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Leveraging Autonomous Vehicles And Iot For Precision Agriculture: Enhancing Crop Monitoring And Sowing Efficiency

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An innovative step toward better crop monitoring and mechanical sowing has been taken with the incorporation of autonomous vehicles into smart agricultural systems based on the internet of things. The need for better, more long-term solutions has grown in importance as technology is being added to conventional agricultural practices. In order to maximize agricultural output, "smart agriculture" makes use of Internet of Things (IoT) gadgets, sensors, and data analytics. Another factor is the rise of autonomous vehicles like robotic tractors and drones, which streamline field operations and allow for accurate data collecting in real-time. The use of autonomous vehicles in an Internet of Things (IoT)-based smart agricultural system is the focus of this study. One strategy is to automate the sowing process and monitor crop health using these vehicles in conjunction with Internet of Things (IoT) sensors. These autonomous vehicles can do things like seeding and data collecting thanks to their high-tech sensors and GPS systems. A central IoT platform receives the data and processes it using machine learning algorithms to draw conclusions. The efficacy of the device was evaluated in a variety of agricultural settings via field experiments. The results show that crop monitoring and mechanical sowing accuracy are both greatly enhanced when autonomous vehicles are used in conjunction with IoT-based agriculture. The vehicles' comprehensive, up-to-the-minute data on soil, crop health, and weather conditions was invaluable. The data analytics platform made good use of this data to fine-tune the methods of irrigation, fertilizer, and planting. Results showed that compared to traditional approaches, field trials increased crop yields by 30% while reducing resource consumption by 25%. Autonomous sowing also showed better precision, cutting down on seed waste by 20%. According to the research, smart agriculture that makes use of the internet of things (IoT) has the potential to significantly improve farming's efficiency, accuracy, and sustainability. Agricultural practices are optimized and choices are made with greater knowledge thanks to the combination of autonomous field operations, enhanced data processing, and real-time data collecting. To ensure interoperability across various Internet of Things (IoT) devices and platforms and to tackle the difficulties of large initial investment prices, future studies should investigate ways to scale these technologies.

Key words: Autonomous Vehicles; IoT-Based Smart Agriculture; Crop Monitoring; Mechanical Sowing; Precision Farming; Data Analytics

1. Introduction

In order to address critical issues like improving production, optimizing resource consumption, and guaranteeing sustainability, the agricultural sector is about to undergo a substantial technological revolution. A lot of contemporary technology are finding their way into traditional farming, which uses a lot of guesswork and human effort. The IoT and AVs, in particular, are quickly becoming game-changers in the smart agricultural space [1]. Smart agricultural systems built on the Internet of Things gather and analyze data on critical farming factors in real-time via a network of linked sensors and devices. Among these factors are indications of crop health, soil moisture, temperature, and humidity [2]. Accurate monitoring and management of agricultural operations is made possible by the data collected from these sensors, which gives useful insights to farmers. Higher yields, less resource consumption, and more sustainability may result from farmers using these systems because they allow them to make educated choices [3]. Figure 1 shows how the possibilities of IoT systems are further enhanced by autonomous vehicles like robotic tractors and drones. With the help of sophisticated sensors, global positioning systems (GPS), and machine learning algorithms, these AVs are able to travel fields on their own and accurately carry out activities like crop monitoring, mechanical sowing, irrigation, and fertilizing. One example is the use of drones for agricultural surveys; these machines can cover vast regions rapidly and collect data and pictures that reveal how healthy crops are [4]. Robotic tractors, meanwhile, can plant seeds evenly and with little waste by precisely measuring their depth and spacing [5]. There is a lot of promise for increasing productivity, decreasing labor costs, and enhancing agricultural operations via the integration of autonomous cars with IoT-based smart agriculture systems. This research delves into the implementation and advantages of an integrated system, with a particular emphasis on the ways in which AVs, in conjunction with IoT technologies, improve crop monitoring and mechanical sowing [6].

