

Fire Bridge Life Saver Drone: An Integrated Drone-Assisted Extendable Bridge System for High-Rise Fire Emergency Evacuation

Sakshi Bhaulal Bodke¹, Sakshi Dinkar Kothule², Vaishnavi D. Sangale³

^{1,2,3}Department of Electronics and Telecommunication Engineering
Matoshri College of Engineering and Research Centre, Eklahare, Nashik
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Guide: Dr. Jayant J. Chopade

Abstract — Fire accidents in high-rise buildings present critical challenges for emergency evacuation, as conventional methods such as ladders and stairwells are frequently inaccessible or overwhelmed. This paper presents the design and prototype implementation of the Fire Bridge Life Saver Drone — an integrated system combining autonomous UAV mobility with a motor-driven extendable telescopic bridge to enable rapid, safe evacuation of trapped occupants. The drone platform, built around an APM 2.8 flight controller with GPS navigation and ESP32-based wireless telemetry, delivers the bridge mechanism to the target floor under autonomous control. A Raspberry Pi 4B with dual normal and thermal camera modules provides real-time aerial surveillance and heat-source detection through smoke and darkness. The extendable bridge is actuated by a DC gear motor interfaced with an L298N motor driver, controlled from a ground operator panel with an emergency override facility. Prototype testing confirmed stable motorised extension and retraction, scaled load-bearing capability, live thermal imaging, and autonomous Return-to-Home functionality. The system significantly reduces response time, eliminates the need for rescue personnel to enter fire zones, and provides a clear evacuation pathway for high-rise emergencies.

Keywords: Fire Rescue Drone, Extendable Bridge, High-Rise Evacuation, APM 2.8, Thermal Camera, ESP32, DC Gear Motor, Autonomous UAV, Emergency Response.

I. INTRODUCTION

Fire accidents in high-rise buildings present some of the most complex and time-critical challenges in urban emergency management. As modern cities grow vertically, incidents on floors beyond the reach of conventional fire ladders — typically above the 10th floor — become increasingly difficult to address through traditional means. Manual evacuation via staircases is often hampered by smoke, heat, structural damage, and crowd panic, while external ladder platforms are limited in height and deployment speed.

The Fire Bridge Life Saver Drone addresses these limitations by combining two technologies: a GPS-guided autonomous quadcopter UAV capable of rapid deployment to any floor of a high-rise structure, and a motor-driven telescopic bridge that extends from the drone to create a stable, load-bearing escape pathway for trapped occupants. The drone further provides real-time normal and thermal video surveillance, enabling ground control personnel to assess the situation — even through dense smoke — before and during the rescue operation.

This paper presents the full system architecture, component selection rationale, operational workflow, and prototype testing results, demonstrating the feasibility and life-saving potential of the proposed rescue platform.

II. LITERATURE REVIEW

Table I summarises prior works that inform the design of the Fire Bridge Life Saver Drone system. The review spans drone surveillance, IoT-based UAV telemetry, sensor-based navigation, and mechanical rescue platform designs.

TABLE I. LITERATURE SURVEY

Sr.	Paper Title	Author(s)	Year	Technique Used
1	Real-Time Drone Surveillance Using Raspberry Pi Camera	<i>J. Lee, M. Chen</i>	2020	Video Streaming & Remote Monitoring
2	UAV Delivery System Using IoT Monitoring	<i>K. Sharma, N. Joshi</i>	2021	IoT-Based Wireless Telemetry Control
3	Real-Time Drone Surveillance Using Raspberry Pi Camera	<i>J. Lee, M. Chen</i>	2022	Video Streaming & Remote Monitoring
4	Smart Drone Navigation Using Sensor-Based Stability Control	<i>Rahman A.</i>	2023	Gyroscope + Obstacle Detection Sensors
5	Smart Fire Evacuation Bridge for High-Rise Buildings	<i>M. Singh, A. Verma</i>	2022	IoT, Sensors, Microcontroller, Motor Control
6	Hydraulic Assistive Rescue Platforms for Fire Emergencies	<i>H. Shah, K. Solanki</i>	2023	Hydraulic Actuators, Sensors, Control Valves

Lee and Chen [1, 3] established the viability of Raspberry Pi-based real-time video streaming for drone surveillance applications. Sharma and Joshi [2] demonstrated IoT-based wireless telemetry for UAV delivery systems, providing a communication framework directly applicable to emergency drone control. Rahman [4] integrated gyroscope stabilisation with obstacle detection sensors, informing the flight stability subsystem of the present work. Singh and Verma [5] proposed a smart fire evacuation bridge for high-rise buildings using IoT and microcontroller-based automation — the closest prior work in concept, though it lacked aerial deployment capability. Shah and Solanki [6] introduced hydraulic rescue platforms for fire emergencies, highlighting the structural and safety requirements for load-bearing rescue mechanisms. The proposed system advances beyond each of these works by unifying aerial UAV deployment with a motorised telescopic bridge and dual-mode camera surveillance in a single integrated prototype.

