

IOT-ENABLED AGRICULTURAL ROVER FOR REMOTE CHEMICAL SPRAYING AND MANAGEMENT

¹ Dr. Nagesh H, ²Abhishek S Kotagi, ³Adarsh, ⁴ Goutam Kulkarni, ⁵ Shreyas H C

¹Assoc. Professor, ^{2,3,4,5}B.E. Student

^{1,2,3,4,5}Department of Electrical & Electronics Engineering,

^{1,2,3,4,5}Acharya Institute of Technology, Bengaluru, India

Abstract: Efficient and safe pesticide application remains a major challenge in modern agriculture, as conventional manual spraying exposes operators to harmful chemicals and often results in uneven distribution. This paper presents the design and development of an Internet of Things (IoT)-based agricultural rover that automates pesticide preparation, dispensing, and field monitoring, while enabling full remote operation. The proposed system integrates multiple embedded controllers: a Raspberry Pi for video streaming and user interface management, an ESP32 microcontroller for solenoid valve actuation and automated mixing control, and an Arduino Nano for navigation and liquid-level sensing.

A web-based dashboard with live video streaming and intuitive control options (WASD and joystick interface) allows farmers to operate the rover remotely, ensuring user safety and improved accuracy in spraying operations. The rover is powered by a solar-assisted battery, enabling off-grid operation and extended field deployment. Field experiments conducted on varying terrains demonstrated reliable mobility, rapid control response times (80–120 ms), and stable wireless communication (<50 ms internal and ~150–300 ms remote latency). The system achieved a consistent runtime of 1.5–2 hours under moderate solar input.

Experimental evaluations confirmed uniform pesticide application in both manual and automated modes, validating the rover's efficiency and precision. By minimizing human exposure and chemical wastage, this IoT-enabled agricultural rover offers a sustainable, safe, and cost-effective alternative to traditional pesticide spraying techniques.

I. INTRODUCTION

Agriculture still uses manual labour in the full performance of its activities like pesticides spraying and field surveillance. Such traditional methods are labour-consuming, time consuming, and farmers are exposed to agro chemicals that are very hazardous. Also, the manual spraying usually causes uneven distribution of chemicals, causing over- and under-application at the same time to the crops, which negatively impacts the crop production, decreases the usage of chemicals, and presents severe environmental hazards [1], [4].

New developments in agricultural robotics and precision spraying technologies have shown that these challenges can be overcome through better spray accuracy and a lowered role of manpower. The research into intelligent spraying systems and site-specific application techniques can point to the fact that chemical efficiency and crop protection can be greatly improved when automation and sensing technologies are used [1], [3], [5]. Simultaneously, the precision spraying has been increased with the efficiency of deep learning-based weed and crop recognition approaches that allow the researcher to apply chemicals to specific areas [4], [6].

The increasing need to pursue sustainable farming methods, as well as the lack of labour, have increased the uptake of Internet of Things (IoT), robotics, and renewable energy solutions to agriculture. Smart farming systems that can be implemented with the help of IoT allow tracking changes in real-time, making decisions automatically, and using resources efficiently, which contributes to the current trends in precision farming [7]. Robotic platforms powered by solar energy and consuming less energy have also attracted interest to facilitate agricultural applications on the off-grid remote field settings [8].

In this respect, the proposal is a semi-autonomous IoT-based agricultural rover that can be used to automate the agricultural processes of spraying pesticides and surveying the fields. The system will be aimed at navigating through agricultural lands, video feedback in real-time, as well as manual and automated spraying procedures depending on a set of predetermined conditions. It involves several controllers, including Raspberry Pi Zero W, which controls communication and dashboard, ESP32, which controls solenoid valves and mixing of chemicals, and Arduino Nano, which controls the motor and detects the level of the tank. The use of a web-based control interface that allows live video streaming and WASD navigation will provide an intuitive and remote functionality [2], [4].

