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IoT-Based Smart Aquaponics System Using Arduino Uno

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Abstract— **As global population continues to rise, several challenges among which are climate variation, soil degradation and water scarcity continue to impact agricultural productivity. These challenges bring rise to lack of access to water sources for different activities such as vegetable watering with fish cultivation, thereby impacting food security negatively. The solution to the latter can be provided through aquaponics farming. This paper proposes an aquaponics system that saves water through circulation and utilization of ammonia released by fish to produce minerals such as nitrites and nitrates for plants in an aquarium tank. The system uses sensors, actuators, and microcontrollers to monitor and control water quality. The sensors are used to collect data and the data are transmitted with the aid of a Wi-Fi module to an IoT cloud platform called Thingspeak and actuators are applied to resolve the abnormalities detected by the sensor. The experimental results show that the quality and water circulation were well preserved. These are presented in this paper through linear regression analysis and *R*-squared plots that showed strong relationship between days and plant height as well as fish weights. The system reduces water wastage and increases aquaponics yield.**

Keywords— Arduino Uno, Aquaponics, IoT, Microcontroller, Smart, Thingspeak

I. Introduction

Studies have shown that a continual increase in human population globally seems unavoidable as the birthrate across the different continents of the world continues to rise [1].

This population increase negatively affects the land in many ways, some which are: climate variation, soil degradation, food security, and water scarcity. This is evident as climate change result in increase of pests, disease risks and high global temperature that in-turn have negative impact on agriculture activities [2]. Furthermore, an increase in population often leads to more agricultural land that are used for human settlement and this in-turn affect farming lands and their activities. In this regard, agricultural land particularly for farming is becoming smaller, thereby leading to a need for new strategic farming techniques. Considering, that water is essential to all forms of life, and this is evident from the fact that the earth's surface is covered with 71% of it [3]; one effective means of strategic farming technique could be the use of Aquaponics farming.

Aquaponics is an approach that combines aquaculture and hydroponics techniques [4]. Aquaculture is the farming of aquatic organisms which includes fish, molluscs, crustaceans and aquatic plants, and the hydroponics is used for the cultivation of plants in water without soil [5, 6]. The advantage of aquaponics farming is the fact that it relies on the nitrification process whereby the excretion of the fish that contains ammonia is transformed by the nitrifying bacteria to nitrites and further to nitrates that are subsequently used by plants as nutrients in the system [7]. In this regard, fish waste is used to fertilize the crops, thereby leading to the production of organic and chemical-free crops.

Different aquaponics research works have been conducted in the literature and the monitoring of water level is a major area under study in aquaponics farming. A system was developed for the monitoring of water usage with different sensors and the data collected through the sensors was sent to the data processing unit using a Global System for Mobile Communications (GSM) module [3]. The limitation of the system was, however, its high cost. The use of the buzzer was implemented to alert the user of any abnormality in tank's parameter levels in [8]. The system is, however, not efficient for long distance control. The process of recycling the nutrients that are created through fishes as fertilizers for plants were identified to have environmental and economic advantages as this subsequently generate profitable produce [9].

Given that an enhanced data collection and processing with efficient real-time remote monitoring approaches are required for aquaponics farming, an Internet-of-Things (IoT) based aquaponics system is proposed in this paper. The system uses a Wi-Fi module to offer real-time control at any distance. The system remotely monitors PH level, water level, humidity, and temperature of aquaponics in real-time, and as well perform water and nutrients circulation between plants and fish while also incorporating water cleaning. The benefits that the proposed system brings are: minimization of human interaction with remote monitoring in real-time, saving of time, money, water and power/electricity.

The remaining parts of this paper are as follows: section II briefly review some related works; followed by the methodology in section III; results and findings are presented in section IV, while last section provides the conclusion and future work.

II. RELATED WORKS

This section discusses the work that relates to this paper. It identifies the similar work and concludes by providing the solution brought to the disadvantages identified by the similar work.

