Research

Design and implementation of a wireless communication-based sprinkler irrigation system with seed sowing functionality

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Abstract
This study addresses the critical health risks faced by farmers owing to the use of harmful chemical pesticides in agriculture. The primary objective is to create an effective solution to minimize these risks and reduce the use of pesticides. To achieve this, a smart irrigation system has been implemented by connecting various sensors, such as moisture sensors and thermal imagers through the Internet of Things. These sensors collect vital data on crop moisture levels and thermal images that are securely stored in a cloud-based system. The data collected were subjected to extensive analysis to ensure accurate pesticide use and to identify specific pests affecting crops. In addition, the smart irrigation system includes an Android phone for remote monitoring and pesticide spray detection, thus offering a convenient remote-based operating system for farmers. This innovative system not only proved to be cost-effective but also proved to be significantly more efficient than traditional methods, resulting in reduced labor costs. Importantly, it not only addressed the health risks associated with pesticide use but also led to a significant reduction in overall pesticide use in agriculture. This research provides a comprehensive and effective approach to address the health risks farmers face from harmful pesticides, thereby promoting sustainable and safe farming practices for the future.

Article Highlights

- Agriculture revolution: Agricultural resource utilization and environmental impacts will be minimized using Bluetooth-controlled disinfectant spraying robots and wireless irrigation systems. This innovative approach fundamentally transforms crop management by improving crop health, reducing pesticide use, and conserving waterthis innovative approach fundamentally transforms crop management.
- Cost-Effective and Eco-Friendly: The system is also attractive from a financial standpoint because of its transformative potential and cost savings. By reducing labor costs and pesticide expenses, agricultural operations of all sizes can promote sustainable and eco-friendly agriculture.
- Adaptability in rural and urban areas: A game changer for modern agriculture is that this system can be

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adapted to both urban and suburban settings. A broader range of users will benefit from efficient and controlled irrigation, allowing resource conservation and precise pesticide application without the drawbacks of traditional equipment. In contemporary urban and suburban farming landscapes, this adaptability reflects growing interest in urban agriculture and sustainable food production.

Keywords Agriculture · Internet of Things · Health risks · Pesticides

1 Introduction

Agriculture is the backbone of the country's economy and food security, accounting for nearly 60% of India's population [1]. This sector has historically adapted to changing climatic conditions and available resources to meet the ever-increasing food demands of a growing population [2]. However, the relentless pursuit of greater agricultural productivity often necessitates extensive use of pesticides, leading to complex challenges related to pest management, crop diseases, and environmental factors [3].

In recent years, the combination of agricultural mechanization and expanded farm acreage has made these challenges increasingly untenable for manual management. Farmers use a variety of pest control methods, ranging from manual pesticide application through backpack sprayers to indiscriminate spraying implemented through tractor-mounted systems [4]. Despite their effectiveness, these methods present inherent risks and require strict safety precautions [5].

The advent of robotics and automation technologies has ushered in a new era in agriculture, offering innovative solutions to these challenges [6]. Agricultural vehicles with advanced capabilities, including navigation, detection, and operation, have emerged as indispensable assets in contemporary farming practices [7]. These vehicles can seamlessly execute a wide range of tasks, from basic agricultural operations to the early detection of plant diseases, which is an indispensable part of preventing widespread crop damage [8].

Conventional approaches to the identification and classification of plant diseases have traditionally relied on expert visual inspection, a method characterized by its cost and time-intensive nature [9]. However, technological advances, particularly in image and video processing, have paved the way for automation of disease detection and control [10]. These state-of-the-art technologies leverage the variations in crop color induced by invading pathogens to automatically detect and classify plant diseases [11]. This revolutionary development not only increases accuracy but also reduces the burden on labor and financial resources.

