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IoT based Aquaponics Monitoring system.

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Abstract: As industrialization and urbanization grow to be a concern in food production and scarcity, urban farming was introduced to cope with the above conditions. aquaponics, where plants and aquatic animals were grown together for a better outcome, was considered as one of the effective types of urban farming. as with any method of farming aquaponics came with its own set of cons: so in this paper, we discuss a fully automated aquaponics system (smart aquaponics) with the integration of Internet of things (IoT) Applications to double the outcome of the production more efficiently and sustainably.

1. INTRODUCTION

A. Definition

Aquaponics is defined as a "combination of hydroponics and aquaculture in one model". In hydroponics, water must be added with adequate nutrients for the plants, and in aquaculture, ammonia present in the water must be treated constantly which is from fish waste. In aquaponics, the plants oxygenate the water for wish and the bacteria convert the ammonia from fish waste to nitrates which serve as nutrients for growing plants. Aquaponic is a successor of hydroponics and is a lot like it when it comes to structuring. It consists of a water tank and a bed where plants are grown in a closed loop of circulating water, as in aquaponics plants and fish are grown together symbiotically. Aquaponics is a sustainable technology that will become even more valuable as resources become limited. The viability of aquaponics must be examined in detail though if the researchers are going to rely on something so radically different to provide something as essential as food.

B. problem statement

As communities grow, less and less agricultural and farmland is available. In addition, due to climate change, producing crops progressively is a difficult thing to do with existing agriculture practices, to cope with rising food scarcity and food demand an effective and sustainable method that does not exploit additional natural resources should be incorporated.

C. Background - of the problem

Agriculture is both a cause of and sensitive to environmental degradation, such as biodiversity loss, desertification, soil degradation, and global warming, which cause a decrease in crop yield.[1] Agriculture is one of the most important drivers of environmental pressures, particularly habitat change, climate change, water use, and toxic emissions. Agriculture is the main source of toxins released into the environment, including insecticides, especially those used on cotton.[2][3].The 2011

UNEP Green Economic report stated that agricultural operations produced 13 percent of anthropogenic global greenhouse gas emissions. This includes gases from the use of inorganic fertilizers, agrochemical pesticides, and herbicides, as well as fossil fuel energy inputs. [4]

livestock issues

A senior UN official, Henning Steinfeld, said that "Livestock are one of the most significant contributors to today's most serious environmental problems". [5] Livestock production occupies 70% of all land used for agriculture or 30% of the land surface of the planet. It is one of the largest sources of greenhouse gases, responsible for 18% of the world's greenhouse gas emissions as measured in CO_2 equivalents. By comparison, all transportation emits 13.5% of the CO_2. It produces 65% of human-related nitrous oxide (which has 296 times the global warming potential of CO_2) and 37% of all human-induced methane (which is 23 times as warming as CO_2 .)) It also generates 64% of the ammonia emission. Livestock expansion is cited as a key factor driving deforestation; in the Amazon basin, 70% of previously forested area is now occupied by pastures and the remainder is used for feed crops. Through deforestation and land degradation,

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livestock is also driving reductions in biodiversity. Furthermore, the UNEP states that "methane emissions from global livestock are projected to increase by 60 percent by 2030 under current practices and consumption patterns."

Fig.1 farmyard anaerobic digester converts waste plant material and manure from livestock into biogas fuel.

Land and water issues

Land transformation, the use of land to yield goods and services, is the most substantial way humans alter the Earth's ecosystems and is the driving force causing biodiversity loss. Estimates of the amount of land transformed by humans vary from 39 to 50%. [6] Land degradation, the long-term decline in ecosystem function and productivity, is estimated to be occurring on 24% of land worldwide, with cropland overrepresented.[7] Land management is the driving factor behind degradation; 1.5 billion people rely upon the degrading land. Degradation can be through deforestation, desertification, soil erosion, mineral depletion, acidification, or salinization. [8]

Fig.2 Circular irrigated crop fields in Kansas. Healthy, growing crops of corn and sorghum are green (sorghum may be slightly paler). Wheat is brilliant gold. Fields of brown have been recently harvested and plowed or have lain in fallow for the year.

Pesticides

Pesticide use has increased since 1950 to 2.5 million short tons annually worldwide, yet crop loss from pests has remained relatively constant. [9] The World Health Organization estimated in 1992 that three million pesticide poisonings occur annually, causing 220,000 deaths. [10] Pesticides select for pesticide resistance in the pest population, leading to a condition termed the "pesticide treadmill" in which pest resistance warrants the development of a new pesticide.[11] An alternative argument is that the way to "save the environment" and prevent famine is by using pesticides and intensive high yield farming, a view exemplified by a quote heading the Center for Global Food Issues website: 'Growing more per acre leaves more land for nature. [12][13] However, critics argue that a trade-off between the environment and a need for food is not inevitable, [174] and that pesticides simply replace good agronomic practices such as crop rotation.

