drones

Review

Independent Control Spraying System for UAV-Based Precise Variable Sprayer: A Review

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Abstract: Pesticides are essential for removing plant pests and sustaining good yields on agricultural land. Excessive use has detrimental repercussions, such as the depletion of soil fertility and the proliferation of immune insect species, such as *Nilaparvata lunges* and *Nezara viridula*. Unmanned aerial vehicle (UAV) variable-rate spraying offers a precise and adaptable alternative strategy for overcoming these challenges. This study explores research trends in the application of semi-automatic approaches and land-specific platforms for precision spraying. The employment of an autonomous control system, together with a selection of hardware such as microcontrollers, sensors, pumps, and nozzles, yields the performance necessary to accomplish spraying precision, UAV performance efficacy, and flexibility in meeting plant pesticide requirements. This paper discusses the implications of ongoing and developing research. The comparison of hardware, control system approaches, and data acquisition from the parameters of each study is presented to facilitate future research. Future research is incentivized to continue the precision performance of the variable rate development by combining it with cropland mapping to determine the need for pesticides, although strict limits on the amount of spraying make it difficult to achieve the same, even though the quality is very beneficial.

Keywords: pesticide; control systems; spraying distribution; water-sensitive paper (WSP); simulations; environmental parameters; nozzle

Citation: Hanif, A.S.; Han, X.; Yu, S.-H. Independent Control Spraying System for UAV-Based Precise Variable Sprayer: A Review. *Drones* **2022**, *6*, 383. https://doi.org/10.3390/drones6120383

Academic Editors: Görres Grenzdörffer and Jian Chen

Received: 12 October 2022
Accepted: 25 November 2022
Published: 28 November 2022

1. Introduction

Due to their efficacy in field work, agricultural drones are becoming an option for modern farmers. When market demand for food is high, customers realize they must reconsider how to boost agricultural production and efficiency to directly effect the success of their farming enterprise. To determine which elements required improvement, soil quality, rainfall patterns, temperature, climatic change, wind speed, and the presence of weeds and insects were evaluated [1]. To increase and organize productivity in accordance with market demand, farmers must work diligently to develop innovations. However, there are numerous paradoxes in rural contexts, where knowledge and technology are still used conventionally, despite the fact that the number of food requirements is not significantly different from that of metropolitan areas. In addition, pests and plant diseases are the principal issues that have a direct impact on the quality of land productivity. Chemicals and pesticides can be utilized as the principal means of eliminating and stabilizing the biotic composition of crops to circumvent this issue. However, using pesticide spraying equipment in the field is essential due to the diverse pesticide requirements of each crop. More than 88% of manually operated sprayers in China are knapsack air-pressure or electric sprayers and knapsack mist-blower sprayers [2].

Currently, consumers prefer the usage of precision variable spraying systems mounted on unmanned aerial vehicle (UAV)-based sprayers over ground plant protection vehicles due to their speed of operation. Farmers are beginning to consider limiting the use of pesticides and regulating the environment to preserve the nutrient content of their land, in light of the high speed of drone operations. As researchers, we must also introduce public innovations that meet the demands of farmers [3]. Moreover, by the end of 2020, the adoption of pesticide spraying technology that is high in efficiency, product safety, resource efficiency, and environmental friendliness will be promoted, with the ultimate objective of attaining a zero percent growth in overall pesticide use. The application of pesticides by unmanned aerial vehicles (UAVs) can limit chemical waste to precise levels. However, due to external factors such as wind and the effect of the UAV itself, such as fluid dynamics caused by propeller blowing, UAVs experience droplet drift and adhesion, resulting in non-uniform spraying [4].

According to Phang et al. (2014) [5], a UAV has greater benefits over terrestrial vehicles such as tractors in terms of mobility. It is 40 times faster than the conventional backpack sprayer and can replace it. Using a UAV sprayer results in a 90% reduction in water usage and a 30–40% reduction in insecticides. Reducing pesticide use has a significant influence on the environment by preserving soil fertility and pest resistance to pesticides as a result of the correct treatment quantity. Wheat and soybean farmers can save an estimated $1.3 billion annually in expenses and money from crop yields, according to this calculation. It is required to establish a dynamic model between affecting elements and spraying quantity. This system and technology can be efficiently applied to rice and soybeans, the two main carbohydrate-based agricultural products in Asia.

According to statistical evidence, temperate climates are also home to rice, the world's most important crop. Additionally, rice provides calories to more than one-third of the world's population. Rice does not inevitably become a commodity with a high production quantity value due to the magnitude of the monetary value of these needs. Numerous insects that feed on rice inhabit this crop. The brown plant-hopper (BPH) is the most devastating insect pest recorded in Asia during the past decade [6]. BPH has wreaked havoc on rice farms in China, Japan, South Korea, and Vietnam. In 2005 and 2008, China reported a combined yield loss of 2.7 million tons of rice due to direct damage by BPH. Grassy stunt virus (RGSV) and ragged stunt virus (RRSV) are other plant pests that BPH can spread [7,8]. Aside from rice, one of the most economically significant pests that infest soybeans is the southern green stink bug, *Nezara viridula* (L.PH) [9,10], which can be found in Europe, Asia, Africa, and the United States. This pentatomid is extremely polyphagous, feeding on more than 145 plant species [11–14].

Recent research has been conducted actively and extensively on variable quantity spray technology. Cruvinel et al. (2016) [15] established relationships between operating velocity, nozzle height, and spray flow. To achieve consistent spraying, this approach only modulates the flow rate based on speed and altitude. Nevertheless, environmental conditions and spray system characteristics impact the spray effect [16]. Temperature, relative humidity, and wind speed influence droplet deposition by causing droplet drift and evaporation. The spacing between nozzles in the fuselage's structural characteristics has an effect on spray uniformity [17]. Furthermore, the rotor's pitch changes its airflow field and influences droplet deposition [18]. Deng et al. (2016) [19] built a constant-pressure sprayer governed by a proportional integral derivative algorithm with a closed-loop. This sprayer's pressure was altered by manipulating the solenoid valve's opening, hence altering the spray volume. In the same field, crops are affected by pests and diseases of varying severity, whereas environmental factors and flight characteristics affect spraying efficiency. To imitate the spray operation of an unmanned aerial vehicle (UAV) in a wind tunnel, Ling et al. (2018) [20] established varying wind speeds and flight angles. Finally, a correlation between the influencing factors and spray volume was established. However, the classic linear relationship model of traffic flow and many variables is inflexible, making it impossible to differentiate the degree of influence of each item. The linear relationship model between spray quantity and flight speed at the flight altitude cannot accurately adjust the flow rate [21] due to the fact that environmental conditions and flight parameters vary in real time during plant protection operations.

In China, intense use of precision spraying technologies for plant pest control has begun and is increasing rapidly. Aviation technology in the agriculture sector is still in its infancy, but is evolving rapidly due to its greater adaptability in contrast to ground-based plant treatment vehicles. UAV has great precision control characteristics and rapid response to field-specific parameters. In certain situations, the design of a plant protection UAV variable spray system is based on the interpretation of the task prescription map. The system collects prescription information for real-time position via graphical interpretation of plant protection UAV, and PWM proportional–integral–derivative (PID) control is employed to swiftly and precisely modify the spray volume. Experiments verify the system's stability and practicability, providing a theoretical reference for the study of plant protection UAV variable spray systems and extending to the field of contemporary agricultural aviation for plant protection [22]. The PID control algorithm is based on a system error control law. The algorithm is a proportion (P), integration (I), and differentiation-adjusted optimum control (D). It possesses a simple principle, high control accuracy, simple implementation, and strong applicability [23]. The PID control algorithm has discernible implications on the dynamic system calibration procedure for continuous systems. The PID control technique is used to accomplish closed-loop system control [19] in order to precisely control the flow of the system and assure the precision and stability of the variable spray operation.

Most of this study is devoted to the development of a variable rate spraying system with near-precise performance for use with unmanned aerial vehicles. The ultimate objective of establishing an autonomous spraying system that takes into consideration environmental and platform characteristics is to spray a precise amount of pesticide on plants without affecting the quality of the point of land owing to excessive pesticide use. Pesticides are substances that, when applied in excessive quantities, are detrimental to both the environment and humans [24,25]. Pesticides, on the other hand, can be the most effective solution if applied correctly, especially when paired with high-precision agricultural equipment and machinery within a UAV-based spraying system.

