Environment and Ecology 42 (3) : 1069—1078, July—September 2024
Article DOI: https://doi.org/10.60151/envec/LBMW6544
ISSN 0970-0420

An Autonomous Unmanned Ground Vehicle: A Technology Driven Approach for Spraying Agrochemicals in Agricultural Crops

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Received 14 December 2023, Accepted 15 May 2024, Published on 15 July 2024

ABSTRACT

The application of chemicals through spraying is an essential component of agricultural management systems. However, the use of these chemical products results in the accumulation of residues in the soil, leading to a decline in soil fertility and plant diversity. Additionally, farmers who manually spray pesticides onto their crop fields are at risk of developing health issues such as tumors, hypersensitivity, allergies, and skin diseases. As the global population continues to grow and climate change impacts farmland ecosystems, the occurrence of pest epidemics in crops is becoming more frequent. Consequently, there is a greater demand for enhanced tools and methods to improve crop production. Unmanned ground vehicles (UGVs) have the potential to revolutionize agricultural spraying by offering efficient and effective applications of crop protection agrochemicals. This article provides an overview and consolidation of the present research and advancements in UGV application technologies and different sensors that are specifically designed for spray applications of agrichemicals. It examines the features of both hardware and software architecture for implementing control strategies, obstacle detection, and avoidance systems with real-time integrated systems, and the ability to perform variable-rate agrochemical applications.

Keywords UGVs, Autonomous vehicles, Smart spraying technology, Vision sensors, Robotic agriculture, Artificial intelligence, Arduino uno.

INTRODUCTION

The green revolution has been instrumental in demonstrating how to enhance agricultural production to meet the growing food demand of the world's population. However, the increased production has also led to a rapid rise in the use of agrochemicals with a total consumption of 58,720.12 metric tonnes in 2020, which has become a major environmental concern that needs to be addressed urgently. It is worth noting that India holds the position of the fourth-largest producer of agrochemicals worldwide (Bao *et al.* 2015). In FY2019, the Indian agrochemicals industry had a total value of approximately INR 420 billion. Out of

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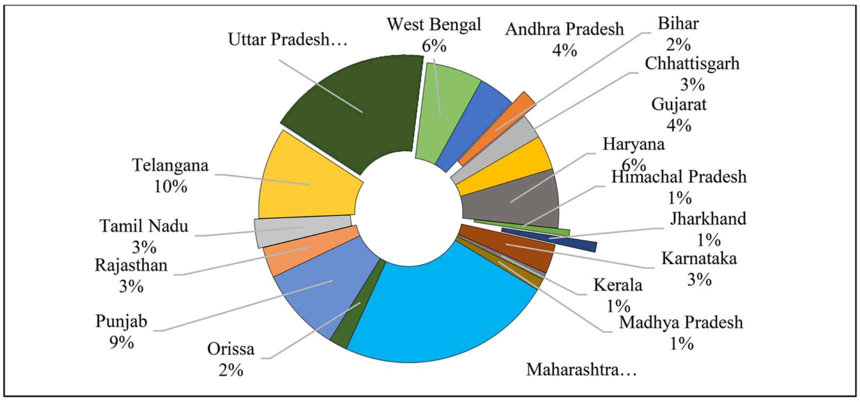

Fig. 1. State-wise agrochemical consumption share percentage in India.

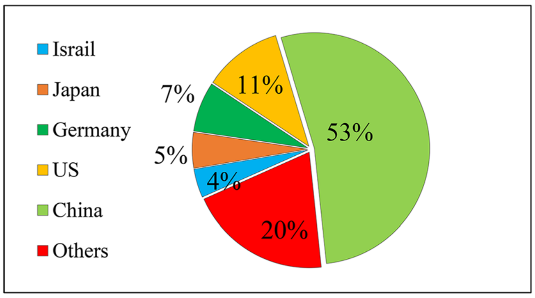

Fig. 2. Major contributor of agrochemicals in India.

this, domestic consumption accounted for around INR 200 billion, while exports amounted to around INR 220 billion. The industry heavily depends on imports for raw materials and technical intermediates, with China contributing around 53% to India's pesticide imports in FY2020, valued at INR 90.96 billion (Anon 2021).

