Research, design and manufacture unmanned aerial vehicles (UAV) for specialized tasks

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Abstract— Unmanned aerial vehicles (UAV) for search and rescue have been accelerating research in recent years. With superior capabilities than other specialized equipment, such as supporting a rapid response team in search and rescue missions and detecting victims in harsh terrains that are difficult for human to access. The purpose of this research is to compute in detail the components of UAV, including drag coefficient, lifting force coefficient, robotic load, rotor lift force, engine power, battery capacity, etc. UAVs structure has been built to work for specialized purposes. The experiment results showed that UAVs capable of combining an automated or individual flight with the software on their computers and collecting data from the camera mounted on the robots marks a significant advancement, providing crucial information for the central processing station. With a maximum flight time of 15 minutes under ideal conditions and a stable signal range of up to 413 meters, these outcomes open up new prospects for the application of unmanned aerial robots in various fields.

Keywords— UAV, drone, quadcopter, flight controller, RFD 900x, Ts – Re 832, Triple Feed Patch – 1.

I. INTRODUCTION

Nowadays, tremendous technological advancements have opened up opportunities for the development of unmanned aerial vehicles [1, 2]. Researching and designing these systems not only meet the increasing demands for search and rescue operations, but also present new prospects for specialized applications [3].

Distinct from other devices, unmanned aerial vehicles not only assist rapid response rescue teams in searching and rescuing in challenging terrains, but also unveil various distinctive application possibilities [4, 5]. From meticulously calculating fundamental components such as drag coefficient, and lift coefficient, to load and engine power, this research has made significant strides in enhancing the operational performance of unmanned aerial vehicles.

The experimental results are not only the successful fabrication of two unmanned aerial robot models, but also their ability to autonomously coordinate or operate individually. Gathering image data from cameras mounted on the robots marks a significant advancement, providing crucial information for the central processing station. With a maximum flight time of 15 minutes under ideal conditions and a stable signal range of up to 413 meters, these outcomes open up new prospects for the application of unmanned aerial robots in various fields.

These achievements not only hold promising prospects for the search and rescue field, but also affirm the pioneering and innovative spirit of the research and technological development sector in today’s society.

This paper is organized as: Solved II will highlight the current issues that need to be resolved, Section III will present detailed solutions, Section IV will present the results of the research, Section V will draw conclusions.

II. PROBLEMS FORMULATION

When a natural disaster occurs in a large area such as heavy rain, storms, or flash floods, the ability to quickly and effectively search and rescue becomes the top goal [6-8]. Notably, the idea of using combined UAV (Unmanned Aerial Vehicles) swarms is attracting great interest [9-11].

Combining multiple individual UAVs into a swarm not only enhances coverage, but also provides the ability to collect clearer and more comprehensive data from hard-to-reach areas. Advances in technology and data analytics also provide a solid infrastructure for the effective deployment of UAV swarms in the rescue industry [12].

From the above idea, this article addresses to designing and manufacturing unmanned aerial robots capable of effectively serving search and rescue purposes. Fig. 1, shows main problems that should be solved in this paper.
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III. SYSTEM DESIGN

With the aim of reducing response time and increasing effectiveness in search and rescue operations during disasters, this UAV swarm control system must minimally fulfill two critical requirements:

Requirement 1: The UAVs must be synchronized and capable of autonomously dividing the operational area to avoid collisions with each other.

Requirement 2: Each UAV must be equipped with a data collection device to transmit imagery data to the central processing station for detecting individuals in distress.

Once the control system requirements have been clearly defined, the issues are divided into three main solution directions. The first direction involves the research, construction, and assembly of the frame structure. The second direction entails the study of an integrated control system for the frame structure. The third direction focuses on developing software suitable for the entire system. This paper will primarily concentrate on elaborating the first research direction

A. UAV design ideas

It is very important to have a design idea before starting construction and installation, thereby giving an overview and the goals to be achieved:

- Determine the type of UAV: Quadcopter,
- Maximum take-off load: ~ 2 kg,
- Maximum flight time: ~ 15 minutes.

Detailed design ideas to simulate flying robots using Solidworks software before going into the installation step, frame structure includes: Airframe, Landing gear, Motor, ESC, Propeller, Relief box, FC, Camera, GPS, PMU, battery, are shown in Fig. 2.

