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Application of Drone Systems for Spraying Pesticides in Advanced Agriculture: A Review

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Abstract. The farmers in agriculture fields face health problems due to diseases caused by pesticides and insecticides. Thousands of cases result in adverse health effects when spraying pesticides manually onto crop fields. The use of drones for spraying pesticides is a promising alternative to manual spraying. It represents a major emerging field in India. Therefore, this article is an attempt to explore the latest technological advances and applications in Hardware, Flight Controller (FC) & Electronic Speed Controller (ESC), Smart Agricultural Sensors, and Spraying Systems. To make a mention, a few key advancements in drone systems are: The crops can be monitored by the use of a multispectral camera, mounted on a drone. The drone spraying system makes use of GPS coordinates to auto-navigate GPS coordinates to spray the pesticides on the infected areas in real-time as soon as the camera takes a picture of the spraying area. Different types of nozzles are applied to lead to specific sprinkling speeds and adaption of Bluetooth Low Energy (BLE) via smartphone. Auto control of the quantity of pesticide as per the speed of the drone and use of Artificial Intelligence (AI) for smart drone path control. Along with challenges in spraying technology, the possible direction of future research is highlighted. These technology upgrades lead to precision spraying, along with uniformity and less time. It could attract more and more farmers to spray pesticides by drone and increase crop yields in the coming years.

1. Introduction

In today's transforming world, the need for food resources has increased with the increasing population. With this increase in the food requirement, the demands from the agriculture sectors have increased tremendously. To fulfill this food demand and increase the food production rate, the agricultural sector needs to adopt automation that combines information and communication technologies (ICT), robotics, artificial intelligence (AI), big data, and the internet of things. This use of technology for increasing the food production rate to meet is called Smart Agriculture. Drones are one of the major technologies used in smart agriculture. Drones are unmanned aircraft, also called unmanned aerial vehicles (UAVs) in technical terms. In other terms, the drone is a robot that can be controlled remotely by a human or can fly autonomously, data acquired from sensors and other peripheral devices as well as commands from the mission planner. The drone is used for applications like search and rescue, monitoring, firefighting, surveillance, and agriculture, and the most common application is ariel photography [1]. Due to their great speed, accuracy, and effectiveness, drones are becoming more and more popular for carrying out different tasks [2]. Even the use of multiple drones for carrying out a similar task is possible which could reduce the time of completing the task [3].

In the history of drones, the United States, the United Kingdom, Russia, Germany, and Israel were the first countries to conduct research on drones. The first time an unmanned flying vehicle was used by the Austrians was in August of 1849. Charles Kettering, one of the first creators of drones in collaboration with Elmer Sperrym, Orville Wright, and Robert Milikanem created in 1915. They named the aircraft "Kettering Bug" which was automatic aircraft, which used to fly based on sensors barometer for height, the amount of engine spins for the calculating distance traveled, and the position [4].

Currently, drone technology is used to monitor real-time activities, manage disasters, provide security, and observe activities in the agriculture sector, mining sector, energy sector, and construction sector, among others [5]. With new upgrades coming up in drone technology it has stepped into performing different operations for various agriculture tasks. Talking about the use of drones in the agriculture sector it has a lot of applications which range from mapping and surveying to crop dusting and spraying [6]. So, in this article, reviews different types of drones, their working, different components used in drones especially concentrating on the crop spraying application using drones.

2. UAV Platforms

Different types of drones have been used based on their application of use. Although they were used primarily for military functions, in the beginning, drones are expanding in different sectors of the industry.

A drone is classified according to its size, range, ability, and weight. Drones can be classified into two main types: fixed-wing drones and rotary-wing drones [7].