The rover has a battery system supported by solar energy, which allows it to work off-the-grid and use the energy sustainably. The proposed system was developed by combining IoT communication, robotic automation, and renewable energy sources, which have led to spraying precision, lessening of chemical exposure, and safety and efficiency of the whole operation in the proposed agricultural spraying application [1], [5], [8]

II. LITERATURE REVIEW

The recent studies in the field of agricultural robotics aimed at increasing the accuracy, efficiency, and safety of the pesticide spraying process. The article by Lochan et al. was a review of the developments in precision spraying robots that included the use of sensing, automation, and intelligent control systems to cut on the waste of chemicals as well as minimize human contact with

pesticides [1]. Their work focused on the increasing presence of robotics contributes to the realization of sustainable and site-specific agricultural spraying.

Intelligent spraying robots have been evaluated at field level, and it has been shown that the accuracy of spraying and the coverage of the crop have greatly improved. Seol et al. designed and experimented with a deep learning-based spraying robot with adaptive flow control on pear orchards demonstrating that automation of flow control and perception vision-based approach can substantially increase spraying performance when applied to real-life fields [2].

In order to become site-specific in application of pesticides, adjustable and automated spraying systems have been identified as the subject of studies. Berenstein and Edan have offered an automatic adjustable spraying machine that is able to adjust the parameters of spray according to the needs of the field on the fly and, thus, minimizes the use of chemicals and enhances the uniformity of the application [3]. Likewise, Hejaziipoor et al. created an intelligent spraying robot which also regulates the production of pesticides based on the bulk volume of the plants and allows them to target the plants and achieve a reduced environmental impact [5].

Accurate farming systems have also been enhanced through the use of deep learning and image processing methods. Investigating vegetable plantation, Jin et al. showed the effect of the deep learning models in effective weed identification to selectively spray and decrease herbicides [4]. Bharman et al. thoroughly reviewed the deep learning applications in agriculture, which is crucial especially in crop monitoring, weed detection, and automated spraying systems [6].

Smart agriculture through the application of Internet of Things (IoT) technologies has made real time monitoring and automation possible. Karthik et al. talked about IoT-based smart agriculture systems that could help in making data-driven decisions, remote sensing, and enhance farm productivity [7]. Modern agricultural robotic platforms are based on such IoT-based architectures.

Recent research has also been done on real-time accuracy sprayer systems on particular crops. The article by Arsalan et al. presents a real-time precision spraying system of tobacco plants, which shows a higher precision of spraying and a decrease in the amount of chemicals used based on intelligent sensing and control systems [8]. These developments indicate the success of the integration of robotics, sensing and automation in contemporary agricultural spraying tasks.

