



Design of a Pesticide Spraying Quadcopter

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Abstract

Today, coupled with technological development, UAV (Unmanned Aerial Vehicle) systems show an important improvement in civil area applications. UAV systems have active tasks with cost-effective solutions in several areas like defense, logistics, engineering, and agriculture. Especially in agricultural applications, UAV system usage contributes to improvement of the critical parameters of this sector as efficiency and sustainability. Thus, in agricultural areas, improvement and usage of unmanned systems are of importance. In this study, a remote-control rotary wing UAV system that can perform irrigation and spraying and its design, production and application processes are discussed. The designed, verified and all test operations completed UAV system is planned to be used in remote control liquid rejection in the agricultural area.

Keywords

Unmanned aerial vehicle (UAV)
Rotary Wing UAV
Spraying, Remote Control UAV
Sustainability

Time Scale of Article

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1. Introduction

The entirety of system elements that are differ from each other and required for flight such as an unmanned aerial vehicle (UAV), control station, command and control data connection and takeoff and landing systems is called a UAV system. UAV is the most critical part of this entirety of systems, while it is defined as an aerial vehicle that is operated remotely by a UAV pilot or autonomously planning by a UAV pilot without having a pilot onboard [1]. Although UAV systems have started to be used for military purposes, especially with the prevalence of commercial off the shelf products and technological developments, they have found their place in several civilian areas such as environmental applications, land mapping, forest fire detection, search and rescue and sensitive agriculture practices. In particular, UAV systems have been used since the beginning of the 20th century in tasks that are monotonous, long-term, where human focus would be lost, that require excessive attention, in dangerous and risky environments [2].

In comparison to manned aerial vehicles, UAV systems

have different sizes, weights, endurance and performance (slow flight velocity, angle of climb, etc.) characteristics. For this reason, it is complicated and difficult to compare UAV system to today's manned aerial vehicles. Some UAV systems are designed as small size and weight so that they could not be detected by other manned aerial vehicles, and they can be managed from any location. Some of them, on the other hand, operate at very high altitudes and can stay in the air for a very long time. This is why UAVs are categorized based on criteria like size, range, altitude, velocity and endurance. The National Aviation Authority name as Directorate General of Civil Aviation (DGCA) categorizes UAV systems based on maximum take-off weights as in Table 1 [1].

Table 1. Classification of UAV systems [1]

Category	Maximum Takeoff Weight
UAV 0	500 g (including) – 4kg
UAV 1	4 kg (including) – 25 kg
UAV 2	25 kg (including) – 150 kg
UAV 3	150 kg (including) or more

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UAV systems are designed as fixed wing and rotary wing systems for requirements in different platforms. Among these, rotary wing UAV systems are designed as UAVs that can take-off and land vertically, hover and fly with a lower range and altitude in comparison to fixed wing ones [3]. Rotary wing UAV systems that have more effective design, production and operation capacity in comparison to others are named based on the number of rotors on them. Nowadays, UAV systems with rotary wings and four rotors (quadrotor, quadcopter, etc.), with their capacity of maneuvering, effective load carrying capacity, simple mechanical structure and design, are used in different civilian applications such as airborne imaging, monitoring of electricity transmission lines and following of agricultural products.

It is estimated that several civilian applications made with manned systems today will be made with UAV systems in the future based on the development of technology. It is expected for the future flight operations of UAV systems to be included at all stages of the airspace where manned aerial vehicles' flight operations are conducted. According to the Annex 11 document, the International Civil Aviation Organization (ICAO) divided airspaces into 7 classes from A to G. In this approach, air traffic service and flight requirements vary for each airspace [4]. On the other hand, the European Organization for the Safety of Air Navigation, or EUROCONTROL, defines airspaces for UAV systems in three parts [5]. Figure 1 shows these parts.

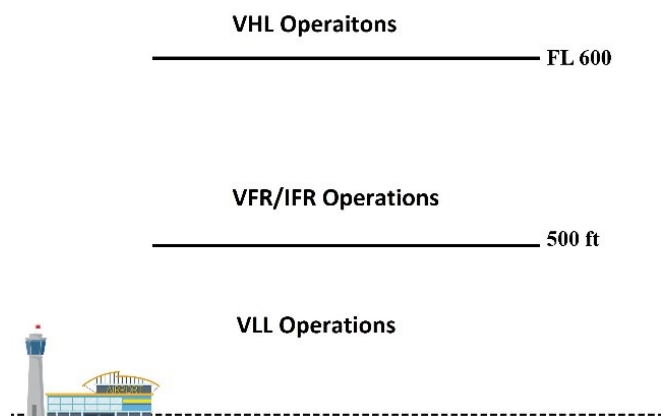


Fig. 1. Definition of airspace for UAV systems [5]