In many developing countries, plant diseases are a serious threat to agricultural productivity and result in reduced crop quality and quantity. Automated systems designed for disease detection and control represent promising solutions for reducing these risks [12]. Moreover, the integration of automation in agriculture aligns with a critical need to ensure the safety of human operators. This system, combined with automation and robotics, reduces direct contact with harmful chemicals, minimizes manual pesticide application, targets pesticides using real-time sensor data, and enhances safety through remote monitoring, thus decreasing pesticide usage and exposure risks in agriculture. This study explored the integration of automation and robotics in agriculture, with particular emphasis on reducing pesticide use, increasing safety, and enhancing crop health. By surveying the current landscape of agricultural robotics and advances in disease detection and control, this study underscores the novel and urgent potential of these technologies to drive the transformation of modern agricultural practices, reduce environmental impacts, and strengthen food security. This study presents an analysis of modern agricultural technologies in Indian farming. We then explore innovative advances in disease diagnosis and productivity enhancement in Sect. 2. The development of agricultural robots is described in Sect. 3, emphasizing health risk reduction as a part of the systematic methodology. An overview of the robot's operation is provided in Sect. 4. A robot control flowchart is presented in Sect. 5, and the sprinkler irrigation system is discussed in Sect. 6. Section 7 discusses the results and benefits of innovative resource management and cost-savings. We conclude Sect. 9 with a discussion of ways to reduce the environmental impact of agriculture. Both urban and suburban settings benefit from the system's low-noise performance and environmental friendliness. In addition to providing a seamless and eco-conscious solution for urban and suburban environments, it offers the advantages of efficient and controlled irrigation.

2 Literature review

The challenges of reducing the environmental and health consequences of agrochemicals and maintaining agricultural productivity have led to significant technological advances. Nicolopoulou-Stamati et al. [13] emphasized the adverse effects of agrochemicals on both human health and the ecosystem but acknowledged their role in ensuring food security. To address these critical concerns, researchers have pioneered innovative technologies aimed at reducing agrochemical effects and optimizing crop yields.

Among these innovations, the dropleaf technique [14] uses water-sensitive markers to accurately estimate the coverage area, particularly during insecticide spraying. By enhancing the accuracy of pesticide application, this approach not only reduces waste, but also demonstrates the potential of employing environmentally sustainable practices.

Kotkar et al. [15] proposed an automatic insecticide spraying system that uses convolutional neural network (CNN) algorithms to diagnose plant diseases promptly and accurately. The combination of advanced machine learning techniques with agriculture has potential for targeted and effective pest management.

Automation has found a place in this quest, as demonstrated by Suganya and Jayaranjani [16], who introduced a solar-powered agricultural machine that can streamline agricultural operations, thereby reducing dependence on renewable energy sources and the environmental footprint. Furthermore, Chand et al. [17] presented an intelligent multipurpose agricultural robot (MpSFR) that uses IoT and computer vision (CV) technology to perform tasks ranging from precision pesticide spraying to irrigation.

Advances in automation and robotics have shaped modern agriculture. Chaitanya et al. [18] design an automated system for pesticide treatment with L293d motor driver, Raspberry Pi3 system and robot. This integration not only enhances efficiency, but also reduces human exposure to harmful chemicals.

Recognizing the need for sustainable solutions, Ramesh et al. [19] emphasized the need for cost-effective solar-powered technologies to protect crops and reduce losses. Similarly, Chaudhary et al. and Olabanji, Olayinka Mohammed [20, 21] introduced an intelligent robotic insecticide spraying system that uses a Node MCU microcontroller as the core to reduce direct human contact with pesticides, while increasing productivity.

Furthermore, the incorporation of Internet of Things (IoT) technology in agriculture, highlighted by Suganya et al. [22], has the potential to optimize resource use by providing accurate nutrient requirement estimates and enabling real-time monitoring of land and crop conditions, thereby reducing labor and input costs.

The nexus between technology and agriculture promotes the development of sustainable and efficient agricultural practices. These advances, exemplified by Kumbhare et al. [23] and Sai Yeswant et al. [24], show promise in reducing the environmental impact, ensuring food safety, and enhancing occupational safety for agricultural workers. In this innovation landscape, this literature review emphasizes the importance of novel solutions that can reshape the future of agriculture.

3 Methodology

This study provides a methodological framework for developing a robotic model designed for agricultural applications with a focus on reducing the health risks associated with conventional agricultural practices. The methodology includes the following key steps.

(1) *Robotic Model Assembly*: The construction of the robotic model includes the integration of essential components, including the Bluetooth module, ATMEGA328 microcontroller, DC motors for motion control, and specialized mechanisms for functions, such as weeding, pesticide application, and irrigation.
(2) *Control Mechanism:* A Bluetooth module was used to facilitate remote control of the robotic system through an Android application interface. The coordination of the ATMEGA328 microcontroller, Bluetooth module, and DC motors enabled precise control. The data received through the Bluetooth module served as the input to the microcontroller, which orchestrated the movement of the robot.
(3) *Motion Control*: The robot's locomotion is achieved using the L293DN IC motor driver, which allows seamless control of forward, backward, right, and left movements.
(4) *Functional Abilities*: The robotic model is equipped with a suite of functional elements such as a rotating blade for weed management, coupled wheels for ease of movement, pesticide delivery system, and water pump for irrigation purposes.
(5) *System Architecture*: The architectural design of the system is represented graphically in Fig. 1, providing an overview of the component interconnections and data flow in the system.
(6) *Software Platform*: Robotic model development and programming were performed on the Arduino platform, providing a user-friendly interface for control via a mobile application.
(7) *Programming Language*: The control algorithm is implemented using the embedded C language, ensuring efficient communication and coordination between the microcontroller, Bluetooth module, and robot motor.
(8) *Arduino platform*: The Arduino Integrated Development Environment (IDE), based on the Java programming language, serves as a software platform for coding and uploading algorithms to the microcontroller.

