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Automation in Agriculture using Smart Instruments

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Abstract: *Now a days Automation in agriculture is very useful and meaningful for farmers. After using of latest technologies in agriculture industries farmers make lots of profits, reduces their efforts. Smart irrigation systems use sensors and automated controls to supply the right amount of water to crops, reducing waste and increasing efficiency and productivity of food products. Smart sensors useful for monitor soil conditions, temperature, humidity, and crop health, allowing farmers to make meaningful decisions. Drones are also playing an important role by assisting in crop monitoring, spraying pesticides, and also useful for many applications. This review paper discusses different types of smart irrigation systems, the role of sensors, and how drones are improving modern farming.*

Keywords: Soil Moisture, Smart Irrigation, Smart Sensors, Crop Monitoring, Smart Agriculture

I. INTRODUCTION

Agriculture is one of the most impactful industries, but there are several challenges like water shortages, unpredictable weather, and providing wages to labour, and labour shortages which make farming more difficult. Automation and smart technologies are helping to solve these problems by making farming more efficient. Smart irrigation systems automatically control water supply based on soil moisture and weather conditions, ensuring crops get the right amount of water. Smart sensors help farmers track soil quality, temperature, and other important factors in real time. Drones are also being used for spraying, monitoring crop health, and mapping large fields. This paper explores how these technologies are making agriculture smarter and more sustainable.

II. DIFFERENT TYPE OF SMART IRRIGATION TECHNOLOGIES

A. IOT-based Smart Irrigation:

Sensors collect real-time data on soil moisture, temperature, and humidity. This data is processed through microcontrollers like Arduino or Raspberry Pi and transmitted via Wi-Fi or MQTT protocols. Farmers can easily monitor and control irrigation remotely through mobile apps or cloud platforms. Prediction of soil moisture is vital for effective irrigation management system.

So, For IOT based smart irrigation they have considered evaporation of soil moisture based on air temperature, air relative humidity, soil temperature, and radiation, And The parameters are considered for analyzing the soil moisture drain (change/difference) pattern based on the recorded data of soil moisture. [6]

This diagram shows some sensors (air humidity sensor, soil moisture sensor, temperature sensor, water flow sensor) provide real time information to the ESP8266 Wi-Fi module, which communicates with the BLYNK app via Wi-Fi. And a relay controls a solenoid valve for automated water flow based on sensor readings, enabling remote monitoring and control through mobile app.

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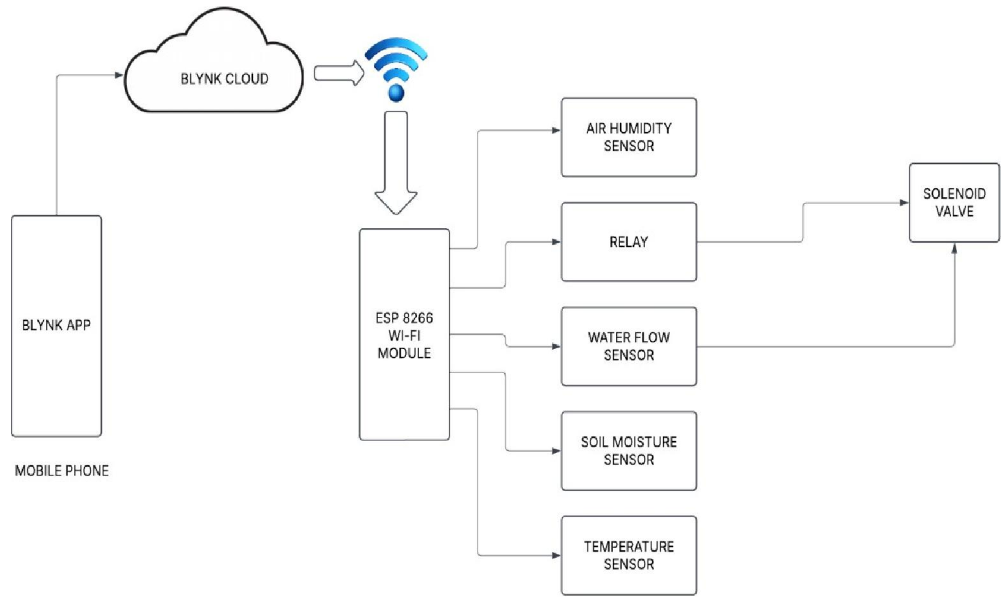

