Design and Implementation of a Low-Cost GNSS-Based Precision Agricultural Monitoring System with Real-Time IoT Visualization

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Abstract: Precision agriculture provides an effective approach for improving agricultural productivity through spatially and temporally informed monitoring of soil, environmental, and crop conditions. However, many precision agriculture technologies remain relatively expensive and technically complex for small- and medium-scale farmers, particularly in developing countries. This paper presents a low-cost GNSS-based precision agricultural monitoring system integrating an ESP32, agricultural sensors, IoT communication, and real-time web visualization. The system acquires soil moisture, temperature, relative humidity, and GNSS data and transmits location-tagged measurements to a web server for remote monitoring. Experimental evaluation recorded 43.2 - 49.1% soil moisture, 28.7 - 29.5 °C temperature, and 66.7 - 69.1% relative humidity, with 10 - 12 GNSS satellites and HDOP values of 1.08 - 1.34. GNSS positioning produced mean errors of 1.28 - 1.82 m, while IoT communication achieved a 97.78% packet reception rate, with an average latency of 1.8s. The results demonstrate that the proposed low-cost system provides adequate positioning, reliable sensing, and near-real-time visualization for agricultural field monitoring, with potential applications in precision irrigation and location-based farm management.

Keywords: *Precision Agriculture, GNSS, GPS, Internet of Things, ESP32, Smart Farming, Soil Monitoring, Real-Time Visualization, Low-Cost Agricultural Monitoring.*

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I. INTRODUCTION

Agriculture is increasingly required to produce more food while operating under constraints associated with water availability, climate variability, soil degradation, rising production costs, and limited availability of agricultural labour. Conventional farming practices generally apply management decisions uniformly over an entire field even though soil properties, moisture conditions, crop requirements, and environmental conditions can vary considerably from one location to another. Precision agriculture addresses this limitation by using sensing, positioning, communication, and information technologies to support location-specific agricultural decisions [1], [2].

Global Navigation Satellite Systems (GNSS), including GPS, GLONASS, Galileo, and BeiDou, have become important technologies for precision agriculture because they provide geographic information that can be associated with field observations. GNSS is used in applications such as field mapping, machinery guidance, crop monitoring, variable-rate application, and agricultural navigation [3]. Recent research has demonstrated that relatively inexpensive multi-frequency and multi-GNSS receivers can provide useful positioning performance for agricultural applications, reducing the cost barrier associated with conventional high-end surveying equipment [4], [5].

At the same time, the Internet of Things (IoT) has enabled agricultural sensors to communicate measurement data to remote users and cloud platforms. IoT-based agriculture can continuously collect soil and environmental information and make the information available to farmers through mobile or web-based interfaces [6]–[9]. Recent studies have demonstrated IoT systems for precision irrigation, soil monitoring, agricultural weather monitoring, and remote farm management [7], [10].

Despite these advances, several challenges remain. High equipment costs, complicated installation, unreliable rural communication infrastructure, energy limitations, and inadequate technical support can restrict the adoption of digital agricultural technologies by small-scale farmers. These limitations are particularly important in developing agricultural regions where affordable and easily maintainable systems are required. An IoT sensing platform developed for rural Africa, for example, emphasized the need for viable,

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seamless, and affordable sensing technologies suitable for small-scale farming environments [6].

Another limitation of many low-cost agricultural monitoring systems is the absence of spatial context. A soil-moisture measurement without an accurate geographic reference provides information about a sensor location but does not directly support spatial field analysis. Integrating GNSS with IoT sensors addresses this limitation by attaching latitude, longitude, and time information to every measurement. The resulting data can be displayed geographically and used to construct field maps and identify spatial variations.

This research therefore proposes a low-cost GNSS-based precision agricultural monitoring system with real-time IoT visualization. The proposed system integrates a low-cost GNSS receiver, ESP32 microcontroller, agricultural sensors, wireless Internet connectivity, database storage, and a web-based dashboard. The main objectives are to design a low-cost agricultural monitoring node capable of acquiring environmental and soil parameters, integrate GNSS positioning with agricultural sensor measurements, develop an IoT communication architecture for real-time transmission of field measurements, develop a web-based visualization platform for monitoring agricultural parameters and geographic location, and evaluate the positioning, sensing, communication, visualization, and overall operational performance of the developed prototype.

