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Transformable Drone with Four Propellers for Agricultural Use

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Abstract: *A transformable drone with four propellers is applicable for farmers to identify weeds that grow in farmland areas efficiently. When such a drone flies in the small mode, it can easily maneuver between tall crops or small barns, increasing its agility. When the drone flies in the large mode, the efficiency of flight increases, and less energy is required. By adding a camera that contains algorithms to distinguish crops and weeds, farmers could effectively identify weeds and apply herbicides accurately, which saves time and prevents potential pollution caused by herbicide overuse. The drone uses a parallelogram structure that connects the four mechanical arms carrying the propellers, so all mechanical arms can simultaneously turn in the same direction. Two more mechanical arms attach the parallelogram structure and the flight control, which is placed at the center of the drone body. When the steering engine fixed below the flight control spins, the whole structure and the flight control also turn in the same direction as the structure to maintain routine flight. Later experimentation proved that the novelty of a turning instead of fixed flight control could support flight with transformation in midair. The wingspan of the drone could be shortened by approximately 50% when turned to small mode. In floating and flying tests, the large mode shows a remarkable advantage in battery efficiency and velocity within the tested period. However, the camera technology used to identify weeds must be fixed and perfected.*

Keywords: *Transformable Drone, Four Propellers, Mechanical Arms, Mechanical Structure*

1. Background

Agriculture has been a major part of human life since the beginning of civilization, and it continues to play a vital role in the modern world. It provides food, helps maintain the environment, and provides employment for many people. Additionally, it is a significant source of income for many countries. As time moves on, however, the agriculture industry is also facing many challenges. One particular problem the farmers face is that they spend too much time removing weeds, which greatly reduces their productivity – they have to use herbicides and pesticides. And there is the conundrum: Overusing herbicides and pesticides is extremely hazardous to the surrounding environment. One viable solution is to equip farmers with drones that can identify weeds from crops.

The capabilities and theories of drones have developed significantly in the past few decades. During this period, drones, the symbol of high technology that common people could hardly gain access to, started to play increasingly important roles in people's daily life as well as in professional research. Apart from being suitable for mass production and low price, drones' advantages include size, agility, and stability; drones have become indispensable in several fields, such as aerial filming, agriculture, logistics, and emergency rescue operations.

Although different kinds of drones have several similar advantages, the characteristics of individual drones depend primarily on their specialized structure and, equally important, their sizes. Generally, a relatively small drone is more agile and capable of moving in narrow areas. Larger drones are more stable in the air and can usually fly for a longer period due to their higher efficiency. In some cases, however, a task requires agility and efficiency. For example, biologists sometimes use drones to scrutinize animals in forests. The drone may need to fly for a long distance to track the behavior of animals, yet to gain a closer look, the drone must be agile enough to make way through dense branches, something more suitable for a small drone. In the field of emergency rescuing, a similar situation arises. Rescue drones must be agile enough to maneuver in the ashes while searching for survivors. Yet, the advantage of long duration of life, which belongs to larger drones, is also desirable for rescues could last for as long as weeks, and the time required for recharging could turn out crucial to the rescue. The

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design of this specific project is aimed at assisting farmers in dealing with weeds that harm the growth of crops. If farmers apply herbicides across the entire farmland, a great deal of damage would be done to the environment as most herbicides are harmful to the soil and may pollute water sources when overused. Identifying weeds in person and using herbicides is rather inefficient. Thus, a drone that could maneuver between tall crops and small barns while flying efficiently is very appropriate. To solve the issue of transforming in midair, researchers considered the possibility of developing drones that can transform in midair such that their wingspan can change size from small to big and vice versa.

Research Status:

Existing research proposes new designs of deformable quadrotors with generic modeling and adaptive control strategies. Due to its adaptive geometry, the proposed UAV is able to change its flight configuration by independently rotating its four arms around a central body. In order to simplify and lighten the prototype, a simple mechanism with a lightweight mechanical structure is proposed; a new generic model is developed taking into account all these variations as well as aerodynamic effects [1].

A simple and lightweight design of a deformable quadrotor has been proposed by a scholarly article focusing on the characteristics of the center of gravity during the flight of a quadrotor that can lead to changes in the inertia and control matrices depending on the desired shape, compared to a conventional quadrotor [2].

A remarkable insight has also been offered on two deformable UAV variants that have been assembled taking into account different deformation modes and mechanisms. The first proposed quadcopter uses servomotors on each propeller arm to achieve in-flight folding motion, while the second proposed quadcopter uses a new approach that utilizes miniature linear actuators to reduce its size in all directions [3].

