Design and Optimization of Agricultural Machinery Autonomous Control System Integrating TRIZ Method and Internet of Things Technology

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ABSTRACT: This paper presents the design and optimization of an autonomous agricultural machinery control system integrating TRIZ methodology and Internet of Things (IoT) technology. Traditional farming relies heavily on manual operations, resulting in high labor costs, inefficient resource usage, and reduced productivity. The proposed system utilizes sensors such as soil moisture, GPS, and obstacle detection for real-time field monitoring. A microcontroller-based unit processes sensor data and controls irrigation and spraying mechanisms. IoT connectivity enables remote monitoring and control through a cloud platform. The TRIZ approach is applied to resolve engineering contradictions and enhance system efficiency. The system improves precision in irrigation and fertilizer application while reducing energy and chemical wastage. Overall, it enhances productivity, reduces labor dependency, and promotes sustainable precision agriculture practices.

Keywords: Autonomous Agricultural Machinery, TRIZ Methodology, Internet of Things (IoT), Precision Agriculture, Smart Irrigation System, Embedded Control System, Sustainable Farming.

I. INTRODUCTION

This Agriculture remains a fundamental sector for economic growth and food security, particularly in developing countries. However, traditional farming practices are often characterized by excessive labor dependency, inefficient resource utilization, and lack of real-time monitoring systems, which significantly reduce productivity and increase operational costs. Recent advancements in the Internet of Things (IoT) have enabled the development of smart agriculture systems that facilitate real-time data collection and automated decision-making processes [1], [4].

IoT-based agricultural solutions utilize sensor networks to monitor parameters such as soil moisture, temperature, and humidity, thereby improving irrigation efficiency and crop management [2], [5]. These systems help reduce water wastage and ensure optimal crop growth conditions by enabling precision farming techniques. Furthermore, wireless sensor networks (WSNs) have been widely adopted for remote monitoring applications, though they face challenges such as energy consumption and system scalability [7].

In addition to IoT, intelligent optimization techniques are required to address engineering contradictions in agricultural system design. The TRIZ (Theory of Inventive Problem Solving) methodology, introduced by Altshuller, provides a systematic framework for solving complex engineering problems and improving system efficiency [3]. TRIZ has been successfully applied in various engineering domains to enhance innovation and optimize system performance.

Designing an effective autonomous control system for agricultural machinery involves complex challenges, including system reliability, adaptability to dynamic environments, and optimization of multiple conflicting parameters such as energy consumption, cost, and performance. To address these issues, the **TRIZ (Theory of Inventive Problem Solving)** methodology is employed as a systematic innovation tool. TRIZ facilitates the identification and resolution of engineering contradictions, leading to optimized design solutions without compromising system efficiency.

Moreover, the integration of artificial intelligence and smart automation in agriculture has further improved decision-making capabilities, enabling predictive analysis and efficient resource management [6]. Autonomous agricultural machinery, combined with IoT and optimization techniques, has the potential to revolutionize traditional farming practices by minimizing human intervention and maximizing productivity. Despite these advancements, existing systems often lack a unified framework that integrates IoT-based monitoring with systematic problem-solving methodologies like TRIZ. Therefore, this paper proposes the design and optimization of an autonomous agricultural machinery control system that combines IoT technology with TRIZ principles to enhance efficiency, reduce resource wastage, and improve overall agricultural productivity.

