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Sustainable Smart Aquaponics Farming Using IoT and Data Analytics

Bikram Paul, M.S. Ramaiah University of Applied Sciences, India
Shubham Agnihotri, M.S. Ramaiah University of Applied Sciences, India
Kavya B., M.S. Ramaiah University of Applied Sciences, India
Prachi Tripathi, M.S. Ramaiah University of Applied Sciences, India
Narendra Babu C., M.S. Ramaiah University of Applied Sciences, India

ABSTRACT

Traditional agriculture is facing numerous serious issues such as climate variation, population rise, water scarcity, soil degradation, and food security. Though aquaponics is a promising solution, research on building an economically feasible smart aquaponics system is still a challenge. In this paper, a sustainable smart aquaponics system using internet of things (IoT) and data analytics is proposed. The acquired data from sensors such as Ph sensor and temperature sensor is analyzed using machine learning techniques to interpret the health of the system. Further, the proposed system includes automated fish feeder which is controlled by Raspberry Pi to automate and reduce the maintenance issues. The Android application helps the user to remotely control and monitor the health of the system and also track the critical system parameters. Further, the system is driven by the solar power to make it sustainable. A comprehensive survey on the key aspects of aquaponics including comparison of the proposed model with the traditional aquaponics model is also presented.

KEYWORDS

Android Application for Farming, Aquaponics, IoT, Machine Learning in Aquaponics, Smart Farming

INTRODUCTION

India is a country with vivid distribution of land and less availability of water for domestic and agricultural purposes. In need of a good alternative against food and environmental problems Aquaponics farming method approach guarantees to be an amazing alternate. Therefore, it is worth exploring how a Cloud-based Sustainable Smart Aquaponics farming using IOT-based predictive analytics affiliates the classical traditional farming methods for efficient growth and information utilization.

Aquaponics is a symbiotic system which enables aquatic life and plants to coexist in a closed loop system. Aquatic animals produce nutrients rich by-product (Ammonia) of their waste which is used by plants as fertilizer. Nitrifying microorganism (Nitrosamines) converts the ammonia to nitrite. Another nitrifying microorganism (Nitro-bacteria) then converts the nitrite to nitrate. The water becomes

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high in nitrate content, which is the food for plants, but is harmful to the aquatic animals. Plants are grown in a grow media with a constant supply of this water. The plants successively assimilate the nutrients, reducing or eliminating the toxicity of the water that was harmful to the aquatic animal. The water, now clean, is returned to the aquatic animal surroundings and the cycle continues (Hussain et al., 2013). Thus, this nutrient removal not only cleans or improves water quality for the aquatic animals but also reduces the overall water consumption. Water is added externally to compensate for the water loss from soaking up by the plants or evaporation. Several mechanical and biological processes such as heating, pumping, filtering etc. are involved in this system. The data analytics and sensor technology allow to setup optimum conditions for both plants and fish unites, thus ensuring high productivity and enhancing resource efficiency.

Researches over the decades have evolved basic form of aquaponics into modern food production systems of today. Initially, in 1980s, most attempts to integrate hydroponics and aquaculture had very few successes. The 1980s and 1990s advances in the system design were noticed: bio-filtration and the identification of the ideal fish-to-plant ratios led to the generation of closed systems that allowed the recycling of water and nutrient build-up for plant growth. In its early aquaponics systems, North Carolina University (United States of America) manifested that the consumption of water in an integrated system was just 5 percent of that used in pond culture for growing plants (Somerville et al., 2014). This invention among other key initiatives pointed to the compatibility of integrated aquaculture and hydroponic systems for growing vegetables and raising fish, particularly in arid and water scarce regions. Although since 1980's, aquaponics is in use, still it is a relatively new method to produce food with a small number of researches and practitioner hubs worldwide with limited aquaponics experience (Somerville et al., 2014). The aquaponics system has certain weaknesses as described in a United Nations Food and Agriculture report, the system is knowledge intensive and researchers around the globe are trying to make the system more sustainable and efficient, the system is expensive to start-up, it is energy and resource demanding, requires daily maintenance and has fewer management choices compare to agriculture and aquaculture. Traditionally, such systems can be replaced and managed by making this system automated. This automated system includes three sections: production process at the bottom that is sensors, actuators, hardware, etc. while the second section, enterprise resource planning systems for managing data includes Data-Acquisition system and Mobile-based Application. The last section is a Photovoltaic System for making system sustainable by using renewable energy. These sections reflect the characteristics of information of the automated system such as requirements for real-time, frequency of transmission, data-acquisition, and other requirements.

By analyzing the features of each section, the enhancement which can be created by IOT can be observed. The IOT is defined as the connecting of physical things to the internet which makes it feasible to access remote sensor data and manage the physical world from distance (Karimanzira & Rauschenbach, 2019). Furthermore, it would be precipitous to not use the technologies being developed that pull in data, from smart sensors to satellites that can be crunched using diverse cloud-based analytic software program gear such as artificial intelligence, to make aquaponics operations more efficient and eco-friendly..

RELATED WORK: AQUAPONICS SYSTEMS

The concept of Aquaponics farming existed for thousands of years: practiced in Asia and South America (Somerville et al., 2014). People argue whether the Chinese or the Aztecs were the first people to use aquaponics. The Chinese used a system in the 6th century. They raised and reared ducks in cages (with partial open floors opening above finfish ponds). The waste from the ducks would feed finfish. They also reared catfish in another pond which used water from finfish. So, any excess waste would be supplied to the catfish. The waste of the fishes went to the fields of paddy. This was a system in harmony where nothing went waste whereas the Aztecs, they called their aquaponics system "chinampas". In this system, they grew a variety of crops including maize, squash, and other plants on rafts in water which were used to rear the fish too. The Aztecs used these systems from 15th Century (Kledal et al., 2018). The Chinese and Aztec's work helped in building the Modern Aquaponics Systems. In 1969, John and Nancy Todd along with William McLarney founded the New Alchemy Institute. They researched on developing a "proto-ark" which was powered by solar to be self-sufficient and would allow a family to survive a year-round using holistic methods (Southern & King, 2017). In the 1980's Mark McMurty and Professor Doug Sanders created the first "closed loop" aquaponics system. In their system, excrete from the fish tank was used as nutrition source for growing tomatoes and cucumber on sand beds acting as bio-filters (Kledal et al., 2018).

Currently, the largest indoor commercial sized aquaponics system is in Watsonville, California (Goldstein, 2013). Even in Australia, interest in aquaponics took off because it showed an effective solution for water restriction problems and poor soil conditions challenges. It was proved by Wilson Lennard (an Australian academic with practical commercial aquaponics experience and knowledge) that by using the same water continually within the system it to possible to achieve an optimal balance of fish to plants. Therefore, this proves that the aquaponics system is the most water efficient food growing mechanism (Pountney, 2015).

The Caribbean island of Barbados started aquaponics systems at home initiative: to reduce growing dependence on imported food and generating revenue by selling produced products to tourists(Rahman & Amin, 2016), In Bangladesh, a Professor named Dr. M.A. Salam at the Department of Aquaculture of Bangladesh Agricultural University, leads a team to develop plans for a low-cost chemical free aquaponics system to produce crops and fishes. This initiative is focused on people living in adverse climatic conditions such as the salinity-prone southern area and the flood-prone area in the eastern region. Dr. Salam's work innovates a form of subsistence farming for micro-production goals at community and personal level (Sultana et al., 2017).

Despite the researches, the biggest challenge in commercial aquaponics is its multi-disciplinary, needing further expertise in economics, finance, and marketing. These factors are the reason of why this system is not being used by major industries and has not replaced the traditional farming. The system performances and environmental burdens could be reduced by using proper eco-design enhancing economic profitability. The eco-design information of a process could be gathered using the LCC (Life Cycle Costing) and LCA (Life Cycle Assessment) approach. This analysis method allows computing the strengths and weaknesses of system before actual construction (Forchino et al., 2018).

Other than aquaponics, there are some different farming techniques such as hydroponics, aeroponics. A hydroponics system has two main parts: the grow beds and the reservoir. The reservoir contains the nutrient solution, or the water mixed with various nutrients that plants need to grow successfully in the media bed. The grow beds, on the other hand, contain the media and the 'cups' that will hold the plants in place. In hydroponics, the water supply needs to be changed continuously, because the nutrient solution builds up salts and chemicals in the water which can kill the plants.

Aeroponics is a variation of hydroponics, but instead of using a grow bed filled with media, the plants are instead suspended, with roots facing a sprinkler system connected to the main nutrient reservoir. Aeroponics system is made up of high-pressure pumps, sprinklers, and timers. If any of these break down, plants can be damaged or killed easily.