The principal contribution of the work is the integration of low-cost GNSS positioning and IoT agricultural sensing into a single affordable monitoring platform. Unlike systems focused only on environmental sensing or only on agricultural navigation, the proposed system provides location-tagged agricultural observations that can be visualized remotely.

II. LITERATURE REVIEW

➢ *Precision Agriculture and Digital Farming*

Precision agriculture uses information technology to manage agricultural variability. The technology generally combines sensing systems, positioning systems, communication networks, geographic information systems, and decision-support tools. Recent reviews identify smart sensors and IoT as important components of modern precision agriculture because they allow continuous acquisition of soil, environmental, and crop-related information [1], [2].

IoT-based agriculture has developed rapidly because distributed sensor nodes can collect measurements and transfer them to centralized or cloud-based platforms. Shahab *et al.* reviewed IoT-based agriculture management approaches and identified wireless communication, sensing, automation, and data processing as major components of smart agricultural systems [7]. Similarly, Dhanasekar discussed the role of IoT technologies, communication protocols, and sensing systems in precision agriculture [8].

➢ *GNSS in Precision Agriculture*

GNSS provides the spatial reference required to associate agricultural observations with geographic locations. GNSS-based positioning can support field boundary mapping, machinery guidance, soil sampling, crop monitoring, and variable-rate agricultural operations.

A recent review specifically examining GNSS applications in precision agriculture identified field mapping, machinery guidance, and variable-rate technology as important application areas [3]. The review also highlighted developments involving GPS, GLONASS, Galileo, and BeiDou.

The cost of GNSS receivers has historically limited their adoption in some agricultural applications. However, research has demonstrated that low-cost multi-frequency and multi-GNSS receivers can provide useful positioning accuracy. Nguyen and Cho evaluated a low-cost multi-frequency multi-GNSS device and reported centimeter-level positioning performance under appropriate RTK conditions during agricultural testing [4]. Carvalho *et al.* also investigated relative positioning using low-cost GNSS receivers on agricultural rovers [11].

Low-cost GNSS positioning is therefore increasingly feasible for agricultural monitoring systems, especially where sub-centimeter positioning is not required. For environmental monitoring, field condition mapping, and location-tagged soil measurements, meter-level or decimeter-level accuracy may be sufficient depending on the application.

➢ *IoT-Based Agricultural Monitoring*

IoT sensing platforms provide a means of collecting agricultural information continuously. Oliveira-Jr *et al.* developed an IoT sensing platform for digital farming in rural Africa and demonstrated monitoring of soil and environmental parameters including soil moisture, pH, temperature, and light [6].

Gaikwad *et al.* developed an IoT-based precision farming system capable of monitoring soil and atmospheric parameters and providing field information through a smartphone application [9]. These studies demonstrate the potential of low-cost sensing and communication technologies for agricultural monitoring.

Communication technology is an important consideration because agricultural fields may be located far from conventional Internet infrastructure. LoRa and LoRaWAN have consequently received considerable attention because of their long communication range and relatively low power consumption. Rivera Guzmán *et al.* developed a LoRa-based agricultural monitoring system for Andean areas, demonstrating the applicability of long-range communication for agricultural monitoring [12]. Similarly, Zhang *et al.* developed a LoRaWAN-based IoT system for precision irrigation and demonstrated the feasibility of continuous soil-moisture monitoring and remote irrigation management [10].

➢ *Smart Sensors for Agricultural Monitoring*

Agricultural monitoring systems require sensors capable of measuring soil and environmental conditions. Typical parameters include soil moisture, soil temperature, ambient temperature, relative humidity, electrical conductivity, pH, light intensity, and nutrient concentration.

Soussi *et al.* reviewed smart sensors and smart data technologies for precision agriculture and emphasized their role in resource optimization, crop management, and sustainable agriculture [1]. Bristow *et al.* demonstrated a LoRaWAN agricultural node incorporating ion-selective electrodes for soil nitrate measurement, illustrating how low-power wireless nodes can be expanded to support soil nutrient monitoring [13].

For a low-cost prototype, sensor selection should be based not only on accuracy but also on availability, power consumption, calibration requirements, environmental protection, and replacement cost.

Existing studies have demonstrated either IoT-based agricultural sensing or GNSS-based agricultural positioning. However, there remains a practical need for integrated, low-cost systems that combine geographic positioning, soil and environmental sensing, real-time Internet connectivity, database storage, geographic visualization, and simple web interface suitable for small and medium-scale agricultural operations.