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Fig.3 Spraying a crop with a pesticide

Climate change

Climate change and agriculture are interrelated on a global scale. Global warming affects agriculture through changes in average temperatures, rainfall, and weather extremes (like storms and heat waves); changes in pests and diseases; changes in atmospheric carbon dioxide and ground-level ozone concentrations; changes in the nutritional quality of some foods; [14] and changes in sea level. [15] Global warming is already affecting agriculture, with effects unevenly distributed across the world.[16] Future climate change will probably negatively affect crop production in low latitude countries, while effects in northern latitudes may be positive or negative. [16] Global warming will probably increase the risk of food insecurity for some vulnerable groups, such as the poor. [17]

Fig.4 Winnowing grain: global warming will probably harm crop yields in low latitude countries like Ethiopia.

Sustainability

Current farming methods have resulted in over-stretched water resources, high levels of erosion and reduced soil fertility. There is not enough water to continue farming using current practices; therefore how critical water, land, and ecosystem resources are used to boost crop yields must be reconsidered. A solution would be to give value to ecosystems, recognizing environmental and livelihood tradeoffs, and balancing the rights of a variety of users and interests. Inequities that result when such measures are adopted would need to be addressed, such as the reallocation of water from poor to rich, the clearing of land to make way for more productive farmland, or the preservation of a wetland system that limits fishing rights.

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Fig.5 Terraces, conservation tillage, and conservation buffers reduce soil erosion and water pollution on this farm in Iowa.

Energy dependence

Since the 1940s, agricultural productivity has increased dramatically, due largely to the increased use of energy-intensive mechanization, fertilizers, and pesticides. The vast majority of this energy input comes from fossil fuel sources. [18] Between the 1960s and the 1980s, the Green Revolution transformed agriculture around the globe, with world grain production increasing significantly (between 70% and 390% for wheat and 60% to 150% for rice, depending on geographic area) [19] as world population doubled. Heavy reliance on petrochemicals has raised concerns that oil shortages could increase costs and reduce agricultural output. [20] Industrialized agriculture depends on fossil fuels in two fundamental ways: direct consumption on the farm and manufacture of inputs used on the farm. Direct consumption includes the use of lubricants and fuels to operate farm vehicles and machinery. [20]

Fig. 6 Mechanised agriculture: from the first models in the 1940s, tools like a cotton picker could replace 50 farmworkers, at the price of increased use of fossil fuel.

D. Extent of the problem.

Modern agriculture is an evolving approach to agricultural innovations and farming practices that help farmers increase efficiency and reduce the number of natural resources like water, land, and energy necessary to meet the world's food, fuel, and fibers needs. Agribusiness, intensive farming, organic farming, and sustainable agriculture are other names of modern agriculture.

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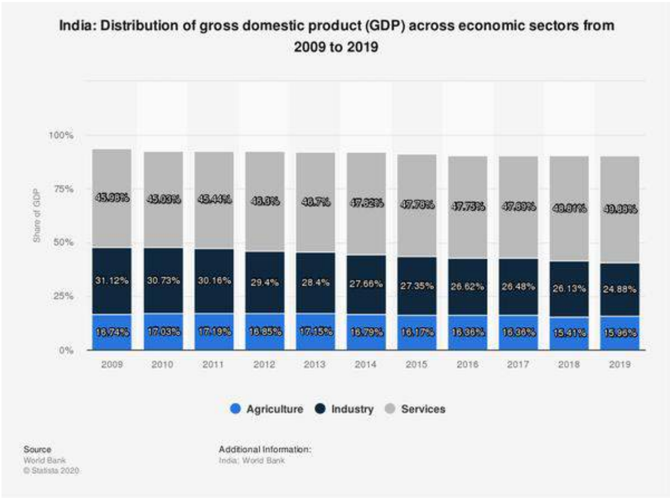

Graph showing the drop in agricultural sector contribution to GDP (Courtesy: Wikimedia Commons)

Impact of Modern Agriculture on the Environment

As we know that modern agriculture improved our affordability of food, increases the food supply, ensured food safety, increases sustainability, and also produces more biofuels. But at the same time, it also leads to environmental problems because it is based on high input–high output technique using hybrid seeds of high-yielding variety and abundant irrigation water, fertilizers, and pesticides.