Aquaponics system solves the drawbacks of hydroponics and aeroponics. Aquaponics is a combination aquaculture and hydroponics. Aquaculture is essentially just ðsh farming, generally but not always referring to farming in controlled environments, in contrast to farming in the ocean, or ðshing wild ðsh. Hydroponics is farming without soil. Instead the plants roots are grown in a nutrient rich solution providing all their water and mineral needs. These plants can be grown in environments with either no substrate, just growing out of the water pipe, or an inert substrate such as gravel. Aquaponics combines these by taking the nutrient rich solution created by the ðsh and using that to water the plants, which in turn ðlter the water so it can be returned to the ðsh.

In the interest of highest efficiency and productivity, some numerical trade-offs are recommended and are outlined below.

pH Stabilization

pH is critical for all living organisms within a cycling system which includes fish, plants, and bacteria. The optimal pH for every organism is different. Most plants need a pH value between 6 and 6.5 (Villaverde, 1997). The fish species achieves best growth performance between pH 7.0 and 9.0. The nitrifying bacteria have a higher pH i.e. above 7, Nitrobacter: 7.5, Nitrosomonas: 7.0 - 7.5 (Villaverde, 1997). pH imbalances lead to the accumulation of ammonia in the system. The highest possible pH value should be consistent to prevent ammonia accumulation. The ideal pH value for the system is between 6.8 and 7.0.

Nutrient Balance

Fish feed: main nutrient input is divided into assimilated feed, uneaten feed, soluble and solid fish excreta. Soluble excreta are mainly ammonia and most available mineral until it is transformed into nitrite and nitrate by nitrifying bacteria (Lekang & Kleppe, 2000). Both uneaten feed and solid faeces are solubilized from organic material to ionic mineral forms assimilated by plants. Minerals have different solubilization rates and do not accumulate equally, influencing their concentrations in the water. The wastes are externally filtered, and can be mineralized and reinserted into the hydroponic beds (Lekang & Kleppe, 2000).

Pest and Disease Management

Conventional pesticides used in hydroponics cannot be used in aquaponics because of toxicity risk to the fish and to the desired biofilm (Nichols & Savidov, 2012). The need to maintain the nitrification biofilm and other nutrient solubilizing microorganisms also prevents the use of antibiotics and fungicides for fish pathogen control and removal in the aquatic environment (Saraf et al., 2014). Furthermore, antibiotics are not allowed for plant application (Lagos-Ortiz et al., 2017) so their use against fish pathogens must be avoided in aquaponic systems (Saraf et al., 2014). These constraints demand innovative pest and disease management solutions for fish and plants that minimize impacts on fish and desired microorganisms (Lagos-Ortiz et al., 2017).

Socio-Ecological Challenges

Aquaponics responds to diverse ecological and social challenges, which point to the importance to focus on efficient and sustainable forms of agricultural production.

Mineral Recycling

In terms of sustainability, both phosphorus and potassium are major components of agricultural fertilizers. Increasing usage and depletion of these minerals without reuse or recapture has a negative impact (Sverdrup & Ragnarsdottir, 2011). Nutrient recycling policies, especially for phosphorus, are crucial in order to avoid global food shortages.

Water

Countries are facing water scarcity leading to a growing incapability in feeding their people. On average, global agriculture uses around 70% of the available freshwater resources (Greenlee et al., 2009). Compared to conventional agriculture, aquaponics uses less than 10% of water, depending on the climatic conditions. Aquaponics can reduce freshwater depletion associated with irrigation whilst guaranteeing safe encouraging sustainable farming and food production practices. System related water losses that occur in evaporation, plant transpiration and the water content of the agricultural products can be compensated for by capturing water from air humidity or by reverse osmosis desalination plant in coastal areas.

Energy

The energy requirements of aquaponics are likely to be based on system configuration (design, scale, technologies) and geographic location (climate, available resources). For each location, different measures are needed to ensure that each system will have a suitable sustainable energy source all year round to provide stable conditions for fish and plants. This is crucial, as fluctuations in temperature might harm fish, plants, and nitrifying microorganisms. This requirement constitutes a mandatory factor in regions with constantly and seasonally changing climatic conditions as well as in hot and arid climatic zones. Ensuring stable conditions may be achievable in equatorial areas without additional technology. Harnessing solar energy can be beneficial in order to either run climate control systems within, or to heat up a low-energy greenhouse with passive solar heating.

Sustainable Aquaponics Farming

Environmental Sustainability

Water Scarcity is a major issue in India, Niti Aayog report of 2019 says: 21 cities will arrive at zero day. Around 40% of population in India will not have access to clean drinking water (Dutta, 2013). It will directly impact the food security of India. Practicing Intense Aquaculture results in contamination of large water bodies, resulting in water pollution (Blidariu & Grozea, 2011). Aquaponics farming uses recirculation of water, the waste generated by aquatic animal while practicing Aquaculture, now can be used by plants, resulting in purification of water. This process prevents the contamination of large water bodies also lowers the agricultural water utilization by 90%.

Socio - Economic Sustainability

There is a rise of farmers suicides in India, the main reason is failure to pay back loans due to crops sold at lower prices or crop failure (Dutta, 2013). Traditional farming requires farmer to work for couple of months to gets results i.e. crops and by selling them they can repay their loans. But couple of months is a big tenure, crops fails due to numerous reasons like fire, weather, nutrients, etc. This is not the case with Aquaponics farming, the production here is throughout the year. The plants are not affected by weather, and the chances of failure of crop once the system is established are very less. The price and demand of Aquaponics farming is increasing, the profit margins are high resulting in faster payback of loans and more money earned. As this farming require same care everyday unlike traditional, it generates a stable employment and runs the local economy of the area.

Considering all the above numerical trade-offs, the benefits of aquaponics relate not just to the efficient uses of land, water and nutrient resources but also allow for increased integration of smart energy opportunities such as solar power.

METHODOLOGY

India is a country with a population of 1.5 billion and is expected to grow more. Due to problems like less available water and vivid distribution, it suffers problems in cultivating crops. Even the farming technique adapted requires extravagant lands, never-ending manpower, continuous fertilization, and wavering crop production. These lead to a huge rise in hunger, this is the same at global scale resulting in global hunger (von Grebmer et al., 2019).

To resolve the above problems, we propose a system, a Sustainable Smart Aquaponics Farming using IOT and Data Analytics. The Aquaponics System not only requires 90% less water (Greenlee et al., 2009), no use of pesticides and gives higher yield and by making it smart and sustainable, but also gives a new, better, and efficient farming experience to the farmer. Besides the monetary savings in water use and fertilizers, the importance of preservation of natural resources for future generation justifies the use of this system. The limitation is that it requires constant management of aquatic life and the adjoined farm which sometimes becomes unmanageable. It is also necessary to constantly monitor the water conditions to grow media manually.

Components Used in the Automated Aquaponics System

pH Sensor

The pH sensor provides the acidic or basic nature in the system. The total range of the pH sensor is 1-14 (acidic to basic). The pH sensor is used to determine the extent of ammonia excretion by fishes, more the pH the more ammonia is being produced which could be harmful for fishes and with low pH that indicates that enough ammonia is not being generated for the plants to grow. The pH value of ammonia (excreted by fishes) is 10, the ideal pH sensor value for the system should be in the range of 6.8-7.0 to maintain the health of the fishes and plants (error of + 0.3 is acceptable).

Temperature Sensor

The temperature sensor helps in reading the temperature of the system. The resolution of the sensor is upto 12 bits and a measuring range of -55°C to 110°C. The measuring accuracy is ±5°C. The temperature sensor is used to determine the temperature in the fish tank so that deaths of fish could be avoided due to extreme heat and cold. With changes in temperature the caretaker/user could take measures to maintain the temperature of the water in the tank.

Ammonia Alert Kit

The ammonia alert kit is an indicator which changes color from yellow to green to blue based on the concentration of ammonia present. The alert kit is in addition to the pH sensor to indicate the ammonia presence in the fish tank. The color indicator of yellow indicates < 0.02 ppm, green indicates 0.05 ppm, light blue indicates 0.2 ppm and dark blue represents 0.5 ppm. And so, this would allow the caretaker to determine if the readings by the pH sensor matches the actual presence of ammonia in the system.

Arduino Uno Board

The Arduino uno board consists of 14 Digital I/O pins, 6 Analog pins, 16MHz quartz crystal. It operates at 5 volts, recommended operating condition is 20mA and maximum operating condition of 40 mA. The Arduino uno is a microprocessor and is used to collect data from the pH and temperature sensor.

