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Abstract: In this work develop a system that uses a combination of advancements in fuel cell technology, solar power, and hydroponics. The developed system effectively distributed in the agricultural sector, resulting in a drastic increase in urban farming and the enhancement of traditional rural farming methodologies. Hydroponic farming is a technique by which the crops are grown without soil, it benefits the environmental by eliminating erosion and water consumption by the crops, it also reduces the labor-intensive work involved in traditional framing technique. The introduction of automation in this hydroponic system and improve the monitoring of the consistency of the yield. The implementation of fuel cell technology and solar panels aids in reducing the carbon footprint of the system. As good as it sounds in efficiency and protecting the environment, it is challenging to get the right and ambient conditions for the plants to grow. Water and nutrients must be provided in a required ratio while being constantly monitored with the help of an array of sensors calibrated and coded with Raspberry Pi. The automated system helps us to maintain optimal conditions for plant growth. The primary power supply is provided by a fuel cell or even magnesium salt water fuel cell. which uses an anion exchange membrane to generate electricity to power the automation equipment for the hydroponics system. The function of solar cell is used to facilitate the fuel cell to generate hydrogen which then circulated to the fuel cell. This potentially replaces the need for setting up of massive external power source for electrolysis.

Keywords: Urban farming, Fuel cell, Solar power, Sensors, Raspberry Pi, Electrolysis, Hydroponics

1. Introduction

The method using nutrient solutions for growing crops without the use of natural soil is known as hydroponics. A plant requires selected nutrients, water, and sunlight to grow. Not only do plants grow without soil, they often grow a lot better with their roots in water instead. To further make it sustainable, we introduce the technique of passive environment using latest technology such as sensors, IoT devices, Fuel cells and Heat induction systems. Attaining sustainability in any industry is necessary when the world faces climatic problems. Till date the agricultural sectors have contributed huge quantity of greenhouse gasses directly or indirectly, which has put forth for the rise in CO_2 level. Hence, being dedicated engineers to attain sustainability and bring agricultural sector to an industrial level of financial evolution, the team dedicates to automate the hydroponics system to eliminate the use of soil, excessive water and large area of land. To attain the main objective of sustainability, the heating for the environment is done using solar heat energy and cooling by the underground cu tubes. Further to add highest degree of sustainability, we use the AEM Fuel cell technology. The fuel cell along with the help of solar arrays generates hydrogen, which is act as energy storing device. During the absence of sunlight, the hydrogen is passed through AEM electrolyser and electric power is generated to power the hydroponics system. The heat liberated from the fuel cell is used for heating the high humid environment, hence making this system sustainable to produce consumer food products without any chemical pesticides and reducing the carbon footprint of the entire system.

