AETHER UAV:
Advanced Electronic Tactical Hybrid Emergency Reconnaissance Unmanned Aerial Vehicle

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Introduction

In this modern time, reconnaissance and surveillance are a major requirement for civil and military defence. From monitoring disaster zones to assessing potential threats and conducting rescue missions, the need for agile, autonomous aerial systems has grown significantly. Drones, or unmanned aerial vehicles (UAVs), have emerged as vital tools capable of performing a wide range of operations that are too dangerous, time-consuming, or costly for direct human involvement. This project presents the design and development of a multi-role UAV platform capable of carrying reconnaissance, defense, and civil defense missions. The UAV is built using a powerful combination of high-efficiency brushless motors, a robust foldable frame, an advanced flight controller, and a 4 K-capable low-light camera system. Additionally, a GPS module and long-range radio system ensure precise navigation and control over extended distances. To enhance its firefighting and rescue capabilities, the drone is equipped with a thermal imaging module (MLX90640), allowing it to detect heat sources through smoke or darkness, which is ideal for locating fire hotspots or survivors. The system is designed with modularity and versatility in mind, enabling adaptation to a wide variety of mission profiles in both civilian and tactical environments. Through this project, we aim to demonstrate how a compact UAV can be transformed into a cost-effective, field-deployable tool for real-time monitoring, early threat detection, and emergency response, supporting both academic research and real-world applications.

Background

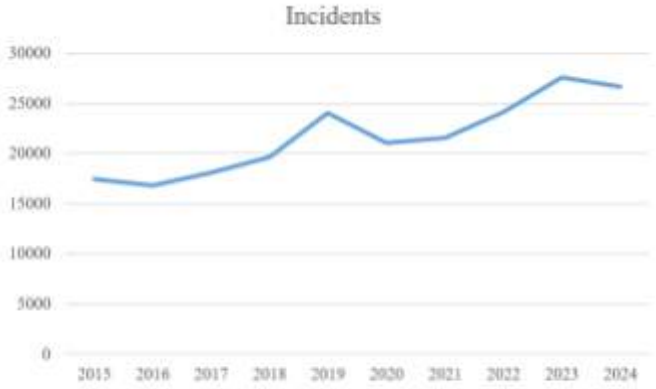


Figure 1 : Fire Incident trend from 2015 to 2024 in Bangladesh

In recent years, Bangladesh has witnessed a significant rise in major public fire incidents and natural disasters, particularly in densely populated urban areas, growing industrial zones, and river-surrounded regions. This surge is largely attributed to the rapid expansion of industries, residential structures, and public restaurant chains driven by increasing consumer demand and urbanization. According to official records, the year 2022 saw 24,102 reported fire incidents, resulting in 98 fatalities and 407 injuries. In 2023, the number of incidents rose to 27,634, with 102 deaths, 281 injuries, and an estimated financial loss of 792 crore BDT. Overall, fire-related incidents in the country have increased by approximately 50% from 2015 to 2024. Simultaneously, Bangladesh continues to face recurring floods that displace thousands annually, especially in low-lying and river-adjacent areas. In such conditions, accessibility becomes a critical issue, and rapid aerial surveillance and delivery systems can make a life-saving difference. These alarming challenges underscore the urgent need for intelligent, versatile aerial platforms capable of providing real-time reconnaissance, early fire detection, and assisting in rescue missions for flood-affected individuals. Developing a multi-role drone offers a cost-effective and practical solution where conventional response methods may be delayed or inaccessible.

Objectives

The primary objective of this project is to design and implement a versatile multi-role unmanned aerial system (UAS) that can effectively perform multiple operational tasks, including reconnaissance, defense support, and firefighting. Specific objectives include the development of a modular drone platform capable of adapting to diverse mission requirements through interchangeable payloads and flexible configurations. The aerial system will be equipped with a thermal imaging sensor (MLX90640) for real-time fire detection, enabling efficient deployment in search and rescue operations and urban firefighting scenarios. Additionally, the thermal imaging capability can be leveraged for border surveillance and patrolling, especially in low-visibility conditions or at night. High-performance components such as VELOX V2812 BLDC motors and the GEPRC F722 flight stack will ensure reliable flight dynamics, while the integration of a 4K camera system will support high-resolution visual reconnaissance. Overall, this project aims to

create a compact, intelligent, and adaptable aerial platform that demonstrates practical applications of embedded systems and mechatronics in addressing modern security, environmental, and emergency challenges.