The state-wise share percentage for consumption of agrochemicals and major countries importing agrochemicals to India is shown in Figs. 1 - 2 (Anon 2017). The agricultural industry is projected to experience a compound annual growth rate (CAGR) of 8-10% until 2025 (Pandey *et al.* 2020). This growth will be fuelled by various factors such as a rising population, a decline in arable land, a surge in demand for high-value agricultural goods, and increased initiatives from both the industries and government sector to promote awareness and latest technology adoption. The major products used are herbicides, insecticides, fungicides, biopesticides, and plant growth regulators as agrochemical products, serving various purposes such as weed control, pest management, and enhancing plant growth and yields (Gavrilescu *et al.* 2015). The breakdown of the volume of usage for these major agrochemical products in agricultural production is

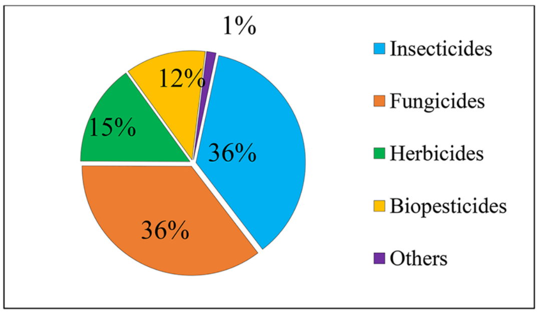

Fig. 3. Agrochemical share percentage by type.

Fig. 4. Manual pneumatic knapsack sprayer.

shown in Fig. 3 (Anon 2015).

The continuous and uncontrolled use of agrochemicals has been observed to have a detrimental impact on our lives, environment, and biosphere. This is due to the lack of scientific regulation and the exaggerated application of these agrochemicals. Not only do they contribute to water, air, and soil pollution, but they also disrupt the nutrient balance. Thus, putting a significant portion of both macro and microflora and fauna at risk. Furthermore, these agrochemicals pose severe health hazards to humans, and can even lead to death when individuals come into direct or indirect exposure. In countries like India, where there is immense pressure from a rapidly increasing population, governments tend to prioritize industrial benefits and crop yield (Sarwar 2015). However, to achieve sustainable development, it is crucial to address these issues at their core on a priority basis. A recent study on agrochemical spraying revealed that approximately 385 million individuals working in agriculture suffer from acute pesticide poisoning annually, with up to 220,000 deaths occurring in developing countries due to pesticide spray and its human handling farmers have reported various symptoms ranging from weakness, and headaches, and vomiting to birth abnormalities, diarrhea, skin rashes, blood diseases, tumors, and nervous system disorders (Colosio *et al.* 2013). Shockingly, 44% of all workers worldwide experience at least one poisoning per year, with certain countries experiencing even higher rates. Therefore, it is crucial to implement the most advanced precision technologies for agrochemical spraying to minimize its impact on both humans and the environment.

Traditional method

The farmer engages in a range of agricultural tasks such as seedbed preparation, sowing, irrigating, applying pesticides, and harvesting to cultivate crops. These methods are predominantly carried out manually by farmers. Pest control is an essential activity undertaken by farmers to safeguard crops from diseases and insects. In conventional agriculture, a common method of applying agrochemicals involves a human operator walking along the crop rows and manually spraying the desired targets using a backpack sprayer equipped with long rods, lances, or spray guns to distribute liquids to different areas (Fig. 4). However, this manual spraying process is not ergonomically good and requires more time and energy (Rincon *et al.* 2018). Using wide-area spray nozzles for hand spraying in large areas can lead to higher operator exposure compared to narrowly focused spray nozzles. When using air blast sprayers mounted directly on tractors, the degree of operator exposure is also higher than when using spraying implements attached to the trailer (Fig. 5).

Fig. 5. Trailed air blast sprayer system.

The deposition of agrochemicals on the operator's body can very depending on the individual's working habits. Tractor-mounted sprayers are

Fig. 6. Tractor-mounted boom sprayer system.

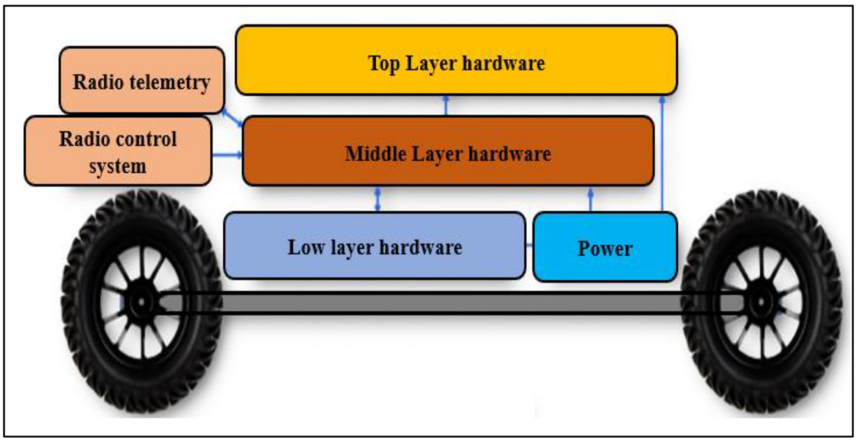

Fig. 7. General architecture of the unmanned ground vehicle system.