2. Research background

A hydroponic plant's growth rate is 30 to 50 percent faster than that of a soil plant. Because of multilayer vertical production, hydroponics may benefit from automatic irrigation and fertilisation, as well as provide a clean growing environment and save space[1]. System can monitor the environment of a hydroponic device in real time and in a reliable manner using a number of sensors and automatically communicate data such as temperature, humidity, light intensity, water level, and ph. Hydroponics can be linked to a social communication network, allowing users to engage with their hydroponic plants online via a mobile terminal, realising a fantastic dream[2)]. The wafter pump pumps water from the fish tank into the grow bed. The Arduino controls the pump, which is handled by the relay and configured to turn on and off at predetermined intervals. The grow bed must be emptied and refilled when the water level reaches the upper limit of the siphon bell. If the siphon bell fails or is insufficient to discharge the water at the same rate as the pump fills the grow bed for unknown reasons, the two side outputs must ensure that the water level inside the grow bed does not rise to the point where it overflows out of the aquaponic system[3)]. Peppermint antioxidant activity was impacted by the growing circumstances. Planting material cultivated in cylindrical and continuous hydroponics systems had 1.6-1.9 times lower antioxidant qualities than other variations. In the case of sweet basil, however, the difference is insignificant. In both situations, however, lipid free radical oxidation pathways were suppressed Stepan[4)]. By integrating IoT and a mobile phone to automatically operate and monitor an automatic hydroponics vegetable system, users who need to plant hydroponic vegetables would gain ease and productivity. The system can self-regulate and check the nutritional level, as well as provide a graphical user interface for easy management and control[5)]. In this experiment, used a 3:1 mix of LED red and blue light bulbs to create a reddish-purple color. When growing light vegetable salad in a confined environment for ten days, 16 hours a day, the results show that the plants grown steadily under the LED light. The temperature and the light from the LED can be adjusted at a constant level in the test. Salad vegetables thrive better in natural sunlight and at room temperature[6)]. The Internet of Things concept is applied to the system to make the process of growing food hydroponically easier by streamlining the growing and monitoring processes over a secure cloud. By using the IoT , it addresses one of the most pressing concerns in automation today: maintenance, by offering a platform for monitoring the entire system from the cloud, lowering maintenance costs by a factor of ten[7)]. Based on user-specified settings and system constraints, a novel objective function can offer the best water and humidity level. With the current and optimised data of the water and humidity levels in the experimental environment, the fuzzy logic control module was used to discover the ideal operating level and operational time for the actuators[8)]. Aeroponics considerably increased root growth, with significantly higher root biomass, root/shoot ratio, total root length, root area, and root volume, according to the findings. However, due to the limited availability of nutrients and water, more root growth did not result in greater shoot growth when compared to hydroponics[9)]. The developed system's data is collected on ThingSpeak and displayed on the "IoT MQTT Panel" mobile application, which allows the user to quickly monitor and control plant conditions[10)]. Nivesh Patil et al. (2020). Using the 400 MHz wireless spectrum and the IEEE 802.15.6 standard, a reliable wireless control system for hydroponic tomato cultivation has been developed. The 400 MHz spectrum, which is lower than the 2.4 GHz band, has good obstacle diffraction, and zero-data-loss transmission is possible because to the IEEE 802.15.6 standard's guaranteed time-slot approach[11)]. The implementation of a fuzzy logic algorithm to autonomously adjust the temperature and RH of the greenhouse, as well as the EC and pH of the nutrient solution, is the emphasis of the fuzzyponics system. In relation to preset language outputs and solutions, the identified input parameters were categorized accordingly[12)]. This would increase work prospects in rural areas, promoting not only rural development but also economic development[13)]. Young people are also influenced by such circumstances to stay in the community, retain land use as an agricultural system, and promote sustainable agriculture[14)]. gives more economical and energy saving drying solution for the commercial purpose drying [15)]. The silica-gel desiccant wheel dehumidification and Maisotsenko cycle evaporative cooling achieve the latent and sensible loads of air-conditioning, respectively. According to the study's findings, the desiccant wheel performs better dehumidification in climatic condition 'A' than in the other climatic conditions due to higher ambient air relative humidity[16)]. Due to abundant Na resources, sodium-ion batteries have become a compelling alternative contender for lithium-ion batteries, and organic electrode active materials for sodium-ion batteries have the potential to deliver substantial cost savings[17)]. Fuel cells are one of the most promising choices for reducing greenhouse gas emissions and petroleum use, according to recent studies[18)]. A fuel cycle in which hydrogen is created through solar-electrolysis of water or gasification of renewable-grown biomass and then used in a fuel-cell powered electric-motor vehicle (FCEV) would produce minimal or no pollution on a local, regional, or global scale[19)]. With the exception of marine eutrophication, the environmental performance of all lettuce treatments demonstrated a decrease in all effect categories, particularly freshwater eutrophication and mineral resource shortages[20)]. It makes use of a fertiliser solution and typically regulated environmental conditions, making it more energy expensive but also more productive than traditional agriculture[21)]. When the nutrient media must be carefully managed and unbroken roots must be retrieved for downstream uses, a hydroponic growth system is the best option[22)]. The Internet of Things enables Machine to Machine interaction as well as autonomous and intelligent control of the hydroponic system[23)]. The EC and PH control processes are very nonlinear and have a pure time delay connection. When compared to neural networks and least square fits, the optimal controlling approach is specifically explained, and the least square fit using neural BP networks is subsequently used[24]. Despite an increase in the cost of the constituent unit in soilless culture, the vast amount of production quickly offset the cost. Soilless culture is a means of cultivating new and advanced cultures that necessitates the search for human cadres qualified for this activity, which is a rare, sadly[25].

3. Establishment of Hydroponics System

Design principle conducts the quality and performance of any system which is developed. Dedicated to make best possible hydroponics system, the design details are categorized into hardware and software. The hardware components include every physical aspect of the project. It will cover the support structure, description of the material selection and the hardware design of PCB and other electrical components. The Software design details will cover everything from the graphical user interface (GUI) to the backend working of the PCB which monitors the fuel cell control system. This would increase work prospects in rural areas, promoting not only rural development but also economic development.

