Next-Generation IoT-Driven Agriculture System for Sustainable and Efficient Farming

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Abstract

Agriculture constitutes a critical segment of economy and provides jobs for a significant portion of global population. The importance of agriculture extends beyond merely being a career for individuals who live in developing and rural nations; it is also essential within developed nations such as India, where 70% of the country's population depends upon agriculture to make a living, and will therefore become increasingly difficult to provide for as India continues to grow. Traditional methods of agriculture will no longer be sufficient under current conditions; therefore, modern applications of technology such as smart agriculture through IoT tools (for example) must be developed to help improve efficiency, reduce waste, decrease disease, and increase yield on the farm. This proposed smart agriculture system would utilize various sensors to monitor agricultural conditions such as soil moisture, temperature, and crop health as well as measure crop movement. These monitored conditions would then be transmitted from each sensor to a cloud storage facility in "near" real time so farmers could use their smartphones to control the operation of their system by issuing commands (ie. activating watering, adding pesticides, etc.). In this manner, farmers' toil is reduced, and valuable time that otherwise would have to be spent can be saved. The proposed smart agriculture system must be thoroughly tested prior to being made available for commercial use to ensure there are no bugs associated with hardware or software updates related to the operation of the system. This paper discusses and presents a comprehensive overview of how to establish a smart agriculture system through use of IoT tools and utilizing the Arduino UNO microcontroller. Through the use of multiple sensors, various parameters related to agriculture can be accurately monitored on an agricultural land, and farmers will be able to access accurate data on the parameters they are monitoring and utilize this data to make timely and informed decisions to physically improve their agricultural productivity. Automated and remote control mechanisms within the system allow farmers to operate at maximum efficiency. In 2026 and forward, there will be a continuation of integrating AI, Edge Computing & LoRaWAN into IoT Agriculture; This integration allows for real time decision making with much less latency and will allow for sustainable smart farming. Current IoT applications within modern agriculture include predictive irrigation, crop health monitoring, energy-efficient communication, and precise planting.

Keywords: **Internet of Things (IOT), Smart Agriculture using IOT, Arduino, Soil Moisture Sensor, Water Level Sensor, Animal Decter, DHT 11, etc**

1. Introduction

Many farmers do not have any education related to agriculture or crops. The weather affects how well your plants will grow, so there is a chance that you may lose all of your crops due to the weather. We are all aware of how important soil and air are, but we need to remember that irrigation also plays an important role. Crops are dependent on other factors as well; heat and dampness are two of the most common factors that affect how well crops grow. This is why many farms around the world utilize technology to improve crop production and quality through what is referred to as Smart Farming. Smart Farming uses technologies such as the Internet of Things (IOT), GPS technology, soil scanner and more, to help farmers monitor their crop production. You can use a soil moisture sensor or rain sensor to test the moisture levels in the soil. In smart agriculture, technology is used from planting season right up to harvesting season. Technology is used to solve many problems faced by farmers, among them are to increase crop production to meet the needs of increasing population, to overcome the problem of global warming, and to reduce the number of farmers who abandon their work to earn a living. Monitoring agriculture using IOT technology is able to convert every process and activity related to agriculture into data. Thus, Smart Agriculture can reduce the negative externalities of modern agriculture and its growth and development is imperative. Even in smart cities, data from IOT devices such as sensors, light, and meters are harnessed to support decision making to optimize public utilities and services, improve infrastructure and other services. Although there are many benefits in incorporating technology into farming, it is still challenging to make farmers aware of the advantages of smart agriculture and to make them understand how technology is used in the process. In fact, people have found out that IOT device can really aid farmers to use resources efficiently and to make farming sustainable [1] [4]. Hence, this paper proposed a system of monitoring and recording temperature, soil moisture, water level, and crop destruction caused by external factors in the agricultural area using a number of IOT sensors that can take appropriate action based on user input in order to develop and explore the ideas and concept of smart agriculture. It is a pioneer project that uses current technology to help farmers monitor the crop and other things that are surrounding the crops.