The proposed system addresses this gap by combining these functions within a modular ESP32-based architecture. The design emphasizes affordability and practical deployment rather than high-cost autonomous agricultural machinery.

III. MATERIALS AND METHODS

➢ *System Architecture*

The proposed system comprises five main layers: sensing, GNSS positioning, embedded processing, IoT communication/server, and visualization layers. The sensing layer acquires soil-moisture, temperature, humidity, and other optional agricultural parameters. The GNSS layer provides the latitude, longitude, time, and positioning-quality information required to geographically tag each measurement.

The ESP32 serves as the central controller, acquiring and processing the sensor and GNSS data before transmitting the combined data through Wi-Fi or other IoT communication technologies. At the server, the received measurements are stored in a MySQL database for real-time and historical analysis. A web-based dashboard provides graphical and geographic visualization of the agricultural parameters and monitoring-node location. The overall data flow is shown in Figure 1.

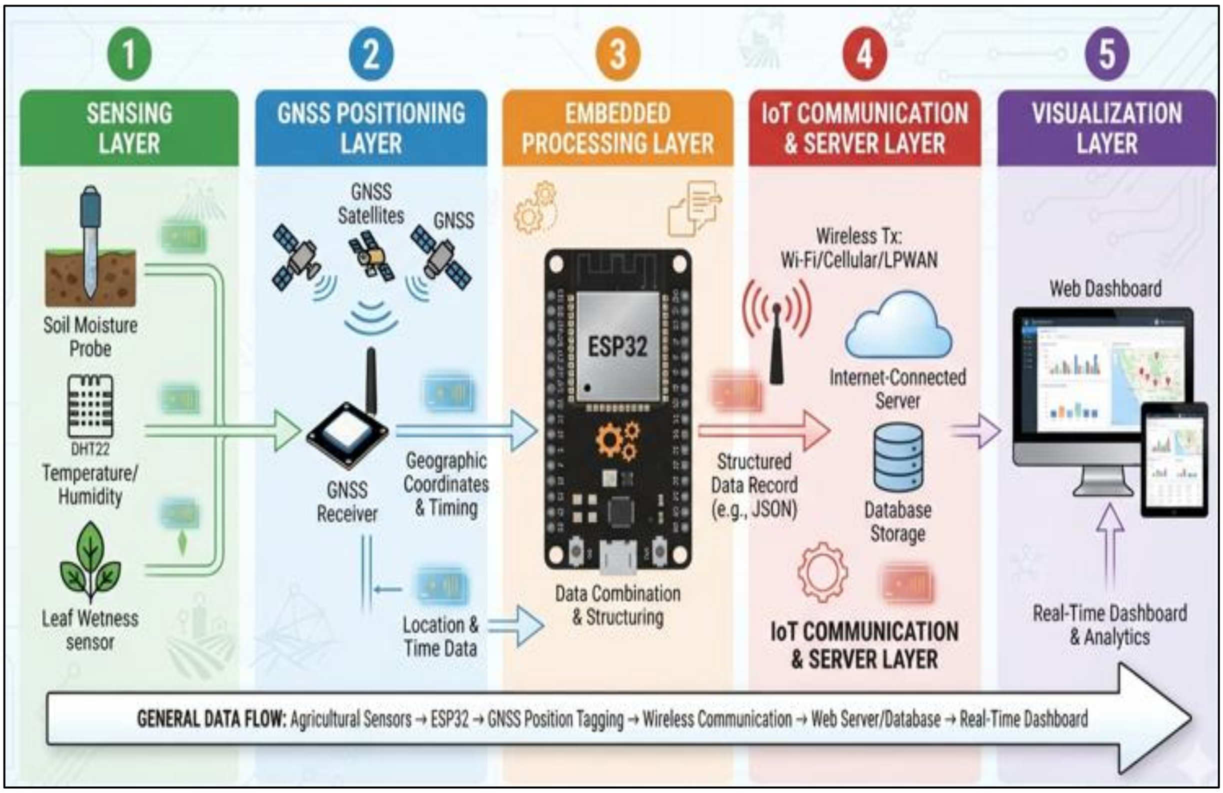

Fig 1 System Architecture and Sequential data Flow of the IoT-Based Precision Agriculture System.

