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Design of Rescue Drone Grips

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Abstract: *To address the challenges of low material delivery efficiency and high operational risk in forest fire rescue operations, this paper proposes a precision material delivery system equipped with a UAV gripper mechanism. By integrating high-precision positioning with adaptive delivery control technology, the system enables emergency rescue operations in complex fire environments. The system utilizes the Pixhawk 2.4.8 flight controller as its core; by presetting three-dimensional flight point paths via the QGroundControl ground station, it achieves autonomous path planning and flight. Through the integration of a multi-source module—comprising a PX4Flow optical flow sensor and a sonar sensor—with a PID algorithm, the system achieves wind-resistant hovering and stable flight attitude above fire zones. Leveraging the designed UAV gripper in conjunction with a high-precision GPS module, the system enables precise material delivery at high altitudes. Experimental results demonstrate that the precision of the UAV material delivery system equipped with this gripper reaches 95%, thereby improving the efficiency of rapid and accurate material delivery in forest fire rescue operations.*

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I. Introduction

As a major threat to global ecological security, forest fires are characterized by rapid spread, which poses challenges for traditional fire and rescue operations, including a short rescue window, high risks associated with personnel approach, and poor precision in the delivery of supplies. Data indicate that from 2020 to 2023, secondary casualties caused by delays in supply delivery accounted for as much as 34% of total forest fire-related casualties in China. To address these issues, this paper proposes a drone delivery system based on multimodal perception. The system utilizes a QGroundControl ground station for flight path planning and combines PX4Flow optical flow with sonar-based GPS positioning to achieve precise hovering, while an intelligent servo gripper controls the timing of supply deployment. Field test results demonstrate that the system achieves a supply delivery precision of 95%, representing a significant improvement over traditional airdrop methods and providing an efficient solution for forest fire emergency rescue.

1.overall scheme design

This paper aims to design a long-range emergency medical supply delivery system for drones based on the Pixhawk 2.4.8 flight control system. The system primarily consists of five core components: the flight control system, ground station communications, path planning, hover stability, and supply delivery. This solution employs Pixhawk 2.4.8 as the core flight control system for the drone. The drone communicates data with the QGroundControl ground station, which enables real-time monitoring of flight status and supports path planning functionality. Before task execution, users can preset waypoints on the ground station, allowing the drone to fly autonomously to the target area. To ensure the drone's stability during supply delivery, the system is equipped with a PX4Flow optical flow sensor; by calculating optical flow information together with altitude data and combining them withThe inertial measurement unit (IMU) within the flight control system enables precise hovering. This visual-inertial fusion approach effectively mitigates drone drift caused by weak or lost GPS signals, thereby enhancing stability in complex environments. For material delivery, high-precision intelligent servo grippers are employed; these grippers are mounted beneath the drone and use servo motors to control the grasping and release of materials. The grippers support remote control; the flight control system can trigger servo rotation via specific commands, ensuring the precise delivery of materials to designated locations. After takeoff, the drone flies along a preset route to the target area and maintains a stable hover via the PX4Flow optical flow sensor. The flight control system then commands the servo gripper to release the materials. Upon completion of the mission, the drone can return to its starting point, enabling efficient and precise long-range material delivery. By integrating flight control, visual sensing, path planning, and remote delivery technologies, the system is suitable for scenarios such as emergency rescue and material delivery in disaster zones. It improves the efficiency and accuracy of material deployment and provides a viable technical solution for drone

transport in forest fire rescue operations. The long-range emergency material delivery system for drones based on the Pixhawk 2.4.8 flight controller is illustrated in Figure 1.

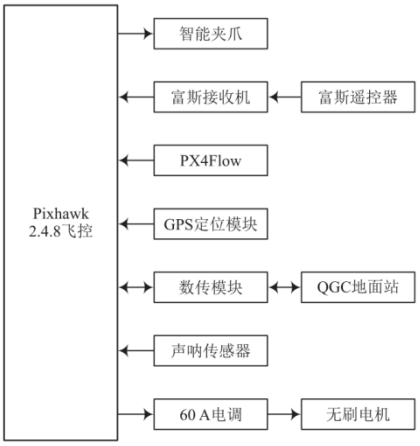


Figure 1 System hardware architecture

2. hardware design

2.1 Selection of Flight Control Hardware

Pixhawk 2.4.8 is a high-performance open-source flight controller that supports PX4 firmware and is suitable for autonomous flight and remote control. It is equipped with an STM32F427 processor and features a built-in MPU6000 IMU and MS5611 barometer, enabling high-precision attitude and altitude estimation. It supports a variety of sensors, including GPS, optical flow, LiDAR, and ultrasonic sensors, allowing for multi-sensor data fusion to improve flight accuracy and stability. It is compatible with the QGroundControl ground station, supports the MAVLink protocol, and provides real-time data transmission and path-planning capabilities. The flight controller can control servo grippers, offering excellent scalability to meet the requirements of different missions. The Pixhawk 2.4.8 flight controller is shown in Figure 2.



