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A Multi-Disaster Response and Surveillance Drone System Using CNN-Based Real-Time Detection

Ms. Khadija Md. Umar Patwegar, Ms. Juveriya Anis Chabukswar, Mr. Yash Rajaram Patil, Mr. Juned Dastagir Shikalgar, Ms. R. K. Choudhari
Student of Third Year, Department of Electronics and Telecommunication Engineering
Lecturer, Department of Electronics and Telecommunication Engineering
Sanjay Ghodawat Institute, Atigre, Maharashtra, India

Abstract: *Natural disasters such as cyclones, earthquakes, floods, and wildfires pose significant threats to human life and infrastructure. Rapid detection and response are critical for minimizing damage and ensuring timely rescue operations. This paper presents MDRS (Multi-Disaster Response and Surveillance Drone System), a cost-effective and offline-capable disaster monitoring solution. The proposed system integrates a drone-mounted camera with a Convolutional Neural Network (CNN)-based disaster classification model to analyze real-time video feeds. The system classifies disaster events into five categories: cyclone, earthquake, flood, wildfire, and background.*

The architecture consists of three main components: a drone platform for aerial surveillance, a ground station for processing and monitoring, and an environmental sensor module for data acquisition. The video feed is transmitted via RTSP and processed using OpenCV and TensorFlow, enabling real-time inference without requiring GPU acceleration. The system achieves an overall classification accuracy of approximately 90% with an average inference time of around 80 ms per frame, making it suitable for real-time deployment on low-resource systems .

Additionally, the system features a web-based dashboard for live video streaming, alert generation, and event logging, operating entirely offline to ensure functionality in disaster-affected regions with limited connectivity. The modular design allows for future integration of GPS-based tracking and advanced environmental sensing. The proposed system enhances situational awareness and supports rescue teams in executing safer and more efficient disaster response operations.

Keywords: Disaster Detection, Drone Surveillance, Convolutional Neural Network (CNN), Real-Time Monitoring, IoT Sensors, Offline System, Computer Vision

I. INTRODUCTION

Natural disasters such as cyclones, earthquakes, floods, and wildfires continue to pose serious threats to human life, infrastructure, and the environment. Rapid detection and effective monitoring of such events are crucial for minimizing damage and ensuring timely rescue operations. With the advancement of technologies such as Unmanned Aerial Vehicles (UAVs) and Artificial Intelligence (AI), there is significant potential to improve disaster response systems by enabling real-time surveillance and automated analysis of disaster scenarios.

1.1 Background

Traditional disaster monitoring methods, including manual observation, satellite imaging, and ground-based inspection, often suffer from limitations such as delayed response, high operational costs, and restricted accessibility to hazardous or remote areas. In recent years, UAVs have emerged as an effective tool for aerial surveillance due to their ability to quickly access difficult terrains and provide live visual data.

Additionally, the integration of AI techniques, particularly Convolutional Neural Networks (CNNs), has enabled automated analysis of visual data for detecting and classifying disaster events. These advancements provide an opportunity to develop intelligent systems capable of assisting disaster management teams in real-time.

1.2 Problem Statement

Despite technological advancements, existing disaster monitoring systems face several challenges. Many systems rely heavily on internet connectivity, cloud-based processing, or high-end hardware, making them unsuitable for deployment in disaster-affected regions where communication infrastructure may be unavailable or damaged.

Furthermore, existing solutions are often expensive and lack integration of multiple functionalities such as real-time video analysis, environmental sensing, and centralized monitoring. This creates a need for a low-cost, efficient, and offline-capable system that can operate reliably in resource-constrained environments.

1.3 Objectives of the Project

The main objectives of the MDRS system are as follows:

- To develop a drone-based system for real-time disaster monitoring and surveillance.
- To implement a CNN-based model for automatic detection and classification of disaster events.
- To design an offline-capable system that functions without internet dependency.
- To integrate environmental sensors for monitoring parameters such as temperature and humidity.
- To develop a user-friendly dashboard for real-time visualization and alert generation.
- To enhance disaster response efficiency while reducing risks to human life.

1.4 Scope of the Project

The scope of this project includes the design and development of a prototype system capable of detecting selected disaster types such as cyclone, flood, wildfire, and earthquake using drone-captured video data. The system operates on a local network and performs real-time processing using CPU-based hardware.