Figure: 1 IOT Based Smart irrigation using BLYNK app And ESP8266

a. ESP8266 Wi-Fi Module for Irrigation:

A low-cost system using an ESP8266 Wi-Fi module along with sensors to automate irrigation based on soil Moisture levels. This setup helps farmers make better decisions by providing real-time data and visualization (24*7).

This paper represent this kind of smart irrigation system has pH sensor, water flow sensor, temperature sensor and soil moisture sensor that measure respectively and based on these sensors and then Arduino microcontroller drives the servo motor and pump, and in this method Arduino received the information and transmitted with ESP8266 Wi-Fi module wirelessly to the website through internet. [2]

The ESP8266 Wi-Fi module is inexpensive, and has a very small microcontroller which is consumes a very less power, and it is use for both wired (by using Arduino) or wireless communication

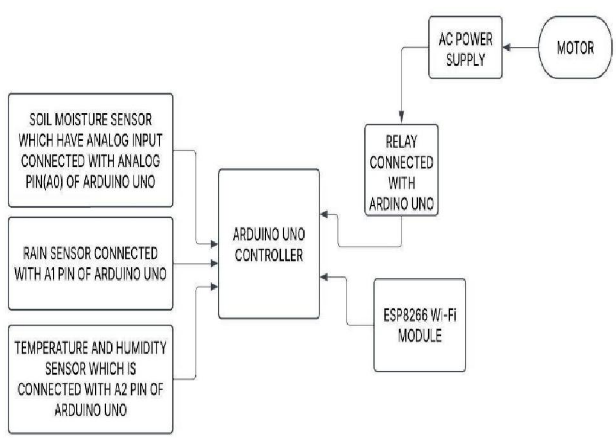

Figure 2: Smart irrigation system using Arduino Uno controller and ESP8266 Wi-Fi module

Figure 2 integrates temperature and humidity sensors and rain sensors and soil moisture sensors to monitors in environmental conditions. And the ESP 8266 Wi-Fi modules enables remote monitoring, while a relay controls a motor powered by an AC supply for automated irrigation based on sensor inputs.

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b. MQTT Protocol for Irrigation

This protocol used in smart irrigation systems to ensure effective communication between sensors and cloud platforms. This reduces the need for manual intervention and enables automated irrigation control.

The basic irrigation system like soil moisture sensor, and DHT22 humidity sensor and some different type of methods for initiate water pump, and in this basic system sensor senses this all information which is transferred data through ESP8266 mode using this Message Queuing Telemetry transport protocol (MQTT).

Ravi Kishore and Borade Samar also said that, The Esp8266 is then connected to the MQTT server which is used for the display purpose. The soil moisture sensor measures the data and that data is sent to the user via MQTT server. [3]

c. LORA communication module for Irrigation:

In this system, the irrigation node is mainly composed of a Lo-Ra communication module, solenoid valve and hydroelectric generator.

In this paper the author says that by using the irrigation node sends data to cloud through Lo-Ra gateways via wireless transmission, And The system can be controlled remotely by mobile applications. [8] And yes this Lora communication module is very effective for long distance communications and large-scale farms.

