Real-Time Monitoring and Positioning of Agricultural Tractors Using a Low-Cost GPS and IoT Device

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Abstract
This research aims to develop a low-cost GPS receiver device for positioning agricultural tractors, incorporating Differential GPS (DGPS) technology for enhanced accuracy using the Open-Source GIS Stack (OSGS). Integrated with Internet of Things (IoT) technology, the device was tested to receive GPS data and other relevant information, including geographic coordinates (latitude and longitude), tractor speed, tractor direction, date, time, and the number of satellites receiving signals. The DGPS setup involves using one receiver as a base station and another on the tractor, where the base station provides correction data to improve positioning accuracy. The data collected by the receiver is transmitted to a signal processing device for mapping the coordinates, creating a route of the tractor's movement that is displayed on a real-time Web Map Application. This process includes error correction to ensure high accuracy. The IoT device was installed on the left rear wheel of the agricultural tractor. Test results show that the data from the developed device has an accuracy of around 30-90 centimeters, which is acceptable and sufficient for agricultural tractor positioning applications. Furthermore, this system enables real-time monitoring of the tractor's operations.

Keywords: Differential GPS, GPS Receiver, IoT Technology, Positioning Accuracy, Real-Time Monitoring

1. Introduction

The evolution of precision agriculture has transformed traditional farming, offering the potential for heightened efficiency, reduced environmental impact, and improved crop yields [1] and [2]. Central to this shift is the integration of advanced technologies, including Remote Sensing (RS), Geographic Information Systems (GIS), and Global Navigation Satellite Systems (GNSS) [3] and [4]. Accurate positioning and real-time monitoring of agricultural machinery, particularly tractors, have emerged as crucial elements for optimizing productivity and resource management in modern farming practices [5] and [6]. GNSS plays a pivotal role in precision agriculture by supporting applications such as automated guidance, variable rate technology, and field mapping.

The system relies on three primary components: satellite constellations, ground monitoring stations, and user-end receivers. Its ability to provide all-weather, omnidirectional, and high-precision positioning makes GNSS indispensable for a wide range of agricultural activities [7]. The implementation of high-precision GNSS systems, such as real-time kinematic (RTK) GNSS, remains cost-prohibitive for many farmers. These systems, capable of delivering horizontal accuracy up to 2 centimeters and vertical accuracy up to 4 centimeters, are often out of reach for small-scale operations, especially in developing regions [8]. The financial burden associated with such systems has hindered the broader adoption of precision agriculture technologies.

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Recent technological advancements have introduced more affordable GNSS solutions, creating new opportunities for their application in agriculture. Low-cost GPS modules, when combined with open-source correction libraries and inexpensive computing platforms, offer a promising alternative [9]. These innovations democratize access to precision agriculture, making high-accuracy GPS solutions more attainable for small and medium-scale farmers. Furthermore, integrating Internet of Things (IoT) technology with GPS systems enables real-time data collection and monitoring [10]. IoT devices can transmit comprehensive data sets, including geographic coordinates, speed, direction, and environmental factors, providing farmers with valuable, real-time insights to inform their operations [6] and [11].

This research aims to develop a low-cost GPS receiver device for positioning agricultural tractors, incorporating Differential GPS (DGPS) technology to enhance accuracy using the Open-Source GIS Stack (OSGS). A set of open-source geospatial tools and frameworks that can be used to create unique geographic information system (GIS) applications is known as the Open-Source GIS Stack (OSGS). Since most of these tools are free to use, alter, and distribute, anyone can do so without having to pay high license costs. Some essential elements frequently seen in the OSGS such a QGIS, GRASS GIS, GDAL/OGR, PostGIS, GeoServer, Leaflet or OpenLayers.

The system integrates with IoT technology to provide real-time monitoring and data transmission capabilities for tractor operations. The DGPS setup, which involves a base station and a mobile receiver on the tractor, employs differential correction to improve the precision of the tractor's positioning [9]. By offering an affordable and accurate positioning solution, this research seeks to lower the financial barriers that limit access to precision agriculture technologies. The ultimate goal is to make these technologies more accessible to a broader range of farmers, promoting sustainable and efficient agricultural practices worldwide [12]. The following sections will describe the materials and methods used to develop the system, present the field test results, and discuss the broader implications of this technology for modern agriculture.

