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Design and Development of IoT based Hydroponic Farming Setup for Production of Green Fodder

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Abstract

Hydroponics is a modern farming technique proposed as an alternative to traditional farming. Hydroponics agriculture is a soilless cultivation method where the plant is grown with the help of nutrients and water alone and hence it provides a solution to the growing scarcity of agricultural land. In this paper, a hydroponics farming setup is designed and developed specifically for the cultivation of green fodder required for livestock rearing. Commercially available hydroponic based fodder cultivation setups use a timer-based water spraying system for maintaining the moisture required for the growth of the plants and it does not account for external environmental conditions. In the proposed setup the changes in the weather and environmental conditions would be considered and accordingly the moisture retention required for the fodder cultivation would be maintained. Further, the proposed setup can monitor the pH, turbidity levels and it also has autonomous light intensity adjustment and water holding systems that maintain the proper mixing ratio of nutrients in the water tank. The developed setup also has an inbuilt Internet of things (IoT) feature that provides the capability to monitor the system remotely through a mobile application. A custom mobile application is also developed specifically for the proposed setup which helps in continuous monitoring of the system. Thus the proposed hydroponic setup requires minimal manual labour except for sowing and harvesting and it helps in ensuring proper moisture content based on the environmental conditions and hence efficient plant growth also through continuous monitoring and supply of nutrients based on the crop's growth.

Keywords: Modern Farming Technique

1. Introduction

Hydroponics is a farming technique utilized where there is lack of space for performing traditional land based farming. In hydroponics instead of soil, water is used as a medium for developing vegetation. The hydroponics approach has been widely applied for growing various variety of vegetables, fruits and green leaves, and comparatively there is less focus on growing fodder required for rearing livestocks. In India, the livestock industry is huge with over 482 million cattle, buffaloes, goats, sheep, and pigs according to the 19th livestock census-2012, all India report [1]. Increasingly people are finding it difficult to meet the green fodder requirement for this huge population of livestock due to scarcity in agricultural land and labour. Hence the quality of the livestock being reared is getting affected. Especially in urban areas raising livestocks is near to impossible due to shortage of green fodders which helps in meeting the nutrition requirements for the livestock. Urban land scape does not have enough space to grow plants for livestock food. They are always dependent on external sources which increases the raising cost of livestock, which in turn affects the market price of livestock products. Further there is heavy demand for eggs, livestock meat and dairy products.

In order to meet this demand hydroponics method of farming could be adopted to grow green fodder since it requires only minimal space. Hydroponics utilizes trays of different dimensions wherein the seeds of corn or any grain utilized as green fodder are spread and periodically water would be sprayed over the seeds in order to maintain the moisture content and after nine days the crop reaches its maximum growth and it can be harvested and fed directly to the livestock. With conventional methods it requires a minimum of 40 days to harvest the fodder and hence hydroponic fodder cultivation provides an attractive solution and steps involved in this method along with its water requirements are reported in detail in literature [2]. Hydroponics offers a best solution to small-scale farmers with insufficient agricultural land for growing green fodder. In order to ensure proper growth of the plants and to achieve a maximum yield, the two important parameters that need to be monitored regularly are moisture content and proper nutrients intake. The proposed hydroponics has a relay-based water spraying setup which would spray water based on the moisture content available in the trays thus based on climatic changes the moisture would be maintained appropriately. In hydroponics there should be proper control over supplying of nutrients to the plants which is difficult to do manually and hence in the proposed setup the proportion of nutrients present in the water tank is tracked and monitored regularly through sensors. Manual control of nutrients supply also has some disadvantages with regard to the growth of the plants [3]. Thus the plants are fed with proper level of nutrients and water automatically without any manual intervention helping to achieve maximum yield.

The proposed hydroponic system is a fully automatic setup which takes care of the quantity of nutrients required based on the input from the sensors monitoring its proportion present in the tank. The water requirements are met by taking climatic conditions into account and hence over supply and under supply of water is eliminated. In addition the proposed setup has provision for lights and exhaust fan which would operate based on the surrounding environmental conditions and hence maintaining proper humidity and lighting conditions. Further the proposed setup has Internet of things (IoT) capability which would allow us to monitor and regulate the entire system remotely and in this regard a mobile application with appropriate features is developed. Since the system is IoT enabled, the data related to plant growth can be shared in the cloud which help us in acquiring suggestions and feedback from agriculture experts. Thus the proposed hydroponic farming setup with remote farming capability is fully automatic requiring minimal labour and helps in achieving maximum yield of green fodder required for livestock rearing in minimal space.

2. Literature Review

In literature it has been observed that there are few works related to IoT based hydroponic system for fodder cultivation. Most of the research concentrated on hydroponics based cultivation of conventional vegetables such as tomato, spinach, pepper, chilli, etc. An automated hydroponics system which transfers and receives data from a mobile application to control and monitor the plant growth was developed by Peuchpanngaram et al., [4] where with proper utilisation of sensors they were able to monitor the temperature, humidity and water level. Peuchpanngaram et al. [4] also discussed the need for developing a mobile application for an IoT based hydroponic plant growth monitoring system.By using lettuce plants as research test, Shekhar et al., have employed nutrient film technique (NFT), to measure pH, total dissolved solids (TDS), and nutrient values on an agriculture system with various sensors [5].