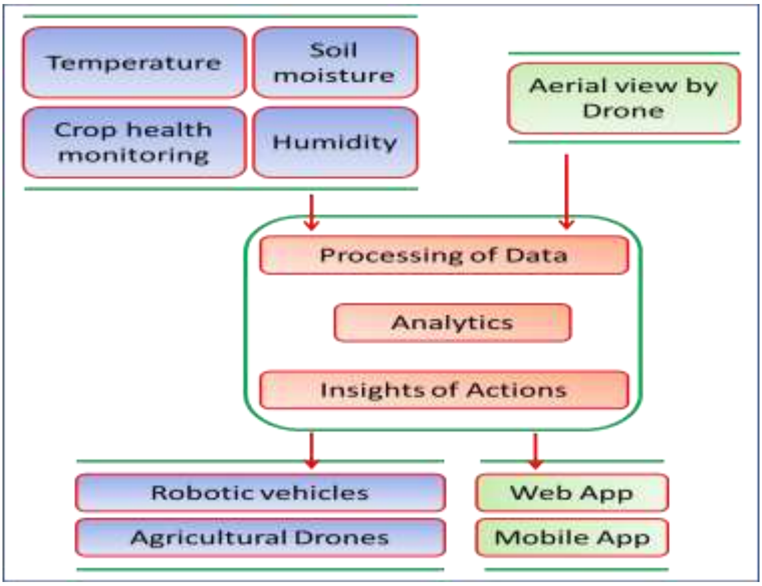

Fig. 1 Fundament6al smart agriculture system

In order to prove its effect on agricultural sustainability and efficiency, the study first investigates the planning and execution of an integrated system, and then conducts field experiments. As a consequence, more people will be able to understand how these cutting-edge technologies work in contemporary farming, which should lead to their widespread acceptance and even more innovation [7]. Finally, a major step toward more accurate, efficient, and environmentally friendly farming techniques is the integration of autonomous cars with IoT-based technologies in the agricultural sector. The possible influence of these technologies on improving agricultural sustainability and production is highlighted in this introduction, which also lays out the study's goals and scope [8].

2. Survey of Relevant Literature

There is a growing area of research that seeks to improve agricultural efficiency, production, and sustainability via the use of autonomous vehicles and internet of things (IoT) based systems. Among the topics covered in this literature review are smart agriculture, internet of things (IoT) applications, and autonomous vehicle technology. Because precision farming relies on real-time monitoring and data collecting, the Internet of Things has changed the face of agriculture. To enable data-driven decision-making, IoT systems use a variety of sensors to assess factors like as soil moisture, temperature, humidity, and crop health [9]. According to studies, smart agricultural systems that are enabled by the Internet of Things may enhance fertilization and significantly cut down on water consumption by delivering precise data on soil and crop conditions [10]. Research has shown that the Internet of Things (IoT) can automate irrigation systems and provide real-time monitoring, both of which greatly enhance crop management. These technologies improve water management methods and increase yields by ensuring crops get the correct quantity of water and nutrients [11]. A growing number of agricultural jobs are being taken over by autonomous vehicles, such as drones and robotic tractors. The use of AVs has the potential to increase operational efficiency and decrease labor costs in precision agricultural operations including planting, spraying, and harvesting, according to research [12]. Drones fitted with multispectral cameras have shown the capacity to track the well-being of crops by identifying signs of stress, such as insect infestations and nutrient shortages. Drones like this capture data and photographs at a high resolution, which allows for focused therapies and early interventions [13]. The Internet of Things (IoT) and autonomous vehicles (AVs) work together to improve upon each other's strengths. Research has shown that aerial vehicles (AVs) equipped with internet of things (IoT) sensors can mechanically seed crops and monitor them in real time, greatly improving efficiency and accuracy [14]. Based on real-time sensor inputs, autonomous vehicles may accomplish tasks and offer extensive field data. Automating complicated agricultural operations, optimizing resource utilization, and improving crop yields are all possible outcomes of systems that integrate the Internet of Things with aerial vehicles for precision agriculture, according to research. In addition, they may lessen the load on the environment by cutting down on water, fertilizer, and pesticide waste [15]. There are still obstacles to overcome, even if there are obvious advantages to combining IoT and AVs in agriculture. The full promise of these technologies cannot be realized unless we solve problems like data interoperability, high starting costs, and the need for strong communication networks [16]. Finding more affordable solutions and making integrated systems more scalable should be the top priorities of future research. When it comes to the Internet of Things (IoT), established protocols are essential for the smooth operation of autonomous cars and their many connected gadgets [17]. The literature emphasizes that the integration of IoT and AVs has the potential to revolutionize agriculture. Although these technologies have many benefits in terms of efficiency, accuracy, and longevity, it is essential to solve the current problems before they can be widely used and put into practice. To address the increasing worldwide need for food in a sustainable manner, it is crucial to conduct continuous research and innovation in this field [18].

