Abstract - This paper presents a way to automate the growth of plants with hydroponics in deep water culture using a simple algorithm to maintain the pH level in water and supply nutrients to the nutrient solution when necessary. Despite hydroponic crops being highly nutritious and free from pest, it is difficult to grow hydroponic crops since it requires constant attention to maintain the suitable conditions for the plants and requires knowledge about the hydroponic system to grow them. A sensor is used to log the data from the pH meter and electrical conductivity meter. This data is then used to identify different phenomena and notification is sent to a person. The automated system is designed to take the required action when a certain phenomenon occurs.

Index Terms - Hydroponics, Automation, Soil-less culture, pH, Nutri-culture

I. INTRODUCTION

The use of pesticides and other chemical fertilizer to grow crops have led to the introduction of chemical residue into the food chain which can cause adverse effect on the consumers. This also means that the product produced from that crop also has pesticide residue which causes problem in meeting the food safety standards of different countries. The increase in crop demand with decrease in agriculture land also means that more crops have to be produced in a small area of land. These problems can be solved by establishing hydroponic systems to produce crops since hydroponics can produce a significantly large output of crop from the same area and does not require agricultural land. But due to the complications, it’s initial cost and because hydroponics requires a lot of attention it has not been used extensively.

The yield from hydroponics is far greater than the yield from the same area when cultivated with conventional methods [1]. Hence by improving the workaround for the problems in hydroponics the crop production can be improved greatly.

To grow the plants in a hydroponic system it is important to maintain the conditions required for the plants to grow. It is not common to see plants growing with roots fully submerged in water. But, this is possible because it is not the excess of water itself which is injurious. It is, rather, a lack of aeration resulting from root-submersion which is harmful [2]. Hence an aeration system has to be used in Deep Water Culture technique to supply a continuous supply of air to the roots. The plants require a range pH value to be maintained to ensure the availability of all the nutrients for uptake by the plants[3]. The electrical conductivity of the solution tells us about the concentration of the nutrients available in the nutrient solution [3]. The nutrients required by the plants are added into the system by using a 3-part nutrient made for the growth of vegetable crops. The nutrients required by the tomato plants [8] are found in contained in the 3-part nutrient salts. It is required to change the nutrient solution periodically since the residual ions in the nutrient solution which are not absorbed by the plants can mislead the electrical conductivity meter. It also can reduce the yield when nutrient solution is not changed [9]. The energy required for the photosynthesis process is given by sunlight. In hydroponics, the plants are grown in a closed environment and hence light of the required wavelength has to be produced for photosynthesis using a grow light [4]. It is important to measure and maintain the pH value to the required level because a little drift in the pH value can make a lot of nutrients unavailable for the plants[10].

Section 2 gives the overview of the automated system with block diagram of the system and the working of various components of the system. Section 3 deal with the effect of various parameters on the plants, how the sensors measure the value from the solution and the components used in the system. Section 4 shows the complete layout of the designed automated system. The last section, Section 5 shows snapshots of the implemented prototype.

II. OVERVIEW OF THE SYSTEM

Atmega328 is 8-bit AVR microcontroller based on RISC architecture. It has the required number of GPIO pins and has a USART serial communication interface to communicate with ESP8266. The pH meter for measuring the pH of the solution, Electrical conductivity meter for calculating the Total Dissolved Solids in the solution, distance meter and the water level sensor are connected to the microcontroller. The microcontroller gets the value from the sensor, converts it to digital value using an Analog to Digital Converter and process the value to control the...
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A submersible pump which pumps nutrients, acids and water to the nutrient solution. It also communicates with the user to send alerts when required.

The topology of the proposed system is given in Fig. 1.

![Fig. 1 The Atmega328 will be used to control all the parameters and log the data.](image)

The Hydroponic growing medium used is Hydroton in the prototype. Hydrotons are expanded clay balls heated to make it porous and suitable for hydroponics. They provide the anchorage required for the plants. DS18B20 is a digital temperature sensor by Dallas Temperature. It gives the temperature of the nutrient solution to the microcontroller with OneWire serial communication. Aeration system is used to continuously supply the air to the roots of the plant to protect the roots from suffocation. Electrical conductivity meter is just a pair of conductive probes kept at a constant distance from each other. It is connected in the form of a potential divider. The meter is calibrated programmatically. pH meter has two electrodes and the electrodes produce a voltage of -412mV to 412mV. This value is voltage level shifted to 0-5V which is the converted to a digital value by the ADC in the microcontroller. The pH meter is also calibrated programmatically. The grow light is used to replace the sunlight required for photosynthesis. Plants require radiation with wavelength of the UV spectrum, visible light spectrum and infrared spectrum. The plant reacts differently to different colors of light. LED lights are used for the implemented system[7]. The ESP8266 is Wi-Fi SoC used to host a server which enables the user to monitor the parameters of the solution remotely through the network.