Project Description

Overview

The main platform consists of a convertible multi-role quadcopter capable of delivering a payload of up to 1 kg. It is built on a modular carbon fiber frame that ensures structural strength while keeping the system lightweight. Its architecture is centered around the GEPRC F722 flight controller, which oversees the drone's flight stability, orientation, and localization. The drone is equipped with four brushless motors, providing the necessary thrust and agility for maneuvering in a complex environment. A high definition 4k camera enables real-time visual monitoring and reconnaissance, while a thermal imaging sensor detects heat sources and living objects, allowing the drone to assist in firefighting and search-and-rescue operations. Also, the drone is equipped with an mmWave radar, which allows it to detect humans even when the subjects are motionless or obscured by debris or smoke. The drone communicates with the ground control with a 5.8 GHz digital FPV system with an Express Long Range System (ELRS) radio-transmitter module for low-latency command and feedback using a 2.4 GHz communication link. The modular design allows for payload customization depending on the mission requirements, such as fire-fighting chemical dispensing modules, beacon droppers, or extra sensor systems. The Drone is powered by a high-capacity 4S lithium-ion battery, ensuring extended flight time and stable operation. GPS Navigation enables autonomous mission-oriented navigation and return to home features. The drone also features sensors to read environmental data to assess the air quality and detect toxic gases. The project not only highlights core concepts in electronics and control systems but also addresses real-world applications in civil safety, disaster response, and tactical operations.

