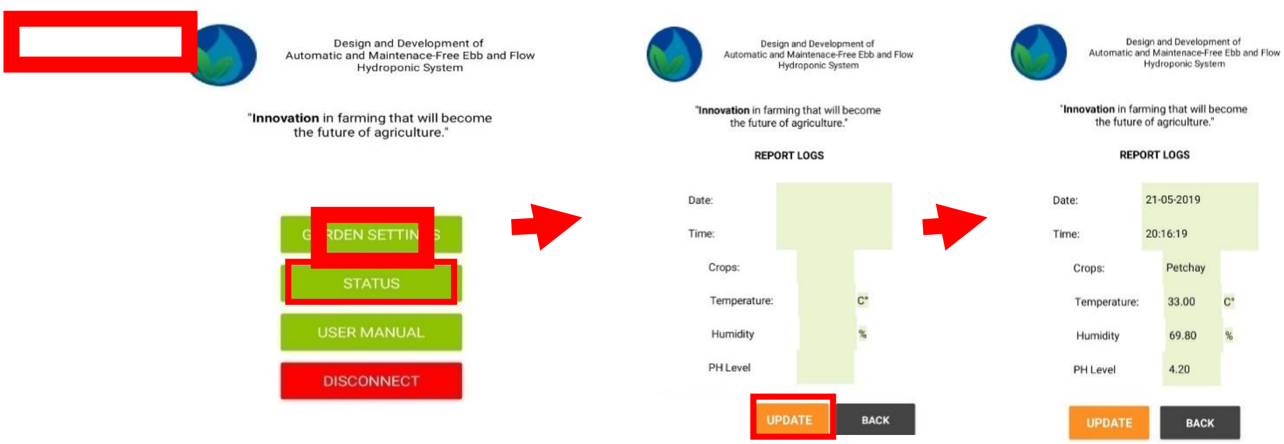

Figure 50. Report Logs

A user manual was also built in the mobile application. This enabled new users to understand how the Ebb and Flow Hydroponics system's mobile application works. The user manual also comprises a brief explanation of the different garden settings.

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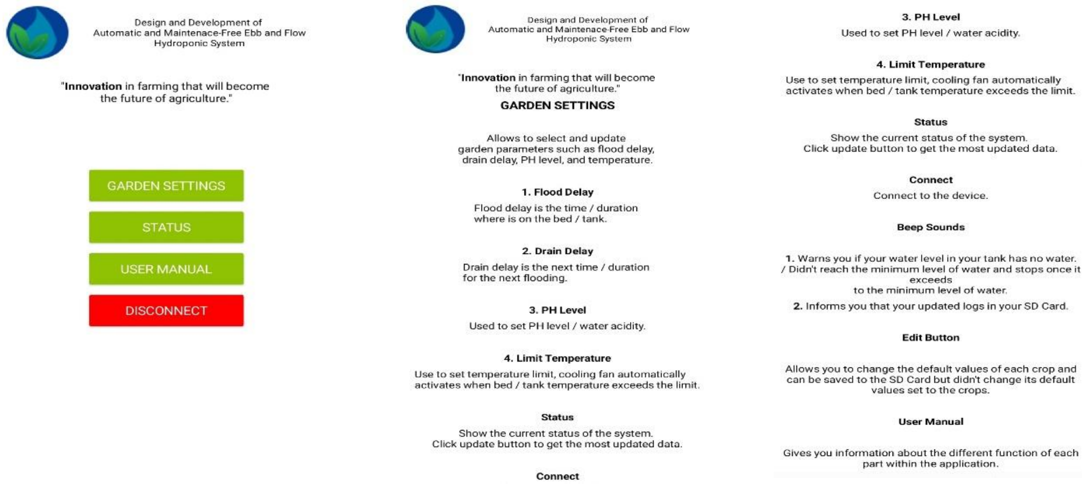

Figure 51. User Manual

Disconnecting the mobile application was also made easy. This was done by just clicking or tapping the disconnect button as shown on the figure 52 below. Once the mobile application was already disconnected to the device, the device would work according to the settings entered by the user. The settings would not be altered until the user connected the mobile application again and change the settings.

