Agricultural Drone: A Cost-Effective Aerial Spraying System for Small-Scale Farming

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ABSTRACT

This paper outlines the design, fabrication, and performance evaluation of an affordable agricultural drone engineered to optimize the application of fertilizers and pesticides for small-scale farming operations. Traditional spraying methods present significant drawbacks, including farmer exposure to chemicals, excessive time consumption, and general inefficiency. Our proposed drone-based system utilizes a quadcopter platform with a manually controlled spraying mechanism. The modular design prioritizes both low cost and operational simplicity. Results from field evaluations demonstrated consistent spraying performance, stable flight characteristics, and considerable savings in labor and expenses. This project presents a viable step towards making precision agriculture more accessible, striking a balance between performance and affordability, especially for farming communities with constrained resources.

Keywords: Agricultural drone, precision farming, unmanned aerial vehicle (UAV), crop spraying, low-cost automation, pesticide application, smallholder agriculture.

INTRODUCTION

Agriculture is a critical component of global economic health and food security. This is particularly true in developing nations, where it represents the main livelihood for most rural inhabitants. The Food and Agriculture Organization (FAO) projects that by 2050, global food production must increase by 70% to support a population of 9.7 billion people. To meet this escalating demand, the agricultural industry is undergoing a technological transformation focused on enhancing sustainability, efficiency, and automation.

In India, agriculture supports approximately 58% of the population, with the majority operating small farms averaging just 1.08 hectares. These small-scale farmers encounter substantial hurdles, including labor shortages, steep input costs, and unreliable access to mechanized equipment. A primary concern is the application of agrochemicals, such as fertilizers and pesticides. Manual application often leads to inconsistent coverage, overuse of chemicals, and poses direct health risks to farmers.

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have emerged as a compelling solution to these challenges. Originally developed for military and surveillance operations, UAVs have since evolved into versatile tools for complex agricultural tasks. Recent technological strides have allowed UAVs to be fitted with precision spraying systems, offering benefits like targeted chemical delivery, reduced human exposure, and minimal environmental damage.

Current research emphasizes the advantages of UAV-based spraying, which include reduced labor, lower costs, and greater accuracy. For example, studies have shown that UAVs can decrease pesticide use by up to 30% while maintaining or even improving pest control outcomes. Despite these benefits, most commercial agricultural drones are prohibitively expensive and technically complex for smallholder farmers. Moreover, regulatory policies and technical support infrastructures in developing countries frequently lag behind technological progress, further hindering widespread adoption.

This study details the creation and field testing of an affordable, user-friendly UAV system for aerial spraying in small-scale agricultural contexts. By focusing on core functionalities—such as stable flight, consistent chemical delivery, and intuitive controls—while minimizing cost and complexity, this work aims to facilitate the adoption of UAVs in under-resourced farming communities. The research also explores the trade-offs between performance and cost, evaluating the UAV's impact on spraying efficiency, chemical consumption, labor reduction, and environmental safety.

We present a comprehensive overview of the design, development, and field validation of this cost-effective UAV system. The central objective is to bridge the technological and financial divide between advanced agricultural UAVs and the practical requirements of small or resource-limited farmers. The research focuses on creating a UAV platform that delivers reliable flight, uniform spray patterns, and simple controls, all within a framework that keeps manufacturing, operation, and maintenance costs low.

Through an iterative design process and field experimentation, the system integrates lightweight materials, an efficient propulsion setup, and a calibrated spray mechanism to achieve precise droplet sizes and targeted delivery. The study also prioritizes user-friendliness and safety, featuring a straightforward ground control interface suitable for operators with limited technical skills. Flight stability algorithms are implemented to ensure consistent spraying across different field conditions.

The field validation stage assesses the UAV's real-world performance in controlled trials, comparing its spray uniformity and efficiency against traditional manual methods. This paper also offers insights into how cost considerations influence design choices, payload capacity, and battery endurance. It highlights the drone's potential to cut pesticide waste and reduce human exposure to hazardous chemicals, advancing the vision of a more technologically inclusive and environmentally sound farming future.

Related Work

In the last two decades, drone technology has expanded from its origins in military and recreational fields into agricultural applications. This shift has revolutionized practices such as crop monitoring, irrigation management, field mapping, and aerial spraying.