E. Objectives

The main objectives of this paper are to make an efficient and automated aquaponics system using various compatible fish such as Goldfish for small scale aquaponics, Bluegill sunfish for indoor environment, and Tilapia with access and control of various parameters such as humidity, temperature through IoT and microcontroller and observe the growth of plants in it. We specifically aim to (1) construct a fully automated aquaponics that will be able to monitor and control the parameters such as temperature, humidity, light, Ph (2) to integrate internet of things interfacing and access to the automated aquaponics data through an SMS alert to the user (3) to compare the crop yield from traditional aquaponics and hydroponics.

2. METHODOLOGY

A. Aquaponics

Aquaponics is defined as "the integration of aquaculture and hydroponics in one system", In aquaculture, water must be treated to control ammonia, which is from fish waste, and in hydroponics, water must be added with nutrients for the plants. In aquaponics, the fish waste serves as nutrients for the plants which in turn cleans the water for the fish, It is an ecosystem wherein plants and fish lives in a symbiotic relationship.

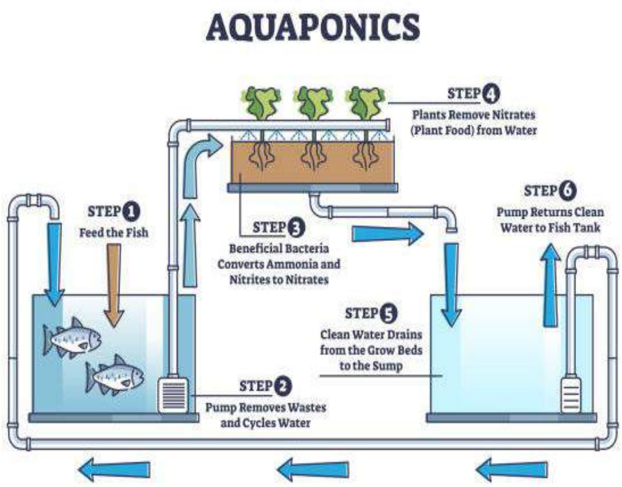

Fig. 7 Aquaponics System

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In the production of crops in aquaponics, making use of the nutrients from the effluent water from the aquaculture. Channeling the nutrient-rich wastewater into secondary crops is an alternative treatment of water that is both cost-effective and environmentally friendly. In aquaponics, the farmer feeds the fish. The fish produce waste and ammonia, which are harmful to the fish in larger quantities. The water from fish is guided to plants where beneficial bacteria break ammonia first into Nitrites and then into Nitrates. Plants feed on Nitrates and other nutrients, thus cleaning the water. Solid waste can be filtered out of the water by either grow beds, in a media bed system, or by an additional filter. Clean, oxygenated water is returned to the fish tank.

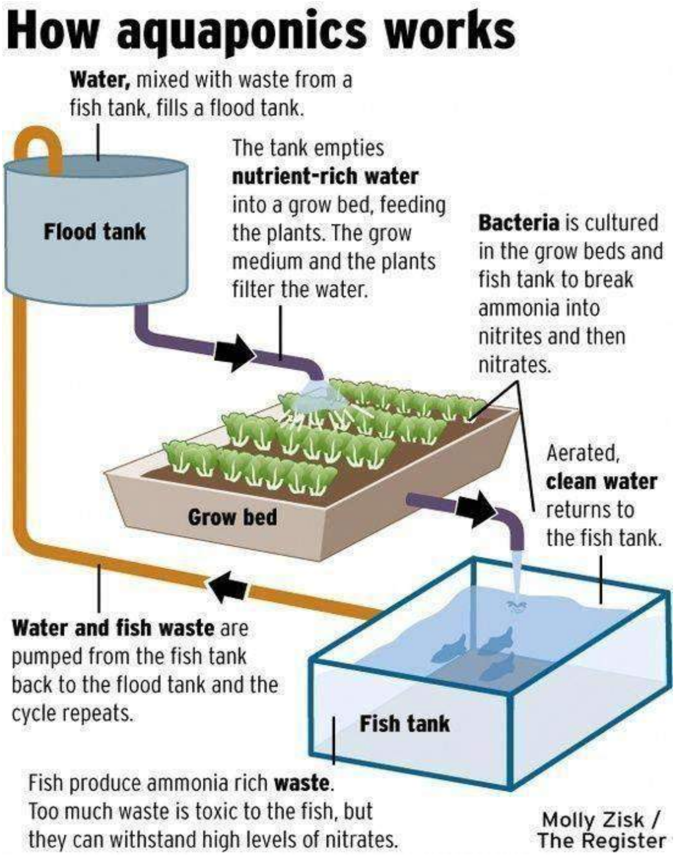

Fig.8 working of aquaponics.