III. PROBLEM STATEMENT

Traditional fire rescue operations in high-rise buildings suffer from the following critical limitations: (i) fire ladders have a physical height limitation and cannot reach upper floors of tall structures; (ii) stairwell evacuation becomes dangerous or impossible when fire and smoke block access routes; (iii) rescue personnel entering fire zones face extreme personal risk; (iv) delayed rescue response leads to casualties from smoke inhalation and panic; and (v) current UAV-based systems provide only surveillance capability without physical rescue means. There is a compelling need for a system that combines aerial mobility with a deployable physical rescue structure, operable remotely by a ground operator without requiring personnel to enter the hazard zone.

IV. OBJECTIVES

The primary objectives of this project are to:

- Design and develop a drone-assisted rescue system combining autonomous UAV flight with a motor-driven extendable bridge for high-rise fire evacuation.
- Enable fast, safe, and contactless evacuation of trapped building occupants without risking rescue personnel.
- Provide real-time dual-mode visual monitoring (normal + thermal camera) for situational awareness through smoke and darkness.
- Integrate wireless telemetry via ESP32 for real-time flight data, altitude, battery status, and command feedback.
- Implement GPS-based autonomous navigation with ground-station monitoring via Mission Planner.
- Achieve stable motorised bridge extension and retraction with emergency override capability.
- Reduce dependency on manual rescue operations and improve response time significantly.

V. SYSTEM ARCHITECTURE

A. Overview

The Fire Bridge Life Saver Drone is structured around five integrated subsystems: (1) the autonomous drone flight platform, (2) the surveillance and vision subsystem, (3) the wireless communication and telemetry subsystem, (4) the extendable bridge mechanism with motor actuation, and (5) the ground control and monitoring station. These subsystems interact through UART serial, I2C, and PWM buses, coordinated by the APM 2.8 flight controller for aerial functions and the ESP32 microcontroller for bridge actuation and telemetry relay.

B. Drone Flight Platform

The aerial platform is a quadcopter frame equipped with an APM 2.8 flight controller running ArduCopter firmware. Four 1000KV brushless DC motors paired with 30A ESCs provide the necessary lift and thrust. A Ublox NEO-6M GPS module delivers real-time positioning at up to 5 Hz for waypoint-based autonomous navigation to the target floor. The MPU-6000 IMU onboard the APM 2.8 continuously fuses gyroscope and accelerometer data for PID-based stabilisation. An HC-SR04 ultrasonic sensor monitors altitude and detects structural obstacles. The flight mission — including floor-level GPS coordinates, hover altitude, and return path — is programmed via Mission Planner and uploaded prior to deployment.

C. Surveillance and Vision Subsystem

A Raspberry Pi 4B+ serves as the onboard vision computer. It is connected to both a standard Raspberry Pi Camera Module V2 (8 MP, 1080p@30 fps) for normal visible-light surveillance and an AMG8833 infrared thermal array sensor for heat-source detection. The thermal sensor detects temperature distributions across its 8×8 pixel array, enabling identification of fire zones, hot spots, and human body heat through smoke that would obscure the normal camera. Video streams are transmitted to the ground station over Wi-Fi using Python-based GStreamer/OpenCV scripts running on the Raspberry Pi OS.

D. Communication and Telemetry Subsystem

The ESP32 dual-core Wi-Fi/BT microcontroller serves as the drone-to-ground communication bridge. It receives flight telemetry from the APM 2.8 via UART (MAVLink protocol) and re-broadcasts GPS coordinates, altitude, battery voltage, and flight speed to the ground operator's dashboard. An XBee telemetry module supplements this for longer-range, low-latency command links. The ground station runs Mission Planner for flight data logging, command feedback,

and mission monitoring. An emergency override switch at the ground station allows the operator to immediately halt bridge extension, command RTH, or take manual control at any stage.

E. Extendable Bridge Mechanism

The extendable bridge consists of lightweight aluminium or steel telescopic sections mounted to the drone undercarriage. Extension and retraction are driven by a DC gear motor interfaced via an L298N motor driver module, which controls forward/reverse direction and speed. A safety stopper/locking mechanism prevents over-extension. The bridge is designed to span the gap between the drone (positioned adjacent to the building window or ledge) and the building, forming a stable walkway for one evacuee at a time in the prototype stage. The operator deploys the bridge by activating the motor through the ground control panel once the drone is in hover position at the target floor.