3.1 Hydroponic system

Integration of the all individual system stitches the entire sustainable setup shown in fig. 1. The growing environment is isolated from the outer environment so as to achieve the required condition for the plants to grow at a rapid phase. The electronics involved to monitor and run the system is enclosed in a protective case made of stainless-steel back and hard polycarbonate sheet. The sensors and the control unit help the system to coordinate with the electric power system and the growing environment.

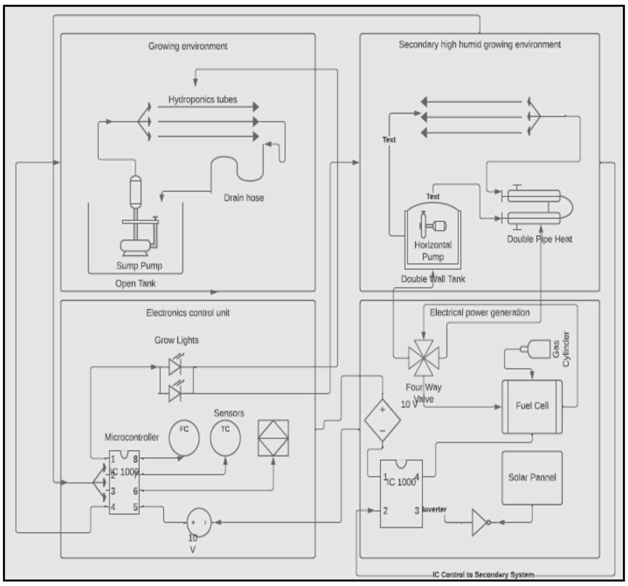

Fig. 1: Block Diagram of Hydroponics System

3.2 The hydroponics growing environment

The growing environment for the plants is designed using steel framework with aluminium reinforcing windows for structural rigidity and to prevent corrosion in the long run. Considering the key factors like environment where the setup is built, types of plant, input and the output of the hydroponics system, and financial investment etc., Clear Polycarbonate sheets are used to cover the system and the edges are sealed off with silicon sealant as to prevent the temperature and humidity loss in the system. The plants are grown under grow lights which have specific spectrum and lumens required by the plants, these details will be covered in upcoming subsections. The PVC channels act as a supporting structure for the plants. It also houses small wired mesh to support smaller saplings shown in fig. 2.

Fig 2: Hydroponic growing Environment

3.3 High humid crops growing environment

The High humid crops growing environment shown in fig.3, which we have developed, has a feature which facilitates the growth of crops which require high water flow, high humidity and temperature. Crops such as rice and wheat can be grown in this system. To achieve the required condition, we have developed a setup to heat the nutrient water and pass through the valve control. The control system monitors the liquid temperature and flows it to the planting bed. The following materials such as aluminium reflective sheets, Black high temperature plumbing tubes and closed tank with stone wool insulation for heat retention system are used in the heating system. Passive heating is obtained from fuel cell. As the fuel cell runs, it emits heat up to 75℃, which can be used to heat the system.

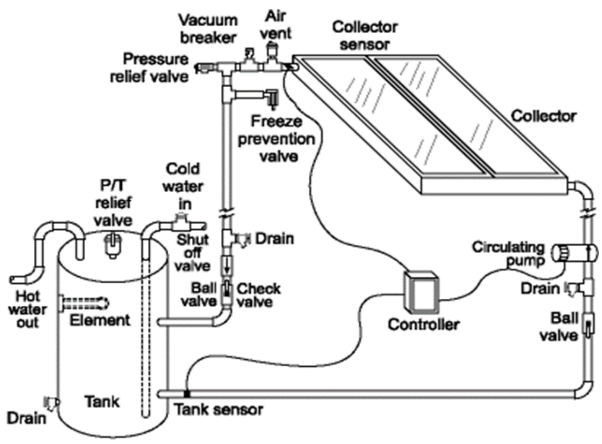

Fig 3: High humid crops growing environment

3.4 Fuel cell system

The Fuel cell for the system powers the entire hydroponics system in absence of solar energy, the schematic arrangement of fuel cell system shown in fig.4. PEM Electrolyser can be replaced with AEM Electrolyser which is more economically feasible and has the hydrogen generation at pressure of 30Bar, hence it eliminates the requirement of external compressor. Solar Panels are used to power the electrolyser during day time. 2KW solar panel can run the entire system. The hydrogen is generated during the availability of sunlight, which can be used to produce hydrogen and store as energy storage system. In turn the stored hydrogen can be passed to the fuel cell for generating electric power in absence of sunlight. The heat from the fuel cell can be used to provide heat for high humid crops. The fuel cell is monitored using Electronic Fuel Cell Control System. We have designed a PCB which monitors and controls the flow of the fuel cell.

