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Design of a Quadcopter Drone for Firefighting Support

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Abstract
Fires in densely populated areas are often difficult to handle due to limited access for firefighting vehicles, especially in narrow alleys. This research designs and tests a quadcopter drone as a solution to help the firefighting process in hard-to-reach areas. The drone was designed using a polyamide fiberglass F450 frame, Sunnysky 1250kv brushless motor, 10-inch propeller, 2200 mAh LiPo battery, and Pixhawk control system. The research method involves 3D design, component assembly, and testing the drone's performance against power consumption with and without load. The test results showed that the drone was able to fly stably with a lift of up to 5.3 kg and a flight duration of 45 minutes and was able to carry a sprayer with a hose length of 7 meters. Average battery consumption was in the range of 47–57% per 5 minutes, depending on the load. The drone proved effective in assisting firefighting in areas with limited access.

Keywords: Quadcopter, Firefighting, Pixhawk, Battery Consumption, Drone

Introduction
Fire in densely populated residential areas, especially in areas with narrow alleys, is one of the most serious problems in big cities (Narendran et al., 2023). This condition is exacerbated by the use of flammable building materials and limited access for firefighting vehicles, making the response process slow and difficult (Kabul, 2021). Human negligence increases the potential for fires to occur in this region, calling for innovative solutions to improve the effectiveness of emergency response (Tampubolon, 2020).

Studies in Pontianak show that building density and limited road access are major factors in the high risk of fire in the area (Affrilyno et al., 2024). Analysis of the road network in dense areas shows that narrow alleys that cannot be traversed by fire vehicles are a major obstacle to emergency response (P.A. Chen et al., 2019). In addition, the lack of accurate and consistent data on fire incidents and their contributing factors hinders effective fire risk mitigation efforts. (Rush et al., 2020). The development of UAVs specifically designed for forest fire detection has shown promise in enhancing early warning systems and mitigating wildfire risks (Kadioğlu et al., 2023).

One technology that is developing as an alternative solution is the use of drones. Quadcopter drones have the advantage of reaching narrow areas that are difficult to access by conventional vehicles (Ahnaf, 2022; Manimaraboopathy et al., 2017). Some types of drones are even equipped with water spraying systems or fire extinguishers, so they are able to contribute directly to the extinguishing process without endangering officers (Hidayatullah et al., 2018; Sujiwa & Widodo, 2023).

The use of drones in fire suppression has demonstrated its effectiveness in various studies. For example, drones can be used to establish fire separation lines by precision dropping extinguishing balls, which has proven effective in containing the spread of fire in hard-to-reach areas (Jin et al., 2024). In addition, a drone swarm system has been developed to provide a continuous flow of extinguishing fluid, simulating the effect of rain, which can improve the efficiency of firefighting (Ausonio et al., 2021).

Seeing this potential, this research is focused on designing a quadcopter-type extinguisher drone that can help the extinguishing process in hard-to-reach locations (Mugnai et al., 2024; Perez-Saura et al., 2023). Considering that battery life is a crucial factor in firefighting drone operations, the study shows that power consumption increases significantly with load, which impacts flight duration and effectiveness in the field (Jahan et al., 2024).

The purpose of this research is to produce an optimal fire drone design and determine the effect of loading on battery consumption. Hopefully, the results of this research can be a reference in the development of more effective and efficient firefighting drone technology, as well as provide benefits for related agencies in fire disaster mitigation efforts in densely populated areas.

Materials and Methods
This research uses an experimental method with stages that include design, assembly, system installation, and drone performance testing. The 3D design was carried out using 3D CAD software to ensure the efficiency of weight distribution and stability during maneuvers (Danesh & Prach, 2023). The main components used include the polyamide fiberglass F450 frame, which is known for being lightweight yet strong and resistant to high temperatures (Vimalkumar. R, 2020). A 1250 kv Sunnysky brushless motor and a 10-inch propeller are used to generate optimal lift according to the

operational load. The control system uses a Pixhawk PX4 2.4.8 flight controller, equipped with electronic speed controller (ESC), GPS, and telemetry to support stability and automatic navigation. A sprayer system is installed as a key feature to support the outage function, adapting the design approach of agricultural drones and liquid spraying (Aguilar et al., 2023; Ausonio et al., 2021). A 2200 mAh 14.8 V LiPo battery was selected to support power requirements during operations, considering the efficiency of energy consumption during outage missions (Jahan et al., 2024).

