Review on Phoenix – An IoT Based Fire Extinguishing Drone

Krushna Rumale[1] Mayuresh Dinde[2] Nakshatra Kulkarni[3] Trusha Raut[4] Ms. Soniya Bhor[5]
[1,2,3,4]Student [5]Lecturer
[1,2,3,4,5]Department of Information Technology
[1,2,3,4,5]MVPS's Rajarshi Shahu Maharaj Polytechnic, Nashik, India

Abstract — Phoenix is a drone-based fire-fighting system designed to autonomously detect and extinguish fires using an onboard fire suppression system. The drone is equipped with a small fire extinguisher capable of spraying a suppressant agent when detecting a nearby fire. Powered by a Raspberry Pi 5 and utilizing Mavlink protocol for communication, the system operates on Linux with Python controlling the drone's automation and sensor input. This paper provides a detailed explanation of Phoenix's design, hardware, and software architecture, along with its implementation and performance evaluation in various fire scenarios. We also discuss the potential improvements to increase fire-fighting capacity and robustness in real-world conditions.

Keywords: Autonomous Fire Detection, Fire Suppression Drone, Raspberry Pi 5 Linux Operating System, Linux Operating System

I. INTRODUCTION

Fire-fighting drones provide a versatile solution for hazardous environments where human intervention can be dangerous or inefficient. Traditional methods often face delays due to obstacles and limited access, especially in high-rise buildings, forests, and industrial areas. The Phoenix drone system addresses these challenges by autonomously navigating, detecting, and extinguishing fires before they escalate, particularly in confined spaces or high-risk areas like chemical plants and dense urban settings. With real-time fire detection through advanced thermal sensors, a lightweight fire-extinguishing unit for autonomous suppression, and a Raspberry Pi 5-based control system for real-time data processing and flight control, Phoenix significantly enhances fire-fighting capabilities and safety in critical situations.

II. SYSTEM DESIGN

A. Drone Architecture

The Phoenix drone utilizes a quadcopter design, featuring custom 3D-printed mounts for housing the fire suppression unit and thermal camera. Its key specifications include a lightweight frame made of carbon fiber and aluminum alloy, powered by four 2200 KV brushless DC motors controlled by 40A electronic speed controllers (ESCs). The drone is equipped with a 4S 5000 mAh Li-Po battery, providing an impressive flight time of 18-20 minutes under moderate payload conditions. For navigation and control, it employs a Pixhawk flight controller, which communicates with the Raspberry Pi 5 using the Mavlink protocol for efficient telemetry and operational management.

Fig. 1: Carbon Fibre Hexacopter Frame

B. Fire Suppression System

The fire suppression system consists of a custom 3D-printed mount housing a CO2 or foam-based fire extinguisher. The fire-extinguishing system operates using a solenoid valve controlled by the Raspberry Pi 5, which releases a pressurized fire suppressant through a small nozzle.

C. Sensors

- Thermal Camera: Detects heat signatures indicative of fires and provides input for the autonomous fire suppression system.
- Optical Camera: Offers visual feedback for manual control and provides real-time footage during flight operations.

III. SOFTWARE ARCHITECTURE

The Phoenix drone's software stack is built on the Raspberry Pi 5, running a Linux-based OS. MAVLink protocol facilitates communication between the flight controller and the Raspberry Pi, enabling the transmission of telemetry data and fire-related commands. Python is used for automation scripts and a fire detection algorithm that processes real-time thermal camera input, activating the fire suppression system instantly upon detecting a fire for a rapid emergency response.

A. Fire Detection Algorithm

The fire detection algorithm in the Phoenix drone leverages the thermal camera's feed to identify hotspots indicative of active fires. The process begins with image capture, where continuous infrared data is collected. The algorithm then performs temperature analysis by conducting pixel-wise evaluations to detect temperatures exceeding 200°C, which signals the presence of a fire. Upon detecting a hotspot, the system generates a bounding box around the area and calculates its distance from the drone. Once the drone approaches a safe distance—typically 2-3 meters from the fire—the algorithm triggers the suppression system by

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activating the solenoid valve to release the fire suppressant, ensuring effective and timely intervention.