The project also includes basic environmental sensing and a web-based dashboard for monitoring. However, certain features such as full-scale GPS tracking and advanced sensor integration are not fully implemented in the current version and are considered as part of future development.

1.5 Overview of the Proposed System

The MDRS system integrates drone-based video acquisition, AI-based disaster detection, and IoT-based environmental sensing into a unified platform. The drone captures live video, which is processed using a CNN model at the ground station. The results, along with sensor data, are displayed on a web-based dashboard that provides alerts and system status information.

The system is designed to be low-cost, portable, and capable of operating offline, making it suitable for deployment in disaster-prone and resource-limited environments.

II. LITERATURE REVIEW

Several research works have explored the use of drones, artificial intelligence, and sensor systems for disaster monitoring and response. The following studies are closely related to the proposed MDRS system and provide a strong foundation for its development.

In *"EmergencyNet: Efficient Aerial Image Classification for Drone-Based Emergency Monitoring Using Atrous Convolutional Feature Fusion" [1]* presents a lightweight CNN-based model for real-time aerial image classification. The study focuses on achieving high accuracy while maintaining computational efficiency, making it suitable for deployment on resource-constrained systems such as drones. This approach directly supports the MDRS system, where real-time disaster detection is performed using a CNN model on CPU-based hardware.

In *"AI-Driven Drone Mapping for Disaster Response and Urban Planning Using GIS" [2]*, the authors propose a system that integrates drone-based data acquisition with Geographic Information Systems (GIS) for improved disaster response. The study emphasizes real-time monitoring, spatial analysis, and visualization, which are essential for effective decision-making. This work influenced the dashboard and monitoring aspects of the MDRS system.

The paper titled *"Integrated Drone for Effective Disaster Management" [3]* presents a comprehensive system combining drone surveillance with IoT sensors and machine learning techniques. The system is capable of detecting disaster conditions using both visual data and environmental parameters. This research directly inspired the integration of temperature and humidity sensors in the MDRS system.

The study *"Thermal Infrared Sensing for Near Real-Time Data-Driven Fire Detection and Monitoring Systems" [4]* explores the use of UAV-mounted thermal sensors for wildfire detection. The research highlights the importance of multi-sensor systems in improving detection accuracy, especially under challenging environmental conditions. Although thermal sensing is not implemented in the current MDRS system, this work supports the concept of sensor integration for enhanced monitoring.

In *"Unmanned Aerial Vehicles for Search and Rescue: A Survey" [6]*, the authors provide a comprehensive overview of UAV applications in disaster response and rescue operations. The study highlights advantages such as rapid deployment, accessibility to hazardous environments, and improved operational efficiency. These findings strongly justify the use of drone-based systems like MDRS for real-world disaster management.

Overall, the reviewed literature demonstrates that the integration of drone technology, artificial intelligence, and sensor systems can significantly enhance disaster detection and response. However, many existing systems depend on high-cost infrastructure or internet connectivity. The MDRS system addresses these challenges by providing a cost-effective, offline-capable solution for real-time disaster monitoring.

III. PROPOSED SYSTEM AND METHODOLOGY

The proposed MDRS (Multi-Disaster Response and Surveillance Drone System) is designed as a real-time, offline-capable disaster monitoring system that integrates drone-based video surveillance, artificial intelligence, and IoT-based environmental sensing. The system is structured into multiple layers, including data acquisition, processing, and output visualization.

3.1 System Overview

The MDRS system consists of three major components: a drone unit, a ground station, and a sensor module. The drone captures live video footage of the environment and transmits it to the ground station using WiFi-based RTSP streaming. The ground station processes the incoming video frames using a Convolutional Neural Network (CNN) model to detect and classify disaster events such as cyclone, earthquake, flood, and wildfire.

The system is designed to operate completely offline, making it suitable for deployment in disaster-affected areas where internet connectivity is unavailable

3.1.1 Hardware Implementation

The hardware implementation of the MDRS system consists of a drone platform, an environmental sensing module, and a ground communication unit. A low-cost camera drone is used to capture real-time aerial video, which is transmitted to the ground station for processing.

