Abstract: This paper braces the importance of the soilless agricultural technique, as expansion of the habitable zones has led to the depletion of agricultural lands and increased food demand. So, to withstand this situation, one of the prominent techniques applied is Hydroponics, where plants are grown using nutrient solutions in a water solvent. Further, integrating hydroponics with the IOT technology [1] escalated the yield profoundly by automating the collection of sporadic data of targeted factors for proper nurturing of crop. This paper proposed a monitoring unit for Controlled Environment Agriculture (CEA) that is designed using the state-of-art hardware specifications and multiple sensors. The proposed device can be readily used in practice in the Hydroponics environment and has great potential for other applications like green house agriculture, vertical farming etc. In addition, the device has been specifically designed to analyse the environment and report to the farmer, round-the-clock, using the Wi-Fi connectivity integrated into it. Further, the readings from the device has been plotted for various regions of India over the four seasons and has been proven reliable for the conditions of Indian agriculture. Summing up the results, the system demonstrates ubiquitous as it can be monitored distantly, analysed and displayed as needed.

Keywords: Hydroponics, Controlled Environment Agriculture (CEA), Temperature, Humidity, light detection, soil moisture, IOT, Arduino MEGA, LAN, sensors, Wi-Fi, sensor networks, TFT.

1. Introduction

Enormous growth of human population, rapid industrialization and expansion of habitable zones have led to the depletion of agricultural lands. The prolongation of these circumstances can be extremely alarming and urge nations like India for abundant food production. Considering the increased need to meet the food demand, many contemporary techniques have been established. One of the most prevailing technique is soilless agriculture. Specifically, hydroponics is a subset of soilless plantation, where plants are grown using nutrient solutions in a water solvent. On a small scale, hydroponics can provide ample food for a faction of people, while on a large scale it can suffice the need of growing population.

2. Literature Survey

In this section, we discussed the state of art contributions by other researchers in this field. More of the work had been done on Controlled Environment Agriculture which mainly focused towards cultivating on minimal or no land of which the few contributions are discussed below: Kadge.et.al proposed Wireless Control System for Agriculture Motor in which he designed a system to control the throughput utilizing the SMS [1] feature of the mobiles. The communication can be through SMS, i.e. the farmer can get message when the motors are ON or when they are OFF. This project implementation has been done in India successfully and helped during non-deterministic weather conditions. The motor is turned off whenever the farmer receives an alarm about single phasing. He emphasizes there is a need for personal GSM connection for this type of implementation. Finally, the author points out that GSM can be used with the digital mobile phone system and it compresses the information basically and transfers it down the channels with other two stream of the user’s data with the intervention of service providers.

3. Design and Modelling of CEA

In this section, we proposed various aspects regarding the design along with implementation of CEA. CEA’s system provides automated control and monitoring programme. This proposed work is intended to offer ease of use, effective and reliable control system. It helps in reducing the amount of water and energy required. From an economical view, agriculture is the fount of living for over half of the world’s population. Moreover, this system will increase yield for farmers at a moderate and accessible cost. This section initially explains about the functional and non-functional requirements and the next sections deal with system architecture, hardware and software design.
3.1. Functional Requirement

The successive requirements specify the functions and units of the proposed system. They characterize the behaviour of the system relating to necessity:

- Measure Temperature.
- Gauge Humidity.
- Quantify the water level.
- Estimate the light intensity.
- Sense the Air Toxicity.
- Display the sensor readings on the LCD screen.
- Allow user to modify the optimal values for the sensor.
- Respond to sensor readings and send alerts to the user.

3.2. Non-functional Requirement

The non-functional requirements of this proposed work assess the following:

- Availability: The proposed system is manoeuvred successfully all the time.
- Reliability: The system has longer lifespan and the measurements are accurate.
- Maintainability: The proposed system can be upgraded at ease by simply integrating additional components with enhanced features.
- Ease of use: The proposed system is easy to comprehend and grasp. The usage of the system doesn’t require any prior knowledge.

3.3. System Architecture

The proposed system is modelled using Arduino mega development kit which connects to light sensor for measuring the light intensity, environment temperature/humidity sensor for getting the temperature and humidity in the surroundings, soil moisture sensor for volumetric water level, and air toxicity sensor for measuring carbon monoxide and oxygen levels. Moreover, this system can be used to continuously analyse the temperature, water level and the amount of light reaching the plants which is vital for greenhouse systems.

Temperature and humidity measurement are required for the analysing the environmental surrounding of the plants. Various plant species have distinct ideal temperature and humidity ranges. Examining and controlling the temperature and humidity of the plant surroundings is a must to protect plants from droughts and extreme temperatures. The wielded temperature and humidity sensor is shown below. Furthermore, the light sensor is essential in measuring the information regarding the levels of light received by the crops.