widely favored by farmers due to their affordability, effectiveness, and time-saving capabilities (Fig. 6). However, it is important to acknowledge the potential health risks are also associated with pesticide exposure in this technology too. To prevent excessive pesticide usage, these sprayers must be accurately calibrated and well-maintained. Furthermore, the process of mounting and dismounting tractor-mounted sprayers, especially those with front tanks, can be laborious (Erbaugh *et al.* 2019). Additionally, their carrying capacity is limited, and the ground clearance is determined by the pick-up height of the tractor's hitch point system. Adapting tractor-operated sprayers can be challenging for farmers due to prevailing cropping patterns, land holdings, and field problems in the rainy season.

Despite the utilization of safety equipment such as head masks and filtration systems for both manual and mechanized methods of spraying, individuals remain vulnerable to the harmful effects of pesticides, which can result in health issues and agrochemical loss that contribute to degrading the environment. Studies have indicated that the hands and forearms are also prone to contamination, especially when handling and applying agrochemicals. It is also noted that other parts of the body like the thighs, chest, and back can also be affected. According to the World

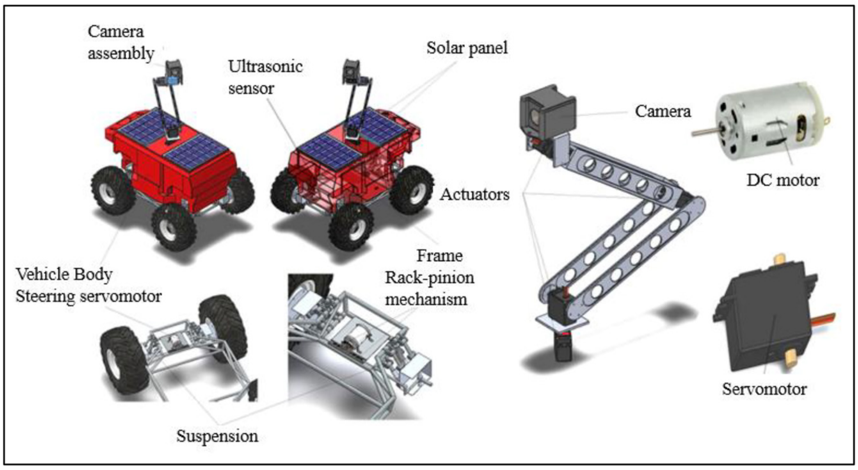

Fig. 8. Unmanned ground vehicle with controls units.

Health Organization (WHO), manual pesticide spraying in crop fields has resulted in one million cases of negative effects (Zhang and Liu 2013). While this method yields good results, it is also time-consuming and requires a large amount of liquid per plant. Additionally, it is challenging to ensure even and effective coverage of the entire plant.

To address concerns about environmental pollution caused by excessive pesticide use and to improve efficiency, it is crucial to identify suitable alternatives. Implementing automated spraying machines on a large scale can help overcome the challenges faced in various agricultural spraying practices. These technologies have the potential to reduce pesticide usage, improve its sustainability, and mitigate its adverse impact on the environment. With the use of a target-specific automated sprayer, the volume of pesticides applied in today's agriculture can be substantially decreased, and human intervention during the spraying process can be minimized or eliminated. Research indicates that directing the spraying material toward the intended target can result in a reduction of up to 60% in pesticide usage.

Proposed method

Over the last twenty years, there has been significant research conducted on automation technologies for various agricultural activities, including transplanting, trimming, spraying hoeing, and harvesting. Among the numerous innovations in modern agriculture, the utilization of unmanned ground vehicles for spraying agrochemicals has emerged as a notable technology. It is important to note that this trend of using unmanned ground vehicles for agrochemical spraying in agriculture is not a recent development (Vikram 2021). Over the course of numerous decades, this technology has undergone advancements and improvements, resulting in more intelligent versions that possess the ability to autonomously make decisions based on various input parameters (Nakao *et al.* 2017). It is anticipated that this technology will have a beneficial influence on both the environment and human health, as it will reduce chemical waste, improve food security, optimize resource utilization, and decrease the need for manual labor.