III. SYSTEM OVERVIEW

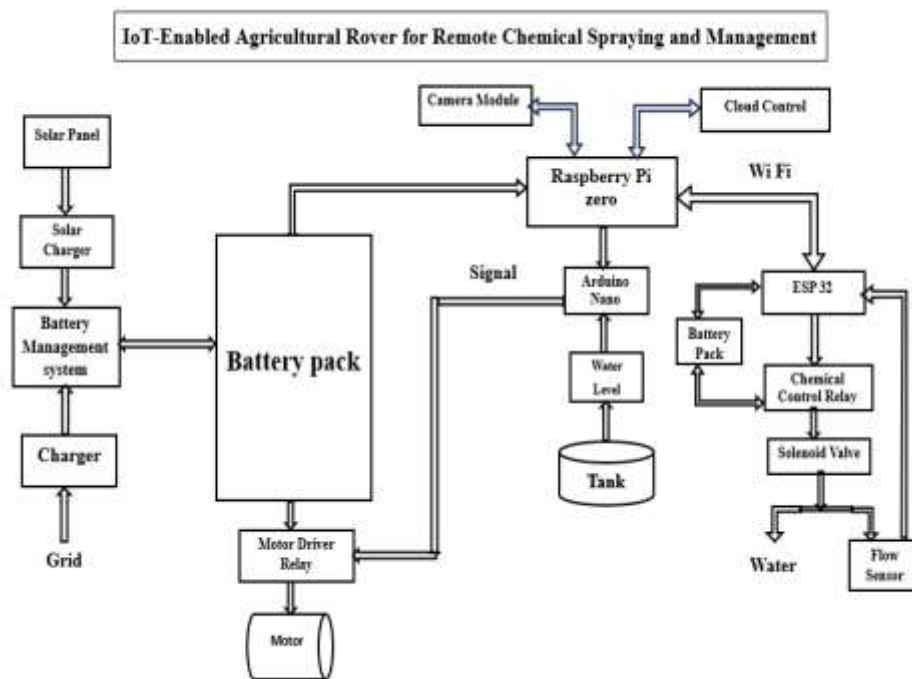


Figure 1. Block diagram

The semi-autonomous IoT-based field rover will be proposed to be used in the practice of pesticide spraying and real-time field observation remotely. The system has incorporated renewable energy, embedded superiority, wireless and a web-based interface, which provides an efficient, safe and sustainable solution to precision agriculture.

The basic building blocks of the system are a solar-powered energy unit that comprises of a solar panel, charge controller, battery management circuit, and rechargeable battery. This will provide constant off-grid power supply by providing stable power to all onboard modules. It also controls the flow of information to subsystems, and this provides the smooth coordination of navigation, spraying and sensor responses to operate the field efficiently. The interface allows easy navigation of the rovers with the use of the keyboard or touch-touch and allowing real-time status of the system, including battery status, tank status, and connectivity

This design gives it accurate speed and direction control and enables the rover to rove with accuracy and motor response to various terrain conditions. The same control type connects to a liquid-level sensor to watch over the level of chemicals and pass information to the dashboard, so the user is aware of the information. A spraying subsystem which is driven by an ESP32 microcontroller controls chemical combination and dispensation. It operates solenoid valves through a relay circuit and flow through a flow sensor.

It supports both manual mode and automatic mode, in manual mode, the operator can be able to have selective control of the chemicals used whereas in automatic mode the ratios of the chemicals are taken care of depending on the type of crops used and the type of environmental conditions chosen by changing the dashboard. The proposed rover, combining both IoT automation with solar-assisted power, will increase the precision of spraying and reduce human services to chemicals, as well as allow operating sustainable farming activities.

Manual operation enables selective control of chemicals automatic mode adjusts ratios of chemicals depending on the type of crop, and environmental conditions chosen using the dashboard automatic modes are provided automatic modes allow the choice of crop type and environmental conditions The suggested rover adds precision to spraying by incorporating IoT automation with solar-assisted power, reduces the amount of human exposure to chemicals, and ensures sustainable farming activities.

IV. EXPERIMENTAL SETUP

The design of the IoT-enabled agricultural rover prototype was based on a small four-wheel platform that was able to support electronic components, power modules and chemical storage tanks. Its design focused on the durability, modularity and adaptation to outfield farming conditions.