Other scholars have proposed a new design for a well-known quadrotor UAV. The design is based on a variable form that can be modified immediately during flight depending on the mission and the trajectory followed. It is able to change the rotation and extension of its arms independently [4].

Existing studies show that the parameters of the quadrotor are considered unknown but bounded. The proposed control algorithm combines switching techniques with adaptive mechanisms to overcome the difficulties associated with underdriving and uncertainty [5].

A design modification has been proposed and experimentally validated to increase the degree of freedom of quadrotor flight and improve its hovering capability. The propeller makes four additional rotations around an axis perpendicular to the arm, resulting in a hyperactuated system [6].

A novel quadrotor Unmanned Aerial Vehicle (UAV) structure has been proposed to modify the dynamics during flight. The proposed mechanism is presented, which consists of retractable plates that move along the horizontal axis from the body frame respectively [7].

Existing researchers have proposed a novel quadrotor design in which the tilt angle of the propeller with respect to the quadrotor body is controlled by employing the parallelogram principle simultaneously through two additional actuators [8].

An adaptive tracking controller based on output feedback linearization has been proposed, which compensates for the dynamic changes in the center of gravity of the quadrotor. The effectiveness and robustness of the proposed adaptive control scheme are verified by simulation results [9].

For the transformable quadrotor vehicle exposed to external perturbations a synergistic control (SC) has been proposed by the researchers. The control strategy has a simple structure, smooth dynamics and good tracking performance.SC is applied to our system, which has the special characteristic of changing its morphology during flight [10].

2. Related Work

There are many different parts in a drone to ensure its safe flight. This includes the flight controller, which determines the speed propellers move to control the drone's velocity and height. The body of the drone is made of carbon or other materials and contains the battery and flight controller. Four rods extend out of the body, each connecting to a propeller. To design a drone that can transform, researchers raised drastically different approaches.

The first method is to completely change the rods' structure that connects the propellers to the

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drone’s body so that the rods can contract and expand by themselves. The disadvantage of this method is that the rod's structure may be very complex, but the rod’s weight must be limited to sustain a flexible flight.

The second method is to work on the joints that connect the rods to the drone’s body. If some mechanism can control the rods to turn, the drone size could be significantly altered quickly, even during the flight. Some models of drones of this type turn the two rods on the left and right toward each other, transforming the drone into a thin, long rectangular shape. Although this does make passing through a small hole easier, turning through small holes remains challenging as the long body of the drone may get stuck in the holes. Some researchers decided to design the structure of the joints such that the rods turn in a uniform direction, just like the shape of a windmill. After the transformation, the drone turns smaller, but its shape is unchanged. The difficulty in realizing this design includes the following. The first one is that when the rods contract toward the center, the propeller might hit each other, which makes flight highly dangerous. The second problem is that the flight controller controls the velocity and height of the drone base on the default position of the propellers. If the propeller’s relative direction with the propellers is altered, the flight controller can no longer rely on the original code to control the flight. Thus, some researchers decided to rewrite the code of the flight controller, which is a complex process.

2.1. Mechanical Structure

Figure 1: Transformable drone in contracted mode

Figure 2: Transformable drone in extended mode

The drone has four propellers that are fixed on the four protruding mechanical arms from the drone body. A rhombus-shaped piece with four holes is then fixed on each of the four corners of the drone

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body. The ends of the mechanical arms are then fixed on the one hole of the rhombus-shaped pieces so that the mechanical arms can turn. Next, a metal rod is fixed between every two rhombus-shaped pieces next to each other and on one hole of each two rhombus pieces. This forms an interconnected parallelogrammical structure such that when one mechanical arm turns clockwise, the other three arms turn in the same direction at the same angular speed. The drone then can be transformed between two modes. The appearance of fully contracted drone is presented in Figure 1, and the appearance of fully extended drone is presented in Figure 2.

The flight control is placed at the center of the drone body. For the flight control to change its direction, so it turns at the same angle as the mechanical arms that carry the propellers, two rods connect the flight control with two opposite corners. When the initial angle between the rod and the rhombus-shaped piece and the angle between the rod and the flight control is under a particular relationship, the turning angle between the flight controls is equal to the turning angle of the four propellers so the drone can maintain routine flight when transformed in midair. A steering engine beneath the flight control powers the whole structure's transformation.

A landing assist is connected below the drone. The battery is placed on top of the landing assist. An LED lightbulb is placed on the flight control to identify the direction the drone faces after transformation in midair. When this drone model is used to detect weeds in farmland areas, the camera used to identify weeds is placed at the side of the landing assist with its lens facing downward.

