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IoT and AI in Agriculture: Enhancing Productivity and Optimizing Resources - A Review

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***Abstract** –IoT (Internet of Things) technologies are essential to supplying the world's expanding food demand, and the change in farming methods has brought along both benefits and challenges. IoT sensors monitor essential parameters like soil pH, moisture, and water levels. For instance, water volume sensors, integrated with Arduino UNO modules, ensure precise irrigation by supplying the required amount of water and preventing overflow. Networking technologies enable remote operation, improving efficiency. IoT's ability to connect agricultural tools, sensors, and experts has enhanced productivity, reduced costs, and improved service accessibility, particularly in off-grid areas. This research explores current and future IoT applications in agriculture, focusing on security, trends, and technology implementation. IoT devices support smart farming by enabling precision farming, livestock monitoring, crop health assessment and smart irrigation systems. The study highlights the potential of IoT and wireless sensors in agriculture and discusses the challenges of integrating these technologies into traditional farming methods. AI technologies also assist in reducing crop diseases and pest infestations with autonomous farming equipment and improved forecasts based on data analysis. IoT and AI are revolutionizing agriculture by enhancing efficiency, reducing costs and providing actionable insights with the potential to transform global farming practices.*

***Keywords**- IoT, smart agriculture, crop disease identifications, sensors, communication technologies, applications, machine learning, deep learning, security*

I. INTRODUCTION

The agricultural sector is undergoing a transformation driven by the adoption of Internet of Things (IoT) and Artificial Intelligence (AI) technologies [1]. As global food demand continues to rise the need for more efficient, sustainable and precise farming practices has never been greater. Traditional agricultural methods often limited by manual processes and insufficient data are increasingly being replaced by innovative technologies that enhance productivity, improve resource management and reduce environmental impact. Global warming has further intensified challenges, leading to shifts in weather patterns caused by rising global temperatures [2]. Unpredictable climate conditions such as frequent droughts and excessive rainfall create uncertainties for agricultural output. Considering these limitations the agricultural industry needs to grow in order to satisfy the rising demand for food. IoT-based smart farming offers a transformative solution. This approach integrates sensor-based agricultural field observation systems to automate and optimize farming processes making them more efficient than traditional methods [3]. IoT technology enables farmers to monitor real-time field conditions remotely providing actionable insights that boost productivity while reducing costs. The primary objective of IoT systems is to maintain optimal growing conditions for crops. Farmers can access data on their mobile devices through a specialized online interface [4]. With the help of informative toolbars, the farmers able to monitor temperature, soil moisture and other vital indicators, facilitating better crop management through educated decision-making. Incorporating IoT technologies not only improves resource utilization but also mitigates the impacts of climate change and unpredictable weather patterns [5]. It empowers farmers to address agricultural

Various Internet of Things architecture layers that are employed in intelligent agricultural systems

Leading Sensor Technologies used for Data Collection and Monitoring in Agricultural field.

Since it gathers data from the field in real time the perception layer is the core of an agricultural IoT system [6]. Higher layers of the system subsequently get the data to process, assess and use in decision-making. When farmers and agricultural specialists have access to fast and accurate data on the agricultural environment they can make decisions about cultivation, fertilization, pest management and other crucial farming factors [7]. A list of several tools and sensors commonly utilized at the perception layer for agricultural applications is provided below [8].

Arduino Mega: The Arduino Mega is based on the ATmega microcontroller and offers 16 analog pins, 54 digital I/O pins, a 16 MHz crystal oscillator, a USB port for communication and an ICSP header. It is used as the main controller for processing input from sensors and managing other components in the system.

ESP8266 Microcontroller: The ESP8266 is a system-on-chip (SoC) that provides Wi-Fi connectivity. It allows the microcontroller to connect to a Wi-Fi network and enables remote communication, making it ideal for Internet of Things (IoT) applications in agriculture.

nRF24L01 Radio Transceiver Module: The nRF24L01 module operates on the 2.4 GHz ISM frequency band and facilitates wireless communication between devices. It is used to send and receive data between different components in the agricultural network, especially useful in remote farming areas.