1. Hardware Configuration

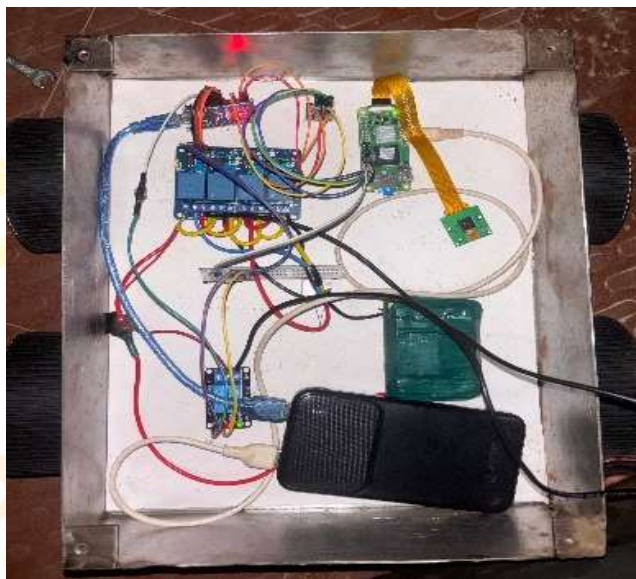


Figure 2. Hardware Connections

The overall design of the control system is supported by three microcontrollers: The Raspberry Pi Zero W, ESP32, and Arduino Nano, which each have distinct functions in order to facilitate coordination of the control system. These microcontrollers work in a model system together, providing effective distribution of tasks, real-time data transfer, and steady operation of the system when used in the field.

Power that is provided by the 12v lithium-ion battery can be recharged using a 15v and 0.3A solar panel interconnected with the solar charge controller, it can be used at the rural areas and in the agriculture fields where there is no other power supply. DC motors of high torque with a motor driver relay are associated with good traction and the motion along with an uneven surface. Metal and waterproof plastic enclosures shelter all the electronic modules to be secure against dust or moisture and chemical exposure. The spraying component has a flow sensor, a liquid level sensor, and solenoid valves in the spraying assembly that monitor the conditions of the tank and regulate the discharge of the fluid. The wiring and cable routing was planned based on the use of flexible conduits to enhance the safety and facilitate the maintenance process.

Research Through Innovation

2. Software Architecture



Figure 3. Web Dashboard Interface

This system had a software architecture that was shared among the three controllers to be moderately functional and to provide these controllers an effective communication module.

1. The central control centre is the Raspberry Pi Zero W which is a flask-based web server controlling the dashboard interface. It allows live video plays, control the rover with WASD keys, and sends operational data in the UART and MQTT protocols.
2. Arduino Nano is a programmed embedded C++ sensors board that manages and controls real time navigation by using serial commands to activate motors and check tank levels using analog.
3. The logic of chemical mixing and spraying is controlled by ESP32, which is developed on the ESP-IDF platform and includes the MQTT libraries. It obtains crop season information by MQTT and regulates solenoid valves to the established time patterns to achieve proper chemical blending and application.

3. Field Deployment and Testing

Field testing was done in an external field that was in the farm simulating the real farm conditions. A mobile hotspot was also used to offer Wi-Fi connectivity, with Ngrok tunnelling being used to access the dashboard remotely, securely over the internet. The testing was carried out in four steps:

1. **Navigation Test:** The dashboard was used to test the manual movements of the rover on the WASD commands. The use of UART as a method of motor control was tested in non-hazardous smooth and uneven surfaces to evaluate the responsiveness and stability. **Spraying Test:** To determine the reliability of the flow rate during the spraying process, the accuracy of the switching and the maintenance of the chemical in the solenoid-controlled lines, the dashboard was used to switch the active line per line.
2. **Auto-Mix Evaluation:** The automated spraying was controlled using the preset parameters of crops and seasons. The observation of solenoid valves timing and sequence was done to maintain proper ratios and successful mixing of chemicals.
3. **Communication Validation:** MQTT communication and UART command transmission was carried out by analysing the latency under varying network conditions. Low delay and stable operation were also upheld during testing in the system.

V. FLOWCHART FOR ROVER OPERATIONS

The operational process of the IoT-powered Agricultural Rover is created to make certain that there is a smooth flow between the user interface, control modules, and actuator systems. It is a combination of both manual and automated capabilities that allow users to control the navigation of the rovers and the spraying of chemicals with little effort. The following flowcharts will describe the logical mechanism of the navigation control, automatic chemical mixing, and system coordination.