2. Materials and Methods

This study focused on developing and testing a low-cost GPS receiver device integrated with IoT technology for real-time monitoring and positioning of agricultural tractors. The research methodology encompassed hardware selection, system integration, and field testing.

2.1 GPS Receiver and IoT Device

The core component of our system, the ITEAD GPS Shield, is designed for Arduino platforms and enables the integration of GPS functionality to track geographical location data such as latitude, longitude, and time. This functionality is significantly enhanced by the u-blox GNSS Multiband Antenna ANN-MB-00, a high-quality, multiband GNSS antenna known for its superior sensitivity and robust signal reception across various GNSS bands (Figure 1b). This module can track signals from multiple global positioning systems, including BeiDou, Galileo, GLONASS, and GPS, allowing for improved accuracy and reliability [13]. Central to our setup is the Arduino WeMos D1 equipped with an ESP8266 Wi-Fi module (Figure 1a), which serves as the primary controller. The WeMos D1 processes the GPS data received from the shield (Figure 1c) and leverages its Wi-Fi capabilities to transmit this information over the internet to the database server for real-time tracking and remote data monitoring (Figure 1d).

This integration of the GPS shield with a high-performance antenna and a powerful Wi-Fi-enabled controller allows our system to offer precise location tracking alongside efficient data communication, making it ideal for applications requiring real-time geographical data acquisition and IoT implementations [14].

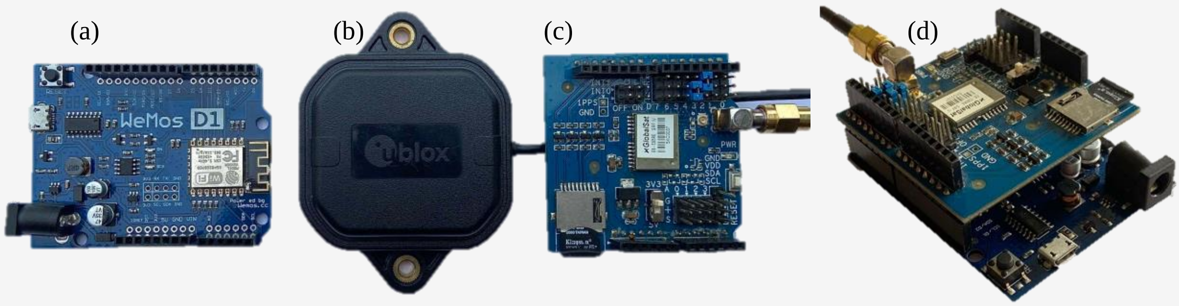

Figure 1: Overview of the IoT components used in the system. (a) WeMos D1 board controller, (b) the u-blox GNSS multiband antenna ANN-MB-00, (c) the ITEAD GPS shield, (d) the connected of GPS shield and WeMos D1

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The data transmission is managed using the MQTT protocol, which sends data from the IoT device to an MQTT broker. From there, NodeRED is employed to manipulate the data received from the MQTT broker and forward it to the database. This setup ensures efficient, real-time data flow and processing. The TinyGPS++ library plays a crucial role by interfacing seamlessly with the ITEAD GPS Shield and u-blox antenna. It decodes the NMEA sentences transmitted by the GNSS module into usable location data. The WeMos D1 can effectively handle data transactions with TinyGPS++, guaranteeing timely and accurate location data, which improves the dependability of IoT and geographic data collection systems. This configuration is particularly valuable for applications like asset tracking, navigation, and automatic geographic data logging where accurate and up-to-date data is essential (Figure 1).

2.2 Implementation of the Differential GPS (DGPS)

We implemented a DGPS setup to enhance positioning accuracy. DGPS is an enhancement to the conventional GPS that provides improved location accuracy. DGPS uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the GPS satellites' signals and the known fixed positions [15]. These stations broadcast the difference between the measured satellite pseudoranges and actual (internally computed) pseudoranges, and receiver stations utilize these differences to correct their own satellite measurements. The DGPS system operates on the principle of error correction, as described by equations 1 and 2:

$$\Delta R = R_{true} - R_{GPS} \qquad \text{Equation 1}$$

$$R_{corrected} = R_{GPS} + \Delta R \qquad \text{Equation 2}$$

Where:

ΔR = The differential correction

R_{true} = The true or known position of the DGPS based station (Reference station)