Soil Moisture and Soil Compaction Sensors: These sensors measure the water content in the soil helping farmers decide when and how much water to use for irrigation. Soil Compaction Sensors measure the level of soil compaction which can affect root growth and crop health.

Air Quality Sensors: These detect pollutants or gases in the air which can affect plant health and overall crop productivity.

Humidity Sensors and Temperature: These sensors track the temperature and humidity in the environment which is important for understanding how climate affects agricultural growth.

Weather Stations: Weather stations collect meteorological data such as temperature, wind speed, humidity and precipitation providing valuable insights for agricultural planning.

Remote Sensing Devices: Devices like satellites or drones are used for capturing images or data that can help assess crop health and detect early signs of stress or disease.

Wind Sensors: These sensors measure wind speed and direction which affect irrigation, pollination and pesticide sprayings.

pH Sensors: pH sensors measure the acidity or alkalinity of the soil which influences nutrient availability and plant health.

Light Sensors: Light sensors measure sunlight intensity and help optimize crop placement in fields or control artificial light in greenhouses.

Water Flow and Water Level Sensors: Water flow sensors monitor irrigation systems for leaks and ensure optimal water distribution. Water level sensors track water levels in reservoirs, tanks or other water sources to ensure sufficient water supply for irrigation.

Crop Health Sensors: These sensors monitor the overall health of crops including detecting environmental stress, diseases and leaf chlorophyll content.

Weather Radar or Satellite Sensors: These sensors provide detailed weather data and forecasts to assist in agricultural decision-making. Carbon Dioxide (CO_2) sensors measure CO_2 levels in greenhouses and controlled environments optimizing plant growth and photosynthesis.

1.2 Communication Protocols Used In IoT-Based Smart Agriculture

1.2.1 Perception Layer Protocols

RFID (Radio-Frequency Identification): RFID technology assigns a unique identifying number to each object in the data it records. In agriculture IoT, RFID tags can be used to track and keep an eye on a range of assets such as products, livestock and agricultural equipment. RFID tags are available in a range of forms and sizes and passive tags are less costly than active tags. Important facts about the tagged objects such as temperature, humidity and moisture content may be revealed by these tags. RFID technology is particularly useful for environmental monitoring and real-time asset tracking [9].

Bluetooth: Bluetooth is a wireless communication technology that uses ultra-high frequency (UHF) radio transmissions to help in short-range communication. Many agricultural IoT equipment can communicate wirelessly[10]. Bluetooth uses the 2.4 GHz radio band to link devices up to 100 meters apart. Its low cost and power efficiency are its main advantages and it safeguards data transport utilizing encryption and authentication procedures [11].

Ultra-Wideband (UWB): Ultra-wideband is a wireless technology designed for close-quarters communication between devices. UWB enables precise distance measurements between transmitters since it runs at a wider frequency range of 3.1 to 10.6 GHz. Billions of radio pulses are sent over a broad frequency range to achieve this great level of precision. UWB can be used in IoT for agriculture applications that need precise positioning and location tracking like asset tracking and precision farming [12].

Infrared : A cheap and low-cost method for wirelessly transmitting little amounts of data is infrared communication. Thermometers and cameras that track temperature and environmental factors are examples of its use in agriculture and the Internet of Things. Remote controls and basic electronics frequently use infrared technology and protocols like NEC and RC5 are used to relay data. It works well for localized short-distance communication [13].

Network Layer Protocols For Agriculture IoT

LoRaWAN: LoRaWAN, a low-power, long-range wireless network that is perfect for Internet of Things applications is based on long-range chirp spread spectrum (CSS) modulation. It is utilized in a wide range of industries such as agriculture, smart cities, metering and logistics. LoRaWAN enables reliable and effective communication to address critical concerns such as disaster prevention, resource preservation and energy management [14].

Wi-Fi: The IEEE 802.11-based Wi-Fi standard operates across a broad frequency range from 2.2 GHz to 5 GHz. Wi-Fi can connect at a distance of 20 to 100 meters and has data transmission rates between 1 Mb/s and 7 Gb/s. Since Wi-Fi efficiently and securely connects remote monitoring and control devices it has become a common feature in IoT-based agriculture systems to link and monitor a range of assets such as weather stations, irrigation systems and farm machines [15].