1. System Architecture Coordination

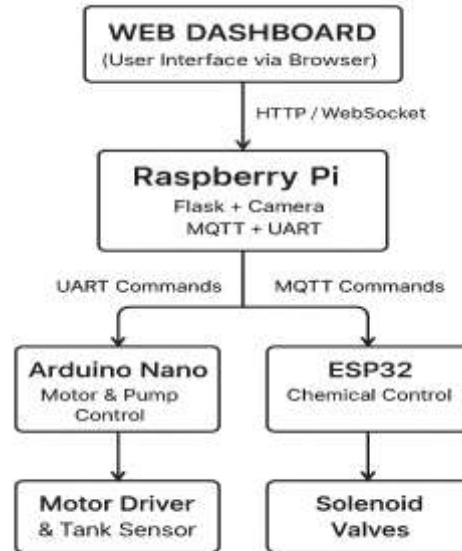


Figure 4. High-Level Architecture Diagram

Three basic microcontrollers co-ordinate with each other in the entire system architecture. Web dashboard, video streaming, and central data management are done by the Raspberry Pi Zero W. Arduino Nano deals with motor control and tank-level sensing whereas ESP32 oversees the work of chemical mixing and spraying. These controllers communicate with each other via serial (UART) and MQTT and make sure that the data exchange and the operation are synchronized. This service-oriented control system will add greater reliability, scalability, and simplicity of troubleshooting in the face of a real-world implementation

2. Navigation Control Flow

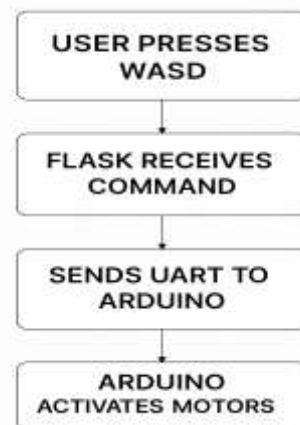


Figure 5. Navigation Flowchart

In the manual mode, the operator inputs the movement instructions (using WASD keys) with the help of the web dashboard interface. The Flask-based backend server that will run to the Raspberry Pi Zero W transmits the user inputs into serial instructions by use of these commands. The motor driver module is controlled by sending the commands on the UART communication to the Arduino Nano where it is interpreted and executed. The Arduino uses the motor relays and the correct motor depending on the command sent to it to move the rover forward, backward, left, or right. The design provides a low-latency level and high-precision control, which means that the manoeuvrability is possible in a real-time in various conditions in the field

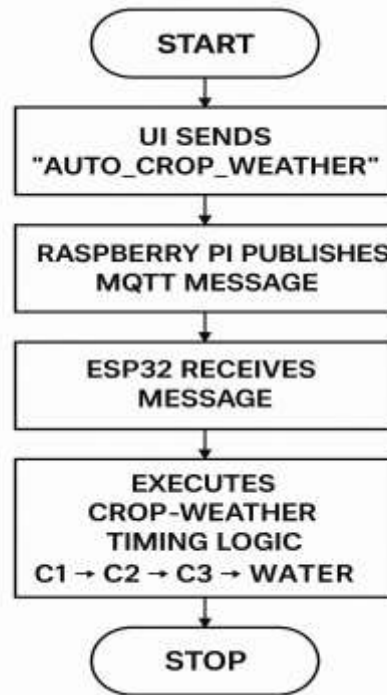


Figure 6. Auto Mix Flowchart

Under automated spraying mode, the operator can choose the crop type and seasonal condition on dropdown options on the dashboard. After the user makes a selection of the configuration, the Raspberry Pi transmits pre-defined instructions on chemical mixing to the ESP32 using the MQTT protocol, which provides the automatic and controlled operation of the spraying process. When the instructions are received, the ESP32 triggers a series of controlled solenoid valves, and the correct amount of pesticides, insecticides, nutrients, and water are dispensed in certain ratios. Valve actuation happens on a programmed crop-weather basis, meaning that chemical blending and accurate application will occur automatically without human intervention. This smart automation is beneficial in resource conservation and enhancing spraying and crop safety.