The agricultural application of UAVs first gained traction in Japan during the 1980s, primarily for spraying rice paddies where challenging terrain and labor limitations made conventional methods impractical. Huang et al. documented the first successful deployment of small-scale helicopters for agricultural spraying, paving the way for future technological advancements.

More recently, commercial drones designed for precision agriculture have incorporated advanced features like GPS-guided autonomous flight, multispectral imaging, and electrostatic spraying systems. Industry leaders such as DJI, Yamaha, and HSE have introduced drones with substantial payload capacities and automated route-planning software. However, these sophisticated platforms often remain financially and technically out of reach for smallholder farmers, particularly in developing economies.

Recent studies have investigated the practicality of low-cost UAVs for pesticide spraying on small farms. For instance, Yallappa et al. developed a drone-mounted sprayer for row crops in India, reporting a 30% decrease in chemical usage and improved application uniformity compared to manual techniques. Similarly, Kulbacki et al. explored the creation of open-source UAV platforms using hobby-grade components to lower the barrier to entry. Their research indicated that while basic functionality is achievable at a low cost, limitations in flight duration, payload capacity, and spray precision persist.

Spraying efficiency is heavily influenced by factors like nozzle type, droplet size, and the drone's flight altitude. A study by Ferguson et al. concluded that flat-fan nozzles provide optimal coverage for low-volume applications when the drone flies at an altitude between 1.5 and 2.5 meters above the crop canopy. Research by Wang et al. also confirmed that UAV application results in greater uniformity and reduced operator exposure when compared to conventional backpack sprayers.

Significant challenges remain in developing affordable, autonomous systems that can operate reliably under variable field conditions. The adoption of open-source flight controllers like ArduPilot and PX4 has enabled the customization of drones for agricultural purposes. Ebeid et al. have highlighted how these platforms facilitate research into control optimization and sensor integration, both of which are critical for precision tasks like spraying.

The body of existing literature reveals a growing focus on adapting UAVs for accessible agricultural use. Nonetheless, a gap exists in achieving an optimal balance between performance, cost, and usability, especially within the context of small-scale farming. This research addresses that gap by evaluating a cost-effective UAV spraying system specifically designed for these operations.

MATERIALS AND METHODS

Design Methodology

The development of the agricultural UAV system followed an iterative, component-based design strategy aimed at maximizing functionality while minimizing expenses. Initial requirements were established using field-use constraints and performance benchmarks from existing agricultural UAV literature. The primary design objectives were a minimum flight duration of 12 minutes with a full payload, spray coverage of at least 0.1 hectares per flight, and a total system cost under $1000.

The design process was divided into four main stages:

1. **Requirements analysis and field constraint modeling:** We assessed operational needs to establish performance specifications and utilized computational models to forecast system behavior.
2. **Component selection and frame design:** Lightweight yet durable materials were selected for the airframe to enhance the thrust-to-weight ratio. The propulsion units, batteries, and spray components were chosen based on their efficiency and reliability.
3. **Integration of flight and spraying systems:** The mechanical, electrical, and fluidic subsystems were assembled in a modular fashion to simplify maintenance and component replacement.
4. **Testing and validation:** A series of tests were conducted first in controlled laboratory settings and then in field trials to validate the design. Iterative adjustments were made based on these results to ensure all design objectives were met.

UAV Frame and Propulsion System

A quadcopter layout was selected for its mechanical simplicity, superior maneuverability, and inherent stability during low-altitude, low-speed flight, which are all vital for agricultural spraying. The frame was constructed from carbon-fiber reinforced polymer (CFRP) due to its excellent strength-to-weight ratio and resilience. A diagonal wheelbase of 450 mm was chosen to provide an ideal balance of structural rigidity, payload capacity, and agility.

The propulsion system comprised four Racerstar BR2212 980KV brushless DC motors, each paired with 10×4.5-inch polymer propellers. This configuration produced sufficient thrust to support a total takeoff weight

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of approximately 2.4 kg. Each motor was managed by a 20A BLHeli-compatible Electronic Speed Controller (ESC), which connected to a Pixhawk 4 flight controller to handle flight stabilization and navigation. This integrated setup ensured consistent flight stability and smooth operational performance.

Power and Control Architecture

The power system was engineered to deliver a stable and efficient energy supply. A 3-cell (11.1 V) 5200 mAh lithium-polymer (Li-Po) battery served as the primary power source, allowing for flight times between 12 and 15 minutes, depending on conditions. A Power Distribution Board (PDB) guaranteed uniform current delivery to all components.