**III. METHODS AND PROCEDURES**

A model of an automated system which logs the data to make the growth of hydroponic crops possible by using the data to automatically maintain the required parameters is developed. The parameter to be maintained for the growth of hydroponic crops are pH, electrical conductivity or the nutrient concentration, electromagnetic radiation in visible and UV region of the spectrum, aeration, humidity, nutrient solution temperature and availability of CO₂ in the atmosphere.

1. **pH of the nutrient solution**

The pH value of the nutrient solution greatly affects the growth of plants. This is because the nutrients added in the nutrient solution all are available for the plant to take in are soluble in water only in particular pH levels.

![Fig. 2. All the nutrients are soluble in water at a pH of 6.2](image)

The solubility of various elements in different pH levels are shown in Fig. 2. For most plans the optimum range of growing crops in hydroponics is a pH of 5.5 to 6.5. The value of pH changes as the plant absorbs nutrients from the solution. The plants give Hydrogen ions into the nutrients in exchange for the ions of elements they require. They do this to be electrically neutral. The Hydrogen ions that the plants get are a result of photosynthesis. These Hydrogen ions combine with water to produce Hydronium ions which increases the pH of the water. This has to be counteracted by adding acids like phosphoric acid into the nutrient solution to ensure the solubility of all the elements in the nutrients.

The automated system measures the pH value of the solution and adds the required amount acid when the pH changes. There are various other factors that influences the change in the pH of the solution. Hence, if the pH changes abnormally a notification is sent to the person in charge by the automated system using a webservice. The system proposed is to solve these problems when growing the crops by using an algorithm which identifies these problems and alerts the person in charge immediately.

2. **TDS of the nutrient solution**

The nutrient concentration in the nutrient solution is measured by Total Dissolved Solids in the solution.
The Total Dissolved Solids is measured by an electrical conductivity meter. The TDS value to be maintained cannot be determined exactly as the plants require different concentration of nutrients in different phases of its life. The required levels can be determined by feedback the plant itself. If the Total Dissolved Solids increases as the plants take in water, too much nutrient is added to the solution and vice versa. Hence the perfect level is when the Total Dissolved Solids does not drop when the water is absorbed provided the temperature, humidity and pH of the solution is maintained. But the Total Dissolved Solids value measured does not necessarily indicate the availability of the nutrients in the nutrient solution as there can be left over ions which the plant does not require in the nutrient solution[6].

This effect of plants on Total Dissolved Solids in the solution is monitored by the system and the perfect conditions are maintained.

3. Preparation of the nutrient solution

It is important to use RO water or water with Total Dissolved Solids less than 250ppm to ensure there is no unwanted effects on plants being able to absorb nutrients. An eggplant was grown with 1250ppm nutrient solution made with hard water with 650ppm of Total Dissolved Solids. This had led to decolorization of plant leaves and roots and the pH started drifting rapidly. Then when the eggplant was grown with Reverse Osmosis water this did not occur.

It is also required the identify the perfect level of nutrient concentration required for the plant of that size and for the climate. A batch of 15 tomato plants were grown with 2500ppm of Total Dissolved Solids Nutrient solution which was well above the required levels. It was identified that the Total Dissolved Solids levels started rising as the plants started taking in water and the pH level started drifting fast. When a normal automatic system which pumps acid into the nutrient solution when the pH goes above 6.3 was employed, excessive acid (H3PO4) was added into the system. This changed the concentration of the system and cased the plants to dry out in water in two days.

IV. AUTOMATED SYSTEM

1. Atmega328

Fig. 3 is the connection diagram of the Atmege328. Atmega328 uses a 16MHz crystal oscillator. The water level sensors LS1-LS5 and the relay pins S1-S6, temperature sensor, ultrasonic distance sensor are connected to the digital pins of the microcontroller. The EC meter, and pH meter are connected to the ADC of the microcontroller. The hardware serial ports tx and rx are connected to the serial ports of the ESP8266.

2. Electrical conductivity meter

Fig. 4 shows the circuit diagram of the electrical conductivity meter. The electrical conductivity meter is a potential divider with two probes connected at EC-1 and EC-2 terminals.

3. Calibration of Electrical Conductivity Meter

The calibration is done by comparing the value from the sensor with the value from a calibrated sensor. The constants are chosen such a way that the values match.