Wi-Fi module ESP8266

The Wi-Fi module is a microchip with full TCP/IP stack and microcontroller capability. This module is used to store the data in the thingspeak cloud channels.

Raspberry Pi3

The raspberry pi3 is a microprocessor and is used to execute machine learning model and fetch data from the thingspeak cloud, process it and send the output to the Arduino Uno. The processing speed is 700MHz to 1.4GHz with a memory range of 256MB to 1GB.

Servo Motor

The servo motor is used to rotate the fish feeder. The servo motor has an operating voltage of 4.8V~6.0V, operating speed of 0.12sec/60 degree, output torque of 1.6kg/cm 4.8V, dimension of 21.5 x 11.8 x 22.7mm and can support a weight of 9g. The servo motor is connected to the microcontroller and based on output the motor rotates the fish feeder and drops the food.

Solar Panel

The solar panel is to generate electricity from the solar rays into DC electricity. The solar panel has a capacity of 16 – 18V. The aquaponics system requires pumping of water 24/7 which leads to high electricity consumption, but this could be avoided or reduced with the use of solar energy harnessed from solar panels to provide power to the water pump and the other components to function on solar power. To make the system self-sustainable five solar panels of 18V would be efficient and capable to generate the power required for the complete system to function without pause. The correct placement of solar panels maximizes the power generation.

Bulk Converter

The bulk converter is used to stabilize the voltage generated from the solar panel (16-18V) to 12V, the DC battery has a capacity of 12V and so the voltage needs to be stabilized before it could be stored.

DC Battery

The DC battery is used to store the DC charge generated from the solar rays. The total capacity of the battery is 12V. The power generated during the day using the solar panel is stored in batteries for the system to be able to function at night or during low sunlight.

Inverter AC to DC

The first stage is a DC to DC conversion process that raises the low voltage DC at the inverter input to around 300 volts DC. The second stage is the actual inverter stage that converts the high voltage DC into 230 V, 50 Hz AC voltage. The AC voltage is used to provide energy to the pump and the micro-controllers making the system to operate 24/7 with naturally generated electricity.

Water Pump

The water pump is used to pump water from the fish tank to the grow bed. The power capacity of the water pump is 35W, operating at a voltage of AC 165-220V, 50Hz. The water pump has a maximum lifting height of 2.5m and operates at an output power of 1HP (Horsepower).

Android Device With the Android Application Installed

The android device is used to receive data about the system and determine the health of the system and get the data in the form of graphs about the pH and the temperature sensor. An android application is created to monitor the system and provide real time updates to the user. The application allows the user to add channel data (allowing to fetch data from the cloud), view real time data and display in graphs, delete channel details, click, and save pictures from the application. The application also allows to check for the system health which is updated after the raspberry pi computes the result using the machine learning model.

Labor Reduction Automation and Vertical System Built

Figure 1 and Figure 2 represents the system design. Figure 1 represents the system flow diagram: system consists of a fish tank, a grow bed, bell-siphon, sensors: pH and Temperature, ammonia detector/alert kit, a solar panel, micro-controllers, battery, water pump and a fish feeder system. The pH and temperature (DS18S20) Sensor are to be placed inside the fish tank. The sensor data is received by the Arduino Uno which transmits the data to cloud using Wi-Fi module (ESP8266). It is also integrated with an android app, which would help any user to fetch and visualize data from the thingspeak API.

Figure 2 represents the block diagram of the system and represents the integrated sections mentioned in Figure 1.

The Raspberry Pi would fetch the data from the thingspeak cloud and run a DNN on it. The system also consists of a solar panel which would generate electricity and is stored in a battery. The voltage stabilizer would provide the required voltage to the battery and to the pump. Inverter converts DC to AC and supplies power to pump and to the other components of the system. The pump enables

Figure 1. System flow diagram of the smart aquaponics system

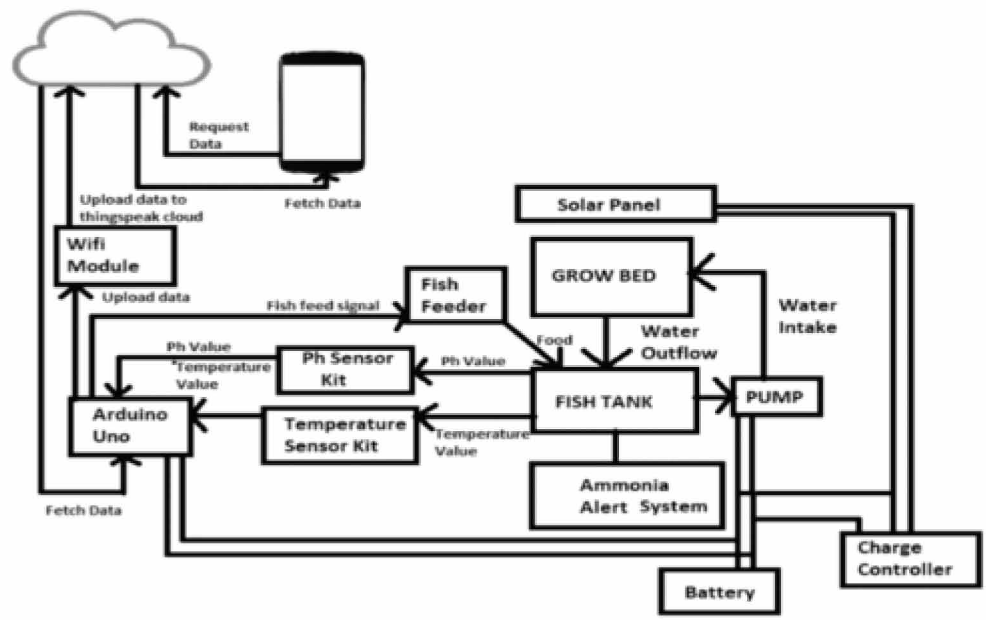
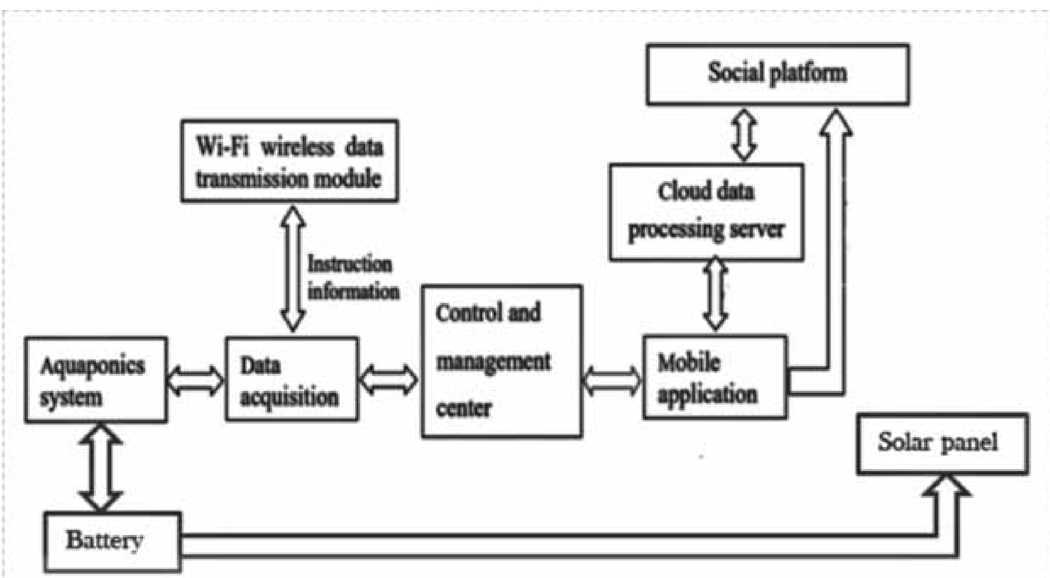


Figure 2. Block diagram for the smart aquaponics system



water flow from the fish tank to grow bed. This system is based entirely around the nitrogen cycle. More than 50% of the waste produced by fish is in the form of ammonia secreted in the urine and, in small quantities, through the gills. Ammonia is toxic to fish in high concentrations, so it must be removed (Kulkarni et al., 2019).

Nitrosomonas turns ammonia into nitrite, while nitrobacter converts into nitrate. Both nitrates can be used as plant fertilizer (Joyce et al., 2019). Nitrate-rich water is introduced to the hydroponically grown plants (plants grown without soil) through pumps. These plants are placed in beds that sit on tubs filled with water, and the water is enhanced by nitrate harvested from the fish waste. The plants' bare roots hang through holes in the beds and dangle into the nutrient-laden water (Kulkarni et al., 2019). The roots of the plants absorb nitrates, which act as nutrient-rich plant food. These nitrates, which come from fish manure, algae, and decomposing fish feed, would otherwise build up to toxic levels in the fish tanks and kill the fish. But instead, they serve as fertilizer for the plants (Kulkarni et al., 2019).