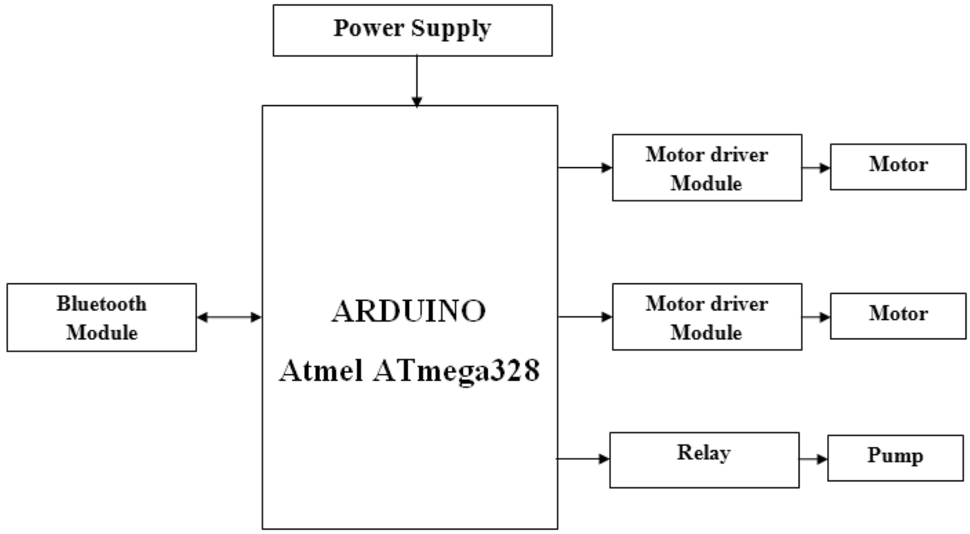

Fig. 1 Block diagram of the proposed work

(9) *Open-Source Philosophy*: The project conforms to the open-source hardware and software principles of the Arduino community, allowing the distribution of products under open licenses. Commercial assembly and do-it-yourself (DIY) kit options are available to promote accessibility and adaptability.

(10) *Reproduction and Innovation*: The methodology was designed to ensure reproducibility, allowing researchers to replicate and validate a robotic model for agricultural applications. An innovative aspect of this approach is the use of readily available components and open-source platforms to develop autonomous agricultural robots, contributing to the evolution of sustainable and technology-driven farming practices.

In summary, this methodology not only provides a systematic approach to the development of an optimized robotic model for agricultural tasks, but also emphasizes its novelty in introducing state-of-the-art automation solutions to the agricultural sector. It emphasizes the potential to revolutionize ancient agricultural practices by providing innovation and technology, while addressing contemporary challenges in the agricultural sector.

4 Module description

The system under consideration comprises of embedded C language, Arduino microcontrollers, power sources, DC motors, motor drivers, Bluetooth modules, and Automatic Speech Recognition (AMR) capabilities. In Fig. 2 shows the Proposed Assembling of Hardware Schematic.

4.1 Arduino controller

The Arduino boards use AVR microcontrollers with varying amounts of flash memory, pins, and features as shown in Fig. 3. The 32-bit Arduino Due, based on the Atmel SAM3X8E, was introduced in 2012. The boards use pins or female headers that facilitate connections for programming and incorporation into other circuits. These may connect with add-on modules termed shields. Most boards include a 5 V linear regulator and a 16 MHz crystal oscillator or ceramic resonator. Some designs run at 8 MHz and dispense with the onboard voltage regulator due to specific form-factor restrictions.

4.2 Power supply

A power supply is a device that provides electrical or other forms of energy to an output load or group of loads. Typically, the term "power supply unit" or PSU is used to describe such devices or systems. Although power supplies can provide various types of energy, the term is most frequently associated with electrical power supplies, and less commonly with mechanical or other types of energy.