B. Parameters of the proposed UAVs

- Estimated total weight

Based on Section III.A and the above necessary equipment parameters, we can estimate the total weight and expected size of the UAV as follows:

<table>
<thead>
<tr>
<th>Parts</th>
<th>Weight (grams)</th>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airframe</td>
<td>550 g</td>
<td>S500 (500 mm x 500 mm x 55 mm)</td>
</tr>
<tr>
<td>Flight controller(FC)</td>
<td>59 g</td>
<td>Pixhawk 6C (Imax=1.5A)</td>
</tr>
<tr>
<td>Power Main Unit (PMU)</td>
<td>36 g</td>
<td>PM07 (2-12s,Imax=120A)</td>
</tr>
<tr>
<td>Driver</td>
<td>15*4=60 g</td>
<td>ESC – (4s,Imax=20A)</td>
</tr>
<tr>
<td>BLDC</td>
<td>55*4= 220 g</td>
<td>2213 (980Kv, Pmax=200w, Imax=18A)</td>
</tr>
<tr>
<td>Camera Ratel 2</td>
<td>55 g</td>
<td>Full HD, 3S</td>
</tr>
<tr>
<td>video receiver module</td>
<td>65 g</td>
<td>VTX</td>
</tr>
<tr>
<td>Battery</td>
<td>315 g</td>
<td>Pin Lipo 3s 7000Mah/70c</td>
</tr>
<tr>
<td>RF receiver module</td>
<td>15 g</td>
<td>RFD900x</td>
</tr>
<tr>
<td>GPS modul</td>
<td>21 g</td>
<td>F9p</td>
</tr>
<tr>
<td>Parts other</td>
<td>204 g</td>
<td>Relief box,Propeller(9x45),</td>
</tr>
<tr>
<td>Total aircraft weight</td>
<td>1600 g</td>
<td>PA</td>
</tr>
</tbody>
</table>

- Theoretical and computational:
  - Ratio of pulling force and lifting weight.

The thrust-to-weight ratio is the ratio between the motor’s thrust and the weight of the model, indicating the motor’s power.

For search and rescue operations, a suitable ratio ranges from 1.5 to 2.5.

Depending on the Kv data of the motor, we can determine the lift force and select an appropriate propeller diameter.

In this case, we are using a 2213 980 Kv motor, which is suitable for medium-sized propellers like the 1045 and 9045. Here, we will choose the 9045 type. At full power, one motor can lift 0.9 kg, but in practice, we will only use 60-70% of the power, which is approximately 0.63 kg. Using 100% power can lead to motor damage.

- Wing load

Wing load (WL) = (Aircraft weight/Wing area) = \( \frac{PA}{S_r} \) (1)

In there:
- WL: Wing load (g/cm²);
- PA: Aircraft weight (g);
- \( S_r \): Wing area (cm²).

Change PA= 1600 g, \( S_r = 413 \text{ cm}^2 \) ⇒ WL= 3.87 (g/cm²).

- Maximum lifting load

To calculate the maximum lift force of a quadcopter (a drone with 4 propellers), we need to calculate:

- Maximum power consumption of an engine:
\[ P_{\text{Max}} = U \times I_{\text{Max}} \quad (2) \]

In there:
- \( P_{\text{Max}} \): Maximum power consumption of an engine;
- \( U \): Voltage is supplied by the power source;
- \( I_{\text{Max}} \): Maximum allowable current of the motor.

Normally, the maximum current consumption parameters of the motor will be recorded on technical documents or on the motor body. The voltage supplied to the motor is usually determined by the battery or power supply. Then:
\[ P_{\text{Max}} = 11.1 \times 18 = 199.8 \text{W} \]

- The static thrust of an aircraft is calculated according to the formula:
\[ T = \left[ \frac{\pi}{2} \times D^2 \times J \times P_{\text{Max}}^2 \right]^{1/3} \quad (3) \]

In there:
- \( T \): Maximum lifting force of 1 motor (N);
- \( D \): Diameter of rotating impeller (m);
- \( J \): Density of air \((\text{kg/m}^3)\) \((1.2 \text{ kg/m}^3)\).
- \( P_{\text{Max}} \): Maximum power consumption of an engine (W)

