PROJECT REPORT

(January 2022 – May 2022)

Automated Indoor Farming

Under the Guidance of:

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January 2022 to May 2022

DECLARATION

We, hereby, declare that the project work entitled "**Automated Indoor Farming**" is an authentic record of our work carried out as a requirement of the Major Project for the award of the degree of B.E. (Electronics and Communication Engineering), Punjab Engineering College (Deemed to be University), Chandigarh, under the guidance of **Dr Neena Gupta,** Prof & HOD, ECE Dept, Punjab Engineering College (Deemed to be University), Chandigarh.

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Certified that the above statement made by the students is correct to the best of my knowledge and belief.

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We wish to express our sincere obligation to our mentor **Dr Neena Gupta, Prof & Head ECE Department, Punjab Engineering College** for their incessant encouragement and inspiration throughout the project. Without their enduring spur, generous guidance and help, we would not have been able to cope up with the project work.

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ABSTRACT

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An indoor farm is an indoor structure where plants are grown. Indoor farms are often used for growing flowers, vegetables, fruits, tobacco plants, etc. Basic factors affecting plant growth are sunlight, the water content in the soil, temperature, etc. These physical factors are hard to control manually inside an indoor farm and a need for automated design arises. Automatically controlling all the factors that affect plant growth is also a difficult task as it is expensive and some physical factors are interrelated, for example, temperature and humidity are related in a way when temperature raises humidity reduces therefore controlling both together is difficult. Because the temperature and humidity of the indoor farm must be constantly monitored to ensure optimal conditions, a wireless sensor network can be used to gather the data from point to point. The data from the indoor field will be measured by the sensor and the data that are collected will be sending to the receiver. The data that has been read will be displayed on the LCD screen. By using this system, the process of monitoring is easier and it is also cheaper for the installation and maintenance processes.

Current systems do not use data captured from sensors for analytics purposes, this limits the efficiency of the greenhouse. For this project, we have used raspberry pi and integrated it with other sensor modules. Raspberry Pi offers better internet connectivity, more RAM and allows us to use complex machine learning algorithms. We have made use of web application interface for providing the capability of remote control and monitoring. Raspberry Pi's superior computing power and memory storage ability has been utilized to use it as a webserver. Machine learning has been used to develop numerous applications. The indoor farm prototype presented here involves monitoring and control of three vital parameters of the field system namely temperature, the water level in soil, and light intensity inside the indoor farm. The details of system implementation can be presented in two parts- hardware and software. Because of the use of technology, the field parameters can be monitored and controlled continuously and the collected real-time data from the sensors can be displayed on web pages or applications from anywhere in the world at any time. The variation in individual sensor's data over time can be graphically plotted for improved monitoring and analysis.

1. INTRODUCTION

INTRODUCTION

An indoor farm is mainly used to provide a controlled environment in terms of temperature and humidity in order to grow certain types of plants throughout the year. It is also used for plants that can produce better yield in terms of quality and quantity when subjected to continuous monitoring and control. At present most of the indoor farms are manually controlled and monitored. Indoor farms mainly deal with the vital environmental parameters for plant growth such as humidity, temperature, moisture, and light. Thus we can conclude that the indoor farm system helps in boosting the efficiency and profitability of farming. The innovative design presented here can perform the monitoring and control activity from remote locations using IoT. Thus farmers or indoor farm workers need not go to the site to control any parameter of indoor farming. For example, it may be required to turn on and off the water pump, sliding the windows, turning on and off sprinklers etc. which may be performed sitting at home without going to an indoor farm. The designed system consists of various sensors such as temperature sensors, humidity sensors, and LDR sensors along with windows application for controlling indoor farm parameters. The sensors continuously send real time data values to the microcontroller and when the value reaches a certain threshold or critical value microcontroller takes control action automatically. For example; fan can automatically start when the temperature inside the indoor farm crosses the critical value.

It is important to describe the indoor farm climate to design a good control system since it is a way of manipulating the variables that affect its behavior. The indoor farm climate control provides a favorable environment for cultivation and this achieves predetermined and optimal results. Another topic of interest derived from the production of indoor farm crops is energetic consumption, in which solar energy is presented as a viable substitute for traditional sources (fuel and electricity). Solar energy is better than traditional sources because fuels are not renewable and represent high cost. Traditional energy sources can be replaced with other sustainable energies, such as solar energy, wind energy, biomass, geothermal energy, cogeneration systems, among others. However, use of solar photovoltaic cells or solar thermal energy in indoor farms are more widely used and can commonly be combined with other sustainable energy systems. Solar indoor farms provide a controlled system cultivation, the most focus is to reduce heating energy requirements, i.e., the heating requirement is largely derived from the sun. Furthermore, solar energy represents a primary element in the heating of indoor farms and makes it possible to minimize production costs. Several studies have been carried out in which energy savings are sought, where methods such as genetic algorithms (GA) have been applied to optimize energy collection, also physical models, as well as computational fluid dynamics (CFD) techniques to predict the microclimate of solar indoor farms.

Gaps and Learnings

- Current systems do not use data captured from sensors for analytics purposes, this limits the efficiency of the greenhouse.
- The greenhouses are also not energy efficient, optimization is not sufficient enough.
- For this project, we learnt about raspberry pi and its integration with other sensor modules.
- Raspberry Pi offers better internet connectivity, more RAM and allows us to use complex machine learning algorithms.
- We gained knowledge on web application interface and controlling the various parameters through machine learning.
- This project offers us exposure to new technologies such as Raspberry Pi and Android Studio.

2. LITERATURE REVIEW

LITERATURE REVIEW

An overview of related research work has been presented in this section. The researchers have carried out a preliminary study of the automation in agriculture literature, reputed international journals and conferences which has been presented in this review of literature. Several authors have carried out work using the IoT concept in indoor farms.

Prakash H. Patil [1] in 2013 have developed an indoor farm monitoring system using GSM which monitors the levels of temperature, humidity, light, and CO2. Their system uses different sensors for parameter measurement and GSM for messaging. The system offers a mechanism to alert farmers regarding the parameter changes in the indoor farm. However, both systems lack a real-time graphical representation of the measured data and the feature of controlling the indoor farm system remotely. This paper mainly aims to describe the indoor farm monitoring system which will display the sensed data on a webpage and will also provide the facility of controlling and monitoring the system remotely.

Paul B. McNulty and Patrick M. Grace [2] discuss the automation of agricultural activities around the world. The rate of growth of automation of agriculture should be on par with growing world population. Today machines have partially replaced the human energy and animal power. The authors stated that first America and Europe are leading the agricultural automation revolution followed by Japan. Now the other part of the world also started adopting automation aggressively. Agricultural automation is the primary area of research to improve the food quantity and quality, use of appropriate quantity of agro chemicals, energy conservation and environment.

Agricultural Machinery Industry India report presented the growth market structure and business strategies facts about availability of farm power decade wise from 1952- 2016 and tabulated facts about animal, mechanical and electrical power utilization for agricultural activities. This paper has also tabulated the Indian agriculture machinery stocks comparison with that of countries such as Japan, UK, Germany and France. The growth of different agricultural machines from 1992 to 2003 is also presented. This paper gives a holistic picture about the agriculture machinery availability in India with comparison to developed countries.

Manasi R. Kulkarni [3] carried out the implementation by designing a microcontroller-based system which monitors and records the values of various parameters such as temperature, light intensity, humidity. All these values are continually monitored and controlled in an order to get maximum yield. It involved creating a webpage to observe the real time data of different sensors. Some of the important sensors that were used in this project are- Light Sensors, Temperature and Humidity Sensors, and Soil moisture sensor. The implementation, use of IoT for indoor farm automation has resulted in a great benefit in terms of remote monitoring and graphical representation of parameters. The smart indoor farm automatically optimizes the various parameters for the plant growth. It sends the real time data of parameters to a customized web page for continuous and effective monitoring.

Uday A. Waykole [4] showcased that automation and high efficiency on indoor farm environment monitoring and control are crucial. Applying ZigBee-based WSN technologies to indoor farms is a revolution for protected agriculture which overcomes the limits of wire connection systems. Such a system can be easily installed and maintained.

Ferdousi Rahman, Israt Jahan Ritun and Jia Uddin [5] approached the project with an effusively indoor cultivation system based on the modern farming concept called aeroponics, in a controlled environment using Arduino and different parameters measuring sensors. Aeroponics is the modern agricultural conception in which the plants are grown without soil using a nutrient solution sprayed in the roots and is more efficient than soil farming. The longstanding farming techniques are mostly dependent on the soil conditions and outer atmosphere, but using this technology, the cultivation process is more resourceful with better control system and data monitoring as well as convenient for general urban outdoors. The proposed system states easily available and user-friendly components, allowing people to reproduce and modify without needing advanced technological skills and tools.

Kirtan Jha, Aalap Doshi and Poojan Patel [6] talk about different automation practices like IOT, Wireless Communications, Machine learning and Artificial Intelligence, Deep learning. The paper talks about areas which are causing the problems to agriculture field like crop diseases, lack of storage management, pesticide control, weed management, lack of irrigation and water management and all these problems can be solved by above mentioned different techniques. The paper also discusses a proposed system which can be implemented in botanical farm for flower and leaf identification and watering using IOT.

R. Sharath Prasanna, V. Karthikeyan, M. Mohamed Armoon Shaliq [7] present the concept of automated agriculture that is a track-based farming technique for large area farming. Machine design is carried out in such a way that it receives a single command from the user, after which it assesses and analyses geographical conditions and begins to send the analysed data to the user. The fully automated system assists to select the seeds by itself and sow the seed according to the optimal weather conditions in appropriate time.

K. Swarna Krishnan, K. Jerusha, Poonam Tanwar, Shefali Singhal [8] in their paper 'Self-Automated Agriculture System using IoT' develop a self- autonomous agriculture system works by connecting physical devices and systems to the internet. The paper aims at making the agriculture smart using IoT technologies. The projects include a GPS based robot to perform tasks like weeding, spraying, moisture sensing, bird scaring, keeping vigilance, etc. This project requires smart irrigation with smart control and best decision making based on accurate real time data.

A remote sensing and control irrigation system using distributed wireless sensor network aiming for variable rate irrigation, real time in field sensing, controlling of a site specific precision linear move irrigation system to maximize the productivity with minimal use of water was developed by Y. Kim.

3. OBJECTIVES

OBJECTIVES

Objective 1: Smart Irrigation System

The Smart Irrigation System is capable of automating the irrigation process by analyzing the moisture of soil and the climate condition.

Purpose: The need of an automated irrigation system is to overcome over irrigation and under irrigation. The purpose of the smart irrigation system is that to defeat the conventional methods of irrigation done by farmers.

● Sensor is used to take sensor readings of soil like soil moisture, temperature, air moisture.
● The decision making is controlled by the user (farmer) using a microcontroller.
● The irrigation will be automated when the moisture and temperature of the field is reduced.

Objective 2: Indoor farm Climate Control

Indoor farms will have different sensors to measure the ambient temperature, the external temperature, the soil moisture and the luminosity.

Purpose: The goal is to regulate the temperature inside the indoor farm and to maintain a quite constant level of soil moisture with a pump all by receiving temperature, soil moisture and luminosity measurements.

● The prototype designed for this particular research will allow better monitoring of the climate condition in an indoor farm by integrating several sensor elements such as CO 2 , temperature, humidity, light, soil moisture and soil temperature into the system.

Objective 3: **Physical Construction of Indoor farm**

Constructing an indoor farm, keeping in mind all the necessities to be attached.

Fig 1. Prototype physical construction of an indoor farm

Objective 4: Integration of Machine Learning to Automate Indoor Farming Controls

Based on the data collected using various sensors, the amount of fertilizer and other substances required for maximum yield can be determined based on the crop.

Purpose: Maximize crop yields, help manage energy costs, and help with water and fertilizer conservation.

Different things we can work upon:

- **Yield Prediction:** A comprehensive multidimensional analysis of crops, weather, and economic conditions to make the most of the yield
- **Crop Quality:** The accurate detection and classification of crop quality characteristics can increase product price and reduce waste.
- **Disease Detection:** Machine Learning is used as a part of the general precision agriculture management, where agro-chemicals input is targeted in terms of time, place and affected plants.

- **Weed Detection:** Computer vision and ML algorithms can improve detection and discrimination of weeds at low cost and with no environmental issues and side effects.

Objective 5: Hardware Analysis for Better Yield

Comparison of different hardware components on the basis of various parameters to ensure that the model proposed is efficient and gives out the best possible results.

Objective 6: Web Application

A web application using which all data can be monitored and analyzed. The indoor farm is controlled remotely if required.

Purpose: Completes full integration of hardware with software for maximum ease.

This project offers a solution where it integrates between the Internet of Things (IoT) system and Android apps to monitor the plant's growth with real-time data monitoring and also provides the system control. IoT is a shared network of objects which interact with each other.

Web Interface:

- Home Page
- About
- Control
- Contact Us

4. WORKING

4.1 Hardware Circuitry

4.1.1 Hardware Used:

Table 1 below, shows the list of hardware components that have been used in this project. Further, a detailed description of each one of them is given in this section.