They achieved better accuracy through the implementation of K- Nearest Neighbour (k-NN) algorithm to predict the various nutrient conditions and accordingly supplying nutrients based on requirements.

Alipio et al. [6] utilised Bayesian Network (BN) to control and monitor a hydroponic system, and reported increase in crop yield of about 67.67% higher than manual control of nutrients. An automated system with sensor data corresponding to moisture and temperature has been collected and (KNN) classification machine learning algorithm has been deployed for analysing and predicting the nutrient and water management by Mehra et al. [7]. Herman et al. [8] deployed Artificial Neural Network (ANN) in predicting the pH and electric conductivity which corresponds to the quality of water and variety of nutrients dissolved in the water. Herman et al. [9] proposed monitoring and control of hydroponics precision agriculture with IoT and Fuzzy logic. IoT is utilized for regular monitoring of plant's nutrition and water needs, while fuzzy logic is used for control and monitoring of nutrients and water supplied to the plants. Kularbphettong et al. [10] have controlled the environment for the hydroponic system with the help of various sensors measuring temperature, humidity, and light intensity. They have designed an application for planning, managing, and recording of harvest data for further analysis and machine learning algorithms were utilized for decision making. Tambakhe et al. [11] conducted an extensive survey regarding the implementation of modern technologies in developing state of the art hydroponics systems. Their survey also reported the status on implementation of IoT and various machine learning and deep learning algorithms for the control and monitoring of hydroponics system.

Through the literature survey it has been observed that most of the research efforts concentrated on hydroponics for growing vegetables. In this study we are presenting an IoT based control system for hydroponic fodder setup to monitor and control water spraying, water level, humidity, pH of water, ambient light and nutrient level. Further web and mobile applications were developed with a user-friendly graphical user interface (GUI) to visualize the sensor information and also to manually control the device if needed. The proposed hydroponics system helps in continuous monitoring of the growth of plants and thus ensuring higher yield.

3. Objectives

A survey conducted on the needs and requirements from farmers and industries related to dairy and poultry products shows an immediate demand for the increase in livestock production in order to meet the increasing growth of human population. Hence implementation of advanced technologies in rearing livestock is the need of the hour. Green fodders provide major nutrients to the livestock and it also utilized for preparing various poultry feeds. The regions with very less water table and areas which are prone to droughts, moisture-based fodder cultivation methods are more suitable. Hydroponic based fodder cultivation requires a moisture level of 80% to be maintained for good yield and the system will also act according to the environmental conditions and thus ensures optimum use of water. Manually adding of nutrients may result in increased or decreased nutrient content in the water and both these conditions will affect the growth of the plant. Hence regulated nutrient supply is provided in the proposed system with the help of turbidity sensor which measures the nutrient content and accordingly supply the nutrient through solenoid valves. Further the quality of water needs to be maintained by regulating the pH and which may result in better quality of the fodders being produced. It is also prescribed by microgreen fodder producers that to maintain 17 hours of light and 7 hours of dark for good yield [12]. Hence controlling the ambient light with the help of light sensor will also help the plants grow effectively.

Lack of farm labours and space are observed in the urban areas for fodder cultivation. Hence a hydroponic system is apt because of its minimal space requirements and further a control and monitoring interface is required for automatic and remote farming. In this regard a combination of web and mobile applications are required for an automated hydroponic system which can send and receive data through cloud to control and monitor the entire hydroponic system.