Table 1. Specification of Drone

No	Specifications	Size
1	Drone Weight	1kg
2	Weight Load	1kg
3	Flight Duration	45 minutes
4	Hose Length	7 meters
5	Nozzle	15 cm
6	Drone Thrust	5.3 Kg
7	Drone Size	30 cm height, 58 cm width
8	Voltage operational	14.8v
9	Propeller Size	10 inch
10	Batteries	2200 mAh
11	Weight Total	2.2 kg

Figure 1. QuadCopter Drone Design

Next, the Pixhawk flight controller was calibrated using Mission Planner software. The operation of UAV swarms demands a reliable software framework that supports autonomous route planning and enables synchronized collaboration among units in dynamic environments (Madridano et al., 2021). This calibration process includes setting the accelerometer, compass, and flight mode configurations to ensure the stability and responsiveness of the drone during operation. Flight modes such as Stabilize allow manual control with self-leveling features. The integration of edge computing and lightweight deep learning models in drones significantly enhances real-time fire detection capabilities, improving response time and situational awareness (Titu et al., 2024). on the roll and pitch axes, which is important for maintaining the drone's stability when operating in complex environments.

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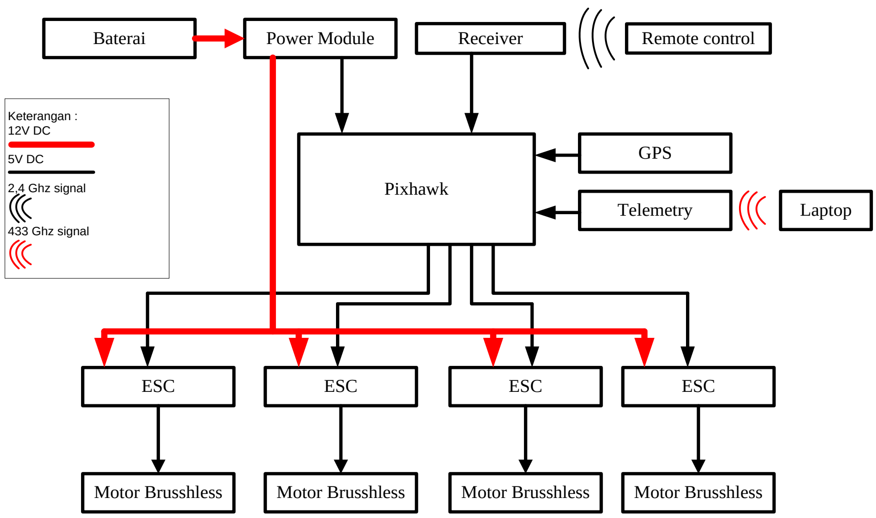


Figure 2. Drone System Wiring

The wiring diagram of the firefighting quadcopter drone illustrates the connection between major components such as brushless motors, Electronic Speed Controller (ESC), Power Distribution Board (PDB), flight controller (Pixhawk), LiPo battery, and telemetry system. Each component is connected via a cable line designed to deliver power and transmit control signals from the flight controller to the motor accurately and in real-time. Wiring must be done with great care, especially on the main power line connecting the battery to the ESC, as high currents risk short circuits, overheating, or even fire if not properly protected (Karthikeyan et al., 2025). In addition, a neat and isolated wiring arrangement also helps reduce electromagnetic interference that can interfere with navigation or communication systems (Kim et al., 2021).

This research was conducted at Sekolah Tinggi Teknologi Kedirgantaraan (STTKD) Yogyakarta by analyzing the results of the quadcopter extinguisher drone trial. The analysis focused on flight stability, spraying system effectiveness, and battery power consumption when the drone was carrying a load. Observed changes include the suitability of drone components to the transport power requirements and the integration of the sprayer mechanism. Data was obtained through literature study and direct observation during the stability testing process and water spraying while the drone was operating.