Zigbee: Zigbee is a widely used standard for data transfer between agricultural equipment. Using the 2.4 GHz frequency spectrum, Zigbee has a longer communication range than Bluetooth. It is composed of processing gateways, network routers and end devices and has a mesh network architecture [16].

NB-IoT (Narrowband IoT): NB-IoT is a wireless communication technology that focuses on wide-area, low-power Internet of Things applications [17].

6LoWPAN: Low-power wireless mesh networks that give each node a unique IPv6 address are known as IPv6 over Low-Power Wireless Personal Area Networks or 6LoWPAN. This makes it possible to connect directly to the internet using open specified protocols. 6LoWPAN makes it possible for even the tiniest devices with the least amount of computing power to join the IoT ecosystem . IEEE 802.15.4-based networks send standard IPv6 packets using header compression and encapsulation. 6LoWPAN facilitates seamless sensor connectivity with middleware systems and network routers enabling agricultural sensors to connect to IP networks [18].

LTE-M (Long-Term Evolution for Machines): A wireless networking technique called LTEM was created especially for Internet of Things gadgets. Because it has a lower latency and a faster data throughput than NB-IoT, it is suitable for real-time data transfer applications [19]. On large farms and horticultural plantations, LTEM is used in agriculture IoT to monitor equipment, track animals and manage storage [20].

Sigfox: Sigfox is a low-power wide-area network solution that allows Internet of Things devices to communicate across large distances. It is appropriate for agricultural Internet of Things (IoT) applications that need efficient and affordable connectivity.

LTE Cat-M1: LTE Cat-M1, a low-power, wide-area wireless communication technology, increases the range and battery life of Internet of Things devices. It performs admirably for Internet of Things applications in

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agriculture that require dependable, long-range connectivity, such as soil monitoring, asset tracking and remote equipment management [21].

II. LITERATURE REVIEW

Jitendra Patidar et al [22] outlined the advantages of IoT-based farming over conventional farming by utilizing a variety of metrics and programming hardware. Palazzi et al [23] demonstrated an RFID-based temperature measuring system that is compatible with leaves. G. S.Nagaraja et al [24] said that the use of efficient fertilizers, new agricultural technologies and improved seed varieties had all contributed to an increase in crop yield. However, the agriculture sector will continue to lag behind if smarter technologies are not used. The conventional approach mostly relies on human intuition, which is subject to error. Nisar Ahmad et al [25] suggested that to increase the amount and quality of their agricultural output, farmers have been utilizing more equipment over time. With the use of the Internet, this study offers a multi-parameter observation system that will alert users and farmers. According to Pankaj Mohan Gupta et al. [26], many farming cultures, including Indians, continue to adopt traditional farming methods. They must contend with problems including crop-attacking insects, climate change, water scarcity, and rising food demand, which calls for higher yields. Rana Gill et al [27] suggested a low-cost IoT-based sensor node architecture for agriculture. The sensor node is constructed utilizing a Node MCU and four different sensors in order to monitor important parameters related to the soil and environment inside the greenhouse. Sudhir K. Routray et al [28] defined precision agriculture (PA) as the process of precisely engineering the needs and yields of plants. These days, PA uses a networked design with a high number of sensors to gather data on the productivity and unique demands of plants. R. Nageswara Rao et al [29] suggested a method for using IoT and automation to make farming smarter. Applications such as irrigation decision support, crop growth monitoring and selection and more are made possible by the Internet of Things (IoT). According to Kamlesh Kalbande et al. [30], India is combining IoT with advanced, ultralow-power technology to enable precision farming. It is essential to assist farmers in addressing issues such unorganized process automation, ineffective goods, a lack of resources that causes equipment damage, and so on. Sashant Suhag et al [31] suggested an Internet of Things infrastructure for monitoring plant diseases and soil nutrients. To collect the data in the form of pictures over various time periods, it makes use of a variety of sensors, including smart sensors. Sebastian Sadowski et al [32] one method of achieving smart farming is precision farming, which involves using cutting-edge technology and measuring tools to monitor crops and provide precise treatments as required. Yash Bhojwani et al [33] suggested that working does this by keeping an eye on environmental factors that affect crop development such as temperature and soil moisture and helping farmers choose the best crop for them based on the information they have collected and the conditions in their environment. N. Sneha et al [34] in order to improve agriculture, research focuses on expanding two studies that use data mining technologies including DBSCAN, PAM, CLARA, Chameleon and a regression technique.M. Suresh et al [35] suggested that the objective is to fully implement mechanization in the agricultural sector to manage electrical motors. It is a natural work because of the sparse dispersion of devices. It is quite challenging for farmers to operate and manage these devices in real time. Dr. Akey Sungheetha et al [36] were suggested that the system integrates image processing techniques to increase its accuracy. The rules have been established to increase the real detection rate.Carlos Kamienski et al [37] outlined the project's pilots, scenario-based development approach and sustainable wetlands adaptation and mitigation program (SWAMP) perspective.