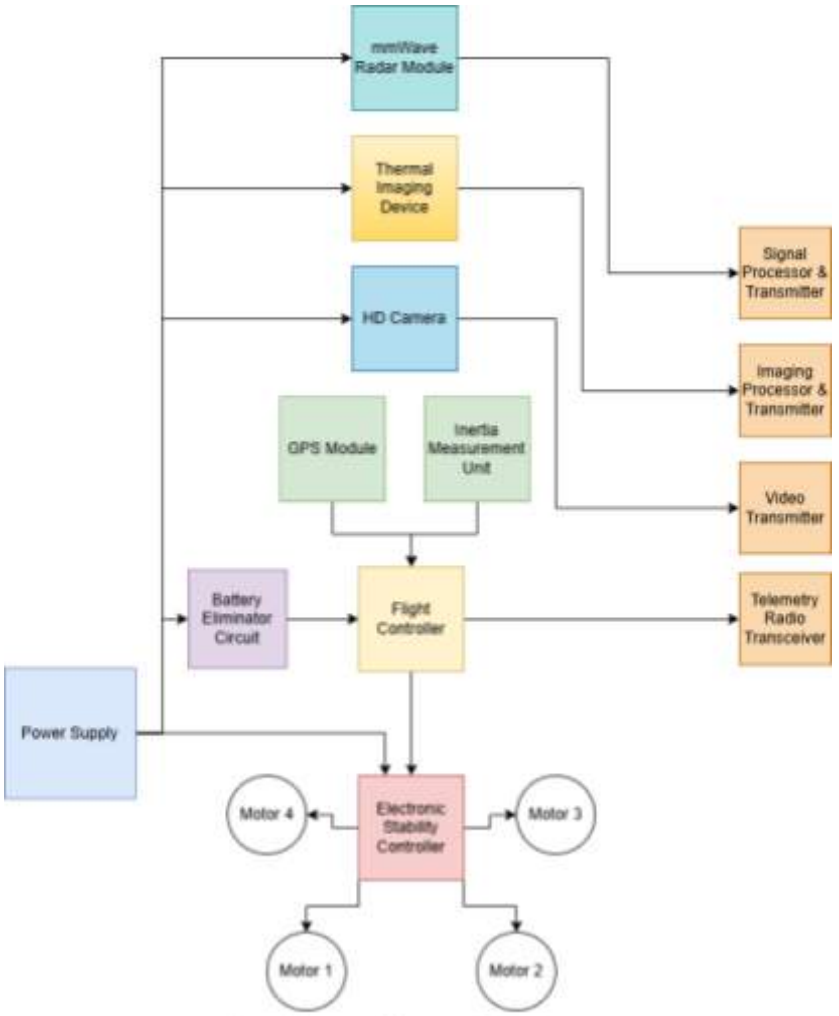


Figure 2: System Architecture of AETHER

When the UAV is in a search-and-rescue role, it can be equipped with a location beacon transmitter. The location beacon transmitter can be useful for locating survivors and marking their location. The beacon transmitter is equipped with a powerful long long-endurance power supply, a loud sound-generating device, high performance GPS device, a LoRa-based radio that is capable of running for a long time using very low power and transmitting location over a

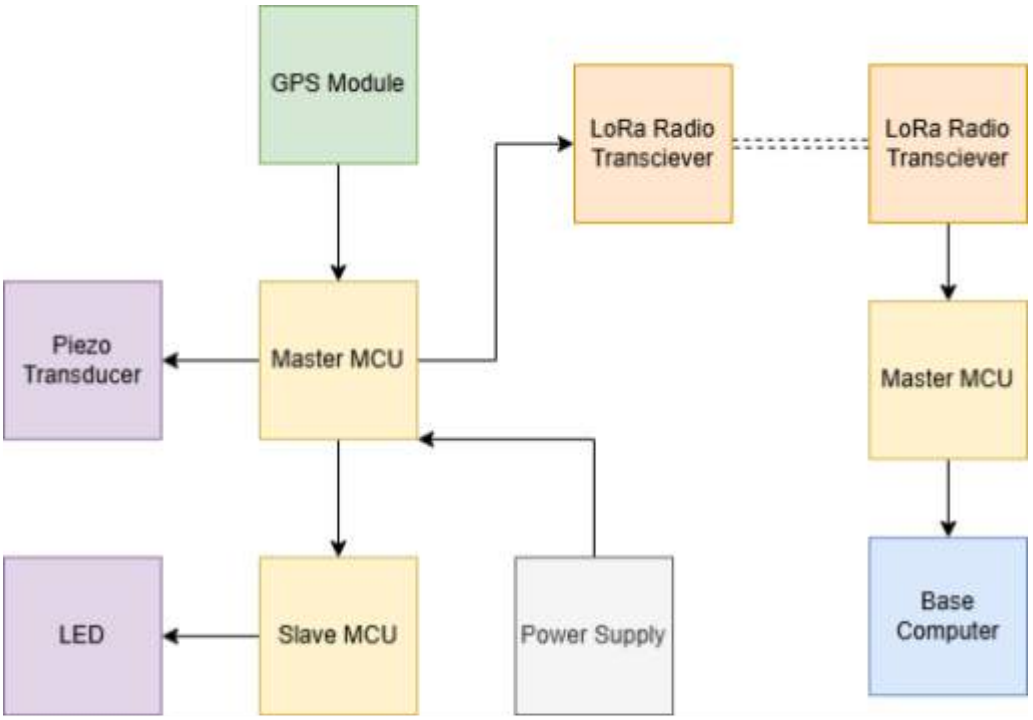


Figure 3: Location Beacon Device Architecture

long time over a long distance. The beacon also features a bright flashing light to spot the beacon in dark regions. The transmitted location data can be received at the drone base station.