The power supply section is an essential component that converts the incoming AC signal to a DC signal while reducing the signal's amplitude. In particular, the AC voltage signal from the mains (230 V/50 Hz) needs to be converted to a DC voltage (with no frequency) with an amplitude of + 5 and + 12 V for various applications. This section typically includes a transformer and bridge rectifier, which are connected in series. The output is then passed through voltage regulators for + 5 and + 12 V (7805 and 7812), connected in parallel via a capacitor (1000 μF), as shown in the circuit diagram in Fig. 4.

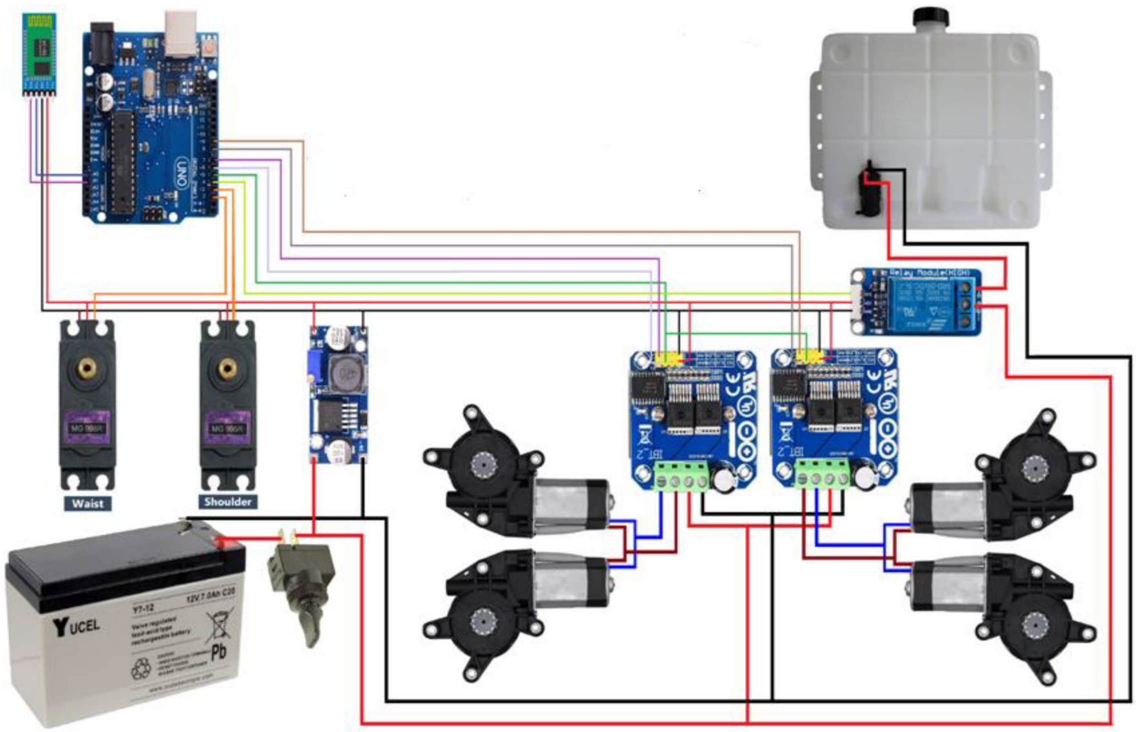

Fig. 2 Proposed assembling of hardware schematic

Fig. 3 Arduino controller

Each voltage regulator's output is again connected to a set of capacitors (100, 10, 1, 0.1) connected in parallel, from which the corresponding output (+ 5 or + 12 V) is taken into consideration. Overall, the power supply section plays a crucial role in providing stable and reliable DC voltage signals to power the various components of the circuit.

4.3 DC motor

A DC motor is a mechanical device that converts electrical energy into mechanical energy. To understand the operating principle of a DC motor, it is essential to comprehend Fleming's left-hand rule, which determines the direction of force on the armature conductors of a DC motor. According to this rule, when the index finger, middle finger, and thumb of the left hand are extended in a way that the current-carrying conductor is placed in a magnetic field (represented by the index finger) that is perpendicular to the direction of current (represented by the middle finger), the conductor experiences a force in a direction (represented by the thumb) that is mutually perpendicular to the direction of the field and the current in the conductor. Figure 5 shows the circuit diagram of the DC motor.