An environmental sensing module is mounted on the drone using an ESP32 microcontroller, which collects parameters such as temperature and humidity. The sensor module operates independently and transmits data wirelessly to the ground station.

Additionally, an ESP32 development board is used for interfacing and testing purposes, connected to the ground station via USB for data monitoring and debugging. The overall hardware setup is designed to be lightweight, cost-effective, and suitable for real-time deployment in disaster-prone environments.

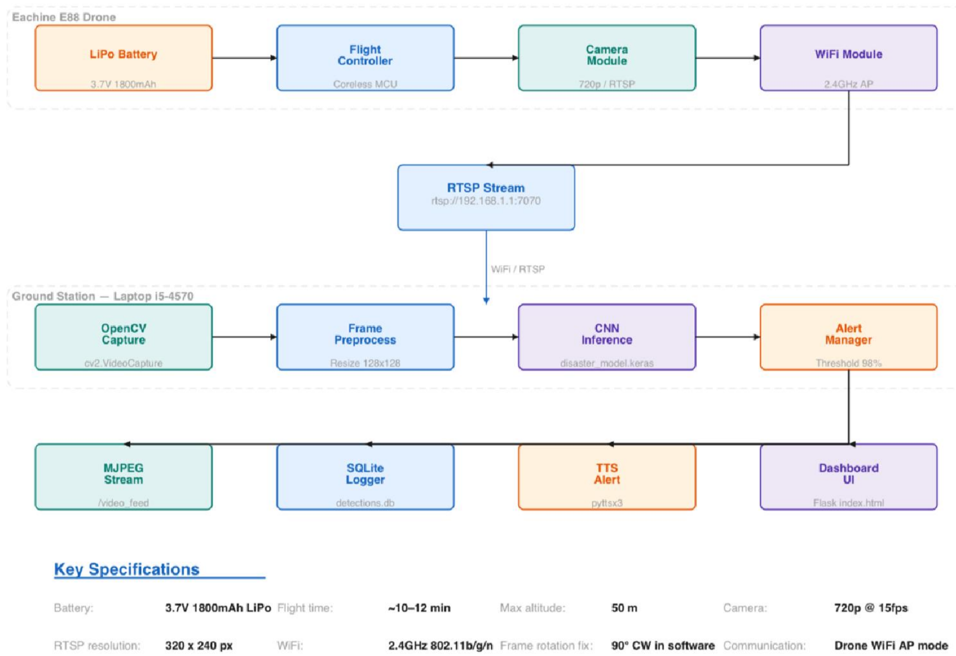

Figure 1: Overall System Block Diagram

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Figure 2: MDRS Drone with Integrated Sensor Module

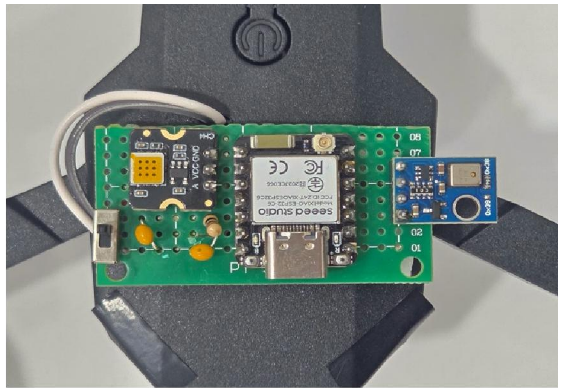

Figure 3: Environmental Sensor Hardware Module

Figure 4: ESP32 Development Board

3.2 Video Acquisition and Processing

The drone camera provides a real-time video stream, which is captured using OpenCV. The frames are preprocessed by resizing them to a fixed resolution (128×128 pixels) before being passed to the CNN model. The trained model performs classification and outputs the predicted disaster class along with confidence scores.

The model is optimized for CPU-based inference, ensuring efficient real-time performance without requiring GPU acceleration. The average inference time is approximately 80 ms per frame, enabling smooth real-time monitoring.

3.3 CNN-Based Disaster Detection

A custom Convolutional Neural Network (CNN) model is used for disaster classification. The model is trained on a dataset containing images of different disaster categories, including cyclone, earthquake, flood, wildfire, and background. The architecture consists of multiple convolutional layers, pooling layers, and fully connected layers to extract features and perform classification.