Future research directions 2025–2026: integration of AI, Edge Computing and IoT for improved crop monitoring with reduced cloud dependency in rural environments. Future use of Low-power wide area network (LPWAN) technologies such as LoRaWAN and NB-IoT for long-range monitoring in agriculture with reduced power consumption. Future applications for rural farmers for improved decision making and real-time notifications to farmers for optimised irrigation using predictive capabilities.

I.1 Obstacles in Agriculture Assisted by IoT IoT implementation in agriculture confronts a number of operational and technological obstacles despite its advantages: Limitations on Connectivity: The lack of broadband infrastructure in rural locations frequently results in erratic or sporadic network connectivity[6]. Sensor problems happen when soil sensors are used for a time. This is because they are exposed to the environment and that causes them to give accurate results.[3],[9].

The cost of setting up these sensors is also very high. This is a problem for small farmers who cannot afford the cost of sensors and other equipment [7].

These sensors also need a lot of power to work. If they do not have a kind of power the batteries need to be changed often. There is also a risk of hacking and other cyber threats. This is because these systems can be easily fooled and the data can be changed [10].

Farmers also have a time understanding the data, from these sensors. This is because the data is very complex and they need training to understand it [12].

These Sensor Degradation and other challenges show that we need to make IoT systems that're efficient and cost-effective for farmers. We need to make sure that these systems are also very secure [2].

I.2 Problem Statement

The way we do farming now is not very good. We have to make decisions without knowing what is really going on. This causes a lot of problems, like: Using much water. Not noticing when crops are sick until it is too late Not giving crops the amount of food . We need a lot of people to work on farms.

We also do not do a job of taking care of the environment. We need a way of farming that uses the internet and special devices to help us make good decisions. This new way of farming should be cheap. This will help fix the problems we have now with farming.

I.3 Objectives of the Study

The particular goals of this study are: To create an IoT agricultural ecosystem with multiple sensors for ongoing observation. To use real-time moisture feedback to automate irrigation. To incorporate cloud-based analytics for remote access and data visualization.

To assess the efficiency, crop health, and water consumption of IoT-based farming in comparison to conventional techniques. To create an affordable, scalable framework for real-world implementation.

I. Methodology

A. *Literature Review*

Agricultural IoT (Internet of Things) has attracted a lot of attention from researchers due to its possibilities for precision agriculture, automation and sustainable growing practices. Research consistently finds that IoT offered improvements on accuracy of decision making, improvement on water use efficiency, and improved monitoring of environment. In [17], the authors develop a current irrigation optimization framework using sensors and developed system was tested in a controlled manner in Konthum area of Thailand. Authors will consider three main areas of cost: hardware components, web-based application(s), and mobile applications. They utilize the hardware control box to receive and collation of data collected from crop conditions. Next, they utilize the web-based app to make changes to the information on crops and fields. Lastly, they utilize data mining to analyse and predict the temperature and moisture levels for the effective management of crops. In this area, they also have developed a mobile app. The mobile app provides the same way to control the irrigation of smart devices through the use of an interface (LINE API) and will provide notification for a system that has received a recent notification or change to its state. The proposed system was tested and implemented at the Makhamtia district in Suratthani province, Thailand. The proposed system is estimated to only cost approximately $93.25 per field, demonstrating it as a cost-effective alternative to other types of irrigation systems. There is also no applicability for mixed farming enterprises. As a result of major natural disasters, such as hurricanes or floods, the damage to agricultural land can be evaluated. Based on these results, the government will be able to assess how much financial compensation to provide for the estimated damages and allow for forward production to occur at the facilities that produce sugar.

B. *Trends, Benefits, and Limitations*

I.B.1 Trends:

- Increased adoption of LoRaWAN for long-range communication [3].
- AI-assisted IoT systems for crop disease diagnosis [7].
- Cloud and mobile-based dashboards for remote monitoring [4].
- Multi-sensor integration for accurate feedback [1].

I.B.2 Benefits:

- Up to 60% reduction in water consumption [3].
- Enhanced soil nutrient monitoring [1].
- Improved crop vitality and growth efficiency [7].
- Reduced labor due to automation [4].

I.B.3 Limitations:

- Power limitations for remote IoT nodes [10].
- Calibration drift of sensors [9].
- Cybersecurity vulnerabilities in IoT devices [12].
- High initial system cost [7].

