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# Design of a Modular Mobile Robot with Intelligent Pesticide Spraying Mechanism

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**ABSTRACT**

In recent years, the applications of mobile robots for agriculture have gained significant attention due to their potential to enhance crop management practices. This paper presents the design, development, and evaluation of a mobile robot equipped with an intelligent pesticide spraying mechanism. The main objective of this research is to discuss the recent utilization of mobile robots in agriculture and to design a mobile robot system that can spray pesticides with minimal manual control requirements. To maintain precise positioning and avoid collisions, the mobile robot is designed to drive independently within a designated region utilizing a mix of sensors such as GPS and obstacle detection. The spraying mechanism integrates a fuzzy logic-based control system that dynamically adjusts spraying parameters based on environmental factors such as crop density, wind speed, and pest infestation levels. This intelligent approach ensures optimal pesticide usage, reducing chemical wastage and minimizing environmental impact. The mobile robot features a robust spraying mechanism comprising a sprayer unit, storage tanks, and an adaptive control system for real-time decision-making. The development process required the integration of mechanical, electrical, and software components to build a reliable and efficient system. Extensive testing and validation were conducted to assess the robot's effectiveness in various agricultural contexts, considering factors such as terrain variation, crop density, and operational constraints. This study contributes to the advancement of agricultural robotics by addressing pesticide spraying challenges through automation and environmentally conscious solutions.

## 1. Introduction

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A mobile robot is an automated machine that use sensors and other technologies to identify its surroundings and maneuvers its environment. Mobile robots function using a combination of artificial intelligence (AI) and physical robotic elements, such as wheels, tracks and legs. Mobile robots are becoming increasingly popular across different sectors, such as agricultural and industrial. They are used to assist with work processes and even accomplish tasks that are impossible or dangerous for human workers [1,2]. A mobile robot with a pesticide spraying mechanism is a type of agricultural robot that can navigate crops independently and spray pesticides to manage pests and diseases. These robots are built with sensors and mapping technology that enable them to maneuver the fields without the need for human involvement, while their pesticide spraying mechanism applies chemicals precisely and efficiently [1,3,4]. Additionally, proper selection of nozzle type and size is critical for proper pesticide application. The nozzle provides an important role in determining the volume of spray given to an area, the uniformity of application, the coverage obtained on the target surface, and the amount of potential drift [5].

According to Madsen and Jakobsen [5], the choice of mobile robot architectural idea includes traction, steering, robot size, frame, and power supply, as indicated by the authors. The flow chart is illustrated in Fig. 1. The primary components of mobile robots are traction, steering, robot size, frame, and the power supply. Generally, there are three considerations must be made before developing a mobile robot: weather conditions, terrain and barriers, and safety aspects [6,7].

In terms of weather considerations, the type of environment in which the mobile robot will be experimented must be determined, since climate change in different nations necessitates this. Even though there are only two types of climate change in Malaysia—heat and rain—the presence of high humidity may come from improper frame selection, causing the frame to rust, and the appearance of moisture from humidity may damage the electronic circuit if it is not adequately enclosed.

For terrain and obstacles consideration are to make clear of which area will the mobile robot. For this research scope, the purpose of the mobile robot will execute task in palm oil farm crops area. Normal practice of planting palm oil tree, the gap between trees will be 9meter x 9meter for 145 trees per hectare. The trees height could rise up to 9meter per tree [8]. Regarding the topography, palm oil trees are often planted in mountainous areas. By converting this information into data, the design of the mobile robot may describe the robot's size in relation to the distance between palm oil trees in order to account for the obstacle, as well as the terrain in order to account for the appropriate sort of traction for the mobile robot.