II. SYSTEM ARCHITECTURE

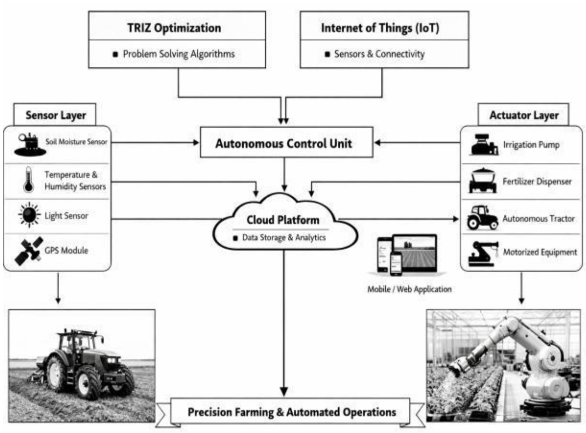

Fig. 1

The block diagram illustrates the architecture of an autonomous agricultural machinery control system that integrates Internet of Things (IoT) technology with TRIZ-based optimization. The system comprises multiple layers, including sensing, communication, control, optimization, and actuation. Initially, environmental parameters such as soil moisture, temperature, humidity, and light intensity are continuously monitored using sensor modules. The collected data is transmitted through IoT communication networks to the central control unit, where it is processed and analyzed in real time. The control unit makes intelligent decisions based on predefined thresholds and system requirements. Additionally, TRIZ methodology is incorporated to resolve design contradictions and enhance system efficiency, reliability, and performance. The processed decisions are then executed through actuators such as irrigation pumps, valves, and autonomous machinery. Furthermore, the cloud platform enables data storage, remote monitoring, and analysis, allowing farmers to access real-time information and historical records. Overall, the system ensures efficient resource utilization, reduced human intervention, and improved agricultural productivity through smart and automated operations.

III. RELATED WORK

The advancement of agricultural automation has attracted significant research interest, particularly in the integration of **Internet of Things (IoT)** technologies, autonomous machinery, and intelligent optimization techniques. This section reviews the key contributions in these domains and identifies the limitations that motivate the proposed work.

IoT-based smart agriculture systems have been widely developed to enable real-time monitoring and control of farming operations. In [1], an IoT-enabled irrigation system utilizing soil moisture sensors was proposed to optimize water usage. Similarly, [2] presented a wireless sensor network for monitoring environmental parameters such as temperature and humidity to improve crop yield. Although these systems enhance data acquisition and remote control, they primarily focus on monitoring and lack advanced decision-making and optimization capabilities.

Research on autonomous agricultural machinery has also gained momentum. In [3], a GPS-based autonomous tractor system was developed for precision farming applications. Another study in [4] introduced machine vision techniques for crop detection and navigation in agricultural fields. While these approaches reduce human intervention, they are often associated with high implementation costs and limited adaptability to varying field conditions.

Sensor-based control systems form another important area of research. In [5], a microcontroller-based system was designed to automate irrigation using soil moisture data. Similarly, [6] utilized multiple environmental sensors to control greenhouse conditions. However, such systems typically operate as standalone units without integration into a comprehensive intelligent framework.

Optimization techniques have been applied to improve the efficiency of agricultural systems. Genetic algorithms and fuzzy logic controllers were employed in [7] and [8] to optimize irrigation scheduling and resource utilization. Additionally, machine learning approaches were explored in [9] for predictive analysis in agriculture. Despite their effectiveness, these techniques often require significant computational resources and may not be suitable for real-time, low-cost implementations.

The Theory of Inventive Problem Solving (TRIZ) has been applied in various engineering fields to address design contradictions and enhance system performance. In [10], TRIZ was used for product design optimization, while [11] demonstrated its application in mechanical system improvement. However, the integration of TRIZ with IoT-based agricultural systems remains largely unexplored.

From the reviewed literature, it is evident that although significant progress has been made in individual domains, there is a lack of integrated approaches that combine IoT, autonomous control, and systematic optimization methodologies. Most existing systems either focus on monitoring, automation, or optimization independently, without achieving a unified and efficient solution.

IV. PROBLEM SOLUTION

Agricultural machinery in conventional farming systems predominantly relies on manual operation and basic automation, resulting in inefficiencies such as high labor dependency, excessive resource consumption, and inconsistent field performance. Existing systems often lack real-time monitoring, intelligent decision-making, and effective coordination between sensing, control, and actuation components.Although **Internet of Things (IoT)** technologies have been introduced to improve agricultural practices, most current implementations are limited to data collection and monitoring, without incorporating advanced optimization or autonomous control mechanisms. Similarly, autonomous agricultural machinery developed in recent studies is often expensive, complex, and lacks adaptability to dynamic environmental conditions.

Furthermore, existing optimization techniques, such as genetic algorithms and machine learning approaches, are computationally intensive and not always suitable for real-time, cost-effective agricultural applications. The application of structured problem-solving methodologies like **TRIZ (Theory of Inventive Problem Solving)** in agricultural automation remains largely unexplored.

As a result, there is a need for an integrated system that combines IoT-based real-time monitoring with an efficient and systematic optimization approach to enhance the performance, adaptability, and cost-effectiveness of agricultural machinery.