R_{GPS} = The position calculated by the GPS receiver

$R_{corrected}$ = The corrected position after applying the DGPS correction

Figure 2 depicts a GPS-based tracking system in which a base station and a GPS rover (vehicle) gather geographic location data (latitude, longitude, and time). These data are communicated to Node-RED over MQTT, a lightweight IoT messaging protocol, and then processed and stored as spatial data in PostgreSQL/PostGIS. The position correction method compares and recalculates the latitude and longitude of both the Rover and the Base record by record. The method refines the rover's data based on the known base station's position, increasing location accuracy. The revised location data is then shown in real time on a web map application, allowing for exact tracking and navigation of the vehicle. This integration of GPS technology, IoT protocols, data processing, and real-time web mapping exemplifies a robust system for advanced location tracking applications.

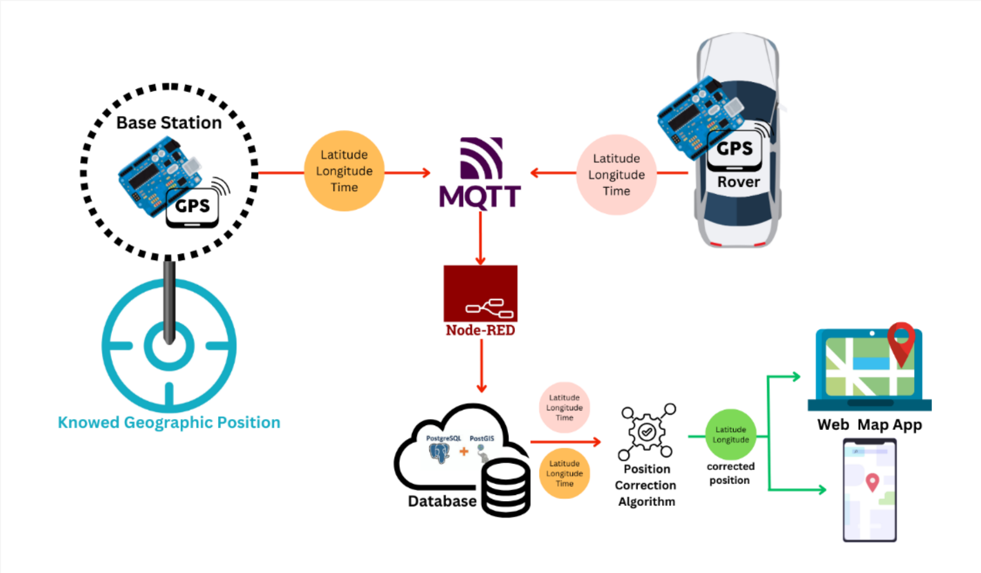

Figure 2: The process framework

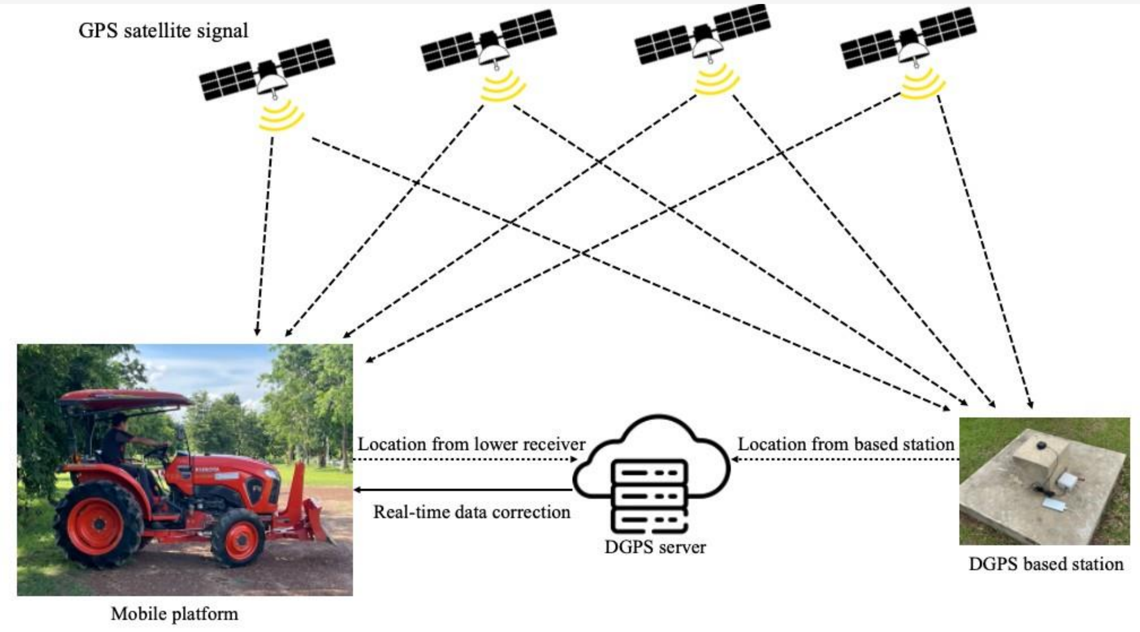

Figure 3: The differential GPS (DGPS) system operation

The base station calculates the difference between its known position and the GPS-calculated position, then transmits this correction to the mobile unit on the tractor. Figure 3 illustrates the operation of the DGPS system of this work. The DGPS system operates by placing a reference station at a known fixed coordinate location, where it receives GPS satellite signals and calculates its position. By comparing its known exact location with the calculated GPS data, the station identifies discrepancies and computes corrections for timing, satellite positions, or atmospheric delays [16]. These corrections are transmitted to a DGPS server and then broadcasted in real-time to DGPS receivers on the tractors. As the tractor's DGPS receiver receives both GPS signals and these corrections, it applies them to significantly enhance the positional accuracy of the data it collects.