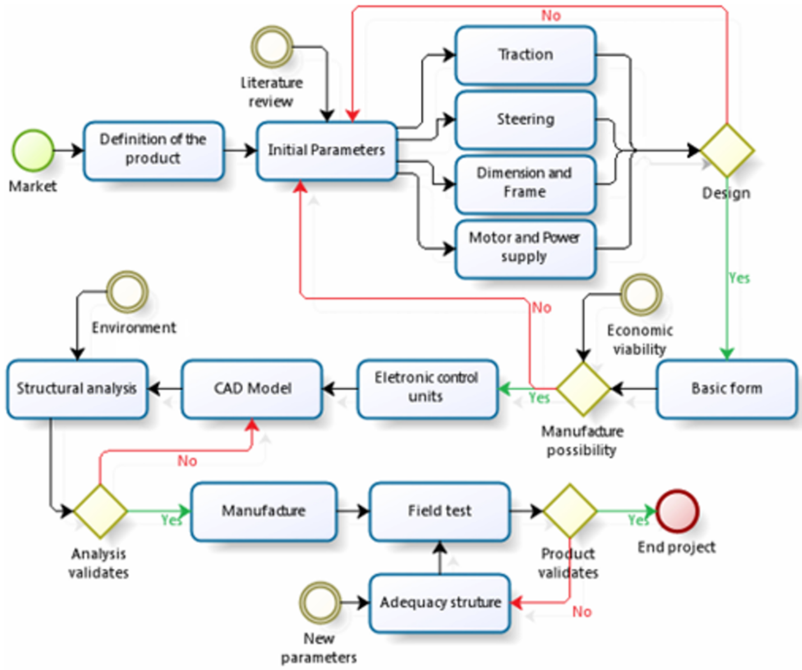



**Fig. 1.** The flowchart on designing mobile robot [5]

The design of a mobile robot must consider the presence of humans and animals for safety considerations. By this criterion, the design of the mobile robot must cause minimal harm to humans and animals participating in the work. However, as this is the initial prototype of the mobile robot frame, the design goal for agricultural land protection and encountering animals or other external factors that harm crops is not the target at this time [6,9].

There are several mobile robots designs available on the market today. Each and every design is purposeful for the specified objective. This includes agricultural enterprises, particularly those involving cropland and undulating terrain. Several studies were conducted to identify the mobile robot's design idea. In contrast, modular mobile robots appear to be in strong demand in industry today. Unlike conventional robots, which consist of a single mechanism, modern robots cannot adapt to different environments and task. Numerous studies have been conducted on the use of modularity in mobile robots due to its unique benefits in terms of reconfigurability, reusability, and manufacturing simplicity [9-11]. This modular design implements the Cell Structured Robotic System (CEBOT) modular system, which is comprised of heterogeneous discrete units that may bond together and replicate biological organisms [12].

The concept of a modular mobile robot is based on the design of a single-module mobile robot that can be easily re-configured in order to take use of its multifunctionality. Dan *et al*., [11] emphasized that the concept of constructing modular type mobile robot is about decomposing one complex module into many simple modules, which is advantageous for system design and analysis, and also plug-and-play system can be easily exchanged. Moreover, depending on these, there are several guidelines that must be considered before constructing the modular frame, followed by the mechanism and electrical module especially when deploying Internet of Things (IoT) technology [13-15]. Other related studies are summarized in Table 1.

**Table 1**
Studies related to the topic

| Paper | Summary | Objectives | Methods Used | Applications |
|---|---|---|---|---|
| Terra [15] | The paper presents a modular system for autonomous agricultural sprayers utilizing machine vision and nozzle control, enabling precise pesticide application. It incorporates low-cost components like Arduino, solenoid valves, and sensors, making it suitable for various row-planted crops. | Automate sprayers for precision agriculture using machine vision. Reduce pesticide application for environmental and food safety. | The paper proposes a modular system of precision agriculture using computer vision and individual nozzle control. The system uses low-cost equipment such as Arduino boards, solenoid valves, and Raspberry Pi. | Automating sprayers for precision agriculture. Reducing pesticide application in row crops. |
| Jat [16] | The paper presents an automated mobile robotic sprayer (AMRS) designed for polyhouses, utilizing embedded sensors and controllers for intelligent pesticide spraying, optimizing parameters like forward speed, spray distance, and working pressure to enhance efficiency and minimize human exposure to agrochemicals. | Develop automated mobile robotic sprayer for polyhouse management. Minimize human exposure to agrochemicals and health hazards. | Development of automated mobile robotic sprayer (AMRS). Response surface methodology for optimization of spraying parameters. | Automated mobile robotic sprayer for polyhouse management. Minimizing human exposure to agrochemicals during spraying. |
| Bawden [17] | The paper focuses on a modular robotic platform for weed management, incorporating a heterogeneous weeding array that combines mechanical and chemical methods, but does not specifically address the design of an intelligent pesticide spraying mechanism. | Develop autonomous system for weed management in agriculture. Design and test modular robotic platform for precision tasks. | Vision-based online weed detection and classification. Combination of chemical and mechanical methods for weed destruction. | Online weed detection and classification using robots. Selective mechanical and chemical weed management methods. |
| Hu[18] | The paper presents a robotic system for micro-volume herbicide spraying, featuring a stereo camera, inertial measurement unit, and multiple actuating nozzles. It focuses on optimal nozzle assignment and motion planning for precise weed control, enhancing pesticide application efficiency. | Develop an automatic micro-volume herbicide spray system. Optimize nozzle assignment for effective weed coverage. | Proposed a new scene representation for spray operation using candidate line segments. Developed a binary linear programming-based algorithm for optimal nozzle assignment | Robotic micro-volume herbicide spray for weed control. Precision weed management to enhance crop yield. |
| Wu [19] | The paper discusses a modular weed control unit mounted on a BoniRob robot, integrating mechanical and chemical weeding tools, but does not specifically address the design of a mobile robot with an intelligent pesticide spraying mechanism. | Design a multi-camera weed management system. Integrate weed detection, tracking, and predictive control. | Non-overlapping multi-camera system for weed control. Naive Bayes filtering, 3D visual tracking, and predictive control. | Selective mechanical weed control. Chemical in-row weeding. |