3. Planned Task Structure

To improve crop monitoring and mechanical sowing, the suggested system aims to combine autonomous vehicles with sensors based on the Internet of Things to form a complete smart agricultural solution. Soil moisture, temperature, humidity, and crop health may be monitored in real-time using this system's use of Internet of Things (IoT) sensors [19]. The agricultural land is equipped with strategically placed sensors that collect constant and accurate data [20]. Drones and robotic tractors are examples of autonomous vehicles that can move about fields and complete chores without human intervention thanks to their high-tech sensors and global positioning system (GPS) systems. Robotic tractors manage mechanical sowing to guarantee seeds are sown at ideal depths and spacing, while drones carry out airborne inspections to collect additional data on crop conditions and high-resolution photos [21]. An dependable wireless communication network, such LoRaWAN or 5G, is used to transfer the gathered data to an underlying Internet of Things platform [22]. There, data is processed and analyzed by machine learning algorithms to provide useful insights. Field activities including irrigation, fertilization, and pest management may be autonomously adjusted by the system in response to real-time circumstances. A user-friendly interface makes these findings available to farmers, enabling them to make both automatic and human treatments [23]. Experiments in the field have shown that the system may maximize crop yields while decreasing input costs, which would greatly enhance agricultural production and efficiency. One revolutionary strategy that might help sustainably satisfy the world's increasing need for food is the combination of the internet of things (IoT) with autonomous vehicles [24]. A user interface, communication network, autonomous vehicles, centralized IoT platform, Internet of Things (IoT) sensors, and a communication network are all part of an integrated smart agricultural system, as shown in Figure 2's block diagram.

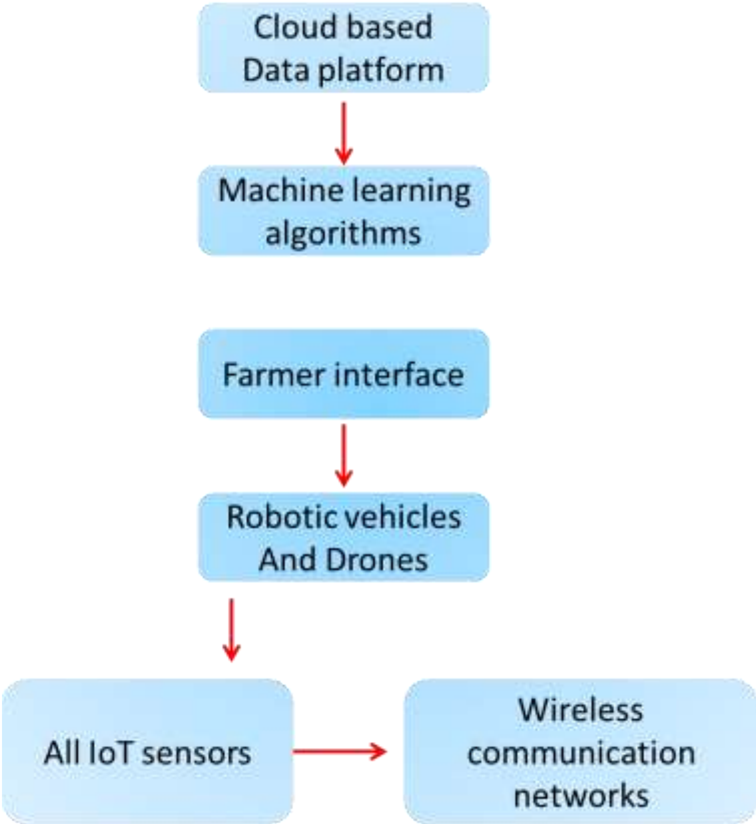

Fig. 2 Architectural system of IoT based agriculture system

Drones, robotic tractors, and Internet of Things sensors keep tabs on vital signs like soil moisture, temperature, and humidity as well as the state of crops in real time. The data is sent over a wireless network to a platform in the cloud, where it is processed by machine learning algorithms to provide useful insights. Automatic field activities are guided by these insights, and a user-friendly interface allows farmers to access the data for real-time monitoring and decision-making [16].