Results and Discussion

Design and Assembly

The drone was successfully assembled in accordance with the design specifications and has undergone a series of tests to ensure its physical stability, both under static and dynamic conditions. The selection of the F450 frame proved to provide good mechanical stability due to its lightweight yet sturdy polyamide fiberglass material, which was able to optimally support the weight of the components without causing structural deformation during the flight test. The use of a 10-inch propeller also contributes to generating adequate lift, allowing the drone to fly stably both in unloaded conditions and when carrying sprayers and hoses as part of the extinguishing system. The balance of thrust and weight distribution is precisely calculated to maintain power efficiency during maneuvering. In addition, the integration of all major components such as the Sunnysky 1250 kv brushless motor, ESC, Pixhawk flight controller, GPS, and telemetry system is seamless, ensuring precise control response and minimal delay, which is critical for firefighting missions in tight areas prone to environmental disturbances such as wind or smoke.

Figure 3. Assembled Drones

Battery Consumption Testing

Battery consumption testing was conducted under three different scenarios to obtain comprehensive data on power efficiency during drone operations, namely no load, with passive load (sprayer installed but inactive), and with active load (sprayer activated during flight). Each scenario was designed to simulate real field conditions so that the test results can accurately reflect the drone's performance under various workload levels.

1. **No Load**

Table 2. No-Load Battery Consumption

Test No.	Flight Time (minutes)	Initial Battery (%)	Battery consumption (%)	Battery remaining (%)
1	5	100	15	85
2	5	100	17	83
3	5	100	19	81
4	5	100	21	79
5	5	100	15	85

In the first scenario, without additional load, the drone was able to fly stably with an average battery consumption of 17.4% per 5 minutes. This condition shows that the main components of the drone, such as the F450 frame, Sunnysky 1250 kv brushless motor, and 10-inch propeller, work efficiently without overloading the battery power. Flight stability was also well maintained, indicating that the propulsion and power distribution systems were optimally integrated to support the drone's basic performance in light conditions.

2. With Sprayer and Hose Load

Table 3. Battery Consumption with Sprayer and Hose Load

Test No.	Flight Time (minutes)	Initial Battery (%)	Battery consumption (%)	Battery remaining (%)
1	5	100	43	47
2	5	100	55	55
3	5	100	52	38
4	5	100	43	47
5	5	100	47	43

In the second scenario, with the addition of a sprayer load and a 7-meter hose, there was a significant increase in average battery consumption, reaching 48% per 5 minutes. This substantial rise in energy usage indicates that the propulsion system had to work harder to compensate for the added weight and potential aerodynamic drag caused by the hose. Despite the increased power demand, the drone successfully maintained stable flight throughout the test, demonstrating that the overall design — including motor selection, frame durability, and power distribution — was robust enough to accommodate operational stress under heavier payload conditions. This result highlights the effectiveness of the system integration in adapting to more demanding missions, ensuring the drone remains functional and controllable even when subjected to non-standard loading scenarios.

3. With Sprayer and Foam Load

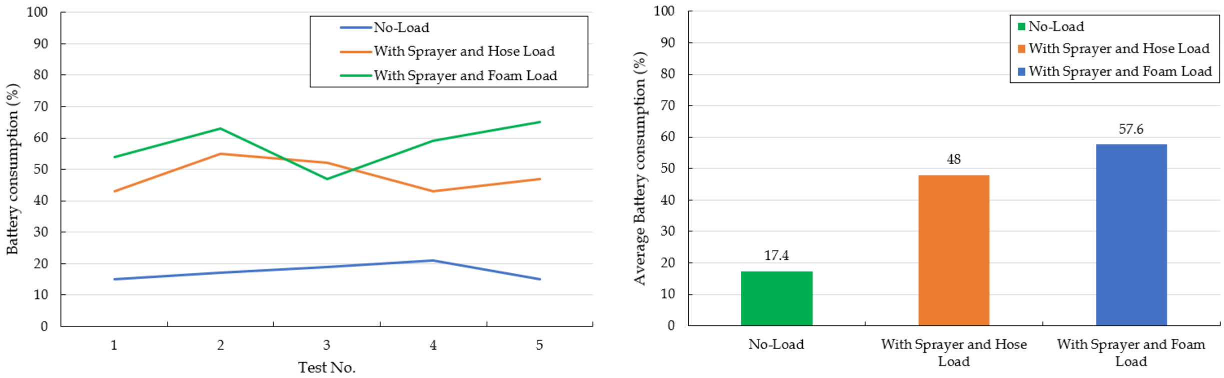
Table 4. Battery Consumption With Sprayer And Foam Load