UAV systems are expected to conduct their flight operations in a mixed space within the air traffic control where the flight operations of existing manned aerial vehicles are carried out depending on the requirements of the relevant airspace. These are [6]:

- VHL (Very High Level) Operations: Include above FL600 and under orbit IFR (Instrument Flight Rules) operations.
- IFR (Instrument Flight Rules) or VFR (Visual Flight Rules) Operations: Include similar rules applied in manned aviation.
- VLL (Very Low Level) Operations: Include operations below 500 ft.

UAV systems to be used in agricultural activities are usually expected to have capacities to conduct flight operations below 500 ft and closer to the ground. It is seen that UAV systems that would conduct flight operations below 500 ft have more advantages in terms of minimum equipment requirements, accessibility and usage variation in comparison to UAV systems to be used in other airspaces. In addition to this, for the purpose of using UAV systems for increasing efficiency and sustainability of agricultural products, several research and development studies are carried out [7-9].

Logan et al. stated that if UAV systems to be used in agricultural activities helped only 1% of improvement in product quality, there would be an increase of 1.43 million dollars in product sales (assuming that only 10% of 310 million decares of agricultural land in the US would be used by UAV systems) [10]. Torres-Rua et al. used a UAV system with the capacity of image processing for the purpose of monitoring the development of agricultural products to examine several factors such as soil humidity, evaporation rates, chlorophyll and nitrogen rates in a certain area, and they reported that this had a positive contribution on production [11].

Additionally, in comparison to high-resolution satellite and airborne sensors, usage of UAV systems in such applications provides a substantial advantage [12]. Some of the benefits of agricultural activities conducted by using UAV systems include increased production, improved productivity, reduction of environmental effects and having measurable data [13-14]. On the other hand, in cases where meteorological conditions are inadequate, and human access is difficult during pesticide application on some agricultural products, usage of UAV systems is one of the solutions that are cost-effective which increase productivity.

Therefore, technological developments to be achieved in UAV systems to be used in the agricultural field are important in terms of production, monitoring, analysis and sustainability of agricultural products. This study designs a quadrotor UAV that can be used in pesticide application and irrigation when needed in the field of agriculture and showed that the UAV system structure successfully served its function by flight and implementation trials.

2. Design, Production, and Implementation Process

The developed UAV has a rotary wing structure. Additionally, the developed quadrotor UAV has the ability to manually and autonomously fly with the autopilot system on it. The autopilot system used in the study is the naza model produced by DJI company. It contains inner damping, controllers, 3-axis gyroscope, 3-axis accelerometer and barometer in its light and small Main Controller. It can measure flying altitude, attitude and therefore can be used for autopilot/automatic control.

In the rotary wing UAV system, there are hardware components as brushless direct current (DC) motors, electronic speed controllers (ESC), propellers, a battery, global positioning system (GPS), telemetry system and autopilot system. The relationship among the hardware components of the produced UAV system is shown in Figure 2. To increase the stability of the UAV, the fans of the propellers fixed on the DC motors are made out of hard plastic material.

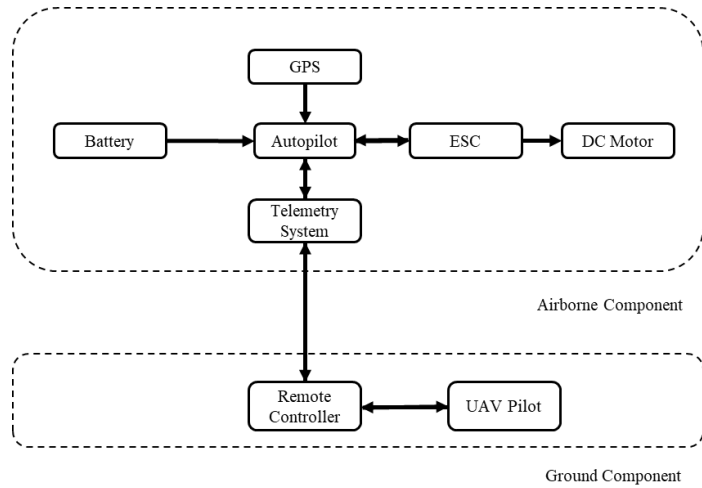


Fig 2. System component structure of the quadrotor UAV system

Onto the UAV system that is developed to be used in the field of agriculture to release liquid material from the air in a remote-controlled way, a liquid container was added as seen in Figure 3. By this way, the UAV system with the liquid container is equipped with pesticide spraying capacity, and its necessary test and validation processes are completed with success. For using the pesticide spraying system, the input and output terminals of the autopilot system are defined as shown in Figure 4. By means of this, the pilot is able to use the pesticide spraying system remotely and safely in a manual or autonomous mode at a desired phase of the flight. Furthermore, the UAV system finds its position based on its GPS sensor successfully during the flight tests.

