Automated Hydroponics System

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Abstract - *Growing crops in extreme environments will be more challenging and will decline food production. This problem can be resolved, by using hydroponics which produces higher yields in a short period, only by using water. This paper aims to develop an Automated Hydroponic System, which will periodically measure essential water parameters and maintain the nutrient availability for the plants by adding nutrients into the water through motor pumps. The whole system will be available for monitoring and controlling over a website hooked up on a microprocessor(Raspberry Pi).*

***Key Words*: Nutrient Film Technique, pH, Electrical Conductivity, Automation control, Monitoring, Web Application.**

1. INTRODUCTION

Soil is a determinate resource, meaning its loss and degradation cannot be recovered within a human lifespan. Soil, being the key to food security and our sustainable future, plays a major role in food production. Soil is getting affected more and more due to land pollution and modern civilization which is keen on improving accommodation for their livelihood. United Nations organization projects that the global population will increase from a population of 7.7 billion in 2019 to 11.2 billion by the end of the century. This population explosion will require humans to produce more amount of food for survival. Degradation of soil quality, water scarcity, and increased air pollution will make our environment not suitable for traditional farming. We can overcome these environmental drawbacks by adopting hydroponics, which increases yield by consuming fewer amounts of resources. Hydroponics is widely accepted as the future of farming and is done commercially in foreign countries.

In India, Hydroponics is getting a great response, since hydroponics requires less space and uses as much as 10 times less water than traditional soil-based farming. In traditional farming, insect and pest attacks force us to use pesticides on edible crops, which sometimes make them unhealthy to consume. The key point of hydroponics is that irrespective of the environment it can be implemented anywhere. Using hydroponics, we can also produce non-seasonal plants by breaking the seasonal barriers with the help of the controlled environment. The controlled environment increases crop yield by consuming nutrient-rich water. The water can be circulated into the system for about 3 months and it can be treated and reused.

In our study, we use the Nutrient Film Technique (NFT) to grow hydroponic crops since it is well suited for leafy greens. There are many other Hydroponic techniques - Wick System, Ebb and Flow, water culture, Drip, Aeroponics, etc. Depending on our requirements, we can choose any of the techniques. In soil, nutrients are produced from decomposed animal waste and dead plants, the atmosphere, weathering of rocks and bacteria conversions. Along with these healthy nutrients, the plants are also prone to soil-borne diseases. As a workaround, we provide food-grade nutrients to the hydroponic system which will be rendered directly to the plants through the water.

2. Proposed Methodology

2.1 Overview

Growing crops through Hydroponics needs immense care and patience. The pH level and Electrical Conductivity of the water should be continuously monitored since they are crucial factors affecting plant growth. Along with EC and pH levels, we also need to take care of the water temperature, air temperature, humidity, water level, etc., Performing these tasks manually will be tedious. Therefore, these tasks can be effectively performed by automating the whole setup.

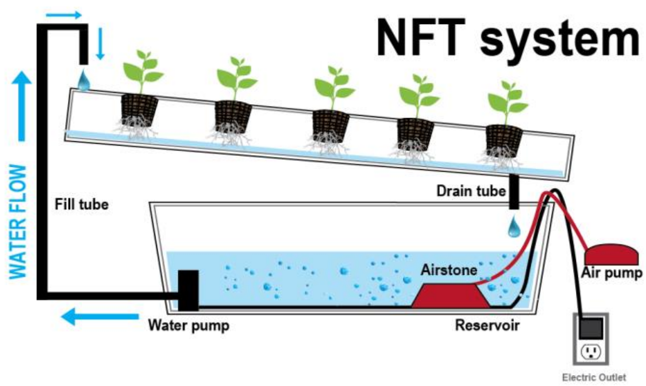

Fig -1: A basic Hydroponic NFT System

2.1.1 The Setup

We are making use of the Nutrient Film Technique which is a recirculating system (i.e) We only need to monitor and maintain the water parameters at the main water reservoir. The NFT System involves placing one or more Hydroponic Gully to place our net pots. The net pots should be filled with a medium. The media replicates soil's role by providing support to the roots and stems of plants, but don't have any of the nutrients that plants need to grow. Growing media are typically porous to hold oxygen and nutrient-rich water. Some of the commonly used media are - Rock wool, Lightweight Expanded Clay Aggregate (called, Hydro corn or Grow Rock), Coconut Fibre/Coconut chips, and Perlite or Vermiculite. In our system, we used Coconut Fibre which is easily available.

