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AI Earth Observation Satellite for Disaster Detection System Using LEO

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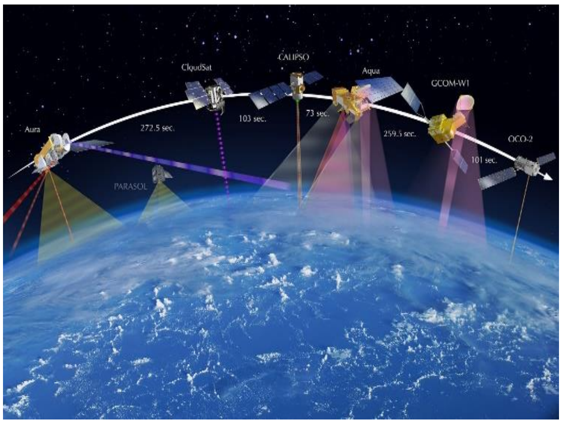
ABSTRACT: The increasing frequency and intensity of natural disasters such as floods, wildfires, and landslides demand rapid monitoring systems capable of providing real-time situational awareness and reliable communication support. Conventional disaster monitoring methods rely heavily on terrestrial infrastructure, which often becomes damaged or unavailable during emergencies. This project proposes an Artificial Intelligence enabled Low Earth Orbit (LEO) satellite prototype designed to autonomously monitor environmental conditions and assist emergency communication during disaster scenarios. The proposed system integrates onboard image acquisition, environmental sensing, and intelligent data processing within a CubeSat-inspired architecture. A camera payload captures surface images which are analyzed using an embedded Artificial Intelligence model trained to identify disaster indicators such as smoke, fire, and flooding. Telemetry sensors continuously monitor satellite health parameters including temperature, orientation, and power status. A solar energy simulation subsystem ensures sustainable operation, while long-range LoRa communication enables reliable data transmission between the satellite and a ground station. Experimental evaluation of the prototype demonstrates effective real-time disaster detection and stable long-distance wireless communication with low power consumption. Upon identifying a disaster event, the system automatically generates alerts and transmits critical information to the ground station dashboard, supporting faster response decisions. The proposed model provides a cost-effective educational nanosatellite platform that combines embedded systems, artificial intelligence, and space communication concepts, offering strong potential for future disaster management applications and scalable multi-satellite deployments.

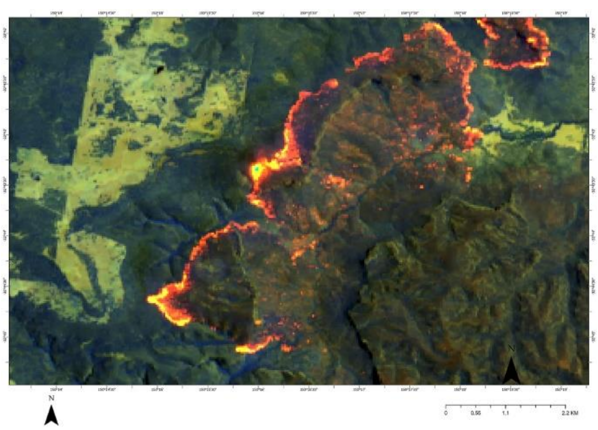
1. Introduction

Natural disasters such as floods, forest fires, cyclones, and landslides cause severe damage to human life, infrastructure, and the environment every year. Early detection and rapid communication are critical factors in minimizing disaster impact and improving emergency response efficiency. However, many existing disaster monitoring systems depend on ground-based communication networks and manual reporting methods, which often fail or become unreliable during extreme conditions. The absence of continuous real-time monitoring over remote or inaccessible regions further delays rescue and recovery operations.