**Table 1** ***(Continued)***

| Paper | Summary | Objectives | Methods Used | Applications |
|---|---|---|---|---|
| Lin [20] | The paper focuses on an electrostatic spraying system for agricultural unmanned vehicles, enhancing pesticide efficiency and droplet uniformity. It discusses droplet charging principles, system design, and the impact of voltage and pressure on droplet characteristics, but does not cover modular robot design. | Develop advanced plant protection equipment. Improve efficiency of plant protection and pesticide utilization. | Measurement of droplet charge mass ratio and droplet particle size. Field pest control comparative experiments with different application methods. | Agricultural plant protection using electrostatic spraying systems. Field pest control comparative experiments with different application methods. |

## 2. Methodology

### *2.1 Research Flow and Organization*

This section will focus on the research's execution methods, beginning with planning and progressing through the improvement of the mobile robot's body structure and spraying mechanism. The researchers use the main flow chart method in this section of the section. This suggests that they are concentrating on the fundamental or main qualities of the product under consideration and thoroughly analysing them. The researchers are utilizing various methods and approaches as part of their research process. Below is the breakdown of each method: Research schedule and milestone, research planning, design improvement planning, part selection, design study, and prototype improvement. In summary, the paragraph highlights the elements of a section or section that will discuss a research research's technique, procedure, and data analysis. The research flow is summarized in Fig. 2. The design planning method entails conducting research on the robot's design within the constraints of the research. The frame, mechanism, and arrangement of pieces that complement the frame are all critical components of the robot. Robot frame design concepts are developed using journals, research papers, and internet-accessible materials. Several details from the publications are combined to construct the mobile robot idea design. Design planning is the first step in the design process, and it is based on sketches or hand-drawn draughts.

As a part of the selection procedure. Several components must be carefully placed into the mobile robot's chassis. However, the scope of this research is limited to the actualization of the robot's mobility and the theoretical calculations required for the component to permit the mobile robot's functioning. The mechanism's support system, which includes the wheel and power transmission system, is one of the associated components.

This is necessary for the placement on the frame to monitor the adequacy of the placement in relation to the robot's movement in order to prevent the power transmission component (such as a belt or chain) from being struck by an external element (such as soil, which will cause the chain to become stuck, or stone, which will damage the system part). Theoretically confirming the mobile robot's ability to do agricultural activities requires consideration of the power supply and motor. The component motor must be chosen using a calculation technique that takes into account the speed of the mobile robot, the other components, and the weight of the mainframe. The material for the mobile robot's chassis is another component option. Given that this mobile robot is expected to perform agricultural chores, it is critical that the frame be made of agricultural-compatible materials.