A Pixhawk 4 flight controller, running on PX4 open-source firmware, managed flight control and navigation tasks. It processed data from an Inertial Measurement Unit (IMU), a barometer, and a GPS receiver to maintain accurate position and altitude information. A 915 MHz radio link enabled real-time telemetry and monitoring through QGroundControl software, which offered a user-friendly interface for mission planning and live data visualization.

Figure 1: Working Prototype

Spraying Mechanism

The aerial spraying system was built for precise and uniform chemical application. It included a 2-liter high-density polyethylene (HDPE) tank, valued for its chemical resistance and light weight. A 12V diaphragm pump provided a steady fluid flow from the tank, while a pressure regulator maintained a consistent 2.0 bar output pressure for uniform droplet formation.

The spray boom, positioned beneath the frame, was equipped with four XR8001VS ceramic fan nozzles that produce fine droplets suitable for effective coverage. This arrangement provided an effective swath width of around 1.2 meters. A mesh filter at the tank's outlet prevented nozzle blockages. The spray function was electronically controlled via a relay linked to the flight controller, permitting both manual and autonomous operation.

Assembly and Integration

The system was put together in modular stages to guarantee precision and ease of maintenance:

1. **Mechanical frame and landing gear:** The airframe and landing gear were assembled to create a stable and robust foundation.
2. **Propulsion system mounting:** The motors, ESCs, and propellers were installed and balanced to minimize vibration.
3. **Flight controller installation:** The Pixhawk 4 controller and all associated wiring were centrally mounted and carefully routed to prevent interference.
4. **Spraying system integration:** The tank and plumbing were securely attached, and the system's center of gravity was calibrated to accommodate the liquid payload.
5. **Ground control setup:** The telemetry link was established, and all system parameters were configured and validated.

Testing Protocol

Component-level tests were performed to evaluate motor thrust, pump flow rate, and battery characteristics. System-level tests involved:

1. Hover endurance evaluations both with and without a payload.
2. Flight stability assessments under a variety of wind conditions.
3. Spray coverage consistency analysis using water-sensitive paper.
4. Area coverage calculations performed at fixed altitudes and speeds.

Field trials were carried out with water as the medium to assess real-world performance, concentrating on spray uniformity, swath width, flight duration, and operational reliability. Safety features, such as the GPS-based return-to-home function and low-voltage alarms, were also rigorously tested.

RESULTS AND DISCUSSION

The UAV spraying system's performance was evaluated based on multiple indicators, such as flight endurance, payload capacity, spray consistency, and operational efficiency.

Flight Performance

The quadcopter's flight capabilities were tested under both loaded and unloaded conditions. With a full 2.4 kg payload, the UAV averaged a flight time of 12.7 minutes. In no-wind hover tests, this increased to 14.3 minutes. Return trips with an empty tank could exceed 18 minutes. The drone consistently held its position within ±0.5 meters and maintained its attitude with deviations of less than 2° in winds up to 15 km/h, confirming its stability for agricultural use.

Spray System Efficiency

The spray system's flow consistency and coverage were tested. Operating at a flow rate of approximately 150 ml/min, each flight covered an area between 0.08 and 0.1 hectares. The effective swath width was a steady 1.2

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meters. An analysis of water-sensitive paper revealed a coefficient of variation (CV) in droplet deposition of 12%, which is well within the acceptable agricultural norm (CV < 20%), signifying dependable and even coverage.

Power and Battery Analysis

The UAV's electrical system was assessed for power consumption and battery endurance. With a full payload, the system drew an average current of 28.4 A. The 5200 mAh Li-Po battery delivered reliable power for up to 50 charge cycles, retaining over 90% of its capacity. The battery's temperature remained within safe operational limits, rising by 12–15°C over a single flight. Optimization of flight parameters and hardware choices resulted in a 15–18% improvement in flight time, underscoring the system's efficiency.

Operational Stability and Reliability

During more than 100 hours of flight testing, the UAV demonstrated exceptional operational stability and reliability, with no critical hardware failures. Minor issues, such as GPS drift near tree cover, were addressed through software adjustments and sensor recalibration. The drone consistently exhibited stable flight and dependable spray control. Its redundant safety systems all performed as expected, confirming its suitability for repeated spraying missions.

Comparison with Manual Spraying

The UAV system was benchmarked against conventional backpack sprayers to quantify its practical advantages.

