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Target Pesticide and Fertilizer Spraying Robot

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Abstract: In the field of agriculture, efficient use of resources such fertilizers is crucial for sustainable farming. Overuse of chemicals can lead to environmental damage and health risks to farmers, while underuse may lead to poor crop yields. A potential solution to this problem is the implementation of an autonomous, targeted spraying robot. This project presents a novel robotic system that leverages artificial intelligence (AI) and image processing techniques to detect targeted plants in real time and auton-omously spray fertilizers. The robot is equipped with a camera for image capture, which transmits data to a laptop for processing. The AI algorithms on the laptop analyze the captured images to identify the plants. The robot is manually controlled using a Bluetooth app for movement, while the spraying of the liquid is automatically triggered when the target plant is identified. The robot, constructed using DC motors, a motor driver, and an Arduino microcontroller, operates with high precision, reducing chem-ical waste, protecting farmers from hazardous exposure, and enhancing crop productivity. This project demonstrates how targeted applications of chemicals can optimize agricultural practices, contributing to environmental conservation and improving farmer safety.

Keywords: Agricultural Robot, Crops, Microcontroller, ESP32, Pesticide Sprayer.

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I. INTRODUCTION

Agriculture is the backbone of many economies, ensuring food security and livelihoods for a significant portion of the population in the world. Fertilizers have become an integral part of agriculture as they enhance soil fertility, leading to high crop yields. However, the overuse and blind application of chemical fertilizers lead to severe environmental and health problems, such as soil deterioration, water pollution, and farmer exposure to harmful chemicals [1]. Sustainable agri-cultural development therefore needs fertilizer use to be opti-mized: applying chemicals only when and where they are re-quired will optimize fertilizer usage [2]. Fortunately, recent advances in robotics and artificial intelligence now provide new opportunities to address these issues. Integration of AI and image processing in agricultural automation allows for the precise and differential application of fertilizers, reducing waste and other negative impacts [3].

In this regard, the development of an autonomous fertilizer spraying robot is one of the promising methods for increasing resource efficiency in crop management. Therefore, this pro-ject intends to design and implement a selective fertilizer spraying robot with real-time plant identification using AI-based image processing. The robot combines automated spraying with manual navigation through a Bluetooth- con-trolled interface, ensuring precision, efficiency, and safety in modern farming practices.

Contributions

- Design of a low-cost AI-assisted robot for selective pesticide and fertilizer spraying.
- CNN-based real-time plant detection integrated with automatic, event-driven spraying.
- 40–60% reduction in chemical usage, minimizing en-vironmental impact and farmer exposure.
- Experimental validation in real field conditions, demonstrating reliable performance and sustainabil-ity.

II. METHODOLOGY

This system entails the design and construction of a robust four-wheel robot platform fitted with DC motors, a motor driver, and a sturdy frame that is able to traverse through ag-ricultural fields. The robot is fitted with a camera for capturing

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real-time plant images, and an microcontroller controls the movement of the robot and the mechanism for spraying liquids. An ESP32 is interfaced for manually controlling the robot using a mobile application. A camera installed on the moving robot continuously captures images and sends these via wired-connection to a laptop for analysis.

AI-based image processing, especially CNN-based object detection models, is used to detect target plants from the captured images [5][6][7]. Once a target plant is detected, serial communication between the laptop and the ESP32 microcontroller allows the laptop to send commands for spraying via the robot. The spraying system comprises a pump that dispenses the fertilizer precisely onto the identified plants, therefore minimizing wastage.

The movement of the robot remains Bluetooth-controlled; an operator can drive it over different sections of a field while the spraying process is engaged autonomously. The whole system operates on batteries for its effective and continuous operation. Furthermore, UAV-based spraying research provides further updates on spray distribution accuracy and minimizes off-target losses [8][9][10].

Finally, extensive field testing and calibration of the camera, AI models, and spraying mechanism ensure accurate plant detection, consistent liquid dispensing, and optimal performance within real agricultural environments.