This integration removes the problems of running aquaculture and hydroponics systems independently wherein the nutrient-rich wastewater by-product of aquaculture which must be either treated or disposed of is diverted through the hydroponics which is set as the fertilizer for the plants [21].

B. Types of aquaponics.

Within the aquaponics system, three main growing techniques can be implemented: Media Based, Nutrient Film Technique (NFT), and Deep Water Culture.

Media Based.

The media-based method consists of growing the plants in a large container filled with media, which can range from gravel to perlite. This method usually is the one with the fewest components, as the solid waste is broken down throughout the media, removing the need for an extra buffer filter.

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Fig.9 Media Based aquaponics.

However, this system does not produce a maximum output of plant growth. The Nutrient Film Technique and Deep Water Culture method produce at a faster rate because they have additional components. This method is good for aquaponics being done as a hobby rather than on a commercial scale unless developed further. This may be easier and more inexpensive to implement in a classroom. It also provides for a more secure grow bed to allow for larger plants, mostly of the fruiting variety. In the classroom, fruiting plants are impractical to grow because of their longer growing period. Also, because the current method is not necessarily commercial grade, it may not be the best for teaching about a probable solution to the problem of food insecurity.

Nutrient Film Technique (NFT)

The Nutrient Film Technique is more widely used for hydroponics. However, in some cases, it can be used for aquaponics as well. It involves growing the plants in narrow channels (e.g. gutters), allowing for a continuous but thin flow of water, which gives more oxygen and a constantly new supply of nutrients. This method though is limited in that only certain small plants (such as leafy greens), without large roots, can be grown in the system because of the high risk of clogging.

Fig.10 Nutrient Film Technique aquaponics.

The organic waste from the fish also creates a potential for clogging, so careful attention to plumbing, specifically pipe diameter, must be taken into consideration. Due to the risk of clogging, this method is not widely used in aquaponics systems. Also, it requires the addition of a biological filter because much of the system is not exposed to air. The NFT

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method requires constant maintenance including cleaning the piping consistently and only a small set of plants can be placed in this aquaponics design, so this may not be the best method for classroom integration.

Deep Water Culture

The Deep Water Culture method, also known as the raft method, is the technique that we are using to design our aquaponics systems here at ISB. It involves cutting holes in a raft (here at ISB, we are using styrofoam insulation rafts) to secure the plants and to also allow the roots to be suspended in the water. For additional securing, net grow pots can be placed in the holes and filled with clay/coconut media for plant substrate. Filters are placed throughout the cycle to ensure proper recirculation.

Fig.11 Deep Water Culture/ Raft system aquaponics.

The Raft System of aquaponics, also known as deep water culture (DWC) or floating system, is one of the most efficient aquaponics techniques. This system is generally implemented in large-scale or commercial aquaponics because of its mass production capability. In a raft system, the nutrient-rich water circulates through the long canals, usually at a depth of about 20 cm, while rafts (polystyrene or foam board) float on top. The plants are grown on the raft boards that are supported within holes by net pots. Plant roots hang down in the nutrient-rich, oxygenated water, where they absorb oxygen and nutrients to grow rapidly. The nutrient-filled water flows continuously from the fish tank through the filtration process, then to the raft tank where the plants are grown, and finally back to the fish tank. Most often, the raft tank is separate from the fish tank. The beneficial bacteria primarily live in the biofilter, in the raft tank, and throughout the system. Since the development of aquaponics raft systems (DWC) on a commercial scale by Dr. Rakocy [22] at the University of the Virgin Islands. Many commercial aquaponics farms use this type of system because it allows the plants to grow faster and yield more crops.

C. Components of raft system

Fish Tank**,**

A fish tank is essential in any aquaponic system. The fish tank is where your fish will live, and the tank acts as the collection reservoir for fish waste. The fish waste and water will be pumped into the plant beds, providing them with enough moisture and nutrients for their growth.

Grow Canals,

Like the fish tank, canals can be made out of any strong, inert material that can hold a large water volume. Canals can vary in length, but it is generally recommended that the width should be the standard width of a polystyrene sheet. The recommended depth is 30 cm to allow adequate plant root space. The canals' retention time should be 1 to 4 hours, regardless of size, to allow adequate replenishment of nutrients in the canal. Plants grow faster from a faster water flow rate because the roots will be hit many more ions.