2. Application Development for an Independent Control System

2.1. Unmanned Aerial Vehicle (UAV) in Agriculture Area

UAVs are radio-controlled aircraft capable of flight. Multi-rotor UAVs are the only type that may be further categorized by the number of rotors on their platform. In recent decades, numerous UAV model types have been deployed, as shown in Table 1. Compared to multi-rotor aircraft, the design of fixed-wing UAVs (Figure 1a) is drastically different, and the aerodynamic structure of their two wings makes them easier to fly. Figure 1b depicts a model of a single-rotor helicopter with one large rotor on top and a smaller one in the tail of the UAV. Quadcopters, hexacopters, and octocopters refer to multirotor aircraft with four, six, or eight rotors (Figure 1c–e, respectively).

Single-rotor, quadcopter, hexacopter, and octocopter are subcategories of multirotors. A multi-rotor has a lower flight speed, distance, and duration than a fixed-wing drone since it requires an enormous amount of power to generate lift and maintain flight [48].

The octocopter has all the advantages of the hexacopter, but with increased power. These devices are not inexpensive but are generally obtain the best possible aerial footage. These eight motor drones offer the same, or additional, advantages to the quadcopter, and the hexacopter.

1. Speed: Much faster than their competitors and capable of reaching greater altitudes.
2. Control: Exceptional control that is less impeded by wind and rain and is stronger and more dependable.
3. Safety: Even if one motor malfunctions, the octocopter can be flown just as well as a hexacopter. Furthermore, depending on the position and overall payload, two or three motors could be dysfunctional without the craft crashing. Furthermore, they are very stable and perform better in harsh weather conditions.

The characteristics of each type of drone can be used to determine which species will be used as a prototype in the control system development. Furthermore, the independent control system is expected to include a carrier option feature that farmers can select based on the drone sprayer they own. It is critical to understand the characteristics of the various types of UAV sprayers because the cons that arise can be overcome only with each solution from the drone. For example, if a drone company wants to increase the lifting capacity of a quadcopter, the lifting power must be increased in a way that is directly proportional to the drone's size increase.

Table 1. Types of UAVs distinguished by the number of propellers.

Type	Advantage	Disadvantage	Reference
Single rotor helicopter	Long endurance	More dangerous	[21,23,26–33]
Octocopter	Greater redundancy and lifting capacity	Several components to keep track of	[21,26,34–38]
Quadcopter	Simplest mechanical structure, opposite force stays balanced	Light lifting capacity	[39–41]
Hexacopter	Greater redundancy	Insufficient performance and battery capacity	[21,34–37,42–44]
Fixed wing	Fly faster and longer distances	Reduce mapping efficiency, inflexible take-off and landing	[45–47]

(a) (b) (c) (d) (e)

Figure 1. Different types of UAV: (**a**) Fixed Wing, (**b**) Single rotor, (**c**) Quadcopter (**d**) Hexacopter, and (**e**) Octocopter.

The type of drone can be determined based on the aforementioned advantages; multirotors are commonly used as prototyping materials. The invention of a remote-controlled multirotor with the capability of a drone sprayer begins with the selection of a controller and its customization to the field's requirements. Before carrying additional implements, the UAV's carrying capacity, flight capability, and performance were modified. Considering the performance, weight, and transmission speed of each tool, the underlisted are the materials utilized to manufacture drone sprayers (Table 2).

Table 2. Different controllers and methodologies with respective capabilities and performance.

Controller	Framework	Load	Speed	Reference
Ardu 2.8 FC	RC transmitter	-	-	[21]
UAV ZHKU-0404	-	1–15 dm^3	3.5 m/s	[40]
Arduino mega 2560	WIFI module	-	-	[41]
FC	RC Transmitter	5 dm^3	1 m/s	[44]
Arduino At mega 328,	Radio receiver	-	-	[28,39,49]
Hexa-II Atmega1284p	WIFI	1 kg (camera)	-	[42]
Atom board processor	-	0.6 kg (Laser scanner)	-	[43]
DJIs 900 model	-	-	1.3 m/s	[36]
ARM processor	-	1 kg	8.33 m/s	[38]
TTA M8A	TR-PIV	10 kg	0–15 m/s	[26]
Aero drone PAM-20	Radio Link	25 kg	22.22 m/s	[45]
Pathfinder-plus	Radio link	67.5 kg	13.89 m/s	[46,47]
Z-3	-	20 dm^3	3 m/s	[28]
Yamaha RMAX	-	100 kg	5.56 m/s	[30]
MSP430 single-chip	RC transmitter	25 kg	3–6 m/s	[31]
Rotomotion's SR200	RC Transmitter	22.7 kg (5 kg)	-	[29,32,33]
KK v5.5 Atmega 168	RC Transmitter, WSN	-	-	[50]
Atmega 8bit AVR	-	-	-	[51]
LLP & HLP	Radio Link	1 kg	-	[52]
Arduino	Radio frequency	8 kg	5 m/s	[53–55]
N-3 type	-	25 dm^3	4 m/s	[56]

2.2. UAV Drone Sprayer Basic Components

Not only is the controller a remote device responsible for internal and management controls, but it also plays a crucial role in decision-making. The parameters are read by environment-detecting sensors and the drone itself. Several aspects are utilized as measuring parameters, and sensors are required to read their parameters in terms of drone function needs [48], drone flying performance maintenance [57], drone decision-makers [58], data collection [48], and control implementation [59]. These sensors and hardware components are installed in the UAV to monitor its exterior and interior and to identify other UAV components, such as distinct sensors, applications, and focal points. The roles of the main types of hardware components and peripherals utilized in UAVs are depicted in Table 3.

Table 3. Components and microcontrollers of the UAV sprayer.

Components	Purpose	Reference
Accelerometer	Acceleration measurement	[38,39,41,42,44,49,52,60,61]
Gyro	Rotational movement	[29,31,32,38,39,44,49,52,54,60,62]
BLDC (brushless DC)	Motion control	[39,41,42,44,49–51,53,54,60,62,63]
ESC (electronic speed control)	BLDC's speed control	[39,41,42,44,49–51,53,54,60,64]
Water sensitive paper	Assessing spray coverage	[40,56]
Anemometer	Wind speed measurement	[40]
Filter papers	Fine substances separator	[40]
Digital Temperature	Temperature detectors	[28,40,56]
Humidity indicator	Air moisture measurement	[28,40,56]
Magnetometer	Magnetic field measurement	[29,31–33,42,52,60]
WSN	Sensing environmental conditions	[39,49,65,66]
IMU	Angular rate and forces measurement	[29,32,33,43,51,52,54,55,60,62]
GPS	Provides geo location of an object	[29,31–33,38,39,41,42,44,45,50,52,53,56,60,62,63,67,68]
Telemetry	Obtain real-time data from a UAV	[31,33]
Altimeter	Altitude measurement	[31]
Air Pressure Sensor	Gases or liquids measurement	[38,52,69]
Barometer	Atmospheric pressures	[28,60]
PWM controller	Signal pulse provider	[32,33,54]

2.3. Spraying and Nozzle Systems

In spraying systems, there are various types of nozzles, each with its own efficiency, performance, and technical specifications. This sprinkler system, which is often located at the bottom of the UAV, employs a nozzle connected to the pesticide tank to spray pesticide solution over crops. The two components of a sprinkler system are the spraying control and nozzle systems. The spraying system includes both spraying material (pesticides or fertilizers) and a spraying nozzle. The second component is a controller that regulates the nozzle of the sprayer. A pressure pump is a sprinkler system component that forces insecticide through the nozzle using pressure. A motor driver integrated circuit is utilized to adjust the pump's pressure as required. Table 4 compares the flow rates and nozzles utilized by UAVs for spraying.

Table 4. List of pesticide injection pumps and nozzles and its specifications.