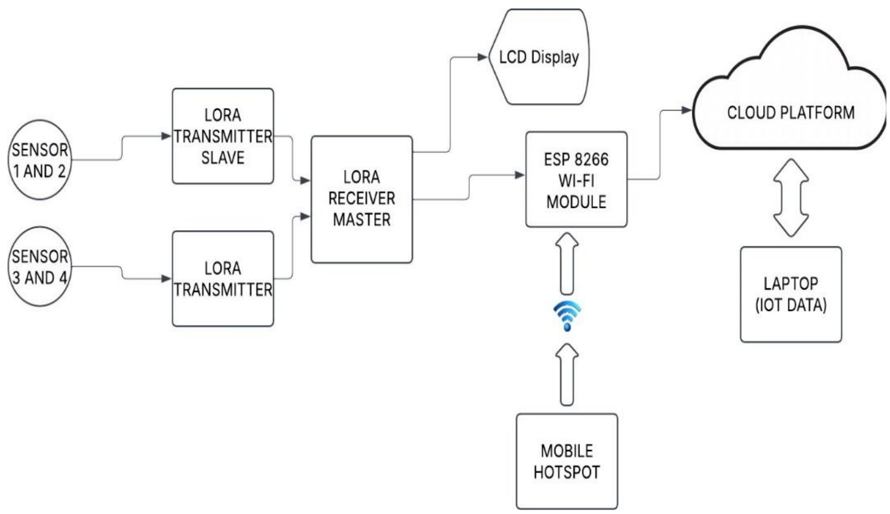

Figure :3 Lora Sensor Based Agriculture Monitoring system

Figure 3 shows that sensor collect data and send it via Lora transmitters to a Lora receiver, which then displays the data on LCD and transmit it to the cloud by using ESP8266. And a mobile hotspot enables internet connectivity, allowing remote monitoring via a laptop.

B. Renewable Energy-Based Smart Irrigation:

Solar-powered irrigation systems help reduce reliance on electricity. These systems use fuzzy logic controllers to analyse soil and weather conditions, ensuring optimal water usage.

So basically in this we first compare two methods for irrigation one is automated irrigation system and second one is normal water supplying system and then we checked that which plant has a better growth.

So sometimes for a big plant we need a large water pump which require a higher amount of energy, and by using normal and solar electricity we cannot provide a sufficient energy so at that TIME Renewable energy based smart irrigation is very impactful.

AND for a fuzzy Logic Controllers we have soil moisture, humidity and temperature sensors by using those inputs fuzzy logic controllers have to build a logic for control of irrigation system. Solar-powered irrigation systems help reduce reliance on electricity. These systems use fuzzy logic controllers to analyse soil and weather conditions, ensuring optimal water usage.

The fuzzy logic controller uses a “if” and “else” condition for operating the solenoid valve. And Base on this conditions the output value is either "True" or "False". "True" indicates the current to the solenoid valve and thus valve is open and water is given to the crops and "False" indicates no current to the solenoid valve and thus the valve remains closed. [7]

The author Ban and Azmi also discuss a new logic for smart irrigation in their paper is that, in order to build the fuzzy control system that will control the water flow to a desired level, we would need to define two inputs; the first one is the soil moisture (SM) and the second one is the outside temperature (TE). These two inputs will be used to control the water flow by automatically changing the switch position in the water pump. [5] so basically the logic in this paper is whenever temperature high at that time the moisture is low so we require a water flow and whenever the moisture is high and temperature is low then we don't require water flow like summer and rainy season.

C. Artificial Intelligence in Irrigation:

AI-based systems analyse past data, weather forecasts, and soil conditions to determine the best irrigation schedules. Machine learning algorithms predict future irrigation needs, helping in conservation of water.

In this basically first of all when all initial investment is done then the role of AI is start, like the latest automated controllers has ability that they can stored minimum 1 year sensory and needed data within them, by use of this AI will take information and see all type information and then build different algorithms for different situation and then it is stored that logic in controller so whenever any data matching (stored logic) situation occurs it will automatically control by AI**,** And it will work in anticipatory manner which will reduces human efforts. But use of AI at everywhere it will still have many challenges.

And intelligent system dedicated to predicting the irrigation water needs of a field is designed based on the ground sensing measurements such as soil moisture and soil temperature, along with the climatic forecast data available on the Internet like precipitation, air temperature, humidity, and UV for the near future, including open-source technologies. [4]

D. Solar Powered Smart Irrigation System

The use of solar energy in irrigation is very impactful for nature, and solar energy source have a very high amount of energy which is perfectly suitable for large farming irrigation system. And the initially investment is high but later after it is very cost effective.