VI. RESULTS AND DISCUSSION

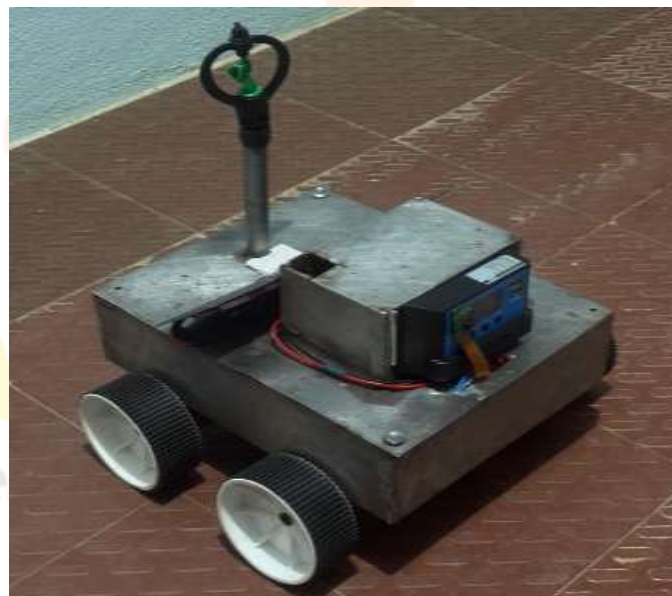


Figure 7. Agricultural Navigation and Spraying Rover

The IoT-based agricultural rover was thoroughly tested on simulated field experiments to prove its capability in navigation, precision of spraying, reliability of communication and functionality of user interface. All subsystems were also tested separately and in harmony with each other to facilitate a smooth integration that would be useful in the field of agriculture.

F. Navigation and Control

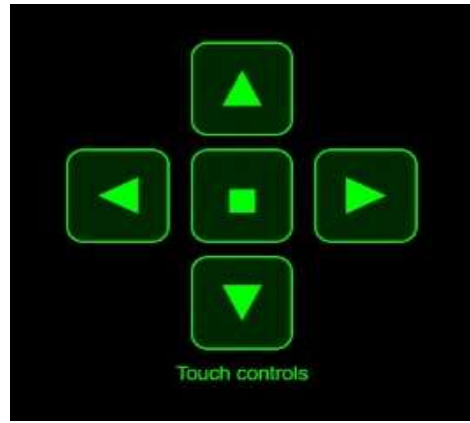


Figure 8. Navigation buttons

The rover was also stable and reliable over flat and fairly rough landscapes. The Arduino Nano controlled high-torque DC motors that gave the robot enough traction and directional accuracy in the process. The commands issued by the web dashboard (either using the keyboard (WASD keys) or touchscreen) were smoother with low latency. The latency between the operator's input and the rover can be considered to be low-latency control as the average reaction time was always less than 300 ms.

The real-time signal transmission and the precision of manoeuvrability were provided with the help of the UART communication between the Raspberry Pi Zero W and Arduino Nano. The orders to stop, reverse and fine directional controls worked correctly indicating the controlled operation is safe even in areas where fragile crop fields are located.