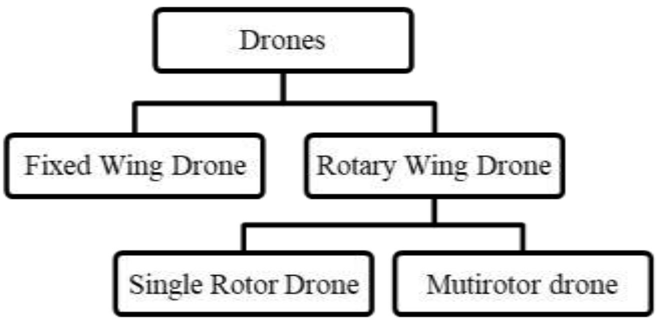

Figure 1. Type of Drones

Figure 2. Type of drones (a) Fixed Wing Drone, (b) Single Rotor drone, (c) Multi-Rotor

2.1. Fixed-wing drone

The rigid streamlined wing structure of a fixed-wing drone (Fig. 2 (a)) induces lift as it moves [8]. It completely looks like a normal aircraft but without a pilot on board. It consists of one or two I.C. engines or an electric motor attached with a propellor that generates the forward thrust. The drone wings are made with a specific airfoil which generated an air pressure difference from the front surface of the airfoil to the end surface of the airfoil. The ailerons, elevators, and rudders installed on the drone's wings are used to regulate its movement. Drones with fixed wings are advantageous because they can fly long distances, reach high altitudes, and operate quietly. They are used mostly for surveillance.

2.2. Rotary-wing drone

Rotary wing drones are those that generate lift by rotating blades called propellers [8]. Single Rotor Drones and Multi-Rotor Drones are the two types of Rotary Wing Drones. The Single Rotor Drones (Fig 2 (b)) are similar to helicopters in that they have a single rotor. They are mostly used in the construction industry for surveillance. Multi-rotor drones, on the other hand, are the most common form of drone in the market. The multirotor drone generates propulsion and manoeuvres by simply changing the speed of individual rotors with the help of a flight controller. The number of rotors on a Multi- Rotor Drone is categorised as follows: Tricopter (fig 3 (a)), Quadcopter (fig 3 (b)), Hexacopter (fig 3 (c)), and Octocopter (fig 3 (d)). The quadcopter is by far the most common type of multi-copter. They are commonly used in real-time monitoring, surveillance, mapping, etc. but the main application of multirotor drones is seen in aerial photography for beautiful cinematic videos.

Figure 3. Multi rotor Drone (a) Tricopter, (b) Quadcopter, (c) Hexacopter,(d) Octacopter [38]

3. Working Principle

Each type of drone discussed above have their working principles but for this article, we will be concentrating mainly on the working principle of the Quadcopter. A quadcopter has 4 rotors that are equally spaced from each other with a definite circular wheelbase on the drone frame.

Drone use BLDC motors and the propellor blades are attached to the cover of the motor. The propellor blades are the most important part of the drone because they help the drone to generate proper amount of thrust which is the lift force for the drone. The blades are so designed that the lift force generated will be in the same direction on both parts of the blades. A flight controller along with the ESC controls the motor speed. The greater the motor speed (Blade speed) the greater will be the lift force.

Now comes the question of how the drone will take off. The lift force increases as the rotor speed increases, and when the lift force overcomes the weight of the drone, it is referred to as climbing. When the drone reaches a sufficient altitude, we reduce the rotor speed until the lift force equals the drone's weight, and the drone begins to hover in the air, which is known as drone hovering in technical terms. All four rotors rotate at the same pace while hovering and climbing.

Now the other question arises how does the drone move forward, sideways, and spin? Talking about moving forward, forward pitch (fig 4 (a)) is achieved when front propellors are spun at lower speed and the back propellor at higher speed. The drone's weight is balanced by the vertical component of the lift force, while the imbalanced horizontal force causes the drone to fly forward, causing a drag force on the body. The horizontal force must be increased until it matched the drag force for attaining constant speed. The same is the case for pitching backward. The same goes for rolling (fig 4 (b)) but here the side pair is spun faster than the opposite side pair. To yaw (fig 4 (c)) means to spin the drone the diagonal rotor spun at a different speed than the other diagonal rotors.