Nozzle and Pump Type	Operating Speed	Operating Pressure	Reference
Singflo Flo-2203 [a] (pump)	2.6 dm^3/min	0.483 MPa	[70]
BPP-25 [b] (pump)	3.5 dm^3/min	1 MPa	[70]
Unbranded/generic [c] (pump)	5.5 dm^3/min	0.9 MPa	[70]
XR80015-VS [d]	0.57 dm^3/min	0.103–0.41 MPa	[44,70]
AI11002 [e]	0.76 dm^3/min	0.27–0.69 MPa	[30,70]
Micron air–A+	27.22 g/min	-	[33]
TX VK-08 [f]	0.5 dm^3/min	0.207–2 MPa	[21,70]
Rotary atomizer	0.85 dm^3/min	-	[56]
TP800067-VS [g]	0.25 dm^3/min	0.207–0.414 MPa	[40,70]

[a] YOUME ELECTRIC CO, LTD., Xiamen, China. [b] JMRRC Co. LTD., Guangdong, China. [c] Pro Pumps Co., China. [d], [e], [f], [g] series (Spraying Systems Co. Ltd., Glendale Heights, IL, USA). Schematics and specifications of all nozzle listed in this table can be found in Spraying Systems Co. Ltd.

2.4. The Use of the Spraying Method

Typically, one of two techniques are utilized by UAVs for spraying pesticides. The first type of UAV-based sprayer has a spraying system on the boom sprayer [71] and the second type has a spraying system under the propeller rotor [72,73]. The location of the nozzle under the rotor affects the movement of the droplets [74] (Chen H. et al., 2021). The V6A drone (Figure 2) is an example of a boom sprayer-type UAV drone that is equipped with four CR80-005 nozzles (Lechler GmbH, Metzingen, Germany). An example of a drone spraying system located below the rotor is the MG-1, which has four XR110-01 nozzles (TeeJet Technologies, Wheaton, IL, USA). The XR110-01 nozzles have 110 spray angles and are flat fan nozzles, while the CR80-005 nozzles have 80 spray angles and are hollow cone nozzles. XR110-01 nozzles have a typical flow rate of 354 mL/min at 226 kPa, whereas CR80-005 nozzles have a typical flow rate of 197 mL/min at 517 kPa.

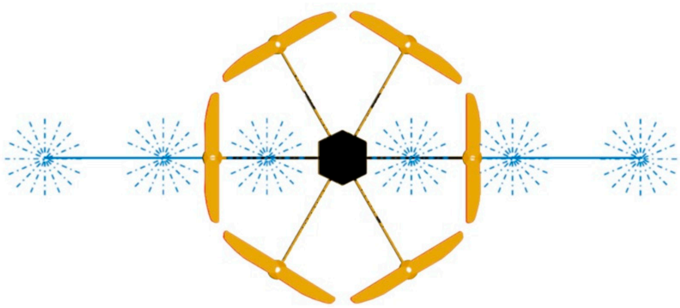


Figure 2. Schematic of HSE V6A, showing rotor configurations and corresponding nozzle locations on spray boom.

Similar to the DJI Agras MG-1 (Figure 3), an octocopter drone is a four-nozzle sprayer system, often positioned on the main propeller shaft [75]. The SG10P (Model SG-10P, Hankook Samgong, South Korea) is a South Korean-made octocopter drone sprayer with this nozzle position.

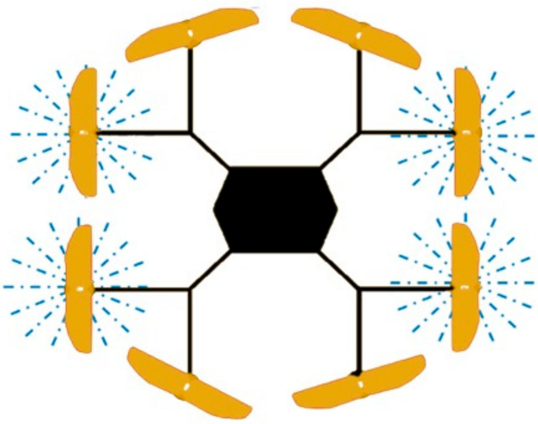
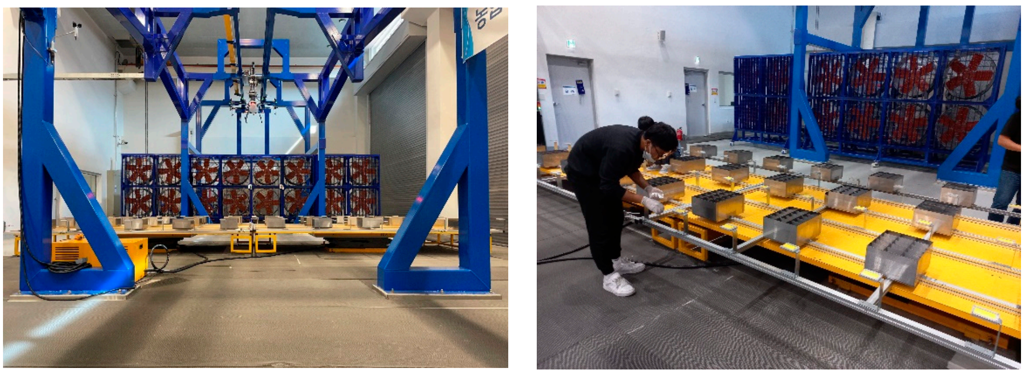


Figure 3. The schematic of DJI Agras MG-1 showing the rotor configurations and corresponding nozzle locations under the rotor.

2.5. Spraying Deposition Data Acquisition Methods

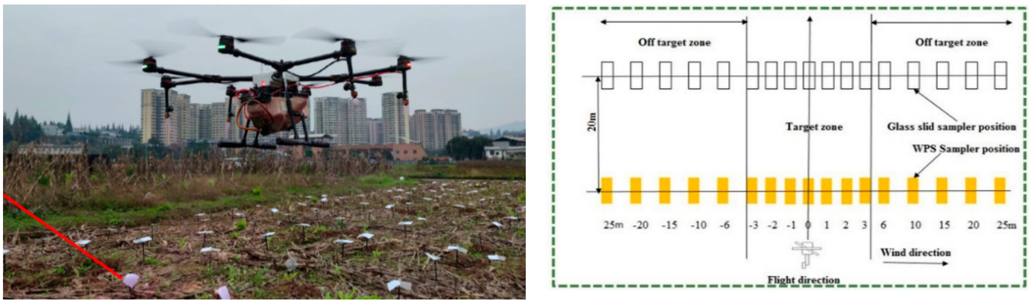
There are two methods of measuring the distribution of environmental treatment spraying. The initial method of measurement utilizes the actual environment (Figure 4), and then the measured value is employed as a parameter. This method involves flying a drone sprayer directly over crop fields and using an automatic weather station (AWS) as a sensor to obtain the environmental treatment parameters [76]. The second measurement approach involves the creation of an artificial environmental climate (Figure 5) in which values can be modified based on the requirements of data gathering [77,78]. Researchers may develop a simulator that can provide controlled environmental conditions, such as a wind generator [71], a rail track that connects the drone sprayer to the simulator, a ground height adjuster [72], or the operation of a drone rotor to generate fluid dynamics that influence the spray nozzle underneath [73].



(**a**) (**b**)

Figure 4. (**a**) Indoor simulator for UAV sprayer using artificial climate; (**b**) utilizing the WSP layout to evaluate spray.

WSP, which records distribution values such as percentage coverage, droplet diameter width, and the number of droplet populations in an area, can be analyzed via image processing. This methodology is commonly employed in other related studies. As demonstrated by [79], the WSP recording method requires image selection strategies because WSP only supports two color schemes (yellow and blue or white and red). Based on the foregoing, the image processing algorithm can easily process the embedded image information.



(**a**) (**b**)

Figure 5. Simulator experiment schematic diagram: (**a**) sample data acquisition site and (**b**) sample data collection sketch map.

2.6. WSP Data Processing Methods

The spray distribution results recorded by WSP are then transformed into concrete values such as coverage, droplet size, and so on after obtaining the results of the spraying performance recorded by WSP. There are numerous methods for measuring WSP recorded data values, which can then be converted using image processing software such as DropletScanTM (WRK, Oklahoma and Kansas, USA) StainAnalysis (Metasystems, Ltd., Bengaluru, Karnataka, India), AgroScan (ECM Naveko International, Inc., Angouleme, France), Gotas (Embrapa, Brasilia, DF, Brasil), SnapCard (Department of Agriculture and Food, South Perth, Western Australia), and others. The procedures used to convert WSP recordings into data values such as coverage, droplet diameter, and population are detailed in Table 5.