Floating Rafts,

This is the place for the plants to grow. Floating rafts are constructed from Styrofoam or other lightweight material lined with foam. Plants are placed in holes on the rafts, allowing their roots to dangle into the water. Net pots are often used for added stability and to prevent the plants from falling through rafts into the system.

Biofilter,

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A biofilter is a place for bacteria to colonize. This is where the beneficial bacteria turn fish waste into usable, nutrient-rich food for the plants.

Filters,

Filters capture the solid waste from the fish, plant material, and anything that might find its way into the system. Filtration in aquaponic systems is essential because the solid particles, fish residual foods, and fish waste can create a severe problem in your aquaponic system. They can clog your piping, nozzles, and plant roots and cause unwanted damage to your system.

Water Pump,

The water pump pumps water from the fish tank, through the filters, and into the grow beds. Pumps are used to recirculate the water in raft systems and keep the water moving.

D. Smart aquaponics

Aquaponics requires expertise as it is a very complex process to manage and monitor the system, the system cannot be left unattained for a long period and requires constant monitoring of the production and working so thus requires daily management and also the cultivators should keep each parameter and conditions in check for effective output. Automating and integrating it with the IoT will reduce these concerns. Internet of Things (IoT) is a construction that combines information and energy processes to control very large collections of different objects [23]. To extend the internet into the real world is the IoTs' target and vision [24].

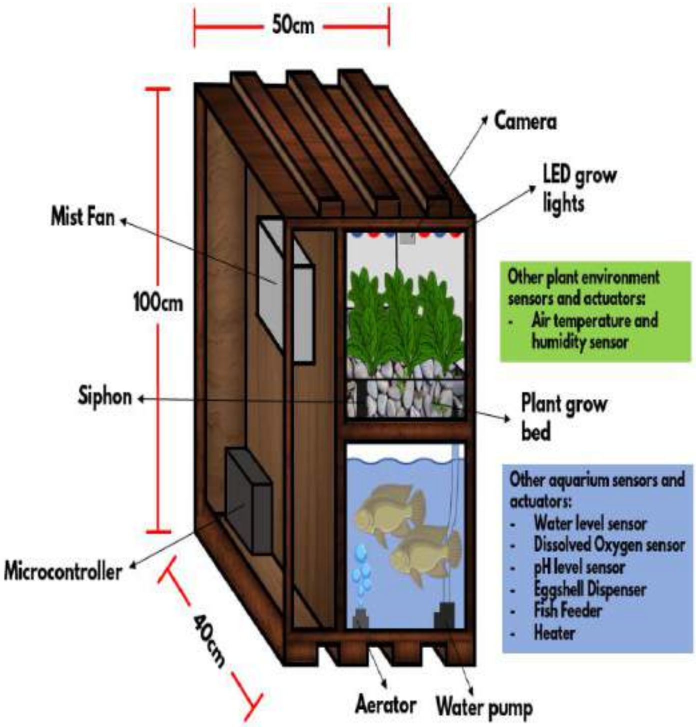

Fig. 12 conceptional picture of smart aquaponics.

Internet of Things is a new revolution of the Internet. Objects make themselves recognizable and they obtain intelligence by making or enabling context-related decisions through communicating information about themselves. They can access information that has been aggregated by other things, or they can be components of complex services [25].

E. Arduino

Arduino board designs use a variety of microprocessors and controllers. The boards are equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards ('shields') or breadboards (for prototyping) and other circuits.

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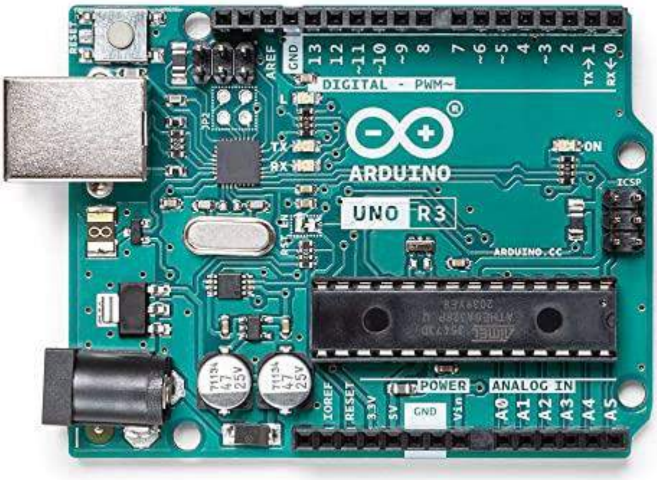

Fig.13 Arduino Uno REV3 [A000066]

The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs. The microcontrollers can be programmed using the C and C++ programming languages, using a standard API which is also known as the Arduino language, originated from the Processing language. In addition to using traditional compiler toolchains, the Arduino project provides an integrated development environment (IDE) and a command-line tool developed in Go.