Sr. No	Component	Description
1.	Raspberry Pi	Raspberry Pi 3
2.	Soil moisture sensor	Resistive sensor
3.	Water pump	6V DC
4.	LEDs	2 pin LED diode
5.	Relay	Electrical Switch
6.	Adaptor	5V
7.	Fan	12V DC
8.	Temperature Sensor	DHT11 5V
9.	Humidity Sensor	DHT511 5V
10.	Light Sensor Module	Photodiode
11.	Breadboard	
12.	Connecting wires	

Table 1. Hardware Components

4.1.1.1 Soil Moisture Sensor

Soil moisture sensors measure or estimate the amount of water in the soil. These sensors can be stationary or portables such as handheld probes. Stationary sensors are placed at the predetermined locations and depths in the field, whereas portable soil moisture probes can measure soil moisture at several locations.

Soil moisture sensors are divided into two categories depending on the technology they use: 1) Sensors that measure volumetric water content and 2) Sensors that measure soil tension when placed in the soil profile.

Sensors should be placed at several different depths and locations in the field. Typically, sensors are placed in pairs at one-third and two-thirds the depth of the crop root zone and at two or more locations in the field, preferably in the representative soil type away from high points, depressions and slopes.

Some fields contain both heavy and light textured soils. In those fields, it is recommended that each soil type be monitored and managed separately for irrigation. Field mapping technologies can be used to identify different soil, such as electromagnetic conductivity (EM) mapping. By identifying different soils (different water holding capacities), management zones can be created that can be managed separately.

Fig 2. Displays a soil moisture sensor. The node senses the moisture content based on capacitive effect, it consists of a hygroscopic dielectric material sandwiched between a pair of electrodes forming a small capacitor, in our case, it is the soil acting as a dielectric material. The dielectric constant of the hygroscopic dielectric material and the sensor geometry determine the value of capacitance in absence of moisture, at equilibrium conditions, the amount of moisture present depends on both the ambient temperature and the ambient water vapor pressure. At normal room temperature, the dielectric constant of water vapor has a value of about 80, which is much larger than the constant of the sensor dielectric material, therefore, absorption of water vapor by the sensor results in an increase in sensor capacitance. By definition, the moisture content is a function of both the ambient temperature and water vapor pressure. Therefore, there is a relationship between moisture content, the amount of moisture present in the sensor, and sensor capacitance.

Fig 2. Soil Moisture Sensor

4.1.1.2 Temperature and Humidity Sensor

Humidity is the presence of water within the air. The amount of water vapor that is present in the air can affect not only personal comfort but can also affect various manufacturing processes within industrial applications. For instance, in the semiconductor industry, moisture or humidity levels must be properly controlled and monitored to ensure proper wafer processing. Humidity control is also frequently important for incubators, respiratory equipment, sterilizers, and biological products. In addition, the presence of water vapor may also influence various other chemical, biological, and physical processes.

Measuring humidity within the environment can be critical due to the fact that the higher the humidity, the warmer it may seem. In industries, humidity measurement is often important because it can affect the health and safety of personnel as well as the cost of the product. As a result, temperature and humidity sensors are often quite important.

The measurement of humidity is also an important element of weather reports because the presence of humidity indicates the chance of dew, fog, or precipitation. Higher relative humidity reduces the effectiveness of sweating in order to cool the body. This occurs because evaporation of perspiration from the skin is prevented. This effect is measured in a heat index table. As a result, it may often feel hotter during the summer in areas where there is higher relative humidity.

Temperature and humidity sensors are among the most commonly used environmental sensors. Humidity sensors are also sometimes referred to as hygrometers. These devices are used to provide the actual humidity condition within the air at any given point or in any given place. Such devices are commonly used in situations in which air conditions may be extreme or where air conditions need to be controlled due to varying reasons.

In choosing temperature and humidity sensors, it is important to keep certain specifications in mind. Among those factors include:

- Repeatability
- Accuracy
- Long-term stability
- Interchangeability
- Ability to recover from condensation
- Resistance to physical and chemical contaminants
- Packaging
- Size
- Cost effectiveness

Fig. 3 diplays DHT11 Temperature and Humidity Sensor along with its various pins. It is a Humidity and Temperature Sensor, which generates calibrated digital output. DHT11 can be interface with any microcontroller like Arduino, Raspberry Pi, etc. and get instantaneous results. DHT11 is a low cost humidity and temperature sensor which provides high reliability and long term stability.

It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and outputs a digital signal on the data pin (no analog input pins needed). Its very simple to use, and libraries and sample codes are available for Arduino and Raspberry Pi.

This module makes is easy to connect the DHT11 sensor to an Arduino or microcontroller as includes the pull up resistor required to use the sensor. Only three connections are required to be made to use the sensor - VCC, GND and Output.

It has high reliability and excellent long-term stability, thanks to the exclusive digital signal acquisition technique and temperature & humidity sensing technology.

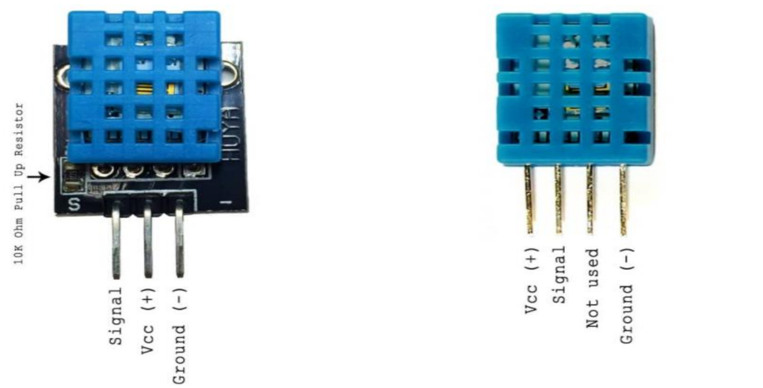


Fig 3. DHT11 Temperature and Humidity Sensor

4.1.1.3 Raspberry Pi

Raspberry Pi is a credit card size low-cost, high-performance computer, which is developed in the United Kingdom by the Raspberry Pi Foundation. We have used model B of the third generation of raspberry pi which is shown in Fig. 4 below. The primary reason to use this particular model its support for wireless connectivity, this model supports 2.4 GHz WiFi 802.11n (150 Mbit/s) and Neel P. Shah et al, International Journal of Advanced Research in Computer Science, 8(9), Nov–Dec, 2017,468-471 © 2015-19, IJARCS All Rights Reserved 470 Bluetooth 4.1 (24 Mbit/s) based on Broadcom BCM43438 FullMAC chip. It also has 10/100 Ethernet port. With its 40 GPIO (General Purpose I/O) pins peripheral interfacing becomes less cumbersome.

Fig 4. Raspberry Pi Module

<u>Features of Raspberry PI Model B</u>

- 512 MB SDRAM memory
- Broadcom BCM2835 SoC full high definition multimedia processor
- Dual Core Video Core IV Multimedia coprocessor
- Single 2.0 USB connector
- HDMI (rev 1.3 and 1.4) Composite RCA (PAL & NTSC) Video Out

- 3.5 MM Jack, HDMI Audio Out
- MMC, SD, SDIO Card slot on board storage
- Linux Operating system
- Dimensions are 8.6cm*5.4cm*1.7cm
- On board 10/100 Ethernet RJ45 jack

4.1.1.4 Light Sensor

As shown in Fig. 5, SN-LIGHT-MOD is a photosensitive resistor module, suitable to detect environmental light intensity and ambient brightness. Its sensitivity can be tuned with an on board potentiometer, where turning it clockwise will increase the sensitivity and increase the detection range.

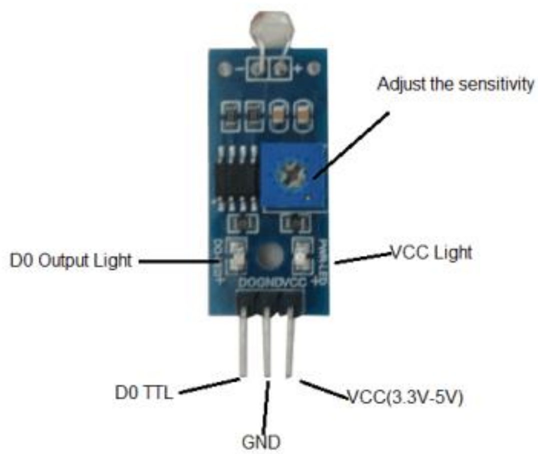


Fig 5. Light Sensor Module

<u>Uses for Light Sensors</u>

- Placement Detection

Light sensors measure illuminance, which can be used to measure more than the brightness of a light source. Because the illuminance decreases as the sensor moves away from a steady light, the light sensor can be used to gauge relative distance from the source. Light sensors are almost always a flat, one-sided surface, so the solid angle occupied by the sensor as viewed from the light source can change depending on its orientation. With the light sensor perpendicular to the direction of the light, it is occupying the largest solid angle possible. As the light sensor rotates away from the light, its solid angle decreases, with the illuminance therefore also decreasing, until the light sensor ultimately detects no direct illuminance when parallel to the light beams or when facing away. This fact can be used to determine the angle of incidence of a light beam on the sensor.

- Brightness Control

Light sensors have a lot of uses. The most common use in our daily lives is in cell phones and tablets. Most portable personal electronics now have ambient light sensors used to adjust brightness. If the device can sense that it is in a dark place, it turns down the screen brightness to save power and not surprise the user with a very bright screen.

Another commonplace use for light sensors is controlling automatic lights in automobiles and streetlamps. Using a light sensor to trigger a bulb when it is dark outside saves the slight hassle of turning on the lights and saves power in the day when the sun is bright enough.

- Security

There are many more uses than consumer convenience, however. Detecting intrusion into containers or rooms is an important security application. When shipping expensive cargo, it can be important to know when a shipping container has been opened, so that cases involving loss of product can be solved easier. A cheap photo-resistor could be used to log each time the container is opened, so it can be determined at what point in the process thieves raided the container, or if the sender was being dishonest and claimed the container must have been robbed.

4.1.1.5 Two Channel Relay Module

This module contains two relays that are electrically isolated from the controlling input. The relays can be used to switch higher voltage and current loads than a microcontroller can traditionally accomplish.

Fig. 6 below shows a Two channel relay module, the relay has two outputs-normally open and normally closed (NO and NC). When the IN1 or IN2 pin is connected to ground, NO will be open and NC will be closed, and when IN1 or IN2 is not connected to ground the opposite occurs. Connecting a circuit or device between one of these two pins, the common pin on the relay output, and a power source will allow you to toggle power to a circuit or device.

Fig 6. Two Channel Relay Module

Using various sensors and hardware components as mentioned in the previous section, we have built an Indoor Farm. Fig. 7 below depicts the working model of our project. As per the block diagram, the circuit connections can be divided into three major components of the automated indoor farm. The automation is complemented by a real time analysis that has been done using Machine Learning. In order to optimize the model in terms of efficiency and yield, hardware analysis has also been carried out.