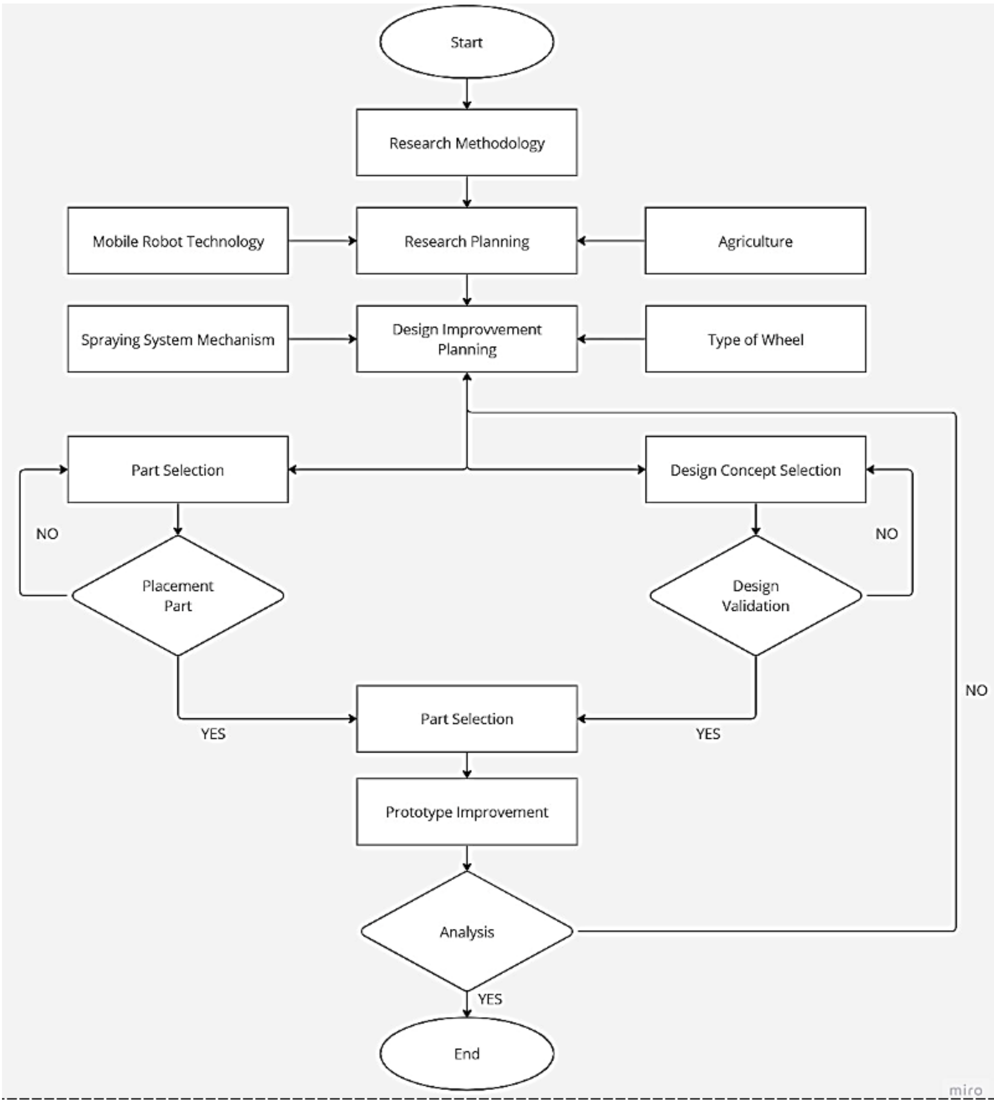



**Fig. 2.** Research flow

The manoeuvrability of a mobile robot under operator direction is examined in this evaluation through a variety of activities that include straight-line mobility, turning, and navigating obstacles. The evaluation emphasises the operator's ability to accurately direct the robot, allowing precision navigation across many settings. Notably, the robot's performance is reflected in its sensitive and nimble movements, which allow it to traverse designated courses and execute turns with precision as directed by the operator. The results highlight the operator's effectiveness in commanding the robot, emphasising its ability to fluidly navigate numerous hurdles. The entire result emphasises the robot's versatility and the operator's ability to achieve regulated and exact motions in a variety of settings, demonstrating the potential for reliable and precise robotic navigation.

The central microcontroller selected for the mobile robot with a pesticide spraying mechanism is the ESP32-S3, a powerful dual-core Xtensa LX7 processor operating at 240 MHz. This board is equipped with integrated Wi-Fi and Bluetooth Low Energy (BLE) 5.0, making it ideal for remote monitoring, firmware updates, and communication with mobile devices or cloud platforms. Its support for vector instructions and external PSRAM allows lightweight AI models to run directly on the board, enabling real-time image classification and sensor-based decision-making. Additionally, the ESP32-S3 supports multiple communication interfaces (SPI, I2C, UART), which facilitates easy integration with various sensors and actuators.

