Control System Design and Experimental Validation of Hybrid Multicopter for Endurance Enhancement

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Abstract

In this paper, we propose a hybrid multicopter that combines an gasoline propulsion system and an electric propulsion system to improve the endurance of the multicopter. The hybrid is equipped with a coaxial inverting thruster using a gasoline engine at the center and an electric propulsion system for attitude control at the side. The control system using a classical control algorithm based on the dynamic model. Finally, flight performance and high-endurance flight of the hybrid multicopter were verified.

Keywords: We would like to encourage you to list your keywords in this section.

1. Introduction

Due to the advantages of a multicopter such as the simplicity of the kinematic structure, vertical takeoff and landing and hovering, research on exploration-rescue missions, gas leakage tracking has been actively conducted in recent year [1][2][3]. Based its advantages, multicopter is attracting attention from global companies such as Google, Amazon, DHL as a next generation delivery and various service means [4].

However, the outcome, performance and basic mission functions gained by active research have a limited effect by the short flight time of existing multicopters [5,6]. As shown above, research is also actively being carried out to improve the flying time which is pointed out as the biggest disadvantage of multicopter. There is a representative study on new types of multicopter such as Dual Quad-Rotor System, Compound Hexa-copter, Variable-Pitch Gasoline-Engine Quad rotor [5][5][6]. There are also studies on Tether powered multicopter [6]. The results of the study are shown in Figure 1 below.

![Figure 1. Multicopter for long endurance](image)

However, the above studies show the problems that it is difficult to maintain due to the kinematic complexity caused by the use of variable pitch and self-weight is too heavy, 40kg. In addition, there are still problems that the flight speed or the degree of freedom is reduced.

Article history:
Received (January 25, 2017), Review Result (March 29, 2017), Accepted (April 20, 2017)
due to the wired connection or improved result through new types of aircraft still have flight
time of less than 40 minutes etc.
In this paper, we propose a hybrid multicopter system equipped with a central coaxial
inverting internal combustion engine thruster for long endurance of more than one hour. In
order to implement the proposed system, the control system was selected and designed. 
Finally, the performance of the fuselage was evaluated by performing long endurance of more
than one hour and various flights.

2. Hybrid multicopter system

2.1. Hybrid multicopter system and expectancy effects

The hybrid multicopter is equipped with two engines at the center for long endurance, and 
the thrust is generated by installing a propeller in a coaxial inverting form. Four BLDC motors
are used for attitude control. The shape of the hybrid multicopter is shown in Figure 3 below.

![Configuration of hybrid multicopter](image)

**Figure 3. Configuration of hybrid multicopter**

Equipped with a central engine, the hybrid multicopter can reduce the power consumption
of an electric propulsion system during hovering and flying. Tables 1 and 2 below show the
comparison of power consumption when using the engine / when not using the engine and the 
estimated flight time. The hybrid multicopter is expected to have a endurance gain effect of up
to 14 minutes or more in ideal conditions.

| Table 1. Prediction of power consumption and flight time of hybrid multicopter |
|---------------------|------------------|
| Mass                | 21.381 kg        |
| Engine Thrust (Coaxial) | 117.7 N        |
| Required Thrust (Each Motor) | 35.41 N    |
| Thrust Input (%)     | 50 %             |
| Current Consumption  | 9.11 A           |
| When using 44.4V / 44,000mAh battery, flying up to 72 minutes |

| Table 2. Prediction of power consumption and flight time of equivalent fuselage (no engine) |
|---------------------|------------------|
| Mass                | 21.381 kg        |
| Required Thrust (Each Motor) | 52.43 N    |
| Thrust Input (%)     | 56.5 %           |
| Current Consumption  | 11.25 A          |
When using 44.4V / 44,000mAh battery, flying up to 58 minutes

2.2. Hybrid multicopter system thrust allocation

When the hybrid multicopter is hovering, the motor thrust was set to 50% considering the margin for control. At this time, the distribution ratio by thruster and thrust required in the electric thruster and the internal combustion engine thruster are shown in the table below.

<table>
<thead>
<tr>
<th>Table 3. Specification of hybrid multicopter</th>
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<tbody>
<tr>
<td>Center Thrust (ratio)</td>
</tr>
<tr>
<td>Side Thrust (ratio)</td>
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2.3. Hybrid multicopter dynamic modeling and control system design

A commonly used 6-DOF equation of motion was used for the dynamic model of the hybrid multicopter. The following equation (1) is the translational equation of motion, and equation (2) is the rotational equation of motion.

\[
\begin{bmatrix}
\dot{u} \\
\dot{v} \\
\dot{w}
\end{bmatrix} =
\begin{bmatrix}
v_r - w_q - g \sin \theta \\
wp - ur + gc \phi \sin \phi \\
uq - vp + gc \phi \cos \phi + \frac{U_1}{m} \text{ (total thrust)}
\end{bmatrix}
\]

\[
\begin{bmatrix}
p \\
q \\
r
\end{bmatrix} =
\begin{bmatrix}
\frac{(l_{zy} - l_{yx})}{l_{yx}} qr + \frac{u_z}{l_{xx}} \\
\frac{(l_{zx} - l_{zy})}{l_{zy}} pr + \frac{u_z}{l_{yy}} \\
\frac{(l_{yy} - l_{zx})}{l_{yx}} pq + \frac{u_z}{l_{zz}}
\end{bmatrix}
\]

The hybrid multicopter has a control system that applies a commonly used linear control algorithm. The control system of the hybrid multicopter is configured as shown in Figure 4 below.

![Figure 4. Control system of hybrid multicopter](image-url)
3. Flight result

3.1. Flight control result – Attitude / Altitude / Position / Velocity

Flight experiments were conducted to verify the actual flight results of the designed system. Figure 5 below shows the results of attitude control and altitude control, and Figure 6 shows the results of X-Y position control and speed control. All of the figure compared with simulation result.

![Figure 5. Attitude / Altitude control flight test result](image1)

![Figure 6. X-Y Position / Velocity control flight test result](image2)
3.2. Endurance test result

The designed hybrid multicopter system was used to check if long endurance is actually possible for more than 1 hour. At this time, the fuselage used the location maintenance function to reduce the fatigue of the operator during long endurance. The experiments were carried out twice in total, successfully performing the flight of 1 hour 5 minutes 8 seconds and 1 hour 25 seconds, respectively.

4. Conclusion

In this paper, we designed the hybrid multicopter using an internal combustion engine thruster and electric thruster for long endurance. The basic attitude control and automatic flight algorithm are designed to accomplish various missions using long endurance and endurance time and this was confirmed through experiments. As a result, it was finally found that flight of more than 1 hour is possible by using the position maintenance function through long endurance flight. Currently, two engines and propellers are mounted in a coaxial inverting form to generate thrust but it is expected that more flight time will be secured by reducing the weight of the fuselage if additional devices such as a coaxial inverting power transmission device are applied. It is expected that the hybrid multicopter can be applied to missions such as exploration, rescue and fixed area monitoring using the long endurance function in the future.
References