So basically in this solar energy is used to initiate a water pump, and also use for stored the energy whenever needed then that energy will be useful.

In this solar power Based smart irrigation system the sensor converts the moisture content in the soil into equivalent voltage. This is given to a sensing circuit which has a reference voltage that can be adjusted by the farmer for setting different moisture levels for different crops. The amount of water needed for soil is proportional to the difference of these two voltages. [1] And then control signal which is given to the control valve which is controlling flow.

E. Advantages and Limitation of Smart Irrigation Systems

- Due to smart irrigation systems it will useful for water conservation, and it will Supplying water only when needed, and yes it will also reduce unnecessary water usage.
- In the solar power smart irrigation system. The use of solar energy it is very effective and efficient use of energy and it is also very eco-friendly.
- By use of automation in agriculture farmers can also control all task like irrigation, spraying on pesticides and ensuring the health of product by remotely and at anywhere in the world. And Use of automation it may have a very high initial installation cost for irrigation system BUT after sometime it will provide healthier crops and also increased productivity of crops
- But the basic necessary conditions for farmers for smart irrigation the farmers must have some technical knowledge for all this kind of smart irrigation methods.
- All this kind of methods for smart irrigation system also require a maintenance regularly because the weather is changing frequently so the irrigation schedule is also changes and the soil moisture sensors, humidity sensors

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are placed in farms which will affect by changing in whether condition and also give false readings which is lead to unnecessary water flow to crops and it will also effect on product quality.

III. DIFFERENT TYPE OF SMART SENSORS

A. Soil Moisture Sensors

Soil moisture sensor is a sensor which senses the moisture content of the soil. The two primary types of soil moisture sensors are resistive and capacitive sensors [28]. Resistive sensors, such as the FC-286 and SEN133227, employ two probes to deliver a current through the soil and detect resistance in order to quantify moisture [10]. A Novel Cosmic-Ray Neutron Sensor for Soil Moisture Estimation over Large Areas [11]. It introduces the development of an innovative instrument which allows estimation of soil moisture from environmental epithermal neutron counts, thanks to implementation of a composite neutron detector [27]. Calibration and Validation of a Low-Cost Capacitive Moisture Sensor to Integrate the Automated Soil Moisture Monitoring System [12]. It is introduces the calibration and validation of a low-cost capacitive moisture sensor for integration into an automated soil moisture monitoring system. The relationship among the measured property and soil moisture is calibrated and it may vary depending on environmental factors such as temperature, soil type, or electric conductivity [9]. Soil moisture has chosen shown in Fig. 1. which consists two probes that are inserted in to soil. For a 3-wire soil moisture sensor, the typical wire colour and connection are followed by TABLE I.

TABLE I: Soil moisture sensor probe wiring table

Sr no.	Wire	Connection
1	Black	GND
2	Red	VCC: 3.3V to 20 V (DC)
3	Blue/White	OUT: 0 to 3V

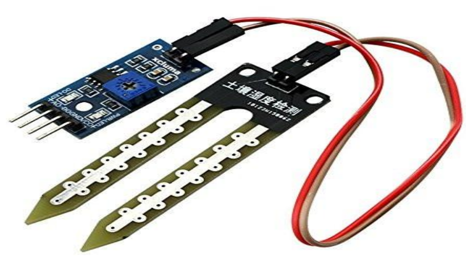

Fig. 4. Soil moisture sensor

Fig. 4. Shows a soil moisture sensor which consists of two metal electrodes and these are inserted into the soil and act as conductors to measure electrical resistance or capacitance.

When the current pass through the probes, the soil contains low moisture offer a less resistance and passes high current. That is variable resistance is the parameter to identify the level of soil moisture [13]. These sensors constantly monitor soil conditions to guide precise irrigation and fertilization practices, avoiding overuse of resources and ensuring optimum nutrient availability for crops [14].