C. *Summary of related work*

Ref .	Author & Year	Technolo gy Used	Scope	Major Contributi on	Key Findings
[1]	Patel(202 4)	Moisture, NPK Sensors	Soil Monitoring	Nutrient accuracy framework	Improved soil nutrient mapping
[3]	Kumar & Rao(2023)	LoRaWA N	Irrigation Control	Smart irrigation system	60% water savings achieve
[4]	Basha et al.(2025)	IoT + Cloud	Precision Farming	Real-time sensing	Higher crop yield and accuracy
[7]	Mehta et al.(2025)	AI Cameras	Disease Detection	Early detection system	Reduced crop infection rate

[9]	Ali & Dube(2024)	IoT Sensors	Environmen tal Monitoring	Multi- parameter sensing	Enhanced greenhouse stability
[12]	Khan(2025)	IoT Security Framewo rk	Smart Farms	Vulnerabili ty analysis	Identified critical attack vectors

I.4 Existing Methodology

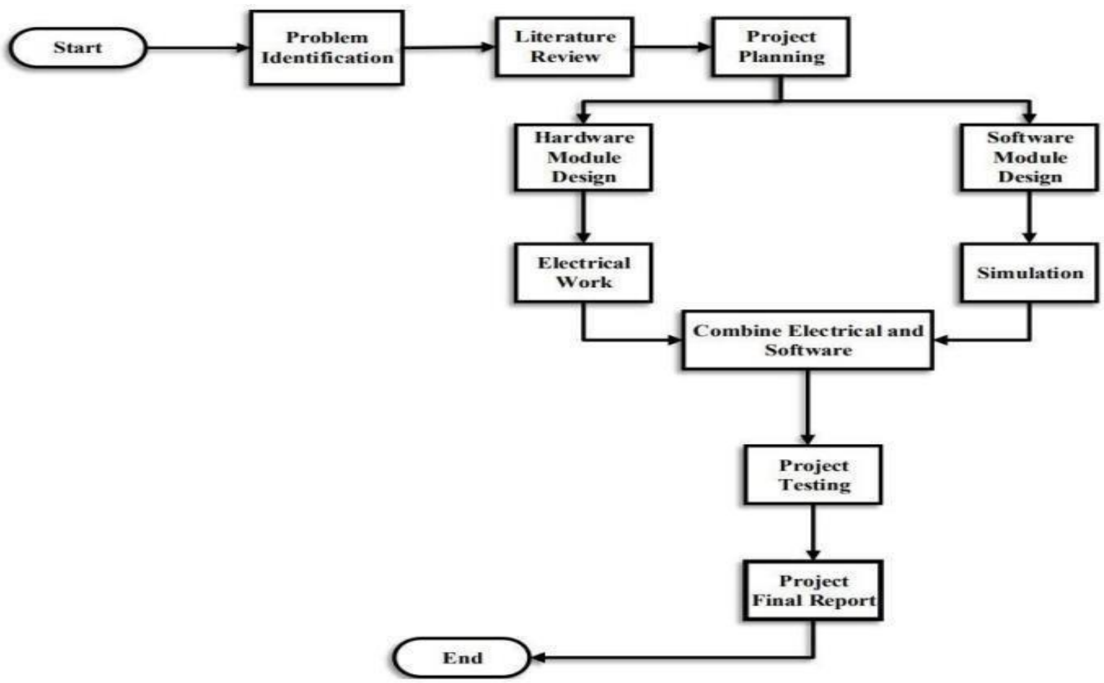
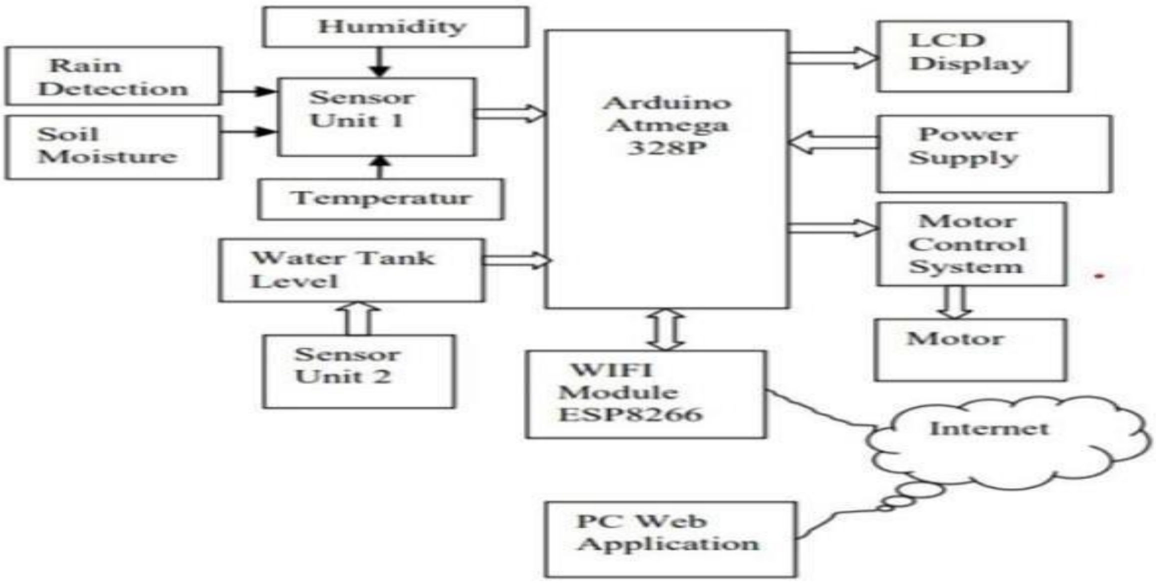