➢ *Hardware Components*

The prototype consists of an ESP32 development board, low-cost Neo-6 GPS receiver, capacitive soil-moisture sensor, BME280 environmental sensor, and regulated power supply. The selected components are summarized in Table 1.

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Table 1 Critical Hardware Components

Component	Function
ESP32 development board	Sensor acquisition, processing and Internet communication
Low-cost Neo-6 GPS receiver	Latitude, longitude, altitude and time acquisition
Capacitive soil-moisture sensor	Soil moisture measurement
BME280	Temperature and relative humidity
Light sensor	Solar/ambient light measurement
MicroSD module	Local data backup
5 V/3.3 V regulated supply	Power management
Solar panel and battery	Optional field power supply
IP-rated enclosure	Environmental protection

The ESP32 was selected because it combines a microcontroller, digital interfaces, analog inputs, and wireless connectivity within a low-cost platform. ESP32-based IoT devices have also been investigated for environmental and agricultural applications [14].

➢ *GNSS Subsystem*

A low-cost GNSS receiver is interfaced with the ESP32 through UART to acquire NMEA positioning data. The system extracts latitude, longitude, altitude, UTC time, satellite count, fix status, and HDOP. These parameters are combined with the agricultural sensor measurements to provide location-tagged field observations. The GNSS data record is represented as:

$$G_i = (\emptyset_i, \gamma_i, h_i, t_i, N_i, D_i) \quad (1)$$

Where: ϕ_i and λ_i are latitude and longitude, h_i is altitude, t_i is UTC time, N_i is the number of satellites, and D_i is the HDOP value.

The geographic coordinates are associated with the agricultural sensor measurements to generate location-tagged observations.

➢ *Agricultural Sensor Subsystem*

A capacitive soil-moisture sensor is used as the primary soil-condition sensor. The sensor output is calibrated using dry and wet reference conditions and converted to a normalized soil-moisture percentage as:

$$M = \frac{V_{dry} - V_{measured}}{V_{dry} - V_{wet}} \, x\, 100\% \quad (2)$$

Where: V_{dry} is the sensor output under dry-soil conditions, V_{wet} is the output under wet-soil conditions, and $V_{measured}$ is the measured sensor output. The DHT22 sensor simultaneously provides ambient temperature and relative-humidity measurements.

➢ *Data Acquisition Algorithm*

The ESP32 follows a continuous sequence for sensor acquisition, GNSS positioning, data processing, and transmission. As shown in Figure 2, the process begins with system initialization and proceeds through sensor and GNSS data acquisition, GNSS fix verification, data integration, packet generation, and server transmission. If transmission fails, the data are temporarily stored locally before the measurement cycle is repeated.

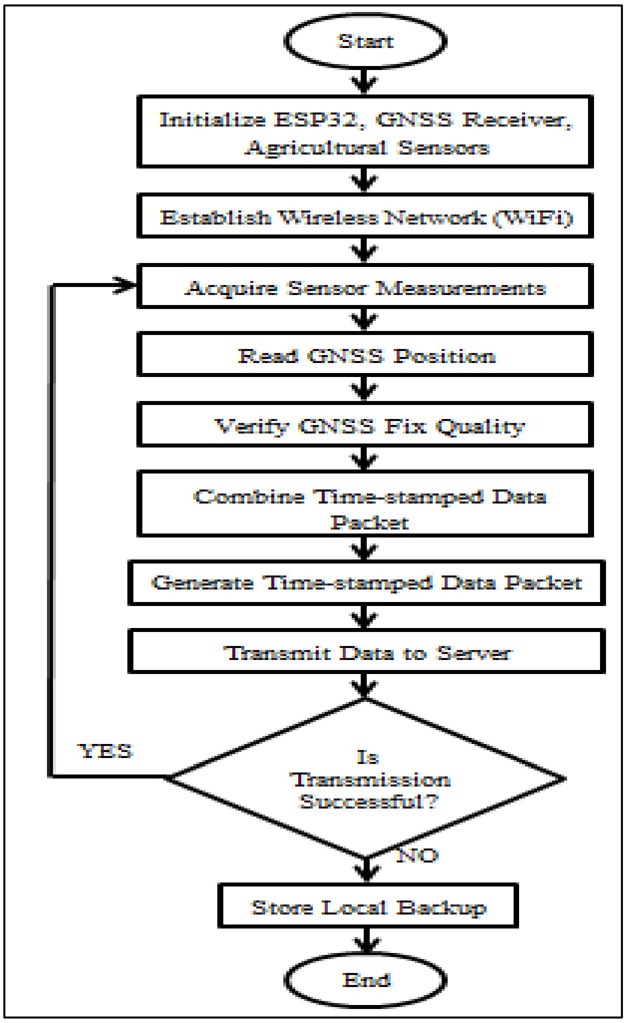

Fig 2 Flowchart of the Proposed Agricultural Monitoring System.