To solve the problem of water scarcity, [10, 11] built an aquaponics system that grows bed water level control using fog architecture by recirculating water and nutrients to grow terrestrial plants and aquatic life. The system make use of four sensors maintaining the integrity of the specifications to acquire information to and from IoT technology, PH sensor used to take out analogue signal which is converted into digital signal by Arduino UNO which was interfaced with the sensor before reaching Raspberry Pi (which is used to link the system to the web, were the values of the system's parameters are stored in the database).

An alternative to reduce the amount of data being sent to the cloud is found, which is an improvement. An appropriate IoT duties are done through advanced cloud computing but the drawback it has is that it can be used where smart devices need to capture events at a hundred meters distance [12]. Furthermore, the use of Raspberry Pi increases the project cost.

On another work, [11] implemented IoT based smart aquaponics to a water containing extra food nutrients utilized by the designed technology as source of nutrition from agriculture ponds. In this system, data was retrieved by the sensors and the internet assisted to access data transmitted by these sensors in real time with the help of Ubuntu IoT cloud server.

The idea of designing and implementing an intelligent aquaponics systems by [13] and [14] was to reduce electrical energy by integrating solar energy to make their system more economical and safer, as they produce chemical-free crops. The system used an Arduino UNO, motor pump, relay, servo motor and 12v battery. Arduino as the control unit, sends signal to LEDs, and if blue LED is ON water motor pump pumps water from fish tank into the aquarium tank but if red LED is on, servo motor operates, and it enables outlet water flow from hydroponics and sends back clean water into aquarium tank. They found out that to easily drain the system the solar panel have to rotate along with the sun or a high technology battery should be used to power up the pump.

A report by [15] state that a solar panel was used to power an automated aquaponics system that was implemented by the sultanate of Oman to sustain farming. It was an economical and environmentally system deployed for local communities of Oman. The units of the system were as follows: (i) a system that moves water between aquaculture tank and hydroponics beds; (ii) sensors, actuators, and GSM module are connected to microcontroller known as Arduino to form a system that controls and monitors aquaponics; and (iii) the sunlight was converted into electricity by solar panel to power the entire system [16]. Furthermore, the proposed system viewed and adopted the idea of using solar energy as the electrical saving model.

An appropriate IoT duties are done through an advanced cloud computing but the drawback is that, it cannot be used where smart devices need to capture events at a hundred meters distance [17]. Furthermore, the use of Raspberry Pi increases the project cost. To reduce the cost of implementing the aquaponics, Arduino UNO was adopted in this proposed aquaponics system [18].

III. METHODOLOGY

This section discusses the materials and methods. Production of good quality protein and vegetables is done by this system [19]. The user can monitor the system remotely by using a mobile phone to access a cloud server web page known as Thingspeak, where data is sent by the system microcontroller, Arduino UNO, by the help of a low cost ESP8266 Wi-Fi module. Fig 1 represents the system architecture.

Described below are different components that make up the proposed system, as shown in the Fig 1.

1) Thingspeak – Stack of layers' form IoT Physical environment is the source where the top layer, perceptron, reads and collects information and application layer then use this information. Conversion of data into signal and reading of signal is done by perceptron layer and application layers, respectively. This signal is sent from layer to layer with the aid of the internet. There are data such as name, price, and stock of goods in minimarkets that have barcodes [18].

2) Arduino UNO – is an open-source electronic board, ATmega328P programmable microcontroller that possesses 6 analog signal pins and 14 digital signal pins that act as inputs and outputs. It operates at 5volts but can withstand a maximum of 20volts. Furthermore, it uses input voltage that is between 7-12V.

3) ESP8266-01 – It is a Wi-Fi module that is affordable. It consists of two functionalities; it can carry and drive the whole application and can control other micro-controller units. Arduino connects to this module for internet so that it can send data to thingspeak platform.

- Power range is 3.0volts to 3.6volts.
- It has a built-in TCP/IP stack.