VI. HARDWARE & SOFTWARE REQUIREMENTS

Table II enumerates all hardware components with their quantities and primary functions.

TABLE II. BILL OF COMPONENTS

Sr.	Component	Qty	Function / Description
1	APM 2.8 Flight Controller	1	Autonomous flight control, stabilisation, GPS navigation
2	Raspberry Pi 4B+ with Thermal Camera	1	Live video/thermal imaging, image processing, ground data relay
3	ESP32 Wi-Fi Microcontroller	1	Wireless telemetry, sensor data, IoT communication
4	GPS Module (Ublox NEO-6M)	1	Real-time positioning and waypoint navigation
5	Brushless DC Motors + ESCs	4	Lift, thrust and flight manoeuvring
6	Ultrasonic Sensor (HC-SR04)	2	Height measurement and obstacle detection
7	Li-Po Battery 5000 mAh 4S 35C	1	Primary power supply for all electronics
8	DC Gear Motor	1	Drives extension/retraction of the bridge mechanism
9	Motor Driver / Relay Module (L298N)	1	Controls motor direction (forward/reverse) and speed
10	Telescopic Bridge Frame (Al/Steel)	1	Extendable structural passage for evacuee crossing
11	XBee Telemetry Module	1	Long-range wireless communication with ground station
12	Power Distribution Board (PDB)	1	Distributes battery power to motors and electronics

The software stack consists of: (i) Mission Planner — for APM 2.8 configuration, GPS waypoint definition, flight mode setup, and telemetry monitoring; (ii) Arduino IDE — for programming the ESP32 to handle ultrasonic sensor data, bridge motor commands, and wireless communication; (iii) Raspberry Pi OS with Python/OpenCV — for dual-camera

streaming, AMG8833 thermal data acquisition, and image logging; and (iv) Tera Term / QGroundControl (optional) — for debugging and telemetry visualisation during development.

VII. WORKING PRINCIPLE

The operational cycle of the Fire Bridge Life Saver Drone is divided into the following sequential stages:

Stage 1 — Initialisation and Pre-Flight Check

On powering the system, the APM 2.8 initialises sensor fusion and GPS calibration. The Raspberry Pi boots Raspberry Pi OS and activates both camera modules and the AMG8833 thermal sensor. The ESP32 establishes Wi-Fi connection with the ground station and begins broadcasting telemetry. The operator verifies GPS lock, battery level (minimum 14.8 V for a 4S pack), and motor calibration before arming.

Stage 2 — Autonomous Flight to Target Floor

On receiving the takeoff command via Mission Planner, the APM 2.8 stabilises the drone using IMU data and executes the pre-programmed flight path to the target building floor. During flight, the Raspberry Pi streams dual-mode live video to the ground station, allowing the operator to assess the rescue zone in real time. The ESP32 transmits telemetry data — location, altitude, battery status, and speed — every 200 ms.

Stage 3 — Bridge Deployment

On reaching the target floor hover position, the APM 2.8 enters LOITER mode for stable positioning. The ultrasonic sensor confirms safe proximity to the building structure. The operator commands bridge extension from the ground control panel; the ESP32 activates the L298N motor driver, which drives the DC gear motor to extend the telescopic bridge sections toward the building ledge. The safety stopper ensures the bridge does not over-extend. LED indicators and a buzzer signal successful bridge deployment to the trapped occupant.

Stage 4 — Evacuation

The trapped occupant crosses the bridge, which is designed to bear a single-person load in the current prototype. The Raspberry Pi normal camera monitors the crossing; the thermal camera confirms body heat presence for crossing verification. Once evacuation is complete, the operator triggers bridge retraction via the ground panel, and the DC gear motor retracts the telescopic sections.

Stage 5 — Return-to-Home

After bridge retraction is confirmed, the APM 2.8 transitions to Return-to-Home mode, navigating back to the launch point at cruise altitude. Automatic landing is executed with ultrasonic sensor assistance for final-metre precision. If battery voltage drops critically during any phase, the RTH failsafe triggers automatically to prevent loss of the drone.

VIII. RESULTS AND DISCUSSION

Prototype testing was conducted across multiple controlled indoor and outdoor trials. Table III compares key performance parameters against design targets.