2.2. Theoretical Model

The first thing to consider is the lift source of Drone. It is well known that the lift of Drone comes from the optional wing. Generally speaking, the lift Ti and torque Mi of single rotor are generally related to the motor speed ϖ_i.

$$Ti = cT\varpi_i^2 \tag{1}$$

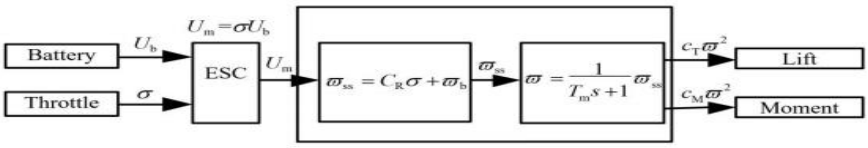

Figure 3: Power model of single rotor system

The power model of single rotor system is illustrated in Figure 3, and the system input is throttle σ and the current battery voltage Ub. The throttle is generally a PWM wave given by flight control in practical application. After ESC receives the PWM wave, according to its duty cycle and the current battery voltage, the brushless motor voltage Um is given, and the brushless motor drives the rotor to rotate. The drive of the rotor can be understood as a first-order inertial link. The rotating rotor will bring lift Ti and counter torque Mi.

Most crucial theoretical model that underpins the transforming ability is the relationship between the turning angle of the mechanical arms that hold the propellers and the turning angle of the flight control that moves together with the parallelogrammical structure.

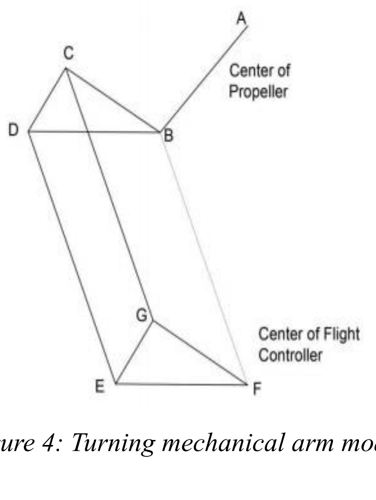

Figure 4: Turning mechanical arm model

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Figure 4 shows a model of a turning mechanical arm. AB represents the mechanical arm, BD represents the radius of the rhombus-shaped piece, DE represents the rod, and EF represents the distance between the rod and the center of the flight control. CB, CG, and GF are the image of BD, DE, and EF after turning the degree of the angle CBD. The angle EFG is thus defined as the turning angle of the flight angle of the transformation.

Connect BF

When BD = EF and BD // EF:

∴BDEF is a parallelogram

∵DE = BF

∴BF = CG

∵CB = DB, GF = EF, DB = EF

∴CB = GF

∵BF = CG, CB = GF

∴CBGF is a parallelogram

∴BF // CG

∴CG // DE

∴CGED is a parallelogram

∴CD = GE

∴ΔCDB ≌ ΔGEF

∴ ∠CBD = ∠GEF

Thus, when the radius of the rhombus-shaped piece is equal and parallel to the distance between the rod and flight control, the turning angle of the mechanical arms that hold the propellers and the turning angle of the flight control is equal to each other.

2.3. Components

The components are shown in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, and Figure 11.

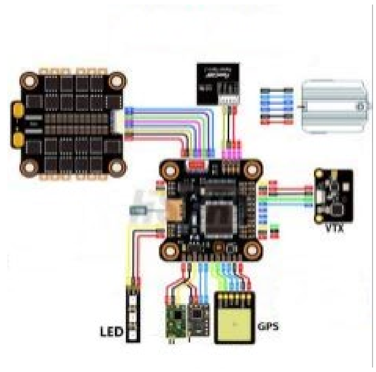

Figure 5: Flight controller (controls the flight of the drone)

Figure 6: Motors and Propellers (create uplifting force)

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Figure 7: Servo (powers the entire structure to transform)

Figure 8: Battery (supplies electric energy)

Figure 9: Remote (sends signals to the flight control)

Figure 10: Receiver (receives signals from the remote control)

Figure 11: Camera (Open MV) trained to identify weeds from crops

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3. Experiments

This experiment tests the difference between the efficiency of the drone's large, medium, and small modes. Theoretically, the smaller the drone's size, the less the efficiency. This results from the fact that when the propellers are folded, much of the downward pushing force acts on the drone body instead of the air. Thus, we hypothesize that the larger the drone's size, the more efficient the drone is.