Calculate: \[ T = \left[ \frac{3.14}{2} \times 0.23^2 \times 1.2 \times 199.8^2 \right]^{1/3} = 15.84 \text{ N} \]

To convert lifting force from Newton (N) to kilogram (kg), we use Newton’s third law, \( F = m \times g \), in which:
- \( F \): Lifting force (N);
- \( m \): Mass (kg) to be converted;
- \( g \): is the acceleration in the field, has an approximate value of 9.81 m/s^2 on the ground.

\[ m = \frac{T}{g} = \frac{15.84}{9.81} = 1.614 \text{ kg} \]

In theory, a 2213 980 KV motor will have a thrust of about 1,614 kg, but in reality the thrust to weight ratio is 2:1 so the aircraft will operate smoothly and safely. If this ratio is lower than the motor and ESC, it will easily overheat, leading to damage during use.

So:

- Total lifting force of 4 motors: \( T_{\text{motor}} = 1.614 \times 4 = 6.456 \text{ kg} \)

Safe lifting weight is: \[ M_{\text{safe}} = \frac{6.456}{2} = 3.228 \text{ kg} \]

Maximum load that the UAV can lift:
\[ M_{\text{L}} = M_{\text{safe}} - P = 3.228 - 1.6 = 1.628 \text{ kg} \]

- Battery performance with flight timeing
\[ Ft = \frac{C \times h \times \%}{AAC} \quad (4) \]

In there:
- \( Ft \): Flight time (h);
- \( C \): Battery capacity (mAh);
- \( h \): Discharge level;
- \( AAC \): Average ampere consumption
\[ AAC = PA \times \frac{P}{V} \quad (5) \]

In there:
- \( AAC \): Average ampere consumption;
- \( PA \): Aircraft weight (g);

\[ P_1 \]: Actual capacity required to lift a load of 1 kg, based on actual practice, choose 150 W/kg as the consumption level when the UAV’s performance reaches 75% of maximum capacity;
- \( V \): Rated voltage of the battery.

\[ \Rightarrow AAC = 1.6 \times \frac{150}{11.1} = 21.62 \text{(A)} \]
\[ \Rightarrow Ft = \frac{7 \times 80}{21.62} = 0.26(h) = 15.54(h) \]

With a consumption level of 80%, it is forced to land to be safer, to avoid the situation where the plane can freely fall because it runs out of energy.

C. Communication equipment

- RDF 900x

The RDF 900x device is an RF (Radio Frequency) modem operating at 900 MHz, widely used in wireless communications. In particular, RDF 900x is popular in UAV (Unmanned Aerial Vehicles) crowd control applications in large-scale rescue situations.

With its long-range and stable data transmission, the RDF 900x plays an important role in maintaining continuous connectivity between UAVs in crowds. This is very important in rescue situations, where UAVs need to coordinate well to optimize system impact. It provides high reliability and interference tolerance, helping to maintain a strong connection even in harsh environmental conditions. This helps ensure that important information can be communicated quickly and reliably.

Effective isotropic radiated power (EIRP). This is an important parameter in wireless communications, measuring the strength of the signal transmitted from a source.

\[ EIRP(\text{dBm}) = \text{Transmit power(\text{dBm}) - Cable loss(dB)} + \text{Antenna Gain(dBi)} \quad (6) \]

In there:
- \( EIRP(\text{dBm}) \): This is the equivalent power distributed at the receiver point, measured in dBm (decibel-milliwatt).
- \( \text{Cable loss(dB)} \): This is the initial signal power at the source, also measured in dBm units. This is the power that the system transmits.
- \( \text{Battery performance with flight timeing} \)

Fig. 3 shows how the RFD900 output power relationship changes with supply voltage.

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Fig. 3. Output Power of RFD900 vs. Input Supply Voltage to the RFD900

Fig. 4 shows how the current through the RFD900 changes with the transmit power level. The current during transmit is shown by the 'High Level' graph and the current in the received mode display is shown by the 'Low Level' plot.

Fig. 4. Current consumption of the RFD900 modem vs. TX power level

Fig. 5 show the occupied bandwidth(-20dB) against the air data rate.

Fig. 5. Occupied bandwidth vs. air data rate

Fig. 6 shows the communication connection structure of RFD 900, (a) point-to-point connection type, (b) multipoint connection type.