Parameter	UAV	Manual Sprayer
Coverage Rate	0.8 ha/hour	0.3 ha/hour
Chemical Use Efficiency	+18% (reduction)	Baseline
Labor Requirement	1 operator	2–3 laborers
Droplet Uniformity (CV)	12%	25–30%
Health Risk	Minimal	High (exposure)

The UAV achieved a coverage rate of about 0.8 hectares per hour, far exceeding the 0.3 hectares per hour possible with manual spraying. Chemical consumption was lowered by approximately 18%, and the labor requirement was reduced from 2–3 individuals to a single operator. Crucially, the UAV almost completely eliminated the operator's health risk from chemical exposure. These outcomes highlight the substantial operational, precision, and safety benefits of the UAV system.

Limitations Observed

Despite its clear advantages, the UAV system exhibited several limitations:

1. **Limited endurance:** Flight time was constrained to 12–15 minutes per battery, necessitating frequent swaps for larger fields.

2. **Wind sensitivity:** Performance was negatively impacted by winds stronger than 25 km/h.

3. **Manual refilling:** The tank required manual refilling between flights, leading to operational downtime.

4. **Operator training:** The system requires basic training for correct operation and calibration.

To mitigate these challenges, we employed a modular battery system for fast replacement, developed pre-programmed flight paths for greater efficiency, and designed quick-connect tanks to accelerate the refilling process.

CONCLUSION AND FUTURE WORK

Conclusion

This research validates the feasibility of a low-cost UAV spraying system for small-scale agricultural use. The drone we developed showed reliable flight, consistent spray distribution, and high operational efficiency. It covered approximately 0.8 hectares per hour, decreased chemical use by 18%, and removed the risk of direct farmer exposure to agrochemicals. When compared to manual methods, the UAV offered significant advantages in labor reduction, application consistency, and time savings. This study reinforces the concept that UAVs can be powerful tools in precision agriculture, particularly in developing areas.

Limitations

The system's primary drawbacks include:

1. Limited flight duration due to battery capacity.
2. The necessity for manual control of spray height over uneven terrain.
3. A dependence on line-of-sight manual control, which constrains scalability.
4. Diminished performance in high-wind conditions.

Future Work

Potential future improvements for the UAV system include:

1. **Autonomous Navigation:** Integrating GPS-based autonomous flight paths to automate field coverage.
2. **Sensor Fusion:** Incorporating ultrasonic or LiDAR sensors for real-time terrain following to ensure consistent spray altitude.
3. **IoT Integration:** Connecting the drone to cloud-based platforms for remote diagnostics and data-informed spraying.
4. **Swarm Functionality:** Coordinating multiple UAVs to operate simultaneously for more efficient coverage of large fields.
5. **Hybrid Power Systems:** Exploring solar-assisted or other hybrid power sources to extend operational flight time.

Ongoing development in these areas will contribute to more resilient and scalable UAV platforms, ultimately helping to boost crop yields, reduce costs, and promote sustainable farming practices globally.

REFERENCES

1. Jiang, Y., Zhang, L., & Yang, C. (2020). Applications and Challenges of Unmanned Aerial Vehicle in Precision Agriculture Monitoring. Smart Agriculture Technology, 1, 100010.
2. Wang, G., Lan, Y., Yuan, H., et al. (2019). Comparison of Spray Deposition, Control Efficacy on Wheat Aphids and Working Efficiency in the Wheat Field of the Unmanned Aerial Vehicle with Boom Sprayer and Two Conventional Knapsack Sprayers. Applied Sciences, 9(2), 218.
3. Kim, J., Kim, S., Ju, C., & Son, H. I. (2019). Unmanned Aerial Vehicles in Agriculture: A Review of Perspective of Platform, Control, and Applications. IEEE Access, 7, 105100–105115.
4. Rejeb, A., Rejeb, K., Simske, S. J., & Treiblmaier, H. (2022). Drones in Agriculture: A Review and Bibliometric Analysis. Computers and Electronics in Agriculture, 198, 107017.