For locomotion, the robot uses two 12V DC gear motors (e.g., SPG30E series), each controlled by a motor driver such as the Cytron MD10C R3 or SmartDriveDuo-10. These drivers support high current and PWM control for smooth and adjustable motion, which is essential for navigating agricultural fields. An MPU6050 IMU sensor provides orientation and acceleration feedback, while optional motor encoders enable accurate speed and distance measurements, allowing for semi-autonomous navigation and path correction.

The spraying system includes a 12V mini diaphragm pump controlled via a relay module or MOSFET switch, enabling on-demand pesticide dispersion. A YF-S201 flow sensor monitors the spray rate to ensure accurate delivery based on movement speed or area coverage. To support intelligent spraying, an OV2640 camera module is interfaced with the ESP32-S3, allowing real-time image capture for detecting crop health or weeds using onboard AI models. Supplementary sensors like HC-SR04 ultrasonic modules or TF-Luna LiDAR are used for obstacle avoidance and plant distance estimation, enhancing autonomous operation safety.

The mobile robot prototype is illustrated in Fig. 3. The pesticide spraying accuracy of the mobile robot was evaluated by assessing the spray coverage over a predetermined region of an oil palm tree, which measured precisely 2 meters, as shown in Fig. 4.

The operator controlled the spraying mechanism to ensure that the pesticide was evenly distributed throughout the desired area. Both visual inspection and measurements were used to determine the extent to which the pesticide spray effectively covered the target area. The goal of this study was to determine whether the robot achieved the appropriate level of spray accuracy inside the prescribed space surrounding the oil palm trees, ensuring that the operator's control over the spraying process was consistent with the desired results.

(a) (b)

**Fig. 3.** Mobile robot with pesticide spraying mechanism with (a) exterior; and (b) interior views

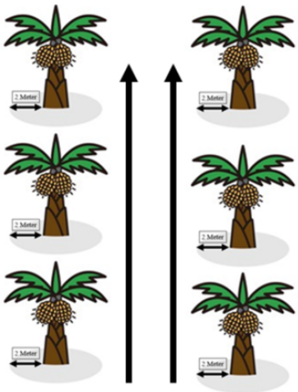



**Fig. 4.** Layout and path plan of the testing site

Meanwhile, the intelligent pesticide spraying mechanism utilizes a fuzzy logic-based control system that dynamically adjusts spray intensity based on three key environmental factors: canopy coverage, wind speed, and pest infestation level. Crop density is classified as low, medium, or high, while wind speed is categorized as low, moderate, or high. Pest infestation levels are also divided into low, medium, and high. The system processes these inputs to determine the optimal spray intensity, ensuring effective pesticide application while minimizing wastage and environmental impact. The rules used are as follow:

- If Canopy Coverage is Sparse AND Pest Infestation is Low AND Wind Speed is High, THEN Spray Intensity is Low.
- If Canopy Coverage is Sparse AND Pest Infestation is Medium AND Wind Speed is Low, THEN Spray Intensity is Medium.
- If Canopy Coverage is Sparse AND Pest Infestation is High AND Wind Speed is Low, THEN Spray Intensity is High.
- If Canopy Coverage is Moderate AND Pest Infestation is Low AND Wind Speed is Low, THEN Spray Intensity is Low.
- If Canopy Coverage is Moderate AND Pest Infestation is Medium AND Wind Speed is Moderate, THEN Spray Intensity is Medium.
- If Canopy Coverage is Moderate AND Pest Infestation is High AND Wind Speed is Low, THEN Spray Intensity is High.
- If Canopy Coverage is Dense AND Pest Infestation is Low AND Wind Speed is Moderate, THEN Spray Intensity is Low.
- If Canopy Coverage is Dense AND Pest Infestation is Medium AND Wind Speed is Moderate, THEN Spray Intensity is Medium.
- If Canopy Coverage is Dense AND Pest Infestation is High AND Wind Speed is Low, THEN Spray Intensity is High.
- If Wind Speed is High AND Pest Infestation is Medium or High, THEN Reduce Spray Intensity to Avoid Pesticide Drift.
- If Canopy Coverage is Dense AND Wind Speed is High, THEN Reduce Spray Intensity to Prevent Excessive Pesticide Accumulation.
- If Pest Infestation is High AND Wind Speed is Low, THEN Increase Spray Intensity for Maximum Effectiveness.