Fig 2.1 Overview of Methodology

In this research, we optimize irrigation by using sensors such as soil moisture and temperature sensors. A DHT11 temperature sensor is positioned in the middle of the field to detect soil temperature in both Celsius and Fahrenheit, while soil moisture sensors are buried in the field to track water levels. After being linked to these sensors, an Arduino gathers the data and sends it to a Raspberry Pi.

I.4 Propose Methodology

Fig 2.2 Proposed Methodology



The user must provide information about the land acreage and crop type planted in the app for this project. We can determine how much water, fertilizer, and pesticides are required for the specified land area using the data provided. The data is gathered and sent to the SMART via the Wi-Fi module.

AGRI APP: This app offers data on field animals, water overflow, humidity, and soil fertility. The water level sensor can be used to determine the tank's water level, and the land can be automatically irrigated and overflow in the water tank detected using the data from the humidity and moisture sensors.

Therefore, a smart irrigation system helps to meet demand by increasing crop productivity. In order to guarantee that crops receive the best possible water resources, this project will remotely measure and monitor the soil's moisture content. It will also automatically activate sprinkler systems to handle low soil moisture levels, preventing crop loss or damage. This concept will manage them and increase agricultural productivity.

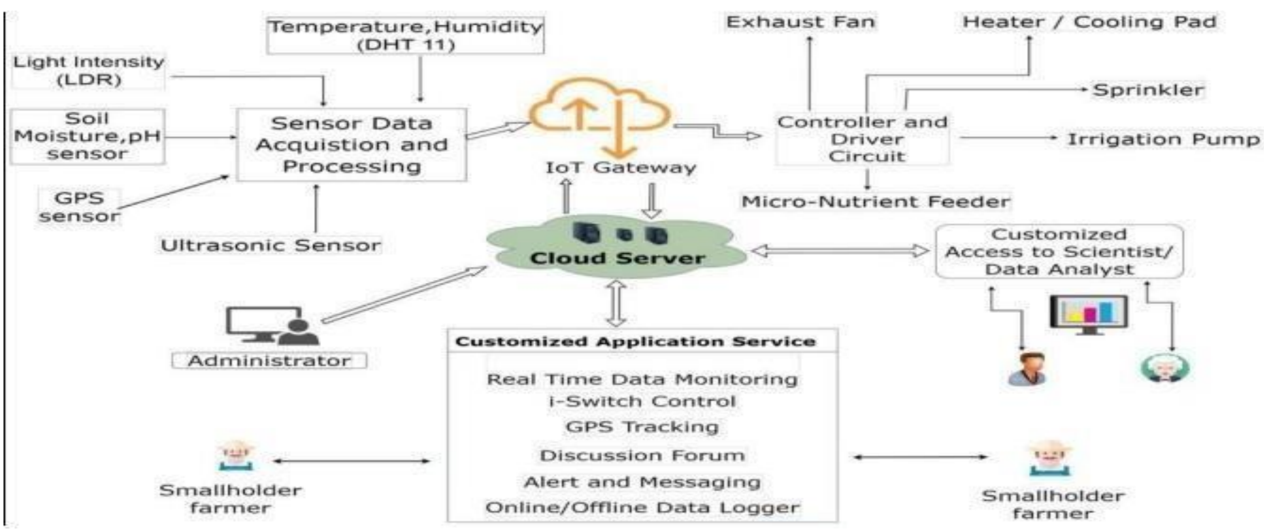


Fig 2.3 IoT platform approach for smart agriculture

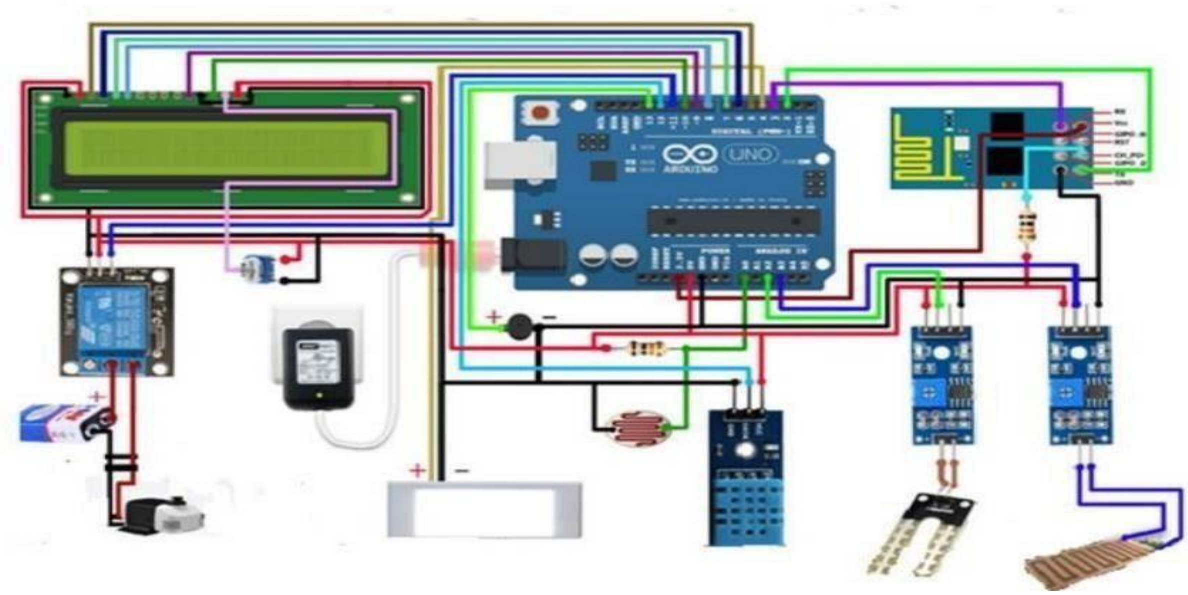


Fig 2.4 Circuit Diagram

Step 1: First, we set up all of the input devices, or the project's sensors. We attach rain and soil sensors to the module that senses moisture: The Arduino Uno micro- controller will be directly connected to the temperature and humidity sensor, LDR, and other sensors that are utilized.

Step2: We will now have the project's output devices ready. An Arduino is utilized in conjunction with a 5V relay module since the Arduino is unable to power the irrigation water pump. Additionally, glow LED is employed in this project as an output device.

Step 3: To transfer data to the phone over a local network, connect the Arduino microcontroller to the Wi-Fi module. In order to connect this module to the Arduino. It is now possible for the ESP8266 Wi-Fi module to communicate with the Arduino.

Step 4: At last, the 5V and GND of the Arduino are linked to the LCD display and Vcc GND of every device. Additionally, the Arduino and the necessary power sources are linked to the WATER Pump.