Table 5. WSP image processing techniques.

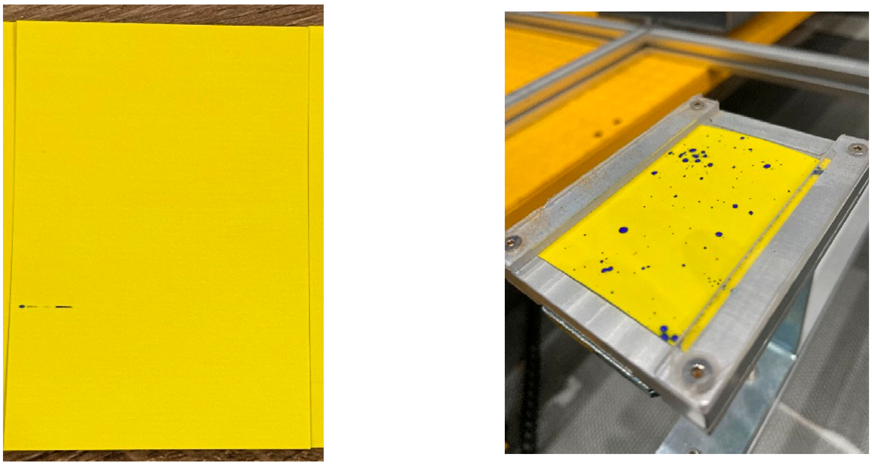
Method	Data Type	References
Spectrometer-fluorometer (Model USB2000+, Ocean optics, Inc., Dunedin, FL)	Number of droplets, spray pattern	[80]
Image J	Spray droplet size (SMD)	[81–83]
DropletScan™	Spray droplet size (SMD), coverage, spray application rate	[84,85]
StainAnalysis	Coverage, droplet density, number of droplets	[86,87]
AgroScan	Spray droplet size (SMD), coverage, number of droplets	[86]
SnapCard	Spray droplet size (SMD), coverage	[87]
Gotas	Spray droplet size (SMD), coverage, Number of droplets	[86]
StainMaster	Spray droplet size (SMD), coverage	[86]
ImageTool	Spray droplet size (SMD)	[81,82,86]

The spectrometer–fluorometer approach is demonstrated in Figure 6 using a Model USB2000+ (Ocean Optics, Inc. in Dunedin, FL, USA). In addition, the orthogonal design approach or other simulation variation methods can be used to retrieve simulation data and analyze spraying pattern parameters [88].

The primary aim of developing an independent control system is to measure spray coverage area by employing several types of deflected nozzles with varying liquid flow rates. Sies and Asmuin (2017) [81] analyzed fluid parameters, such as density, viscosity, and surface tension. The value of the spraying distribution from the UAV sprayer must be determined using a device capable of recording spraying performance. Coverage, population, droplet diameter, and coverage drift are examples of spraying data [89]. These data can be recorded in a single document commonly used for assessing the performance of sprayer equipment, covering low- and high-level test scales, industrial, and agricultural industries [90]. The material under discussion is a water-sensitive paper (WSP), which changes color when exposed to liquids and is therefore utilized well in the spraying value assessment method (Figure 7) [81]. After the WSP has been sprayed, its droplet size must be measured using hardware and software such as DropletScan™ and Spectrophotometer–fluorometer.

(**a**) (**b**)

Figure 6. Detecting spray deposit and pattern: (**a**) image processing of WSP, using (**b**) fluorescence spectrophotometer.



(**a**) (**b**)

Figure 7. Water-sensitive paper (**a**) before exposure and (**b**) after exposure to the spray.

2.7. Expectation of Results and Development of a Control System

Wen et al. (2019) [91] investigated various flight speeds and spraying altitudes in their study. The flight speeds employed are 1 m/s, 3 m/s, 5 m/s, and 7 m/s, with altitude variations in the range of 2 to 4 m. Table 6 summarizes the data collection results using the V6A and DJI MG-1 drones. This data acquisition is carried out in conjunction with the construction of an orthogonal matrix model to obtain the most effective variation value, ensuring that no data acquisition is piled up and that the result value is not required for further analysis. The orthogonal matrix produces variable coverage values, droplet sizes, and population values, which are then applied to the flight plan simulation to generate the coefficient of variation (CV) value. This CV value is used to create the logic for the control system development algorithm.

Table 6. The spray efficiency based on application height and ground speed for the two UAV sprayer platforms.

Platform	Speed (m/s)	Application Height (m)	Effective Swath (m)	Theoretical Application (L/ha)	Measured Application (L/ha)	Spray Efficiency (%)
V6A	1	2	5.2	25.3	14.9	58.8
V6A	1	3	6.4	20.6	14.9	72.6
V6A	1	4	4.0	32.9	6.4	19.3
V6A	3	2	5.8	7.6	6.4	84.6
V6A	3	3	4.6	9.5	4.7	49.2
V6A	3	4	5.2	8.4	2.0	23.8
V6A	5	2	6.4	4.1	5.3	129.9
V6A	5	3	5.2	5.1	2.2	42.5
V6A	5	4	4.0	6.6	1.5	22.5
V6A	7	2	5.2	3.6	1.7	47.0
V6A	7	3	5.2	3.6	1.2	32.9
V6A	7	4	7.0	2.7	1.0	37.2
MG-1	1	2	7.6	31.1	39.9	128.1
MG-1	1	3	6.4	36.9	33.3	90.0
MG-1	1	4	5.8	40.8	29.3	71.8
MG-1	3	2	7.6	10.4	11.3	108.9
MG-1	3	3	7.0	11.3	6.3	56.2
MG-1	3	4	5.8	13.6	8.9	65.6
MG-1	5	2	6.4	7.4	6.5	87.8
MG-1	5	3	7.0	6.8	18.7	276.8
MG-1	5	4	4.6	10.3	5.8	55.9
MG-1	7	2	7.6	4.4	4.9	110.5
MG-1	7	3	5.8	5.8	5.5	95.1
MG-1	7	4	5.8	5.8	3.6	62.2

This table presents data with varying flying speed and altitude parameters. The results of the spraying test using both V6A and MG-1 drone types are shown in Figures 8 and 9. The effective swath results are shown by two types of speed, i.e., flight speed and spraying altitude, for the two examples of UAV sprayer types with their respective characteristics (hexacopter and octocopter) and each spraying placing (boom sprayer and under-rotor sprayer). According to the sample results, the MG-1 drone has a wider swath than the effective V6A of the two second parameters. However, when negative effects from parameters are present, V6A has a more stable performance. These findings are then used to analyze the development of a control system tailored to the performance categories and advantages of drones by adjusting the channel control system settings based on where the system is applied to a drone.

The WSP analysis results in numerical data such as coverage value, droplet size, population, and coefficient of variation (CV), which can be used to develop control systems. This value is derived from outputs that vary depending on the platform and device used. Multiple parameter modifications are integrated into the development of the control system for each collected data point. Figure 10 depicts a method for the development of control systems applicable to precision spraying manufacturing. Figure 10 employs the neural network method by integrating spraying deposition transformation data from the simulation of a spraying drone. This solution employs several control components, including: A. Jetson nano (main core), B. battery, C. digital airspeed sensor, D. altimeter, E. GPS, F. wind-factor sensor, G. spraying system. These parts are integrated to form a unit that serves as the primary spraying system. The role of each sensor is to detect environmental factors in real time and generate values that are fed into the solution algorithm for processing and yielding benchmark values. For example, if the existing parameters are overcome by operation of the nozzle, the resulting solution value will be the pump A or B threshold.

The placement of these four nozzles is determined by the nozzle arrangement [92], which can be either a boom sprayer or an under-rotor sprayer.