4. System Architecture

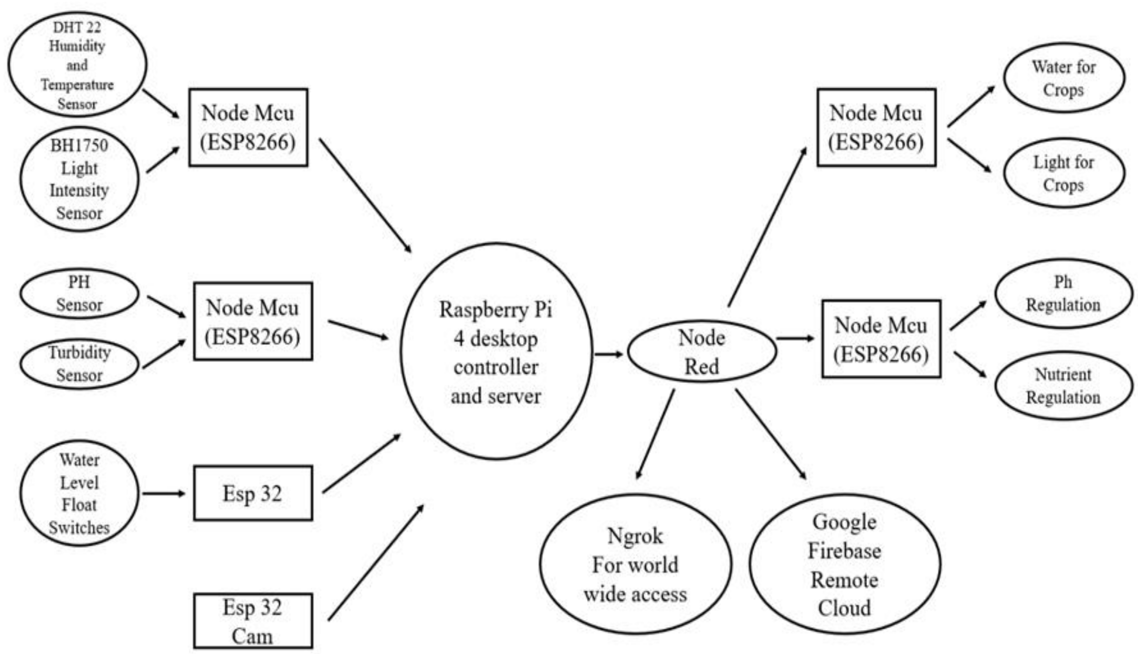
The architecture for the automatic control and monitoring of proposed hydroponic system is shown in figure 1. A single board computer – Raspberry Pi 4 with 4GB RAM (random access memory) is used as a primary controller for all the sensors and actuators, and to send data to firebase which acts as cloud. The Node MCU is utilized as microcontroller unit which helps in incorporating IoT capability and for interfacing various sensors and actuators. Raspberry Pi acts as the master and NodeMCU acts as slave. The communication between Node MCU and Raspberry pi happens through message queuing telemetry transport (MQTT) protocol which is a standard messaging protocol for IoT. There are four NodeMCU boards used in this system for interfacing various sensors and actuators. The first NodeMCU board carries the DHT22 sensor, which has a capacitive sensor used to measure moisture and thermistor to measure temperature of the surrounding environment. It also connected to BH1750 sensor which is used to measure the intensity of light present in the environment. This first NodeMCU board acts as the primary driving board since it monitors the important variable of moisture content available in the hydroponic setup based on which the water requirements are optimally managed for the entire hydroponic fodder system. The second NodeMCU board is connected to pH sensor, float switch, and real-time clock (RTC) module. Float switch is used to measure the amount of water present in the barrel and RTC module keeps track of the current updated time and date in order to help the software in performing time-dependent functions. The probe of the pH sensor will be damaged if it is kept inside the water for more than 24 hours. Hence the water from the barrel will be sent for every one hour to a small chamber which contains the pH and turbidity sensors for measurements and the water would be drained after 10 minutes. The measurement data from the sensors will be sent to the Raspberry pi 4 controller. The timing and sequencing of these step by step procedure will be taken care by the RTC module. The third NodeMCU board consist of turbidity sensor and RTC module. Turbidity sensor is used to measure the total dissolved solids in the water and this data can be related to the total nutrient content present in the water. As like the pH sensor, the Turbidity sensor cannot be inserted inside water for more than 24 hours. Hence the turbidity sensor is also kept in the same chamber where the pH sensor is placed and sends data every one hour with the help of RTC module. The fourth NodeMCU board is connected to the relay board, which controls all the solenoid valves and water pumps. The first three relay switch is supplied with AC current for motor pump, AC solenoid valve and lights. The next five relay switch is supplied with DC current for 24 V DC solenoid valves.

The architecture shown in figure 1 also consist of an ESP 32 camera which is widely utilized for IoT applications. The video footage from ESP 32 cam is sent to a cloud server, from which we can remotely monitor the entire hydroponic system. This cloud server connectionhelps to eliminate the drawback of ESP 32 camerain transmitting the video footage output to only one user because of its less bandwidth. Hence that one footage output is sent to the cloud server, which makes it available for multiple users.

4.1. Data Security

As discussed in the objectives, there will be web and a mobile applications and for web application, the user interface is designed using Node Red and shared to the global network through Ngork. Node Red will be running on a particular port of the Raspberry pi 4, and that port will be exposed to the internet by Ngork. This may attract possible attacks from virus and other cyber threats. To completely avoid cyber infringements, we are protecting the Node Red environment and its user interface with hash password which is one of the hardest security protocols to be cracked. There are different User ID and passwords used for programming environment and user interface so that the user won't have access to the programming environment of Node RED in the internet. The main advantage of having the programming environment to be on internet along with user interface is to trouble shoot or make updates as requested by the user at any time from any place. For mobile application, the security system is taken care of by Google's firebase. It has its own architecture for data security. It is password protected from both the ends (user end and the developer end).