B. Tensiometers:

A tensiometer is a device used to measure soil water tension, which indicates how strongly water is held in the soil and how available it is to plants. The Fig. 2. shows a typical tensiometer which consists of a porous ceramic tip connected to vacuum gauge through a PVC tube.

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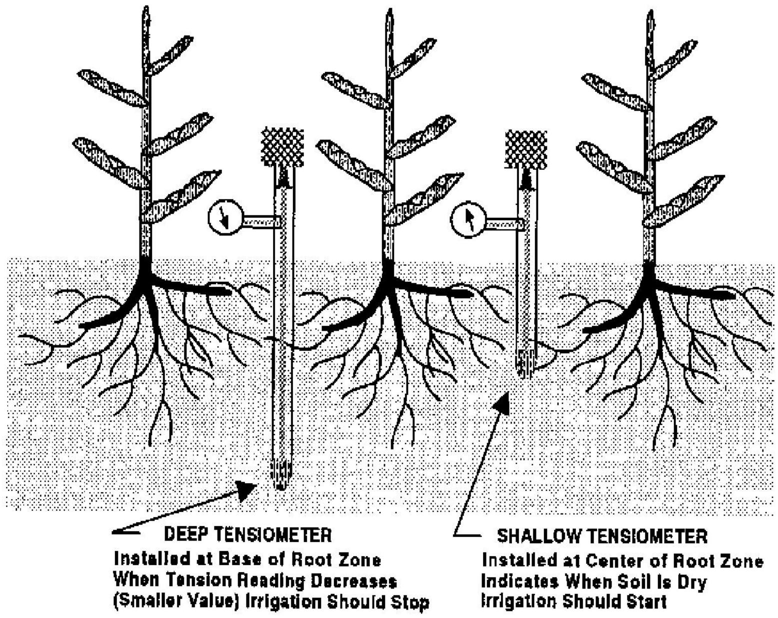

Fig. 5. Tensiometer for soil moisture

This instrument not measure soil moisture content directly, instead it measures soil water tension. Generally, the response time of a tensiometer is 2 to 3 hours. There are tensiometers available which can be automated with the irrigation system with the help of pressure gauge. Measure the water content in the soil to help determine when and how much to irrigate

In time domain reflectrometry, a pulse of radio frequency energy is injected into a transmission line and its velocity is measured by detecting the reflected pulse from the end of the line. This velocity depends upon the dielectric constant. It measures the moisture content by measuring how long it takes for the reflected pulse to come back. The response of a TDR is very quick (≈ 28 sec).

Fig. 6. Time Domain Reflectrometry (TDR)

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Fig. 6. Shows Time domain reflectrometry sensor probes are inserted in to soil for sensing the moisture. TDR is mostly used in fields having mineral crops and crops grown on organic soils. They have listed sweet corn, green bell pepper, and the crops grown on sandy soils for which TDR can be used. It is expensive as compared to TDR.

C. Temperature Sensors

Temperature is the important factor in soil that affect all the processes that occur in the soil such as storage of organic carbon, attainment of mineral nutrients and water content along with these processes plant physiological characteristics like the function of soil microbes and growth and composition of the root are also influenced by soil temperature [15]. We flicked through some of the Temperature sensors like LM20, LM34, LM35, LM94022, LM94023, THERM200 which are locally available low-cost sensors with a wide range of specifications that would suit the farms around. We fabricated a sensor with temperature and EC sensing areas for monitoring the health of cows in previous work [16]. LM358 is applied at DC gain blocks and other types of conventional circuits. The main advantage is easily Operates and implements at single power supply circuits [17]. The DS18B20 is a digital thermometer that does not require an external power source [28]. Thermistor based temperature sensors, are typically inaccurate, and use the complex Steinhart-Hart equation which contains complex calculations such as logarithmic and third order terms, which are difficult for microcontrollers to compute, we can overcome this difficulty with the use of THERM200 [29].