TABLE III. PERFORMANCE RESULTS SUMMARY

Parameter	Expected	Achieved
Bridge Extension / Retraction	Smooth motorised operation	Achieved via DC gear motor + L298N driver
Structural Stability (Load Test)	Support weight of one person (scaled)	Prototype supports scaled single-person load
Drone Autonomous Flight	Stable GPS-based navigation	APM 2.8 + GPS lock confirmed
Thermal Imaging	Detect heat sources in smoke	AMG8833 thermal array + Raspberry Pi functional
Live Video Transmission	Real-time feed < 2 s latency	~1.5 s latency via Wi-Fi (Raspberry Pi)
Emergency Override	Manual override at any stage	Switch panel override responsive
Return-to-Home (RTH)	Auto-return on mission complete / battery low	Triggered successfully in simulation

The motorised bridge extension and retraction mechanism demonstrated smooth, jerk-free operation across all trials. The telescopic steel-aluminium frame showed stable alignment during deployment with no observable lateral deflection. Scaled load testing confirmed that the prototype bridge surface can support the equivalent weight of one person without structural failure. The motor driver and control panel responded accurately to forward/reverse commands with no overheating or stalling observed.

The Raspberry Pi live video feed operated at approximately 30 fps with a latency of ~1.5 seconds over the local Wi-Fi network, providing adequate real-time visibility. The AMG8833 thermal array successfully detected temperature gradients corresponding to heat sources in smoke-filled simulation environments, demonstrating its utility for locating trapped individuals. The APM 2.8 flight controller provided stable hover at the target altitude, and the GPS-based RTH feature triggered correctly in all simulated mission-complete and battery-low scenarios.

Current limitations include a flight endurance of approximately 10–12 minutes per charge when carrying the bridge payload, sensitivity to wind speeds above 5 m/s, and a maximum single-person load capacity in the current prototype frame. These findings align with prior academic rescue drone prototypes [5, 6] and define the primary development targets for Phase II.

IX. ADVANTAGES AND LIMITATIONS

A. Advantages

- **Fast and Safe Evacuation:** The extendable bridge provides a secure escape pathway within seconds of drone arrival, without requiring occupants to jump or wait for ground-based ladders.
- **Reduces Risk to Firefighters:** Rescue personnel remain at the ground station, entirely outside the fire zone, throughout the operation.
- **Dual-Mode Surveillance:** Normal and thermal cameras enable effective situational awareness in zero-visibility, smoke-filled environments.
- **Suitable for Any Floor:** Drone aerial mobility removes the height restriction imposed by conventional fire ladders.
- **Eco-Friendly and Contactless:** Battery-powered operation produces no emissions; the bridge provides a fully contactless evacuation pathway.

- **Rapid Deployment:** Motorised bridge extension and retraction can be completed within seconds under operator control.

B. Limitations

- **Limited Payload and Range:** Current prototype supports one person per crossing; flight endurance is ~10–12 minutes under full bridge payload.
- **Weather Dependency:** Strong winds, rain, or smoke pressure can affect stable drone hovering and bridge alignment.
- **Requires Stable Hover Platform:** Accurate and stable positioning adjacent to the building is essential for safe bridge extension.
- **Mechanical Maintenance:** Moving bridge components (rails, bearings, gear motor) require regular inspection and lubrication.
- **Regulatory Constraints:** UAV operations near buildings may be subject to aviation authority restrictions in urban airspace.

X. CONCLUSION

This paper has presented the design, implementation, and prototype validation of the Fire Bridge Life Saver Drone — an integrated autonomous UAV and extendable bridge system for high-rise fire emergency evacuation. By combining GPS-based autonomous flight, dual-mode (normal + thermal) camera surveillance, real-time IoT telemetry, and a motor-actuated telescopic rescue bridge into a single coordinated platform, the system addresses the core limitations of conventional fire rescue methods.

Prototype testing confirmed stable bridge extension and retraction, scaled single-person load bearing, functional thermal surveillance in simulated smoke conditions, and reliable autonomous Return-to-Home behaviour. The system eliminates the need for rescue personnel to enter fire zones, provides an aerial escape pathway unrestricted by building height, and significantly reduces evacuation response time.

Future development will focus on: (i) strengthening the bridge frame for multi-person load capacity; (ii) replacing manual switch control with fully autonomous microcontroller-based bridge deployment; (iii) integrating proximity sensors for automatic building alignment and safe bridge docking; (iv) implementing wireless remote operation for complete ground-station-only control; (v) developing a foldable compact design for transport in emergency vehicles; and (vi) incorporating heat-resistant and fireproof materials for operation in extreme-temperature proximity conditions.

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