The system achieves an overall accuracy of approximately 90%, making it reliable for real-time disaster detection.

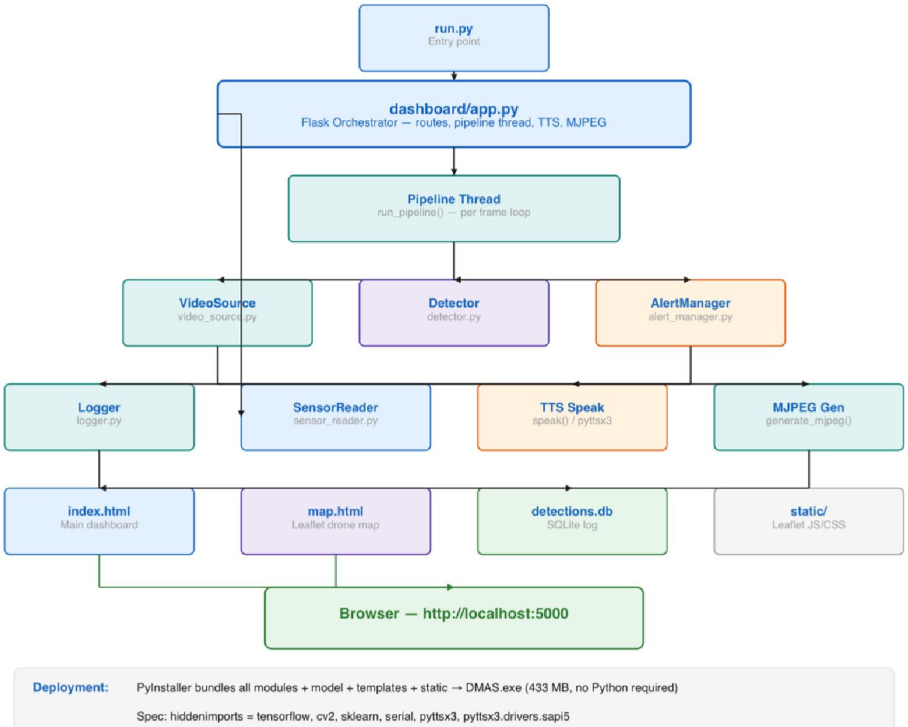

Figure 2: Software Architecture (CNN model)

3.4 Environmental Sensor Integration

To enhance the system's capability, an environmental sensing module is integrated using an ESP32 microcontroller. The sensor module collects parameters such as temperature and humidity, which can provide additional information about disaster conditions.

The sensor data is transmitted wirelessly to the ground station using ESP-based communication and displayed on the monitoring dashboard. Due to hardware limitations, certain sensors such as gas and smoke detection were not fully implemented in the current version.

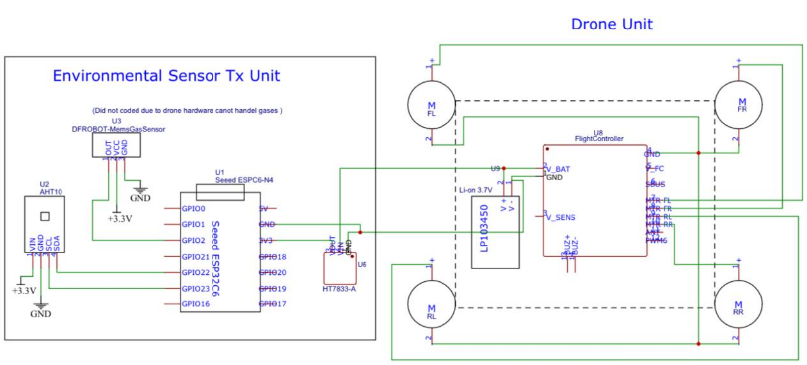

Figure 3: Sensor Circuit Diagram

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3.5 Communication System

The communication between system components is achieved using wireless technologies. The drone transmits video data via WiFi using RTSP protocol, while the sensor module communicates using ESP-based wireless communication. The ground station receives all data and processes it locally without requiring external servers or internet connectivity.

3.6 Monitoring Dashboard

A web-based dashboard is developed using Flask to provide real-time monitoring and control. The dashboard displays live video feed, detected disaster type, confidence level, alert logs, and system status. It also includes features such as audio alerts and detection summaries to assist users in quick decision-making.