II. Results

II . A

The system was implemented in a 5-acre farm, utilizing the following sensors:

Soil Moisture Sensor: Monitored soil water content, enabling precise irrigation and reducing water usage by 40%.

Temperature and Humidity Sensor (DHT11): Tracked environmental conditions to optimize crop growth, resulting in a 25% yield increase.

Rainwater Sensor: Detected rainfall to adjust irrigation schedules automatically, preventing over-watering.

Infrared Sensor: Identified animal movement near crops, protecting them from damage.

Flame Detector: Ensured fire safety by activating water flow during fire hazards, safeguarding crops and equipment.

Light Sensor: Monitored sunlight exposure to optimize plant growth cycles.

II.1 Snapshot Result of Module :

Soil Moisture Sensor : It displays real-time soil moisture level.

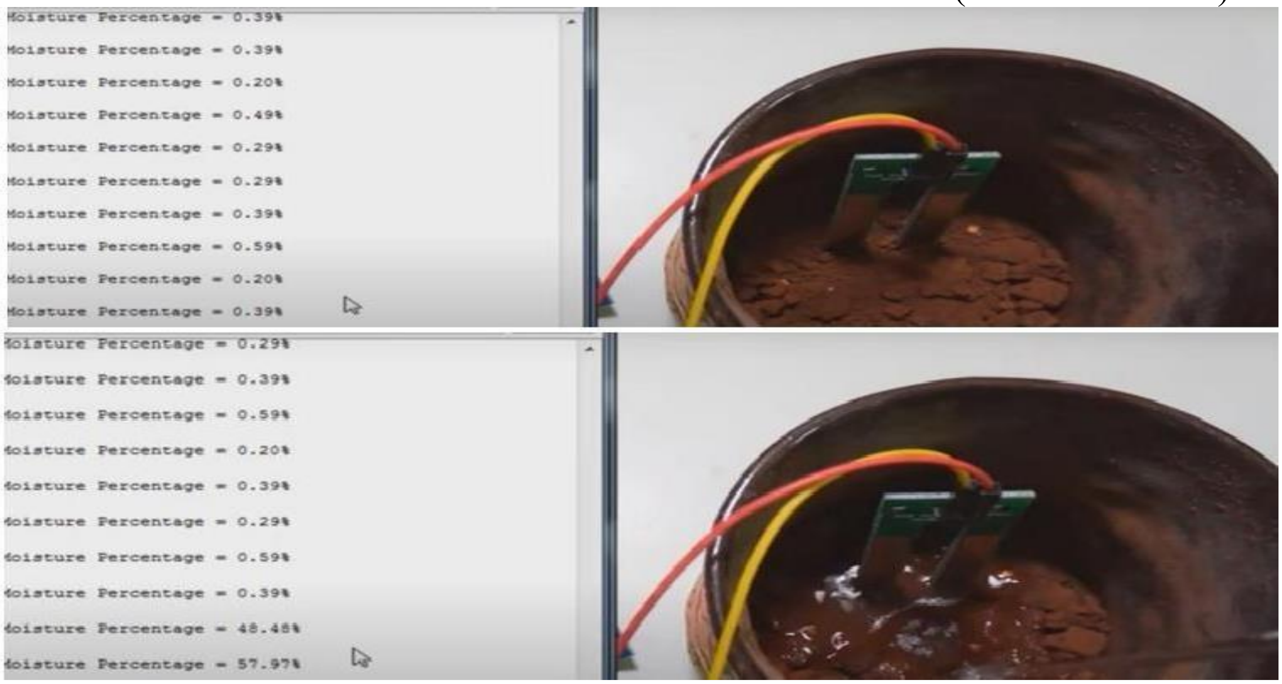


Fig 3.1.1 Soil Moisture Sensor Output

Temperature Sensor(DHT-11) : It shows current temperature readings in degrees in Celsius/ Fahrenheit.

Fig 3.1.2 Temperature Sensor(DHT 11)

Rain Water Sensor: It display whether rainfall is detected to adjust irrigation accordingly.