Components & Modules

Image	Component	Specification	Purpose
	Flight Controller	GEPRC TAKER F722	Flight control and sensor data proces
	BLDC Motors	VELOX V2812 925KV B	Propulsion and maneuvering

	ESCs & Power Distributic	50A 4-in-1 ESC Stack	Power regulation and motor control
	Frame	Modular Carbon Fiber	Structural support and component m
	Battery	6S LiPo (2200–5000mAh	Power supply
	Thermal Imaging Sensor	MLX90640	Fire detection and heat mapping
	Visual Camera System	Walksnail Avatar 4K	FPV and reconnaissance video feed
	mmWave Radar Sensor	Seeed Studio XIAO 24GH Human Presence	Human detection, presence sensing i rescue
	GPS Module	Foxeer M10Q	Navigation and autonomous waypoi support
	5.8GHz Digital FPV + Ra Transciever	Radiomaster RP3 v2 ELR 2.4GHz	Remote control and data transmissio

	Ground Controller	Radiomaster Pocket Crusl	Remote Control
	Microcontroller	ESP32 Dev Kit	Sensor data processing
	Buzzer	5v Active Buzzer	Loud buzzer for rescue beacon
	LoRa Transceiver	LoRa SX1278	For transmitting the GPS location of beacon
	GPS Module for Beacon	Ublox neo6m	For the geolocation of the beacon
	Smoke Sensor	MQ02 Sensor	For the detection of smoke.
	Carbon Monoxide Sensor	MQ09 Sensor	For the detection of smoke and toxic
	Human Presence Sensor	Seeed Studio XIAO 24GHz mmWave Radar For Human Presence Sensing	For human presence sensing

Methodology

Hardware Design & Component Testing

The hardware phase began with selecting high-performance components suitable for a multi-role drone. The frame, motors, ESC stack, and power systems were assembled and tested for mechanical stability and balance. Individual components such as the GPS module, FPV camera, antenna, and thermal sensor (MLX90640) were tested independently to ensure functionality and compatibility with the microcontroller unit. Power distribution, vibration isolation, and weight optimization were considered during frame assembly. The Thermal Camera is powered with 3V from the voltage regulator of the ESP32, which is capable of stepping down 5V to 3V for the required logic level voltage of ESP32 and other attached components. The Camera uses the I2C protocol to transfer camera frames to the ESP32 by sending the frame bit data. As the Thermal Camera processing microcontroller is under heavy CPU load, a secondary MCU is introduced to operate the hook servo and the radar sensor that can pick up a human presence signal.

Software & Firmware Development

The flight controller was configured using Betaflight, allowing customization of PID settings, flight modes, and safety features like failsafe and GPS return-to-home. Custom firmware support was added for the thermal sensor using microcontroller-based platforms (ESP32 or similar) to read and transmit temperature data. Receiver binding, ELRS communication, and OSD configuration were completed to ensure stable telemetry and control. The thermal camera was tested to transmit data over the ESP32 WiFi protocol using Websocket TCP publishing. It was able to transfer data over the air. The Thermal Visualization is alongside the live camera feed on the dashboard. The dashboard is developed using JavaScript, and the firmware is developed using C++ and Python. The base station computer features a dashboard computer that is connected to the Beacon device using a LoRa radio transmitter. It also hosts a websocket server for publishing the Thermal Image Data to the Dashboard. The websocket server will be hosted on the base computer instead of the ESP32 microcontroller itself to reduce load on the air esp32 thermal module.

Integration & Debugging

All tested modules were integrated into the drone frame, ensuring proper wiring, signal routing, and communication between components. Calibration routines for the IMU, GPS, and compass were performed. Debugging focused on identifying electrical noise, firmware mismatches, and communication delays between modules. Thermal and visual feeds were synchronized and validated in test environments.

Tools & Technologies

Hardware

- VELOX V2812 925KV BLDC Motors – High-efficiency brushless motors for stable flight and payload capacity.
- GEPRC TAKER F722 BLS 50A Stack – Integrated flight controller and ESC stack for precise control and motor synchronization.
- SpeedyBee Mario 8 Fold Frame – Foldable drone frame for portability and modular expansion.
- Walksnail Moonlight 4K Camera – Ultra-clear FPV and recording for reconnaissance missions.
- MLX90640 Thermal Sensor – Used for detecting fire hotspots and locating flood-affected individuals.
- Foxeer GPS & Lollipop Antenna – GPS for navigation and antenna for robust 5.8 GHz FPV signal.
- Radiomaster RP3 v2 & Pocket TX – ELRS long-range receiver and transmitter for low-latency control.