Fig 7. Temperature Sensor

D. Thermocouples

Thermocouples is measure temperature based on voltage differences between two different metals. It is classified as contact or non-contact sensors, measure the temperature of their surroundings. TABLE II is representing the various types (Like Class I, Class II, Class III) of thermocouple sensors with their temperature ranges.

TABLE II: Different types of thermocouples with ranges.

Thermocouple Type	Class I Tolerance (°C)	Temperature Class II Tolerance (°C)	Ranges (°C) Class III Tolerance (°C)	Continuous Use (°C)	Short Term Use (°C)
Type E	-40 to 800	-40 to 900	-40 to 906	0 to 800	-40 TO 900
Type J	-40 to 750	-40 to 750	N/A	0 to 750	-180 to 800
Type K	-40 to 1000	-40 to 1200	-180 to 1300	0 to 1100	-180 to 1300
Type N	-40 to 1000	-40 to 1200	-270 to 1304	0 to 1100	-270 to 1300
Type R	0 to 1600	0 to 1600	N/A	0 to 1600	-50 to 1700
Type S	0 to 1600	0 to 1600	N/A	0 to 1600	-50 to 1750

Fig. 8. Shows representing the thermocouple sensor which is sensing the temperature of soil in agriculture. Contact sensors, such as thermocouples and resistance temperature detectors (RTDs), physically come into contact with the object or environment being monitored. The thermocouple consists two wires of different metals which are welded together at the ends.

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Fig. 8. Thermocouple

E. Resistance Temperature Detectors (RTDs)

Resistance Temperature Detectors (RTDs) are widely used in agriculture for precise temperature measurement. RTDs operate based on the principle that the electrical resistance of a metal (commonly platinum, copper, or nickel) changes predictably with temperature. TABLE III is representing the various types of material which can make a sensors with their relative temperature ranges.

TABLE III: RTD Temperature sensor ranges

Sr. No	RTD Material	Relative Temperature Range
1	Platinum	-200°C to +850°C
2	Nickel	-60°C to +180°C
3	Copper	-50°C to +150°C
4	Nickel/iron	-200°C to +200°C

Fig. 9. Resistance Temperature Detectors (RTDs)

Fig. 9. Shows the Resistance Temperature Detectors (RTDs) which is the types of temperature sensor. Applications for the RTDs is a frost protection by activating heating systems in greenhouses. These sensors provide highly accurate and stable temperature readings, making them ideal for agricultural applications where temperature control is essential for plant growth, soil conditions and greenhouse management. Convert temperature changes into electrical signals.

F. pH Sensors

The pH sensors fabricated using Si LSI process are mainly ISFETs or sensors using charge transfer technology [30]. pH sensors measure soil or water acidity/alkalinity, ensuring optimal nutrient availability for crops. pH sensor are commonly used agricultural smart devices used to monitor soil pH values. Soil pH can only be measured manually. Many scientific pH probes are available that accurately measure the pH at room temperature [28]. Fig. 7. Is representing the graphical form of polynomial model.

Fig. 10 pH Sensor

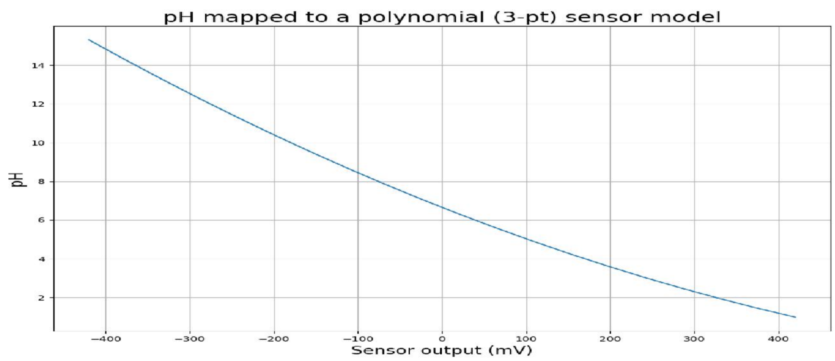

Fig. 11. pH Sensor output

Fig .10 Shows the pH sensor which is inserted into the soil and they are measure the pH of soil to adjust acidity or alkalinity for the agriculture. Several kinds of membrane material have been used [31] such as Si3N4, Ta2O5, Al2O3, SiO2 and so on. By accurately obtaining soil pH information, which is a crucial factor for plant growth and development, farmers can take timely measures to adjust soil acidity or alkalinity, thereby improving crop growth and yield.