➢ *IoT Communication*

Wi-Fi is used as the primary communication interface during prototype testing. The ESP32 transmits the location-tagged sensor data to a PHP-based web server through HTTP requests. The server validates the received data and stores the records in a MySQL database for real-time and historical monitoring. For remote agricultural deployments, the communication layer can be extended to GSM/4G, NB-IoT, or LoRaWAN.

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- *Real-Time Web Visualization*

The IoT platform uses PHP, MySQL, JavaScript, HTML/CSS, and an interactive digital map for real-time visualization. The dashboard displays the current GNSS position, soil moisture, temperature, relative humidity, satellite count, HDOP, timestamp, and historical sensor trends. Each measurement is geographically represented as:

$$P_i = (\lambda_i, \phi_i) \tag{3}$$

Where: λ_i and ϕ_i denote the longitude and latitude of the i^{th} measurement, respectively.

- *GNSS Accuracy Evaluation*

GNSS accuracy is evaluated by comparing the measured position with a known reference position. The horizontal distance error is calculated using the Haversine equation:

$$d = 2R \sin^{-1}\left[\sqrt{\sin^2\left(\frac{\Delta\emptyset}{2}\right) + \cos(\emptyset_1)\cos(\emptyset_2)\sin^2\left(\frac{\Delta\lambda}{2}\right)}\right] \tag{4}$$

Where: R is the Earth's mean radius, and $\Delta\phi$ and $\Delta\lambda$ are the differences in latitude and longitude. The mean positioning error is obtained from

$$E_{mean} = \frac{1}{n}\sum_{i=1}^{n}|d_i| \tag{5}$$

Where: d_i is the positioning error for measurement i.

- *Communication Performance*

Communication performance is evaluated using the packet reception rate (PR) and average latency. Packet reception rate is calculated as:

$$PR = \frac{N_r}{N_t}\, x\, 100 \tag{6}$$

Where: N_r is the number of successfully received packets and N_t is the total number of transmitted packets. Average communication latency is calculated as:

$$L_{avg} = \frac{1}{n}\sum_{i=1}^{n}\left(t_{server,i} - t_{sensor,i}\right) \tag{7}$$

Where: $t_{sensor,i}$ and $t_{server,i}$ represent the transmission and server-reception times, respectively.

IV. RESULTS AND DISCUSSIONS

- *Prototype Implementation*

The developed prototype successfully integrates the ESP32, low-cost GNSS receiver, soil-moisture sensor, DHT22 environmental sensor, wireless communication interface, and web-based monitoring platform. The ESP32 periodically acquires sensor and GNSS data, combines the measurements with geographic and timestamp information, and transmits the resulting data to the server.

The implemented system provides location-tagged agricultural measurements, enabling each sensor observation to be associated with its corresponding field position. This integration supports both real-time monitoring and subsequent spatial analysis of agricultural conditions.

- *Sensor Monitoring Performance*

Table 2 presents the agricultural sensor and GNSS measurements obtained during prototype testing.

Table 2 Agricultural Monitoring Results

Sample	**Soil Moisture (%)**	**Temperature (°C)**	**RH (%)**	**Satellites**	**HDOP**
1	43.2	28.7	69.1	10	1.34
2	45.6	29.0	68.4	11	1.21
3	47.8	29.3	67.8	11	1.18
4	49.1	29.5	66.7	12	1.08
5	46.8	29.4	67.2	11	1.21
6	44.7	29.1	68.0	10	1.31

The results demonstrate successful simultaneous acquisition of soil and environmental parameters. Soil moisture varied between 43.2% and 49.1%, while temperature ranged from 28.7 to 29.5 °C. The GNSS receiver maintained 10–12 satellites, with HDOP values between 1.08 and 1.34, indicating satisfactory positioning conditions during the test. The combination of sensor measurements and GNSS coordinates enables location-based assessment of field conditions.