4.1.2 Hardware Working:

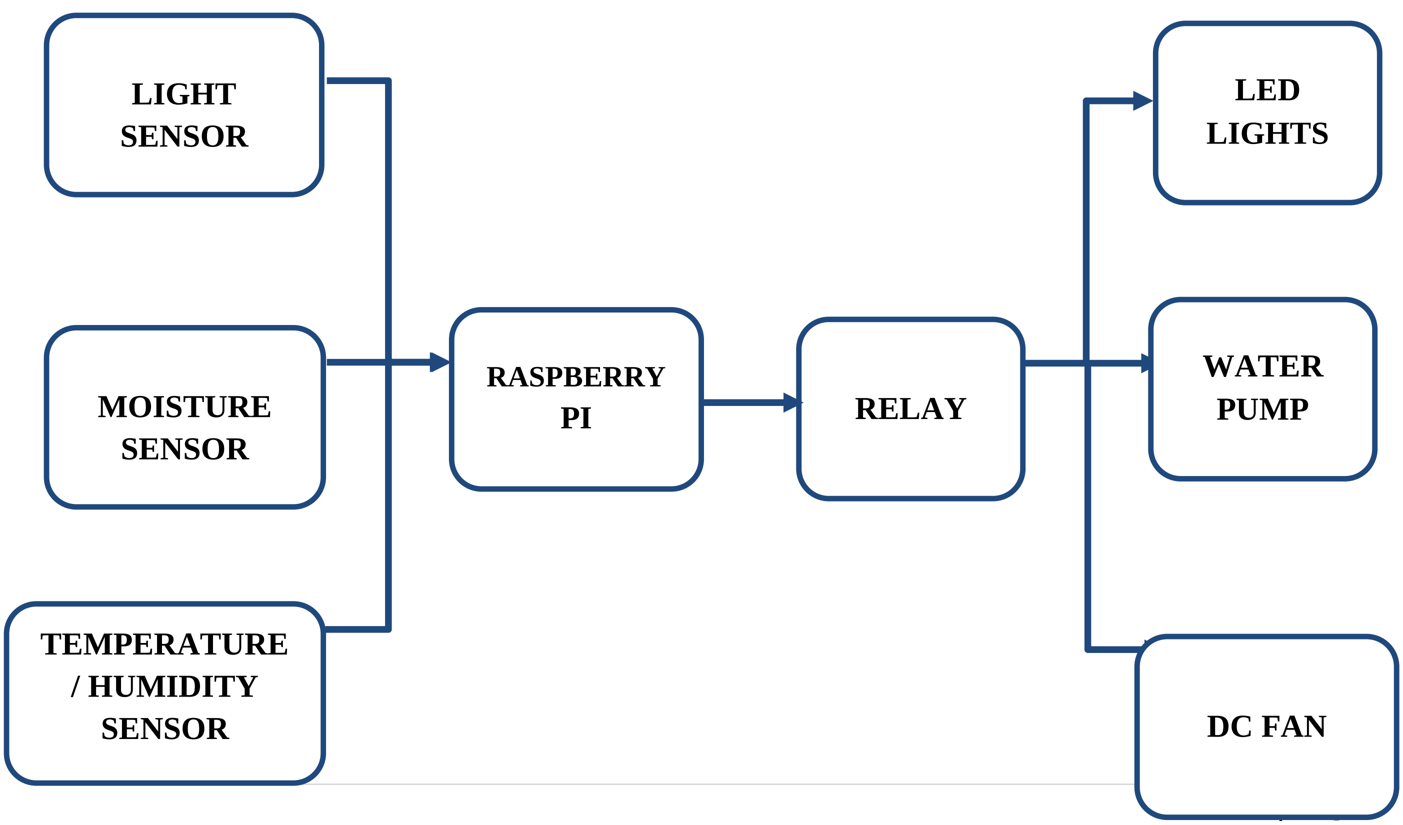


Fig 7. Block Diagram of Circuit

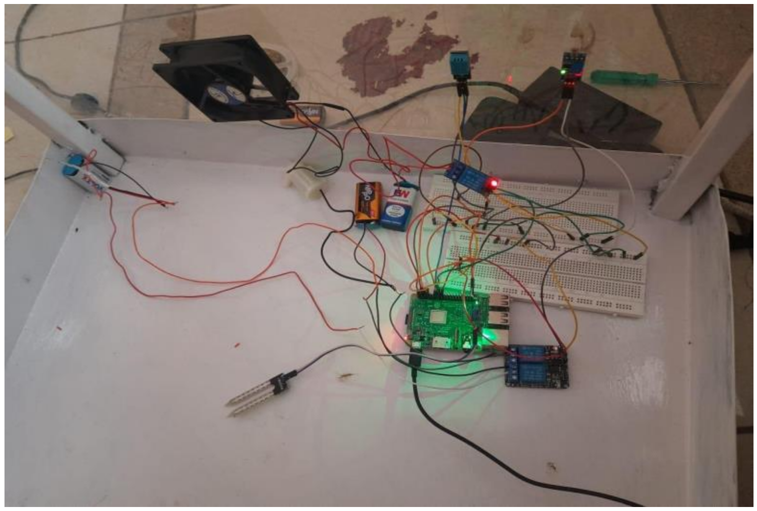


Fig 8. Circuit

Fig 8. Shows all the hardware connections that have been done for successful working of the Indoor farm as per the block diagram circuitry.

4.1.2.1 Light Sensing Circuit

Plants get enough light even on cloudy days, we extend the indoor farm by a bright ~20cm LED. The artificial lighting is only turned on when it is dark. Therefore we use a light sensor module which outputs a digital value, whether the brightness value is above / below a threshold value. In Fig. 9, SN-LIGHT-MOD, a photosensitive resistor module, suitable to detect environmental light intensity and ambient brightness is shown. Its sensitivity can be tuned with an on board potentiometer, where turning it clockwise will increase the sensitivity and increase the detection range.

Features of Light Sensor Module (SN-LIGHT-MOD)

- Comes with a high-quality light dependent resistor (LDR).
- Equipped with an on-board potentiometer to adjust light brightness threshold.
- Digital output
- Fixed bolt hole for convenient installation
- Uses LM393 wide range voltage comparator
- LED indicator – ON when ambient light exceeds threshold

- Operating Voltage is 3.3-5V

Fig 9. Light Sensor Module

This light sensor module has 4 wires: **V**CC, **G**ND, **D**IGITAL, **A**NALOG. The DIGITAL pin is the digital output while the ANALOG pin is the analog output. We can only use digital output directly on Raspberry Pi, because Raspberry Pi doesn’t come with any analog input pin.Fig.10 shows the connections between Raspberry Pi and Light Sensor Module.

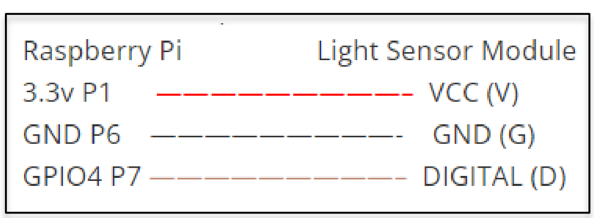


Fig 10. Raspberry Pi and Light Sensor Module Connections

Light sensor is also called photoresistor. Its working principle, as displayed by Fig.11, is based on internal photoelectric effect. The light sensor is equipped with a high precision photoelectric tube. There is a small flat plate in the photoelectric tube which is composed of "needle type two tubes".

When a reverse fixed pressure is applied to both ends of the photoelectric tube, the impact of any light on it will lead to the release of electrons. As a result, the current of the photoelectric tube will also be released when the intensity of light is higher. As the current passes through a resistor, the voltage at both ends of the resistor is converted into a 0-5V voltage that can be accepted by the digital-analog converter of the collector, and the results are stored in an appropriate form. Simply speaking, the light sensor transmits the analog signal of the light intensity to the robot host based on the principle that the resistance of the photosensitive resistor changes due to the influence of the light intensity.

Photo resistor is a kind of resistor made of the photoelectric effect of semiconductor, whose resistance value varies with the intensity of incident light. The greater incidental light intensity, the less electric resistance. And when the incident light is weak, the electric resistance increases. Photo resistor sensor is generally used for light measurement, light control and photoelectric conversion (conversion of light changes to electrical changes).

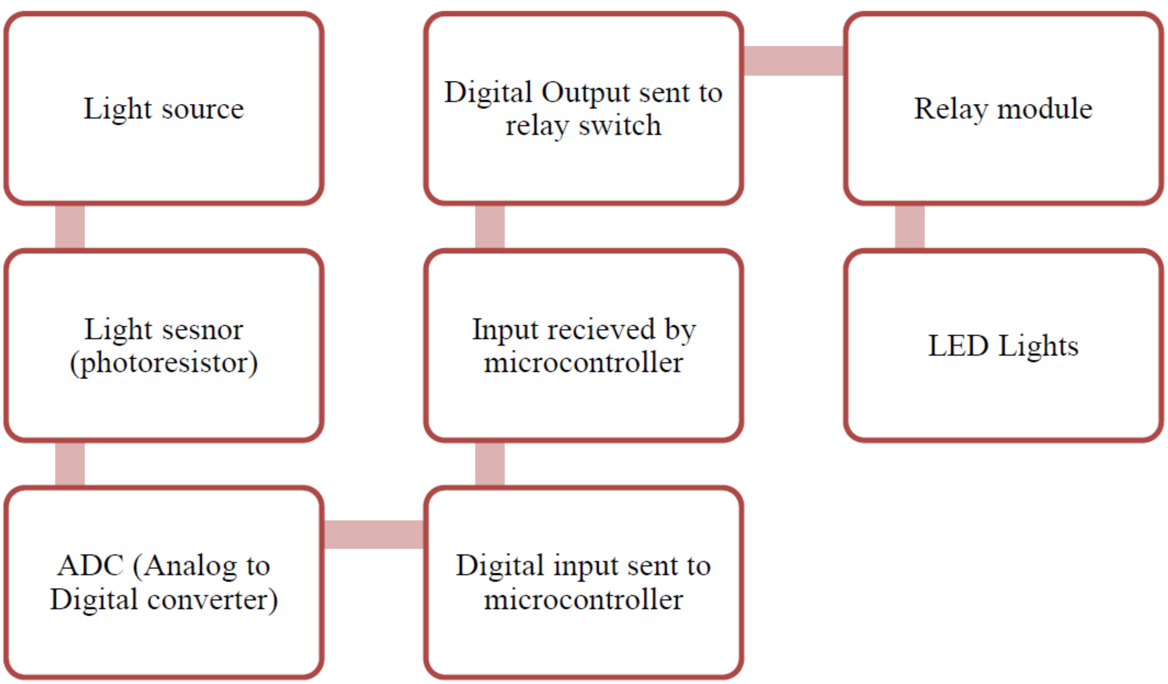


Fig 11. Light Sensing Module

4.1.2.2 Soil Moisture Sensing Circuit

It is essential to know how many times plants should be watered to have optimum results. Often plants are overwatered and lost. We figured it would be circumstantial if we can get the value of water content inside the soil in order to make a decision for watering the plants appropriately.
In this project we have built a circuit which can measure the water content value of the soil and eventually control the flow of water using Raspberry Pi, as can be seen in Figure 12.

The Soil moisture sensor is used for the Measurement of soil moisture. Of course, it is a practical area of application monitoring of potted plants or beds.
We have a choice between digital or analog signal outputs. This can be recognized by the output pins of the signal board. The following are the four pins of the soil sensor, which are followed by their respective connections:

- VCC: supply voltage 2.5 V to 5 V.
- GND: ground
- DO: digital output
- AO: analog output

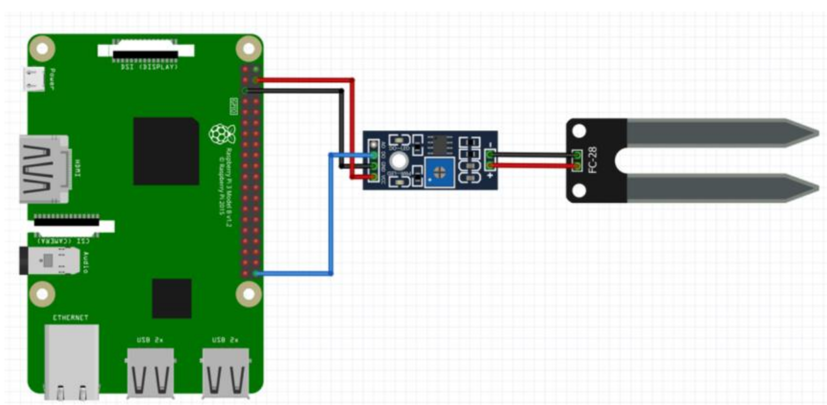


Fig 12. Soil Moisture Sensor Module

Fig 13. Depicts the connections between Soil Moisture Sensor and Raspberry Pi. Connect VCC as usual with the 3.3 V of the Raspberry Pi (e.g. pin 1). GND becomes e.g. on pin 6 to connect it to the ground of the Raspberry Pi.

VCC -> 5V

GND -> GND

SIG -> GPIO 21

Fig 13. Soil Moisture Sensor and Raspberry Pi Connections

Now we come to the special feature of this module: The Pin DO gives a high signal off as soon as a set threshold value has been exceeded. You can do this with check the potentiometer built into the board. However, here is Trial & Error announced, because you cannot immediately know which setting to the water requirement Corresponds to your plant. You should have the right mindset though have found out through some field tests, use the output Signal very simply at any GPIO pin that is declared as an input. We have used the Digital Output pin in our project.

The last pin, AO, outputs an analog signal. To process the signal we have to again make use of the MCP3008.

4.1.2.3 Automatic Irrigation System

Irrigation by soil moisture is the core element of the indoor farm. For this, we need the submersible pumps, a hose and a relay for each pump.

We have used a mini pump that operates with 6V, relays are also required. In this case, we have used one pump. If you use more than 3, you should choose a relay board with more channels.

Fig 14 depicts The Irrigation System module. The system consists of a water pump which will be used to sprinkle water on the land depending upon the land environmental condition such as Moisture and Temperature. It is important to note that different crops require different soil moisture, temperature and humidity conditions. The prototype of smart irrigation control system consists of the raspberry pi board, relay module, water pump, temperature sensor and soil moisture sensor. The power supply is provided to raspberry supply and it is connected to relay channel and temperature sensor and moisture sensor. The raspberry pi will read the temperature and moisture.