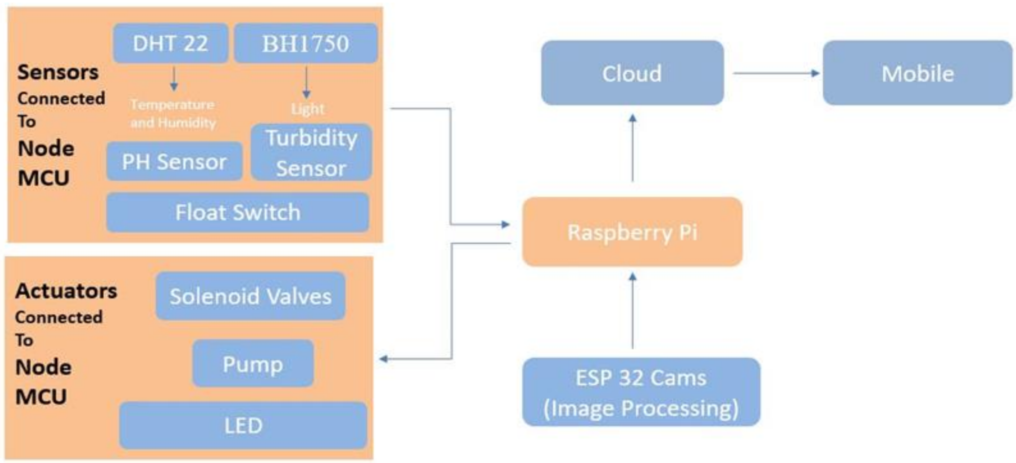
Figure 1. System Architecture



5. Design Methodology

The sensors and actuators along with their signal flow for the proposed hydroponic setup is shown in the block diagram of figure 2. The block diagram shows the direction of signal transmission and reception between the sensors and actuators with the microcontroller and subsequently to the cloud. Raspbian operating system is used in the Raspberry PI – 4, which is a Linux based operating system. A node based programming environment – Node Red, developed by IBM is available in the Raspberry Pi for executing all the required actions through programming. Hence, Node Red becomes the master in Raspberry Pi and Node MCU boards programmed with Arduino IDE becomes the slaves.

Figure 2. Block diagram for the signal flow in the proposed hydroponic setup



The virtual representation of the entire proposed hydroponic farming setup with all its associated sensors, actuators and with various components are shown in figure 3. A 200-litre barrel which is a cylindrical shaped container is utilized for storing water and nutrients. Inside the barrel, four float switches are fixed as shown in figure 3 to monitor the water level and a 0.5 hp water pump is utilized to pump the water-nutrition mixture for spraying on the fodder crop. Adjacent to the barrel a separate enclosure is used to house the pH sensor and turbidity sensor as shown in figure3. For every one hour with the help of a DC solenoid valve, water will be sent from the barrel to the enclosure housing pH sensor and turbidity sensor for monitoring the acidity and clarity of the liquid. A solenoid valve is used for supplying water to the barrel from the water tank whenever the water level goes down and with the help of fogging nozzles the nutrient-water mixture will be sprayed on the fodder crop as shown in figure 3. The DHT 22 and BH1750 are two sensors utilized to measure moisture, temperature and ambient light respectively. The sensors are divided into two parts with DHT 22 and BH1750 placed adjacent to the hydroponic rack setup and the pH sensor, turbidity sensor and float switches were placed close to the barrel. To monitor this entire hydroponic setup and surrounding environmental conditions a camera namely ESP 32 cam is utilizedas shown in figure 3.

The real-time rendering of the proposed setup is shown in figure 4 for better understanding and visualization of the entire design. The sensors are kept inside an enclosure in order to protect them from any environmental interferences during operation. The frames which support the fodder trays are designed using polyvinyl chloride (PVC) pipes. The reasonsto choose PVC pipes for frames areto avoid any fungus or algae formation in the frames, and they are cheaper, easy to construct and does not get oxidized. The trays and barrel are also made of the same PVC material because of its inherent advantages.

Figure 3. Virtual representation of hydroponic farming setup for fodder cultivation

