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Abstract

Rapid assessment and coordinated response are critical during natural and human-induced disasters to minimize casualties and property loss. Unmanned Aerial Vehicles (UAVs) have emerged as agile, cost-effective tools for disaster surveillance, capable of capturing high-resolution data in inaccessible or hazardous areas. However, centralized data processing introduces latency, bandwidth constraints, and privacy concerns.

This work proposes a UAV-based disaster imagery analysis and post-rescue coordination framework integrating **Federated Learning (FL)** and **Integrated Sensing and Communication (ISAC)**. UAVs equipped with multi-modal sensors and high-definition cameras perform on-site reconnaissance, locally training deep learning models for damage assessment, victim localization, and terrain classification. FL aggregates model parameters from multiple UAVs in a privacy-preserving manner, reducing communication overhead. ISAC enables simultaneous data transmission and environment sensing, enhancing spectrum efficiency and real-time coordination between UAV swarms and ground teams.

Experimental evaluations on simulated disaster scenarios and public datasets demonstrate high detection accuracy with significantly reduced latency compared to conventional cloud-based approaches. The system further supports post-rescue operations by generating real-time disaster maps, optimal ground navigation paths, and dynamic victim location updates, enabling a scalable, secure, and resilient disaster management solution.

Literature Review

Unmanned Aerial Vehicles (UAVs) play a vital role in disaster management by rapidly accessing inaccessible zones and providing high-resolution multi-modal sensing (RGB, thermal, LiDAR) [?]. Swarm operations enhance coverage but face limitations in flight endurance, payload, and connectivity [?]. **Federated Learning (FL)** enables privacy-preserving, bandwidth-efficient model training on UAVs [?], yet suffers from non-IID data, communication overhead, and vulnerability to model poisoning [?]. **Integrated Sensing and Communication (ISAC)** allows simultaneous sensing and data transfer via a unified RF chain [?], improving efficiency but introducing waveform trade-offs and interference challenges [?].

Recent works integrate UAVs, FL, and ISAC for resilient, low-latency operations, where UAVs sense, train locally, and share updates for aggregated decision-making [?]. However, current datasets are disaster-type-specific, simulation platforms rarely unify ISAC with FL, and robust security measures remain computationally costly [?]. Key gaps include the absence of unified energy-aware optimization frameworks, multi-modal FL personalization, ISAC-aware model compression, realistic UAV–ISAC–FL benchmarks, and resilience to adversarial conditions [?, ?, ?]. This study addresses these issues through a joint optimization and robust integration framework for UAV-enabled disaster response.

Problem Definition

The inefficiency and delay in disaster response are major challenges in current UAV-based surveillance systems, primarily due to centralized data processing of imagery. This approach presents three significant issues:

- **Latency** – Large volumes of high-resolution imagery require considerable transmission time to a central cloud server, delaying analysis and response.
- **Bandwidth Constraints** – Simultaneous data transfer from multiple UAVs can overload communication channels, limiting operational effectiveness.
- **Privacy Concerns** – Centralizing sensitive data, such as victim locations and personal details, increases the risk of privacy breaches.

These factors impede rapid assessment and coordinated rescue efforts, thereby increasing casualties and property damage during natural and human-induced disasters. This work addresses these challenges by integrating **Federated Learning (FL)** for distributed, privacy-preserving model training and **Integrated Sensing and Communication (ISAC)** for efficient, real-time data exchange and sensing.

Methodology / Planning of Work

1. Literature study on UAV disaster management, FL, and ISAC.
2. Data collection (disaster imagery datasets – floods, earthquakes, etc.).
3. UAV simulation setup with flight path planning.
4. Implementation of Federated Learning framework (e.g., Flower, TensorFlow Federated).
5. ISAC simulation for joint sensing and communication (using MATLAB / Simu5G).
6. Integration of UAV imagery capture, FL model training, and ISAC module.
7. Testing in simulated disaster environments for accuracy, latency, and bandwidth usage.
8. Performance analysis and final optimization.

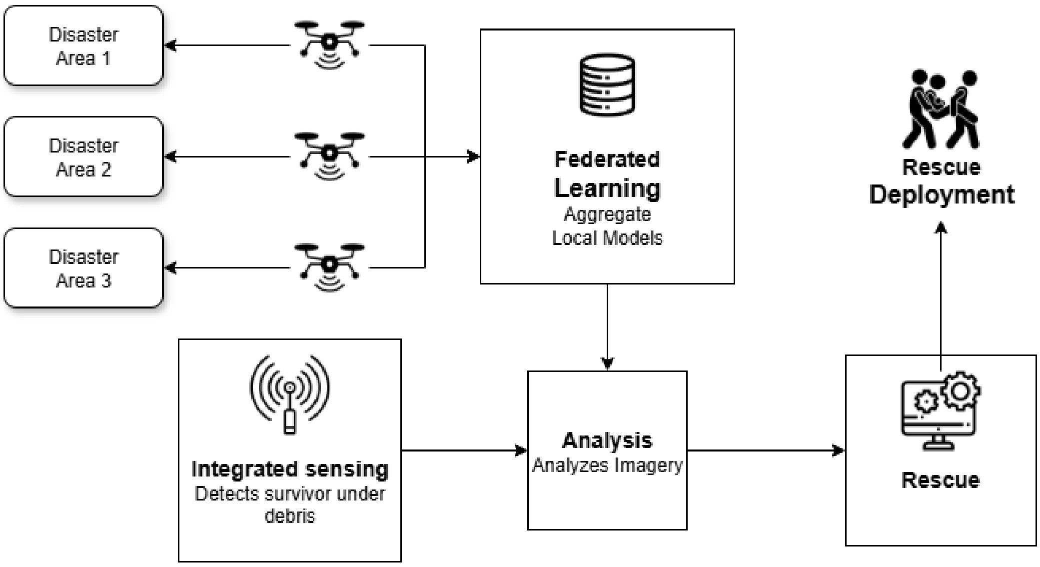

Figure 1: Proposed UAV-based Disaster Response Framework

Facilities Required

Software:

- Frontend: React.js (UI for rescue dashboard & analysis visualization)

- Backend: Node.js with Express.js (API handling, model integration, communication)
- Python (AI Model Training)
- TensorFlow Federated / Flower (FL Framework)
- MATLAB / Simu5G (ISAC Simulation)
- OpenCV (Image Processing)
- ROS (Robot Operating System) for UAV Control
- QGroundControl / DroneKit (UAV Simulation)

Hardware:

- UAV/Drone with camera (DJI, Parrot, etc.) or Simulation Environment
- Edge Computing Device (Jetson Nano / Raspberry Pi 4)
- Ground Station with GPU Server
- Communication Modules (5G / LTE-enabled)

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