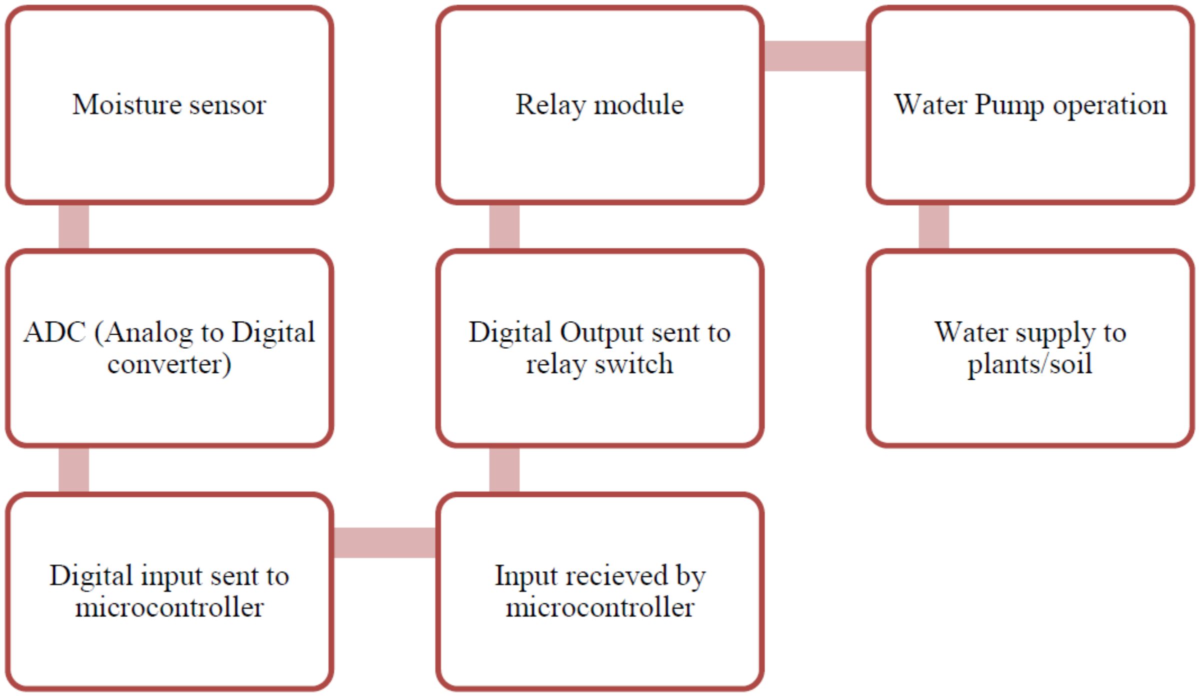


Fig 14. Irrigation System Circuit

4.1.2.4 Temperature and Humidity Sensing Circuit

The temperature and humidity sensor is necessary to reduce the watering frequency. That is when the weather gets cooler, less water is needed whereas vice versa in the other case. DHT11 is a Digital Sensor consisting of two different sensors in a single package. The sensor contains an NTC (Negative Temperature Coefficient) Temperature Sensor, a Resistive-type Humidity Sensor and an 8-bit Microcontroller to convert the analog signals from these sensors and produce a Digital Output. DHT11 uses a Single bus data format for communication. Only a single data line between an MCU like Arduino or Raspberry Pi and the DHT11 Sensor is sufficient for exchange of information. By interfacing the DHT11 Sensor with Raspberry Pi, you can build your own IoT Weather Station. All you need to implement such IoT Weather is a Raspberry Pi, a DHT11 Humidity and Temperature Sensor and a Computer with Internet Connectivity. Below shown, Fig 15 depicts the Temperature and Humidity Sensing Module.

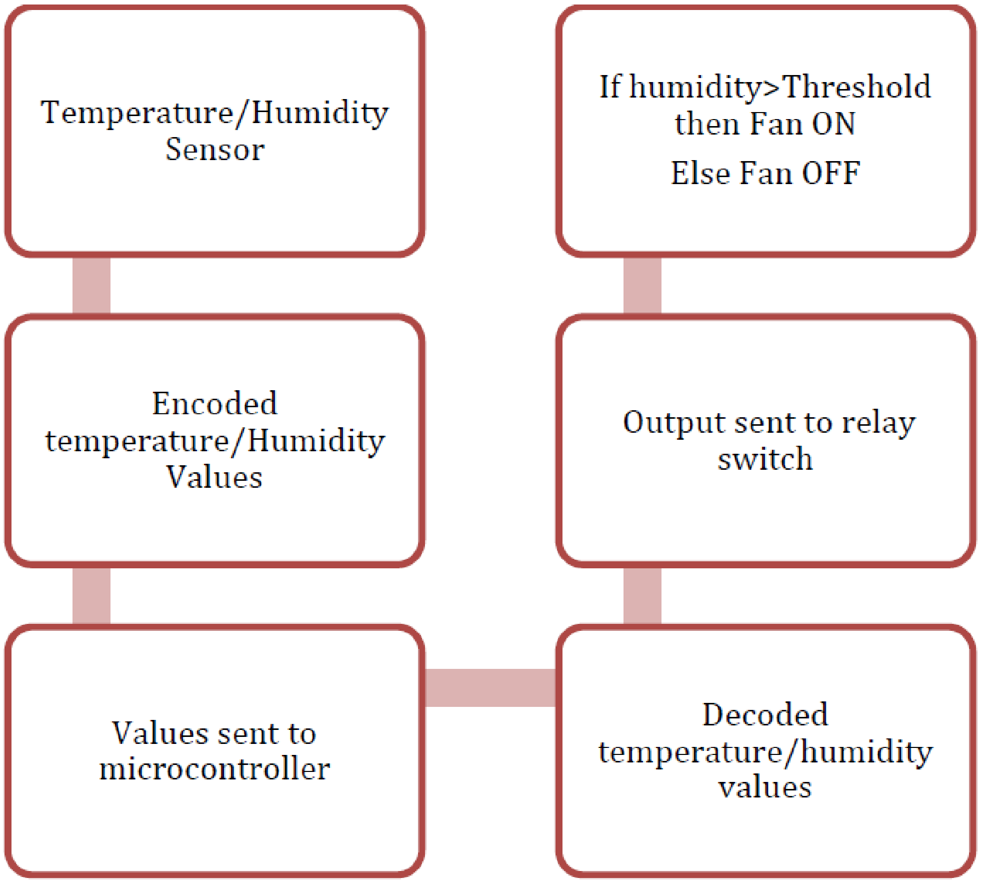


Fig 15. Temperature and Humidity Sensing Module

Fig 16 shows DHTII Temperature and Humidity Sensor along with its connections to Raspberry Pi. The VCC and GND pins of the DHT11 Sensor are connected to +5V and GND of Raspberry Pi and then connect the Data OUT of the Sensor to the GPIO4 i.e. Physical Pin 7 of the Raspberry Pi.

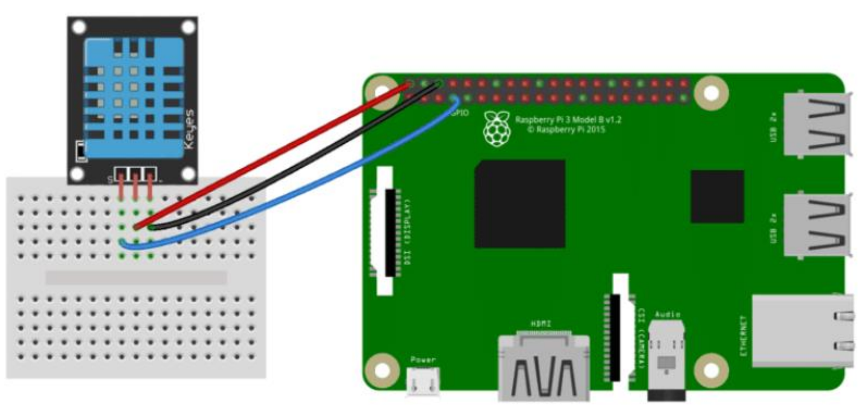


Fig 16. Temperature and Humidity Sensor Connections

4.1.2.5 Raspberry Pi Code

In this section, Raspberry Pi codes for various Sensing circuits have been shown. The following functions are carried out that take input values from various sensors and based on the sensor values the processor sends an output to the output device to carry out the necessary tasks.

Light Sensor Function

```python
def lightSensor():
    for i in range(0,5):
        val = GPIO.input(7)
        if val==True:
            GPIO.output(8, GPIO.HIGH) # Turn on
            sleep(1)                  # Sleep for 1 second
            GPIO.output(8, GPIO.LOW)  # Turn off
            sleep(1)
            print("HEllo")
        print(val)
        sleep(5)
```

Moisture Sensor Function

```python
def moistureSensor():
    for i in range(0,5):
        val = GPIO.input(13)
        GPIO.output(18, GPIO.HIGH)
        if val==True:
            GPIO.output(8, GPIO.HIGH) # Turn on
            GPIO.output(18, GPIO.LOW)
            sleep(2)                  # Sleep for 1 second
            GPIO.output(8, GPIO.LOW)  # Turn off
            GPIO.output(18, GPIO.HIGH)
            sleep(2)
            print("HEllo")
        print(val)
        sleep(5)
```

Temperature and Humidity Sensor Function

```
def temperatureSensor():
    while True:
        humidity, temperature = Adafruit_DHT.read_retry(11, 22) ## pin number 22 for DHT11 input
        print('Temp: {0:0.1f} C  Humidity: {1:0.1f} %'.format(temperature, humidity))
        while (temperature>27 || humidity>50)
            GPIO.output(fanPinNum, GPIO.HIGH)
            humidity, temperature = Adafruit_DHT.read_retry(11, 22)

        GPIO.output(fanPinNum, GPIO.LOW)
        time.sleep(1)
```

4.2 Web Application

4.2.1 Libraries Used:

HTML:

The HyperText Markup Language or HTML is the standard markup language for documents designed to be displayed in a web browser. It can be assisted by technologies such as Cascading Style Sheets (CSS) and scripting languages such as JavaScript.

0Web browsers receive HTML documents from a web server or from local storage and render the documents into multimedia web pages. HTML describes the structure of a web page semantically and originally included cues for the appearance of the document.

HTML elements are the building blocks of HTML pages. With HTML constructs, images and other objects such as interactive forms may be embedded into the rendered page. HTML provides a means to create structured documents by denoting structural semantics for text such as headings, paragraphs, lists, links, quotes and other items. HTML elements are delineated by tags, written using angle brackets. Tags such as <img /> and <input /> directly introduce content into the page. Other tags such as <p> surround and provide information about document text and may include other tags as sub-elements. Browsers do not display the HTML tags but use them to interpret the content of the page. HTML can embed programs written in a scripting language such as JavaScript, which affects the behavior and content of web pages. Inclusion of CSS defines the look and layout of content.

CSS

Cascading Style Sheets (CSS) is a style sheet language used for describing the presentation of a document written in a markup language such as HTML.CSS is a cornerstone technology of the World Wide Web, alongside HTML and JavaScript.

CSS is designed to enable the separation of presentation and content, including layout, colors, and fonts. This separation can improve content accessibility; provide more flexibility and control in the specification of presentation characteristics; enable multiple web pages to share formatting by specifying the relevant CSS in a separate .css file, which reduces complexity and repetition in the structural content; and enable the .css file to be cached to improve the page load speed between the pages that share the file and its formatting.

Separation of formatting and content also makes it possible to present the same markup page in different styles for different rendering methods, such as on-screen, in print, by voice (via speech-based browser or screen reader), and on Braille-based tactile devices. CSS also has rules for alternate formatting if the content is accessed on a mobile device.

Java Script

JavaScript is used to create client-side dynamic pages. It is an object-based scripting language which is lightweight and cross-platform.

It is not a compiled language, but it is a translated language. The JavaScript Translator (embedded in the browser) is responsible for translating the JavaScript code for the web browser.

What is JavaScript?

JavaScript (js) is a light-weight object-oriented programming language which is used by several websites for scripting the webpages. It is an interpreted, full-fledged programming language that enables dynamic interactivity on websites when applied to an HTML document. It was introduced in the year 1995 for adding programs to the webpages in the Netscape Navigator browser. Since then, it has been adopted by all other graphical web browsers. With JavaScript, users can build modern web applications to interact directly without reloading the page every time. The traditional website uses js to provide several forms of interactivity and simplicity.

Although, JavaScript has no connectivity with Java programming language. The name was suggested and provided in the times when Java was gaining popularity in the market. In addition to web browsers, databases such as CouchDB and MongoDB uses JavaScript as their scripting and query language.

React JS

ReactJS is a declarative, efficient, and flexible JavaScript library for building reusable UI components. It is an open-source, component-based front end library which is responsible only for the view layer of the application. It was initially developed and maintained by Facebook and later used in its products like WhatsApp & Instagram.

ReactJs is an open-source JavaScript library that is used to build user interfaces specifically. This is usually used for single-page applications. It is used to handle all views of an application for any web or mobile application. It is also used to reuse UI components.

React allows developers to create large web applications that can change data, without reloading the page. The main purpose of React is to be fast, scalable, and simple. It works only on user interfaces in the application. This corresponds to the view in the MVC template. It can be used with a combination of other JavaScript libraries or frameworks, such as Angular JS in MVC.

React JS is also called simply to React or React.js.

React.js properties includes the following

1. Simplicity
2. Easy to learn
3. Native Approach
4. Data Binding
5. Performance
6. Testability

JSX

It is called JSX, and it is a syntax extension to JavaScript. We recommend using it with React to describe what the UI should look like. JSX may remind you of a template language, but it comes with the full power of JavaScript.

Node JS

Node.js is a cross-platform runtime environment and library for running JavaScript applications outside the browser. It is used for creating server-side and networking web applications. It is open source and free to use.