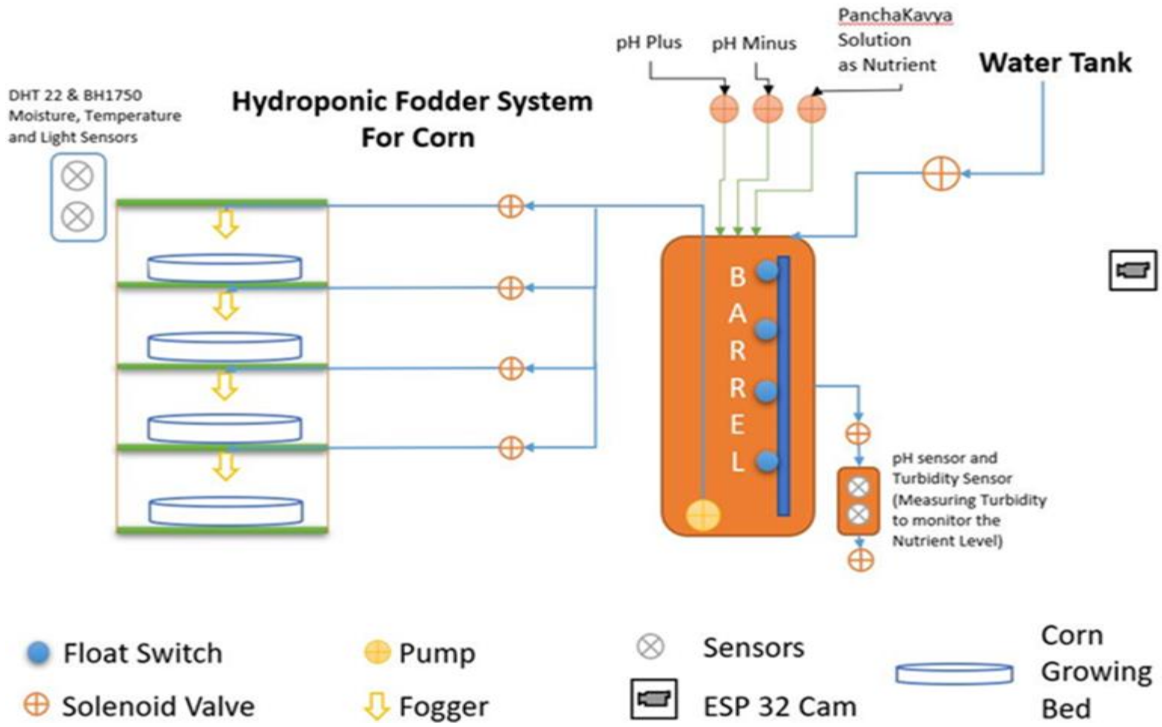
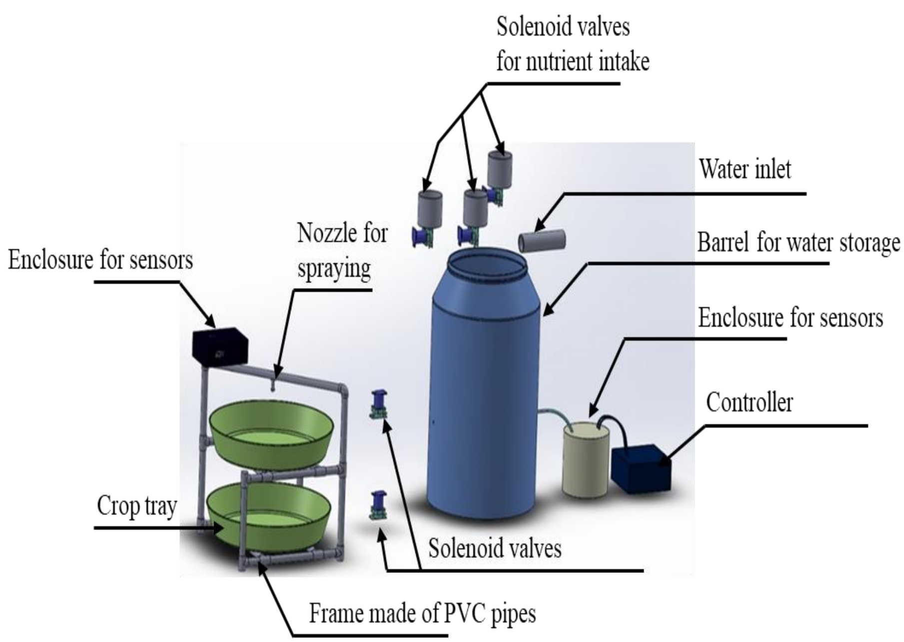


Figure 4. Real-time rendering of the proposed hydroponic setup



5.1. Sensors and Actuators

If the moisture level measured by DHT 22 sensor is below 80 % inside the hydroponic setup then the Node RED which is a microcontroller receiving the signal from the sensor takes action by switching on the water pump to spray water until the moisture content goes above 80 % and there is no wastage of water. If the float switches indicate that the amount of water is falling below 25 % in the barrel then the Node RED will take action by switching on the solenoid valve so that the water from the water tank enters the barrel and thus water level is always maintained so that sufficient water is available for the crop. Through the information received from the pH sensor for every one hour, the Node RED will take appropriate decisions like if the pH levels fall below or raises above than the corresponding pH plus or pH minus solution will be poured through respective solenoid valves. If the turbidity of the sensor decreases, then it will indicate a lower nutrient content and accordingly the microcontroller will send a signal to open the solenoid valve corresponding to the nutrient (Panchakavya solution). The 8-board relay channel controls the action of the actuators and the entire hydroponic fodder system setup is controlled by Node RED in Raspberry Pi – 4 and Node MCU. The functionalities and purpose of the various sensors utilized in the setup are listed in table 1.

Table 1. Functionalities of Various Sensors

Sensors	**Functionality**
pH sensor	Measures the acidity or alkalinity of the water
Turbidity	Measures the relative clarity of a liquid
DHT22	Measures moisture and temperature
BH1750	Measures the intensity of light
Float switch	Measures the water level