To Convert the digital 8-bit input to Electrical Conductivity equation 1 is used.

\[
\text{Voltage drop} = \frac{\text{Analog Input} \times 5}{1024} \quad (1)
\]
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By Voltage division rule the resistance is calculated with the voltage drop with equation 2,

\[ R_c = \frac{\text{Voltage drop} \times R_1}{5 - \text{Voltage drop}} \]  

(2)

 trouve

Resistance across terminals

To account for Digital Pin Resistance the resistance of pin is measured and subtracted in equation 3,

\[ R_c = R_c - R_a \]  

(3)

Ra – Resistance of digital Pin

The electrical conductivity is calculated with the equation 4.

\[ EC = \frac{1000}{R_c + K} \]  

(4)

EC – Electrical Conductivity
K – Constant of proportionality

To compensating for temperature changes equation 5 is used.

\[ EC_{25} = \frac{EC}{1 + \text{Temp Coef} \times (T - 25.0)} \]  

(5)

EC25 – Electrical Conductivity at 25\degree C
T - Temperature

For the conversion of electrical conductivity to Total Dissolved Solids equation 6is used.

\[ ppm = (EC_{25}) \times (\text{conversion factor} \times 1000) \]  

(6)

4. pH meter
The pH meter is measures the pH value of the solution and once the pH value goes beyond the range to be maintained, the Atmega328 pumps the required acid or base to bring the pH within permissible range [5].

5. Calibration of pH meter
The Offset is found by shorting the terminal of the connector and calculating the pH value. This offset value nullifies the error due to the convertor.

The resistance of potentiometer set in the differential amplifier is 1.06 k\Omega. The voltage in the analog to digital convertor, the actual pH value measured by a calibrated pH meter and the pH value calculated by the system is tabulated. By trial and error the value of constant of proportionality is found. Table 1 shows the pH measured by the pH meter with different constant of proportionality used in the equation in comparison with a calibrated pH meter.

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>pH (Actual)</th>
<th>pH (Measured)</th>
<th>Constant of Proportionality</th>
<th>Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.94</td>
<td>3.9</td>
<td>4.02</td>
<td>4.1</td>
<td>0.13</td>
</tr>
<tr>
<td>2.06</td>
<td>8.4</td>
<td>8.6</td>
<td>4.1</td>
<td>0.13</td>
</tr>
<tr>
<td>0.94</td>
<td>3.9</td>
<td>3.92</td>
<td>4.05</td>
<td>0.13</td>
</tr>
<tr>
<td>2.06</td>
<td>8.4</td>
<td>8.343</td>
<td>4.05</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Table 1 Calibration table of pH sensor

The final calibration results are,

- Constant of Proportionality = 4.05
- Offset = 0.13

The resistance of potentiometer set in the differential amplifier = 1.06 k\Omega.

6. Water level Sensor
The circuit diagram of the contact water level sensor is given in Fig. 5. When water touches WL-2 the transistor BC458 conducts and the microcontroller reads zero in its digital pin.

Fig. 5. Circuit diagram of solution level sensor

V. DEVELOPED SYSTEM

The Tomato System is grown by a fully automated system. The parameters to be maintained were,

- pH - 5.5 - 6.5
- EC - 1400 - 3500 ppm
The Table 2 shows the reading taken daily from the Proposed Automated hydroponic system. It is understood from the value of pH the pH raises as the plant consumes nutrients from the nutrient solution.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>pH</th>
<th>TDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>23-March</td>
<td>22:12</td>
<td>5.4</td>
<td>1970</td>
</tr>
<tr>
<td>24-March</td>
<td>10:40</td>
<td>6.8</td>
<td>1890</td>
</tr>
<tr>
<td>25-March</td>
<td>11:35</td>
<td>6</td>
<td>1760</td>
</tr>
<tr>
<td>25-March</td>
<td>19:40</td>
<td>6.6</td>
<td>1750</td>
</tr>
</tbody>
</table>

Table 2 Readings from the Automated System

The Fig. 6 shows the growth of the tomato plant in the automated hydroponic system.

Fig. 6. Implemented Tomato System

The Fig. 7 shows a close look at the tomato plant in the hydroponic system.

Fig. 7. Tomato Plant in the hydroponic System

Fig. 8 shows the eggplant in a hydroponic system.

Fig. 8. Eggplant Plant in the hydroponic System

Fig. 9 shows the hardware developed to control the hydroponic system.

Fig. 9. The hardware made for the automated hydroponic System

RESULTS

The pH and electrical conductivity of the solution is measured once in every five minutes. If the pH is above 6.3 pH down solution or diluted phosphoric acid is added to the nutrient solution. If the electrical conductivity is low then nutrients are added to the system in the required proportion. Whenever the ultrasonic distance sensor reads that the water level has dropped, water is pumped into the system. When the reservoir of pH down solution and nutrient solution is depleted an alert message is given to a person. An alert message is also given to a person when abnormal behaviors are detected and when the temperature of the solution rises to a point where dissolved oxygen is deprived. The plant grows with
the pH meter and electrical conductivity meter helping to maintaining optimum parameters for the plant growth. The system detects if the change in pH value is too fast and alerts the user to change the nutrient solution.

CONCLUSION

This project has implemented an automated system using Atmega328 with Arduino bootloader. This project has introduced the real-time monitoring of pH and EC of the nutrients solution by the feedback control in the deep-water culture system for reusing the nutrients present in solution. The proposed algorithm has shown better performance in terms of growth and yield than the conventional system. A prototype for the cultivation of tomato and eggplant has been developed and the results of the plant growth have been analyzed.

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