The hydroponic plant roots function as a bio filter. They strip ammonia, nitrates, nitrites, and phosphorus from the water. Then, that clean water is circulated back into the fish tanks (Kulkarni et al., 2019). The grow bed consists of a bell siphon which lets the water get accumulated in the grow bed for a certain height and then pumps down the water back to the fish tank. This cycle repeats over and over, with the fish providing nutrition for the bacteria, the bacteria breaking down the fish waste and feeding the plants, and the plants cleaning the water to return to the tank.

The Developed Aquaponics System

A vertical aquaponics system is a water and space efficient way to grow plants and raise fish. The production here is twice the amount of plants compared to a normal aquaponics system in the same area. The prototype for the vertical system has been built with a single row of grow bed and the fish tank to make the system automated and to display the working of the system with the electricity being generated by solar panel and the water pump and the electrical devices being powered by the battery. To power the pump for multiple rows of vertical system requires the usage of multiple solar panels which increases the current budget for the project, but with the proper functionality of the single layer of the vertical grow bed that assures that when multiple layers are increased then the solar panels, battery capacity and the pump power needs to be increased. To determine the required number of solar panels that could suffice the energy requirement of the system with increase in the columns and rows in a vertical system, energy load forecasting is required and it is a necessity to determine the energy load to be able to keep the system functional, various techniques could be used to forecast the energy load such as forecasting by seasonal recurrent SVR using chaotic bee colony algorithm, empirical mode decomposition adaptive noise and support vector regression with quantum-based dragonfly algorithm, and other various methods are available for forecasting the energy load (Hong, 2011; Zhang & Hong, 2019).

Developed Circuits

Figure 3 represents the circuit connection for sensor circuit. The sensors i.e. Servo motor, Temperature sensor, pH sensor and Wi Fi module are connected to Arduino Board which is powered by Raspberry Pi which is used to run the developed Deep Neural Network model. Figure 4 represents the solar panel circuit connection to the buck boost converter and to the battery.

Figure 5 represents the developed Aquaponics System. The aquaponics system consists of a grow bed with a bell siphon placed in the centre for the water circulation and the grow bed consists of pebbles for the bacteria to accumulate to provide nutrients to the plants. For the system to stabilize it took a duration of one month during which the bacteria got accumulated to convert the ammonia into nitrate. The water pump and the micro-controllers receive the charge from the electricity generated by the solar panel and the DC charge being stored in the battery and the components receive the charge after conversion from DC to AC using the inverter. The sensors are connected to the micro-controllers and receive the charge from the micro-controllers. Based on the size of the grow bed and the quantity of plants the quantity of fishes needs to be determined, based on which the duration for the rotation of the fish feeder must be adjusted. The system has been automated for a duration of three months and the growth of plants has been successful with the growth of coriander, the sensors recorded the

Figure 3. Sensor Circuit Diagram

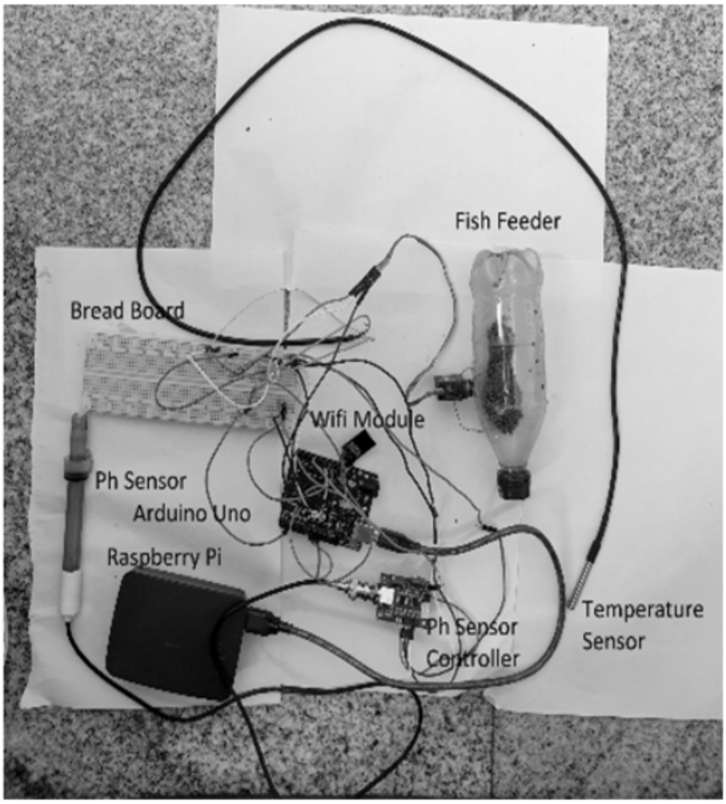
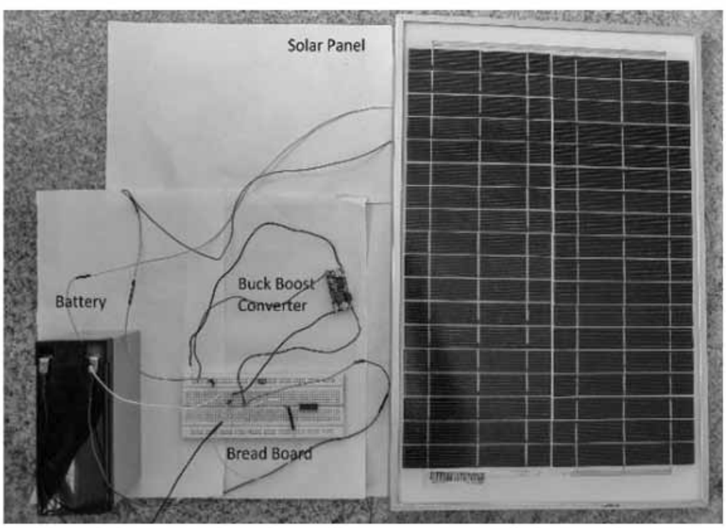


Figure 4. Solar Panel Circuit



readings for 3 months allowing to monitor the health of the system and the fish feeder determining the rotation based on the prediction by the neural network model.

Android Application

An android application is created to provide the user with the real time updates of the system. The android application authenticates the thingspeak channel and downloads the data and displays it to the user. The various tabs in the android application provides the user with graphs of the pH sensor and the temperature sensor readings, provides updates about the current health of the system and allows the user to store images of the aquaponics system and a gallery to display the images. The android application fetches data from the thingspeak channel 'Health Checker' and based on the last entry displays details about the condition of the system.

Data Acquisition

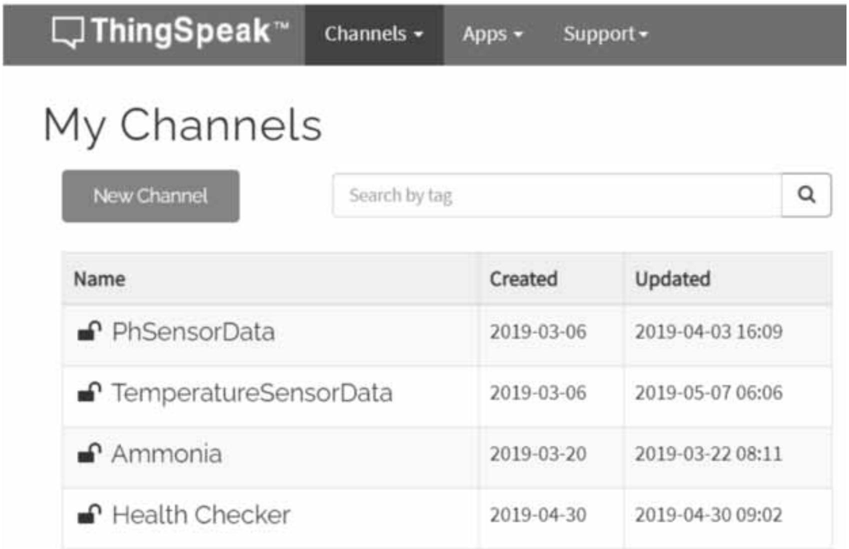
Data Acquisition From the Sensors to the Arduino and Raspberry Pi

The pH and temperature sensors are present in the fish tank of the aquaponics system and aid in checking the health of the aquaponics system. The pH sensor generates the data of the current pH of the fish tank and the temperature sensor records the temperature every 5 minutes. The sensor data is collected by Arduino uno which is powered by raspberry pi and is uploaded to the Thingspeak cloud channel via Wi-Fi Module. The Wi-Fi Module is connected to the internet which allows the data to be uploaded to the thingspeak channels.