4) Soil moisture sensor (YL-69) –Measure amount of water in the soil.

DHT22 sensor – Measure water vapor quantity and temperature in the atmosphere in the hydroponics. According to [20] temperature and humidity are crucial environmental elements in plant growth.

Ultra-sonic sensor – It monitors the level of water in aquarium tank.

PH sensor – It measures the PH of water weather is acidity or alkalinity in the aquarium tank. [21] indicates that acidity lies between 0 and 7, while alkalinity lies between 7 and 14.

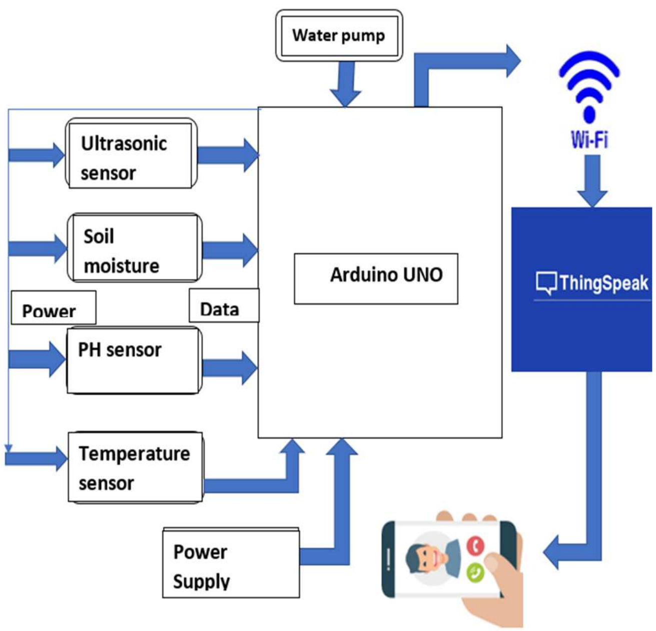

Fig. 1: The system's block diagram

A. *Methodology description*

Fig 2 is a designed model that is made of numerous elements, such as PH sensor, Ultrasonic sensor (water level), Soil moisture sensor and DHT22 sensor (humidity and temperature) that are interfaced with Arduino UNO, which acts as the heart of the system since it processes every signal and takes appropriate response using actuators (pump 1 and 2).

Not only does Arduino UNO use data retrieved from sensors to control water pumps, but it also uses Wi-Fi module to send that data to the cloud platform known as Thingspeak, there, it will be stored, analyzed, and graphically represented to the farmer to view remotely. The water pumps are powered with electricity using 12V chargers.

As illustrated by Fig 3, an ultrasonic sensor is used to measure water level, PH sensor is used to measure PH of the water, DHT22 sensor is used to measure humidity and temperature and all these sensors are connected to Arduino Uno to monitor water and the atmosphere around plants. One water pump is in the reserve tank and once ultrasonic sensor reads the distance in the fish tank that is above 20cm, the pump in the reserve tank starts pumping water into the aquarium tank but if distance goes below 20cm, it stops.