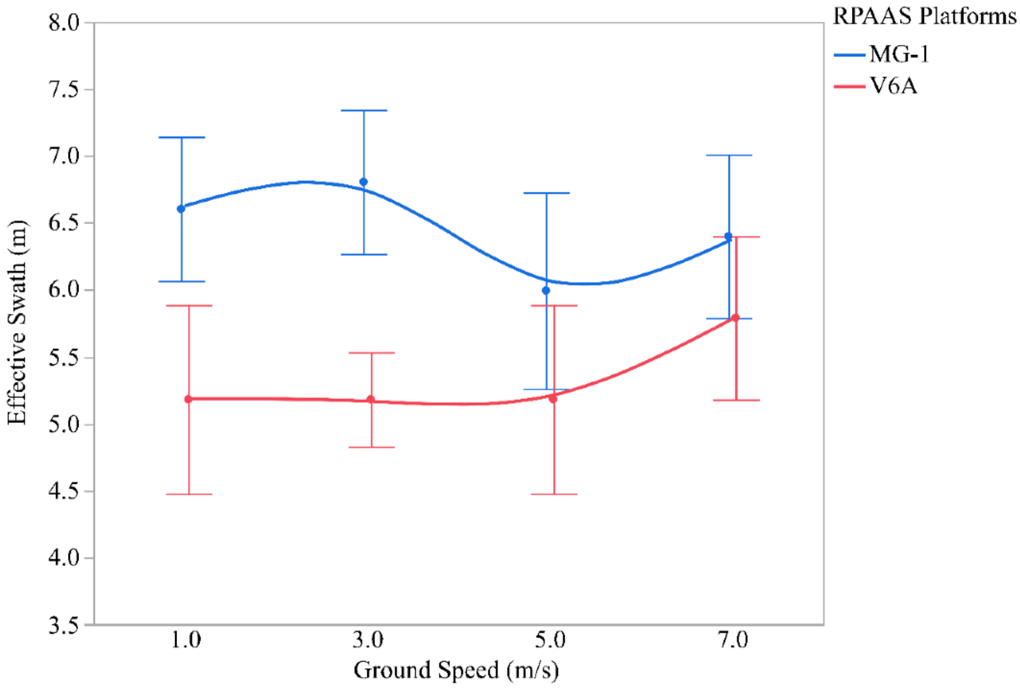


Figure 8. The effect of flying speed on spray pattern uniformity based on the two types of drone sprayers.

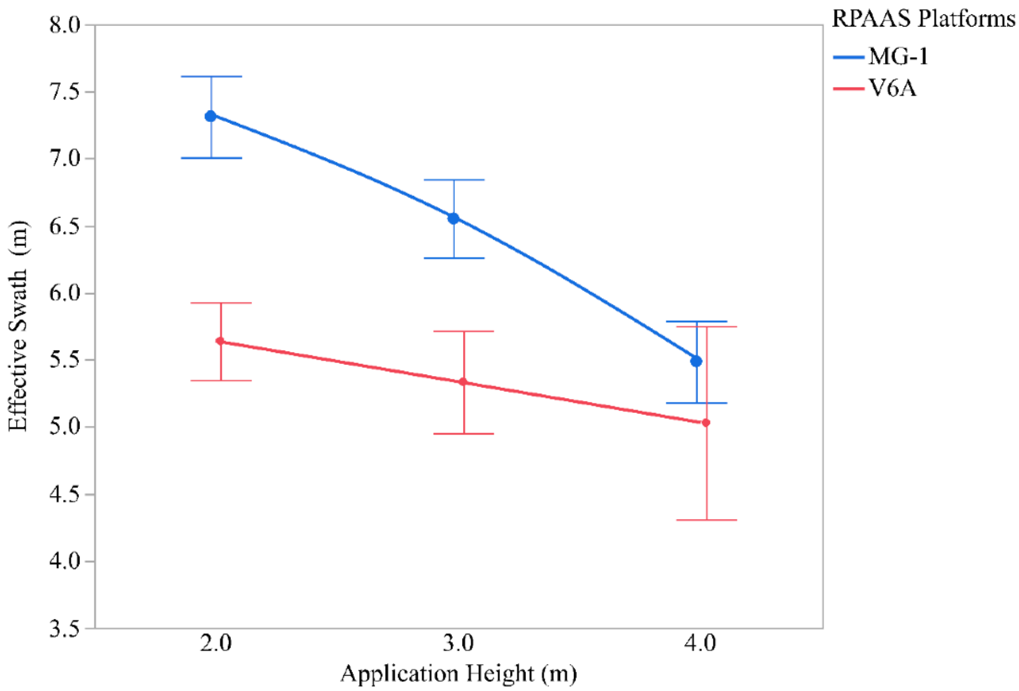


Figure 9. The effect of spraying altitudes on spray pattern uniformity by two types of drone sprayers.

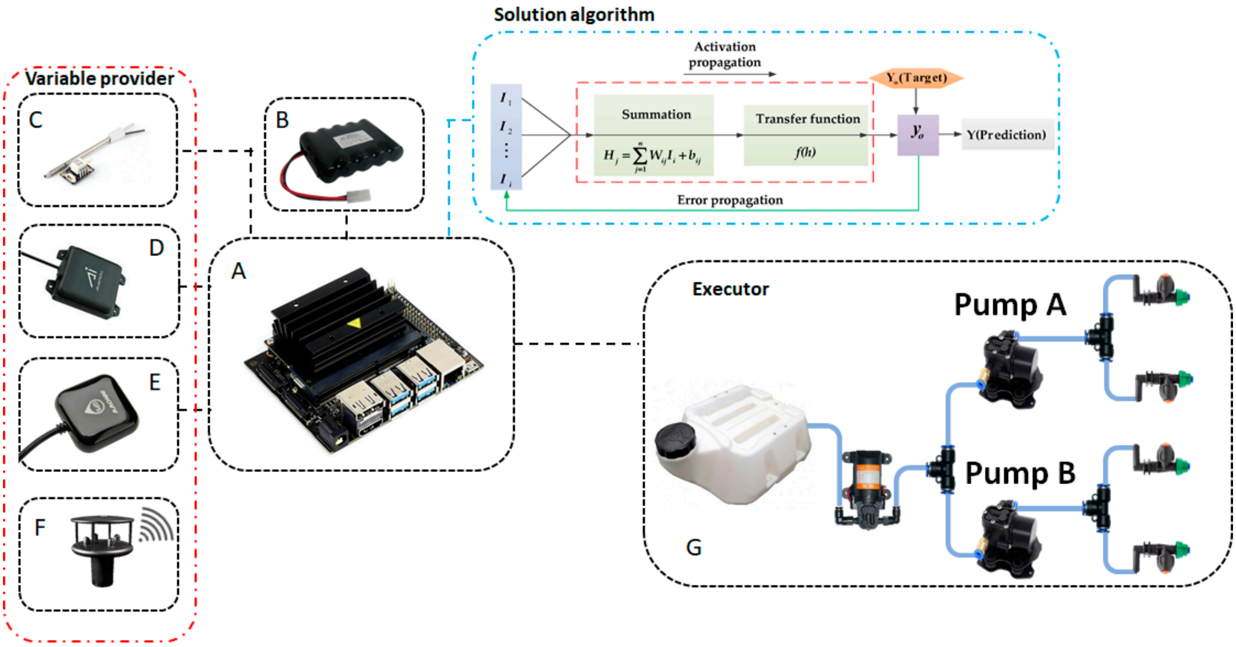


Figure 10. Expected independent control system, including: A. Jetson nano (main core), B. battery, C. digital airspeed sensor, D. altimeter, E. GPS, F. wind-factor sensor, G. spraying system (execution device), employing solution logic as an algorithm.

The fabrication process is then continued by matching the drone sprayer with the control system data requirements based on the independently developed control system results. Changes to the channel could involve utilizing a different type of drone (hexacopter or octocopter), sprayer (boom sprayer or square sprayer) [93], or nozzle. Similar to creating the required independent control system for accurate variable quantity treatment, the expected result is an accurate spray distribution depending on land requirements and specific locations. Following is a description of the development of the variable quantity agriculture sprayer, as well as a consideration of the sustainability of this research and related studies.

3. Benchmarks and Evaluations for Existing Research

3.1. Platform Development and Manufacturing

A UAV sprayer is not always universally utilized. Crop varieties, geographical locations, and treatment types are utilized as a reference to determine the characteristics of the field for UAV spraying. For example, when considering "specialty crops," land management is conducted separately based on the particulars of the specialty [94–98]. These characteristics increase the likelihood of environmental events and must be considered. Certain characteristics and well-defined phenomena, such as the availability of land water, average wind conditions, the intensity of sunlight, and evaporation percentage (relative humidity), are considered to improve land characterization performance [99–101].