2. Spraying Accuracy and Automation

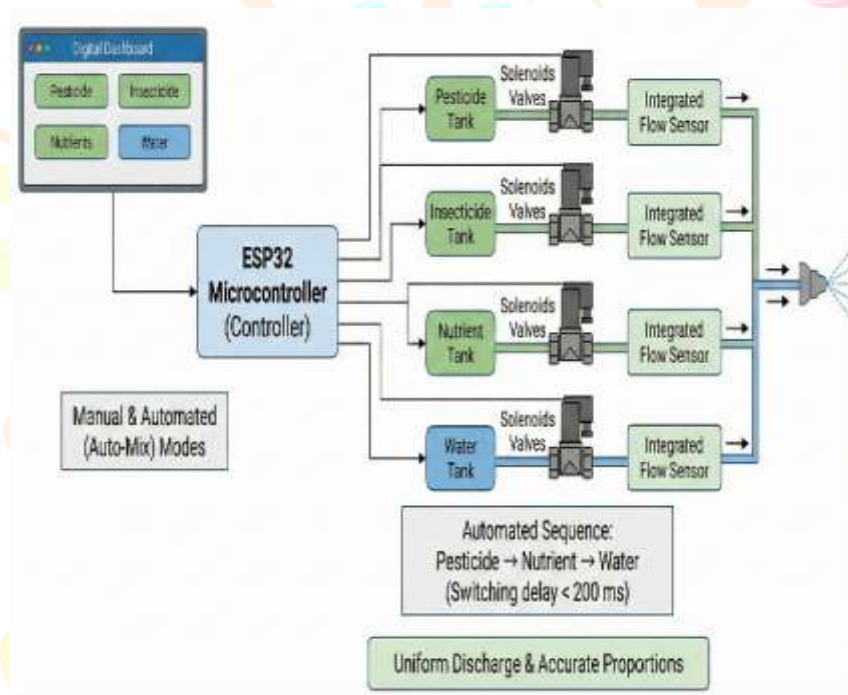


Figure 9. Spraying accuracy and Automation

Performance was evaluated when sprinkles were sprayed in manual and automated mode of operation. Solenoid valves were activated with dashboard buttons in manual mode to selectively dispense pesticide, insecticide, nutrients, water, etc. All the valves were functioning effectively and offered continuous flow rates without wastage or latency. The ESP32 microcontroller in the automated (Auto-Mix) mode ran canned spray patterns depending upon the type of crop and weather conditions chosen via the dashboard. The solenoid valves were switched by a fixed order Pesticide Water Nutrient Pesticide with an average switching delay of less than 200 ms. Flow sensors inbuilt ensured that the rate of discharge and chemical ratios were the same. These findings indicate that the system was capable of allowing the precision and repeatability when the system was automated to spray.

3. Communication Performance

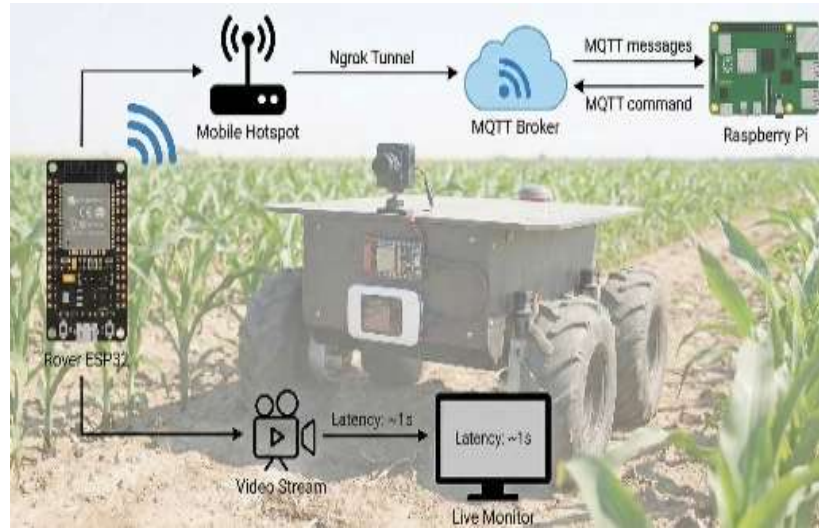


Figure 10. Communication Network

The communication system used MQTT protocol to engage real-time communication between the raspberry pi and ESP32. The system experienced over one hundred trials and delivered more than 98 percent of the messages without a high rate of packet loss or delay. Although the rover was linked to the mobile hotspot and Ngrok tunnelling, it had a steady connection and quality command transfer.

The performance of live video streaming was also satisfactory and average latency of about 1 second was recorded that is good enough to respond to urgent real time field monitoring. It was found that the architecture of communication was strong enough to survive the change of the strength of a network, which validated its applicability to the outdoor agricultural settings.