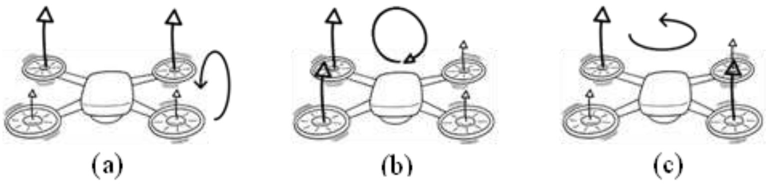

Figure 4. Movement of drone (a) Pitch, (b) Roll, (c) Yaw

4. Components of the Drone

A drone is made up of many different components which are interconnected to each other. But the key components necessary for a drone to work are a flight controller (Fig 6 (a)), BLDC Motors (Fig 6 (b)), ESC's (Fig 6 (c)), propellors (Fig 6 (d)), battery (Fig 6 (e)), and a radio controller (Fig 6 (f)). The drone's brain is referred to as a flight controller. The flight controller receives data from the human-controlled radio transmitter as well as sensors onboard. The controller then processes the information and sends commands to the ESCs, which control the motor's speed. The ESCs are attached to the power distribution board (the battery), and the flight controller receives signals from the ESCs, which govern the power delivered to each of the motors. The primary BLDC motors are used in drones. These motors are responsible for rotational motion. The propellers are connected with the motors which convert the rotational motion of the motors into thrust force which is required for lifting the drone in the air. For all these components to work we need an energy source which is the battery. The battery supplies the electric energy required to each component of the drone. The battery used in the drone is mostly LIPO batteries. Additionally, the drone also consists of two more components which are the accelerometer and the gyroscope. Because the accelerometer monitors both acceleration and force, the descending gravity will be detected as well. We can determine the device's orientation using the accelerometer's three-axis sensors. A gyroscope is a device that monitors angular velocity, or rotational speed around the three axes. A gyroscope is a gadget that helps determine orientation by using Earth's gravity. A freely revolving disc known as a rotor is attached to a spinning axis in the middle of a bigger and more stable rotor [9].

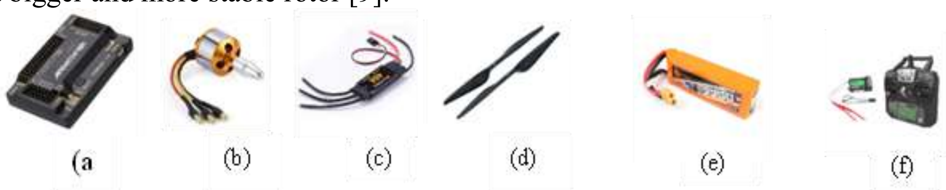

Figure 5. Drone Components (a) Flight controller, (b) BLDC Motors, (c) ESC, (d) Propellors, (e) Battery, (f) Radio Transmitter and Receiver [40]

5. Drone Control Approach

Drones are controlled with two different approaches either manually or autonomously. The manual approach relies on the commands given by humans in real-time by the use of transmitters like radio transmitters [10], Bluetooth, or Wi-Fi. The signal from the transmitter is received by the drone's receiver, which then delivers it to the flight controller for additional processing.

The Autonomous approach does not depend on the real-time control commands from the human but it follows the pre-specified instructions given by the human in the mission planning software. The commands consist of path plan, speed limit, altitude range, etc. The drone operates autonomously without human intervention and does the given task by following the instructions. The different flight controllers with their controlling approaches are given in the table below (Table 1).

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Table 1. Flight controller with control approach

Flight controller	Control Approach	References
NAZA M-lite flight controller	Radio Transmitter	[1]
ATmega328	Radio Transmitter	[3][18][28]
Arduino mega	Wi-Fi	[2]
APM Ardupilot controller	Radio Transmitter	[10]
Pixhawk controller	Autonomous	[22][23][32]
KK 2.1.5	Radio Transmitter	[25][26][31]
Raspberry Pi Model 3 B	Autonomous	[36]

6. Recent Trends and Challenges

The drone is increasingly being used in the agricultural sector with technological advancement. These help in reducing the efforts of farmers and also on other hand providing more accuracy and fast operation. The drone is nowadays used in various fields of agriculture works like crop monitoring, seeding, spraying of insecticides and pesticides, and irrigation [11-13]. The predominant use of drone today in agricultural sector is spraying of pesticides. Details of the drones used by various users in recent time for pesticides spraying along with their technical elements are listed below in Table 2.