3. Results and Discussion

3.1 Experimental Testing

The Figure 4 demonstrates the results of an experimental test conducted to evaluate the performance of a DGPS (Differential GPS) system compared to a standard GPS system. The test involved tracking the same path around a stadium using both GPS technologies to highlight the differences in accuracy and precision between the two systems. In the image, the white stars represent the tracking points obtained from a standard u-blox GPS module, which show a noticeable deviation from the desired path, illustrating typical inaccuracies associated with standalone GPS systems. In contrast, the green circles represent the DGPS tracking points, which adhere closely to the actual path, demonstrating the significantly enhanced accuracy achieved by applying DGPS corrections to the GPS data. This test clearly shows that the DGPS system provides a more reliable and precise set of location data, crucial for applications requiring high precision, such as in precision agriculture or detailed geographic surveys.

During the testing of the DGPS system, the average number of satellites connected was approximately [17]. The positional accuracy of the system showed significant variation between standard GPS and DGPS tracking. The average deviation of each point from the planned path for the standard GPS was about 30 to 200 centimeters, illustrating a broader range of error typical of standalone GPS systems. In contrast, the DGPS system exhibited a much tighter deviation range of approximately 10 to 80 centimeters from the planned path, underscoring the enhanced accuracy provided by DGPS corrections in reducing positional errors. This demonstrates the clear advantage of using DGPS in applications where precision is critical, such as detailed geographic mapping or precision farming, where even small deviations can have significant impacts on the outcomes.