A few notes on the multipoint network (Fig. 6b):
- In order for Node 1 to communicate with Node 2, it has to be able to see Node 0 (the base) and Node 2.
- If Node 4 cannot see Node 0, to communicate with Node 1, it has to be able to see Node 1 and set the SyncAny parameter to 1.
- Please note that there is a maximum number of one node which can have SyncAny = 1 parameter in a network to avoid data corruption.
- More nodes will reduce the bandwidth.

TS – RC 832
The TS-RC832 is a pair of wireless video transmitters used to transmit video from the field to a remote display device. Using 5.8 GHz radio wave technology, the TS-RC832 eliminates the need for direct connection cables, helping to transmit video signals from hard-to-reach locations. Device range and performance may vary depending on the operating environment as well as specific techniques to enhance product range. Fig. 7 shows how to connect this Ts-RC 832 module to a display computer and HD camera.

Fig. 7. TS-RC 832 module connection diagram
The Triple Feed Patch Antenna – 1

The Triple Feed Patch – 1 patch antenna is a diverse type of antenna for transmitting and receiving waves in applications related to wireless communications. The outstanding feature of this antenna is its ability to provide diversity in receiving waves from many different sources, while also being able to transmit signals stably and effectively.

The advantages of the Triple Feed Patch – 1 antenna include the ability to provide a variety of signal sources, allowing the optimization of the performance of the communication system. This makes it a popular choice in applications requiring flexibility and high reliability. Fig. 8 shows the actual front and rear appearance of the Triple Feed Patch - 1 antenna.

Fig. 8. Triple Feed Patch antenna – 1

Fig. 9 shows the 3d radiation simulation results of the antenna, it is easy to see that the largest peak = 9.3 dBiC has the strongest and farthest signal. The purpose of this antenna is to focus and transmit the signal as far as possible like a pan-converging light.

Fig. 9. 3D simulation of antenna radiation

IV. EXPERIMENTAL RESULTS

There was a prototype outlining the design idea before calculating and assembling the flying robot. The model was created in 3D using Solidworks software, as shown in Fig. 10. Details of the actual assembly parts are shown in Fig. 11.

Fig. 10. The manuscript is designed in 3D

Fig. 11. UAV prototype designed

Initially, flying robots have the ability to connect and automatically control remotely via wireless communication devices with Qground control software. Not only can the flying robots be controlled, but they also collect sharp images at the scene, with image quality of HD 720p. Through practical testing, the rdf900 device is capable of wireless communication over relatively long distances in an ideal environment without obstacles.

The TS-RC 832 equipment set combined with the Triple Feed Patch -1 antenna has increased efficiency and operating range, improving the quality of video transmitted to the ground station.

Next, with time-of-flight tests under suitable environmental conditions. The maximum flight time of the flying robots with the configuration is as presented in section III.B, in fact both flying robots reach hold flight mode for about 15 minutes and automatically land safely.

In another development, a practical test of the range and stability of both signals, DATALink and Video. The best and most stable result is 413 meters and a ceiling of 100 compared to the ground control station.

Fig. 12(a, b) shows 02 products that were successfully manufactured and tested.
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Triplet Feed Patch -1 antenna also bring significant improvements in the performance and operating range of UAVs. At the same time, improve the quality of video transmitted to the ground control station.

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Fig. 12. Product 02 uav was successfully designed and manufactured

V. CONCLUSION

In this paper, significant results have been brought in the development and application of unmanned aerial vehicles (UAVs) in search and rescue work.

Calculating and optimizing the basic components of the UAV including drag coefficient, lift coefficient, payload, propeller lift, engine power and battery capacity has created a solid foundation for manufacturing, successfully two flying robot models capable of flying automatically or independently.

Experimental results show that the flying robot has a maximum flight time of about 15 minutes and the longest distance with a stable signal is 413 meters, with a flight ceiling of 100 meters. This is an important step forward in providing flexible and effective solutions for rescue work in emergency situations.

Besides, the research and application of wireless communication devices such as RFD900, TS-RC 832 and Triple Feed Patch -1 antenna also bring significant improvements in the performance and operating range of UAVs. At the same time, improve the quality of video transmitted to the ground control station.