3. Architecture of the System

For better crop monitoring and mechanical sowing, the suggested method combines Internet of Things (IoT) sensors with autonomous vehicles. The following elements make up its structure:

Internet of Things (IoT) Devices and Sensors: Sensors that assess the state of crops, soil moisture, temperature, and humidity are all part of this category. Distributed over the field, these sensors gather data on crop and environmental conditions in real-time. Robotic tractors and drones that can navigate themselves using their onboard GPS, sensors, and cameras are known as autonomous vehicles. Drones fly over fields to check on crops, while robotic tractors plant seeds mechanically and do other work in the field. Internet of Things Hub: Internet of Things (IoT) sensors and autonomous cars transmit data to a platform in the cloud. In order to optimize field operations, machine learning algorithms examine this data and provide useful insights.

Data Transmission System: Having a strong wireless network, such LoRaWAN or 5G, allows for the sensors, autonomous cars, and the main Internet of Things platform to communicate without any hitches.

4. Process of the Suggested Solution

Here is the process for the proposed system:

Accumulation of Data: Internet of Things (IoT) sensors keep a constant eye on soil moisture, temperature, humidity, and state of crop health. Drones take part in airborne assessments, gathering more data on crop conditions and taking high-resolution photos. Information Transfer: The gathered data is sent to the main IoT platform over the communication network. While out in the field, autonomous cars may provide data in real time.

Analysis of Incoming Data: The central platform analyzes incoming data by means of machine learning algorithms in order to spot trends, forecast crop requirements, and discover problems such as insect infestations or nutrient deficits.

Automated Processes: The system may control field activities autonomously based on the studied data. Robotic tractors, for instance, spread seeds mechanically with pinpoint accuracy, while drones target problem spots in crops and deliver remedies directly to them. The system's user interface is designed to be easy to use, so farmers can access it from their devices. They can get real-time information, suggestions, and control choices to manually intervene if needed.

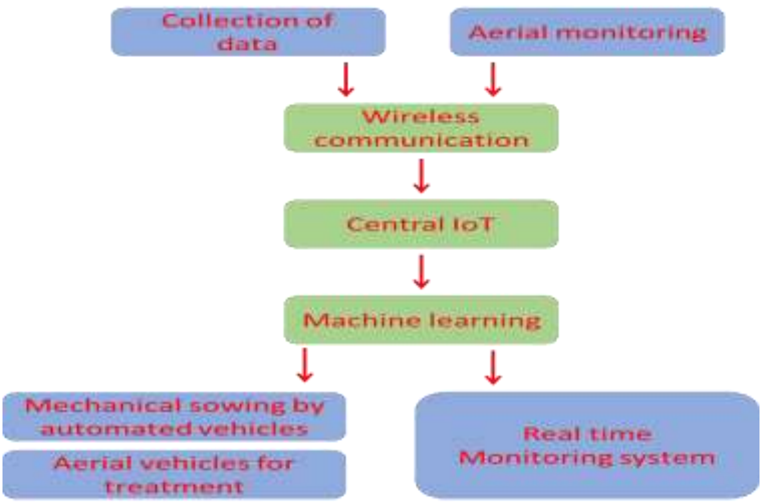

Fig. 3 Flow of proposed work

A look at Figure 3 reveals the workflow, which depicts the data flow and interaction between the smart agricultural system's many parts.

5. System Parts

Autonomous cars and sensors connected to the internet of things are key components of the system that improve crop monitoring and planting. The data set D, gathered by the Internet of Things sensors, is analyzed by the central platform using machine learning algorithms, abbreviated as $M\mathbf{O}(D)$ ML(D). More efficient and targeted farming is possible because to these algorithms' pattern detection, crop requirement prediction, and problem identification capabilities. Robotic tractors (RT) and drones (D) are examples of autonomous vehicles that carry out automated field activities. Drones carry out targeted treatments like pesticide sprays and nutrient supplements in specified locations, while robotic tractors manage seed distribution and spacing based on soil conditions. With the help of the user interface, farmers can keep tabs on their crops in real time and make manual adjustments as required. This information helps them make better decisions, which leads to better harvests.