4.4 L293D IC motor driver

The L293 and L293D are electronic components that function as quadruple high-current half-H drivers. These devices are capable of bidirectional drive currents of up to 1 A, with a voltage range of 4.5 to 36 V. The L293 and L293D have a temperature range of 0 to 70 °C for operation. Each

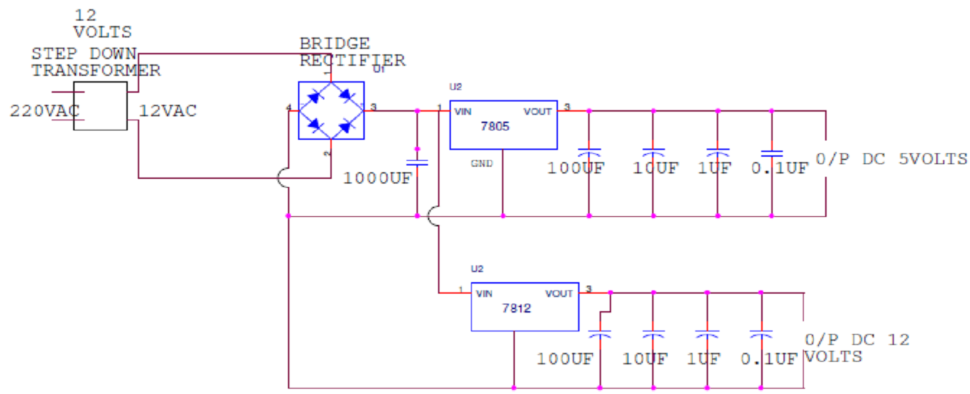

Fig. 4 Power supply circuit diagram

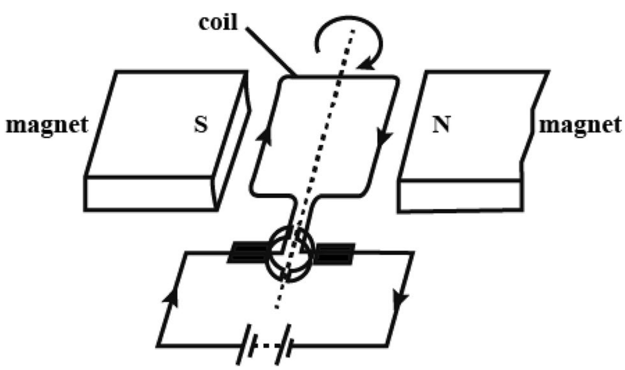

Fig. 5 Circuit diagram of the DC motor

output of the L293 and L293D is a complete totem-pole drive circuit, consisting of a Darlington transistor sink and a pseudo-Darlington source. The drivers are enabled in pairs, with drivers 1 and 2 enabled by 1,2EN, and drivers 3 and 4 enabled by 3,4EN. The L293D IC Motor Driver is shown in Fig. 6 shows the circuit diagram.

4.5 HC-05 serial bluetooth module

Bluetooth is a wireless communication technology that enables the interconnection of mobile phones, PDAs, and personal computers using short-range wireless connections. Bluetooth modules chips can be used to establish wireless communication between two devices, with each device having its unique MAC address. The HC-05 module, depicted in the Fig. 7, is an easy-to-use Bluetooth Serial Port Protocol module that facilitates a wireless serial connection setup. The module operates using the silicon radio BC417 2.4 GHz Bluetooth chip with CMOS technology and employs an external 8 MB flash memory. The HC-05 module requires a 3.3 V power supply. It is noteworthy that the HC-05 module is widely used in various applications, such as wireless control and data transfer, among others.