F. hardware and software development

We first construct the aquaponics system and assemble the hardware to automate the aquaponics, Place the temperature sensors in the grow bed and the fish tank, and the pH sensor in the fish tank. Actuators are also placed to give corrective actions in temperature and pH level.

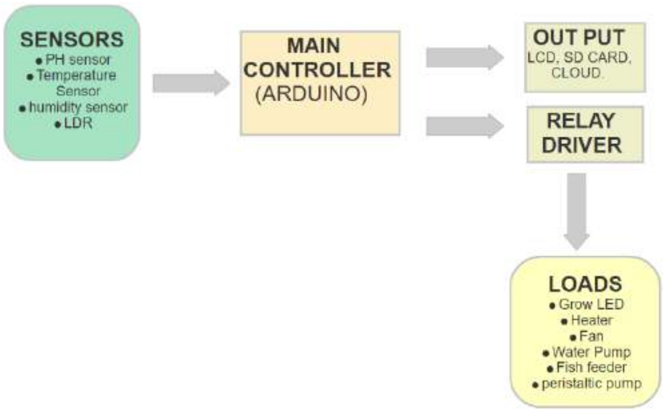

Fig.13 System architecture of smart aquaponics.

Heater and fan to correct the temperature and peristaltic pumps in correcting the pH level. An ultrasonic sensor is also placed to know when to activate the pump for water refilling. The microcontroller used was Arduino.

The research also involves integrating the aquaponics system with the Internet of Things (IoT) wherein the entire structure is powered by the Arduino which collects data from the sensors installed and stores these data in the Internet of Things (IoT) enabled cloud which is the Thing Speak. The Arduino is programmed to monitor the environmental variables of the automated aquaponics and maintain these to the preferred conditions. We use Arduino IDE for programming the Arduino controller and with sensors and load devices using c++ language. The system also comprises an SMS alert-based system that has real-time sensor data monitoring of the automatic system which notifies the user about the readings and parameters.

F. System architecture

The smart aquaponics system was developed by integrating seven modules: data acquisition unit, alarm unit, system rectification unit, central processing unit, web application, mobile application, and cloud server, as depicted in Fig. 14.

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Data acquisition unit

The data acquisition unit continuously collects data using five sensors. Water temperature sensor gathers water temperature of the fish tank. Water flow rate sensor measures water flow rate from the fish tank to plant grow beds. Digital light sensor quantifies light intensity of the environment. pH level sensor detects water pH level in the fish tank. Ultrasonic ranger measures the plant height.

Alarm unit

The alarm unit consists of a green LED light, a red LED light, and a buzzer. This unit displays green light when the system is healthy, but displays red light with buzzing sound to alert the user when the system is unhealthy.

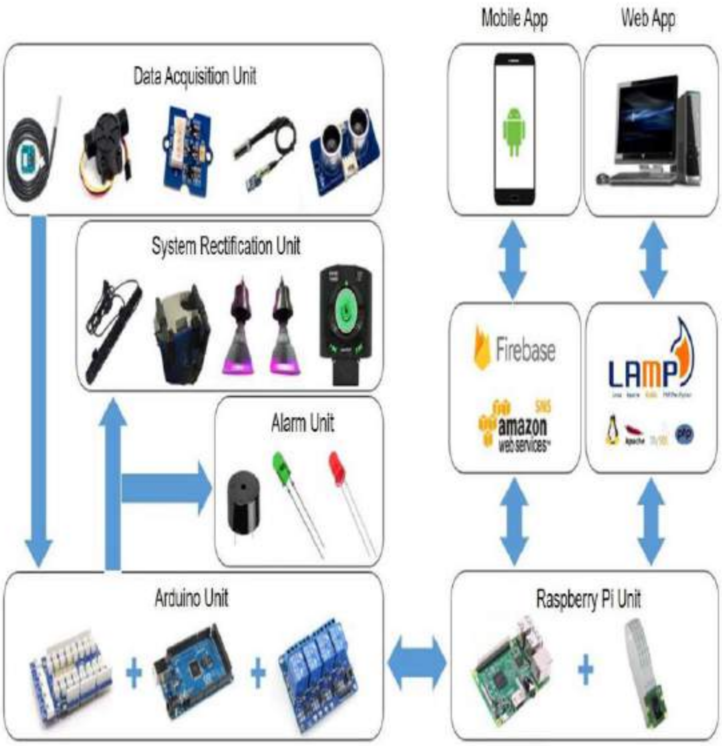

Fig. 13. Design diagram.