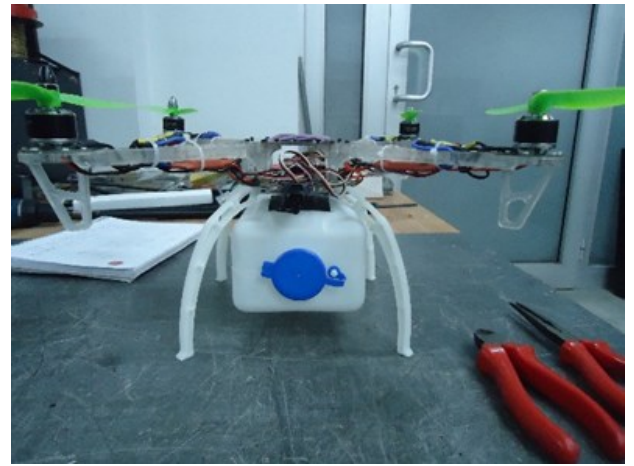


Fig 3. The Developed UAV system

2.1 System Components and Properties

Brushless Direct Current Motor:

In production of rotary wing UAV systems, brushless direct current (DC) motors are among the frequently used motors. Brushless DC motors have several advantages such as high efficiency, easiness of maintenance, long lifespan and silent operation. Technical information about the brushless motor that is used in the design is given in Table 2.

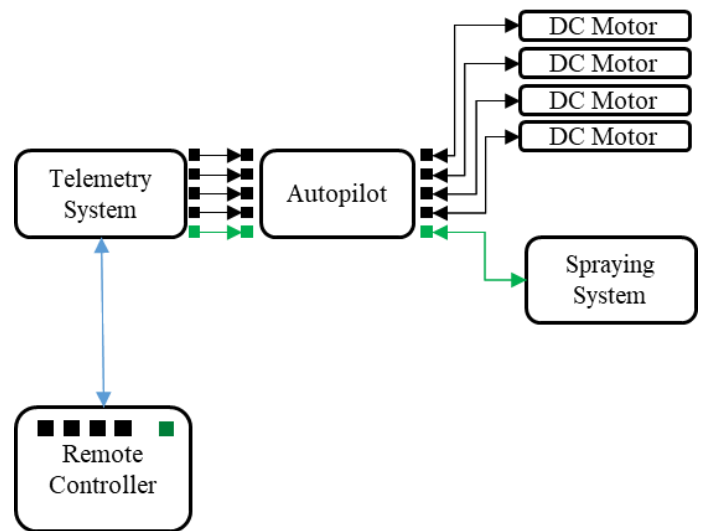


Fig 4. Spraying system positioning structure

Table 2. Technical properties of the brushless motor

Voltage (V)	Unloaded		With Load		
	Current (A)	Speed (RPM)	Current (A)	Carrying Capacity (g)	Power (W)
11.1	0.3	10200	8.5	600	94.4
14.8	0.3	13610	13	940	192.4
18.5	0.4	17000	17.2	1270	318.2

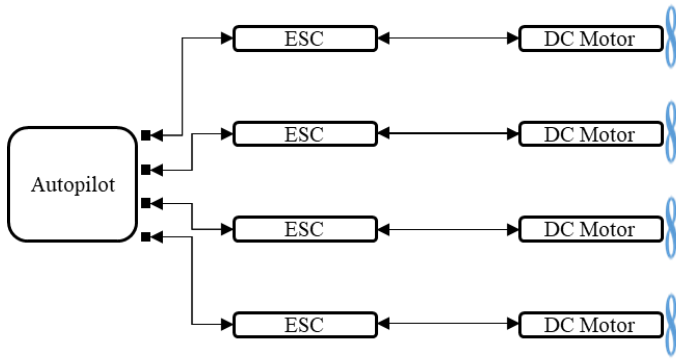


Fig. 5. ESC and motor positioning structure

Propeller

In rotary wing platforms, there are two types of propellers that create lift with the effect of speed. These are:

- Clockwise (cw)
- Counterclockwise (ccw)

Based on the structure of the rotary wing platform and the motor that is used, propeller selection and positioning are carried out. The properties of the carbon fiber propeller used in the project are shown in Table 3.