Many of the basic modules of Node.js are written in JavaScript. Node.js is mostly used to run real-time server applications.Node.js also provides a rich library of various JavaScript modules to simplify the development of web applications. The following diagram specifies some important parts of Node.js:

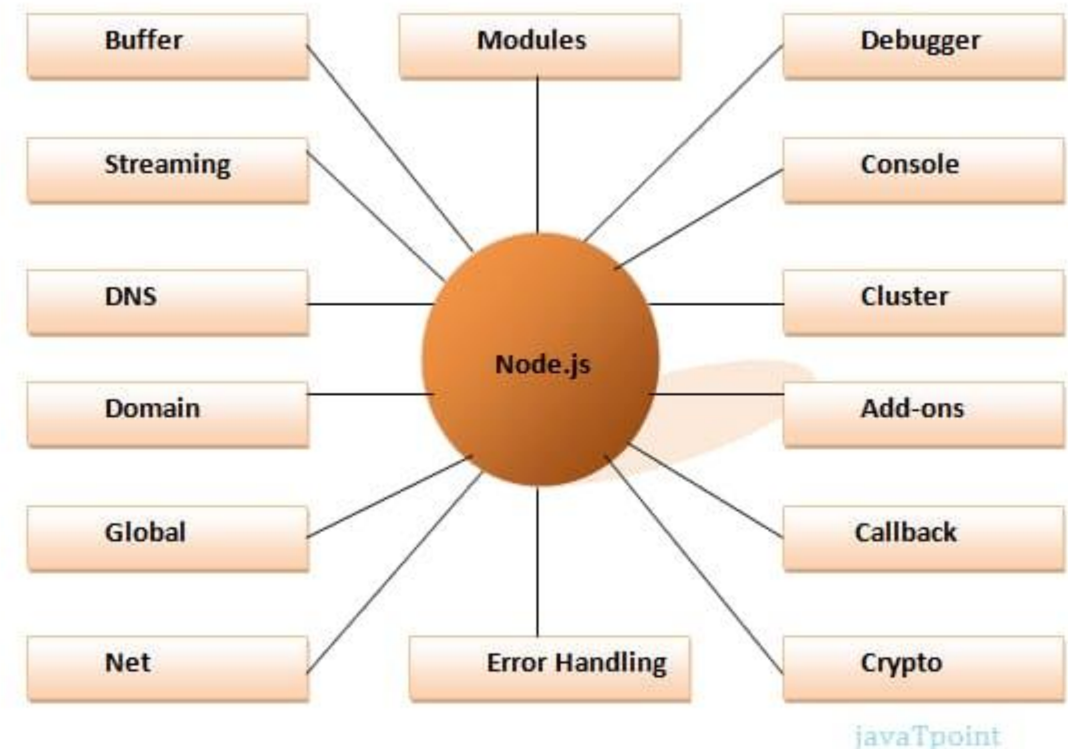


Table 2. Important Parts of Node.js

Socket io Library

Socket.IO enables real-time bidirectional event-based communication. It works on every platform, browser or device, focusing equally on reliability and speed. Socket.IO is built on top of the WebSockets API (Client side) and Node.js. It is one of the most dependent libraries on npm (Node Package Manager).

Socket.IO is a JavaScript library for real-time web applications. It enables real-time, bi-directional communication between web clients and servers. It has two parts − a client-side library that runs in the browser, and a server-side library for node.js. Both components have an identical API.

Why Socket.IO?

Writing a real-time application with popular web applications stacks like LAMP (PHP) has traditionally been very hard. It involves polling the server for changes, keeping track of timestamps, and it is a lot slower than it should be.

Sockets have traditionally been the solution around which most real-time systems are architected, providing a bi-directional communication channel between a client and a server. This means that the server can push messages to clients. Whenever an event occurs, the idea is that the server will get it and push it to the concerned connected clients.

Socket.IO is quite popular, it is used by Microsoft Office, Yammer, Zendesk, Trello,. and numerous other organizations to build robust real-time systems. It one of the most powerful JavaScript frameworks on GitHub, and most depended-upon NPM (Node Package Manager) module. Socket.IO also has a huge community, which means finding help is quite easy.

NPM

npm (originally short for Node Package Manager) is a package manager for the JavaScript programming language maintained by npm, Inc. npm is the default package manager for the JavaScript runtime environment Node.js. It consists of a command line client, also called npm, and an online database of public and paid-for private packages, called the npm registry. The registry is accessed via the client, and the available packages can be browsed and searched via the npm website. The package manager and the registry are managed by npm, Inc.

It helps with installing various packages and resolving their various dependencies.

It greatly helps with your Node development.

NPM helps you install the various modules need for web development and not just given you a whole bunch of features might never need.

4.2.2 WEBSITE INTERFACE

HOME

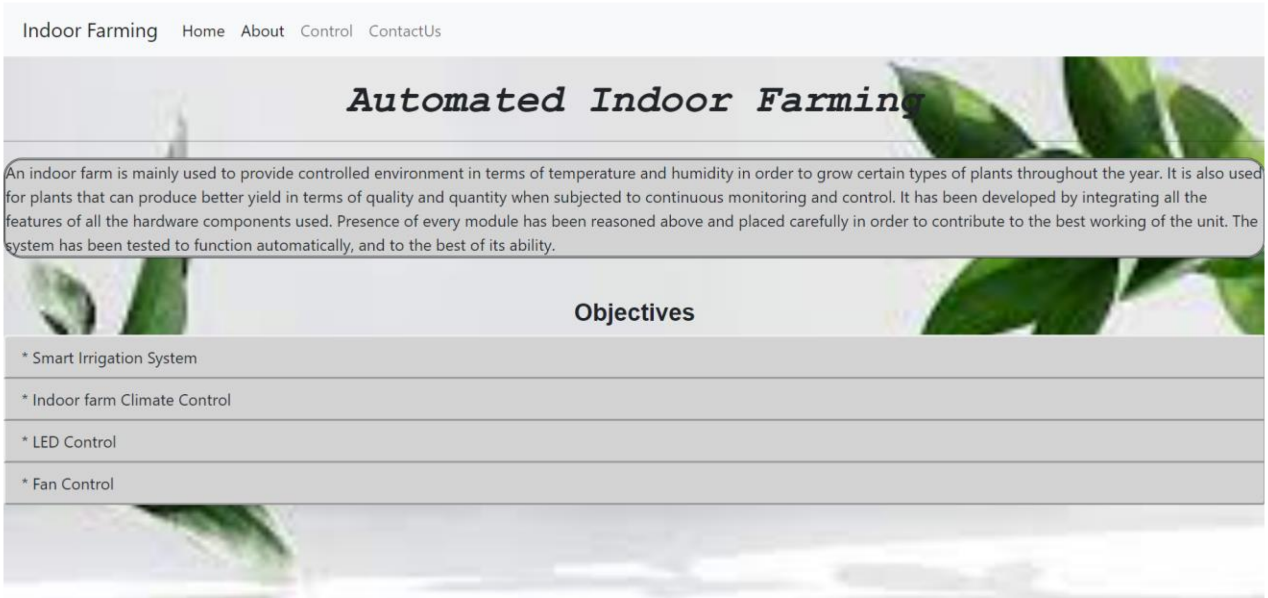


Fig 17. Home Page of Website

ABOUT US

Fig 18. About Us Page of Website

CONTROL

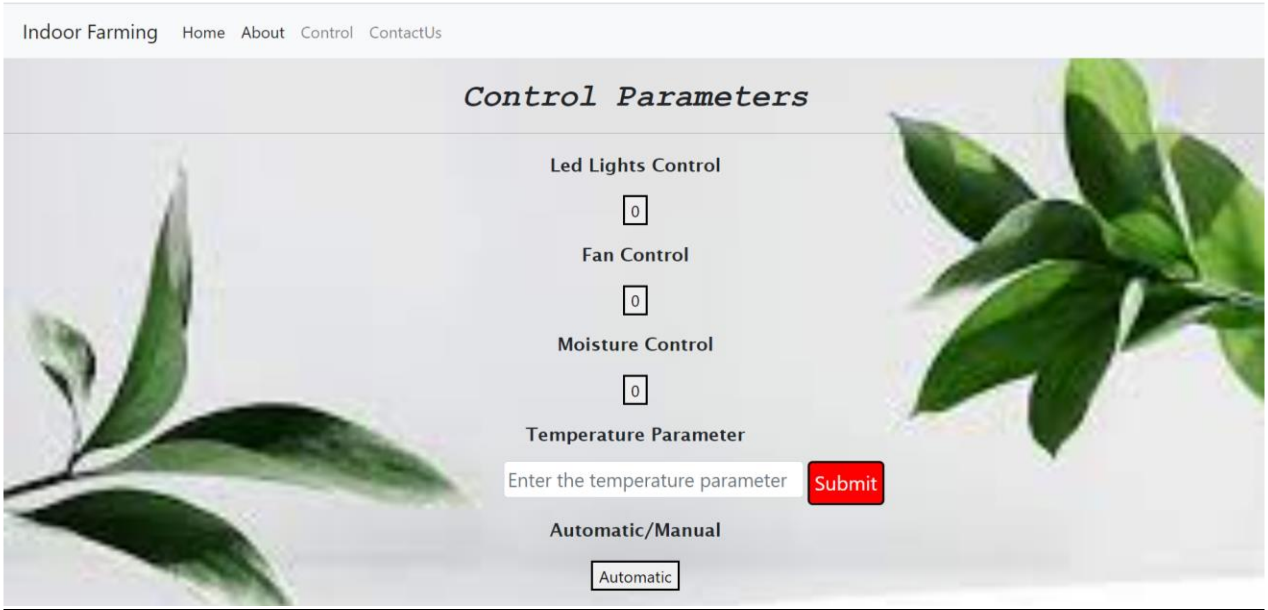


Fig 19. Home Page of Website

CONTACT US

Fig 20. Contact Us Page of Website

4.2.2 Raspberry Pi as a Web Server

The Raspberry Pi can be used as a web server on your main local network or the internet at large. RaspberryPi serves as a web server and hosts the website. Both frontend and backend are hosted on the RaspberryPi. Any device that is on the same network as the Pi can access the website. Through the website we can function the

greenhouse to operate automatically or we can operate it manually and control the LED, fan and water pump ourselves.For devices outside the network of Pi to access the website, we can use PORT FORWARDING. Through this, anyone can access the website and control the greenhouse

.

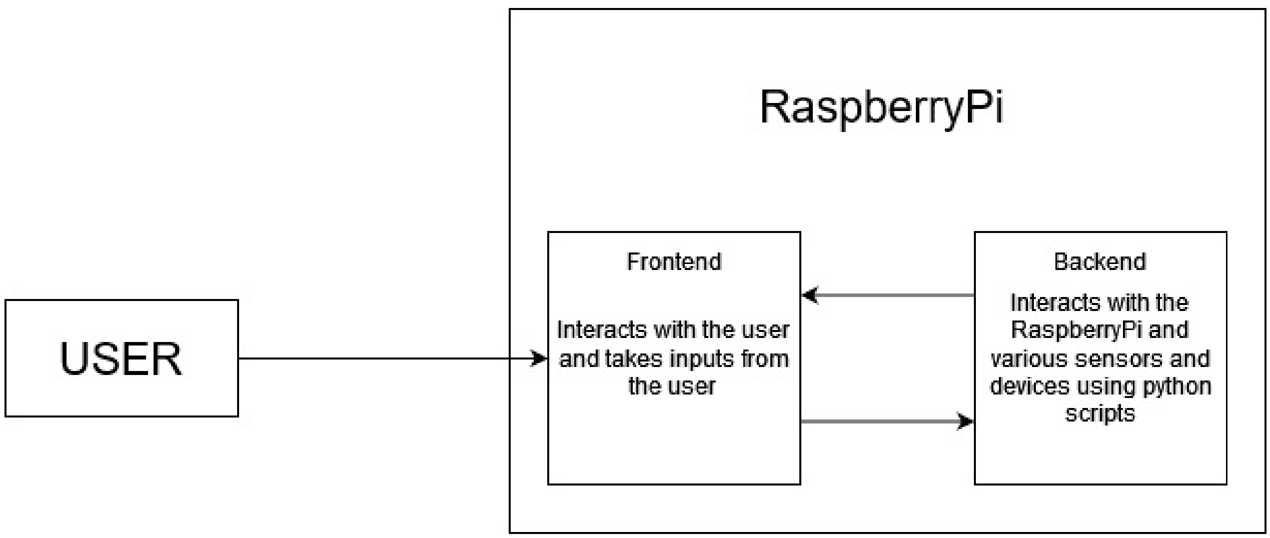


Fig 21. Raspberry Pi Module

User being on the same network sends a request to the frontend being run on the server. All the information and data displayed to the user is done through the frontend. Any information collected by the website is sent to the backend by the frontend for processing.

4.2.3 Website Features

The user through the website can control the various functionalities of the greenhouse. The functionalities that can be controlled are:

1. Switch between Automatic and Manual mode of operation.
2. Control the LED to maintain the illumination.
3. Control the fan to maintain the optimum temperature.

4. Control the water supply to maintain the moisture level in soil.

If the user has any queries, we can store his contact details and contact him later on.