Figure 4: GPS and DGPS tracking

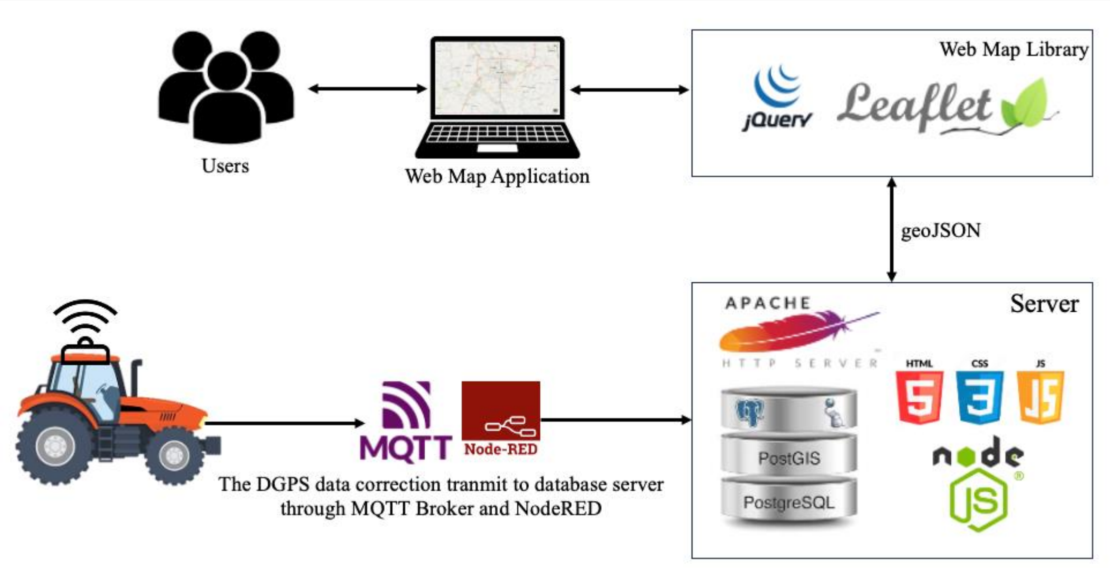

Figure 5: Web map architecture

3.2 Real-time Monitoring System Based on Web GIS

Figure 5 illustrates how we created a web map application to dynamically display and interact with the geographic data gathered from agricultural tractors outfitted with DGPS and Internet of Things technologies. We did this by utilizing Leaflet, a well-known open-source JavaScript package. The application integrates seamlessly with the server-side infrastructure hosted on an Apache HTTP Server, where the geographic data is managed by a PostGIS/PostgreSQL database. This setup allows us to leverage the extensive GIS capabilities of PostGIS along with the flexibility and ease of use provided by Leaflet for real-time data visualization [17] [18] and [19]. We improved the user experience by enabling users to view the positions of tractors in the past and present on interactive maps using Leaflet.

Spatial data was transferred from our PostGIS database to the Leaflet application that users ran on their browsers using the geoJSON format. The location, movements, and other operational data of the tractor are given a real-time geographical context through the rendering of this geoJSON as graphical elements on the map. This works, Node-RED for data flow management, MQTT for messaging, and Node.js for server-side scripting work together to create a powerful backend that enables real-time data processing and communication between the tractors and the web application. Through an user friendly interface, users may engage with this system and get current information that helps them make informed decisions about agricultural management, thereby increasing the sustainability and productivity of farming operations. Figure 6 displays the web map interface where users can track real-time data.

3.3 Field Testing

Figure 7 showcases the practical application of the low-cost GPS and IoT system on agricultural tractor following extensive field tests comparing GPS and DGPS for accuracy improvements. After fine-tuning the system's equations to achieve sufficient accuracy for agricultural operations, the components were installed on an actual tractor to test performance in a real-world setting. Figure 7(a) shows the installation location of the u-blox antenna, a critical component for receiving satellite signals. This antenna is strategically placed on the tractor's hood (Figure 7c) to ensure clear, unobstructed reception of GPS signals, which is crucial for maintaining the high accuracy needed for precise farming operations. Figure 7(b) features the IoT equipment used for transmitting the corrected GPS data from the tractor to the DGPS server. This setup includes devices that not only send real-time data but also receive corrections from the DGPS server, ensuring that the tractor's positioning data is constantly updated and accurate. Figure 8 illustrates a visual representation of tractor movement patterns during a field test, demonstrating the capabilities of the low-cost GPS and IoT system in agricultural field operations. Figure 8(a) captures a real-time scenario where the tractor is actively engaged in fieldwork, showcasing the practical application of the technology in a standard agricultural setting. Figure 8(b) provides a detailed overhead view of the same field, displaying the tractor's movement paths marked by yellow dots. These dots represent real-time positioning data that include not only the tractor's location but also the associated errors and the vehicle's speed. This visualization emphasizes the high-precision tracking results achieved by the system, underlining its effectiveness in monitoring and optimizing agricultural machinery operations with enhanced accuracy and reliability.