Table 2. Existing drones for spraying pesticides in recent time

Exiting Drones	Volume of pesticide	Max. Flight time full load	Max. Speed	Discharge rate	No. of nozzles	Reference
DJI Agrus MG-1S	10 L	10 min	12 m/s	0.379 L/min	4	[38]
3WQF120-12	12 L	30 min	5 m/s	0.8 L/min	2	[39]
3CD-15	15 L	20 min	6 m/s	0.54 L/min	4	[39]
WSZ-0610	10 L	20 min	4 m/s	0.72 L/min	2	[39]
HY-B-15L	15 L	15 min	4.5 m/s	0.38 L/min	5	[39]
N-3 UAV	25 L	-	4 m/s	0.85 L/min	2	[40]
Knapsack-type electric fog sprayer 3WBD	20 L	-	1m/s	1 L/min	1	[40]

Along with the benefits of drones, there are some challenges in agricultural drones. They are like less flight time, balancing of drone with the pesticide tank, harsh weather conditions, etc. The most important challenge is the flight time of the drone, due to the relatively higher payload. The flight time of the drones used in agriculture is short, which ranges from 10-30 minutes which leads to less coverage of land with every charge. The other challenge is that for large area of spraying, drones are less efficient and they are costlier than the other equipment used for the same purpose.

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7. Drone for Crop Spraying

The drone has a wide range of applications in various sectors for different industries and hence it also has some appearance in the agriculture sector. The drone can serve the agriculture sector right from surveying and monitoring the field and crop to spraying of pesticides and seeds on the field. The main problem faced while growing crops are pests and weeds. They tend to damage the crop, which results in loss of money, time, and efforts in a short loss in productivity [14]. To kill pest and weeds, herbicides and fertilizers must be used. However, the WHO (World Health Organization) estimates that over 1 million pesticide cases occur each year. More than one lakh people die each year as a result of pesticides sprayed by humans and pesticide handling, primarily in developing countries [20]. As a result, hand fertilizer and pesticide spraying might result in lethal diseases such as cancer, asthma, hypersensitivity, and other disorders [14-20].

Here's where we'll be able to use the drones. Crop monitoring, as well as the need to spray pesticides and fertilizers at precise plant locations, is a crucial component for increasing crop output. The Drones can complete the task fast and accurately without giving any health hazards to humans. The drones used in agriculture sectors are majorly autonomous drones, which decides by themselves by sensing the surrounding and considering the task allotted to them by the human. The Pesticide spraying drones typically have a storage tank in the lower section of the drone that holds the liquid pesticide, and nozzles are connected to the storage tank through pipes and an electric pressure pump to spray the pesticides down on the crops. The storage tank, nozzle, and pressure pump work in one of two ways: manually with a controller or automatically with previously programmed commands for spraying pesticides at precise spots. The following table lists the spraying systems details /components used in pesticide spraying drones (Table 3).

Table 3. Various types of spraying systems used in drones

Tank capacity (liter)	Nozzle type	Pump discharge	Reference
5 litres	Flat fan	2.5 L/min	[17]
5.7 L	Micronair nozzles	100 mL/min	[19]
-	The Universal nozzle	1 L/min	[20]
10 L	XR11001	0.43 L/min	[21]
13.2 L	flat fan nozzles	46.8 L/ha	[24]
6 L	flat fan nozzles	2.5 L/min	[25]
250ml	-	250 mL/min	[31]
5 L	-	2.4 L/min	[35]

8. Conclusions

There is a vast scope for using drones in agricultural applications. They can be used from soil monitoring and surveying to sprinkling of seeds and pesticides. However, there are some limitations and challenges to overcome. This article briefly summarize pesticide spraying drone systems /various components. It specified various drone platforms, control approaches, and agricultural UAV applications that have been established or are currently being researched. The use of different controlling approaches has been discussed according to their application. It highlights the need to minimize pesticide spraying drone weight, maximize drone flight time and more precise autonomous control of drone.

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