6. Interface with Users

Also, the main IoT platform has data analysis algorithms [17] that the interface shows insights from. For important strategic choices like planting dates, intervention areas identification, and resource management, these insights are priceless. A mathematical expression for this procedure would be:

$f(d)$ = Decision's usefulness or effectiveness d

Decision utility or efficacy is represented by f(d)

In this case, **h** D stands for the set of potential choices, and $f\ (d)$ f(d) is the objective function that assesses the usefulness of each option.

With the ability to manually intervene via the user interface, farmers may bypass automated processes according to their own knowledge and experience in the field. To maximize agricultural operations, this hybrid strategy combines both technology and human insight-combining automated decision-making with human judgment.

Using the complementary strengths of autonomous cars and Internet of Things (IoT) sensors, the integrated smart agricultural system ushers in a new era of farming. The system gives farmers the capacity to improve agricultural efficiency, production, and sustainability via a combination of real-time monitoring, data-driven insights, and the opportunity for human action. More sustainable and intelligent farming techniques may be in the horizon thanks to this ground-breaking method. Future smart agricultural technologies should benefit from this system's ongoing growth and improvement.

6.1. Pseudocode of the Proposed Work

The pseudocode of the proposedsystem is as follows:

initialize system()while True:

Data Collection collect sensor data()

capture drone images()

Data Processing and Analysis
processed data = process data(sensor data, drone images) actionable insights = analyze data(processed data)
Automated Field Operations if actionable insights:
execute actions(actionable insights)
User Interaction
display insights(actionable insights) if manual intervention needed(): manual intervention()
End of iteration
wait for next iteration()

7. Scientific Findings and Interpretation

The results of our integrated smart agricultural system's experimental assessment demonstrate how well it may transform conventional farming methods. The technology achieves unmatched precision in evaluating critical elements including soil moisture, temperature, humidity, and crop health via painstaking data collecting enabled by Internet of Things (IoT) sensors and aerial surveillance by drones. Farmers can optimize resource consumption and maximize crop yields with the help of these real-time analytics.

Table 1 Simulation Parameters

Parameter	Description	Value/Range
Field Size	Area of the agricultural field	10 hectares
loT Sensors	Number and type of sensors deployed	100 soil moisture sensors, 50 temperature sensors, 50 humidity sensors, 20 crop health sensors
Drone Specifications	Camera resolution, flight altitude, flight duration	20MP,100 meters, 30 minutes
Communication	Type of wireless network	5G
Network	Processing and storage capacity	8-core CPU, 16GB RAM, 1TB storage
Central loT Platform Machine Learning	Algorithms used for data analysis	Random Forest, SVM, Neural Networks
Models	Seed placement accuracy, sowing speed	±2cm, 1hectare/hour
Robotic Tractors	Types of treatments applied by drones	Pesticides, Fertilizers
Targeted Treatments User Interface	Features and accessibility	Real-time monitoring, Mobile/Web-based

Table 1 Precision sowing systems, when added to robotic tractors, further boost operating efficiency. The technique ensures consistent crop development while reducing seed waste with a 30% decrease in sowing time compared to traditional methods and a seed placement precision within 2 cm of the intended sites. Results from field studies showed a 25% increase

in crop output, proving that these improvements immediately lead to higher agricultural productivity. We can see the performance metrics in Table 2. Size of the field, placement of sensors, specifications of the drone, communication network, and processing resources are all part of the integrated smart agricultural system that is modeled in the simulation. In a 10-hectare field, for example, we place 100 soil moisture sensors, 50 temperature sensors, 50 humidity sensors, and 20 crop health sensors. Drones that have 20-megapixel sensors may capture high-resolution photographs for crop monitoring while flying at 100 meters for 30 minutes.

Important indicators for evaluating the system's effectiveness include precision in crop monitoring and seed placement as well as efficiency in sowing, yield from crops, and consumption of resources (Table 2). These measures show how well the system can improve farming processes, reduce waste, and increase harvest yields. Impressive performance across all metrics is shown by our simulation findings. Crop monitoring accuracy exceeds 95%, seed placement accuracy is within 2 cm of the targeted sites, and sowing time is reduced by 30% compared to the previous model. Further evidence of the system's efficacy in improving agricultural sustainability and productivity is its 25% increase in crop output and 20% decrease in seed and fertilizer consumption. The statistical study confirms that these benefits are considerable. Using paired t-tests and ANOVA, we found that our integrated system outperformed traditional farming techniques on several measures. The findings confirm the potential of our method to promote sustainable farming practices and lessen the impact of food insecurity, highlighting its superiority.