- *GNSS Positioning Performance*

Table 3 presents the positioning performance obtained during static testing.

Table 3 GNSS Positioning Performance

Test	**Mean Error (m)**	**Maximum Error (m)**	**Satellites**
1	1.82	3.21	9
2	1.54	2.86	10
3	1.37	2.43	11

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4	1.28	2.21	12
5	1.46	2.67	11

The mean positioning error ranged from 1.28 to 1.82 m, with maximum errors between 2.21 and 3.21 m. The results demonstrate that the low-cost GNSS receiver provides meter-level positioning suitable for field monitoring, location tagging, and agricultural condition mapping. However, applications requiring centimetre-level accuracy would require an RTK-GNSS receiver and correction service [4], [5], [11].

➢ *IoT Communication Performance*

Table 4 summarizes the communication performance of the prototype.

Table 4 IoT Communication Performance

Parameter	Result
Measurement interval	10 s
Test duration	60 min
Total packets	360
Successfully received	352
Packet reception rate	97.78%
Average latency	1.8 s
Maximum latency	4.7 s

The system achieved a 97.78% packet reception rate with an average latency of 1.8s, demonstrating reliable near-real-time data transmission under the test network conditions. Communication performance may vary with network coverage, terrain, vegetation, and network congestion. For remote agricultural locations, LoRaWAN or cellular communication can provide alternative connectivity options [10], [12], [13].

➢ *Real-Time Web Visualization*

The developed web dashboard successfully presents the acquired agricultural and GNSS data in real time. The interface provides current sensor values, GNSS position, satellite count, HDOP, timestamps, and historical sensor trends. The geographic display associates each measurement with its corresponding field location, enabling spatial interpretation of soil and environmental conditions. This location-aware visualization provides a practical basis for precision monitoring and future multi-node field mapping.

➢ *Comparison with Existing Approaches*

The proposed system integrates GNSS positioning, agricultural sensing, IoT communication, and real-time web visualization within a single low-cost platform. Unlike conventional sensor-based systems that provide measurements without spatial information, the proposed approach associates each measurement with its geographic location. The use of an ESP32 and low-cost GNSS receiver also reduces hardware complexity and cost while maintaining adequate positioning performance for field monitoring [4]–[6], [9].

Furthermore, the web-based platform provides remote access to both real-time and historical agricultural data. This integrated architecture demonstrates the feasibility of developing an affordable, location-aware monitoring system suitable for small-scale and precision agricultural applications.

V. CONCLUSIONS

This paper presented the design and implementation of a low-cost GNSS-based precision agricultural monitoring system with IoT connectivity and real-time web visualization. The system integrates an ESP32, GNSS receiver, soil-moisture and environmental sensors to acquire and transmit location-tagged agricultural data to a remote database and web dashboard.

The results demonstrate the feasibility of combining low-cost GNSS positioning with IoT sensing for real-time agricultural monitoring. The system provides meter-level positioning, reliable sensor acquisition, and near-real-time data visualization, making it suitable for soil-condition monitoring, field mapping, and precision irrigation support.

The proposed modular architecture can be further enhanced with RTK-GNSS, LoRaWAN, solar power, additional agricultural sensors, and multiple monitoring nodes. Extended field testing under different environmental and network conditions is recommended to further evaluate long-term accuracy, reliability, and energy performance.

REFERENCES

[1]. A. Soussi, E. Zero, R. Sacile, D. Trinchero, and M. Fossa, “Smart sensors and smart data for precision agriculture: A review,” *Sensors*, vol. 24, no. 8, Art. no. 2647, 2024, doi: 10.3390/s24082647.

[2]. S. Dhanasekar, “A comprehensive review on current issues and advancements of Internet of Things in precision agriculture,” *Computer Science Review*, 2024, Art. no. 100694, doi: 10.1016/j.cosrev.2024.100694.

[3]. M. K. K. et al., “Global Navigation Satellite Systems as state-of-the-art solutions in precision agriculture: A review of studies indexed in the Web of Science,” *Agriculture*, vol. 13, no. 7, Art. no. 1417, 2023, doi: 10.3390/agriculture13071417.