Figure 6 represents the four channels created in the thingspeak cloud to store data for various sensors and the predicted values of the machine learning module. The different channels consist of api keys for read and write in thingspeak cloud which is used to update the updated data points into the cloud. The ph sensor data is updated into the 'PhSensorData' channel, temperature sensor data into the 'TemperatureSensorData', the ammonia data has been generated manually based on the readings

Figure 5. Developed aquaponics system

Figure 6. Thingspeak channels



observed from the ammonia alert kit. The channel Health Checker is used by the android application to get the data about the current health of the system, i.e. the health of the plants and fishes. The machine learning module updates the result into the Health Checker module. The data received is updated in the thingspeak channels and the graph is updated instantly with data being received. The channel consists of 29000+ data points collected over a duration of 3 months.

Thingspeak Cloud and Machine Learning Module

The backend of the system has been implemented in python, raspberry pi supports python. Python is used for developing a fully connected DNN model which takes these sensor readings as input and gives the health status bit as an output. The model used is a three layer dense neural network.Libraries used are Keras, Tensorflow, Numpy, and pandas. Based on the output, fish feeding mechanism is automated. The data being stored in the server is split into train and test set, train set is used for learning and testing is used to check overfitting. The model is 95% accurate in real time.

The machine learning code retrieves data from the pH sensor channel located in the thingspeak cloud and converts the data into categories, the pH values has been subtracted by 7 in the dataset thats been provided to the machine learning module as 7 is the pH value for water and the pH content has been labelled and categorized based on the ammonia alert kit and is divided into 4 labels, the four labels are safe, alert, alarm and toxic. The pH in the range of 6-7 is safe, 7- 7.5 is alert, 7.5-8.2 is alarm and 8.2 and above is toxic. The temperature has been excluded from the dataset for the machine learning module, because the temperature could vary based on the location of the system and so the reading recorded a temperature within a suitable range that being considered the temperature is used to determine the health as with increase in the temperature than the threshold limit that would alarm the user via the android application.

Automation of Health Monitoring

The system is accumulated with a machine learning model trained over collected sensor data to monitor the health of plants and fishes and to automate fish feeder to provide food to the fishes (Misra & Chaurasia, 2020). The neural network analyzes the health of plants and fishes by making predictions on the current health status of the plants and fishes. Every morning, the model would fetch the latest uploaded data from the Thingspeak cloud and feed it to Deep Neural Network. Model Inference is done in raspberry pi. With increase in the pH of the water represents more presence of ammonia which is harmful for the fishes as the plants are unable to convert the ammonia into nitrate. To prevent the rate of ammonia from increasing the fish feed would be reduced to provide plants with the time to convert the ammonia into nitrate. The neural network retrieves the current data from the channel and makes the prediction in the health of the plants and fishes. The model gives a binary output depicting the health of the channel and the results are updated back to cloud in another channel which is used by the fish feeder and android application. The data is stored in incremented by 1 and added to the cloud in this case, health is measured in either '1' or '2' where '1' represents poor health condition and '2' represents good health condition. The output data is uploaded in the thingspeak cloud in the channel 'Health Checker', the android application retrieves the last entry into the channel and determines the current health condition of the system and provided appropriate measures to the user that could help improve the health of the plants and fishes, such that death of fishes and plants could be avoided.

Automation of Fish Feeder

The fish feeder rotates with the help of the servo motor which is normally coded to rotate twice a day, the fish feeder rotates from 0° to 45° clockwise and waits for a duration of 5 seconds and rotates back anti-clockwise to 0°. The fish feeder consists of a small outlet for the fish food to drop in the tank in the duration of 5 seconds. The prediction made by the neural network on the health of the system overwrites the number of feeds in a day if the health of the system is good, i.e. the prediction value of the neural network is '1' or '2' in the thingspeak channel then the fish feeder would rotate twice a day, but if the predicted value of the machine learning model is '0' or '1' in the thingspeak channel then the fish feeder would rotate once a day. With this measure with less food being provided would lead to less creation of ammonia by the fishes leading to the stability of the system.

RESULTS AND DISCUSSION

The task to develop automated and sustainable aquaponics system required various steps. Initially there was a need to capture the data in order to understand and predict the feeding pattern and the health of the system. Once the dataset was captured and transformed, optimal neural network was required so that the model wont overfit or underfit and give is the desired result with high accuracy. And finally, the output has to be displayed to the user in form of application. The outputs of each task is described below:

Data Acquisition System

To automate the whole system, data was collected from various sensors i.e. pH Sensor, Temperature sensor and Ammonia sensor and was combined and transformed to form input dataset for machine learning model.

pH Sensor Data

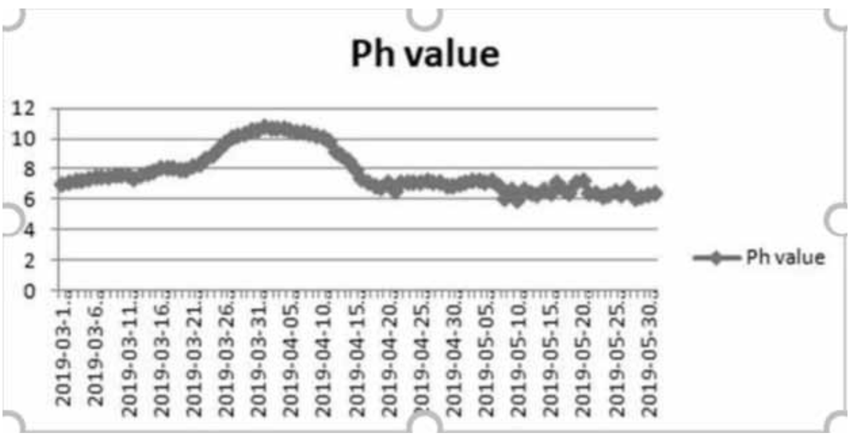
The pH sensor captured data from range 0 to 14. It was always immersed in water and recorded reading every 60 seconds approximately.

The data collected over a span of three months over a single layer vertical aquaponics system has been plotted. The pH values have been plotted in a graph as shown in Figure 8 from the data in Figure 7. There was a rise in pH from 21st march to 5th April because of unused ammonia but then came down but it came down as ammonia started to break into Nitrate and Nitrite.

Figure 7. pH Sensor readings in a tabular format

	A	B	C
1	created_at	entry_id	field1
2	2019-03-12 11:45:03 UTC	1	7.08
3	2019-03-12 11:45:18 UTC	2	7.08
4	2019-03-12 11:46:01 UTC	3	7.08
5	2019-03-12 11:46:53 UTC	4	7.08
6	2019-03-12 11:47:29 UTC	5	7.08
7	2019-03-12 11:48:00 UTC	6	7.08
8	2019-03-12 11:49:03 UTC	7	7.07
9	2019-03-12 11:49:25 UTC	8	7.08
10	2019-03-12 11:49:43 UTC	9	7.08
11	2019-03-12 11:50:00 UTC	10	7.08
12	2019-03-12 11:50:26 UTC	11	7.08
13	2019-03-12 11:51:02 UTC	12	7.08
14	2019-03-12 11:51:24 UTC	13	7.08
15	2019-03-12 11:52:20 UTC	14	7.08
16	2019-03-12 11:52:35 UTC	15	7.08
17	2019-03-12 11:53:22 UTC	16	7.08

Figure 8. pH Sensor reading in graphical representation



Temperature Sensor Data

The sensor was always immersed in the water tank, and recorded reading approximately every minute. The recorded reading is in celcius.

The temperature graph has been plotted as shown in Figure 10 from the data in Figure 9, it is constant throughout the tenure.

Ammonia, Nitrate and Nitrite Data

Ammonia, Nitrate and Nitrite data was recorded using ammonia sensor. The readings are in ppm. This is the most important information as it plays a major role in stabilizing the system. The abundance or scarcity of these minerals can lead to death of fishes and plants respectively.