Backend:

```
const express = require("express");
const http = require("http");
const socketIo = require("socket.io");

const port = process.env.PORT || 4001;
const index = require("./routes/index");

const app = express();
app.use(index);

const server = http.createServer(app);

const io = require("socket.io")(server, {
  cors: {
    origin: "http://localhost:3000",
    methods: ["GET", "POST"]
  }
});

const eventHandler = require("./eventHandler/controlGreenhouse");
const onConnection = (socket) => {
  console.log("New client connected");
  eventHandler(io, socket);
}

io.on("connection", onConnection);

server.listen(port, () => console.log(`Listening on port ${port}`));
```

```javascript
const { spawn } = require('child_process');

let state = 0;
module.exports = (io, socket) => {
    const controlLED = (payload) => {
        console.log(state = state+1);
        // run python script on RaspberryPi
    }

    const changeCondition = (payload) => {
        console.log(payload);
        // run python script on RaspberryPi
    }

    socket.on("controlLED", controlLED);
    socket.on("changeCondition", changeCondition);
}
```

```javascript
const express = require("express");
const router = express.Router();

router.get("/", (req, res) => {
  res.send({ response: "I am alive" }).status(200);
});

module.exports = router;
```

Frontend:

```
import React from "react"
import ReactDOM from "react-dom"
import { BrowserRouter } from "react-router-dom"
import App from "./App"
import "./index.css"

ReactDOM.render(
  <React.StrictMode>
    <BrowserRouter>
      <App />
    </BrowserRouter>
  </React.StrictMode>,
  document.getElementById("root")
)
```

```
import './App.css';
import Header from "./MyComponents/Header";
import { Home } from "./MyComponents/Home";
import { Footer } from "./MyComponents/Footer";
import { About } from "./MyComponents/About";
import { Control } from "./MyComponents/Control";
import { ContactUs} from "./MyComponents/ContactUs";
import {
  Routes,
  Route
} from "react-router-dom";

function App() {
  return (
    <div>
      <Header title="Indoor Farming" searchBar={false} />
      <Routes>
        <Route path="/" element={<Home />}></Route>
        <Route path="/about" element={<About />}></Route>
        <Route path="/control" element={<Control />}></Route>
        <Route path="/contactus" element={<ContactUs />}></Route>
      </Routes>
      <Footer />
    </div>

  )
}

export default App;
```

```
export default function Header(props) {

  return (
    <nav className="navbar navbar-expand-lg navbar-light bg-light">
      <div className="container-fluid">
        <Link className="navbar-brand" to="/">{props.title}</Link>
        <button className="navbar-toggler" type="button" data-bs-toggle="collapse" data-bs-target="#navbarSupportedContent"
          <span className="navbar-toggler-icon"></span>
        </button>
        <div className="collapse navbar-collapse" id="navbarSupportedContent">
          <ul className="navbar-nav me-auto mb-2 mb-lg-0">
            <li className="nav-item">
              <Link className="nav-link active" aria-current="page" to="/">Home</Link>
            </li>
            <li className="nav-item">
              <Link className="nav-link active" to="/about" >About</Link>
            </li>
            <li className="nav-item">
              <Link className="nav-link" to="/control">Control</Link>
            </li>
          </ul>
          {props.searchBar ? <form className="d-flex">
            <input className="form-control me-2" type="search" placeholder="Search" aria-label="Search" />
            <button className="btn btn-outline-success" type="submit">Search</button>
          </form> : ""}
        </div>
      </div>
    </nav>
  )
}
```

```
import React from 'react';
import Button from "./Button";

export const Control = () => {
  return (
    <div>
      <h3> Led Lights Control </h3>
      {/* <button type="button" class="btn btn-primary btn-sm " >Primary</button> */}
      <Button event="controlLED"/>
      <h3> Fan Control </h3>
      <button type="button" class="btn btn-primary btn-sm " >Primary</button>
      <h3> Moisture Control </h3>
      <button type="button" class="btn btn-primary btn-sm " >Primary</button>
      <h3> Temperature Parameter </h3>
      <input type="Value" class="form-control" id="controlparameter" placeholder="Enter the temperature parameter" />
      <h3> Automatic/Manual </h3>
      <Button vals={ ["Automatic", "Manual"] } event="changeCondition" />

    </div>
  )
}
```

4.3 Implementation of Machine Learning to Automate Indoor Farming Controls

The main purpose of the system is to provide an automatic control system. Product functions include provide water according to requirement. Product features are real-time sensing and control, self-controllable, complete elimination of man power.

The main aim of this project is to generate an intelligent irrigation system that measures the moisture of soil and helps to take the decision to turns on or off the water supply. This feature is added to provide an irrigation system that is automatic for the plants so it helps in saving water. The aim of this project is to mainly reduce human work and to save the water and environment

Algorithm Used:

First of all, we make an IoT model. After collecting the data from a model we apply machine learning algorithms to find how much equivalent time has lapsed since last irrigation and based on a particular threshold, we make an automatic decision on turning on the irrigation supply.

To count the water quantity requirement and prediction for the next water cycle, **linear regression algorithm** is implemented.

The entire implementation occurs in following steps:

Step 1: Train and Test machine learning algorithm (Linear Regression)

Linear Regression is a machine learning algorithm based on supervised learning. It performs a regression task. Regression models a target prediction value based on independent variables. It is mostly used for finding out the relationship between variables and forecasting. Different regression models differ based on – the kind of relationship between dependent and independent variables they are considering, and the number of independent variables getting used.

jupyter Linear Reg Last Checkpoint: Yesterday at 6:17 PM (autosaved)

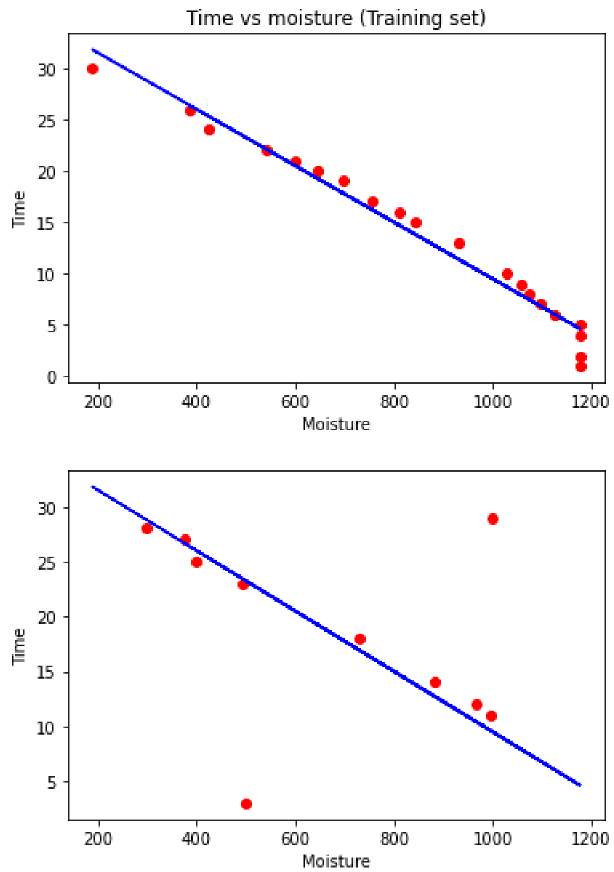
File Edit View Insert Cell Kernel Widgets Help

```
In [25]:
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import pickle
#importing the dataset
dataset = pd.read_csv('moisture_days.csv')
X= dataset.iloc[:, :-1].values
y= dataset.iloc[:, 1].values
#splitting the dataset into the training set and test set
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(X,y, test_size=1/3, random_state=0)
#Feature Scaling
"""from sklearn.prepocessing import StandardScaler
sc_X = StandardScaler()
X_train = sc_X.fit_transform(X_train)
X_test = sc_X.transform(X_test)
sc_y= StandardScaler()
y_train = sc_y.fit_transform(y_train)"""
#fitting simple linear regression to the training set
from sklearn.linear_model import LinearRegression
regressor = LinearRegression()
regressor.fit(X_train, y_train)
#print('X_train=',X_train)
#print('y_train=',y_train)
#print(X_test)
X_test[0]=500;
X_test[1]= 1000;
#print(X_test)
# Predicting the test set results
y_pred= regressor.predict(X_test)
#print('y_pred=',y_pred)
days=y_pred[0]-y_pred[1]
print('\n \n \t Water needed after='+str(days)+'days')


         Water needed after=13.76961813881012days
```

Step 2: Visualize the obtained results in form of moisture vs. time graphs.

```
In [6]:
#visualising the training set results
plt.scatter(X_train, y_train, color='red')
plt.plot(X_train, regressor.predict(X_train), color='blue')
plt.title('Time vs moisture (Training set)')
plt.xlabel('Moisture')
plt.ylabel('Time')
plt.show()
#visualising the test set results
plt.scatter(X_test, y_test, color = 'red')
plt.plot(X_train, regressor.predict(X_train), color = 'blue')
plt.xlabel('Moisture')
plt.ylabel('Time')
plt.show()
print('\n \n \t Water needed after' +str(days)+'days')
```




```
Water needed after13.76961813881012days
```

Step 3: Save the trained model to implement with our micro-controller

```
In [13]: #model.fit(X_train, Y_train)
         # save the model to disk
         filename = 'finalized_model.sav'
         pickle.dump(regressor, open(filename, 'wb'))
```

Step 4: Use the saved machine learning model with a python script and integrate the working with hardware

```
In [33]: import pickle
         #import RPi.GPIO as GPIO
         import time
         filename = 'finalized_model.sav'
         loaded_model = pickle.load(open(filename, 'rb'))

         #Default values
         moisture_val = [[0]]
         irr_status = "No"

         #test 1, moisture value = 1100, threshold = 10 days
         moisture_val = [[1100]]
         result = loaded_model.predict(moisture_val)
         if(result[0]>10):
             irr_status = "Yes"
         print("Last time water supplied is equivalent to =",result[0], "days")
         print("Irrigation requirement status -", irr_status)
         irr_status = "No"
         print()
         print()

         #test 2, moisture value = 900 , threshold = 10 days
         moisture_val = [[900]]
         result = loaded_model.predict(moisture_val)
         if(result[0]>10):
             irr_status = "Yes"
         print("Last time water supplied is equivalent to =",result[0], "days")
         print("Irrigation requirement status -", irr_status)
         irr_status = "No"


         #Switch on the pump
         pump_pin_number = X
         GPIO.setmode(GPIO.BCM)
         GPIO.setwarnings(False)
         GPIO.setup(pump_pin_number,GPIO.OUT)
         print("Pump on")
         GPIO.output(pump_pin_number,GPIO.HIGH)
         time.sleep(10)
         print("LED off")
         GPIO.output(pump_pin_number,GPIO.LOW)
```

Results:

With the help of Machine Learning, we were able to successfully predict the time duration for next water cycle. Thus, helping in increase of operational efficiency and reducing the manual effort. Hence, this integration of the plant and it's sensors with the Machine Learning algorithms helped in data collection and using this data to successfully train and test our model, which was further integrated with our project micro-controller (raspberry pi) for fully automated systems.

4.4 Hardware Analysis for Better Yield

It is widely recognized that indoor farming has many advantages over traditional crop-growing methods. Simply put, despite relatively high setup and operational costs, the production per unit of growth area in vertical farms easily exceeds that in the most advanced greenhouses. But to consistently hit this level of production, there is a need to ensure that growth conditions are continuously at their best. This is where sensors and data play a pivotal role, and why they're ready to transform the future of Indoor farming.

What data needs to be captured?

To use sensors and data effectively, there is a need to know what kind of data is valuable and why. The most important values to measure are the following conditions for growth:

- The Moisture content of the irrigation soil.
- The light level and spectrum (as perceived by the plants)
- Humidity and temperature of the surroundings

These conditions are significant for different reasons. The difference between plant temperature and air temperature is that the leaves' stomata are open. If they aren't, the plant cannot absorb CO_2 and convert it into biomass. Likewise, we can continually measure the pH (acidity) and EC (electrical conductivity) of the irrigation water to ensure optimal plant growth.

Measurement of the light level and spectrum as perceived by the plants is an important aspect. Plants' perceived light level can deviate up to as high as a factor of two from the light level installed depending on the optical properties of the materials used between and above the plants. This value largely depends on the degree to which the plants cover the growth area, and with such a high potential deviation rate, there is a need to measure and track to ensure optimal growth conditions.

Need for monitoring every stage of the growth process

Sensors help in monitoring the growth conditions, recognize anomalies and identify problems. By detecting problems at an early stage such as the temperature deviating from an intended setpoint, it can be rectified easily and actively.

How our sensor and data platform can help

Our sensor platform allows us to measure the conditions most important for plant growth. These conditions include climate parameters and irrigation parameters (including light and temperature sensing). There is a collection of about 1,600 unique setpoint and sensor readings every ten minutes from our eight climate cells.

The sensors can be placed anywhere and communicate the data gathered to the system backend. Cloud applications then retrieve this data and visualize the information that is most relevant and useful to plant specialists and growers.

Soil Moisture Sensors:

Efficient irrigation management can improve yields, grain quality, conserve water and energy, and reduce nutrient leaching. One of the easiest and most effective ways to improve irrigation efficiency is to implement soil sensor technology in irrigation scheduling.

Various types of **Volumetric water content sensors** include:

1. **Capacitance**

   Advantages:

   Response time is very fast

   Remote access available

   Very accurate if site calibrated

   Less expensive than TDR

   Can be used in high saline soils compared to TDR

   Disadvantages:

   Small sensing area

   Affected by soil conditions - salinity, clay content, temperature, bulk density

   Site/soil specific

   Cost

   Rs 19,000 - 25,000 per sensor

   Data logger is Rs 35,000-70,000

Examples:

Spectrum SMEC300, SM100; Sentek Enviroscan, Diviner 2000; METER 5TE, 5TN

2. **Time Domain Reflectometry (TDR) Sensors**

TDR sensors consist of two or three parallel rods inserted into the soil acting as waveguides. When a defined voltage pulse is sent to the sensor it travels along the waveguide. When this pulse reaches the end of the waveguide it reflects back. This reflection is measured by the oscilloscope connected to the sensor.

Advantages:
Very accurate
Soil/site calibration usually not required
Remote access of data available

Disadvantages:
Very small area of influence
Expensive technology

Cost:
Rs 19,000-25,000 per sensor
Data logger is around Rs 77,000.