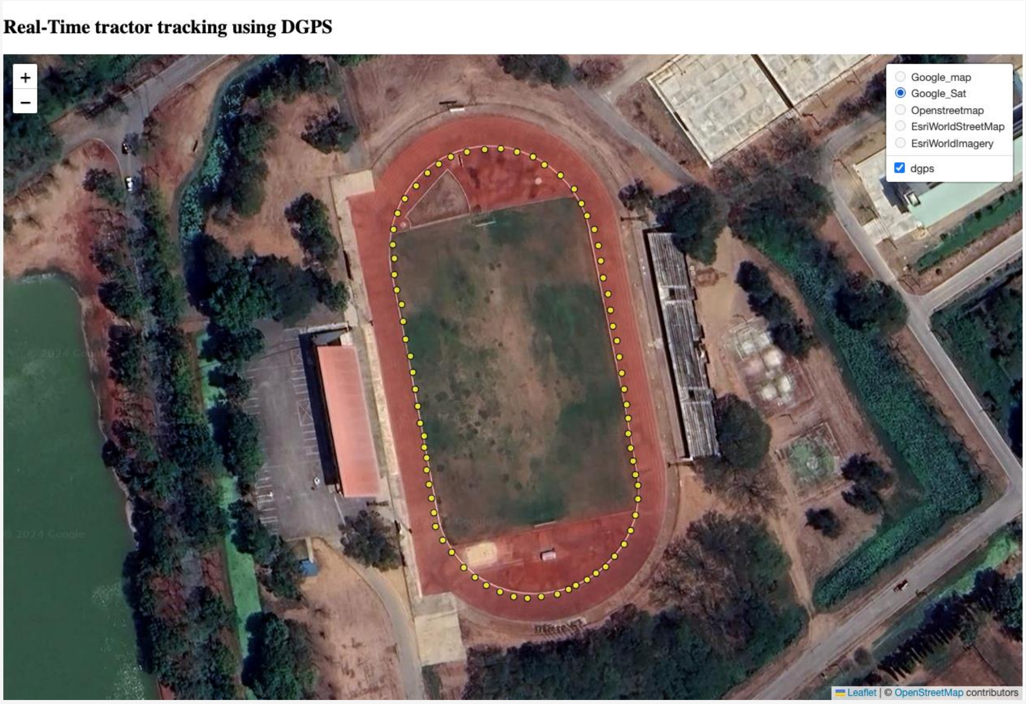

Figure 6: Web map interface

Figure 7: Components of the Low-Cost GPS and IoT system for agricultural tractor positioning: (a) U-blox NEO-M8N GPS module with antenna, (b) integrated IoT equipment set for GPS signal reception and data transmission and (c) equipment installation location on the tractor

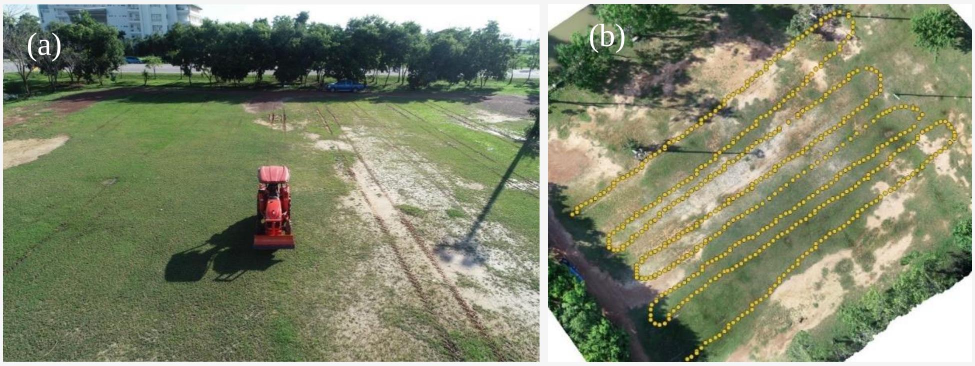

Figure 8: Visualization of tractor movement patterns, (a) the tractor testing in the field, (b) high-precision tracking results from the Low-Cost GPS and IoT system in agricultural field operations

In Figure 7, the DGPS system installed on the tractor shows positional deviations ranging from 30 to 90 centimeters, which is greater than the accuracy observed during tests on a football field. This increased discrepancy can be attributed to factors such as soft or uneven soil, which leads to wheel slippage and affects the tractor's actual position relative to its expected path, and the dynamics of the tractor itself, where movement and vibrations introduce additional variability in the measurements. Despite these factors, the system's accuracy remains well within the acceptable range for agricultural tasks like planting, spraying, and harvesting, where sub-meter precision is sufficient.

With errors ranging from 30 to 90 centimeters, the low-cost GPS and Internet of Things-based system for real-time location and monitoring of agricultural tractors in this study showed notable increases in positioning accuracy. This accuracy range is nevertheless appropriate for many precision agriculture applications, including planting, spraying, and harvesting where sub-meter precision is required, even though it is not as exact as certain expensive RTK GNSS systems.