Figure 9. Temperature sensor readings in tabular format

	A	B	C
1	created_at	entry_id	field1
2	2019-03-12 11:44:11 UTC	1	26.25
3	2019-03-12 11:45:00 UTC	2	26.25
4	2019-03-12 11:45:28 UTC	3	26.25
5	2019-03-12 11:46:04 UTC	4	26.19
6	2019-03-12 11:46:51 UTC	5	26.25
7	2019-03-12 11:47:16 UTC	6	26.25
8	2019-03-12 11:47:57 UTC	7	26.25
9	2019-03-12 11:48:20 UTC	8	26.25
10	2019-03-12 11:48:36 UTC	9	26.25
11	2019-03-12 11:49:08 UTC	10	26.25
12	2019-03-12 11:49:30 UTC	11	26.25
13	2019-03-12 11:50:05 UTC	12	26.25
14	2019-03-12 11:51:06 UTC	13	26.25
15	2019-03-12 11:51:21 UTC	14	26.25
16	2019-03-12 11:51:43 UTC	15	26.25

Figure 10. Temperature sensor reading in graphical representation

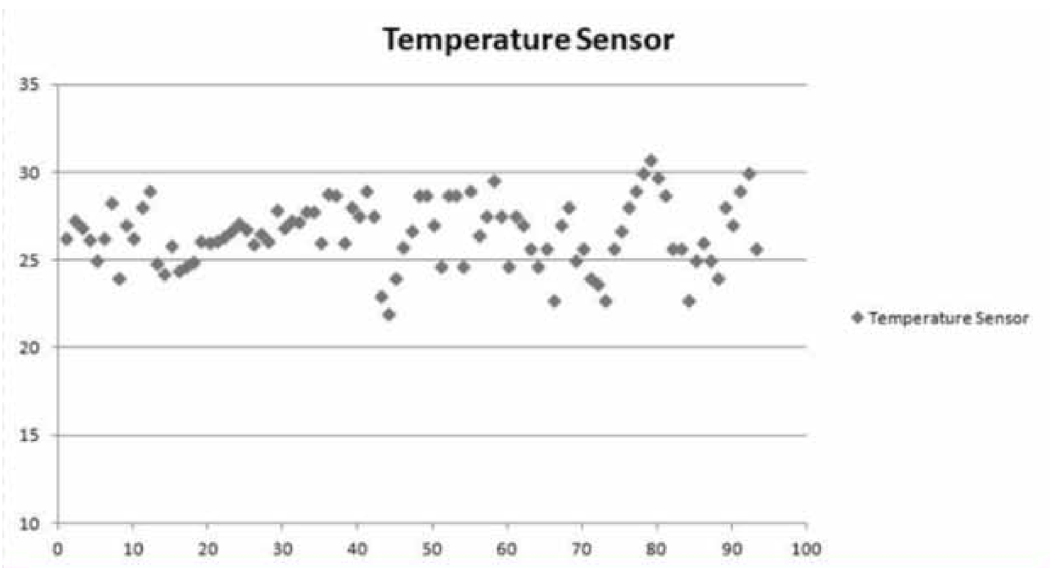


Figure 11 suggests that the ammonia is converted into nitrite and then to nitrate which is beneficial for the growth of crops. The graph is Figure 11 backs our inference made from Figure 8. The content of Ammonia is very high in the initial Tenure, and then it decreases with a slight increase in Nitrate and Nitrite value.

Supervised Data for Machine Learning Module

The dataset which was acquired from pH, temperature and ammonia sensor is combined and manually labelled in two two sets i.e. to classify the health of the system and to classify the feeding pattern for the fishes.

Figure 11. Amount of Ammonia, Nitrate and Nitrite

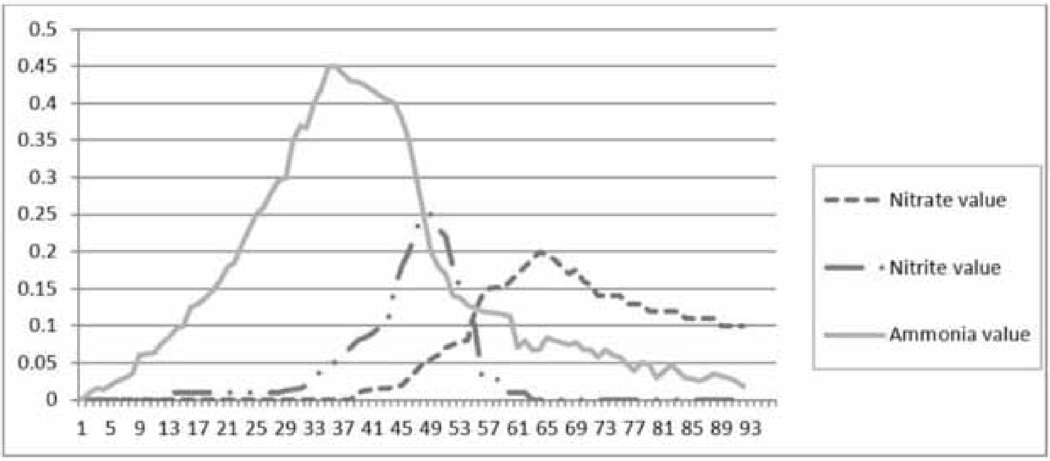


Figure 12 and Figure 13 represents the labelled data for the machine learning module. Here the pH value is converted to a range of -7 to 7. Class column represents the output label, in Figure 12, the higher the class the worse the situation is and in Figure 13, 2 represents to feed thrice a day, 1 represents to feed twice a day and 0 represents to feed once a day.

Automation of Aquaponics

Once the dataset is collected and model is trained. We inferred the model over real time data which correctly predicted the health of the system and gave appropriate feeding rotations. All the outputs and graphs can be viewed remotely using the developed android application.

Fish Feeder Output

The model runs once a day and decides the number of rotations it must make. If the rotation value comes as 2 it rotates thrice a day, else if it comes as 1 it rotates twice a data else it rotates once a day.

Figure 12. Dataset for heath of the system

	A	B	C	D
1	Ph	Ammonia	Ammonia content	Class
2	1.89	toxic	0.5	4
3	1.92	toxic	0.5	4
4	1.79	toxic	0.5	4
5	1.64	toxic	0.5	4
6	1.28	alarm	0.2	3
7	1.55	toxic	0.5	4
8	-0.45	safe	0.02	1
9	0.44	alert	0.02	2
10	1.28	alarm	0.2	3
11	1.32	alarm	0.2	3
12	1.18	alarm	0.2	3
13	0.93	alert	0.05	2
14	0.96	alert	0.05	2
15	1.12	alarm	0.2	3
16	1.12	alarm	0.2	3
17	0.86	alert	0.05	2
18	-0.47	safe	0.02	1

Figure 13. Dataset for feeding pattern

	A	B	C	D
1	Ph	Ammonia	Ammonia	Class
2	1.88	toxic	0.5	1
3	1.91	toxic	0.5	1
4	1.78	toxic	0.5	1
5	1.63	toxic	0.5	1
6	1.27	alarm	0.2	1
7	1.54	toxic	0.5	1
8	1.53	toxic	0.5	1
9	0.4	safe	0.02	0
10	1.2	alarm	0.2	1
11	1.3	alarm	0.2	1
12	1.1	alarm	0.2	1
13	0.9	alert	0.05	0
14	0.9	alert	0.05	0
15	1.1	alarm	0.2	1
16	1.1	alarm	0.2	1
17	0.8	alert	0.05	0

Neural Network Output

The neural network is trained over the combined data retrieved from the thingspeak channels. The Neural Network takes the sensor data as input which are the pH Values, temperature values and Ammonia present in water and decides the number of cycles of rotation during a day and feedback regarding the health of plants and fishes. The cycle of rotation is for the fish feeding Mechanism. Every day is divided in a cycle of 1, 2 or 3 resembling feeding fishes once, twice, or thrice respectively. Another algorithm gives feedback about the system to the user, taking the same input data and classifying the health of the system as good or poor. The model runs once a day and stores the predicted decisions to follow for the rest of the day. The accuracy of the developed model is 95%.

Figure 14 shows that in the tenure of 1st may to 7th may, the system was on average in the safe zone.

Android Application Output

Android is the most used operating system in smart phones, there are in total of 4 functionalities given to the user i.e. Add channels, delete channels, click images and check for system health. Appropriate screens have been made for each functionality.

Figure 15 is the home screen of the Android Application, it allows the user to add and delete channels, view gallery and monitor system's health. Figure 16 is the UI to add a new channel. The user must provide details like the channel id and name, and if private: the private key as well to add the channel and Figure 17 is the channel dashboard.

Figure 18 gives the health of the system. The application fetches the last recorded health and displays the output to the user. Figure 19 and Figure 20 represents the functionality of the application to click images of the system. It will help the user to monitor the growth. Image on the right, represents the gallery where the clicked images can be viewed.