Table 3. Technical properties of the propeller

Fan Length	Torsion Angle
9 inch	4.5 inch

Battery

Lithium-polymer (Li-po) batteries consist of various numbers of cell structures. Each cell has an average voltage. Different voltage values can also be obtained by connecting the cells in series (S) or parallel (P). The symbol C on the battery provides information about the discharge rate. The properties of the li-po battery with a form of 3S1P that is used in the produced UAV system are given in Table 4.

Table 4. Technical properties of the battery

Property	Value
Minimum Capacity	7000 mAh
Configuration	3S1P
Discharge Rate	40 C
Max. Discharge Rate	80 C

Pesticide Spraying System

For the pesticide spraying system, a system consisting of a motor, motor controller, intermediate switching

element, centrifuge, pesticide container and spraying nozzle is designed and used. The intermediate switching element sends a signal to the motor, therefore the spraying element. As the switching element, a BC307 PNP type transistor is preferred. The base of the transistor was connected to the pin of the microcontroller that provided an output of 3.3V. As this output value satisfies the threshold voltage of the base of the transistor, based on the incoming command, the microcontroller will provide the 3.3V to the base of the transistor, and depending on the working principle of the transistor, when the threshold voltage is exceeded, it will pass the battery voltage over itself and start to drive respectively the motor and pump systems. The spraying nozzle on the liquid container attached to the rotary wind UAV system has the capacity to serve its function manually or autonomously. The general structure is seen in Figure 6. It was supported with an external battery so that it would not affect the flight duration. Against vibrations that would occur during the movement of the spraying nozzle on the liquid container, the container is supported with anti-vibration materials.

2.2 The Weight and Endurance of the UAV System

As seen in Table 5, the total weight of the hardware components of the rotary wing UAV system developed for the purpose of pesticide application and irrigation, the frame and the payload is approximately 3 kg. This way, the endurance of the aerial vehicle in a full state of its 500-ml liquid container is theoretically calculated to be 24 minutes. Theoretical calculations are found in accordance with the equation as shown below:

$$Flight\ Time = \frac{Battery\ Capacity\ (ah)}{Total\ Current\ (a)} \times 60 \tag{1}$$

With the testing and validation operations, it is seen that the UAV system stayed airborne by approximately these levels. The distance between the aerial vehicle and the UAV pilot covers an area of 1 km in diameter based on the transponder and receiver of the telemetry system. Approximately, 14.17 m² agricultural area can be sprayed with the proposed system.

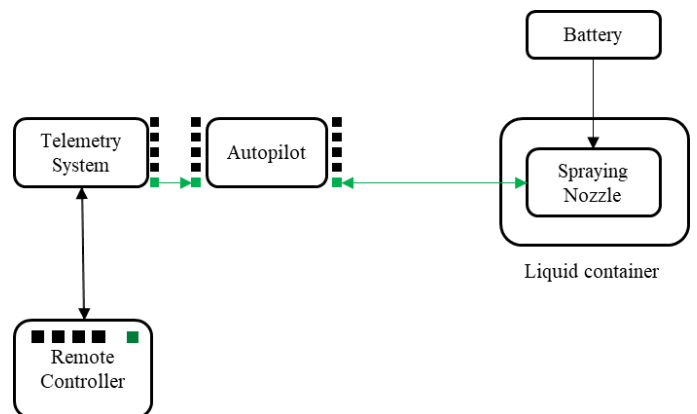


Fig. 6. Structure of the spraying system

Table 5. The total weight of the hardware components of the rotary wing UAV system

Hardware	Total Weight
DC Motor (x4)	320 g
ESC (x4)	64 g
Autopilot (x1)	50 g
Propeller (x4)	40 g
Battery (x2)	1106 g
Liquid Container and Spraying Nozzle	450 g
Frame, Arms and Other Components of the Aerial Vehicle	1050 g
Total Weight	3080 g

3. Conclusion and Future Studies

This study discusses a quadrotor UAV system that is developed for pesticide application and irrigation. Testing and validation activities are successfully completed for this UAV system that can stay airborne for approximately 20 min with a full liquid container and serve its functions manually or autonomously. As the next stage in the project, it is planning to increase the endurance and make improvements on the pesticide carrying capacity and spraying mechanism.

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