This system encompasses a wide range of sensors. The system also includes an Air Toxicity Sensor. The Air Toxicity Sensor is used to measure the toxicity in surroundings, it basically finds the existence of carbon monoxide and alcohol, which are very dangerous to the growth of the plant. The Arduino mega Development kit contains a microcontroller in built, and helps us to integrate all the sensors and display the sensor readings on the LCD screen. Furthermore, this touch LCD screen can also act as an input device. A User Interface is used to take the input from the touch LCD. Moreover, the system has a WIFI module, which sends the sensor readings to the server over the Wireless Network. The...
server further allows the user to access the sensor data at any time.

3.3.1. Parameter and Sensor specifications

- **Temperature and Humidity Sensor:** The DHT11 is a low-cost digital temperature and humidity sensor. This sensor takes input from surroundings and gives digital signal as output. It consists of thermistor and humidity sensor through. As the sensor is of small size, consumes low power and transmit signal up to 20-meter range.

Table 1. Specifications of Temperature and Humidity Sensor

<table>
<thead>
<tr>
<th>Sensor Model</th>
<th>DHT11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>+5V</td>
</tr>
<tr>
<td>Input</td>
<td>Temperature and humidity in surroundings</td>
</tr>
<tr>
<td>Output</td>
<td>Digital Signal</td>
</tr>
<tr>
<td>Units</td>
<td>Temperature in Celsius and Humidity in Percentage</td>
</tr>
</tbody>
</table>

Figure 4. Temperature and Humidity Sensor

- **Light Sensor:** A light dependent resistor also known as a LDR or photo resistor or photoconductor or photocell, is a resistor whose resistance depends on light intensity. LDR’s are light sensitive devices.

Table 2. Specifications of Light Sensor

<table>
<thead>
<tr>
<th>Sensor Model</th>
<th>LDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>+3.3V</td>
</tr>
<tr>
<td>Input</td>
<td>Light</td>
</tr>
<tr>
<td>Output</td>
<td>Analog Signal</td>
</tr>
<tr>
<td>Units</td>
<td>LUX</td>
</tr>
</tbody>
</table>

Figure 5. Light Sensor

- **Water Level Sensor:** The Water Level Sensor uses capacitance to measure the water content in soil by measuring the di-electric permittivity of it. When we insert this sensor into the soil which is to be tested, then the water content present in the soil is reported in percentage.

Table 3. Specifications of Water Level Sensor

<table>
<thead>
<tr>
<th>Sensor Model</th>
<th>SHT10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>+3.3V</td>
</tr>
<tr>
<td>Input</td>
<td>Water</td>
</tr>
<tr>
<td>Output</td>
<td>Analog Signal</td>
</tr>
<tr>
<td>Units</td>
<td>Percentage</td>
</tr>
</tbody>
</table>

Figure 6. Water Level Sensor

- **Gas Sensor:** The gas sensor uses a small heater inside with an electro-chemical sensor. It is sensitive for a range of gases and are used mainly indoors at room temperature. This sensor can be calibrated, but a known concentration of the measured gas or gases is needed for that calibration.

Table 4. Specifications of Gas Sensor

<table>
<thead>
<tr>
<th>Sensor Model</th>
<th>MQ135</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>+3.3V</td>
</tr>
<tr>
<td>Input</td>
<td>Alcohol, dangerous gases like Carbon Monoxide (CO).</td>
</tr>
<tr>
<td>Output</td>
<td>Analog Signal</td>
</tr>
<tr>
<td>Units</td>
<td>Percentage</td>
</tr>
</tbody>
</table>

Figure 7. Gas Sensor

- **Real Time Clock:** The DS1302 is a chip which contains a real-time clock and 31 bytes of static RAM in it. This chip communicates with a microcontroller via a simple serial interface. The real-time clock provides information regarding time (seconds, minutes, hours) and day (date, month, year).

Table 5. Specifications of Real Time Clock
3.4. **Hardware System Design**

3.4.1. **Arduino Development Kit:** The ATmega2560 on the Mega 2560 comes preprogrammed with a bootloader that allows us to upload new code to it without the use of an external hardware. It communicates using the original STK500 protocol. You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header using Arduino ISP or similar.