The use of unmanned ground vehicles has the potential to decrease the amount of savings and resources needed for crop cultivation, such as water, herbicides, pesticides, fertilizers, insecticides, and arable land. Moreover, the expenses related to sensors and instruments used in integrated embedded systems, like electrical motors, computers, hardware, software, and batteries, may decline over time, making these advanced technologies more affordable for farmers and encouraging their adoption. The robot's application requires it to handle uneven terrain and navigate through furrows without causing harm to the plants. To achieve this, the robot is equipped with a four-wheeled and off-road chassis system that has a rear and front suspension mechanism with a high clearance. Figure 7 illustrates the overall structure

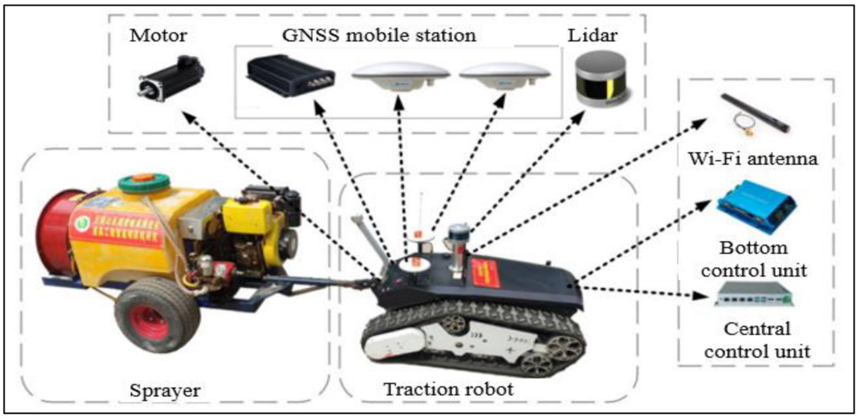

Fig. 9. Spraying unmanned ground vehicle.

of the robot, including its hardware layers and the interconnections between them.

The underlying component of the hardware architecture consists of the motors and motor drivers, which are responsible for the robot's propulsion and steering. The intermediate level of the hardware enables the robot to move autonomously and plan its path. To ensure redundancy in communication and remote control, the robot is equipped with multiple communication systems that are managed by the autopilot board. The middle layer hardware of the system includes the GPS, which is directly utilized by the autopilot board, along with other systems such as the telemetry structure and the remote-controller receiver that communicate with the autopilot board through various interfaces (Zhou and He 2021). On the other hand, the top layer of the architecture consists of a micro-computer and a photosensitive camera. These components are responsible for carrying out computer vision work.

Classification of unmanned ground vehicle

These can be divided into two categories: Autonomous and semi-autonomous. Autonomous system function independently, using their own decision-making abilities and sensors. They can adapt to changing environments and make real-time decisions. Semi-autonomous system requires human control or guidance. They combine autonomous features with manual control, allowing humans to intervene or provide specific instructions. By understanding the distinction between autonomous and semi-autonomous systems, researchers and engineers can develop systems that cater to specific needs and applications, ranging from fully independent machines to collaborative human-robot systems. The mode of operation of these systems can be controlled in different ways as shown below:

UGVs teleoperation

Humans possess the ability to recognize and adjust to various environmental and object conditions. Their sharp perception allows them to handle ambiguous, dynamic situations and a broad range of definitions. These skills make humans well-suited for supervising machines at different levels of collaboration. Teleoperation, a mode of operation, involves direct control of a robot by an operator. Agricultural UGVs can be teleoperated by a human farmer who controls their actions from a safe location using a user interface. This allows the farmer to receive data from the robot's sensors and cameras while directing its tasks. Teleoperation has proven to be effective in various fields, including space exploration, medical applications, and agriculture (Shaik *et al.* 2018).

Human-UGVs interaction

Human-robot interaction (HRI) is a specialized field that focuses on comprehending, creating, and assessing automation systems for human use or collaboration. Remote interaction occurs when the human and the robot are physically or temporally separated, like the Opportunity Mars rover. In contrast, proximate interaction involves humans and robots being close to each other. The main goal of human interaction is to efficiently use these autonomous systems to alleviate humans from repetitive or dangerous tasks (Zhang *et al.* 2020). When dealing with a completely independent autonomous system, the interaction entails the human setting goals while the autonomous system possesses knowledge about the environment, the task, and its limitations, with the human supervising and directing the robot at a higher level (Vasconez *et al.* 2019).