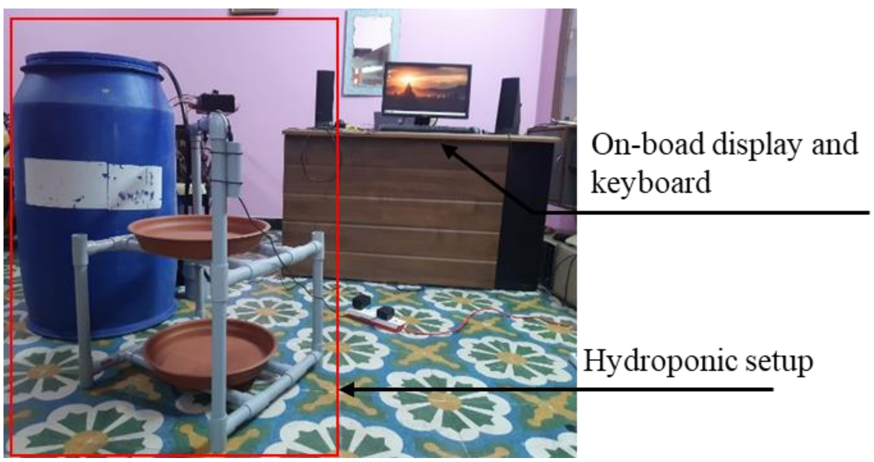
6. Implementation Result

A two-tray prototype hydroponic system for fodder cultivation has been designed and developed as shown in figures 5 and 6. It can be scaledeasily by increasing the trays alone depending upon the requirements and the electronics components will remain the same. Thus the capacity of the hydroponic system can be increased without much expenses. The web user interface has been developed as shown in figure 7which displays all the information regarding the monitored parameters such as environmental moisture level around the trays, temperature, pH, turbidity and water level. There is also an option provided in the user interface as shown in figure 8 for manual control and operation of the entire hydroponic setup through manual operation of switches provided in the user interface of figure 8. The user interface also helps in accessing the camera feed for monitoring the entire system. The ngrok is an application which allows to expose the local server to the internet with minimal effort and it is utilized in the current setup which helps in monitoring and controlling the vital parameters of the hydroponic system from anywhere in the world and thus it provides IoT capability to the proposed hydroponic system. This IoT capability makes it possible for continuous monitoring and control through internet. Also, if any update or change is requested by the user in the web interface then it can also be done through ngorkover the internet from any part of the world and this makes the system more robust and flexible.

On day 1 of cultivation for the corn crop the soaked quality seeds were spread on to the trays and because of the autonomous nature of the proposed hydroponic system it requires no human intervention from day 2 to 8 after the seeding process. Excepting for sowing and harvesting the system needs no manual intervention. The entire system has the capacity to adopt to different weather condition with help of sensors, actuators and associated electronics which alters the moisture, water, nutrient and lighting requirements and thus helps in increasing the yield. Figures 5 and 6 shows the developed prototype of hydroponic system with adisplay and keyboard which is connected to the Raspberry pi 4 single board computer. The on-board display and keyboard helps inlocal monitoring and controlof the system and also in the absence of internet, or failure of internet due to network issues in remote areas.

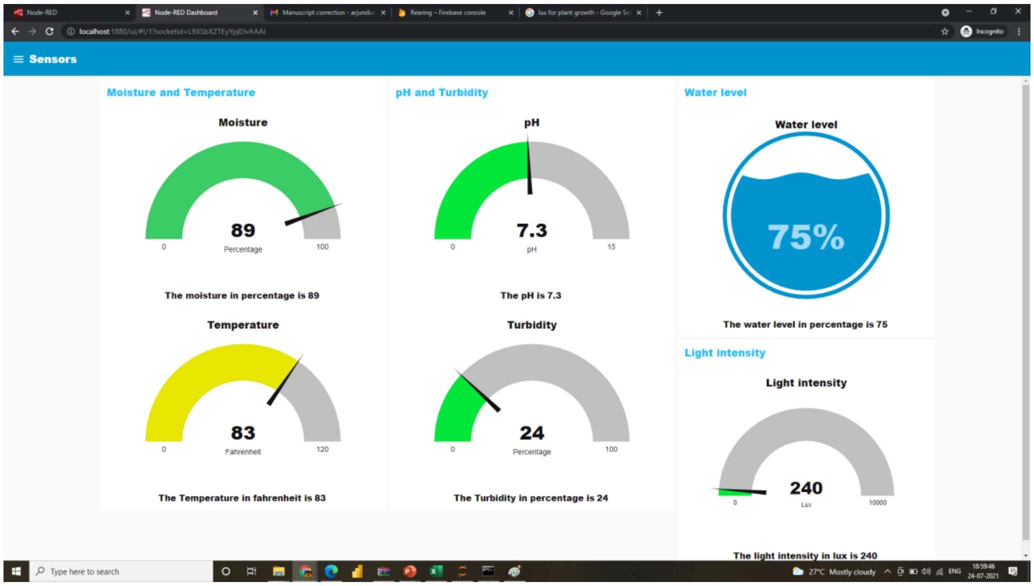
Figure 5. Developed prototype of hydroponic setup

Figure 6. Prototype of entire hydroponic system with on-board display and keyboard