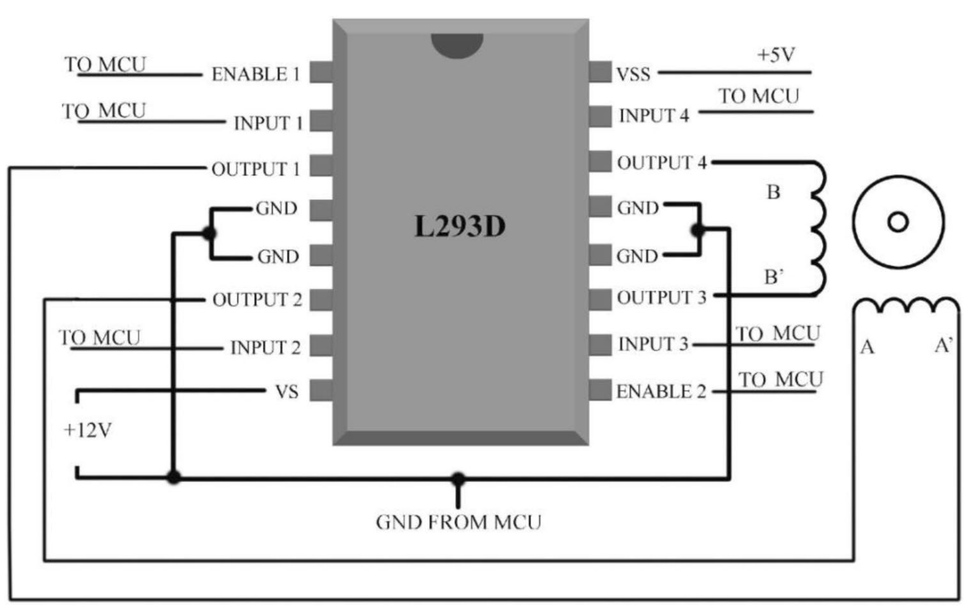

Fig. 6 The circuit diagram of L293D IC Motor Driver

Fig. 7 Bluetooth Module

4.6 Android (AMR voice) app

The present study establishes that voice commands for the robot are analyzed via an android application and transmitted through Bluetooth [25]. After thorough deliberation, the research team opted for an Android OS interface as the speech processing platform, owing to its versatile and extensive functionalities. Furthermore, this platform facilitates a seamless and dependable association with the Google Speech processing libraries, ensuring seamless and precise speech recognition. Andriod application as shown in Fig. 8.

Fig. 8 Android application for voice recognition

5 Flowchart for robot operation

The operation of the robot using Bluetooth control involves several steps, which are illustrated in the flowchart in Fig. 9. The following is a description of the steps:

(1) Start: The process starts with the initiation of the robot system.
(2) Initialize port: The ports of the system are initialized to ensure that they are ready to receive data.
(3) Initialize Bluetooth: The Bluetooth module is initialized to enable wireless communication between the robot and the control device.
(4) Wait for Bluetooth data: The system waits for data to be received via Bluetooth from the control device.
(5) If data received (Yes/No): The system checks whether data has been received. If data has been received, it proceeds to the next step. If not, it goes back to step 4 to wait for data.

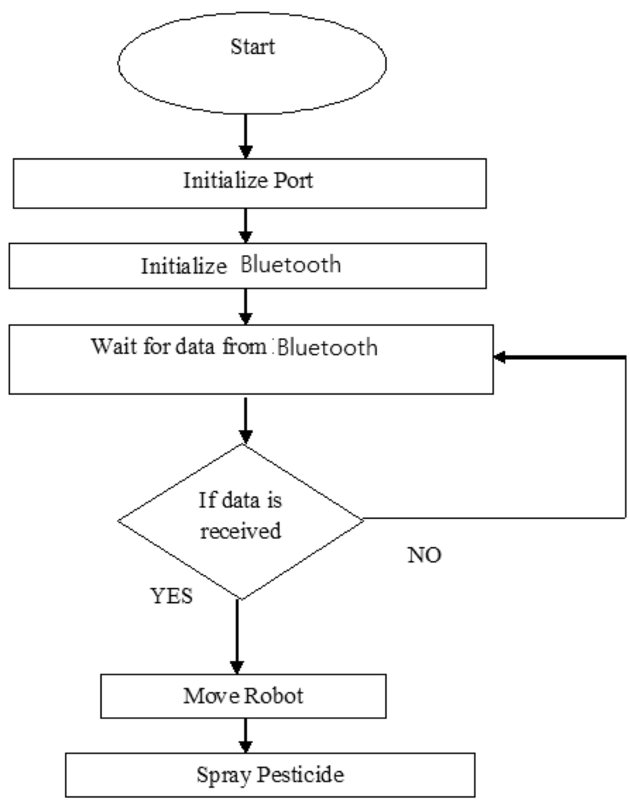

Fig. 9 Flowcharts for robot operation

(6) If Yes: If data has been received, the system executes the command received to move the robot and spray pesticide.
(7) End: The process is terminated.

This flowchart provides a clear representation of the steps involved in controlling the robot using Bluetooth. It enables easy understanding and implementation of the system by users, thereby enhancing the efficiency of the robot control system.