2.1.2 Nutrients

Soils store nutrients through a variety of mechanisms. Cation exchange capacity (CEC) is the ability of a soil surface to temporarily adsorb a nutrient and eventually release it back into the soil solution. CEC is especially crucial for the plant nutrients such as calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and iron (Fe). Soil organic matter (SOM) is a significant reservoir of soil nitrogen (N) and phosphorus (P). Over 99% of soil N is found within SOM. Microbial mineralization releases these organic-bound nutrients into soil solution for uptake by plants [2].

Since we are going soil less, we need to provide nutrients to the plans. The water reservoir should contain a minimum of 2 litres/plant and it should not have dissolved salts in it. Reverse Osmosis water is preferred. Nutrients can be categorized into micro and macro. The primary macro-nutrients are Nitrogen, Phosphorous and Potassium (commonly known as N-P-K) which are the essential nutrients for plant growth. The secondary macro nutrients are Calcium (Ca), Magnesium (Mg), Sulphur (S), Carbon(C), Oxygen (O) and Hydrogen(H). Micro Nutrients are Boron (B), Zinc (Zn), Manganese (Mn), Iron (Fe), Copper (Cu), Molybdenum (Mo), Chlorine (Cl). In our study, two solutions were used as major nutrient sources. Solution A constitutes 2 parts of **N-P-K** (4-18-38)+ Trace elements and 1 part of **Magnesium Sulphate**. Solution B contains 1 part of **Calcium Nitrate**. The nutrients should be mixed into the reservoir at a proportion of (2 parts of A) + (1 part of B).

2.1.3 Essential Water Parameters

To know the quality of the nutrient-rich water, we should measure some essential water parameters which tell the number of dissolved solids (in ppm) and the relative amount of free hydrogen(H^+) and hydroxyl (OH^-) ions in the water. **Electrical Conductivity (EC)** of water is the measure of its ability to allow the transport of *electric charge* (i.e) It is a measure of the salts in your system (Level of nutrients). The higher the EC, the higher the nutrient content. So, the EC level should be maintained depending upon the plants grown by adding the required level of nutrients to the reservoir. For hydroponic leafy crops, the ideal EC value should range from **1.1-1.6 mS/cm** (i.e) a TDS value of **560-840 ppm**. EC can be calculated from **Total Dissolved Salts(TDS)** measurement(in ppm).

$$EC\ (mS/cm) = (TDS * 2)/1000$$

Another crucial parameter of water is its **pH** level. pH is the unit of measure that describes the degree of acidity or alkalinity of a liquid solution. Acids are in a range from 0 to 7, with lower numbers being a stronger acid. Alkaline (Base) is in the range from 7 to 14, with the higher numbers being a stronger base. The pH of the nutrient solution is essential to the plant's hearth because it will affect how well each element can pass through the root cell wall and nourish the plant. When the pH of the nutrient solution is out of balance the plants are not able to uptake the nutrients in the water, basically starving them, even when there is plenty of food. pH can be balanced by using pH Up and pH Down solutions. **Potassium Hydroxide(pH Up)** and **Phosphoric Acid diluted(pH Down)** are widely used to regulate pH. The optimum pH level for hydroponic plants is **5.5-6.0**.

2.1.4 Temperature and Humidity

Water Temperature is also an essential factor to be monitored. Warmer water will carry less oxygen to your plants. Conversely, if the water is too cold the plants will not intake as many nutrients as they normally would. So an ideal water temperature of **65 to 80 F** should be maintained in the water reservoir. Ideal Air Humidity will be at a range of **40- 50% Rh**.

2.1.5 Automation

The pH, TDS and other water quality measurements are made at the reservoir at fixed time intervals. If the TDS or pH falls outside the limits, it will trigger an action to pump out required solution into the water reservoir for regulation. The Raspberry Pi will be our Local Server running a website chained with the database and our hydroponic system. The data is uploaded to the Database and is updated to the server in Real-time. Every time the website is refreshed, new measurements are taken from the reservoir. The system can be connected to the cloud making itself available to be monitored and controlled over the internet.

2.2 Sensors

The system uses 4 different types of sensors for measuring essential parameters and sending them to the server to regulate plant growth. The sensors are – pH sensor, TDS sensor, Water Temperature sensor, and Temperature & Humidity sensor. The server is programmed in a way that 4 tasks are scheduled to run between specified time intervals set by the user. The tasks will measure readings from each sensor and store it in our plant database.