Figure 2: Pixhawk 2.4.8 flight controller

2.2 Intelligent Servo-Jaw Drone

The drone is equipped with an intelligent jaw and integrates GPS positioning with real-time monitoring technology to enable the remote and precise delivery of rescue supplies. When personnel are trapped at a fire scene, the drone can carry small emergency rescue supplies and rapidly fly to the designated area to provide timely assistance. The intelligent jaw consists of a gripping mechanism and a servo motor; the overall structure was designed and refined by our team. Once the drone reaches the target area and achieves stable hovering, the flight control system sends commands to the servo motor, which drives the jaw to release the supplies. This system offers advantages such as a high degree of automation, precise control, and rapid response, providing an efficient and safe remote delivery solution for emergency rescue operations. The intelligent servo-jaw is shown in Figure 3.

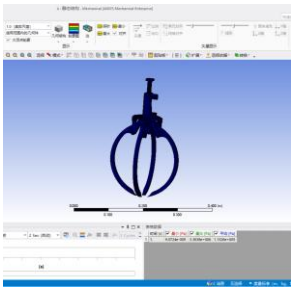


Figure 3: Intelligent Servo Clamp

2.3 Brushless Motor Control System

This system employs a 400 kV brushless motor and an 18-inch carbon-fiber propeller to provide high-efficiency power. Each motor can deliver a pulling load of approximately 3 000 g; the combined pulling load of the four motors can reach 12 kg, ensuring that the UAV can carry more than 3 000 g of rescue supplies in forest environments. A PID algorithm is used to precisely control the motor speed, optimizing response speed and stability so that the UAV maintains stable attitude control under varying loads. The 18-inch carbon-fiber propeller features lightweight construction, high strength, and high aerodynamic efficiency, which enhances the system's flight endurance and load capacity. The entire system ensures stable flight of the UAV in complex environments and enables precise delivery of supplies, meeting the requirements of emergency rescue missions. The brushless motor system is shown in Figure 4.



Figure 4: Brushless Motor System

2.4 UAV Airborne Hovers

This paper integrates the PX4Flow optical flow sensor with a sonar sensor to achieve high-precision hover control for UAVs, providing technical support for the precise delivery of supplies. The PX4Flow optical flow sensor communicates with the Pixhawk 2.4.8 flight controller via an I2C interface; it incorporates a high-resolution camera and a 16-bit gyroscope, with an update rate of 780 Hz. By analyzing the movement of image pixels, it calculates the ground speed in the X and Y directions; the flight control system then adjusts motor speed through closed-loop control to eliminate lateral drift and ensure stable hovering. The sonar sensor measures the distance between the UAV and the ground in real time to obtain Z-axis altitude information; combined with a PID control algorithm, it adjusts motor thrust to maintain stable vertical altitude. This system enables precise hovering and positioning even in environments with weak GPS signals. The PX4Flow optical flow sensor and sonar sensor are shown in Figure 5.



Figure 5: PX4Flow optical flow and sonar sensors

3 Software Design and Implementation of the System

3.1 Selection of the UAV Ground Station

This study selects QGroundControl as the ground station because it offers high compatibility with the Pixhawk 2.4.8 flight-control ecosystem and provides comprehensive functionality, making it suitable for emergency scenarios. The ground station communicates efficiently with Pixhawk 2.4.8 via the MAVLink protocol, ensuring data integrity and enabling mission planning and transmission with a packet loss rate below 0.01%; it supports graphical parameter configuration, reducing the debugging cycle by more than 50%; it features dual-frequency links at 2.4 GHz and 900 MHz, ensuring stable communication with low latency within 1 km; it allows for online updates to flight points, ensuring precise delivery; upon mission completion, it automatically downloads the flight-control logs, analyzes flight data, and optimizes algorithms; and it supports cross-platform deployment, thereby improving emergency response efficiency. The features of the GroundControl ground station are illustrated in Figure 7.