Reality-based interaction

Reality-based interaction refers to a form of interaction that is grounded in real-world experiences and environments. It involves the use of technologies such as virtual reality, augmented reality, and mixed reality to create immersive and interactive experiences for users. This type of interaction aims to bridge the gap between the physical and digital worlds, allowing users to engage with digital content more naturally and intuitively. By incorporating elements of the real world into the digital realm, reality-based interaction enhances user engagement and provides a more realistic and immersive experience (Shalal *et al.* 2015). It has applications in various fields, including gaming, education, healthcare, and training, where it can be used to simulate real-world scenarios and provide

Fig. 10. Dosing Unmanned ground vehicle.

users with hands-on experiences.

Related work done

There are currently several autonomous agricultural unmanned ground vehicles (UGVs) that are already accessible and can perform spraying operations. However, these are expected to be released soon in the market in coming years with more precise working and affordable options (Konam *et al.* 2014). These UGVs are currently too complex, slow, and expensive to be accessible to the general public. This is particularly true in India, where the agriculture sector plays a significant role in the country's economy but still relies on traditional methods and has not fully embraced modern technologies like automated UGVs due to their high cost (Ko *et al.* 2015). The UGVs consist of both an autonomous and manual mode. Initially, the operator manually moves these autonomous systems with the help of the controller along a specific path. Once it is positioned correctly in the crop path, the autonomous mode can be activated. In this mode, the robot moves in a straight line, spraying at regular intervals, until it reaches the end part of the crop field based on the pre-determined distance. The operator can then manually move the robot to the next field or path and repeat the process (Corpe *et al.* 2013).

In general, these automated UGVs are equipped with two outdoor wheels and a caster, allowing them to easily navigate through soil and rough terrain in agricultural fields. In these systems, the steering is effortless using the wheels, as one wheel can be braked while the other is moved in to forward direction. This design choice of using two wheels and a caster simplifies the mechanical system and reduces the overall cost of the agricultural robot, making it an affordable solution (Fan *et al.* 2017). A self-sufficient UGV was introduced based on an AVR microprocessor to control all the inputs and outputs of the system. The robot was guided by hot water pipes, while a gearbox and shaft arrangement transferred power from DC motors to driving wheels (Rafiq *et al.* 2014). A similar system was developed that utilized affordable technology like microprocessors, motors terminal equipment, and wireless cameras to automate agricultural tasks such as pest detection, pesticide spraying, and fertilizer application (Aishwarya *et al.* 2015).

A significant enhancement to a smart spraying automated UGV robot system was made by integrating it with the design of a typical vehicle chassis specifically used in agriculture (Gonzalez *et al.* 2016). This integration allowed the system to interface with the spraying mechanism and control the system by the controller. In recent studies, these automated sprayer UGVs have successfully implemented human-robot collaboration to enable the robot automation system and human to work together in detecting spraying targets, resulting in a higher true positive rate and a reduction in false positives (Berenstein and Edan 2017, Adamides *et al.* 2017). Chen and Meng (2018)

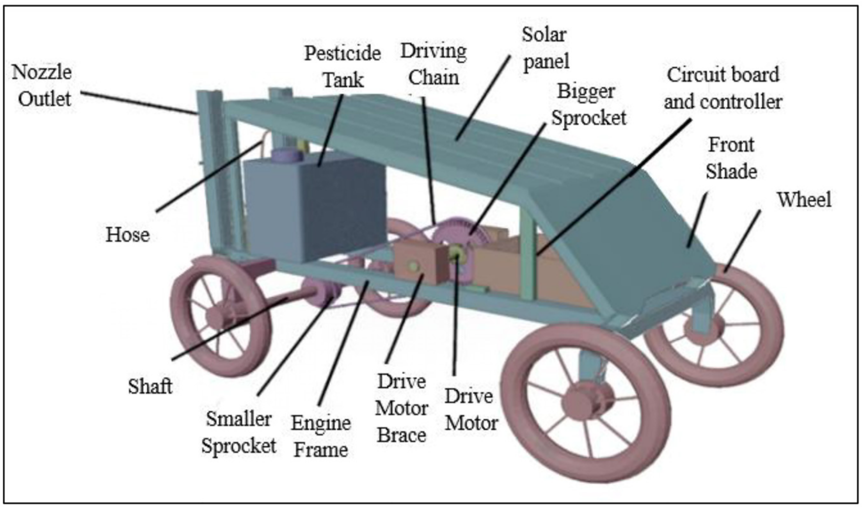

Fig. 11. Solar-powered pesticide sprayer.