B. *Control Algorithms*

The Phoenix drone utilizes MAVLink's waypoint system for autonomous navigation, enabling efficient flight path planning. The Raspberry Pi processes real-time sensor inputs for dynamic trajectory adjustments during fire detection. Upon confirming a fire, the drone stabilizes at an optimal distance and activates its fire suppression system to spray the suppressant effectively. This integrated approach ensures a responsive and precise response to firefighting operations.

Fig. 2: Python

IV. HARDWARE COMPONENTS

Hardware Components in Fire Extinguishing Drone is as follows:

- Raspberry Pi 5: The central processing unit, managing sensor inputs, Mavlink communication, and control algorithms. Fig 3. Raspberry Pi 5
- Thermal Camera: Provides real-time heat mapping and fire detection.
- Flight Controller (Pixhawk): Interfaces with the Raspberry Pi to stabilize and control flight dynamics.
- Electronic Speed Controllers (ESCs): Regulate power to the brushless motors.
- Battery: A high-capacity Li-Po battery supports the payload and flight time.
- 3D-Printed Fire Suppression System: A custom-built CO_2 or foam extinguisher with a nozzle system.

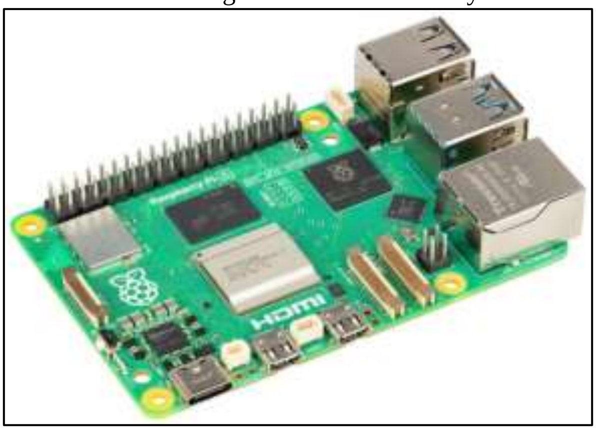

Fig. 3: Raspberry Pi 5

V. PERFORMANCE EVALUATION

Phoenix was tested in controlled environments, simulating small fires in both indoor and outdoor settings. Key performance metrics include:

Phoenix demonstrated impressive performance metrics in several key areas. The drone was able to detect and classify fire outbreaks within 5 seconds of entering a fire zone, showcasing its rapid response capabilities. In controlled tests with simulated wood and chemical fires, Phoenix successfully extinguished flames within 20 to 30 seconds of spraying, effectively suppressing fires in a $1m^2$ area using CO_2. The drone's endurance was approximately 18 to 20 minutes, taking into account the added weight and power requirements of its payload, which included a thermal camera and fire extinguisher system; this setup reduced overall flight time by 2 to 3 minutes compared to standard drones without such equipment. Additionally, during testing, Phoenix maintained stable flight while deploying its fire suppression system, ensuring that the suppressant accurately reached its target without the need for manual intervention. This combination of speed, efficiency, and stability underscores the effectiveness of Phoenix as a fire detection and suppression platform.

VI. LIMITATIONS

Despite its promising performance, Phoenix has notable limitations. Its small fire extinguisher is only effective for small-scale fires, requiring additional payload capacity or multiple drones for larger operations. Additionally, the battery life is limited, especially with the added weight, highlighting the need for more efficient power management solutions in future designs.

VII. FUTURE WORK

Phoenix's capabilities could be expanded by addressing its payload limitations, enhancing sensor accuracy, and integrating AI for more complex fire detection scenarios. Proposed future enhancements include:

- Larger Payloads: Develop larger fire-suppression systems or multiple drone formations (swarm drones) to tackle larger fires.
- Advanced Fire Detection Algorithms: Integrating machine learning models for more accurate fire classification and prediction.
- Extended Flight Time: Exploring more energy-dense battery solutions to increase operational endurance.

VIII. CONCLUSION

Phoenix offers a versatile and efficient solution to small-scale fire hazards. With its ability to autonomously detect and suppress fires in hazardous environments, the Phoenix system demonstrates the potential of drone-based firefighting technologies. Future work will focus on scaling the system for larger operations and improving detection accuracy under real-world conditions.

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