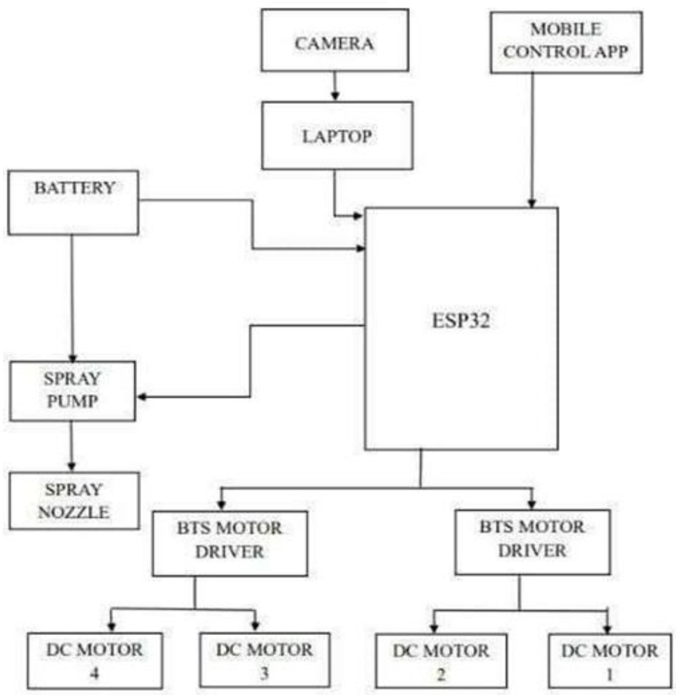

Fig 1. Block Diagram of Target Pesticide and Fertilizer Spraying Robot.

Construction of a robust robot base using a frame that provides support to four DC motors and one motor driver is the hardware and software design of the system. A camera is installed in a robot for capturing plant images in real time. An ESP32 microcontroller is used in controlling the movement of the robot and managing the Spraying mechanism. The ESP32 Microcontroller allows for manual control through a mobile application. When this robot moves, the camera keeps on capturing photos; then, through a wired connection, it sends them to a laptop where image processing is done. AI-based image processing approaches, more specifically CNN-based object detection models, are utilized to analyze and identify targeted plants [11][12].

Serial communication between the laptop and ESP32 microcontroller for sending spraying commands to the nozzle if a plant is detected, while Bluetooth control enables manual control of the robot across the field when necessary. The system can also perform autonomous spraying; the system Software tools such as Google Collab offer an environment on the cloud with GPU/TPU access, pre-installed libraries, Google Drive integration, and real-time collaboration features. However, limitations such as session timeouts and resource constraints exist. TensorFlow was used as the primary machine learning framework; it supports Python and several other languages, is compatible with major operating systems, and offers Tensor Board for visualization. OpenCV is used for image processing and computer vision; it runs on multiple platforms, and its features include image analysis, object detection, feature extraction, and deep learning integration [11][12].

Moreover, PyCharm is also a primary Python IDE that supports Windows, macOS, and Linux; it supports major frameworks like Django and Flask, among others. It also provides features for Python development, including JavaScript, HTML, CSS, SQL, and Jupyter Notebooks in the Professional Edition.

III. IMPLEMENTATION AND SIMULATION

The system starts with the initialization of all involved parts: camera, motors, and the ML model responsible for plant detection. When turned on, the camera, motor driver, and ML model are then ready for real-time image capture, motion control, and detection tasks. Similar methods of initialization are normally followed in modern agricultural spraying robots [16][17].

The robot then receives control inputs from a mobile application through Bluetooth or Wi-Fi, enabling the user to operate the robot in either manual or automatic mode. Upon receiving the command, the robot processes and interprets it and proceeds accordingly-forwards, backward, left, or right. Meanwhile, the camera continues taking images and the ML model processes them for the presence of a plant. The workflow of AI-based detection and image processing is derived based on the general principles of intelligent agricultural systems widely used in [18][19].

If the system is in Auto mode and it detects a plant, it proceeds with the next step; otherwise, the system continues to oversee and move according to the instructions of the user. When the detection of a plant is verified, the robot triggers the spraying

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mechanism by switching on the pump and releasing the needed liquid, such as pesticide or water, directly onto the detected plant. At this point, after spraying, the system goes back to continued plant detection, depending on further input from the user or the fulfillment of the given task. This also falls in line with the most used frameworks for smart pesticide spraying automation in recent works [20][21][22].