April et al. [102] developed a UAV plant protection system in 2019 based on a consideration of various platform operating factors in several related studies, such as the optimization of predatory mite dispensing by multirotor UAVs in wind. They invented a mathematical model that can optimize the autonomous dispensing of wind parameters, altitude, and flight speed using UAVs. As shown in Figure 11, the system development process begins with outdoor experiments and data collection using machine-learning techniques.

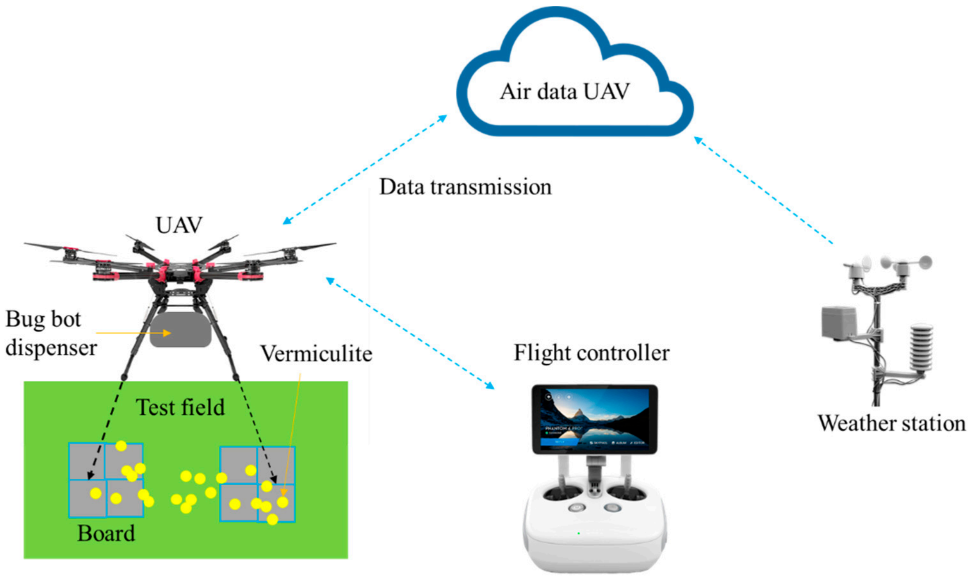


Figure 11. Framework for data collection UAV plant protection system.

The model that was established has an average error of 12.8%, RMSE. Because of its parametric and predictive nature, the model lends itself to the future design of UAV flight controllers that can compensate for wind-induced targeting errors. They also stated that this modeling method can be used in other UAV dispensing applications, such as liquid or granule pesticide deliveries, in addition to developing predatory mite dispensing.

In a study conducted by Lim J. in 2020 [103], titled "Development of a Spray Calculation Algorithm Using Pest Control Drones," an algorithm was developed that considered the type of agriculture aircraft based on spray time depending on platform performance, payload, and flight speed. Lim also considered a pump model with good performance in terms of providing an effective spray width for farming. The study's output was a system that calculates time and effective spraying intervals and suggests an algorithm for accurate pest control area calculation based on the type of pest control drones used.

A UAV sprayer platform upgrade development study was also carried out by Chen et al. in 2016. They considered the spray parameter of a small unmanned helicopter on the distribution regularity of droplet deposition. The researchers used a schematic diagram test at the spray test site with a droplet sampling card test as a means of recording the spread of spraying. The scheme they used can be seen in Figure 12. In this study, the parameters of flight height and flight speed both had a great influence on the mean droplet deposition amount but did not have a significant influence on the uniformity of droplet deposition. The wind field environment is also an influencing parameter, though it was not taken into account [104]. This, of course, can be considered in future studies, as discussed in this paper, to establish environmental factors such as wind speed and direction as parameters that must be addressed.

Another study that obtained a precision variable rate system on a UAV sprayer was conducted in 2018 by Wen S, et al. [22], who designed and experimented with a variable spray system for unmanned aerial vehicles based on PID and PWM control. They used prescription maps as a reference for spraying with different quantities of values at each crop point in their research. The value of the operation of the UAV sprayer is obtained by using GPS data from land mapping [105,106], the processing of raster distribution data added to prescription data on pesticide requirements [107], and geographic information [108], as shown in Figure 13.

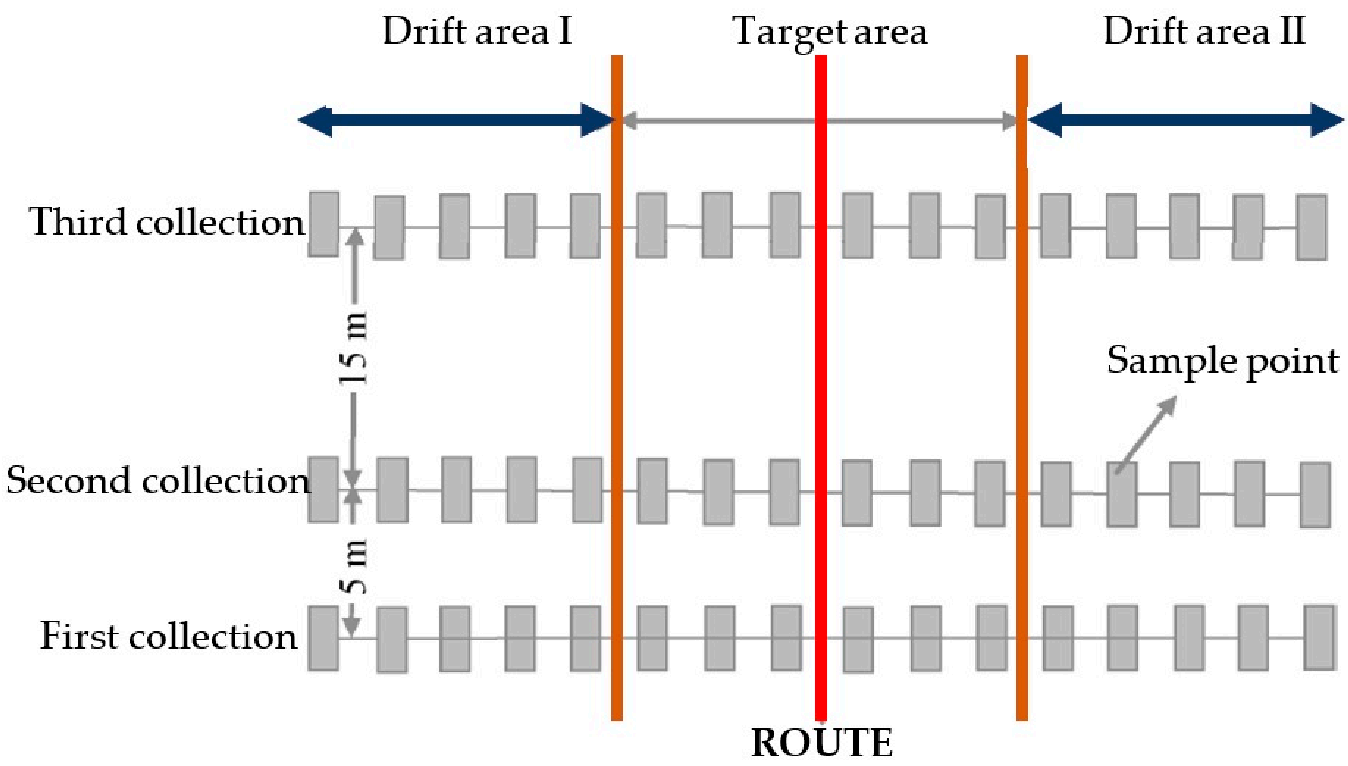


Figure 12. Spraying distribution schematic for the study of the effect of negative factors on UAV performance.

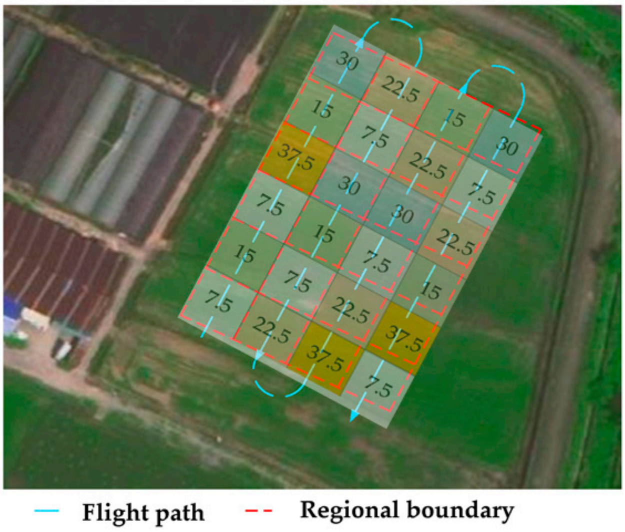


Figure 13. Variable rate sprayer operation strategy using a combination of prescription maps.