2.2.1 pH Sensor

The pH sensor consists of a probe that has two electrodes in it. The glass electrode has a silver-based electrical wire suspended in a solution of potassium chloride, contained inside a thin bulb (or membrane) made from a special glass containing metal salts. The other electrode is called the reference electrode and has a potassium chloride wire suspended in a solution of potassium chloride. The potassium chloride inside the glass electrode is a neutral solution with a pH of 7, so it contains a certain amount of Hydrogen(H+) or Hydroxyl ions. The glass electrode measures the difference in pH between the reference solution and the test solution by measuring the difference in the voltages that are produced by their hydrogen ions. Since we know the pH of the reference solution (7), we can figure out the pH of the test solution. In our system, when the pH sensor measures a pH level below or above the desired range, a measured amount of an acid or base will be added into the water reservoir and the pH sensor will check the levels again. The sensor will continue checking and triggering the addition of an acid or base until the pH level is back within the desired range.

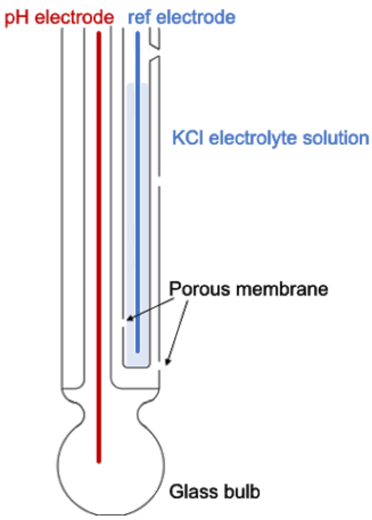

Fig -2: The Cross Section of a pH probe.

2.2.2 TDS Sensor

In the TDS sensor, two electrodes equally spaced apart are inserted into the water and used to measure charge. The result is interpreted by the TDS meter and converted into a ppm measurement. If the water contains no soluble materials and is pure, it will not conduct a charge and will therefore have a 0 ppm. Conversely, if the water is full of dissolved materials, it will conduct a charge, with the resulting ppm measurement being proportional to the number of dissolved salts. This is because all dissolved salts have an electrical charge, which allows the conduction of electrical charge between the electrodes.

2.2.3 Water Temperature Sensor

Compared with the traditional thermistor, the waterproof DS18B20 can directly read the measured temperature in 9 or 12 bit. Moreover, the sensor only needs one port line (one-wire interface) to read and write, and the temperature conversion power comes from the data bus.

2.2.4 Temperature and Humidity Sensor

The DHT11 temperature and humidity sensor calculate relative humidity by measuring the electrical resistance between two electrodes. The humidity sensing component of the DHT11 is a moisture holding substrate with the electrodes applied to the surface. When water vapour is absorbed by the substrate, ions are released by the substrate which increases the conductivity between the electrodes. Higher relative humidity decreases the resistance between the electrodes while lower relative humidity increases the resistance between the electrodes. For measuring temperature this sensor uses a Negative Temperature coefficient thermistor, which causes a decrease in its resistance value with an increase in temperature.

Fig -3: Plant growth

(The Seedlings planted at the end of February in the first photo. Growth of plants captured after the end of March in other photos)

2.3 Hardware

An SoC microprocessor - The Raspberry Pi 3 Model B+ is used. The pi has a 64-bit quad-core processor running at 1.4GHz. The Raspberry pi is the main hub of the setup running a web server on it. The pH and TDS sensors used in this study does not have support with Raspberry pi. There comes Arduino Uno which has analog pins that support readings from pH and TDS sensor. Arduino Uno, a micro controller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), and 6 analog inputs. Four mini submersible motor pumps of voltage rating (3-6)V are used for nutrient dosing. They are capable of pumping 80-120L/H. The submersible motor pumps need to be operated at a specific speed so that we don't overdose