The dashboard runs on a local server and can be accessed through a browser, ensuring ease of use and offline functionality.

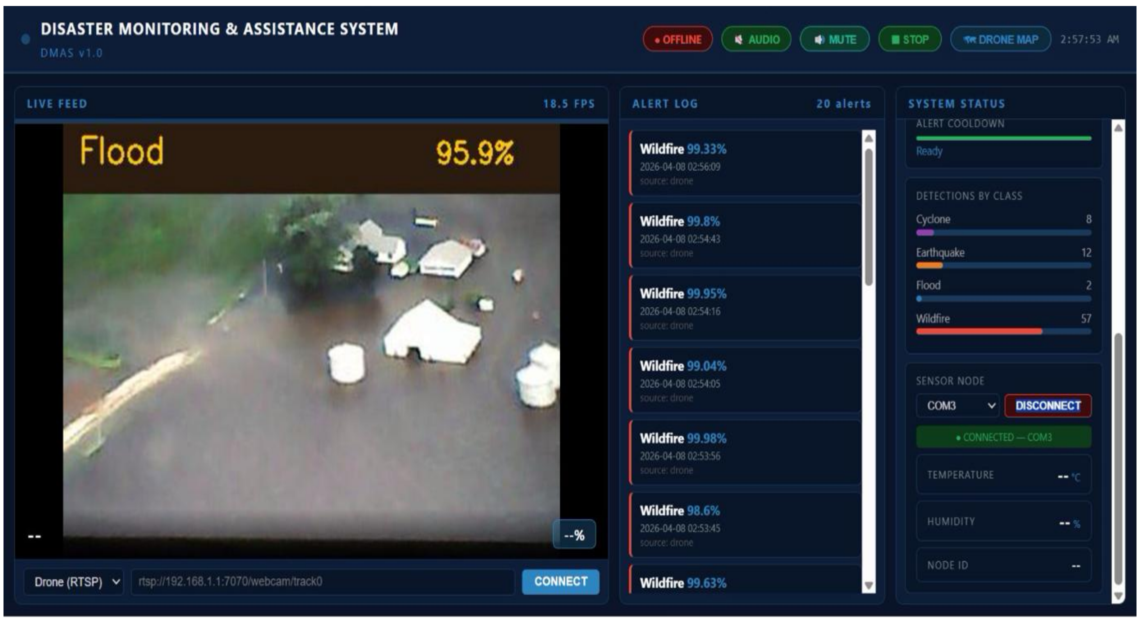

Figure 4: MDRS Monitoring Dashboard Interface

3.7 Working Principle

The overall working of the MDRS system can be summarized as follows:

1. The drone captures live video from the disaster area.
2. The video stream is transmitted to the ground station.
3. Frames are extracted and processed using OpenCV.
4. The CNN model classifies the disaster type.
5. Alerts are generated based on detection confidence.
6. Sensor data is collected and displayed on the dashboard.
7. All results are visualized in real-time for monitoring and response.

This integrated approach ensures efficient disaster detection, monitoring, and assistance while minimizing human risk.

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IV. RESULTS AND DISCUSSION

The MDRS (Multi-Disaster Response and Surveillance Drone System) was successfully implemented and evaluated under simulated conditions to assess its performance in real-time disaster detection and monitoring.

4.1 Disaster Detection Performance

The CNN-based model used in the system effectively classified multiple disaster types, including cyclone, earthquake, flood, wildfire, and background. The model achieved an overall accuracy of approximately 90%, indicating strong performance in identifying disaster scenarios from aerial video data.

During testing, the system was evaluated using various sample inputs, and it consistently detected disaster events with high confidence scores. The average inference time was approximately 80 milliseconds per frame, enabling real-time processing on CPU-based systems without the need for GPU acceleration. This makes the system suitable for low-resource environments.