6 Construction of a sprinkler irrigation system

The sprinkler irrigation system follows a systematic approach, drawing valuable insights from the flowcharts in Fig. 9, which were originally designed for robotic operation. This methodology ensures a well-structured developmental process. During the system design and planning phases, we used the logic of the flowchart to accurately determine sprinkler head positions, sensor placements, and irrigation coverage areas. During the hardware assembly, we interface the Arduino microcontroller with an embedded C code to establish control over the DC motors for precise movement. Inspired by the flowchart principles, we optimized the motor control, used Bluetooth for remote access, and integrated sensors, such as soil moisture and temperature sensors, to improve system intelligence. The sprinkler heads and piping were strategically placed for uniform water distribution. Optionally, Automatic Speech Recognition (AMR) can be used for voice control. Rigorous testing, motivated by the care of the flowchart, validates system functionality, followed by fine-tuning for optimization. After successful testing, the system was implemented and maintained for long-term irrigation.

We adopted the structural approach from the robot operation flowcharts shown in Fig. 9 for our construction approach, as shown in Fig. 10. Our approach introduces innovations in irrigation technology through the use of a sprinkler irrigation system. By following the logic of the flowchart, we precisely planned and designed the system by strategically placing sprinkler heads and sensors. The hardware assembly is guided by flowchart principles, which include the Arduino microcontrollers, embedded C code, and precision motor control. Bluetooth communication improves remote access, and advanced sensors provide intelligent irrigation decisions that reflect a streamlined approach to robot operation. The sprinkler setup ensures a uniform water distribution, and for added innovation, automatic speech recognition (AMR) is integrated for voice control. Rigorous testing was used to verify the functionality of the system, followed by fine-tuning for optimal performance. With expansion and ongoing maintenance, this innovative sprinkler irrigation system ensures efficient and reliable irrigation.

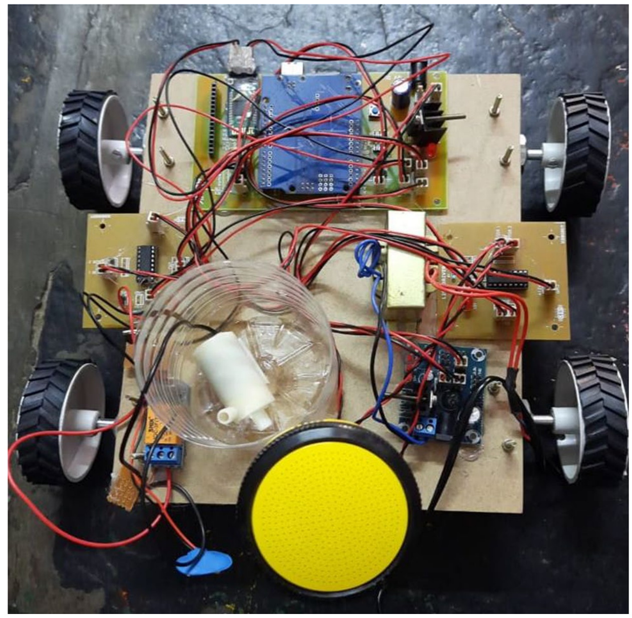

Fig. 10 Sprinkler irrigation system (40 × 30 × 40 cm)

7 Results and discussion

The integration of a wireless communication-based sprinkler irrigation system using Bluetooth mobile technology provides a new approach for agricultural development. Although specific empirical data and comparative analyses have yet to be provided, the anticipated outcomes and potential contributions of this project are discussed below, emphasizing their novelty and relevance in the agricultural research landscape.

7.1 Innovative crop management

This project introduces an innovative approach to crop management through a wireless irrigation system. By combining wireless technology and irrigation, farmers have the potential to revolutionize the way they manage their crops, optimize water use, and promote sustainability.

7.2 Environmental sustainability

The system's use of renewable energy sources not only reduces its carbon footprint but also represents a novel and environmentally conscious approach. This aligns with the global push for sustainable agricultural practices, contributing to reduced air pollution and a more sustainable ecosystem.

7.3 Cost-effective accessibility

The project's emphasis on cost-effectiveness will improve the accessibility of modern irrigation technology, especially in resource-constrained areas. This aspect of accessibility is novel and represents a critical need for developing countries. Table 1 shows the cost estimation between the proposed work and previous work, as well as the proposed equipment, which is suitable for small- and medium-sized forms of land.

7.4 Efficiency and productivity

The integration of automation and remote monitoring offers a new path to improved efficiency and productivity in agriculture. Reducing labor requirements and optimizing irrigation processes holds the promise of improving crop yields and economic outcomes for farmers.