Therefore, this research addresses the problem of designing and optimizing an **autonomous agricultural machinery control system** that integrates IoT technology with TRIZ methodology to achieve intelligent decision-making, improved resource utilization, and enhanced operational efficiency.

V. PROPOSED SYSTEM

The proposed system presents the design and optimization of an **autonomous agricultural machinery control system** by integrating **Internet of Things (IoT)** technology with the **TRIZ (Theory of Inventive Problem Solving)** methodology. The system aims to enhance farming efficiency by enabling real-time monitoring, intelligent decision-making, and optimized control of agricultural operations.

The architecture of the proposed system consists of four major components: sensing unit, processing unit, communication module, and actuation system. These components work collaboratively to achieve automation and optimization in agricultural tasks.

The sensing unit includes various sensors such as soil moisture sensors, temperature and humidity sensors, and light-dependent resistors (LDR) to collect real-time environmental data from the field. This data is continuously monitored to assess soil conditions and crop requirements.

The processing unit, typically a microcontroller or embedded system, receives sensor data and analyzes it to make control decisions. The decision-making process is enhanced using TRIZ principles, which help in resolving system contradictions such as maximizing productivity while minimizing resource consumption. This ensures optimal utilization of water, energy, and other resources

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The communication module enables data transmission between field devices and remote users through wireless technologies such as Wi-Fi or GSM. This allows farmers to monitor and control the system remotely using mobile or web-based applications.The actuation system includes devices such as water pumps, valves, and motors that execute control actions based on the processed data. For example, irrigation is automatically activated when soil moisture falls below a predefined threshold.

The proposed system operates in a closed-loop manner, where continuous feedback from sensors ensures adaptive and accurate control. By integrating IoT with TRIZ-based optimization, the system not only automates agricultural processes but also improves efficiency, reduces operational costs, and enhances crop productivity.

Hardware Components

Microcontroller (Arduino, Soil Moisture Sensor, Temperature and Humidity Sensor (DHT11/DHT22), Light Dependent Resistor (LDR), Water Pump (Motor), Relay Module, Solenoid Valve, Power Supply Unit, Wi-Fi/GSM Module, Display Unit

Software Components

IoT Platform ThingSpeak, TRIZ-Based Logic Implementation, Embedded C / Arduino IDE

VI. WORKING PROCESS

The proposed autonomous agricultural machinery control system operates through a systematic and continuous process involving data acquisition, processing, decision-making, and actuation. The integration of **Internet of Things (IoT)** technology with the **TRIZ methodology** ensures efficient and optimized system performance.

Initially, the sensing unit collects real-time data from the agricultural field using various sensors such as soil moisture sensors, temperature and humidity sensors, and light-dependent resistors (LDR). These sensors continuously monitor environmental and soil conditions and convert physical parameters into electrical signals.

The collected data is then transmitted to the processing unit, typically a microcontroller, through wired or wireless communication. The processing unit analyzes the incoming data and compares it with predefined threshold values to determine the current state of the field.

At this stage, the **TRIZ-based optimization approach** is applied to enhance decision-making. TRIZ principles help resolve contradictions such as reducing water usage while maintaining soil fertility or maximizing productivity with minimal energy consumption. Based on this analysis, the system generates optimal control decisions.

The communication module enables real-time data exchange between the field system and remote users. Farmers can monitor system parameters and receive updates through mobile or web-based applications, allowing remote supervision and control.

VII. ALGORITHM

VIII. RESULTS AND DISCUSSION

The proposed IoT-based autonomous agricultural machinery control system integrated with TRIZ methodology was successfully implemented and evaluated under varying environmental conditions. The system effectively collected real-time data from sensors measuring soil moisture, temperature, humidity, and light intensity, enabling accurate monitoring of field conditions. Based on this data, the control unit performed autonomous decision-making and activated the necessary actuators, such as water pumps and valves, with high precision.