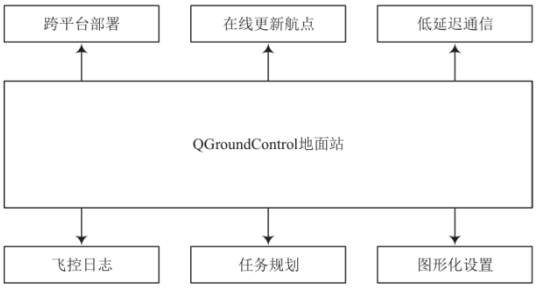


Figure 7: Features of the QGroundControl ground station

3.2 Flight Path Planning

This study employs the Pixhawk 2.4.8 flight controller as the core control system. Data is exchanged between the flight controller and the data transmission module via a USB interface, enabling real-time communication between the UAV and the ground station. Users can create a mission sequence through the ground station, specifying path parameters such as the start point, destination, flight altitude, heading, waypoints, and safety fence. Once mission planning is complete, commands are sent to the UAV via the data transmission module; the Pixhawk 2.4.8 flight controller receives these signals and executes the corresponding autonomous flight tasks [8]. During flight, the flight control system continuously reads and fuses data collected by sensors such as the PX4Flow optical flow sensor to ensure precise UAV navigation, stable hovering, and attitude control. Simultaneously, the UAV transmits its flight status data back to the ground station in real time via the data transmission module, allowing operators to remotely monitor the UAV's flight trajectory, altitude, heading, and other information, thereby ensuring flight safety. The control flow between the GroundControl ground station and the UAV is illustrated in Figure 9.

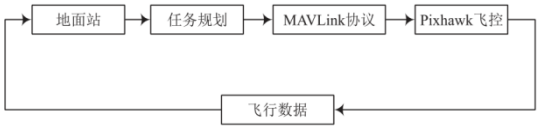


Figure 9: Control flow between the QGroundControl ground station and the unmanned aerial vehicle

4 Experimental Testing and Results

4.1 Power System Testing and Results

(1) Test Objectives: This experiment conducts performance testing on a power system comprising a 400 kV brushless motor, an 18-inch carbon-fiber propeller, and a 60 A electronic speed controller (ESC), to evaluate its actual performance during UAV hovering, load capacity, and payload delivery missions. The following aspects are the primary focus of testing:

① Thrust output: Measure thrust at different throttle settings to ensure that the thrust of each individual motor meets mission requirements.

② Power consumption analysis: Evaluate the motor's power consumption under different loads to optimize the energy efficiency ratio and improve flight endurance.

③ Stability testing: Verify the motor's response capability during prolonged hovering and sudden load changes to ensure flight safety.

④ Temperature rise monitoring: Monitor changes in motor temperature to ensure that the motor does not overheat during extended operation.

(2) Test Environment and Equipment: Power system components: 400 kV brushless motor, 18-inch carbon-fiber propeller, 60 A ESC, and a 22.2 V, 6,000 mAh lithium battery. Measurement equipment: Thrust test rig, current

and voltage meter, temperature sensor, Pixhawk 2.4.8 flight controller, and QGroundControl ground station. Test environment: Indoor laboratory, wind-free environment, temperature of 25 °C, and humidity of 50% RH.

(3) Testing Methodology:

① Thrust testing: Test the thrust of a single motor under 50%,75%, and 100% throttle conditions, and calculate whether the total thrust meets mission requirements. Record current, voltage, and power to assess the relationship between thrust and power consumption.

② Power consumption and efficiency testing: Calculate motor power using the current and voltage meter and analyze the thrust-to-power ratio per unit power. By comparing the thrust-to-power consumption ratio under different loads, the optimal power-efficiency point is selected to optimize the drone's flight time.

③ Stability testing: The drone is operated in hover mode for 10 min to assess the stability of motor thrust. A simulated material-drop experiment is conducted; with the drone carrying loads of 1 kg, 2 kg, and 3 kg, the motor's response at the moment of release is measured, and it is observed whether the flight controller can rapidly adjust the aircraft's attitude to maintain balance.

④ Temperature-rise testing: A temperature logger is used to record changes in motor temperature; measurements are taken every 2 min for 15 min. The analysis determines whether the motor faces a risk of overheating after prolonged operation.

(4) Analysis of experimental results: The experimental results for the power system are presented in Table 1.