![Arduino Mega 2560](image1)

**Figure 9. Arduino Mega 2560**

**Table 6. Specifications of Arduino Mega 2560**

<table>
<thead>
<tr>
<th>Model</th>
<th>Arduino Mega 2560</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller</td>
<td>ATmega2560</td>
</tr>
<tr>
<td>Operating Voltage (limit)</td>
<td>5V-20V</td>
</tr>
<tr>
<td>Digital I/O Pins</td>
<td>54 (of which 15 provide PWM output)</td>
</tr>
<tr>
<td>Analog Input Pins</td>
<td>16</td>
</tr>
<tr>
<td>Flash Memory</td>
<td>256 KB of which 8 KB used by bootloader</td>
</tr>
<tr>
<td>SRAM</td>
<td>8 KB</td>
</tr>
<tr>
<td>EEPROM</td>
<td>4 KB</td>
</tr>
<tr>
<td>Clock Speed</td>
<td>16 MHz</td>
</tr>
<tr>
<td>Length</td>
<td>101.52 mm</td>
</tr>
<tr>
<td>Width</td>
<td>53.3 mm</td>
</tr>
</tbody>
</table>
| Weight | 3.4.2. **Touch LCD Display:** A thin-film-transistor liquid-crystal display (TFT LCD) is a modification of a liquid-crystal display (LCD) that operates on thin-film transistor (TFT) technology to enhance the image features such as addressability and polarity. A TFT LCD is an active-matrix LCD for high resolution display in variation to passive-matrix LCDs or simple, direct-driven LCDs with a couple of fragments. TFT LCDs have many applications including television appliances, computer monitors and mobile phones, mini video game systems, PDAs and projectors. TFT LCDs are utilized in car device clusters as they permit the driver to customize the cluster, as well as provide with the ability to display an analogue view with digital elements.

![TFT LCD Screen](image2)

**Figure 10. TFT LCD Screen**

**Table 7. Specifications of Touch LCD Display**

<table>
<thead>
<tr>
<th>Model No</th>
<th>ST7783</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>2.8”</td>
</tr>
<tr>
<td>Input</td>
<td>User Input</td>
</tr>
</tbody>
</table>

**Table 8. Specifications of External Memory Unit**

<table>
<thead>
<tr>
<th>Model No</th>
<th>ST7783</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>Micro SD Card</td>
</tr>
</tbody>
</table>

3.4.3. **External Memory Element:** External Memory is needed for saving the settings and the LOG files, as the microcontroller doesn’t have enough memory. This module was embedded into the TFT LCD module, so that we can easily interface this with the microcontroller.

![External Memory Slot](image3)

**Figure 11. External Memory Slot**

3.4.4. **Wi-Fi Module:** The ESP8266 Wi-Fi Module is an independent system on chip with built-in TCP/IP protocol stack which allows the microcontroller to access the Wi-Fi network. The ESP8266 has the potential of either hosting an application or discharging the Wi-Fi networking functions entirely from an additional application processor.

3.4.4.1. **Wi-Fi Module:** The ESP8266 Wi-Fi Module is an independent system on chip with built-in TCP/IP protocol stack which allows the microcontroller to access the Wi-Fi network. The ESP8266 has the potential of either hosting an application or discharging the Wi-Fi networking functions entirely from an additional application processor.
**Table 9. Specifications of Wi-Fi Module Unit**

<table>
<thead>
<tr>
<th>Model No</th>
<th>ESP8266</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE Protocol</td>
<td>802.11 b/g/n</td>
</tr>
<tr>
<td>Flash Memory</td>
<td>1 MB</td>
</tr>
<tr>
<td>Wakeup Time</td>
<td>&lt;2ms</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Up to 300 Mbps</td>
</tr>
</tbody>
</table>

![Wi-Fi Module Image](image)

**Figure 12. Wi-Fi Module**

### 3.5. Software System Design

This section contains the details about the software model. The proposed system is developed under the Arduino Genuino (IDE), that is useful for integrating hardware with software and this helps us to connect all the sensors and I/O devices. The below figure shows the algorithm implementation of this device.

![Algorithm Implementation Image](image)

**Figure 13. Algorithm Implementation**

**Algorithm 1 Software Implementation of CEA**

1. **BEGIN**
2. Initialize all ports with identifiers and variables required for touch display
3. Calibrate touch display for better sensing
4. Initialize minimum and maximum pressure for touch screen
5. **while** (until power supply) **do**
6. Display sensor readings along with time and date on touch display
7. Send the data over Wi-Fi to the server
8. **if** button pressed == LOG
9. Display log data on touch display
10. **end if**
11. **if** button pressed == SETTINGS
12. User need to enter threshold values of each sensor
13. **end if**
14. **if** button pressed == HOME
15. Display home screen which consists of sensor readings along with date and time
16. **end if**
17. **end while**
18. **end**

**4. Experimental Analysis and Results**

**Graph Readings:** To illustrate the working of individual sensors which are incorporated in our device the following graphs are plotted.