The fuzzy rules governing the spraying mechanism prioritize efficient pesticide usage while considering the unique characteristics of palm oil plantations. When pest infestation is high and wind speed is low, spray intensity is increased to ensure effective pest control. Conversely, if pest infestation is low and wind speed is high, the system reduces spray intensity to prevent pesticide drift and unnecessary application. In cases where canopy coverage is dense and pest infestation is medium, the spray intensity is adjusted to a moderate level, balancing pesticide use with the need for effective coverage while preventing excessive accumulation.

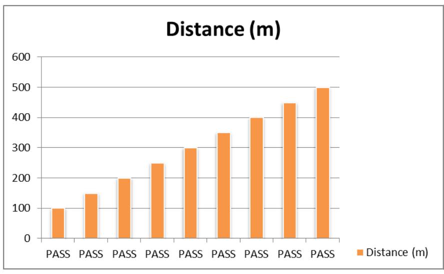
To further refine pesticide application, the system adapts to varying agricultural conditions. For example, if canopy coverage is sparse but pest infestation is high, the spray intensity is increased to target affected areas effectively while ensuring minimal chemical wastage. Similarly, when wind speed is moderate and canopy coverage is dense, the system applies a controlled spray to ensure even pesticide distribution without oversaturation. Additionally, if wind speed is high and pest infestation is medium or high, the system automatically reduces spray intensity to mitigate pesticide drift, ensuring both efficiency and environmental safety.

These fuzzy logic-based adjustments enhance precision and adaptability, making the mobile robot a reliable solution for automated pesticide spraying in palm oil plantations. By dynamically adjusting spray intensity based on canopy coverage, wind speed, and pest infestation levels, the system optimizes pesticide application, reduces environmental impact, and improves overall agricultural sustainability.

## 3. Results

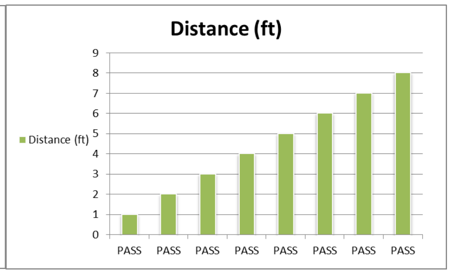
The functional testing included evaluating the integration of the pesticide spraying mechanism with the control system as shown in Fig. 5. During this phase, the microcontroller was programmed to activate the spraying mechanism when the operator issued an appropriate command. The testing procedure included a thorough evaluation of the spraying mechanism's accuracy and precision. This assessment considered elements such as pesticide spraying pattern, coverage, and distribution. The effectiveness of the integration was verified by closely monitoring and analysing the results. The main purpose was to ensure that the integrated system allowed the needed pesticide spraying functionality. This functionality is critical for effective pest control or crop treatment, and the testing phase was critical in proving the system's capabilities to reliably carry out this component of the robotic platform's intended functions.

The pesticide spraying mechanism designed for palm oil trees includes a flexible and adaptable equipment specifically intended to treat trees ranging in range from 1 to 8 feet. This specialised system has a durable nozzle that is smoothly attached to a flexible extension arm, allowing for precise and accurate targeting during pesticide administration. The nozzle is ingeniously constructed to disperse the pesticide as a fine mist, increasing absorption by the palm tree's leaf while reducing potential waste. This novel technique guarantees efficient and uniform treatment across the whole canopy, including the palm tree's most difficult or inaccessible locations. The final result is shown in the Fig. 6, the maximum distance for a pesticide spraying robot is one to eight feet.




(a)

**Fig. 5** Graph for range of distance




(b)

**Fig. 6.** Distance of spraying mechanism

On the other hand, a 3D scatter plot visualizes the output of the fuzzy logic control system, where spray intensity is determined based on three environmental inputs: canopy coverage, pest infestation level, and wind speed. Each axis represents one of these input variables, while the colour and size of each plotted point correspond to the resulting spray intensity, classified as Low, Medium, or High. The plot reveals a clear trend: higher spray intensities are typically associated with combinations of high pest infestation and low wind speed, regardless of canopy density. This behaviour aligns with real-world agronomic practices, where maximum pesticide application is necessary when pest threats are severe and drift risks are minimal. Conversely, in high wind conditions or low pest presence, spray intensity is reduced to avoid chemical wastage and minimize environmental impact.