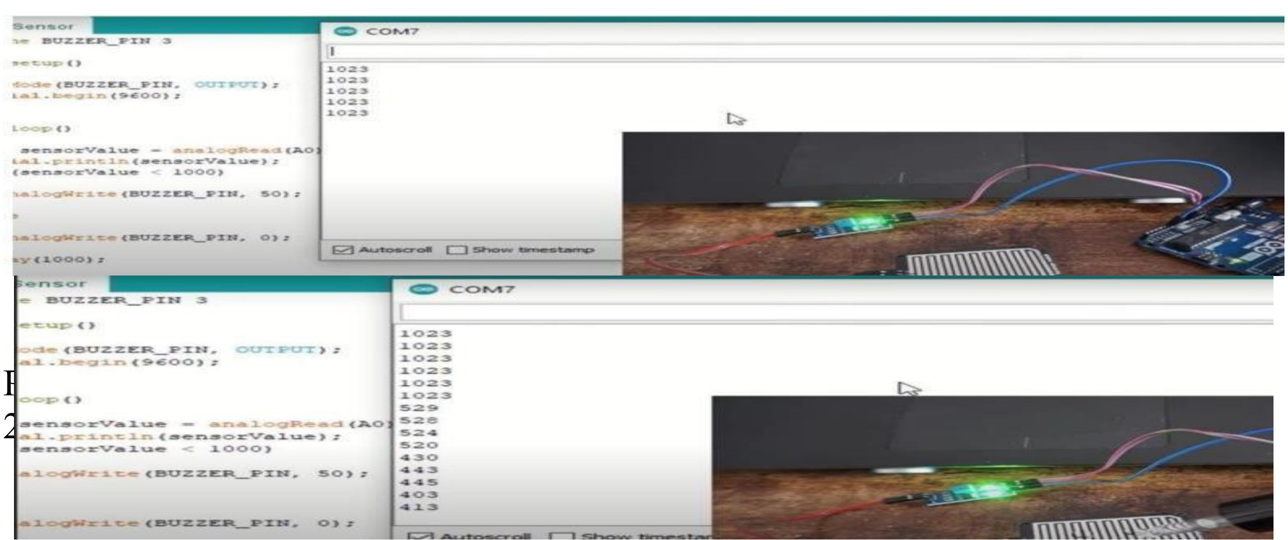


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Fig 3.1.3 Rain Water Sensor

Animal Detection Sensor : It shows alerts or status for the presence of animal in the field.

Fig 3.1.4 Animal Detection Sensor

II.2 *Table*

Study	Focus	Methodology	Findings
Zhang et al.(2018)	Crop monitoring and management	IoT sensors, data analytics	Improved crop yield by 20% through real- time monitoring and optimal resource allocation.
Kumar et al.(2019)	Livestock monitoring	Wireless sensor networks(WS N)	Enhanced animal health and productivity by monitoring vital signs and behaviour using IoT devices.
Smith et al. (2020)	Soil health monitoring	IoT soil sensors, machine learning algorithms	Increased soil fertility by 15% by analyzing soil moisture, pH, and nutrient levels in real- time
Li et al. (2021)	Pest control and management	IoT-enabled pest traps, predictive analytics	Reduced pesticide usage by 30% while maintaining crop yield through predictive pest control algorithms.
Patel et al. (2022)	Water management and irrigation	IoT-enabled irrigation systems	Reduced water usage by 40% by implementing precision irrigation techniques based on soil moisture and weather data.

Table 1 Comparison Table

III. Conclusion

IoT-enabled Smart Agriculture Monitoring System uses the Internet of Things (IoT) to monitor and enhance crops by providing real-time monitoring of climatic variables such as temperature, humidity, soil moisture, and light conditions. This system can be used to detect the early signs of insect infestations, diseases, or nutrient deficiencies so that action can be taken quickly. The system has an automated irrigation and fertilization feature that enables farmers to produce more crops at a lower cost than traditional methods.

Looking ahead, the incorporation of Artificial Intelligence (AI), machine learning, and drones into smart agriculture systems will provide greater effectiveness in the decision-making process and increase the accuracy of predictions. The use of IoT and edge computing technology, along with green communication technology, will enable the creation of intelligent agricultural systems that will be more autonomous, more sustainable, and more efficient in their use of resources, thereby creating a new generation of environmentally-friendly agricultural practices.

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