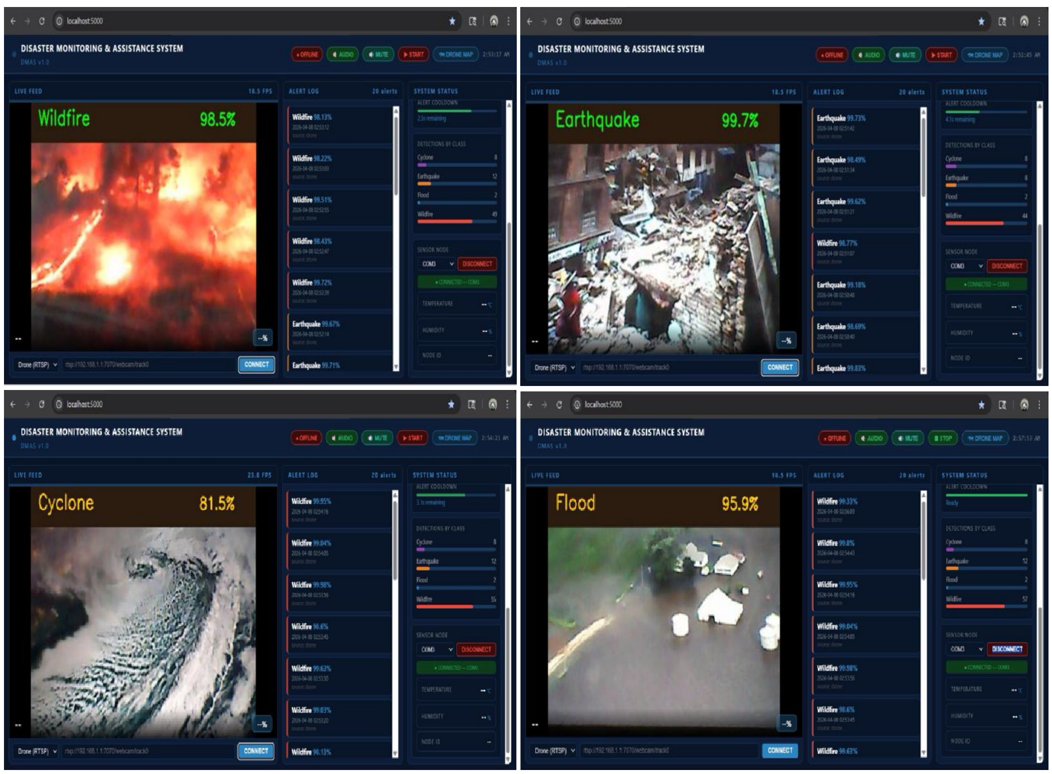

Figure 5: CNN-Based Disaster Detection Output

4.2 Dashboard and Visualization

The developed web-based dashboard provides an interactive interface for real-time monitoring and visualization. It displays the live video feed from the drone along with the detected disaster type and corresponding confidence level.

In addition, the dashboard maintains an alert log that records detected events with timestamps, allowing users to track and review previous detections. System status indicators such as connection status, alert cooldown, and detection summary are also included, enabling effective monitoring and quick decision-making during emergency situations.

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4.3 Sensor Data Analysis

The environmental sensing module successfully captured parameters such as temperature and humidity. The data was transmitted wirelessly using the ESP32 module and displayed on the dashboard in real time.

Although additional sensors such as gas and smoke detection were initially considered, they were not included in the final implementation due to hardware constraints and overheating issues. Despite this, the current sensor module provides useful environmental data that can support disaster assessment and monitoring.

4.4 Drone Tracking Visualization

A prototype drone tracking interface was developed to simulate real-time monitoring of drone position and coverage using a map-based system. The interface displays approximate drone location, movement paths, and coverage area for visualization purposes.

While real-time GPS integration is not fully implemented in the current system, the interface demonstrates the potential for incorporating live tracking features in future development. This feature can significantly enhance situational awareness and assist rescue teams in monitoring operational areas more effectively.