Table 1 Experimental results of the power system

油门/%	推力负载/g	电压/V	电流/A	功率/W	功耗推力比/（g/W）	温度/℃
50	1 986	22.2	13.4	297.48	6.68	38
75	2 542	22.2	20.1	446.22	5.70	55
100	3 015	22.2	26.4	586.08	5.14	78

As shown in Table 1, the maximum thrust load for a single motor is approximately 3 kg, while the total thrust load is 12 kg, which meets the requirement for deploying 3 kg of material. When carrying 3 kg of material, the drone flies stably; the thrust-to-power consumption ratio reaches its maximum at 50% throttle. Therefore, when optimizing flight endurance, prolonged full-throttle operation should be avoided. Temperature rise is well controlled, and there is no risk of overheating during extended flight.

4.2 Material Deployment Testing and Results

1) Test Objective

This experiment aims to evaluate the precision and stability of deploying rescue supplies via an unmanned aerial vehicle equipped with an intelligent gripper, ensuring that the supplies reach their target locations accurately and thereby enhancing the reliability of rescue operations.

2) Test Equipment and Environment

UAV platform: Pixhawk 2.4.8 flight controller and QGroundControl ground station. Power system: 400 kV brushless motor, 18-inch carbon-fiber propeller, and 60 A electronic speed controller. Navigation and positioning: GPS module, PX4Flow optical flow sensor, barometer, and gyroscope. Intelligent gripper system: high-precision intelligent gripper with servo-controlled deployment. Data logging equipment: high-frame-rate camera, rangefinder, and anemometer. Test environment: indoor static testing in a windless environment simulating laboratory conditions to evaluate basic deployment accuracy; outdoor dynamic testing in a windy environment simulating rescue scenarios, with tests conducted at varying wind speeds, flight speeds, and deployment altitudes to evaluate actual mission performance. Deployment target zones: the low-altitude deployment test zone is 1.5–3 m, simulating precise deployment over a small area; the medium-to-high-altitude deployment test zone is 5–10 m, simulating the deployment requirements of actual missions.

3) Test method

① Static precision delivery test objective: Verify the delivery precision of the UAV while it is in a stable hover state. Method: Have the UAV hover at fixed altitudes of 1.5 m, 3 m, and 5 m above the ground. Set target delivery points on the ground and record the delivery locations. After releasing the supplies, measure the error between the actual landing point and the target point. Repeat the test 10 times for each altitude and calculate the average error.

② Outdoor dynamic delivery test objective: Verify the delivery precision of the UAV under different flight speeds and different wind-speed conditions. Method: Fly the UAV at speeds of 3 m/s, 5 m/s, and 8 m/s, and record its trajectory via GPS. Set target delivery areas as 1 m × 1 m grids on the ground and record the

coordinates of the delivery points. After releasing the supplies, measure the horizontal error between the actual landing point and the target point. Repeat the test 10 times and calculate the average error. Compile the statistical data and analyze the impact of different speeds and wind speeds on delivery precision.

4) Analysis of Experimental Results

The results of the material deployment experiment are presented in Table 2.

Table 2: Results of the material deployment experiment

测试项目	条　件	平均误差/m
静态投放 1.5 m	室内无风	0.18
静态投放 3 m	室内无风	0.25
静态投放 8 m	室内无风	0.45
动态投放 3 m/s	室外微风	0.65
动态投放 5 m/s	室外微风	0.95
动态投放 8 m/s	室外微风	1.35

As shown in Table 2, static deployment offers relatively high accuracy, with an error of <0.5 m, making it suitable for precision deployment tasks; low-speed flight deployment (speed ≤3 m/s) allows the error to be controlled, making it suitable for slow approach to the target point; high-speed flight deployment (speed ≥5 m/s) results in a larger error, necessitating optimization of the advance-deployment strategy to improve accuracy. In the future, the algorithm will be further optimized in real-world operational scenarios to enhance deployment accuracy and ensure that drones can precisely deploy emergency supplies in complex environments, such as forest fire rescue operations.

V. Peroration

Based on the Pixhawk 2.4.8 flight control system, this study developed a UAV system capable of autonomous route planning, precise hovering, and remote material delivery; experimental validation demonstrated the system's feasibility and stability in emergency rescue missions. The results indicate that, during low-speed flight and hovering, the delivery accuracy is high, meeting the requirements for precise dispensing. The development and application of this system have significant practical implications for social life, enabling the tracking of medication use among family members affected by natural disasters such as forest fires, earthquakes, and floods. In terms of technical implementation, the mobile app establishes a connection with the main control module of the medication box via Bluetooth.

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