Developed Aquaponics Model

Figure 21 represents the plants that grew on the aquaponics system on June 2019 and Figure 22 represents the plants that grew on the aquaponics system one year later as on June 2020. The prototype

Figure 14. Graphical representation of health of the system

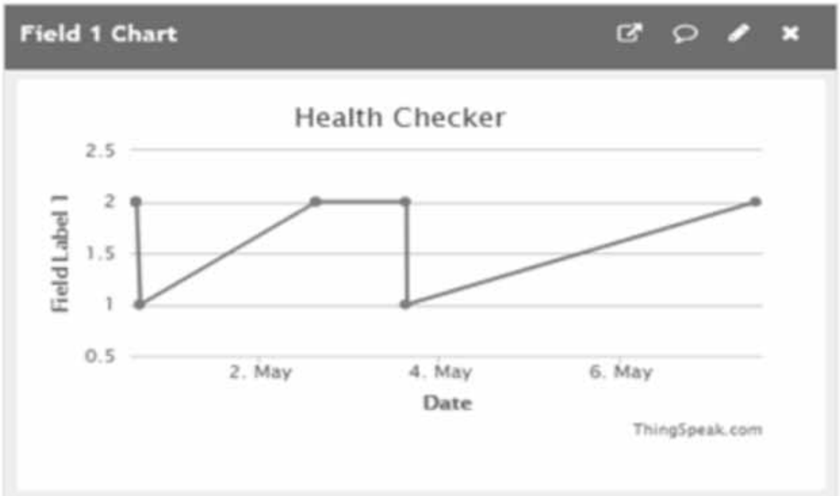


Figure 15. Home Screen

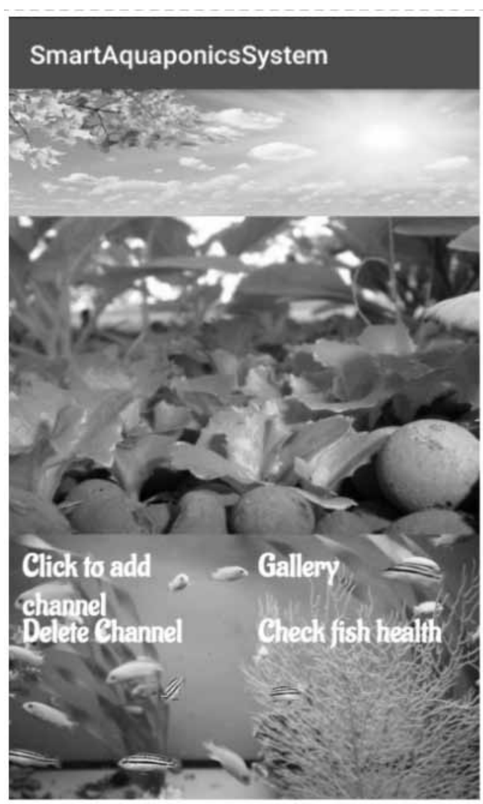


Figure 16. Add New channel

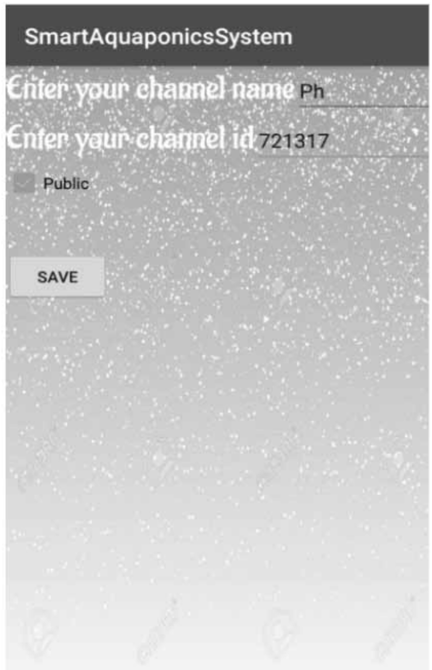


Figure 17. Channel Output Screen

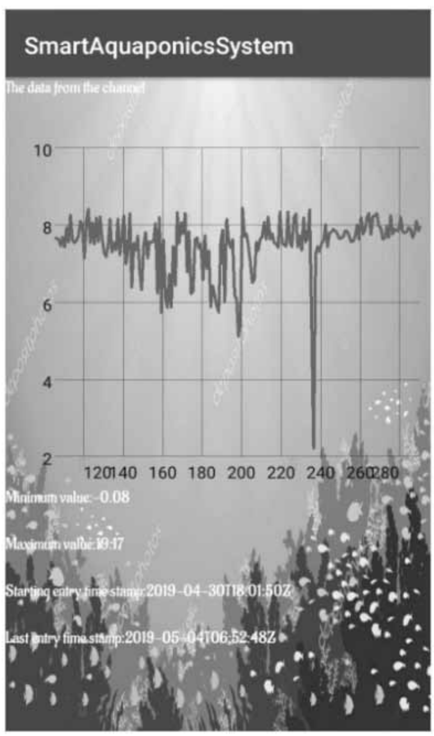


Figure 18. System Health

Figure 19. Gallery functionality

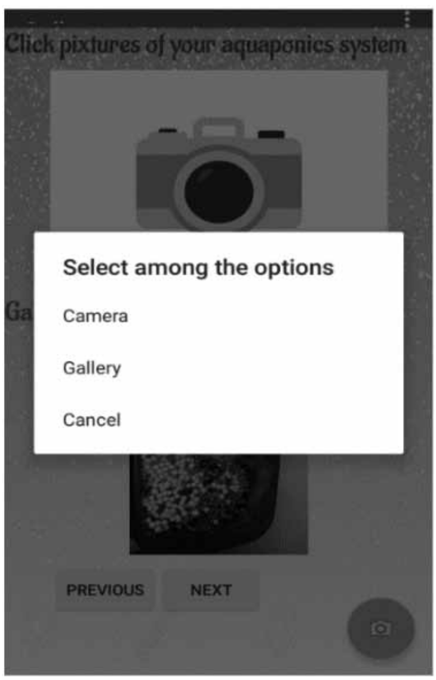


Figure 20. Camera Functionality

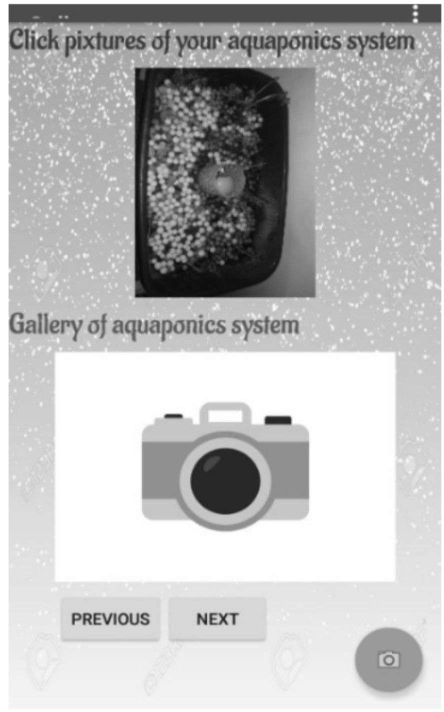


Figure 21. Grown plants on June 2019

system developed consists of a single layer of vertical system and the result has been promising and the same procedure could be implemented for more rows to the vertical system. The appropriate vertical system for an area of 25ft by 30ft would consist of five columns of vertical stands with each occupying a space of 3ft by 5ft and each column would consist of five racks of vertical grow bed stands. Each section would consist of grow bed, bell siphon to prevent the water from over-flowing the grow bed and create a vacuum to pump the water down to below racks with the last rack passing the water to the fish tank and pipes to transfer the water to the grow beds. The fish tank is placed below

Figure 22. Grown plants on June 2020

each column for the aquaponics cycle to continue. Inlet pipes transfers water from the fish tank to the top rack in each column. Grow bed consists of hydrotons and stones of rough edges allowing bacteria to accumulate and grow. Air pump would be placed in the fish tank for proper aeration and multiple solar panels would be required to generate the electricity required to power the complete system.

Cost of the Proposed Aquaponics System

The major factor for any system or product is its economic feasibility and the based on information gathered from research, 1) it has been determined that the larger aquaponics systems are economically superior to smaller ones, 2) profitability is sensitive to retail prices and 3) commercial aquaponics are more profitable through improves business plans which requires the investors to determine the potential customers which can be achieved only by sharing of knowledge and building of legitimation(König et al., 2018)(Greenfeld et al., 2018). Based on surveys conducted, only 30% of the investors has reported of profit (Greenfeld et al., 2018). Therefore, based on certain conditions and design, the probability of profit has been checked and the years required to make profit has been determined.