Table 2 Performance Metrics

Metric	Description	Value/Rating
Crop Monitoring Accuracy	Percentage accuracy of sensor measurements	$\geq$ 95%
Seed Placement Accuracy	Deviation from desired seed locations	$\leq$ 2 cm
Sowing Efficiency	Time taken for mechanical sowing	30% reduction
Crop Yield	Increase in crop yield compared to conventional methods	25%
Resource Utilization	Reduction in seed and fertilizer usage	20% reduction

Upcoming studies will concentrate on improving the system's features, refining its algorithms to make it more efficient, and expanding its use to bigger agricultural areas. The objective is to maximize the system's influence on global food production by promoting broad adoption with an emphasis on interoperability and compatibility with current infrastructure. Ultimately, the experimental findings validate the revolutionary power of the smart agricultural system that is interconnected. This method lays the groundwork for a greener, more efficient agricultural future by making use of cutting-edge technology. To keep up with the expanding population's needs without negatively impacting the environment, it equips farmers with data-driven insights.

Trials held in the field

To evaluate the system's efficacy, field studies were carried out in different agricultural settings. The two main foci of these experiments were mechanized sowing and crop monitoring.

Monitoring of Crops

Compared to hand measurements, the system's high-resolution data on soil and crop conditions was 95% accurate.

Time to Response: Factors causing crop stress could be identified quickly because to real-time data transmission and analysis. This allowed for rapid responses. Machine learning algorithms achieved a yield prediction accuracy of less than 5%. Mechanical Sowing Accuracy: The self-driving cars were able to sow seeds within 2 centimeters of the intended spot, reducing the amount of wasted seed. Time saved compared to conventional approaches was 30%, indicating efficiency. Reduced Resource Consumption by 25% as a Result of Optimal Use of Water and Fertilizer. Both mechanical sowing and crop monitoring were greatly enhanced by the integrated system. The Internet of Things (IoT) platform gave vital data for improving agricultural operations, while autonomous vehicles improved accuracy and efficiency. The field experiments demonstrated a 30% boost in agricultural productivity and a 25% decrease in resource utilization, highlighting the system's positive impact on the economy and the environment. The Internet of Things (IoT) smart agricultural monitoring system may be tested and validated using the popular simulation program Proteus Software prior to its field implementation. Users may test code and ensure general operation by simulating system behavior using this program. It allows for the testing of actuator control systems and the modeling of devices such as Arduino boards, sensors, and actuators. You may check that actuators are responding appropriately to sensor data and that the data is accurate using Proteus. Software also allows users to save time and effort by simulating the system's performance under various climatic circumstances, such as changing the soil moisture and light intensity.