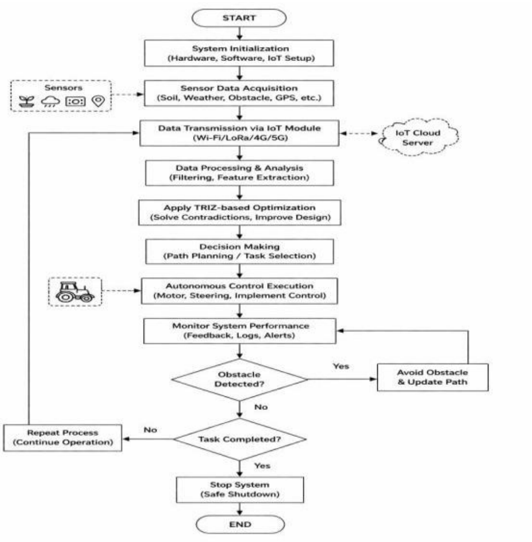

Fig. 2

Step 1 : Initialize system parameters and threshold values Step 2 : Start the system
Step 3 : Collect real-time data from sensors
→ Soil moisture (SM), Temperature (T), Humidity (H), Light (L)
Step 4 : Transmit sensor data to the processing unit Step 5 : Analyze the received data
Step 6 : Compare sensor values with predefined threshold values
Step 7 : Apply TRIZ-based optimization
→ Resolve contradictions (e.g., maximize yield vs minimize water usage)
→ Determine optimal action Step 8 : Decision Making:

- If (SM < Threshold) → Irrigation Required
- Else → No Irrigation Step 9 : Generate control signals Step 10: Actuate devices
- Turn ON/OFF water pump
- Control valves and motors

Step 11: Send system status to user via IoT interface Step 12: Receive feedback from sensors
Step 13: Update system parameters if required Step 14: Repeat steps 3–13 continuously (loop)
Step 15: Stop system (if manual override or fault detected)

The results demonstrate that the system significantly improves irrigation efficiency by supplying water only when required, thereby reducing water wastage compared to conventional methods. The integration of IoT technology enabled continuous monitoring and remote access, allowing users to track system performance and control operations in real time. Furthermore, the system exhibited fast response time and reliable operation due to efficient data processing and threshold-based control.

The incorporation of TRIZ methodology played a vital role in optimizing system performance by resolving key contradictions, such as achieving maximum crop productivity while minimizing water and energy consumption. This led to enhanced resource utilization and improved overall efficiency. Additionally, the system reduced the need for manual intervention, making it suitable for modern precision agriculture.

However, certain limitations were observed, including dependency on network connectivity for remote monitoring and the need for periodic sensor calibration to maintain accuracy. Despite these challenges, the proposed system provides a cost-effective, scalable, and intelligent solution for agricultural automation. Overall, the results confirm that the integration of IoT and TRIZ significantly enhances the performance, adaptability, and sustainability of agricultural machinery control systems.

IX. CONCLUSION

This paper presented the design and optimization of an autonomous agricultural machinery control system by integrating Internet of Things (IoT) technology with the TRIZ (Theory of Inventive Problem Solving) methodology. The proposed system successfully enables real-time monitoring, intelligent decision-making, and automated control of agricultural operations, thereby addressing the limitations of conventional farming systems.

The implementation results demonstrate that the system effectively reduces water and energy consumption through optimized resource utilization while maintaining optimal soil and environmental conditions. The IoT-based framework ensures continuous data acquisition and remote accessibility, enhancing system flexibility and user convenience. Furthermore, the application of TRIZ principles contributes to resolving key operational contradictions, leading to improved system efficiency and performance.

Overall, the proposed system offers a cost-effective, scalable, and reliable solution for precision agriculture. It minimizes human intervention, improves productivity, and supports sustainable farming practices. The integration of IoT and TRIZ provides a novel approach to agricultural automation, making the system suitable for modern smart farming applications.

X. FUTURE WORK

Future enhancements of the proposed system can focus on improving intelligence, scalability, and real-world adaptability. The integration of advanced **Artificial Intelligence (AI)** and **Machine Learning (ML)** algorithms can enable predictive decision-making, crop health analysis, and adaptive path planning based on environmental conditions. Additionally, the incorporation of computer vision techniques can further enhance obstacle detection, crop classification, and yield estimation capabilities.

The system can also be extended by integrating **edge computing** to reduce latency and ensure faster processing of real-time data, especially in remote agricultural areas with limited connectivity. Energy optimization techniques, including solar-powered systems and efficient battery management, can be implemented to improve sustainability and operational duration.

Moreover, future research can explore multi-machine coordination and swarm-based autonomous farming systems to enhance large-scale agricultural productivity. The application of advanced communication technologies such as 5G can further improve data transmission reliability and system responsiveness. Finally, real-time field testing and large-scale deployment will be essential to validate system performance, reliability, and economic feasibility under diverse agricultural conditions.

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