There are two separate sets of experiment groups. In one group, the drone flies laps of a straight line between two markers. In the other group, the drone floats in midair without moving. The height of the drone is set at 2 meters above the ground. Both groups have three participants, or the same drone with the three modes, each using a separate battery. The battery is charged (but not necessarily fully) after each trial. Each trial takes 120 seconds, and the initial voltage of the battery, the final voltage of the battery, and the number of laps each participant completed are recorded. The results are summarized as follows in Table 1.

Table 1: Quantitative comparison of drone's efficiency in different modes

Trials	Mode	Type	Durati on(s)	Height (m)	Initial Voltage (V)	Final Voltage (V)	Difference in Voltage(V)	Full Laps Completed
1	Large	Flight	120	2.00	4.15	4.00	0.15	24
2	Medium	Flight	120	2.00	4.12	3.96	0.16	18
3	Small	Flight	120	2.00	4.11	3.83	0.28	15
4	Large	Suspension	120	2.00	4.14	3.98	0.16	\
5	Medium	Suspension	120	2.00	4.10	3.95	0.15	\
6	Small	Suspension	120	2.00	4.01	3.79	0.22	\

In the first three trials, the difference in voltage, which represents the energy lost in the flight, increases from mode large to medium and to small respectively, while the total laps completed decrease respectively. In the last three trials, the difference in voltage decreases from mode large to medium and then increases from mode medium to small. This does not entirely match our hypothesis that the larger the drone's size, the more efficient the drone is, but the general trend supports our hypothesis. There is also a considerable gap between mode medium and small in both sets of trials for the voltage difference.

A few factors could affect the accuracy of the experiment. First, the drone is controlled by hand, so the distance or height maintained in each trial could be slightly different. When each trial ends, the battery's temperature could affect the resistance within the battery because it may not be thoroughly cooled before measurement. Such factors could account for the mode large having a higher difference in voltage than the mode medium in the suspension test. Still, such factors can hardly explain the vast difference between mode small and the other two modes in the voltage difference.

4. Discussion

Based on the experimental data in table 1, we can observe that in both flight and suspension types, when the drone was in small mode (fully contracted), the battery consumption was both above 0.2 volts. In contrast, when the drone was in large mode (fully extended) or medium mode (half-extended), the battery consumption was only about 0.15 volts. In flight type, the drone in large mode even completed more full laps (24 laps) with lower consumption (0.15 volts), while in small mode only completed fewer full laps (15 laps) with higher consumption (0.28 volts). Such comparative data indicate that the energy consumption in small mode is significantly higher than what is in large or medium mode.

For the drone structure designed in this study, the key is the adjustability of the drone rotor wheelbase. It can be proved by experiments that the decrease of wheelbase increases the power consumption of the drone. We consider the following reasons when explaining this phenomenon.

(1) The folding of the rotor will change the action object of the lift to a certain extent, and part of the lift will change from external force to internal force.

(2) The reduction of the body size will affect the heat dissipation efficiency of the battery, and the state of the battery will obviously affect its power consumption performance.

(3) Obviously, the deformable drone has a wide range of application scenarios and scientific research value. We will consider further research from the following aspects.

(4) This study improves the autonomous capability of UAV, at present, drones still use the way of

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human remote control. In the future, it will be considered to realize fully autonomous planning and control of drones, so that drones can adaptively change the wheelbase according to the environment. This will greatly enhance the application value of deformable UAV in agriculture.

(5) This study gives drones more intelligent perception; the drone can analyze the current plant types, and complete the autonomous mapping and patrol path generation of farmland. The UAV will also have the ability to upload independent data.

5. Conclusion

This transformable drone with four propellers for agricultural use shows a potential solution to help farmers efficiently identify weeds in farmland areas. Through the technique of a connected parallelogram structure and flexible flight control, transformation in midair is successfully achieved. As for the difference in the efficiency of battery use, experiments prove that the small mode is relatively inefficient compared to larger modes.

Still, the current drone is not a completed piece of work. The last part of the project contains a camera that could identify the weeds from crops. By feeding images of weeds and crops to the Open MV camera, distinguishing between crops and weeds is theoretically possible. In reality, however, our testing with the camera demonstrates that the camera cannot identify weeds with satisfactory accuracy. If the Open MV uses more images of crops and weeds in training the AI, such a technical problem can be solved. When such a drone does come to the market, more analysis on the targeted wingspan and power of the propellers could be made. The ultimate goal is to create a drone that fits tightly with the need of a farming situation, and with the help of our model and experimentation, such a goal is not too far to be accomplished.

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