Examples:
Acclima true TDR 315, 315L, 310 S; Spectrum Field Scout TDR; CS 655, 650

3. **Neutron probe**

The neutron probe method is considered to be the most accurate method of measuring soil moisture. Neutron probes consist of a neutron source, detector, and an electronic counting scale. Measurements at desired depths are made by lowering the probe into an access tube installed vertically in the soil.

Advantages:
Accurate measurements.
Samples a relatively large area.
One sensor for all sites & depths.
Unaffected by salinity and air gaps around the access tube.

Disadvantages:
Soil/site specific calibration usually required.
Very expensive (~Rs 7 lakhs)
Heavy
Contains radioactive material (safety hazard). Licensing is required.
Manual reading and recording (~3 min./access tube)
Not good at shallow depths (<6 inches)

Cost:
~Rs 7,00,000 and Rs 2000 for access tubes

Examples:
CPN-Instrotek; Troxller
For Prototype Purposes:
Soil Moisture Sensor Module

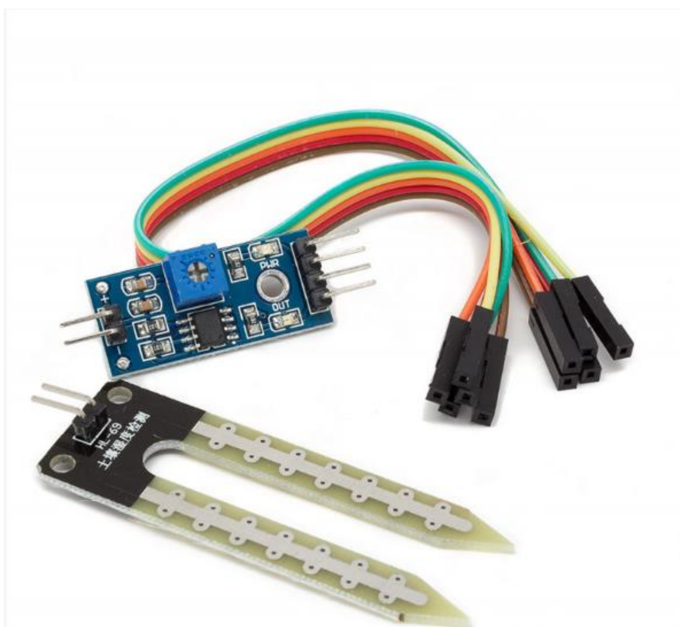


Fig 22. Soil Sensor Module

Fig 22 depicts a Neutron Probe Soil Sensor Module. This is an easy to use digital soil moisture sensor. Just insert the sensor in the soil and it can measure moisture or water level content in it. It gives a digital output of 5V when moisture level is high and 0V when the moisture level is low in the soil.
The sensor includes a potentiometer to set the desired moisture threshold. When the sensor measures more moisture than the set threshold, the digital output goes high and an LED indicates the output. When the moisture in the soil is less than the set threshold, the output remains low. The digital output can be connected to a microcontroller to sense the moisture level. The sensor also

outputs an analog output which can be connected to the ADC of a microcontroller to get the exact moisture level in the soil.

Specifications:

- Operating voltage: 3.3V~5V
- Dual output mode,analog output more accurate
- A fixed bolt hole for easy installation
- With power indicator (red) and digital switching output indicator (green)
- Having LM393 comparator chip, stable
- Panel PCB Dimension: Approx.3 cm x 1.5cm
- Soil Probe Dimension: Approx. 6cm x 3cm
- Cable Length: Approx.21cm
- VCC: 3.3V-5V
- GND: GND
- DO: digital output interface(0 and 1)
- AO: analog output interface

Fig 23. Soil Moisture Detector Sensor Module + Corrosion Resistance Waterproof Probe

In fig 23, the module shows a soil moisture detector sensor module + it has corrosion resistance probes which are compatible with the Arduino. This soil moisture sensor can read the amount of the moisture present in the surrounding soil.This soil moisture arduino compatible sensor uses the two probe to pass the current through the soil, as if in the soil more water is present than that soil will conduct the electricity more easily like less resistance will be offered and if the soil is dry than that soil will offer more resistance and soil conduct electricity will be poor.

Specifications:

- Supply Voltage: 3.3 - 5VDC
- Working Current: <20mA
- Output Current: <30mA
- DO: Digital Output
- AO: Analog Output
- Working voltage: 5V
- Working Current: <20ma
- Interface: Analog
- Depth of detection: 37mm
- Working Temperature: 10℃~30℃
- Low power consumption
- High sensitivity
- Output voltage signal: 0~4.2V

Light Sensors

A light sensor is a photoelectric device that converts light energy (photons) detected to electrical energy (electrons). There is more to a light sensor than just its definition. It comes in different types, used in various applications and more! Hence, in today's light sensor guide, we'll be exploring all you need to know about light sensors.

Types of light sensor

1. Photoresistors (LDR)

The most common light sensor type that's used in a light sensor circuit are photoresistors as shown in Fig 24, also known as a light-dependent resistor (LDR). Photoresistors are used to simply detect whether a light is on or off and compare relative light levels throughout a day.

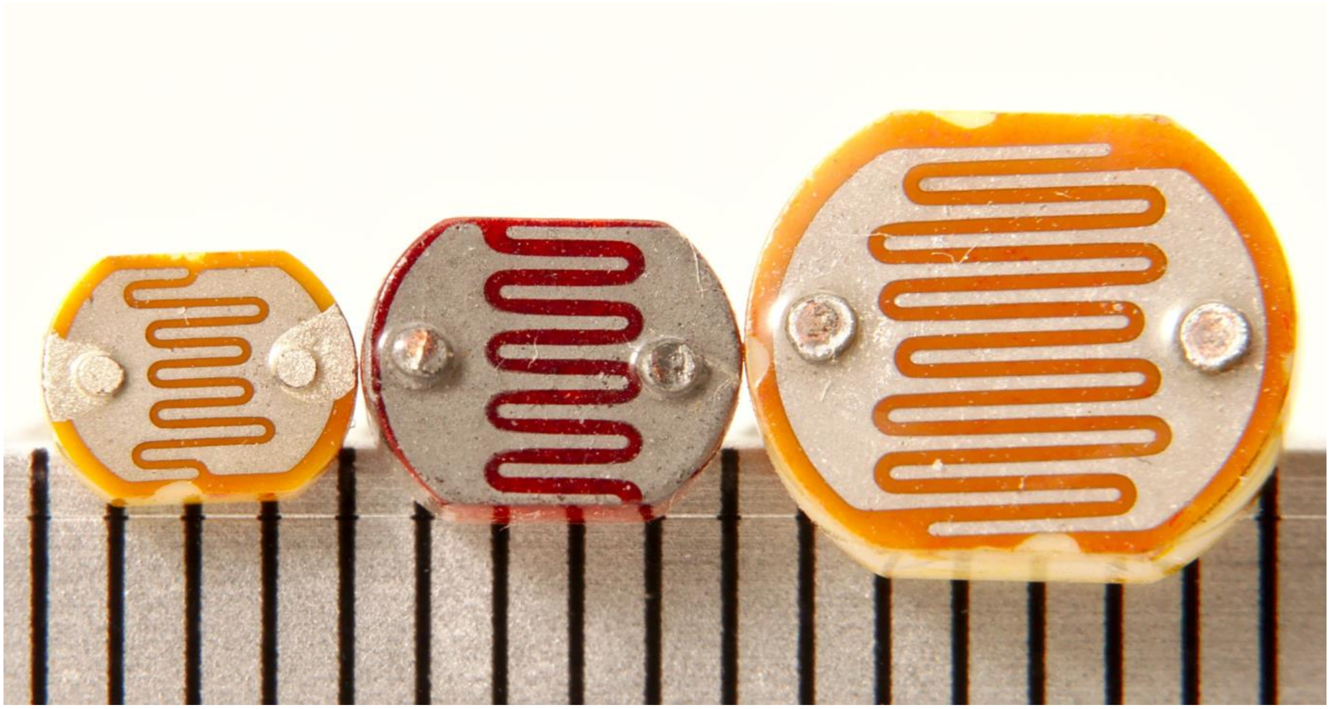


Fig 24. Photoresistors

Features:

- Can detect ambient brightness and light intensity
- Adjustable sensitivity (via blue digital potentiometer adjustment)
- Operating voltage 3.3V-5V
- Output Type
- Analog voltage output -A0
- Digital switching outputs (0 and 1) -D0
- With fixed bolt hole for easy installation
- Small board PCB size: 3cm * 1.6cm
- Power indicator (red) and the digital switch output indicator (green)
- Using LM393 comparator chip, stable

2. Photodiodes

Photodiodes, as shown in Fig 25, are another type of light sensor. But instead of using the change in resistance like LDR, it's more complex to light, easily changing light into a flow of electric currents.

Also known as a photodetector, photo sensor.

Photodiodes are mainly made from silicon and germanium materials and comprise of optical filters, built-in lenses and surface areas.

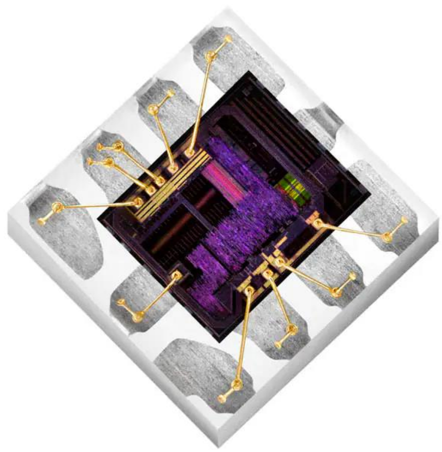


Fig 25. Photodiodes

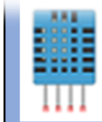
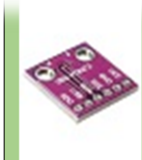
3. Phototransistors

The last light sensor type we'll be exploring today is the phototransistor. The phototransistor light sensor, as depicted in Fig 26, can be described as a photodiode + amplifier. With the added amplification, light sensitivity is far better on the phototransistors.

Fig 26. Phototransistors

Humidity and Temperature Sensor

For humidity and temperature sensors, comparison has been made on the basis of communication protocol, temperature range, accuracy, ease of use, etc. A simple experiment has also been run to measure the temperature in the same environment using all temperature sensors over time.

						
Sensor	**DHT11**	**DHT22 (AM2302)**	**LM35**	**DS18B20**	**BME280**	**BMP180**
Communication protocol	One-wire	One-wire	Analog	One-wire	I2C SPI	I2C
Supply voltage	3 to 5.5V DC	3 to 6V DC	4 to 30 V DC	3 to 5.5V DC	1.7 to 3.6V (for the chip) 3.3 to 5V for the board	1.8 to 3.6V (for the chip) 3.3 to 5V for the board
Temperature range	0 to 50°C	-40 to 80ºC	-55 to 150ºC	-55 to 125ºC	-40 to 85ºC	0 to 65ºC
Accuracy	+/- 2°C	+/- 0.5ºC	+/- 0.5ºC	+/-0.5ºC	+/-0.5ºC	+/-0.5ºC
Resolution	1°C/8 bit	0.1°C/8 bit	0.5°C/8 bit	0.5°C/9 bit	0.01°C/16 bit	0.1°C/16 bit
Response Time (Seconds)	6 Seconds	2 Seconds	4 Seconds	750ms/12 bit	1 Second	1 Second

Used for the hardware circuitry   Recommended

Table 3. Comparitive Analysis of various sensors

Fig 27. DHT11 vs DHT22 (AM2302)

As per Fig 27, DHT11 and DHT22 (AM2302) are digital temperature sensors that measure temperature and humidity. They look very similar and work the same way, but have different specifications. Both sensors can be powered either with 3.3V or 5V. Therefore, they can easily work with Arduino or ESP projects. The DHT22 sensor has a better resolution and a wider temperature and humidity measurement range. However, it is more expensive and can only request readings within a 2 seconds interval.The DHT11 is slightly cheaper, it has a smaller range, and it's less accurate. But you can get sensor readings every second.

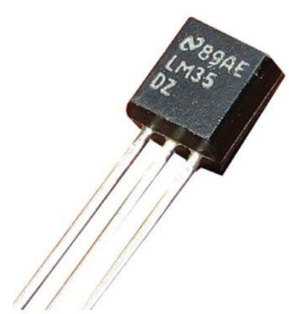


Fig 28. Temperature Sensor

The LM35, LM335 and LM34 are linear temperature sensors that output a voltage proportional to the temperature value. The LM35 comes calibrated in Celsius degrees, the LM335 in Kelvin and the LM34 in Fahrenheit. Fig. 28 shows a sample of a linear temperature sensor.
LM35 or LM34 are recommended over LM335 because subtracting a large number to the LM335 measurements to convert the temperature from Kelvin can compromise the results accuracy.

According to the datasheet, the LM35 and LM34 sensors require very little current to operate, about 60uA. This results in very low self-heating (around 0.08ºC in still air), which means that the temperature measurements won't be affected by the sensor itself.

To read the temperature from the sensors, the sensor's output voltage is read using an analog pin. If using an Arduino, you just need to use the analogRead() function and you'll get temperature readings with two decimal points.

So, if you need a cheap and easy to use sensor to monitor temperature, the LM35 can be a good option. Also, because it consumes very little energy, it's great for portable projects, where low power consumption is required.