![DHT11 Temperature Graph](image)

**Figure 14. DHT11 Temperature**

The above figure shows temperature values taken from DHT11 sensor over different seasons in a year with varying time instances. Usually the time is measured in hours and temperature is measured in Celsius. From the figure, it is noticed that at the time of summer, the temperatures are increasing steadily, as the time progress. In summer it reaches a peak temperature of $36^\circ$C while the lowest is recorded at $25^\circ$C.

During the monsoon and the autumn, there is a substantial increase by 5° – 10° C till 14:00, from where they subsided steeply till 20:00 and remained constant till 00:00. Whereas during the summer, the threshold temperatures remained till 14:00, due to hot winds and land masses. Further, it maintained vantage over others till 20:00, from then they subsided. With regard to the temperature readings from the device, the water levels to be maintained can be decided.

![DHT11 Humidity Graph](image)

**Figure 15. DHT11 Humidity**

The above figure shows humidity values taken from DHT11 sensor over different seasons in a year with...
varying time instances. Usually the time is measured in
hours and temperature is measured in Celsius. It is
perceived from the above image that at the time of
winter, the humidity percent reaches as low as 35% at
01:00 and gradually increasing steadily, as the time
progress. In winter it reaches a peak humidity of 80% as
a result temperature is low. Furthermore, humidity
ranges in monsoon and autumn are relatively close.
We observed that the humidity changes are almost
steady, during all the seasons till 10:00 except in
winter, where the air is dry and the moisture levels are
less. The graph steeply falls from 10:00 onwards till
15:00, as the effect of the Sun during the afternoon.
Then, we observed a rapid increase of 20 – 30 %
humidity till night 22:00 and remained constant
thereafter. With regard to the humidity readings from
the device, the farmer could increase or decrease the air
conditioning appropriately.

The above figure shows soil moisture values taken
from sensor over different terrains with varying time
instances. Usually the time is measured in hours and
moisture is measured in volumetric moisture content. It
is observed from the figure that the soil moisture in dry
land is comparatively less than wet land. We observe
that the Soil moisture changes for every hour provided
that the values are logged in the device. With regard to
the soil moisture readings from the device, the farmer
could increase or decrease the water content
appropriately. In the event that the moisture is low the
device activates the water supply to maintain the water
levels in soil.

The above figure shows lux values taken from LDR
Photosensitive Resistance Sensor over a different
period of time instances. Usually the time is measured
in hours and luminance is measured in lux. It is
observed from the figure that the luminance values are
comparatively higher in summer than winter.
We observed that during summer, the luminous
intensity starts to ascend from 05:00 to maximum of
1100 lux at 15:00. Further it steeply descends to 0 lux
at 20:00. Whereas during winter the luminous intensity
starts to ascend from 07:00 to a maximum of 1000 lux
at 13:00. Further, it descends steeply to 0 lux at 18:30.
Based on the readings, farmer has ability to control the
light intensity artificially. In either case the end user
has an option to manually set the light intensity
required for plantation.

The temperature values in south and west India during
the month of December are shown varying from 20 °C to
35 °C. On the contrary, the temperatures in north and
east are very low ranging from 10 °C to the
maximum of 20 °C. These readings are logged and
stored in memory card which explicitly helps end user
to respond eventually.
varying time instances. As can be seen the time is measured in hours and temperature is measured in Celsius. Furthermore, it is observed from the figure that the humidity declines rapidly in western India from 59% to 20% which results in very high temperatures. Likewise, the humidity range in other regions namely north south and east are identical in nature. The CEA is provided with an option to modify temperature manually which helps to automate the process without user interaction. With regard to the humidity readings from the device, the farmer could increase or decrease the air conditioning appropriately.

5. Conclusion

The results obtained from the device have indicated that the performance is well, especially in collecting, logging and analysing the sporadic data from the sensors that is transferred to central node for farmers’ use. Further, from based on the graphs, we observe that the soilless agriculture shows promise for future of Indian agriculture. Further work is required on shield casing of nodes under severe weather conditions. Power supply from renewable sources or a battery or any other uninterrupted source requires scrutiny. The device accommodates for auxiliary or replaceable sensors to be connected as per the requirement. The device is put to test with the water and small area of soilled plantation. Further investigation is required in the aspects of water and soil variety of various places of India. Further investigation is planned for developing mobile and desktop based application for monitoring, controlling of the device. Also, the economic feasibility for the setup of this type of agriculture and the device is to be investigated. There is opportunity to merge the analytics tools that process the data and act accordingly, which even more reduces the human intervention further. The device can relatively easily operated by the end users, and can be implemented in small as well as large scale farming.

References