G. Humidity Sensors

Humidity is defined as the amount of water present in the surrounding air. This water content in the air is a key factor in the wellness of mankind. For example, we will feel comfortable even if the temperature is 00C with less humidity i.e. the air is dry. But if the temperature is 100°C and the humidity is high i.e. the water content of air is high, then we will feel quite uncomfortable. A capacitive humidity sensor changes its capacitance based on the relative humidity (RH) of the surrounding air. Relative humidity (RH) is the percentage of actual vapor pressure (P) compared to saturated vapor pressure (Ps) [29].

Fig. 12 Digital Humidity

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Fig. 12. Shows a digital humidity sensor, like the DHT11 or DHT22. It is also a major factor for operating sensitive equipment like electronics, industrial equipment, electrostatic sensitive devices and high voltage devices etc. Such sensitive equipment must be operated in a humidity environment that is suitable for the device. The humidity sensor consists of two probes which are used to measure the volumetric content of water. The two probes allow the current to pass through the soil and then it gets the resistance value to measure the moisture value.

Future Scope of Smart Sensors in Agriculture

- Smart sensors will enable real-time monitoring of soil moisture, temperature, pH, and nutrients, optimizing water and fertilizer use.
- AI-driven decision-making will improve crop yield and reduce resource waste.
- Smart sensors will help farmers adapt to climate change by providing early warnings for droughts, floods, and pests
- Data-driven farming will reduce chemical overuse, promoting sustainable agriculture.
- Sensors will track crop conditions from farm to market, ensuring better quality control and reducing post-harvest losses.
- Blockchain integration with sensor data will enhance food traceability and safety.

IV. DIFFERENT TYPES OF DRONE METHODS IN AGRICULTURE

Fixed-Wing Drones:

Fixed-wing drones are designed to resemble traditional airplanes. These drones typically have a longer flight time and can cover vast areas in a single flight, making them particularly suitable for large-scale farming operations. Fixed-wing drones are primarily used for crop monitoring, field mapping, and aerial imaging. They are equipped with advanced sensors such as multispectral, thermal, and LiDAR to capture detailed data on crop health, soil conditions, and irrigation needs. Drones with fixed wings are advantageous because they can fly long distances. [18]

	Advantages	Limitations
Fixed-wing drones	Longer flight times (typically 2-4 hours).	Require more space for take-off and landing.
	Suitable for large areas and extensive monitoring.	More complex in terms of operational setup.
	Higher efficiency in surveying and mapping.	

Rotary-Wing Drones (Multi rotors):

Rotary-wing drones, commonly known as multi rotors, are characterized by multiple spinning blades (usually four to eight) that provide vertical lift. These drones are more versatile and capable of hovering in place, making them ideal for precise operations such as crop spraying, small-scale monitoring, and targeted data collection. Multi rotors are commonly used in precision agriculture for tasks like fertilizer and pesticide application Rotary wing drones are those that generate lift by rotating blades called propellers. [18]

	Advantages	Limitations
Rotary-wing drones	Suitable for smaller and more localized areas.	Shorter flight times (typically 20-30 minutes).
	Easier to use for crop spraying and close-up monitoring.	Lower efficiency over large areas compared to fixed-wing drones.
		Higher operational costs due to frequent battery changes.

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Hybrid Drones:

Hybrid drones combine the features of both fixed-wing and rotary-wing designs, offering the benefits of both types. These drones can take off and land vertically like multi-rotors and transition to horizontal flight like fixed-wing drones. Hybrid drones are particularly beneficial in areas where large-scale operations require the range of fixed-wing drones and the precision of rotary-wing drones.