System rectification unit

The system rectification unit automatically intervenes and rectifies the system abnormality by activating respective actuator. Decision to activate or deactivate the actuators is determined by the central processing unit based on the collected data and user preset values. This unit comprises four actuators. Water heater provides additional heat source when the water temperature falls below a healthy range. Secondary water pump ensures water flow from the fish tank to plant grow beds in the event of primary pump failure. LED grow light supplies stable blue and red light to boost plant growth when the ambient light intensity enters into an unhealthy range. Fish feeder dispenses fish feeds at the user preset timings of the day to increase fish growth.

Central processing unit

The central processing unit has two sections. The first section contains an Arduino Mega, a Grove-Mega shield, and a relay board. Arduino Mega, with 54 input/output pins, is used to communicate with the sensors and actuators from the data acquisition unit and system rectification unit. Grove Mega Shield was mounted on Arduino Mega to reduce the number of connections on the breadboard. Relay board enables Arduino to control the actuators by switching on and off the respective electric circuits. The second section consists of a Raspberry Pi 3 model B and a camera module. Raspberry Pi was configured as a central control unit for the entire system because it has a fast processor, as well as built-in Bluetooth and Wi-Fi modules. Moreover, it has a high-definition multimedia interface port that can be connected to visual display devices. Camera module v2 enables live streaming feature for Raspberry Pi. This camera module was chosen because it is easy to use and can record high-definition video after integrating with Raspberry Pi.

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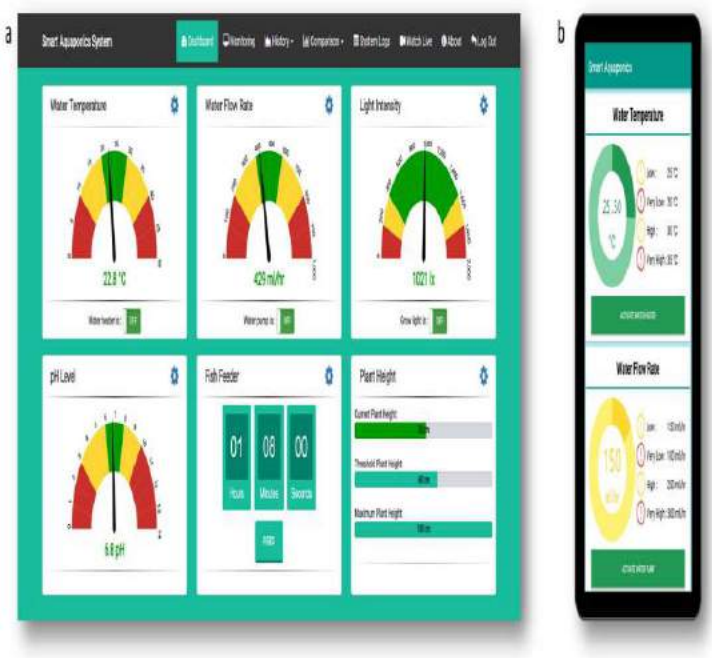

Fig. 14. (a) Web application; (b) Mobile application.

Web application

The web application was developed and hosted on Raspberry Pi to provide GUI for the system. The GUI displays and compares live and historical sensor values, as well as records system events. It also allows the user to timely monitor the aquaponics facilities and remotely control the actuators.

Mobile application

The mobile application was created on Android platform. It displays live sensor values and enables user to remotely control the actuators by using services from the cloud server. Moreover, it permits the user to modify the threshold values for each sensor with real-time latency.

Cloud server

The cloud server is used to establish communication between the central processing unit and mobile application. The main goal for the cloud server is to store the collected data from the data acquisition unit, and to redirect actions, such as activating water heater, from the mobile application to the central processing unit in real-time.

G. System implementation

All hardware components were integrated according to the final design diagram shown in Fig.1. Each component was carefully inspected and tested before the integration. Subsequently, the implemented system was evaluated by simulating different possible scenarios. For example, when the water temperature falls into an unhealthy range, the system should trigger the alarm unit to alert the user, and activate the system rectification unit to rectify the problem by turning on the water heater. Simultaneously, the system should send out alert notifications, such as email, short message service (SMS), and push notification, as well as record the faulty event in the database. When the water temperature returns normal, the system should automatically turn off the water heater and buzzer, notify the user with updated system information, and record the recovery event in the database.