Fig 29. DS18B20 Temperature Sensor

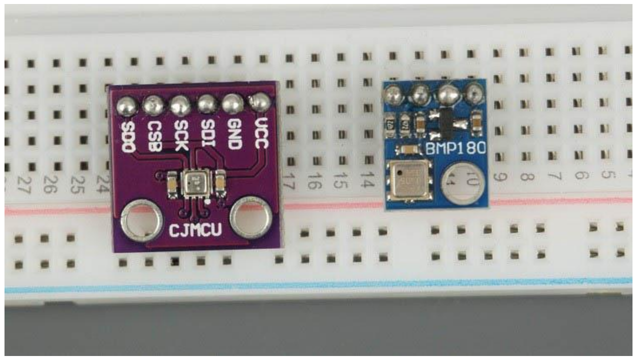
The DS18B20, as shown in Fig 29, temperature sensor is a one-wire digital temperature sensor, i.e. it requires one data line (and GND) to communicate with the microcontrollers.

It can be powered by an external power supply or it can derive power from the data line (called "parasite mode"), which eliminates the need for an external power supply.

Each DS18B20 temperature sensor has a unique 64-bit serial code. This allows to wire multiple sensors to the same data wire. So, temperature from multiple sensors using a single GPIO.

Additionally, the resolution of the temperature sensor can be set to 9, 10, 11, or 12 bits which corresponds to increments of 0.5°C, 0.25°C, 0.125°C, and 0.0625°C, respectively. The default resolution at power-up is 12-bit.

Fig 30. BME280 vs BMP180



As shown in Fig 30, the BME280 and BMP180 are barometric sensors which means they read atmospheric pressure. The BME280 is also equipped with a temperature and a humidity sensor, and the BMP180 with a temperature sensor. Because pressure changes with altitude, these sensors can also be used to estimate altitude.

When it comes to temperature range, the BME280 has a wider measurement range: -40 to 85ºC, while the BMP180 just measures from 0 to 65ºC. The BME280 can use either I2C or SPI communication protocol while the BMP180 can only use I2C communication.

The BME280 sensor is more expensive but it has more functionalities.

Testing All Temperature Sensors

This experiment logged temperature readings from different temperature sensors over time in the same conditions. Testing of the sensors mentioned has been carried out based on the circuit shown in Fig 31 below.

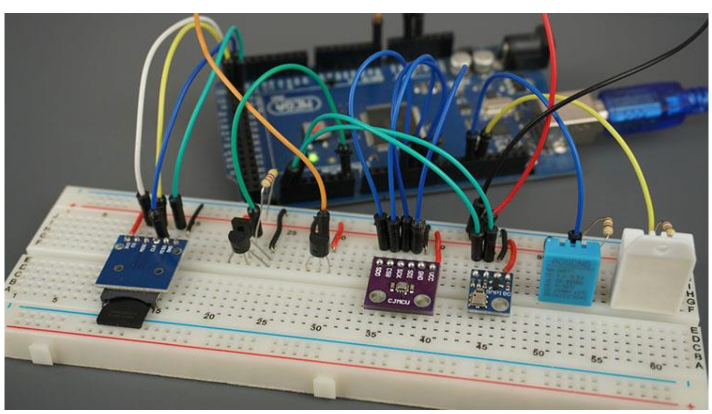


Fig 31. Temperature Sensors in the circuit

The following temperature sensors have been wired to the Arduino Mega:

- DHT11
- DHT22
- LM35
- 2x DS18B20 in the same data bus
- BME280
- BMP180

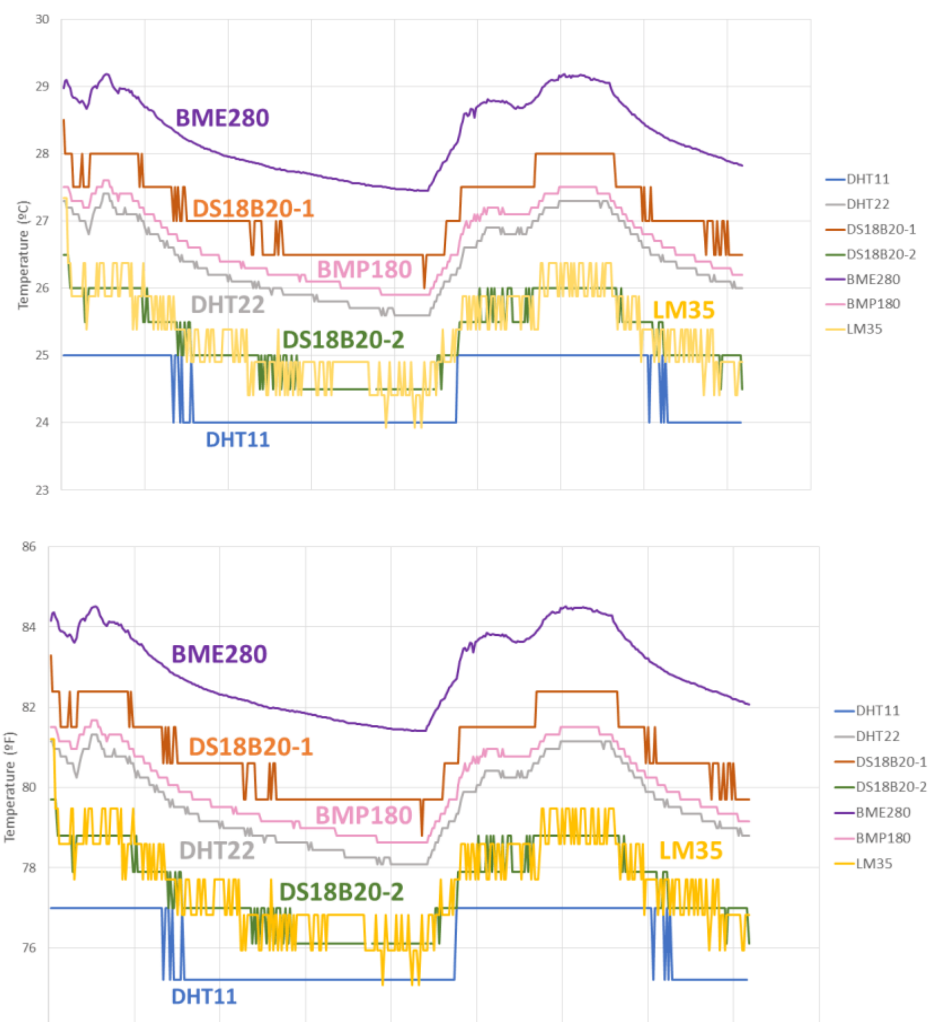


Fig 32. Comparing Temperature Readings

As per Fig 32, Comparing Temperature Readings, BME280 measures slightly higher values than the other temperature sensors mentioned in the list. The module self-heats a little bit and the temperature measurements can be 1 or 2 degrees above the real temperature value.

Additionally, the BME280 gave more stable temperature readings without many oscillations between readings. This result proves that the sensor can detect changes up to 0.01ºC due to its resolution parameter.

In case of the DS18B20 temperature sensors, it can be seen that some oscillations are between readings and it is noticeable that the resolution is not as good as the BME280. Additionally, the DS18B20 temperature sensor was the only one to give some “null” readings throughout the experiment. It is observed that the two DS18B20 temperature sensors are in the same data line and one of the sensors failed to read the temperature 6 times throughout the experiment.

The DHT22 and the BMP180 behave very similarly with little oscillations. The DHT11 couldn’t detect small temperature changes, because its resolution is of 1ºC.

Finally, the LM35 temperature sensor detected changes in temperature between 24ºC and 26ºC but with lots of oscillations between measurements.

Thus, it can be concluded that BME280 sensor is suggested for prototype construction due to its precise and more stabilized readings. Equivalently, Telaire t9602 can be recommended for commercial purposes because of similar properties.

5. RESULTS AND DISCUSSIONS

By implementing a successful automatic indoor farm following results and findings were obtained,

- A smart irrigation system that automatically works based on the input values received from the soil moisture sensors was successfully completed and tested.

- With the increase in temperature and humidity of the closed system, the climate control circuitry was successfully implemented and tested for various temperature ranges, in order to obtain the ambient temperature.

- The third major hardware circuitry involved an LED lighting control system, for getting the ambient light required for our crops. The complete input-output system was tested with different levels of threshold. Thus, completing the automation for customers

- The complete system was shifted to a user friendly online web server for effective control for customers, the web server was hosted with complete integration of micro-controller for effective command interface.

- To increase the irrigation efficiency, a machine learning model that helps in determining the number of days after which irrigation is required was implemented. We obtain an efficiency of 91% for our ML model. This efficiency can be further increased by obtaining more dataset points

- The hardware sensor analysis completed with full-sensor testings' were carried out in order to obtain a sensor type that provides us equivalent results with commercial readings. The readings and results obtained were in line with this equivalency and hence the prototype developed gave considerable and significant results. Also, the recommended sensors for different conditions are also mentioned for ready references.

6. APPLICATIONS AND LIMITATIONS

APPLICATIONS AND LIMITATIONS

Maintaining the field is not an easy task. It demands your attention 24/7/365 to manage heating, lighting, CO2, ventilation, shelter, cooling, humidity, irrigation, shading and more. Also, to maintain these variables and properly operate a commercial indoor farm, you need an automatic grow room controller instead of a manual one. Some of the biggest reasons why growers must adopt a commercial indoor farming automation system are as follows

Maintain a perfect environment

Temperature and humidity changes, equipment failures and power fluctuations or failures can be hazardous for an indoor farm environment as well as the crops that are growing. However, with a remote indoor farm automation system, you can tackle these environmental changes and equipment failures.

An automated monitoring system helps to keep an eye on all the KPIs of a field including heat, light, humidity, CO2 and other parameters to protect plants from extreme indoor weather conditions. This is how indoor farm automation helps to optimize a perfect growth environment and gain high crop yields throughout the year.

Better irrigation control

Watering plants is an important but tedious task. And the health and growth of the plants are directly affected by the amount of water and the duration of watering. With indoor farm automated irrigation scheduling, sensors automatically measure the condition of the crops at their root-level and determine the need for water in real-time.

With the help of an indoor farm automation system, watering plants becomes much easier, as it automates the time, quantity and duration of watering. Moreover, you can customize the watering needs based on the plant’s water content readings.

Efficient temperature control

One of the prime reasons for damage of crops is unpredicted temperature fluctuations. And the temperature in an indoor farm keeps varying due to ventilation and the amount of light it obtains. Generally, indoor farms are designed to store the heat from the sun and if vents in the roof or air conditioning are not controlled then the temperature would keep increasing until the sun sets, or the air conditioning is turned on.

A remote indoor farm automation control system ensures that you protect your plants by maintaining an optimal as well as consistent temperature in your indoor farm. This also helps to prevent the growth of disease-causing factors such as algae or mildew in your plants.

Improve the quality and yield of crops

Accelerate and automate your crop production by using an indoor farm environment control system Such environmental control allows the indoor farm to remain constant in providing optimum conditions that are quite favorable for maximum crop yield. As discussed above, with IoT-based automation control for temperature, CO2, humidity and more, you can provide unvarying growing conditions to increase the quality and production of crops.

Lower the cost of energy

The biggest potential saving in a commercial indoor farm is in addressing energy conservation and efficiency challenges. Every indoor farm manager must prioritize cultivating indoor farm crops in environmentally friendly and energy-efficient climates.

A commercial indoor farm automation system can offer the capability to decrease overall costs by eliminating the loss of profits due to inefficient energy usage. Moreover, with an automatic system that centralizes and controls temperature sensors and controls a single unit, you can prevent the cooling and heating system from running simultaneously. With an IoT-enabled controller, the commercial indoor farm energy spent on lighting, cooling, heating and more can be resourcefully leveraged at the right time in the right way.

However, despite the numerous benefits of automation there are also a few limitations of this system:

- Requires higher initial capital investment for the distribution system and controls
- Expensive to monitor
- Income and ability to grow crops need to be balanced against the cost of the system
- Constant electricity is needed to maintain the system, hence application is difficult in rural areas.
- Currently in any practical indoor farms, the data is not being used for analytical purposes.

7. CONCLUSION

CONCLUSION

The “**Automated Indoor Farming**” has been designed and tested successfully. It has been developed by integrating all the features of the hardware components used. Presence of every module has been reasoned above and placed carefully in order to contribute to the best working of the unit. The system has been tested to function automatically, and to the best of its ability. Hardware analysis has been performed to get the best sensors required for the prototype constructed and also for commercial application. The system uses machine learning to analyze real time data and derive effective insights. Also, a web application has been created to facilitate easy communication of changing parameters and status of the plants to the farmer so that a necessary action can be taken from the comfort of the home. Thus, the functionality of the entire system has been tested thoroughly and it is said to function successfully.

Hence, a completely automated, structurally efficient and economically viable system integrated with machine learning for real-time data analysis and a user friendly web application has been designed.

8. FUTURE SCOPE

FUTURE SCOPE

The project that has been carried out can be further extended using additional features to make the product more enhanced and commercially ready.

- Time bound administration of fertilizers, insecticides and pesticides can be introduced for which a speaking voice alarm could be used.
- GSM technology to improve Short Message Service with the help of embedded technology can be done.
- The Indoor Farm model can be extended to vertical farming adapting to lesser water, chemicals, space required and hence providing better yield.

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