Test No.	Flight Time (minutes)	Initial Battery (%)	Battery consumption (%)	Battery remaining (%)
1	5	100	54	46
2	5	100	63	37
3	5	100	47	53
4	5	100	59	41
5	5	100	65	35

In the third scenario, which involved the use of both a sprayer system and an extinguishing foam load, the drone exhibited the highest average battery consumption UAV systems for firefighting missions have also been developed to operate autonomously inside buildings with minimal human intervention, enhancing safety in confined fire zones. Effective deployment of multiple UAVs in firefighting operations requires comprehensive planning to manage various objectives and ensure optimal task distribution among the drones, especially in dynamically changing environments like forest or dense urban fires, recorded at 57.6% per 5 minutes. The inclusion of the foam, which added not only mass but also potential shifts in weight distribution due to fluid dynamics during flight, significantly increased the power demand on the propulsion system. This scenario posed the greatest challenge to the drone's performance, pushing the limits of its endurance and structural capability. Nonetheless, the drone was still able to operate reliably without any noticeable loss of flight stability or control responsiveness. This outcome indicates that the system architecture — particularly the thrust-to-weight ratio, electronic speed controller (ESC) calibration, and center-of-gravity management — was sufficiently resilient to handle high-stress conditions. It also reflects that the drone's design maintains a safety margin that ensures operational continuity even under maximum payload scenarios. An autonomous UAV equipped with image processing capabilities demonstrated a 90% success rate in accurately discharging water onto targeted areas, highlighting the potential for efficient fire suppression.

4. Comparison of Battery Consumption

Figure 5 illustrates a comparative analysis of battery consumption under three operational conditions: no-load, sprayer with hose load, and sprayer with foam load. Subfigure (a) shows the battery usage trend across five test iterations, where the no-load condition consistently consumed the least energy, while the foam load exhibited the highest consumption. Subfigure (b) summarizes the average battery usage per condition, revealing a significant increase from 17.4% in no-load to 48% with hose load and 57.6% with foam load. These results indicate that the type of load substantially affects energy efficiency, with foam-based operations demanding the most power.



(a) (b)

Figure 4. Baterry Consumption, (a) based on number of test, (b) average each test

Evaluation of Stability and Flyability

Field test results showed that the drone was able to perform various basic maneuvers well, including hovering, navigating forward and backward, and rotational maneuvers (yaw) with precision. Flight performance remained stable despite load variations. UAV-based flying robots have been proposed specifically for urban emergency firefighting, where speed and access are crucial, both in the unloaded condition and when carrying the sprayer system. This indicates that the drone's control and power distribution systems have functioned optimally to maintain flight stability.

In addition, flight mode setting features such as Stabilize and Altitude Hold proved to be very helpful in facilitating the control process, especially when the drone is carrying a spraying load. Stabilize mode provides immediate response to pilot inputs while maintaining basic stability, while Altitude Hold allows the drone to automatically maintain altitude, allowing the operator to focus more on navigating and controlling the sprayer. The combination of these two modes increases the operational reliability of the drone in fire suppression scenarios in areas that demand high precision and responsive control.

(a) (b) (c)

Figure 6. Drone Flight Testing, (a) without load, (b) with sprayer and hose. (c) with sprayer and foam

Conclusions

This research successfully designed, built, and tested a quadcopter drone prototype specifically designed to support firefighting efforts in hard-to-reach or limited-access areas, such as densely populated areas or narrow alleys. The drone is equipped with a sprayer system connected via a 7-meter hose, allowing flexible distribution of water or extinguishing fluid from separate sources. With the ability to generate 5.3 kg of thrust, the drone showed stable and responsive performance in various test scenarios, both under unloaded conditions and when carrying additional equipment. Power consumption testing showed good energy efficiency, with battery utilization levels in the optimal range, averaging between 40% and 57.6% for every five minutes of operation. This indicates that the drone has sufficient endurance to perform critical maneuvers during outage missions. The design and implementation of autonomous UAVs tailored for firefighting have proven to be effective in experimental missions of a certain duration. Overall, the implementation of this quadcopter drone system provides a practical and innovative solution in supporting the tasks of the firefighting team, especially in dense urban environments prone to limited access to conventional vehicles. This technology is expected to increase the effectiveness of fire management while minimizing risks to personnel in the field.

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