Fig. 2. The system setup

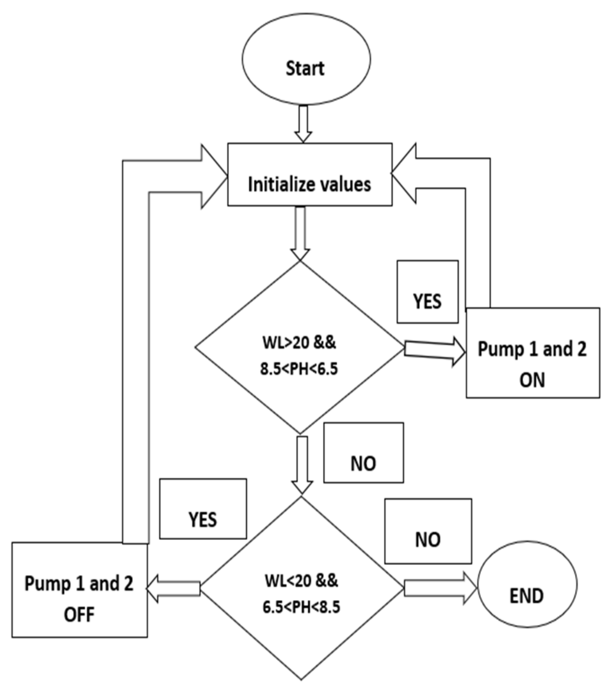

Fig. 3. Flowchart of the proposed system

Moreover, there is another water pump in the fish tank and once PH sensor in the fish tank reads PH between 6.5 and 8.5, the pump will not pump water into the plant growing area but when it goes below 6.5 or above 8.5, it will start pumping water. This water is then cleaned by nitrification process, this is going to benefit plants because they will get nutrients. Cleaned water is then returned to reserve tank, where, once there is water shortage in the fish tank, it will be pumped from reserve tank into the fish tank and fish will use it for its survival. Data collected by sensors is sent to Thingspeak cloud servers; this is achieved by the use of Wi-Fi module known as ESP8266, where the user can access data anytime and anywhere on this cloud platform through internet.

IV. RESULTS AND DISCUSSION

Equation (1) presents a linear regression equation for plant height over a period of 32 days, with R^2 of 0.9826. Furthermore, linear regression analysis is shown in equation (2), for fish weight over same time frame, R^2 is 0.9616.

Both graphical representation and R^2 prove that plants and fish were growing in a good way, as R^2 in both plant height and fish weight is very close to 1, showing that the relationship between days and plant height and fish weight are very strong. Data from sensors was successfully sent to the internet of things as shown in Fig. 6.

$$Y_{(ph)} = 4.7386z + 4.7386 \quad (1)$$

where z is number of days, it took the plant to grow, and $y_{(ph)}$ is the height of the plant.

$$Y_{(fw)} = 0.8096x + 37.616 \quad (2)$$

where x is number of days, it took fish to gain weight and $y_{(fw)}$ is the weight gained by the fish.