Execution of the control system in reading the prescription map is combined and matched with the spraying system (Figure 14) so that the variable rate quantity value is obtained in accordance with the given value [109]. The PID controller will provide feedback on target velocity, actual flow rate, location information, and prescription value, which will be forwarded by the PWM controller during the variable rate spraying [33]. Although this system takes into account operational values such as flight speed and spray height, it cannot overcome negative environmental factors during operation. In windy conditions and with uncertain wind directions, the total mapping variable rate will deviate from the prescription map, reducing accuracy.

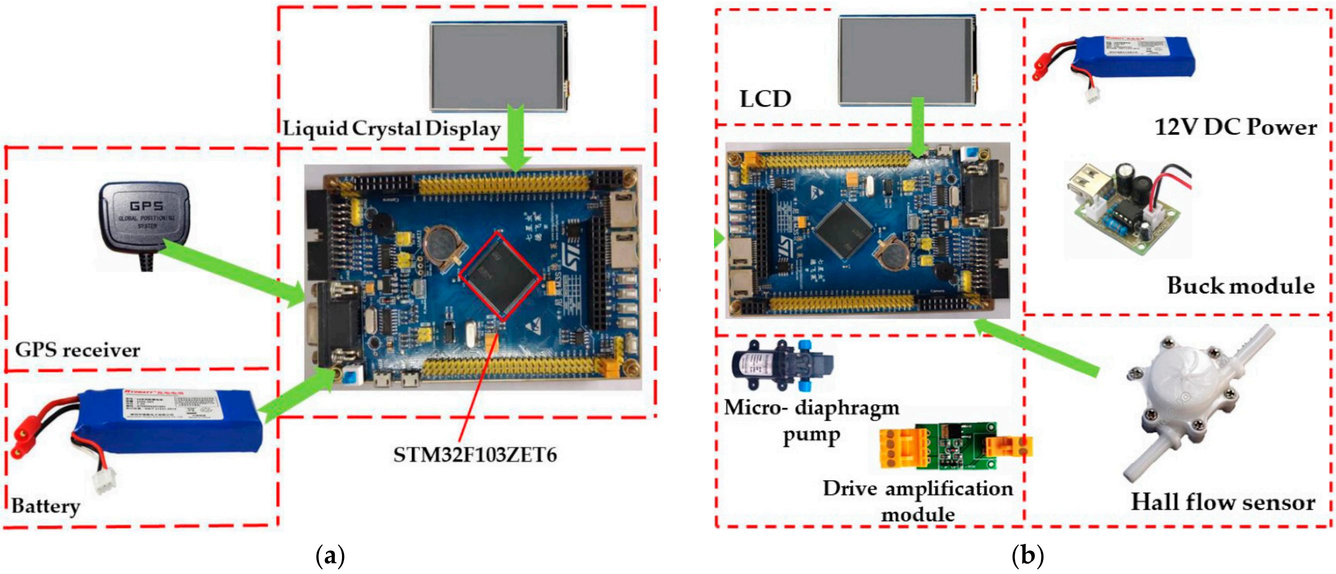


Figure 14. A hardware schematic depicting a prescription graphic translation system (**a**) and a variable spray controller (**b**).

The employment of a UAV-based sprayer for variable-rate and precise-quantity applications, on the other hand, offers various benefits. Wang, G. utilized a battery-powered 3WTXC8-5 six-rotor UAV (Henan Tianxiucai Aviation protection machinery Co., Ltd., Kaifeng, China) (Figure 15) for a spray deposition comparison study in 2019 [21]. The UAV was powered by two 12,000 mAh Li-Po batteries (Shenzhen Grepow battery Co., Ltd., Shenzhen, China). With a full charge, the flight lasted roughly 15 to 20 min. The flight speed was 12.6–14.4 km/h with two rotary cup atomizers positioned on either side. The distance between the nozzles was 0.85 m and the installation angle was vertically downward. The rotation speed of the disk speed was 10,000 rpm. With a flow rate of 1.24 L/min, the chemicals were transferred from the tank to the nozzles using a HXB600 micro liquid pump (Shanghai Hallya Electric Co., Ltd., Shanghai, China). The well-trained operator was responsible for controlling the flight's height and speed with precision. Effective spraying width was 4 m, and flying height was 1 m. Approximately 10 L/ha, or double the tank's capacity, was sprayed in a single sortie.

Figure 15. 3WTXC8-5 six-rotor UAV sprayer (Henan Tianxiucai Aviation protection machinery Co., Ltd., Kaifeng, China).

These parameters enable UAVs to overcome wind speed and direction, contour height, geographical conditions, and crop types [110]. Especially when using UAVs, spraying deposition is affected by wind conditions. Qin et al. (2017) optimized the flying parameters for preventing plant hoppers, demonstrating that a flight height of 1.5 m and a flying velocity of 5 m/s produced the best lower layer deposition and the most uniform distribution for the HyB-15L UAV sprayer (Gao Ke Xin Nong Co., Ltd., Shenzhen, Guangdong, China) [111]. The ideal parameters vary based on the UAV and crop type. In a spraying test of different shapes (open center shape and round head shape) of circus trees, the 3W-LWS-Q60S UAV (Zhuhai Crop Guardian Aerial Plant Protection Co., Zhuhai, Guangdong, China) performed better at a working height of 1 m against 0.5 m and 2 m [48]. Various UAV sprayers are utilized in a multi-spraying swath test to determine deposition uniformity [112].

3.2. Precision Spraying System Effectiveness

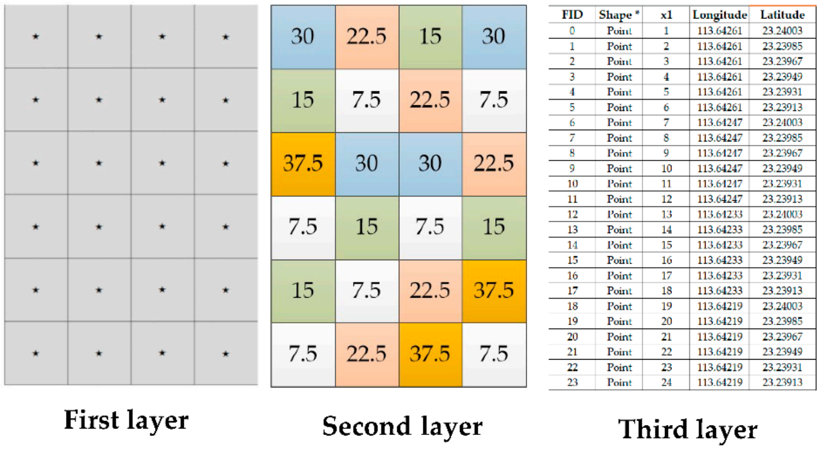
The use of human assistance platforms should always yield superior results compared to manual labor. A platform may be deemed usable as a possible consequence. Using modern platforms as tools has good outcomes in terms of increasing productivity. However, if its main purpose is to help humans work, a technology must continue to develop and exploit its potential. One example is the application of a UAV plant protection system in 2019 by April et al. [102]. They developed a predictive algorithm for plant protection treatment for a variety of parameters, with the goal of obtaining target values based on crop needs while remaining unaffected by various factors during operation. An established model has an average error of 12.8% (RMSE); this value indicates that the use of plant protection materials such as pesticides, fertilizers, or other plant treatments can be reduced, which benefits the environment and even the economy [113].

Afterward, in a study conducted in 2020 by Lim J., who developed a spray calculation algorithm that considers various factors, obtains an output of effective operating time, and selects the type of pump with high efficiency and direct effectiveness at wide intervals, the result was an extraordinary breakthrough in increasing agricultural activity efficiency. Energy and economic aspects will be more affordable as operating time declines. Consideration of the use of devices such as the type of platform, pump, and nozzle becomes important when one is evaluating the effectiveness of other parties in developing a spraying system for the needs of precise plant care. In 2020, Chen et al. used a quadrotor UAV to test droplet deposition against rice plant hopper pest control [114].