The results show that during field tests, the DGPS system exhibited a much tighter deviation range (10–80 centimeters) compared to the standard GPS, which had a broader range of error (30–200 centimeters). The survey-grade RTK GPS systems indeed offer centimeter-level accuracy, typically around 2 centimeters horizontal accuracy and 4 centimeters vertical accuracy, as outlined in a study comparing the accuracy of RTK-based systems for autonomous agricultural vehicles [8]. However, the cost associated with such systems can be prohibitive, often exceeding $20,000 for a complete setup, making it challenging for small-scale farmers to adopt these technologies. For comparison, the low-cost GPS systems we used achieve sub-meter accuracy (30 to 90 centimeters). While they are less precise than RTK systems, their cost of less than $500 makes them an attractive option for farmers looking for an affordable, yet reasonably accurate, solution. Although our system's accuracy was lower, its affordability and real-time capabilities make it a practical solution for small to medium-sized farms.

Similar benefits are offered by our solution in comparison to other systems. In trials where the GNSS stayed in stable solution status, one study tested two low-cost RTK systems and achieved an RMSE of less than 50 millimeters [13]. Even with its less accurate performance, our system is still a cost-effective option for non-critical precision agriculture applications because it can achieve positional accuracy within 30–90 centimeters. The MQTT protocol is efficient for small-scale IoT deployments, designed for low-bandwidth, high-latency environments, making it suitable for real-time data transmission in precision agriculture. However, scalability challenges arise when multiple devices are used in large fields, leading to network congestion and latency. For larger setups or multiple tractors, technologies like NB-IoT or LTE-M provide better performance by enabling low-power, wide-area communication for reliable long-distance data transmission. IoT integration allows real-time monitoring of tractor operations, giving farmers access to critical data on location, speed, and status, improving on-the-spot decision-making and boosting overall productivity [20]. Our findings also align with research on positioning accuracy comparisons between different GNSS receivers used for agricultural machinery. One study reported that low-cost GNSS receivers, like the Quanum GPS Logger V2, showed an average positioning error of 550 centimeters, slightly better than some commercial receivers [21]. Our system's performance falls within this range, supporting the idea that low-cost solutions can achieve practical accuracy levels for agricultural applications.

The study's overall findings show that the inexpensive GPS and IoT-based solution provides a reasonable trade-off between accuracy and cost, making it available to a wider variety of farmers. More efficient and sustainable farming methods, particularly in developing nations, can be encouraged by this approach by helping precision agriculture technologies become more widely adopted. Future development should concentrate on enhancing the system's functionality in a range of field settings and minimizing positional inaccuracies brought on by elements like uneven ground or wheel slippage, which impacted the accuracy during tractor field operations. Furthermore, adding more sensors, such as inertial sensors, could improve the precision and dependability of the system even further, especially in autonomous applications [22]. The placement of the GPS antenna is another critical factor affecting signal quality. Research indicates that positioning the antenna on the tractor's hood may cause interference from the tractor's electromagnetic components. It has been recommended to elevate the antenna or use shielding techniques to reduce interference from onboard electronic systems [15].

4. Conclusion

This study successfully developed a low-cost GPS receiver system, incorporating Differential GPS (DGPS) technology and Internet of Things (IoT) integration, for real-time monitoring and precise positioning of agricultural tractors.

The system achieved notable improvements in positioning accuracy, with deviations ranging from 30 to 90 centimeters. Although field conditions, such as soft soil and tractor dynamics, introduced some variability, the DGPS system consistently provided sub-meter accuracy, which is suitable for a wide range of precision agriculture applications, including planting, spraying, and harvesting.

The integration of IoT technology allowed for real-time data transmission, enabling continuous monitoring of the tractor's position and operational parameters. This real-time monitoring feature enhances the system's applicability in modern farming practices, where timely data is critical for decision-making. By leveraging affordable GPS receivers and open-source geospatial tools, the proposed system offers an accessible solution for small and medium-scale farmers who may not have access to high-cost precision agriculture technologies such as RTK GNSS systems. This research demonstrates the potential of combining GPS, DGPS, and IoT technologies to improve positioning accuracy in agricultural operations. The results indicate that the system can significantly contribute to the wider adoption of precision agriculture, promoting more efficient and sustainable farming practices. Additionally, the implementation of Web GIS within the system plays a pivotal role, enhancing the real-time monitoring capabilities. Web GIS allows for the dynamic visualization and management of spatial data through a web interface, making it an indispensable tool for precision agriculture. Future research should aim to further refine the system’s performance in diverse field conditions and explore its broader application in autonomous agricultural machinery.

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