The plot also highlights how the fuzzy logic controller adapts to varying field conditions by balancing conflicting factors. For instance, a dense canopy may suggest the need for a higher spray dose, but if wind speed is also high, the system smartly moderates the intensity to prevent pesticide drift and accumulation. The medium-intensity spray decisions are often situated in regions of moderate pest infestation or moderate canopy coverage, demonstrating the controller's ability to maintain balance under intermediate conditions. Overall, the 3D visualization as depicted in Fig. 7 confirms that the fuzzy rule set is functioning as intended, prioritizing pest control efficiency while optimizing chemical use in a sustainable and intelligent manner.

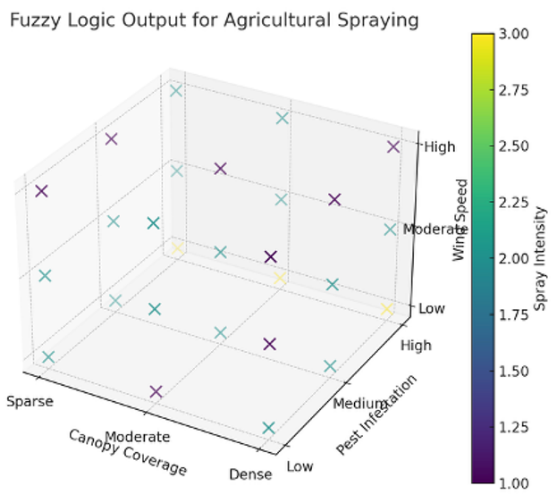



**Fig. 7.** Fuzzy logic output

## 4. Conclusions

In conclusion, the research achieved its objectives triumphantly, as evidenced by improvements to the pre-existing pesticide spraying mechanism and materials on the mobile robot design. The research's success is based on the demonstrated effectiveness of both the robot's navigation capabilities and pesticide spraying systems. These accomplishments are supported by the validation of the research's results, which demonstrate its impact on refining and optimising current technology. The completion of these efforts not only marks a significant improvement in the overall operation of the mobile robot, but also demonstrates the research's significant contribution to the advancement of robotic pesticide application.

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**References**

[1] Meshram, Ashish T., Anil V. Vanalkar, Kavita B. Kalambe, and Avinash M. Badar. "Pesticide spraying robot for precision agriculture: A categorical literature review and future trends." *Journal of Field Robotics* 39, no. 2 (2022): 153-171. https://doi.org/10.1002/rob.22043.

[2] Ghafar, Afif Shazwan Abdul, Sami Salama Hussen Hajjaj, Kisheen Rao Gsangaya, Mohamed Thariq Hameed Sultan, Mohd Fazly Mail, and Lee Seng Hua. "Design and development of a robot for spraying fertilizers and pesticides for agriculture." *Materials Today: Proceedings* 81 (2023): 242-248. https://doi.org/10.1016/j.matpr.2021.03.174.

[3] Li, Hailong, Longzhe Quan, Yinghao Guo, Pengfei Pi, Yihui Shi, Zhaoxia Lou, Wei Jiang et al. "Improving agricultural robot patch-spraying accuracy and precision through combined error adjustment." *Computers and Electronics in Agriculture* 207 (2023): 107755. https://doi.org/10.1016/j.compag.2023.107755.

[4] Raju, K., Roshan Rajeshwar Tulaskar, and Canute Sherwin. "Solar-Powered Pesticide-Spraying RFID Robot." In *Smart Village Infrastructure and Sustainable Rural Communities*, pp. 283-307. IGI Global, 2023. https://doi.org/10.4018/978-1-6684-6418-2.ch016.

[5] T.E. Madsen and H.L. Jakobsen, 2001, *Mobile robot for weeding*. Unpublished MSc. thesis Danish Technical University.

[6] Fauadi, MHF Md, and MN Muhammad Nanda. "AUTOMATED SEED SOWING MACHINE FOR UNEVEN SURFACE." *Journal of Engineering and Technology (JET)* 15, no. 1 (2024).

[7] Fauadi, Hafidz Fazli, Mohd Hisham Nordin, and Zamzuri Mohd Zainon. "Frontal obstacle avoidance of an autonomous subsurface vehicle (ASV) using fuzzy logic method." In *2007 International Conference on Intelligent and Advanced Systems*, pp. 125-128. IEEE, 2007. https://doi.org/10.1109/ICIAS.2007.4658360.