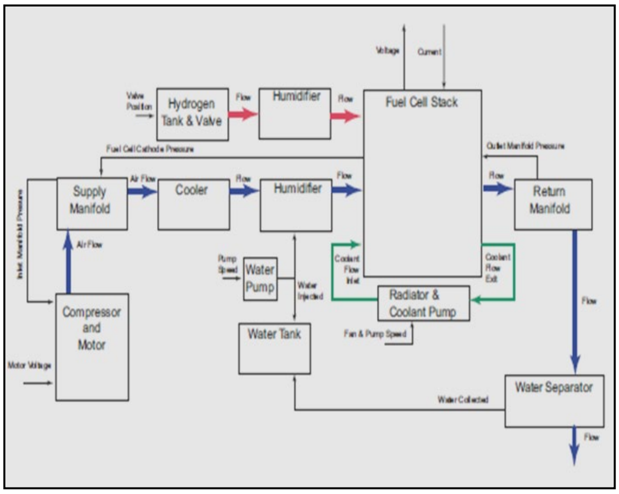

Fig 4: Fuel Cell Schematics

Various sensors were used to build the automation system. A probe holding device was designed to take readings of the nutrient water. It houses pH, Electrical Conductivity (EC) and a temperature probe. This setup helps the sensors to monitor the change in value for every pre-set time. The fuel cell control system is designed with three subsystem which controls the electrical energy flow from the fuel cell system to the hydroponics system. The inbuilt DC/DC converter helps us to eliminate the requirement of external inverter which is used to flow the power from solar panel to the fuel cell stacks. The system redundancy will provide us with state-of-the- art safety levels.

3.5 Software system

The entire hardware stitches together and works along to perform automated system. The software enables the end user to interact with the system seamlessly and can visualise the data in graphical format. The software used in this hydroponics system, monitors and displays the environmental conditions, pH and electrical conductivity of the nutrient water. Open-source software named MyCodo is used in this hydroponics project. This is an open source available in GitHub platform. The Graphical User Interface (GUI) is done using Influx DB, a tool which is used to make the graphical data unit.

4. Experimentation

4.1 Primary system

A frame supports the water channels along with the water inlet and draining pipes. 1” PVC pipes are used to pump water from to the channel supporting the plants. The holes in the channel are supported with the netted hose. To collect the water draining out of the channel, we constructed an open pipe on the outlet to flow the water back to the reservoir. Thus, a cycled water flow is maintained. The pipelines are harnessed in a stiff manner and the channels are fastened with zip-ties to the vertical beam adjoining the longer frames. A water flow meter is installed to the water line feeding the sample reservoir, and is useful for detecting if the pump is operating properly. Mycodo software is used to encode and calibrate the sensors with the help of Raspberry Pi 3B+. The connections are sealed and waterproofed to prevent damages. In summary the primary system more or else resembles an incubation chamber that promotes and facilitates the proper growth of plants. PEM Electrolyser can be replaced with AEM Electrolyser which is more economically feasible and has the hydrogen generation pressure of 30Bar, hence it eliminates the requirement of external compressor. Solar Panels are used to power the electrolyser during day time. 2KW solar panel can run the entire system. The hydrogen is generated during the availability of sunlight, which can be used to produce hydrogen and store as energy storage system. In turn the stored hydrogen can be passed to the fuel cell for generating electric power in absence of sunlight. The heat from the fuel cell can be used to provide heat for high humid crops. The fuel cell is monitored using Electronic Fuel Cell Control System. We have designed a PCB which monitors and controls the flow of the fuel cell

4.2 Secondary system

An arrangement of copper pipes is used with foam that has a capability to retain heat. The heat obtained from solar energy is used to provide the nutrient solution to the high humid crops. This is accomplished by using a concave shield with reflective mirrors to heat the water which is similar to function to a solar water heater. This heat is then trapped into a foam heat retention cover to trap the heat and cycle it through the pipelines. A small water pump that can be attached from any water outlet that is used to supply water into the pipelines. To maintain and control excessive heating water is flown through coolers and then cycled back. The pH content, mineral content and temperature is automated through Raspberry Pi. The heating system is used for increasing the humidity and temperature of the system for crops such as rice and wheat. Materials used for the heating system include aluminium reflective sheets, black high temperature plumbing tubes, closed tank with stone wool insulation for heat retention system. Passive heating is obtained from fuel cell. As the fuel cell runs, it emits heat up to 75℃, which can be used to heat the system. The heat from fuel cell is transferred via high pressure high temperature tubes, which benefits the entire system on sustainability.