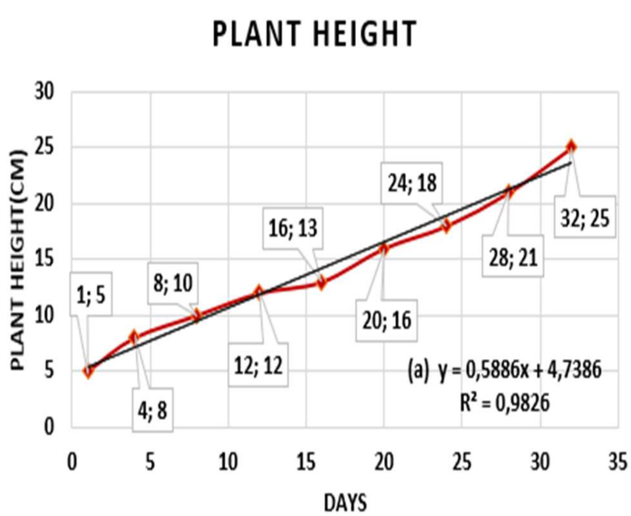

Fig. 4: Analysis using plant height

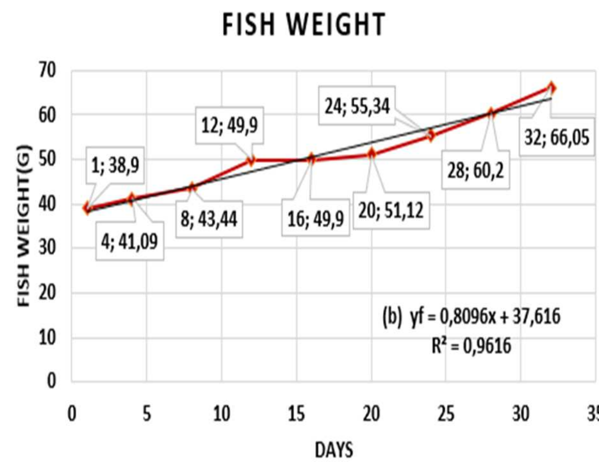

Fig. 5: Analysis using fish weight

Table I demonstrate the height of the plants measured and Figs. 4 and 5 graphically show that they were linearly growing as the days pass by. When z is 0, this would mean that the decision to measure the plant was not yet taken. Graphically it shows as though, $y_{(ph)}$ is 4.7386, but it isn't because it would mean that we have a plant of 4.7386 cm that grew within no days, which is impossible. In short, since the slope is positive, this tells us that as x increase then y increase. R^2 is known as coefficient of determination and it indicates how well the data points are fitted to the linear regression line, it is between 0 and 1 so in this case, R^2 is 0.9826, which shows that data points are well fitted

TABLE I MEASUREMENTS FOR PLANT HEIGHT

Days	1	4	8	12	16	20	24	28	32
Plant Height (cm)	5	8	10	12	13	16	18	21	25

TABLE 2. MEASUREMENTS FOR FISH WEIGHTS

Days	1	4	8	12	16	20	24	28	32
Fish weight (g)	38.90	41.09	43.44	49.90	49.90	51.12	55.34	60.20	66.05

Fish constantly grew as the days pass by, and it was weight after every 3 days, the measurements are shown in Tables 1 and 2. When x is 0, it would mean there is no fish but when its 1, that is the first day that fish was bought. Graphically it shows as though $y_{(fw)}$ is 37.616 but it is not because it would mean that we have a fish of 37.616g that grew within no days, which is impossible. Moreover, as x increases then $y_{(fw)}$ increases because the slope is positive. R^2 is a statistical measure of goodness-of-fit and it designates how well the data are close-fitting to the linear regression line, it is between 0 and 1 so in this case, R^2 is 0.9616, which shows that data points are well fitted. Fig. 6 represent a reserve tank which accept clean water that flows from hydroponics through syphon. It comprises a pump that drives the water into the fishpond, and the same pump, also propel water containing ammonia into the grow bed on top of the tank.

Fig. 6: Reserve tank which accepts clean water that flows

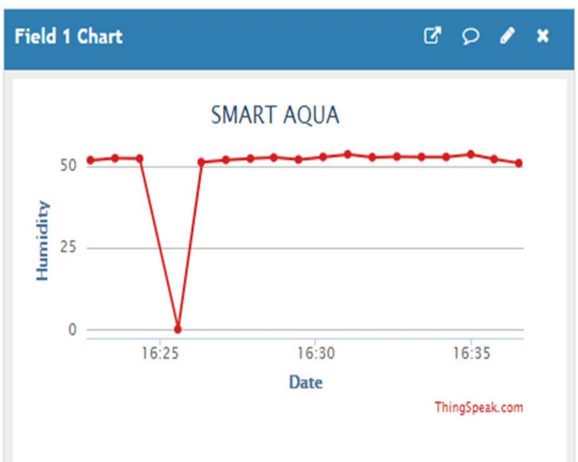

Fig. 7: Relative humidity at certain times of different days

The water then undergoes filtering process. The tank's humidity, PH level, water level, and temperature are remotely monitored with the help Wi-Fi and Arduino UNO. Fig. 7 shows the relative humidity at certain times of different days. The results show that mostly relative humidity it ranged between 50 and 55 and there is no correlation between this graph and previous studies except where it drops to 0. Fig. 8 shows PH at certain times, mostly it ranged between 5 and 7 and most of the time it was 5.2 there is no correlation between this graph and previous studies except where it drops to 0. Fig. 9 shows the soil moisture at certain times of different days, it was going below 50% and above 50%, which means it was dry and its time wet and there is no correlation between this graph and previous