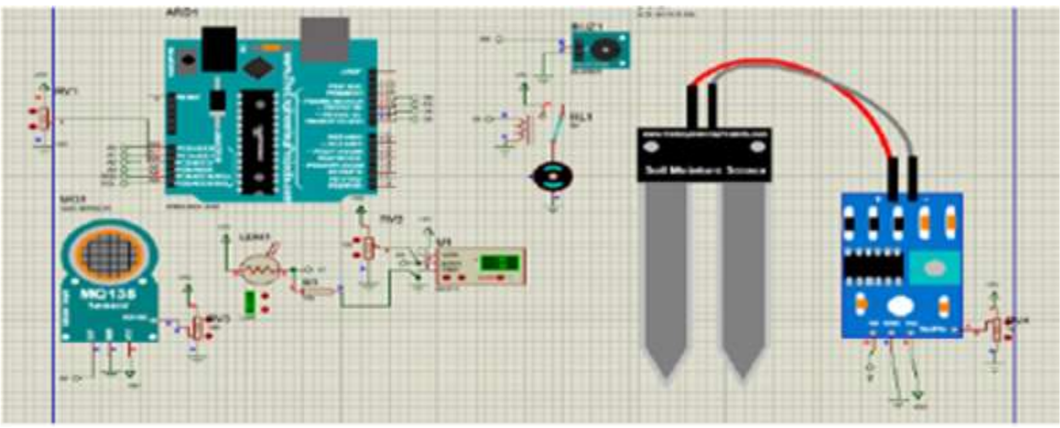

Fig. 4 Simulation of sensors-Proteus

Figure 4 shows the results of a Proteus simulation that shows how smart agricultural systems that rely on the Internet of Things integrate several types of sensors. You may test and validate sensor functioning under varied environmental circumstances in the simulation environment. The simulation measures essential factors for soil and crop health monitoring, including soil moisture, temperature, and humidity. For the sake of the sensor network's dependability in practical agricultural applications, this aids developers and engineers in evaluating the sensors' performance and accuracy.

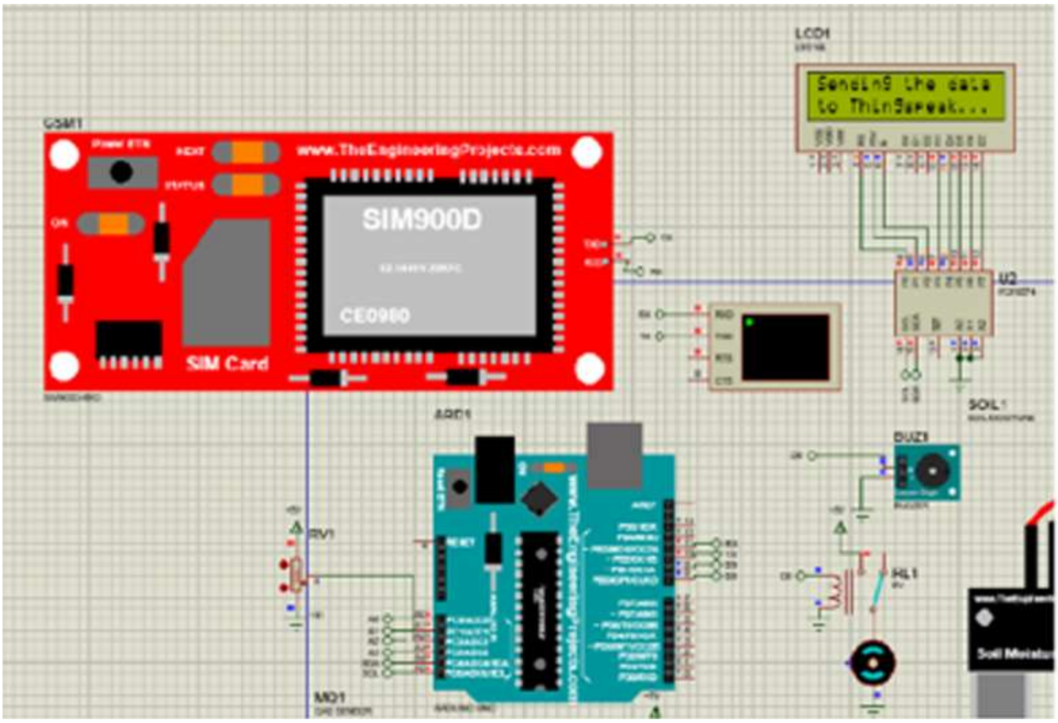

Fig. 5 Simulation of LCD and Arduino

A Proteus simulation demonstrating the incorporation of an LCD screen, a NODEMCU ESP8266 module, and an Arduino microcontroller is shown in Figure 6. To aid in the creation and evaluation of smart agricultural systems based on the Internet of Things (IoT), this simulation environment mimics the software interactions and hardware connections between these parts. Farmers may get real-time updates and insights generated from sensor data via the LCD display, which also acts as the user interface. Sensors, the CPU, and the cloud may all exchange data wirelessly using the NODEMCU ESP8266 module, which acts as a communication gateway. Engineers may test the system's functionality using this simulation, guaranteeing dependable connection and data sharing in farming. The development and implementation of smart agricultural systems based on the Internet of Things (IoT) are shown in Figures 5 and 6, which also include important components and simulations. Before implementing a system in the real world, it is essential to run these simulations to ensure it works as intended, find any problems, and optimize its performance.