[8] Shamsudin, Nur Hazahsha, Norman Koliah Anak Noheng, Siti Amaniah Mohd Chachuli, Nur Asmiza Selamat, Hrithik Tawai, and Nurliyana Abdul Raof. "The evolution of smart sprayer system for agricultural sector in Malaysia." *International Journal of Electrical and Computer Engineering (IJECE)* 14, no. 6 (2024): 6122-6128. https://doi.org/10.11591/ijece.v14i6.pp6122-6128.

[9] Noor, AZ Mohamed, MHF Md Fauadi, F. A. Jafar, M. H. Nordin, S. H. Yahaya, S. Ramlan, and MA Shri Abdul Aziz. "Fuzzy analytic hierarchy process (FAHP) integrations for decision making purposes: A review." *Journal of Advanced Manufacturing Technology (JAMT)* 11, no. 2 (2017): 139-154.

[10] Dan, Zou, Wang Tianmiao, and Liang Jianhong. "Reconfiguration research on modular mobile robot." In *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 1082-1085. IEEE, 2006. https://doi.org/10.1109/IROS.2006.281814.

[11] Chennareddy, S. Sankhar Reddy, Anita Agrawal, and Anupama Karuppiah. "Modular self-reconfigurable robotic systems: a survey on hardware architectures." *Journal of Robotics* 2017, no. 1 (2017): 5013532. https://doi.org/10.1155/2017/5013532

[12] Cheng, Chao, Jun Fu, Hang Su, and Luquan Ren. "Recent advancements in agriculture robots: Benefits and challenges." *Machines* 11, no. 1 (2023): 48. https://doi.org/10.3390/machines11010048.

[13] Wang, Tianhai, Bin Chen, Zhenqian Zhang, Han Li, and Man Zhang. "Applications of machine vision in agricultural robot navigation: A review." *Computers and Electronics in Agriculture* 198 (2022): 107085. https://doi.org/10.1016/j.compag.2022.107085.

[14] N.I. Anuar, M.H.F.M. Fauadi, "A Study on Multi-Objective Particle Swarm Optimization in Solving Job-Shop Scheduling Problems," *International Journal of Computer Information Systems and Industrial Management Applications*, 2021, 13, pp. 051–061.

[15] Terra, Fábio P., Gustavo H. do Nascimento, Gabrielle A. Duarte, and Paulo LJ Drews-Jr. "Autonomous agricultural sprayer using machine vision and nozzle control." *Journal of Intelligent & Robotic Systems* 102, no. 2 (2021): 38. https://doi.org/10.1007/s10846-021-01361-x.

[16] Jat, Dilip, Kumkum Dubey, Rahul R. Potdar, Subir Kumar Chakraborty, Satya Prakash Kumar, Narendra Singh Chandel, and Yogesh Anand Rajwade. "Development of an automated mobile robotic sprayer to prevent workers' exposure of agro-chemicals inside polyhouse." *Journal of Field Robotics* 40, no. 6 (2023): 1388-1407. https://doi.org/10.1002/rob.22181.

[17] Bawden, Owen, Jason Kulk, Ray Russell, Chris McCool, Andrew English, Feras Dayoub, Chris Lehnert, and Tristan Perez. "Robot for weed species plant-specific management." *Journal of Field Robotics* 34, no. 6 (2017): 1179-1199. https://doi.org/10.1002/ROB.21727

[18] Hu, Chengsong, Shuangyu Xie, Dezhen Song, J. Alex Thomasson, Robert G. Hardin IV, and Muthukumar Bagavathiannan. "Algorithm and system development for robotic micro-volume herbicide spray towards precision weed management." *IEEE Robotics and Automation Letters* 7, no. 4 (2022): 11633-11640. https://doi.org/10.1109/LRA.2022.3191240

[19] Wu, Xiaolong, Stéphanie Aravecchia, Philipp Lottes, Cyrill Stachniss, and Cédric Pradalier. "Robotic weed control using automated weed and crop classification." *Journal of Field Robotics* 37, no. 2 (2020): 322-340. https://doi.org/10.1002/ROB.21938

[20] Lin, Zhen, Jinye Xie, Shuo Tian, Xihong Wang, Wenfu Sun, and Xiaoqin Mo. "Research and experiment of electrostatic spraying system for agricultural plant protection unmanned vehicle." *Frontiers in Ecology and Evolution* 11 (2023): 1138180. https://doi.org/10.3389/fevo.2023.1138180