4. Future Scope and Considerations

The development of the precision variable rate is not generalized but can be expanded by merging previous research and using it as a reference for the platform's application. For example, if provided with coordinate data describing the quantity of plant disease treatments, a UAV-based precision sprayer could precisely apply pesticides to plants. Wen et al. (2018) [91] employed agricultural land mapping to analyze land and collect treatment information for pest-damaged plants. Wen et al. (2018) also developed a pesticide requirements map based on the route of the drone sprayer.

Three layers are utilized to develop a prescription map that can be integrated with the performance of a precision UAV sprayer. As depicted in Figure 16, the first layer is the route the drone will traverse throughout the spraying process. Based on pest damage to plants, the second layer offers data regarding the requirement for pesticides. The third and final layer consists of coordinate data illustrating how to provide the drone with a spraying threshold and nozzle opening treatment.



FID	Shape *	x1	Longitude	Latitude
0	Point	1	113.64261	23.24003
1	Point	2	113.64261	23.23985
2	Point	3	113.64261	23.23967
3	Point	4	113.64261	23.23949
4	Point	5	113.64261	23.23931
5	Point	6	113.64261	23.23913
6	Point	7	113.64247	23.24003
7	Point	8	113.64247	23.23985
8	Point	9	113.64247	23.23967
9	Point	10	113.64247	23.23949
10	Point	11	113.64247	23.23931
11	Point	12	113.64247	23.23913
12	Point	13	113.64233	23.24003
13	Point	14	113.64233	23.23985
14	Point	15	113.64233	23.23967
15	Point	16	113.64233	23.23949
16	Point	17	113.64233	23.23931
17	Point	18	113.64233	23.23913
18	Point	19	113.64219	23.24003
19	Point	20	113.64219	23.23985
20	Point	21	113.64219	23.23967
21	Point	22	113.64219	23.23949
22	Point	23	113.64219	23.23931
23	Point	24	113.64219	23.23913

Figure 16. Detail data for each layer prescription map (* is coordinate in the form of shape).

During spraying, the crop protection drone's onboard high-precision GPS sends real-time data to the controller and compares it to the unit area's coordinates on the drone's work route map to determine the UAV's present location. When the UAV position data is correctly matched, the current location prescription value is retrieved. The resulting spray quantity data is then communicated to the variable spray controller to execute the spraying operation.

Kulkarni et al. (2015) [115] discuss the calculation of the spraying mechanism for near-perfect plant care applications. In addition to environmental elements such as wind variables, operating altitude, fluid dynamics, and drone flying speed, the performance of the spraying system itself is a crucial consideration. In the creation of this variable rate, a UAV-based precision platform, sprayer system variables such as gallons per acre (GPA), miles per hour (MPH), gallons per minute (GPM), sprayed width per nozzle (W), output per minute (OPM), and nozzle flow rate (NFR) are computed and utilized as a reference.

Nevertheless, considerations and execution restrictions must be considered. The actual conditions in the field will substantially impact the accuracy level, hence reducing performance. The system considered environmental parameters and calculated them for in-depth analysis; however, the weather is not an artificial factor that can be easily constructed. Figure 17 displays a variable-rate UAV-based application with precise performance, matching the pest and plant disease treatment corresponding to the coordinate data. Even if the spray is highly successful, there is a high probability that the treatment will not satisfy the expected requirements; thus, the quantity must be sufficient. This is generally caused by a system that cannot handle the speed and direction of the wind [116].

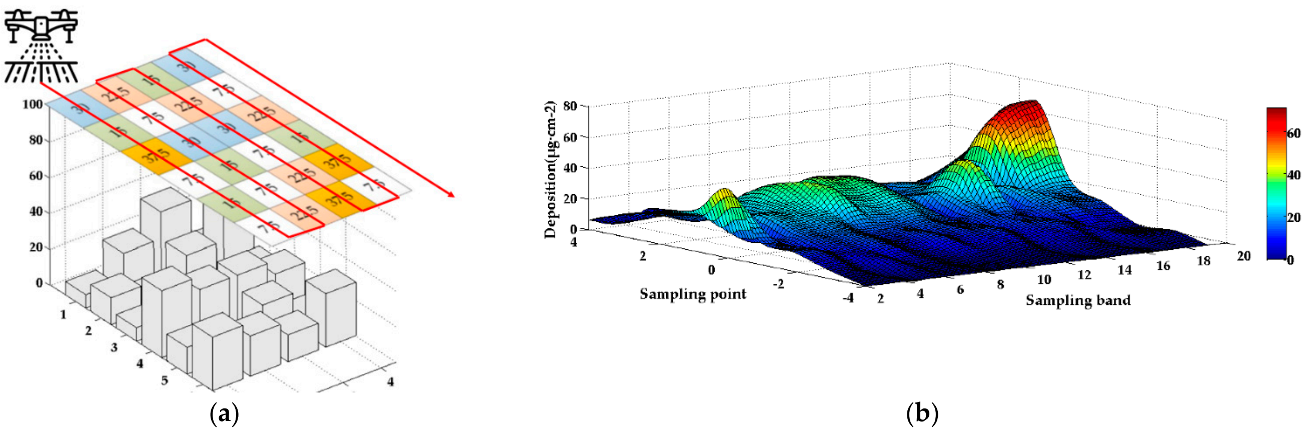


Figure 17. Comparison of reference data (**a**) and spray execution data (**b**) to identify which errors are caused by drifting.

Researchers continue to develop strategies for pesticide resistance. In succeeding studies, each constraint uncovered during a previous research phase might be addressed individually. The concern with the overall analysis of this work is the quantity, which must nevertheless meet the objective. Although the parameters of flying speed, altitude, wind speed, wind direction, and spraying factors are considered, the produced results can meet spraying quality but must be more accurate to fulfill pesticide treatment quantity [117]. Future research must satisfy both requirements so pesticide usage can be regulated sustainably.

5. Conclusions

This article examines the development of UAV sprayers for agricultural applications. This evaluation further identifies the UAV-based drone sprayer innovation technique most closely related to the use of variable quantity precision spraying, whose values and coordinates are generated from image analysis of land requirements. Several elements, including the wind's direction and intensity, the flight's height and speed, the propeller's fluid dynamics, the pesticide's viscosity, and the fluid rate at which it was sprayed, were taken into account during the execution. In implementing this method, the selection and nozzle opening options are determined by the outcomes of the parameter reading that serves as its idea. Thus, the most pertinent spraying system and logic-type algorithm methodologies were evaluated and described, along with their application to agricultural sprayer UAVs for detecting spray quality with WSP recording.

As a result, a number of studies conducted on agricultural sprayers and precision agricultural sprayers are compared to the UAV-enhanced precision sprayer to make improvements. In addition, the most recent spraying system algorithms utilized by agricultural UAVs and the structural problems of sprayer UAVs were outlined. Finally, after examining the primary concerns of autonomous sprayer UAVs on agricultural land, a comprehensive review of recent studies on spraying system methods and algorithmic logic selection is offered.

However, the operational pattern and several constraints of agricultural sprayer UAVs were described in depth. The detection sensors on environmental parameters, UAV performance, and control architectures for threshold nozzle mechanism execution are thoroughly highlighted, opening the way for future researchers to develop their agriculture sprayer UAV systems. The physical construction, liquid load, and sloshing of the sprayer UAV, as well as the most often employed detection sensors, were reviewed.

Due to the impact of environmental modification simulation tests and/or simulations using environmental parameters directly, this research trend generated the notion of a variable-rate spraying platform with a UAV carrier. Its use can assist farmers in decreasing the number of pesticides required while preserving the efficiency of pest management. Furthermore, with the precision of the variable spraying rate UAV platform, it is possible to eliminate the need for multiple pesticides on land and consistently provide the same treatment value.

Author Contributions: Conceptualization, A.S.H. and X.H.; methodology A.S.H. and X.H.; analysis, A.S.H.; and visualization, A.S.H.; supervision, X.H.; reviewing the manuscript, X.H. and S.-H.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This study was carried out with the support of "Cooperative Research Program for Agriculture Science and Technology Development (Project No.: PJ016983)" Rural Development Administration, Republic of Korea.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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