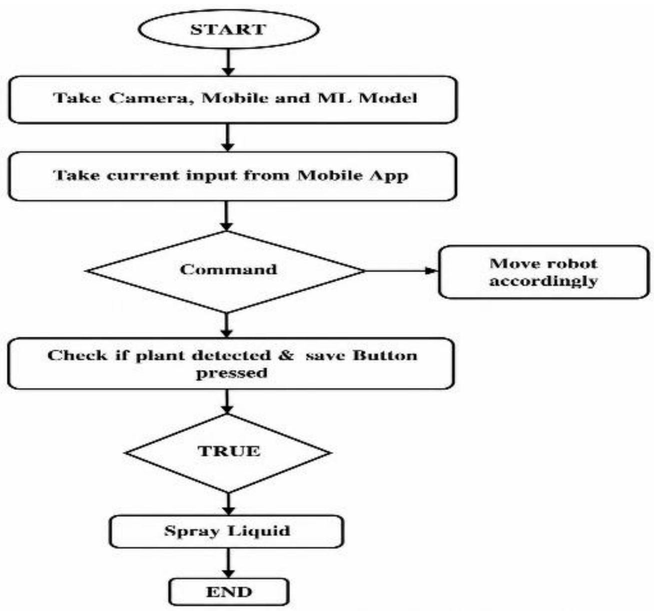

Fig 2. Flow Chart of Target Pesticide and Fertilizer Spraying Robot.

Limitations

1. Semi-Automated Spraying Logic
2. Network Reliability Issues
3. Single-Camera Dependency
4. Bluetooth Communication Range Limitation

IV RESULT AND ANALYSIS

The AI-assisted agricultural spraying robot was evaluated through controlled laboratory experiments and real field trials to assess detection accuracy, spraying effectiveness, communication reliability, and overall system performance.

A. Plant Detection Performance

The CNN-based plant detection model achieved an overall accuracy in the range of **85–95%**, with best performance observed under stable lighting conditions and minimal camera motion. Errors mainly occurred in low-light environments and when plants were partially occluded by soil or surrounding crops.

The image processing and inference time per frame ranged between **0.2–0.5 seconds**, enabling smooth near real-time operation suitable for mobile robotic platforms.

B. Spraying System Performance

The spraying mechanism demonstrated a **spraying accuracy of approximately 90%**, with an activation delay of **less than 1 second** after plant detection. This fast response ensured precise fertilizer delivery only to identified plants. Serial communication between the laptop and ESP32 microcontroller achieved **98% command reliability**, with spraying commands executed **0.5–1.0 seconds** after detection, ensuring synchronized AI decision-making and actuation.

C. Performance Comparison of Spraying Methods

A comparative evaluation was conducted between three spraying approaches:

Method	Chemical Usage	Accuracy	Wastage
Manual Spraying	High	Medium	High
Continuous Spraying	Very High	Low	Very High
Proposed Selective Spraying	Low	High	Low

The proposed selective spraying system reduced chemical wastage by **40–60%** compared to manual spraying and significantly more when compared to continuous spraying methods. This highlights the effectiveness of AI-guided targeted application in precision agriculture.

D. Navigation and Power Performance

Bluetooth-based mobile application control was stable, with command response times of **100–200 ms**, enabling smooth navigation across field plots. The optional line-following feature performed reliably under clearly defined pathways. Power consumption analysis showed that the battery supported **1.5–2.5 hours of continuous operation per charge**, which is adequate for small to medium-sized agricultural fields.

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Detected

Not Detected

E. Overall System Evaluation

Field calibration improved camera alignment, detection accuracy, and spray consistency. Overall, the system demonstrated **effective real-time plant detection, reliable communication, and precise fertilizer spraying**, validating its suitability for precision agriculture applications. Future improvements such as enhanced image stabilization, larger training datasets, and mechanical refinements can further improve robustness and scalability in real-world deployments.

Work	**Detection Method**	**Selective Spraying**	**Limitation**
Zhang et al., 2023	CNN	Yes	High cost
Hassan et al., 2021	Thresholding	Partial	Low accuracy
This work	CNN	Yes	Laptop-based processing

V. CONCLUSION, CHALLENGES AND FUTURE ENHANCEMENTS

Conclusion:

In conclusion, the targeted fertilizer spraying robot offers an innovative approach to modern farming, enhancing crop yield, reducing environmental impact, and improving farmer safety. With further development and scaling, this technology has the potential to revolutionize the agricultural industry, making farming more sustainable and efficient.
SDG 3 – Good Health and Well-being
SDG 6 – Clean Water and Sanitation
SDG 12 – Responsible Consumption and Production

Challenges:

Agricultural robots come with several limitations, including high initial costs that may make them difficult for small-scale farmers to adopt and the technical knowledge required for proper operation and maintenance. Limited battery life can restrict usage in large fields, and navigating uneven terrain may cause accuracy issues. The system also requires regular calibration of sensors and spraying nozzles, and its performance can be affected by weather conditions such as wind or rain. Additionally, AI-based robots need strong data processing capabilities, and many farmers may be hesitant to adopt such technology without proper training and awareness.