[4]. N. V. Nguyen and W. Cho, "Performance evaluation of a typical low-cost multi-frequency multi-GNSS device for positioning and navigation in agriculture—Part 2: Dynamic testing," *AgriEngineering*, vol. 5, no. 1, pp. 127–140, 2023, doi: 10.3390/agriengineering5010008.
[5]. N. V. Nguyen and W. Cho, "Performance evaluation of a typical low-cost multi-frequency multi-GNSS device for positioning and navigation in agriculture—Part 1: Static testing," *Smart Agricultural Technology*, vol. 1, Art. no. 100004, 2021, doi: 10.1016/j.atech.2021.100004.
[6]. A. Oliveira-Jr., C. Resende, A. Pereira, P. Madureira, J. Gonçalves, R. Moutinho, and F. Soares, "IoT sensing platform as a driver for digital farming in rural Africa," *Sensors*, vol. 20, no. 12, Art. no. 3511, 2020, doi: 10.3390/s20123511.
[7]. H. Shahab, M. Iqbal, A. Sohaib, F. U. Khan, and M. Waqas, "IoT-based agriculture management techniques for sustainable farming: A comprehensive review," *Computers and Electronics in Agriculture*, vol. 220, Art. no. 108851, 2024, doi: 10.1016/j.compag.2024.108851.
[8]. S. Dhanasekar, "A comprehensive review on current issues and advancements of Internet of Things in precision agriculture," *Computer Science Review*, vol. 52, Art. no. 100694, 2024, doi: 10.1016/j.cosrev.2024.100694.
[9]. S. V. Gaikwad, A. D. Vibhute, K. V. Kale, and S. C. Mehrotra, "An innovative IoT based system for precision farming," *Computers and Electronics in Agriculture*, vol. 187, Art. no. 106291, 2021, doi: 10.1016/j.compag.2021.106291.
[10]. H. Zhang, L. He, F. Di Gioia, D. Choi, A. Elia, and P. Heinemann, "LoRaWAN based internet of things (IoT) system for precision irrigation in plasticulture fresh-market tomato," *Smart Agricultural Technology*, vol. 2, Art. no. 100053, 2022, doi: 10.1016/j.atech.2022.100053.
[11]. G. S. Carvalho, F. O. Silva, and M. V. O. Pacheco, "Performance analysis of relative GPS positioning for low-cost receiver-equipped agricultural rovers," *Sensors*, vol. 23, no. 21, Art. no. 8835, 2023, doi: 10.3390/s23218835.
[12]. E. F. Rivera Guzmán, E. D. Mañay Chochos, M. D. Chiliquinga Malliquinga, P. F. Baldeón Egas, and R. M. Toasa Guachi, "LoRa network-based system for monitoring the agricultural sector in Andean areas: Case study Ecuador," *Sensors*, vol. 22, no. 18, Art. no. 6743, 2022, doi: 10.3390/s22186743.
[13]. N. Bristow, S. Rengaraj, D. R. Chadwick, J. Kettle, and D. L. Jones, "Development of a LoRaWAN IoT node with ion-selective electrode soil nitrate sensors for precision agriculture," *Sensors*, vol. 22, no. 23, Art. no. 9100, 2022, doi: 10.3390/s22239100.
[14]. M. J. K. et al., "Design and implementation of ESP32-based IoT devices," *Sensors*, vol. 23, no. 15, Art. no. 6739, 2023, doi: 10.3390/s23156739.
[15]. N. Wielgocka, T. Hadas, A. Kaczmarek, and G. Marut, "Feasibility of using low-cost dual-frequency GNSS receivers for land surveying," *Sensors*, vol. 21, no. 6, Art. no. 1956, 2021, doi: 10.3390/s21061956.
[16]. D. Janos and P. Kuras, "Evaluation of low-cost GNSS receiver under demanding conditions in RTK network mode," *Sensors*, vol. 21, no. 16, Art. no. 5552, 2021, doi: 10.3390/s21165552.
[17]. E. Reitbauer and C. Schmied, "Bridging GNSS outages with IMU and odometry: A case study for agricultural vehicles," *Sensors*, vol. 21, no. 13, Art. no. 4467, 2021, doi: 10.3390/s21134467.
[18]. V. Hamza, B. Stopar, O. Sterle, and P. Pavlovčič-Prešeren, "Observations and positioning quality of low-cost GNSS receivers: A review," *GPS Solutions*, vol. 28, Art. no. 149, 2024, doi: 10.1007/s10291-024-01686-8.