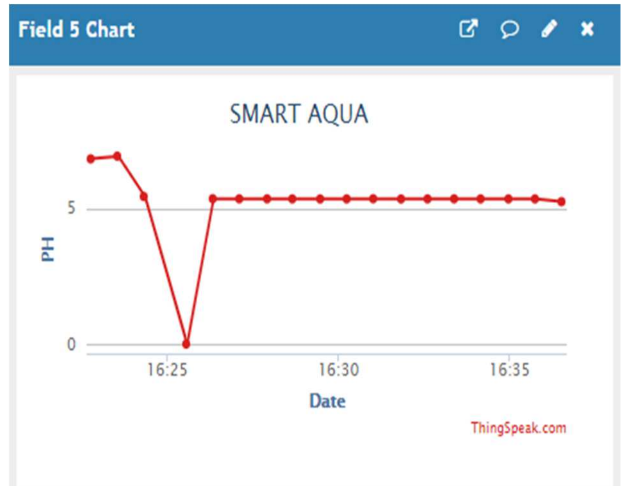

Fig 8: PH at some typical times of the day

Fig. 9: Soil moisture graph on thingspeak

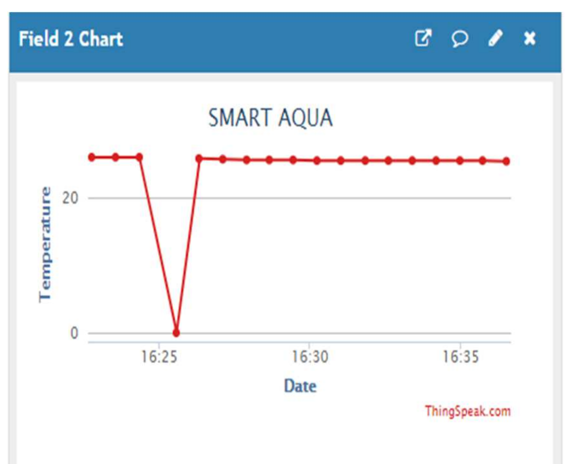

Fig. 10: Temperature graph on Thingspeak

studies except where it drops to 0. Fig. 10 shows the varying temperatures at certain times, mostly it around 25oC and there is no correlation between this graph and previous studies except where it drops to 0. Fig. 11 shows the varying water levels at certain times of different days, mostly it was above 20, which means the water was being pumped and there is no correlation between this graph and previous studies except where it drops to 0.

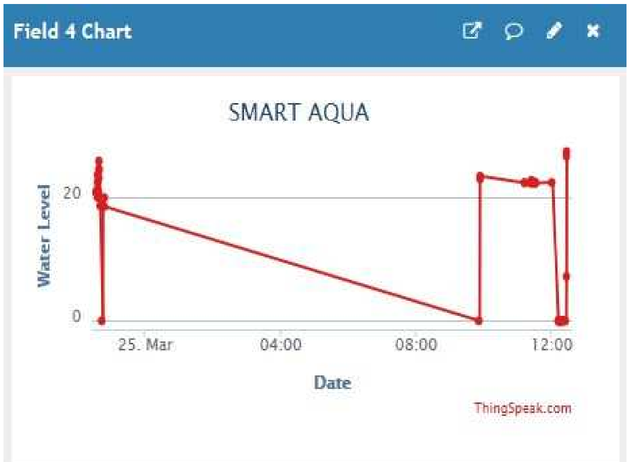

Fig. 11: Water level graph on Thingspeak

V. Conclusion

Water circulation and real-time water quality monitoring makes the IoT based aquaponics system proposed in this paper a promising choice of agriculture. The combination of Arduino UNO and ESP8266 Wi-Fi module made it possible to send data to the cloud platform known as thingspeak. Based on the study that was conducted in this paper, conclusions are drawn that plant grow well in temperature between 20ºC to 25ºC and PH between 6.5 and 8.5. For future work, a study on the suitable battery to be used to power up the system in a portable manner with the appropriate light sensors and lump needed to control light intensity for plants' healthy growth shall be conducted.

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