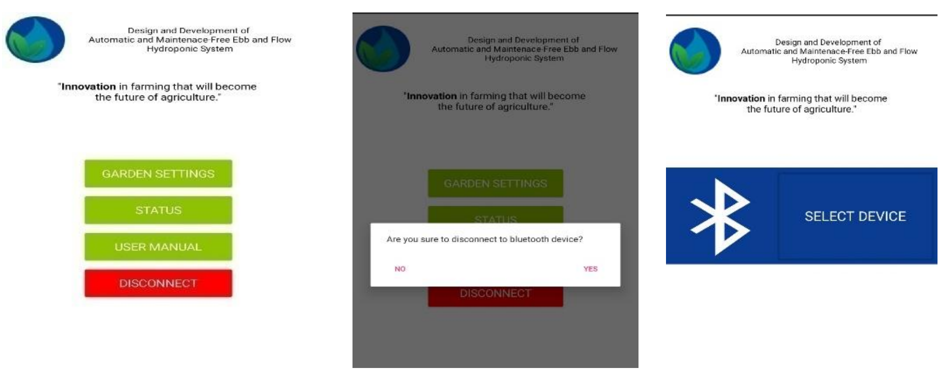

Figure 52. Disconnecting mobile application to the Bluetooth device

e
software and hardware was made. Testing process and revisions in the developed hydroponics system were also accomplished in this stage.

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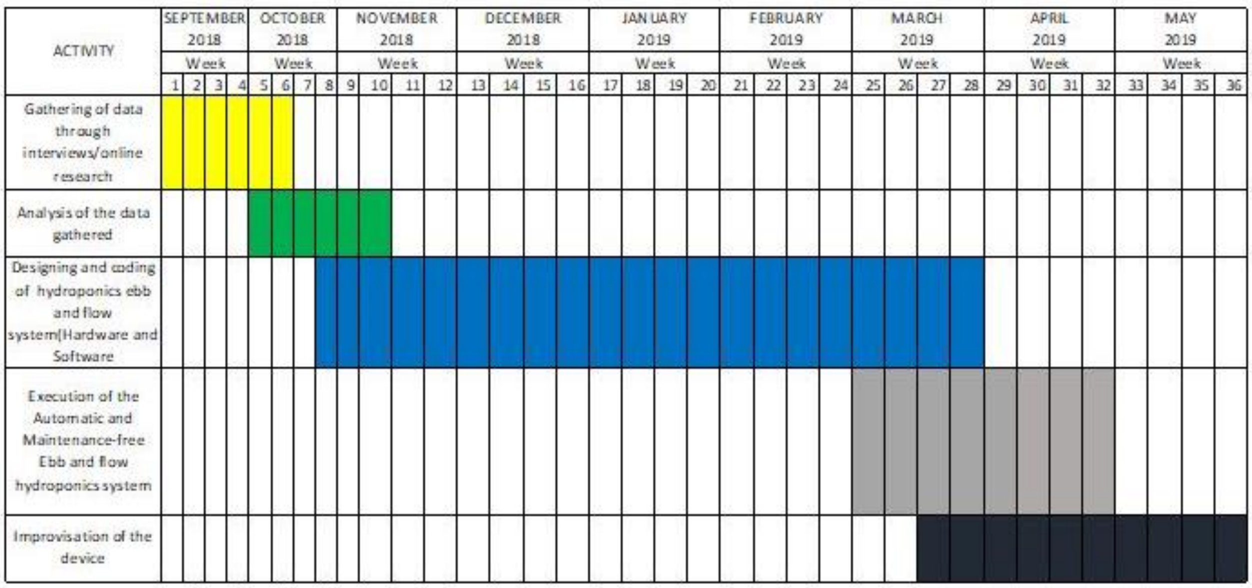
The schedule of activities followed to complete the development of the software and hardware were shown on the Gantt chart below.

Figure 53. Gantt chart of the development of Automatic and Maintenance-free Ebb and Flow hydroponics system



1.3 Improvisation of the Automatic and Maintenance-free Ebb and Flow hydroponics system

After the all the components of the device were successfully tested, it was forwarded to Talavera Senior High School for assessment by IT experts and end-users. After the end-users and IT experts assessed the device, they suggested some revisions which were used by the researcher as basis for its improvement.

The following improvisations were done through the help of the end-users, IT experts, and research panels. Power supply was changed from 5 ampere to 10 ampere. This was done to avoid rupture of the component once short circuit happened. Also, nutrient solution hose was moved from bed to water tank. A terminal block divider was put up and divided in two voltages: one was 5v and the other one was 12v. Moreover, only one power outlet was used for the power supply. Likewise, three 5 volts connected to the solenoid buzzer and pump was removed.

IV. CONCLUSIONS

The Automatic and Maintenance-Free Ebb and Flow Hydroponics System was developed using Robotic Process Automation (RPA) with the following stages: gather, analyze, design, execute and improvise.

Recommendations

1. Schools with limited land area can use Automatic and Maintenance-Free Ebb and Flow Hydroponics System to expose their students in planting crops.
2. Other researchers or developers can develop a system that can detect acidity levels of pH solution, viscosity, oxygen, and other aspects, as well as to develop a wider scale system since the researcher only developed a small scale hydroponic system.

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