7.5 Urban and suburban adaptability

The adaptability of the system to urban and suburban areas without producing air pollution or noise represents a new solution for modern agriculture. This represents growing interest in urban agriculture and sustainable food production.

7.6 Integrated agricultural solutions

The proposed integration of this irrigation system with an agricultural pesticide robot represents an integrated approach to agricultural modernization shown in Vedio 1. This combination of technologies is new and represents a comprehensive solution to contemporary agricultural challenges.

Although specific empirical data and comparative analyses are pending, the benefits and potential impacts of this wireless communication-based sprinkler irrigation system underscore its novelty and potential in agriculture. This innovative agricultural approach offers a multitude of benefits. First, it promotes efficient water use by optimizing distribution and minimizing waste, thereby contributing to water conservation efforts. Furthermore, it aligns with the principles of environmental sustainability, incorporating renewable energy sources to reduce air pollution and lessen the environmental impact of farming. Additionally, this method holds the potential for

Video 1 Sample video moment of sprinkler irrigation system

Table 1 Cost estimation between proposed and previous work in Indian currency (Rupees)

Description	Conventional method (10 Acres) [23]	Automatic pesticide spraying machine (10 Acres) [23]	Automatic pesticide spraying and seeding machine 1 (10 Acres)
Pesticides	5 Liters	4 Liters	5 Liters
Pesticides cost (in rupees)	5*2000 = Rs 10,000/-	4*2000 = Rs 8000/-	5*2000 = Rs 10,000/-
Labor charge	1 Day = Rs. 300/-	1 Day = Rs. 300/-	1 Day = Rs. 300/-
Number of labors	3	1	1
Number of working days	8	2	1.5
Number of cycles	5	5	5
Total charges of labor (in rupees)	Rs 36,000/-	Rs 3000/-	Rs 2250/-
Machine Cost (in rupees)	Rs 3000/- per day rent	Rs 35,000/-	Rs 4500/-
Working charges of battery (in rupees)	–	Rs 600/-	Rs 600/-
Annual maintains (in rupees)	Rs 500/-	Rs 250/-	Rs 250/-
Total Cost (in rupees)	Rs 55,500/-	Rs 46,850/-	Rs 17,600/-
Cost saved (in rupees)			Rs 29,250/-

substantial cost savings for farmers, as it can reduce labor and pesticide expenses. Finally, it enhances crop health and yields through precision irrigation and pesticide application, ultimately improving the overall sustainability and productivity of agricultural practices. Further research and empirical validation are required to confirm these hypothesized results and to place this finding in the context of similar studies in the field.

8 Contributions and innovations

By wirelessly controlling pesticide sprayers and watering sprinklers using Bluetooth communication, this innovative crop management method revolutionizes resource conservation by optimizing crop resources. Automated irrigation and the integration of renewable energy sources ensure accessibility and environmental sustainability, whereas the use of precise irrigation technologies minimizes pesticide and water waste. The significant cost savings offered by this method make it economically attractive to farmers. As a transformative approach to sustainable agriculture, it offers the potential to increase crop yields, reduce environmental impacts, and boost profitability.

9 Conclusion and scope of future work

The integration of a wireless communication-based sprinkler irrigation system with the proposed Bluetooth-controlled disinfectant-spraying robot represents a groundbreaking solution to revolutionize contemporary irrigation practices. Although precision irrigation technologies have been explored, this innovation marks a significant departure by introducing real-time data and adaptive algorithms to redefine crop management. This data-driven approach opens new avenues for scientific inquiry, encouraging researchers to delve deeper into the nuances of data-centric agriculture and to drive this field forward. In addition, the system's focus on sustainable resource management presents an intriguing research frontier. By employing precise water distribution and eco-friendly engineering, a symbiotic relationship between technology and environmental consciousness is established. Researchers have explored the implications of sustainable resource management in agriculture, pushing the boundaries of environmentally focused engineering solutions. This system serves as a beacon of hope for reducing the environmental impact of agricultural practices and stimulating further research on sustainable agricultural solutions. This integration represents a significant step forward in precision agriculture, urging the scientific community to embark on the journey of discovery and innovation.

The challenges in automating algorithms include scalability and system reliability in the face of varying environmental conditions, while opportunities lie in improving pest and disease detection accuracy with artificial intelligence and machine learning, exploring alternative energy sources, and refining remote control systems.

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Data Availability All data generated or analyzed during this study are included in this published article.

Declarations

Conflict of interests The authors have not disclosed any competing interests..

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