Different programming languages were adopted in the proposed system, for example, Python, PHP, JavaScript, Node.js, and Java. Open-source libraries such as CircularGaugeView for Android, Bootstrap front-end framework, and notification services like Amazon SNS service and Google Firebase were also utilized. Google Firebase was selected because it can provide real-time database for storing data and offer push notification to the mobile application. Amazon SNS was also used to send SMS notification.

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H. Results and discussion

The proposed smart aquaponics system was continuously tested for 28 days. All sensor values for water temperature, water flow rate, light intensity, pH level, and plant height were acquired. Furthermore, manual measurements of plant height and fish weight were made for data mining and analysis. The plants are Chinese water spinach, also known as kangkong, and the fish is tilapia. Linear regression models were devised and their respective R2 value (goodness-of-fit measure) were calculated. The linear regression model of yp = 0.8814x + 5.8796 with R2 value of 0.9732 was formulated for plant height over time, as evidenced in Fig. 16 (a), where yp is the plant height (cm) and x is the number of days. In the same fashion, yf = 0.5916x + 57.7370 with R2 value of 0.9848 for fish weight over time, as evidenced in Fig. 3 (b), where yf is the fish weight (g) and x is the number of days. Since both R2 values are very close to 1, which represents a perfect fit, the two devised models can respectively describe the relationships between the plant growth and the fish growth over time.

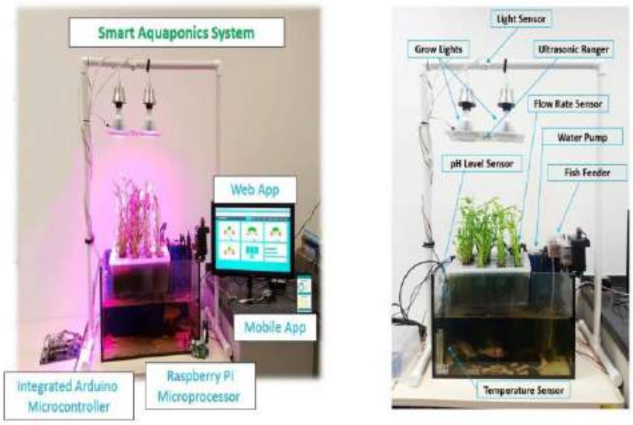
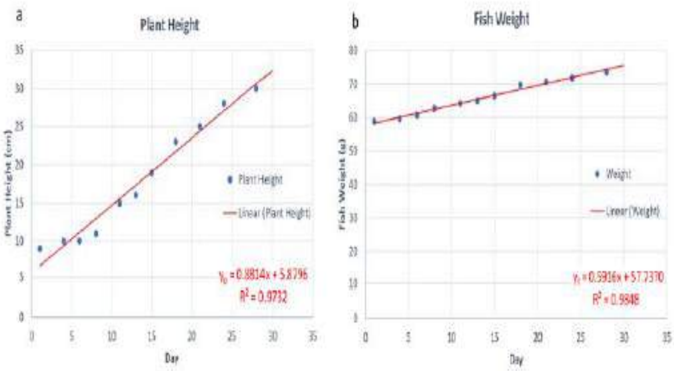


Fig. 15. Smart aquaponics system.



Day	1	4	6	8	11	13	15	18	21	24	28
Plant Height (cm)	9	10	10	11	15	16	19	23	25	28	30
Average Fish Weight (g)	58.75	59.50	60.75	62.75	64.25	65.00	66.50	69.75	70.75	71.75	73.50

Fig. 16. (a) Regression analysis for plant height; (b) Regression analysis for fish weight.

3. CONCLUSION

A smart aquaponics system was designed and developed by integrating data acquisition unit, alarm unit, system rectification unit, central processing unit, web application, mobile application, and cloud server, as presented in Fig. 15. The proposed system can continuously monitor and control water quality, light intensity, and fish feed; automatically send early warnings in form of email, SMS, and push notification; and rectify system abnormality without human interference. Future work includes (1) adding a dissolved oxygen sensor and a nitrate sensor to detect oxygen level and nitrate concentration level in the water respectively, (2) incorporating solar panels to harness solar energy to power the actuators, and (3) providing live video streaming of the aquaponics system using the mobile application. With a large-

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scale implementation, the proposed system can significantly reduce labour and operating costs, while increasing livestock production and profitability, which contributes towards sustainable and liveable cities.

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