Software

- Betaflight – Configuration and tuning of the flight controller and ESC settings.
- Arduino IDE / PlatformIO – For custom firmware development and MLX90640 integration.
- Python (for simulation/visualization) – Used for debugging and visualizing thermal data.
- ExpressLRS Configurator – For updating and binding the radio system.
- JavaScript - For Dashboard Development

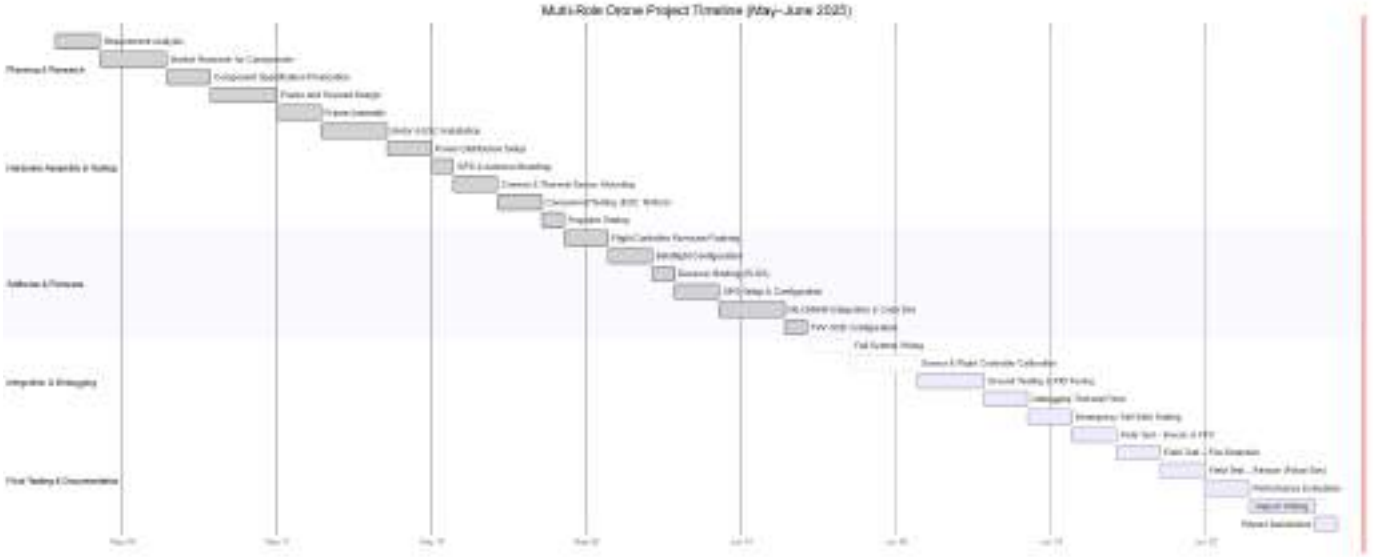
Networking Protocols

- ExpressLRS (2.4GHz) – Lightweight, low-latency radio communication protocol between the transmitter and receiver.
- FPV Video over 5.8 GHz Analog/Digital – Transmits real-time video feed from the onboard camera to the ground station or goggles.
- MAVLink (Optional for future expansion) – Can be used for telemetry and ground control communication with extended onboard systems.
- Websocket - For Thermal Image Data transmission.
- LoRa - Location beacon data transmission.

Communication Protocols

- I²C – Used to interface the MLX90640 thermal camera with a microcontroller.
- UART – For GPS communication with the flight controller.
- SBUS / CRSF – Used by the ELRS system for fast and reliable signal transmission between the receiver and FC.
- PWM – For motor control through ESCs.

Project Timeline



Budget Estimation