An accurate cost of an Aquaponics system cannot be determined because it is governed by various factors on daily basis like if the system is infected by a disease, the production will be low whereas investment rises. It also requires a high initial maintenance for a commercial scale which depend on various factors like size, etc. Thus, some approximations are made in the cost. Therefore, the cost is calculated as an average profit made per day and total time left to cover the initial investment. To develop a vertical scale garden, the initial investment requires to setup a system includes cost for the fish bed, grow bed, grow media, filters, water pump, connecting pipes, fishes, plants, and fish food. The everyday expense consists of salary of a person monitoring the system, fish feed, electricity supply to run the system and water supply to prevent the water from drying up (and cost to disinfect the system from diseases on a disease spread). All these expenses are recovered from profits made from the sales of crops and fishes grown in the system.

Approximate Initial Investment

The cost to develop a 5-layer Vertical Space Aquaponics System of Area: 25 ft X 30 ft = 750 ft^2 = 70 m^2 (Approx.), the total area required for construction of the greenhouse would be 1,000 ft^2 = 93 ft^2 considering the variable cost mentioned in Table 1 and fixed cost mentioned in Table 2. The cost

Table 1. Variable Cost to develop a 5-layer Vertical Space Aquaponics System for a year (Nair, S & John, 2018)

Component	Units	Cost
Personnel Salary (Rs 12,000/month)	1	Rs 1,44,000
Power Requirement (Electricity)	1000 units (kWh(5/unit))	Rs 60,000
Plant Seed	50 unit/ month	Rs 30,000
Water	10,500 (litre(2/litre))	Rs 2,52,000
Fish Meal	105 kg/month	Rs 30,000
Fish	20(70/fish)/ month	Rs 16,800
Maintenance Cost	-	Rs 1,20,000
Miscellaneous Cost	-	Rs 60,000
Gross Operating Cost		**Rs 7,12,800**

Table 2. Fixed Cost to develop a 5-layer Vertical Space Aquaponics System for a year (Nair, S & John, 2018)

Component	Units	Cost
Area Cost (Rs 5,000 sq. Ft)	1,000 sq.Ft	Rs 50,00,000
Cost of pond production/ Tanks installation	30 ton	Rs 20,000
Expenditure of aerator	-	Rs 13,000
Establishment of green house	-	Rs 85,000
Electrical equipment: water pump, air pump and connections	-	Rs 7,000(water pump) + Rs 6,000(air pump) + Rs 2,000(connection) = Rs 15,000
Plumbing costs	-	Rs 5,000
Establishment of grow bed	-	Rs 20,000
Solar panel and components	2 kW (Rs 60 pew Watt)	Rs 1,20,000
Cost of fish fingerlings (Rs 70/fish)	117	Rs 9,000
Cost of plant seeds	4,080 unit	Rs 2,00,000
Miscellaneous items	-	Rs 3,000
Plumbing: pipe, pipe fittings and connections	-	Rs 3,000 + Rs 500 + Rs 500
Gross capital expenditure		**Rs 54,94,000**

calculated for the complete setup it consists of 25 layers as 5-layer vertical system with five level in each column. The cost considered might vary based on location in India and the profit can vary based on the type of plants grown such as kale, swiss chard, lettuce, etc will earn more revenue. The proposed system is automated and so the labor requirement is less and so one person would be able to maintain the system. The data has been referred from a survey where people from India having an aquaponics system participated and provided the data (Nair, S & John, 2018).

The aquaponics system takes time for the system to get stabilized and once the ammonia production has stabilized and the plant growth has started then the system would start the production of crops along with the fishes and the expected income from the production would be approx. Rs 47,18,405 (approx.) in a year as mentioned in Table 3.

The system will be up in profit in 2.2 years and will be making profits at an enormous scale shown in Table 4.

Comparison With Traditional Aquaponics

In most aquaponics systems today, there is a lot of manual labour to keep the system running properly. Pumps must be manually turned on and off, temperature control is generally manual as well, and it requires a lot of human input to keep running. The proposed system does not require any human input other than to reðll the water, when water gets evaporate, and harvesting the ðsh / vegetables when they are ready. There are some aquaponics systems, which focuses on making the system smart by employing various sensors, actuators, microcontrollers in the system to monitor and control the water quality and fish feed. To ensure healthy growing environment for fish and plant, short message service, and push notification are automatically sent to the user when the sensor detects any abnormal condition. Moreover, fish feed is dispensed at the user pre-set timings of the day. All system activities and live sensor measurements are securely stored in a cloud storage for data analysis. User-friendly web and mobile applications were also created to provide graphical user interfaces between the aquaponics system and the user. But these approaches failed in making the system sustainable. These approaches require continuous grid power supply to run the system. The other big innovation of proposed system is to make the system suitable for more environments than just the industrial world. The proposed system can solve this problem by employing the solar panel to generate the solar power, so that our aquaponics system could be implemented in areas without reliable grid power.

CONCLUSION

The traditional aquaponics system has been modified with the data acquisition methods, Machine Learning model along with the IOT components which make the aquaponics system smart and reduces the human involvement in the maintenance of the system which in fact reduces the cost of human labour (Sofia & Ilham, 2018) (Misra & Chaurasia, 2020). Using renewable energy as power source to power the electrical components reduces the power requirement and reduces the cost of electricity. This makes the system sustainable and long-time running compared to the traditional

Table 3. Expected production in a year for 5-layer (Nair, S & John, 2018)

Outcomes	Total Revenue
Revenue from fish	Rs 41,53,880
Revenue from plant	Rs 5,64,525

Table 4. Recovery time for a 5-layer system

Costs and Profits	Value
Fixed Cost	Rs 54,94,000
Operational Cost	Rs 7,12,800
Total	Rs 62,06,800
Revenue	Rs 41,53,880 + Rs 5,64,525
Recovery	2.2 years

aquaponics system. The cost of the components is one-time investment and in the long term run the cost of this modified aquaponics system would be less compared to the traditional aquaponics system. The developed system reduces the total cost as it cuts down the daily labour required for maintenance and giving predictions and precautionary messages based on the situation can prevent system failures and can save that maintainance cost.

The proposed system was implemented along with two major sensors and an ammonia detection kit, which would provide certain data that can be used for maintenance for small scale systems, but for bigger systems more sensors could be implemented helping in much better insights. There are nitrate, nitrite and ammonia sensors used to detect the level of the respective compounds. Nitrate sensors consists of two electrodes a nitrate ion electrode and a chloride ion electrode. The nitrate sensor is to be kept in the grow bed as the nitrate is accumulated in the roots, therefore determining the nitrate value giving insights of total plants to be grown aiding is faster stabilization. The ammonia detection sensor could be used to replace the ammonia test kit giving more precision. Some fishes are critical to aeration such as trout and so if those fishes are being grown in the aquaponics system then the dissolved oxygen sensor would be helpful in determining the concentration of oxygen in the fish tank and respective measures could be taken to avoid the death of fishes. A temperature controller would be implemented for larger systems to stabilize the temperature of water and so the health of the system would improve. These above mentioned components and sensors would form the future work for the system.

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Bikram Paul graduated in Bachelor of Technology in Computer Science and Engineering from Ramaiah University of Applied Sciences in 2019. He is currently pursuing Master of Computer Science from University of Wollongong with specialization in Machine Learning & Big Data and Intelligent Systems. His research interest includes Artificial Intelligence, Deep Learning, Reinforcement Learning, Perception & Planning, Computer Vision, and Machine Learning.

Shubham Agnihotri graduated in Bachelors of Technology in Computer Science and Engineering from M. S. Ramaiah University of Applied Sciences in 2019. His research interest includes Deep learning, Reinforcement Learning, Quantum Machine Learning and Quantum Cryptography.

Kavya B. graduated in Bachelors of Technology in Computer Science and Engineering from Ramaiah University of Applied Sciences in 2019. She is currently pursuing Masters of Technology in Computer Science and Engineering from University Visvesvaraya College of Engineering. Her research interest includes Machine Learning.

Prachi Tripathi graduated in Ramaiah University of Applied Sciences in Electronics and Communications from Ramaiah University of Applied Sciences in 2019. Her research interest includes Multithreaded Database Applications, Servlets, Applets and JDBC.

C. Narendra Babu graduated in BE (CSE) from Adichunchanagiri Institute of Technology, Chikmagalur in 2000. He received his Masters Degree in M.Tech (CSE) from M.S.Ramaiah Institute of Technology, Bangalore in 2004. He obtained his Ph.D in computer science and Engineering from JNT University, Anantapur. He is presently serving as an Associate Professor in the Dept. of Computer Science and Engineering, M. S Ramaiah University of Applied Sciences. His research interests include predictive analytics, machine learning, and artificial intelligence.