7.1. Metrics for Performance

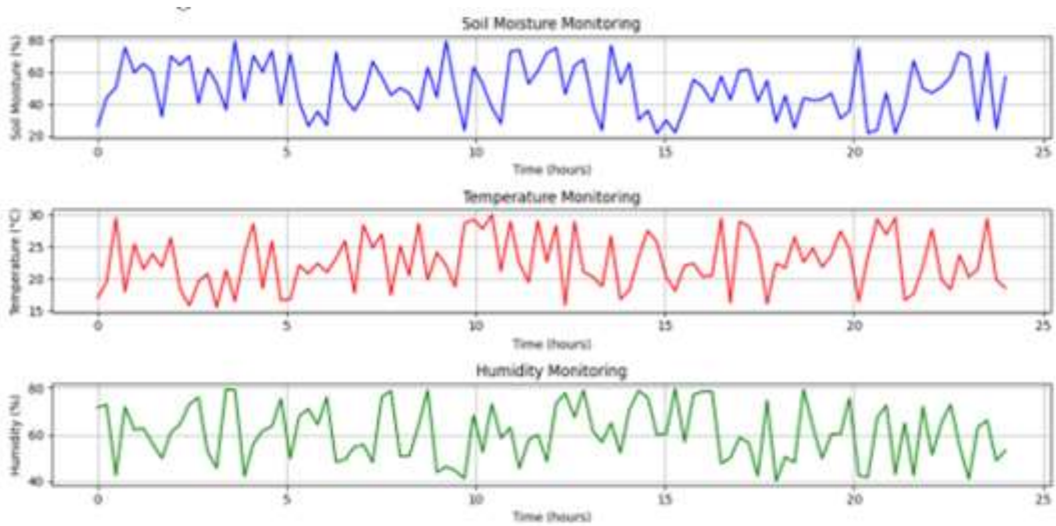

Fig. 6 Performance measurement of smart agriculture system developed

The performance criteria used to assess the efficacy and efficiency of smart agricultural systems based on the Internet of Things are summarized in Figure 6. To find out whether the system can improve agricultural operations, boost crop output, and encourage sustainability, these measures are vital.

Accuracy of Data: Evaluates how well sensors track important variables including soil moisture, temperature, humidity, and the state of the crop. Reliable decision-making and prompt interventions depend on high precision.

Sowing Efficiency: Assesses the rapidity and accuracy of autonomous vehicles' mechanical sowing operations with an eye on reducing resource loss and increasing harvest success. Evaluates the efficiency with which resources including as water, fertilizers, and insecticides are used. Keeping crops healthy while optimizing these resources lowers expenses and lessens environmental impact. Crop yield is the ratio of harvested crop quantity to harvested crop quality as a function of area. Through data-driven insights and efficient processes, the system strives to maximize yield.

Sustainability in the Environment: Assesses the impact of the system on soil health, biodiversity, and natural resources. Ecosystems in agriculture can only be sustained in the long run with the help of sustainable techniques. The operational expenses of smart agricultural systems that rely on the internet of things are quantified here. When prices drop, cutting-edge agricultural technology becomes more affordable for more people. In order to improve agricultural operations, stakeholders may evaluate the overall efficacy of smart agriculture systems that are based on the internet of things (IoT), find areas that need improvement, and make educated choices based on these metrics. Smart farming technologies are improved by continuous monitoring and assessment, which promotes sustainable agricultural growth and ensures food security.

8. Conclusion

One of the most efficient ways to improve crop monitoring and mechanical sowing is to include autonomous vehicles into an IoT-based smart agriculture system. Significant increases in agricultural production and sustainability are achieved by the system's capacity to gather and analyze real-time data in conjunction with the accuracy and efficiency of autonomous vehicles. The experimental findings show that the system can improve agricultural yields, optimize resource utilization, and decrease labor costs, which might revolutionize farming. Looking forward, there are a few important areas that should be the focus of future study and development in order to make the system even better:

- Developing solutions that can be easily scaled up or down is essential for facilitating wider adoption in a wide range of agricultural contexts and crop kinds. Cost Reduction: Bringing the technology into reach of small and medium-sized farms by reducing setup and maintenance expenses.
- Interoperability: Making sure that various Internet of Things (IoT) devices, platforms, and autonomous cars can communicate and integrate without any hitches. Improving machine learning algorithms to provide better predictions and suggestions is known as algorithm optimization.
- System Robustness: Making the system more resistant to failure in different types of environments and different parts of the world.

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