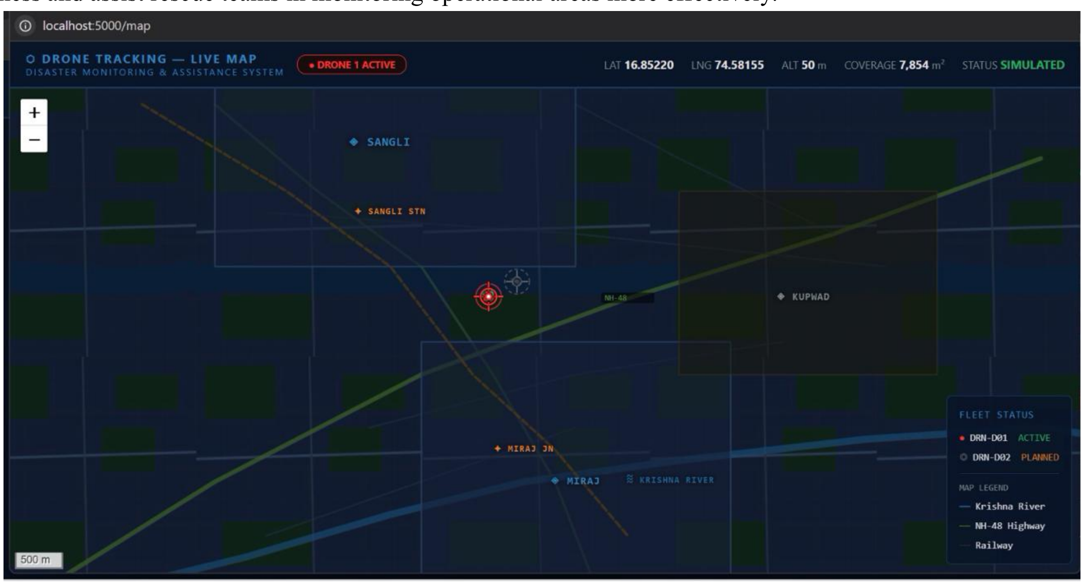

Figure 6: Drone Tracking Map Interface

4.5 System Limitations

Although the MDRS system performs effectively, certain limitations were identified during implementation:

- The drone platform used is a low-cost model, which limits payload capacity and restricts the integration of additional sensors.
- The system currently supports a limited number of disaster categories.
- The CNN model is trained on a predefined dataset, which may affect performance in real-world or unseen conditions.
- Real-time GPS tracking is not fully implemented, limiting precise location identification.

4.6 Discussion

The results demonstrate that the MDRS system is capable of providing real-time disaster detection and monitoring in an efficient and cost-effective manner. The offline functionality of the system makes it highly suitable for deployment in disaster-prone areas where internet connectivity is unavailable.

Compared to traditional monitoring methods, the proposed system reduces human risk and improves response time by providing instant visual and analytical information. The integration of drone surveillance, AI-based detection, and sensor data makes the MDRS system a practical and scalable solution for modern disaster management applications.

V. FUTURE SCOPE

The current MDRS system provides a strong foundation for disaster monitoring; however, several enhancements can be incorporated in future development:

- Integration of real-time GPS tracking for accurate drone positioning and disaster location identification.
- Implementation of additional sensors such as gas, smoke, and air quality sensors for advanced environmental monitoring.
- Use of higher-capacity drone platforms to support additional hardware and longer flight duration.
- Improvement of the CNN model using larger and more diverse datasets to increase accuracy and robustness.
- Integration with cloud-based systems for remote monitoring and large-scale deployment.
- Development of autonomous drone navigation features such as path planning and obstacle avoidance.
- Implementation of multi-drone coordination systems for wider area coverage and efficient disaster management.

These improvements can enhance the scalability, reliability, and real-world applicability of the MDRS system.

VI. CONCLUSION

The MDRS (Multi-Disaster Response and Surveillance Drone System) presents an efficient and cost-effective solution for real-time disaster monitoring and analysis. The system successfully integrates drone-based surveillance, CNN-based disaster detection, and IoT-based environmental sensing into a unified platform.

The proposed system demonstrates the ability to detect multiple disaster types such as cyclone, flood, wildfire, and earthquake with an overall accuracy of approximately 90%. The use of an offline-capable architecture ensures that the system remains functional even in disaster-affected regions with limited or no internet connectivity.

The developed dashboard provides a user-friendly interface for real-time visualization, alert generation, and monitoring, enabling faster and safer decision-making. Additionally, the integration of environmental sensing enhances situational awareness by providing supporting data related to disaster conditions.

Overall, the MDRS system contributes to improving disaster response efficiency, reducing human risk, and enabling faster rescue operations through the effective use of artificial intelligence and drone technology.

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