5. Radoglou-Grammatikis, P., Sarigiannidis, P., Lagkas, T., & Moscholios, I. (2020). A Compilation of UAV Applications for Precision Agriculture. Computer Networks, 172, 107148.
6. Tripicchio, P., Satler, M., Dabisias, G., et al. (2015). Towards Smart Farming and Sustainable Agriculture with Drones. 2015 International Conference on Intelligent Environments, 140–143.
7. Mogili, U. M. R., & Deepak, B. B. V. L. (2018). Review on Application of Drone Systems in Precision Agriculture. Procedia Computer Science, 133, 502–509.
8. Yallappa, D., Veerangouda, M., Maski, D., et al. (2017). Development and Evaluation of Drone Mounted Sprayer for Pesticide Applications to Crops. 2017 IEEE Global Humanitarian Technology Conference (GHTC), 1–7.
9. Kulbacki, M., Segen, J., Klempous, R., et al. (2018). Review of the Application of Drones in Agriculture. International Journal of Information and Electronics Engineering, 8(1), 13–18.
10. Ferguson, B., Chao, P., & Rains, G. (2016). Drone-Based Spraying System Performance Analysis in Low-Volume Pesticide Application. Transactions of the ASABE, 59(4), 1003–1011.
11. Huang, Y., Hoffmann, W. C., & Lan, Y. (2013). Development of a Small Unmanned Helicopter for Agricultural Spraying. Biosystems Engineering, 114(1), 58–65.
12. Ebeid, E., Fayek, M., Zawbaa, H., & Hassanien, A. E. (2018). Open-Source UAV for Precision Agriculture: A Design Review. Journal of Intelligent & Fuzzy Systems, 34(6), 3579–3592.
13. Martin, D., Singh, V., Latheef, M. A., & Bagavathiannan, M. V. (2020). Spray Deposition on Weeds (Palmer Amaranth and Morningglory) from a Remotely Piloted Aerial Application System and Backpack Sprayer. Drones, 4(2), 59.
14. Parmar, R. P., Singh, S. K., & Singh, M. (2021). Bio-Efficacy of Unmanned Aerial Vehicle Based Spraying to Manage Pests. Indian Journal of Agricultural Sciences, 91(9), 1373–1377.
15. Gatkal, N. R., Nalawade, S. M., Bhanage, G. B., et al. (2025). Review of UAVs for Efficient Agrochemical Spray Application. International Journal of Agricultural and Biological Engineering, 18(1), 1–9.
16. Ragiman, S., Talluri, K. B., N. R. G. V., et al. (2024). Unmanned Aerial Vehicle (UAV)-Assisted Pesticide Application for Pest and Disease Prevention and Control in Rice. International Journal of Agricultural and Biological Engineering, 17(5), 88–95.
17. Lyu, Y., Yu, S.-H., Lee, C.-G., et al. (2025). Performance Evaluation of a UAV-Based Graded Precision Spraying System: Analysis of Spray Accuracy, Response Errors, and Field Efficacy. Agriculture, 15(19), 2070.
18. Zhou, Q., Xue, X., Qin, W., et al. (2020). Analysis of Pesticide Use Efficiency of a UAV Sprayer at Different Growth Stages of Rice. International Journal of Precision Agricultural Aviation, 3(1), 38–42.
19. Senthil Kumar, M., & Jaganraj, R. (2025). Agri-Drone Spraying Systems. International Journal of Research in Agronomy, 8(3), 194–198.
20. Yallappa, D., Veerangouda, M., Maski, D., et al. (2023). Experimental Investigation of Drone-Based Insecticide Application for Effective Pest Management in Groundnut Field Crop. Journal of Agricultural Engineering (India).
21. Krishna, U., Reddy, S. P., & Palkuru, M. (2025). Integration of UAV Remote Sensing and Variable-Rate Spraying in Efficient Rice Blast Control. Journal of Experimental Agriculture International, 47(10), 109–118.
22. Shan, C., Wu, J., Song, C., et al. (2022). Control Efficacy and Deposition Characteristics of an Unmanned Aerial Spray System Low-Volume Application on Corn Fall Armyworm Spodoptera frugiperda. Frontiers in Plant Science, 13, 900939.
23. (2025). Optimizing UAV Spraying for Sustainable Agriculture: A Life Cycle and Efficiency Analysis in India. Sustainability, 17(13), 6211.
24. (2023). End-to-End Precision Agriculture UAV-Based Functionalities Tailored to Field Characteristics. Journal of Intelligent and Robotic Systems, 107, 23.
25. (2023). The Economic Effects of Unmanned Aerial Vehicles in Pesticide Application: Evidence from Chinese Grain Farmers. Precision Agriculture, 24, 1965–1981.