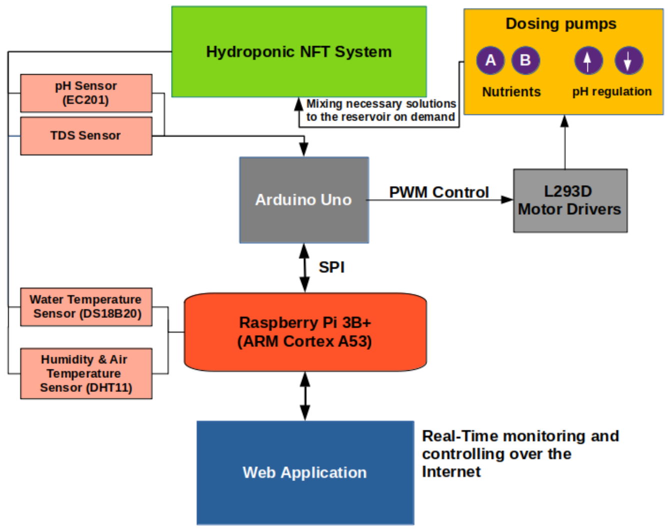

Fig -4: Block Diagram

nutrients into the water reservoir. The speed control is done by using PWM. So, for a hassle free experience we use Arduino Uno, which can be used for both anaolg measurements and motor speed control. The Arduino Uno is connected as a Slave in Serial Peripheral Interface (SPI) with Raspberry Pi as the master. For getting measurements from pH and TDS sensor and for triggering motor pumps the raspberry pi will send a request through SPI.

2.4 Software

In our setup, Python rules the majority of the system. The General Purpose Input Output (GPIO) pins, Serial Peripheral Interface and One-wire Interface are programmed to communicate using Python. The Web Server is programmed in a Python micro framework Flask. The pH and TDS sensors along with the dosing motor pumps are programmed using Arduino IDE which uses C++ as its language. A Heroku Postgres Database is linked with the web app to save and retrieve our plant data. The website has a page to configure time intervals for sensor measurements, admissible range and optimum range for every measurement. The Detailed-View page has all the measurements measured between fixed intervals along with its timestamps. The testing option is for testing the motors before deploying them into the system. Each time when the page is refreshed, the raspberry pi requests fresh measurements from the Arduino. Measurements from the sensors are fetched through Arduino and are updated to the dashboard gauge meters.

The measurements of pH are a voltage difference between the reference solution and our nutrient-rich solution. Before deployment, the pH probe must be calibrated with known standard solutions. The measurements of pH is a voltage difference between the reference solution and our

Fig -5: Dashboard of our Website.

nutrient-rich solution. Before deployment, the pH probe must be calibrated with known standard solutions. The voltage difference is returned in the form of an analog value which is converted into voltage. Each voltage reading maps to a specific pH value. The same process repeats for TDS measurement. A Python scheduler will be running in threads to capture measurements from each sensor and store it in the database. While the scheduler captures measurements, it also checks the measurement to be in our bounds.

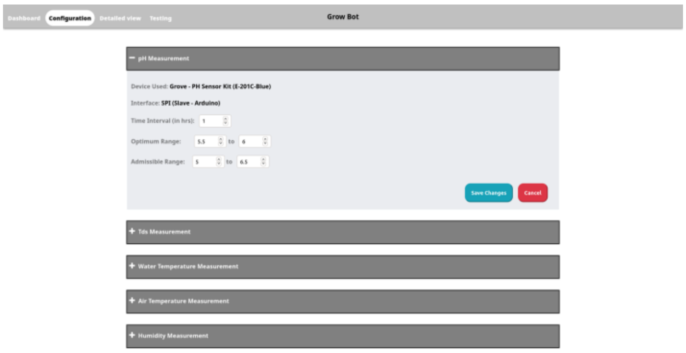

Fig -6: Page to Configure measurement time intervals and allowed range.

If the measurements do not lie in the admissible range, the raspberry pi sends a motor trigger request along with a label to the Arduino through SPI. The Arduino generates a PWM signal for 5 seconds which will mix 4ml of the corresponding solution.

3. Conclusion

The project has successfully been completed and all of our plants grew much faster than the traditional method of growing them in potted soil, giving them access to sunlight and watering them by hand. The crops are pesticide-free. The nutrients we used in our setup are food-grade and are healthy to consume. Plants grown hydroponically will mature on average 25% faster and deliver up to 30% greater yield than plants grown in soil.

Table-1: A table comparing Yield per acre on Hydroponic Farming and Traditional Soil-based Farming

Crop	Yield in Traditional Farming(per acre)	Yield in Hydroponic Farming(per acre)
Lettuce	36,000 heads	400 Tonnes
Cucumber	65,000 heads	200 Tonnes
Tomato	10 Tonnes	200 Tonnes
Beans	6 Tonnes	21 Tonnes

Requiring only a small space, hydroponic farming can produce higher yields compared to traditional farming as shown in Table 1. Even though Hydroponics has many pros over traditional farming, it also has some disadvantages. A Hydroponics System demands a higher setup cost and it also requires technical expertise to grow crops hassle-free. But, the costs incurred in the setup will not be an issue since Return on Investment (ROI) is higher.

Unlike traditional farming, creating the conditions necessary for increased plant efficiency requires very close monitoring of the growing environment. One can easily overcome this issue through automation.

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