employed a microsoft camera equipped with an RGB and a depth sensor camera to create an automated pesticide spraying UGV. This innovative system was capable of adjusting its spraying height according to the plant's height with the help of three nozzles that were strategically positioned in a vertical arrangement on the front part of the robot system. A similar study was carried out by Cantelli *et al.* (2019), Alam *et al.* (2020), and Chaitanya *et al.* (2020) with the incorporation of real-time visual streaming/recording and advanced machine learning techniques.

Oyekola *et al.* (2022) developed an unmanned ground vehicle incorporated with a DC motor employing the Pulse Width Modulation technique, which allows for the control of the motors' rotational speed by adjusting the average voltage delivered to them. However, this technique was not effective in changing the direction of rotation. The complete setup of the integrated electronic and mechanical components is shown in Fig. 8. Similar automated integrated spraying vehicle was developed comprised of a spraying and dosing robot (Figs.9 -10). To enable cooperative navigation, the spraying and dosing robot communicated with each other via wireless routers, exchanging navigation information (Qin *et al.* 2022). For precise positioning, the spraying robot employed the RTK-GNSS system. The other components included the LIDAR model, control unit, BLDC motor, and base station by Sinan (Fig. 11).

An innovative solution for pesticide spraying was introduced by developing a solar-powered robot vehicle that can be controlled remotely and partially automated (Kayode *et al.* 2024). By harnessing the energy from four 30W solar panels, the robot vehicle was operated using a 100 AH battery, reducing the reliance on electricity. The power generated (120W) was utilized to drive the motors and pump, ensuring efficient operation. Additionally, the vehicle incorporated a 12V hub motor for propulsion and steering, as well as a 12V window regulator/wiper motor. The remote-control functionality was achieved through a transmitter (HC-05) and receiver, pre-program in ATMEG-32, which was connected to a relay board. To facilitate the automated spraying process, the robot vehicle was employed with a 116-psi pump. This innovative solution not only minimized manpower but also promoted sustainable energy usage.

Future

Artificial Intelligence in robotics is revolutionizing our daily lives, reshaping various industries. These cutting-edge technologies are gradually penetrating areas that were once deemed inaccessible. In the field of precision agriculture, these technologies have been employed for many years. However, with recent advancements, they have become increasingly dependable, versatile, and responsive to the specific demands and necessities of the sector. The future of UGVs in agriculture poses challenges due to the fast progress in existing work and the growing development of new systems incorporating innovative technologies. Although regulatory issues are constantly changing in various countries, it is undeniable that UGVs will increasingly be integrated into the agricultural sector. As with any new technology introduced to a well-established field, UGVs have the potential to improve and intersect current practices. The latest advancements in the field of UGVs and their numerous successful applications in the agricultural sector for the application of agricultural agrochemicals have been witnessed in the past few decades. Ongoing research aims to further improve these technologies and develop new ones that ensure the effective and safe utilization of these agrochemicals.

CONCLUSION

The agriculture sector is anticipated to benefit from the automation of agricultural processes as it will lead to waste reduction and improved food security through efficient resource utilization. Precision spraying, a technique employed to minimize losses during agrochemical application, plays a crucial role in reducing the waste of harmful chemical deposits on the soil. This study offers an overview of the latest advancements in spraying agrochemicals using unmanned ground vehicles (UGVs) and highlights the key obstacles that need to be addressed. This review has the potential to significantly enhance the identification of valuable automated solutions and applications for spraying, which can effectively minimize human participation in dangerous, repetitive, and labor-intensive tasks. The integration of autonomous vehicles with spraying management systems offers a technologically advanced solution for precise and autonomous spraying in various agriculture operations. The future advancements of multi-purpose autonomous UGVs can be greatly influenced by these solutions, which not only fulfill efficiency and competitiveness needs but also promote safer and healthier working environments. However, it is crucial to continue research on developing protocols, standard operation procedures, user-friendly interfaces, power technology, real-time quality imagery, robust mechanical features, and improved sense and avoidance technology to meet the demands of agricultural unmanned ground vehicles for autonomous actions in real-time.

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