Future Enhancement:

The targeted fertilizer spraying robot can be further improved to increase efficiency, autonomy, and adaptability. Incorporating GPS or RTK-based navigation would enable fully autonomous field operation, while additional sensors such as LiDAR or ultrasonic modules could improve obstacle detection and terrain adaptability. Expanding the AI model with larger and more diverse datasets would enhance plant detection under varied lighting and weather conditions. Upgrading the power system with higher-capacity batteries or solar charging could extend operational time. Introducing multi-nozzle or variable-rate spraying systems would allow the robot to handle multiple crops or adjust fertilizer quantities as needed. Finally, integrating cloud-based monitoring and data analytics, along with a more intuitive mobile interface, would support real-time farm management and broader adoption among farmers.

DECLARATION STATEMENT

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval or consent to participate, as it presents evidence that is already publicly available.
Availability of Data and Materials	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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Mr. Girish K. A. received his M.Tech degree in Digital Electronics and Com-munication Systems from Malnad Col-lege of Engineering, Hassan**.** He is cur-rently pursuing a Ph.D. in Cryptography applied to Medical Imaging at The Na-tional Institute of Engineering (NIE),
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Ms. Chiranthana Shreya, a final-year Electronics and Communication Engineer-ing student at Maharaja Institute of Tech-nology, Thandavapura. Possesses a strong academic

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embedded systems, hardware–software integration, and practical engineering problem-solving. Technical skill areas include mi-crocontrollers, digital electronics concepts, and programming for system-level applications. Actively explores emerging technolo-gies through academic and project-based learning, with the ob-jective of developing real-world engineering solutions and gain-ing meaningful industry exposure in embedded systems, IoT, and related engineering domains. Motivation is driven by curiosity, innovation, and a commitment to continuous learning.

Ms. Nischitha H E, is an undergraduate Bachelor of Engineering student in Elec-tronics and Communication Engineering at Maharaja Institute of Technology, Thanda-vapura, Mysuru, with a strong passion for applying electronics and intelligent sys-tems to real-world challenges. Her tech-nical interests include Embedded Systems,
IoT, AI & ML, VLSI, and Automation, and she has completed projects such as a Smart Door Lock System using Arduino with RFID, biometric, and mobile-based access, as well as a Water Level Detector for monitoring and alerts. She has hands-on ex-perience in Python, C programming, MATLAB, Arduino, and CAD tools, complemented by strong problem-solving and team-work skills. Through professional certifications in VLSI, Python Fundamentals, AI & ML, and Arduino, she demonstrates a com-mitment to continuous learning and aspires to build a career in Electronics and Intelligent Systems by contributing innovative and reliable technology-driven solutions.

Ms. Veda K T K, a final-year Electronics and Communication Engineering student with a genuine interest in VLSI design, digital and analog circuits, and embedded systems. With a strong academic founda-tion and hands-on experience in digital electronics, microcontrollers, and pro-gramming using C, C++, Python,
MATLAB, and Verilog, enjoys working at the intersection of hardware and software. Currently exploring IoT and machine learning through practical projects, motivated to build real-world solutions and gain meaningful industry experience in embedded, IoT, and semiconductor-related domains, driven by curiosity, creativity, and a passion for innovative hardware technologies.

Ms. Reethu K R, a final-year Electronics and Communication Engineering student at Maharaja Institute of Technology, Thanda-vapura, with an interest in Embedded Sys-tems and microcontroller-based applica-tions. Has basic hands-on experience in em-bedded programming and hardware inter-facing. Demonstrates strong enthusiasm for
applying theoretical knowledge to real-time applications through practical projects. Actively involved in developing embedded-system-based solutions and aims to gain hands-on experience and technical expertise in Embedded System Design and related domains.