III. METHODOLOGY

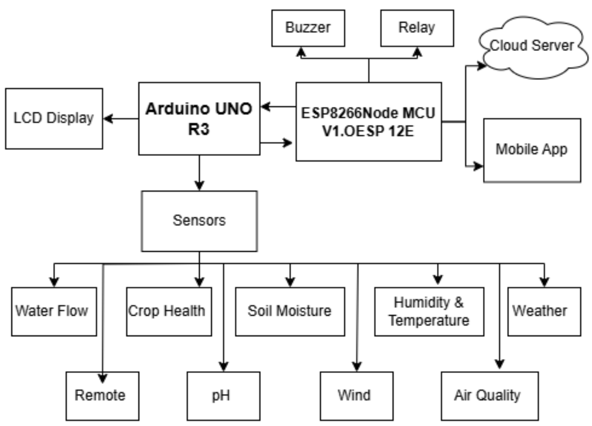

Figure 1: IoT-based agriculture monitoring and managing system using an Arduino UNO

IV. RESULT

The integration of IoT and AI-based sensors in agriculture has revolutionized the industry by enhancing efficiency, productivity and sustainability. Key outcomes include:

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1. **Yield and Increased Productivity:** IoT sensors monitor soil moisture, temperature and pH levels and enabling precise control of irrigation, fertilization and pest management. AI analyses this data to optimize farming practices, boost yields, and reduce waste.
2. **Cost Reduction and Resource Optimization:** IoT water sensors track soil moisture and environmental conditions in real time, while AI optimizes irrigation schedules to conserve water and lower costs. AI minimizes chemical use, cutting costs and reducing environmental impact. Automation through AI-driven drones and autonomous tractors reduces labour costs and improves energy efficiency by optimizing machinery operations.
3. **Livestock Management and Improved Crop:** AI-powered systems analyse drone and sensor data to detect early signs of diseases or pests, enabling timely interventions. Predictive analytics anticipate threats like pest outbreaks and extreme weather, helping farmers take preventive actions.
4. **Environmental Impact and Sustainability**: AI and IoT technologies promote sustainability by optimizing resources, reducing chemical usage, minimizing waste and lowering carbon footprints. Precision farming practices support healthier ecosystems and long-term agricultural viability.
5. **Forecasting and Remote Monitoring**: Farmers can monitor fields and equipment remotely via IoT-enabled devices, enabling quick decisions and predictive maintenance to reduce downtime. AI analyses data from weather patterns and historical yields to improve decision-making, crop rotation and market strategies.In summary, IoT and AI technologies enhance productivity, reduce costs, optimize resources, and support sustainability, ensuring agriculture adapts to future challenges efficiently.

V. CONCLUSION

In conclusion, a significant change in farming methods is being driven by the combination of Artificial Intelligence (AI) and Internet of Things (IoT)-based sensor technologies. Farmers can collect real-time data on vital environmental parameters like crop health, temperature and soil moisture. This data-driven strategy minimizes waste, maximizes resource use and enables precision farming. In addition to facilitating effective water management, IoT-enabled devices also track the health of livestock and offer insightful information about agricultural conditions all of which increase overall sustainability and production.
By analysing the vast amounts of data gathered by sensors and providing useful insights AI enhances IoT. AI can forecast weather patterns, improve irrigation schedules and predict crop diseases, assisting farmers in making proactive, well-informed decisions.

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