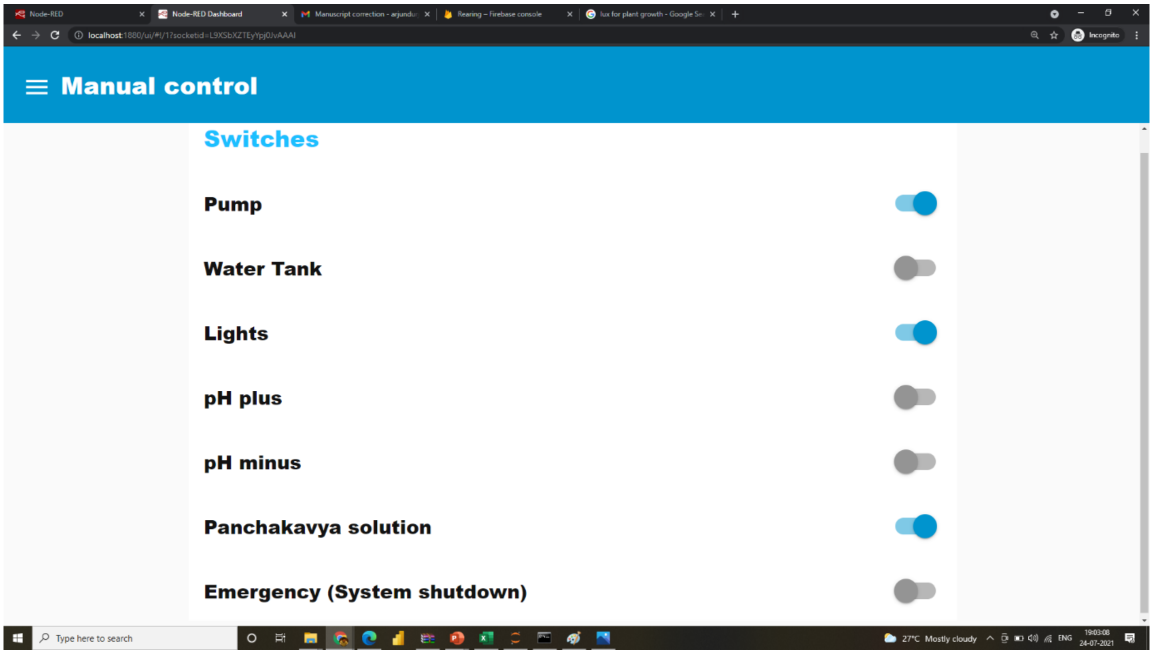
The graphical user interface (GUI) shown in figure 7 represents the output from various sensors such as the amount of water in the barrel, the humidity, temperature, light present in the environment, dissolved solids (turbidity) and pH. Thus the GUI of figure 7 helps in communicating the current status and values of monitored parameters of the hydroponic system.

Figure 7. Graphical user interface for hydroponic system



The GUI of figure 8 allows manual control of the system in case of any requirement for the user or during any emergency. This GUI allows switching on or off of all the actuators present in the hydroponic system such as the water pumps, various solenoid valves, lightings, and emergency alarm or system shut down. For security reasons the manual access of the system through the GUI of figure 8 will be communicated to the system owner through email in order to avoid any wrong doing by strangers.

Figure 8. Graphical user interface for manual access



The outdoor arrangement of the hydroponic system for testing its functionalitiesis shown in figure 9. The capabilities and benefits of the proposed hydroponic system were demonstrated by growing a selected variety of corn crop as shown in figure 9 (b). The electrical components and its associated wiring connections were properly insulated in order to avoid any damage due to spilling of water. The sensors were safely kept inside the enclosure as shown in figure 5 and hence the safety of the system is ensured for operating it under real-time conditions. The water supply can also be controlled for each individual trays based on the age and growth of the plants.

The date received from the sensors will be sent to the microcontroller (Node RED) and then to the cloud through the Google firebase. The firebase cloud plays a major role in collecting the data and storing it for further analysis as show in figure 10. It plays as an interface for communication between the hydroponic system and the mobile application. A mobile application was developed with a simple user interface as shown in figure 11 so that it would be easy for the user to control and monitor the system. The user interface for the mobile application was developed using the programming language Java script. The mobile application has all the options similar to those provided in the web application

Figure 9. Outdoor arrangement of hydroponic system for crop cultivation

(a)

(b)