4. User Interface and Operational Safety



Figure 11. Web Dashboard Interface

The web dashboard interface provided a centralized control to all the rover functions such as the navigation, chemical spraying and living system monitoring functions. The rover was easy to use and accessible to the user since it could be operated by a keyboard or touchscreen with ease. The dashboard made live updates on tank levels, battery health and system reports so that the operator can keep track of the status of the rover and keep the flow running continuously.

An emergency-shut down system was incorporated into the system with a special system called Kill Switch which would automatically shut down all the chemical spraying activities in case of an emergency. Moreover, the fluid height sensor constantly observed the fluid position of the tank that gave real time feedback at 0 percent, 50 percent and 100 percent flask levels. All these safety and monitoring characteristics caused safe, reliable, and easy operational performance of the rover during field testing and improved the operational control and user confidence

VII. CONCLUSION

This paper introduces the creation of a semi-autonomous agricultural rover with an IoT-based computer system that can be remotely controlled, monitored, and automatically sprayed. A distributed control framework that combines Raspberry Pi Zero W with the ESP32 and Arduino Nano provided an efficient task management in motion, spraying, and communication modules.

By integrating MQTT based communication, solar energy and web-based control interface, the system guaranteed reliable and responsive service even in locations where traditional power infrastructure is not available. The rover has manual and automated

spray options, which use the chemical optimally, and reduce the level of exposure of the farmers to dangerous chemicals. Field tests also ensured proper navigation, control and even chemical application. In general, the created prototype is a quality, eco-friendly, and cost-effective solution to precision farming, which demonstrates its possibilities to improve automation and efficiency in contemporary agriculture.

VIII. REFERENCES

- [1] K. Lochan, A. Khan, I. Elsayed, B. Suthar, L. Seneviratne and I. Hussain, "Advancements in Precision Spraying of Agricultural Robots: A Comprehensive Review," in *IEEE Access*, vol. 12, pp. 129447-129483, 2024, doi: 10.1109/ACCESS.2024.3450904.
- [2] Seol, J., Kim, J. & Son, H.I. Field evaluations of a deep learning-based intelligent spraying robot with flow control for pear orchards. *Precision Agric* 23, 712–732 (2022). <https://doi.org/10.1007/s11119-021-09856-1>
- [3] Berenstein, Ron & Edan, Yael. (2017). Automatic Adjustable Spraying Device for Site-Specific Agricultural Application. *IEEE Transactions on Automation Science and Engineering*. PP. 1-10. 10.1109/TASE.2017.2656143.
- [4] Jin, Xiaojun & Che, Jun & Chen, Yong. (2021). Weed Identification Using Deep Learning and Image Processing in Vegetable Plantation. *IEEE Access*. PP. 1-1. 10.1109/ACCESS.2021.3050296.
- [5] Hejazipoor, Hojat & Massah, Jafar & Soryani, Mohsen & Asefpour Vakilian, Keyvan & Chegini, Gholamreza. (2020). An intelligent spraying robot based on plant bulk volume. *Computers and Electronics in Agriculture*. 180. 105859. 10.1016/j.compag.2020.105859.
- [6] Bharman, Pallab & Saad, Sabbir & Khan, Sajib & Jahan, Israt & Ray, Milon & Biswas, Milon. (2022). Deep Learning in Agriculture: A Review. *Asian Journal of Computer Science and Information Technology*. 13. 28-47. 10.9734/AJRCOS/2022/v13i230311.
- [7] Karthik, S.L. & Kurella, Prudhvi & Reddy, L.. (2024). IoT enabled smart agriculture. *MATEC Web of Conferences*. 392. 10.1051/mateconf/202439201150.
- [8] Arsalan, Muhammad & Rao, Ahmed & Rashid, Ahmar & Yu, Zhang & Khan, Khurram & Imran, Abid & Cheema, Hammad. (2024). Real-Time Precision Spraying Application for Tobacco Plants. *Smart Agricultural Technology*. 8. 100497. 10.1016/j.atech.2024.100497.