4.3 Automation System Using Raspberry Pi

To assemble the automation circuit, the below steps are to be followed to connect the terminals to the raspberry Pi. Note the connection to right specific pins else the system may not get the accurate reading. The LCD display, the pump system will connect via the 4 pins which enable the communication from AC power source with ground pins and 5-volt input. For many sensors, the connection is done via the breadboard, hence 2 breadboards are used alone with the male-male and male-female jumper cables. The CO_2 gas sensor is connected to the UART to USB board. Check if all the I2C components are 3.3-volt compatible. Make sure the 5-volt are not connected here. The atlas scientific components are set default to the UART communication. Connect the temperature and humidity sensor exactly on top of the plants housing. The power control box is used to connect the AC powered devices such as grow lights, pumps and the valve control module. It uses a 2- channel 10Amps mechanical relay and 2 Amp solid state rely to connect the AC powered adapters to the Pi. The below connection depicts the actual connection to be made.

4.4 Installation of MyCodo Software

MyCodo is an open-source software which is used to monitor and automate the hydroponics system. This has to run on the raspberry pi OS. Prior to installing the MyCodo, the raspberry pi OS called the Buster Lite, latest version must be installed in a SD card. The O.S for the pi can be downloaded from the raspberry pi website

To flash the buster lite OS to the SD card, imager such as Balena Etcher can be used. Once the OS is flashed successfully, the card can be inserted in the Pi and can be powered with adapter provided. The Pi setup now can be connected to a Wi-Fi to get internet connectivity by entering the details given saving it as wpa_supplicant.conf, extension. The date, time and the country details can be configured using Putty, a software which connects the raspberry pi to the host laptop with windows OS. For iOS users, terminal platform can be used. MyCodo can be installed using the GitHub directed link. Once the software is installed, port forwarding can be done to access the hydroponics setup with any other host platform without the requirement of common LAN or putty. Once all the steps are covered, the sensors are configured and input/output trails are made. The hydroponics setup is completed and now it can run almost as an independent system.

5. Result

For testing purpose, we were able to sprout rocket lettuce variety in the flow channel with the help of automated system to control water flow and pH levels. Agricultural waste particularly coconut coir bundle was used as a precursor growth medium for the seeding development. Later the setup was transferred to netted holders placed in the 75mm (D) PVC pipes with 6-inch gap between each holder. The holder consists of a clay infused medium with water passing through the perforations in the holder to supply nutrients to the plants. The positive outcome of higher efficiency of the fuel cell has been proved with the analysis of the fuel cell. The automation of the system and the GUI eases the use of the application without any complexity. The environment monitoring system is flexible to adapt to different crops and the pH changes according to the requirements of the plant that is being grown. The Graphical user interface is programmed via Grafana and mobile application via Blynk. The Software for Raspberry pi is provided via GitHub library. The performance of the fuel cell is analyzed by running various test in MATLAB and Simulink. It determines the output voltage and all conditions which is crucial for the safety of the system. Tests are conducted on the standard application of generating electric current at various stack temperatures and gas passing pressure.

6. Conclusion

Make an intensive impact in the agriculture sector by providing a sustainable system of hydroponics that uses of less or without electricity. By doing so, we can even use this technology in rural as well as urban areas. With an intention to create an agriculture system by tapping into the potential of solar power in hydroponics systems to maintain heat. Foods grown by this method have a lower risk for foodborne human pathogens, less reliance on pesticides. Arable land is not being used for food production, thus saving it for future generations to use sustainably. The global hydroponics market size was valued at USD 1.33 billion in 2018, and this is expected to grow at a compound annual growth rate (CAGR) of 22.52% from 2019 to 2025. With the implementation of fuel cells and green hydrogen, this rate is projected to grow exponentially as the cost of electric power is reduced. This makes the high sustainable way of growing crops. Hydroponic systems also enable apartment dwellers or inhabitants of small homes and yards to produce some of their own veggies, which are a significant benefit for some families in this era of foodborne illness, economic hardship, and limited space. Clearly, there are numerous hydroponic systems for a variety of settings and plants, and every application or family will be able to find one that meets their requirements.

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