	Advantages	Limitations
Hybrid drones	Flexible flight capabilities (vertical and horizontal).	More complex and expensive to design and maintain.
	Suitable for a range of agricultural applications, including large and small fields.	Require more advanced navigation and control systems.
	Better fuel efficiency and longer flight times than multirotor.	

Swarming Drones:

Swarming drones are a new concept in which multiple drones work collaboratively in a coordinated manner to cover large areas efficiently. In agriculture, this method is being explored for tasks such as planting seeds, monitoring large fields, and conducting large-scale data collection. The swarming technique enhances operational efficiency by allowing drones to divide tasks and function as a unit, reducing the time and labor required for specific agricultural tasks.

	Advantages	Limitations
Swarming drones	Increased efficiency through distributed workloads.	Requires advanced algorithms for coordination and communication.
	Potential for autonomous operation with minimal human intervention.	Complex to implement and manage due to the need for real-time data exchange between drones.
	Can cover large areas in a short period.	

Application of Drone Technology in Agriculture:

Crop Monitoring:

Drones equipped with high-resolution cameras and Multispectral sensors can capture detailed image of crop. [19] These images can be Processed to monitor crop health, Assess the overall condition of the fields. The data coming from the multispectral camera through telemetry was analysed by the geographic indicator normalized difference index (NDVI) represented in equation.

NDVI = (RNIR- RRED)/(RNIR+RRED)

RNIR = Reflectance of the near infrared band

RRED = Reflectance of the red band [20]

Land Mapping:

Drones can Generate 3D maps and topographic models that Aid in understanding the terrain and water flow Patterns, which is crucial for efficient land use [19].

Livestock Management:

Drones can be used to monitor and manage Livestock. They can help count cattle, check on Their health, and even search for missing Animals. [19]

Soil Health Monitoring:

Drones produce NDVI maps and determine soil moisture and nutrients that drive the upgrading of soil management and crop yields. [21] This enables farmers to practice more efficient and sustainable farming. AI-powered software can analyse this data to forecast soil health, allowing farmers to better prepare for the upcoming seasons.

Irrigation Management:

Precision irrigation is crucial since 70% of the water used on earth is for crop irrigation. [22] drone can apply irrigation based on crop needs.

Pesticide Spraying:

Drone based pesticide spraying revolutionizing application methods pesticides application is a crucial aspect of protecting crops from pets and diseases. [23] Drones can be programmed to fly along specific routes and precisely spray only the designated areas.

Sprinkling System:

Generally, the sprinkling system is attached to the lower region off the UAV which as a nozzle beneath the pesticide tank to sprinkle the pesticide towards downstream. [24] The sprinkler system consists of two modules: the sprinkler system itself and the controller. A pressure pump is a component of the sprinkler system that pressurizes the pesticide to enable it to flow through the nozzle.

Crop insurance

Drones play a pivotal role in transforming the landscape of crop insurance, especially in initiatives like the Pradhan Mantri Fasal Bima Yojana in India. [25] These unmanned aerial vehicles offer an innovative method for evaluating and managing crop insurance, providing advantages for both farmers and insurance companies. Farmers greatly benefit from the integration of drones in the insurance process.

Geo-Fencing:

Thermal cameras mounted on drones can detect animals, birds, and humans, protecting fields from external damage. [26] Geo-Fencing drone technology creates virtual boundaries that keep drones from entering restricted areas.

V. CONCLUSION

Automation in agriculture using smart instrumentation has significantly improved farming efficiency. Technologies like smart irrigation systems, sensors, and drones help farmers monitor soil conditions, manage water efficiently, and reduce manual labour. Drones play a crucial role in monitoring crops, spraying fertilizers, and mapping fields. These advancements make agriculture more sustainable and cost-effective. While the initial investment may be high, the long-term benefits outweigh the costs, making automation a promising solution for modern farming.

But we also think that this kind of solution only applicable in large scale farms, so in future we have to think about on that one how we can apply smart irrigation systems in small scale farms.

And we should also think about that how we can use AI in agriculture industry in future because use of AI at currently have many challenges.

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