Figure 10. Data storage in cloud

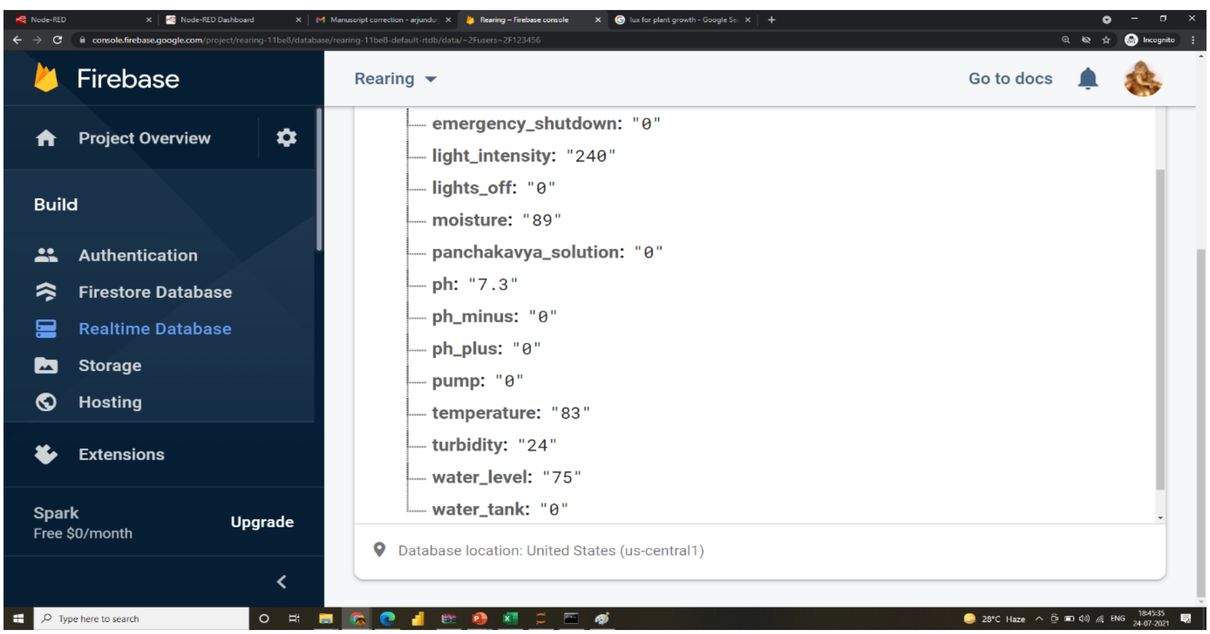
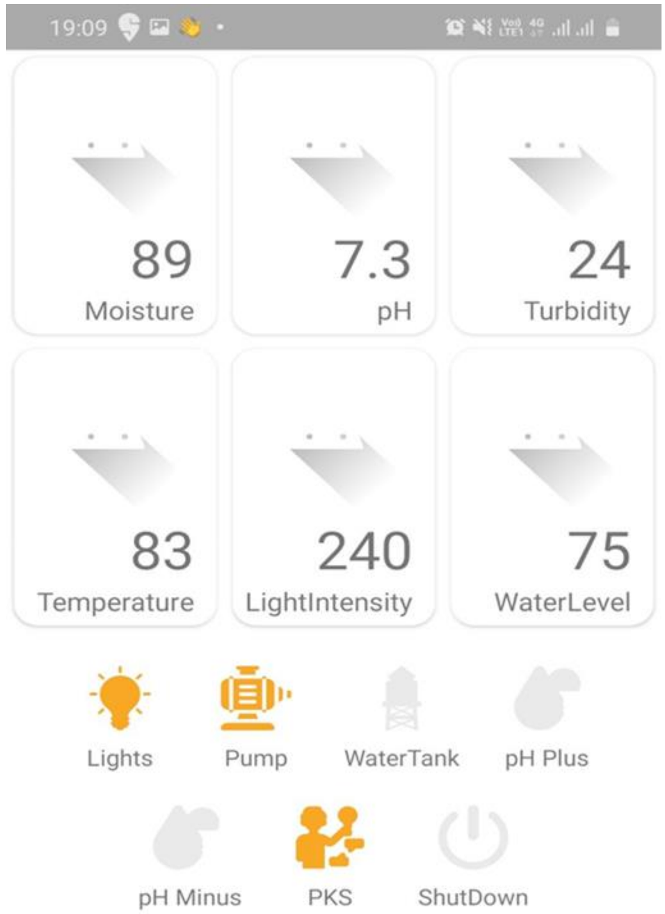


Figure 11. User interface of the mobile application



The developed hydroponic prototype was implemented for growing corn crop and its various stages of growth was observed and recorded as shown in figure 12. The capabilities of the hydroponic system were tested by growing the corn crop without manual intervention except during sowing and harvesting. The corn variety called manjolam was initially soaked in water and then the seeds were spread in the trays as shown in figure 12 (a). The crop growth was monitored every day till the eighth day as shown in figure 11. By visual inspection it was confirmed that around 90% of the seeds got sprouted and they had a uniform growth, see figure 11 (b). Around 380 grams of seed were sown and on the eighth day close to 1.78 kilo-grams of green fodder was harvested in 7 days which can be used as the feed for most of the livestock such as cow, chicken, horse, quails, and ducks.The entire system was controlled and monitored remotely through the mobile application and all the components of the system executed their tasks properly leading to proper growth of the plants. Thus the automated hydroponic system has been demonstrated successfully for growing corn which can be extended to other fodder crops like millets, different types of grass, pulses and sorghum.

Figure 12. Growth monitoring of corn crop in hydroponic system

(a) Day 1 (b) Day 3

(c) Day 4 (d) Day 7

7. Conclusion

An automated hydroponic farming setup for green fodder cultivation with IoT capability was developed and implemented for growing corn crop to validate its functionalities and benefits. The proposed IoT based hydroponic farming setup addresses all the requirements for a medium to large-scale livestock industry and through implementation results it can be realised that it will help them achieve a good yield ofquality green fodder feed with minimal resources. This system does not require manual intervention except during sowing and harvesting and hence it reduces the farming labour who are of greater demand. The proposed system has the capability to adopt based on the environmental conditions and accordingly the water supply, nutrient intake and lighting could be altered automatically through various sensors and actuators. The remote farming capabilities of the proposed hydroponic setup have been demonstrated with the help of both a mobile and a web application. Because of its IoT capability it is connected to the cloud and hence it makes it possible to monitor and control all the vital parameters remotely without any manual intervention. The design of the proposed hydroponic setup is simple and modular so that it can be extended based on the requirements without much effort. The cost of establishing this hydroponic setup is much less for all its functionalities and it can also be scaled at lesser cost.The proposed hydroponic setup can be made intelligent by including technologies like machine learning and fuzzy logic algorithms and the efficiency of the system will improve further in providing greater quality and yield of the fodder crop.Thus a portable and modular automated hydroponic farming setup for green fodder cultivation has been developedwith various capabilities which would be of greater help to the farmers rearing livestock especially to those in urban areas where there is scarcity for agricultural land.

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