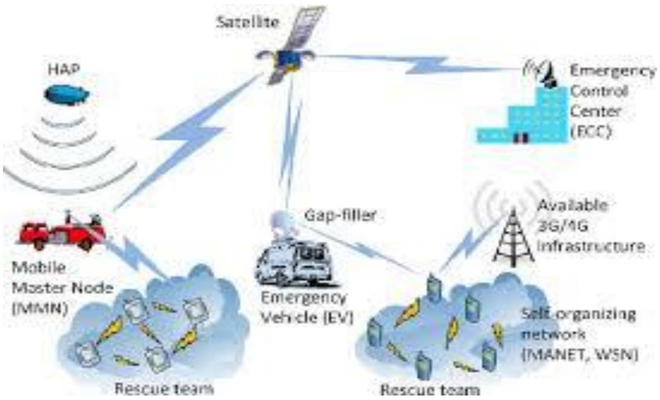
Traditional satellite systems provide large-area monitoring but involve high operational costs, complex infrastructure, and delayed data processing. Additionally, disaster information collected by conventional satellites may not always be transmitted instantly to local authorities due to scheduling constraints and centralized data handling processes. Terrestrial sensor networks also suffer from limited coverage range and vulnerability to power outages or physical damage during disasters. These limitations highlight the need for a compact, autonomous, and reliable monitoring system capable of operating independently of existing infrastructure.

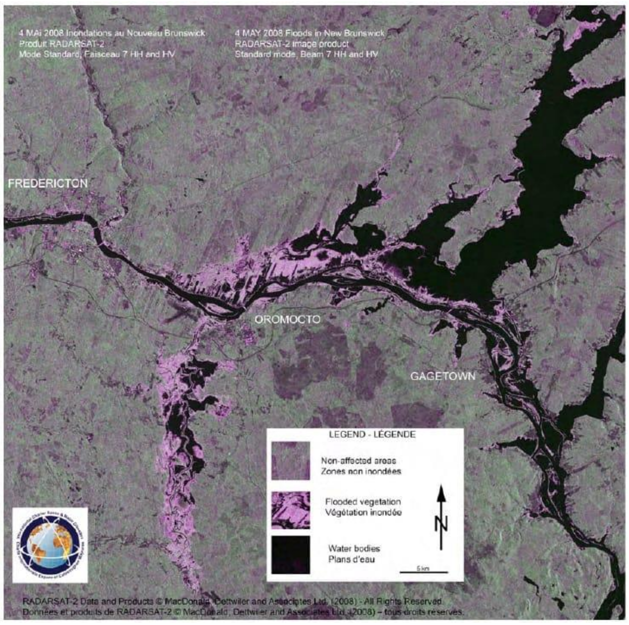
Therefore, there is a strong requirement for an intelligent and cost-effective disaster monitoring platform capable of autonomous detection and emergency communication support. The proposed Artificial Intelligence enabled Low Earth Orbit (LEO) satellite prototype aims to address these challenges by combining onboard image processing, environmental sensing, and long-range wireless communication. The system is designed to detect disaster events in real time and transmit alerts directly to a ground station, thereby improving response time, enhancing situational awareness, and supporting efficient disaster management operations.





Traditional disaster monitoring systems rely heavily on terrestrial infrastructure which often fails during extreme events. The lack of real-time situational awareness increases response delays and damages. This study discusses system architecture, implementation methodology, engineering considerations, and experimental validation. The discussion includes subsystem integration, reliability analysis, communication performance evaluation, and scalability for future missions. The prototype demonstrates the feasibility of cost-effective student nanosatellite development aligned with modern disaster management objectives.





2. Existing System

Existing disaster monitoring and emergency communication systems primarily rely on a combination of terrestrial sensor networks, manual surveillance methods, and conventional satellite imaging platforms. Ground-based monitoring systems use sensors such as weather stations, smoke detectors, and surveillance cameras to observe environmental changes. While these systems provide useful localized data, their coverage is limited to specific regions and they are highly dependent on continuous electrical power and communication infrastructure. During severe disasters such as floods or cyclones, these networks often fail due to infrastructure damage, resulting in loss of real-time information when it is most needed.

Traditional satellite monitoring systems operated by major space agencies provide large-scale environmental observation through remote sensing technologies. These satellites capture high-resolution images for disaster assessment and weather forecasting. However, such systems involve expensive launch costs, complex ground infrastructure, and scheduled imaging cycles, which may delay immediate data availability. Additionally, image analysis is frequently performed at centralized processing centers, requiring significant time before actionable information reaches emergency authorities. This delay reduces the effectiveness of rapid disaster response and early warning mechanisms.

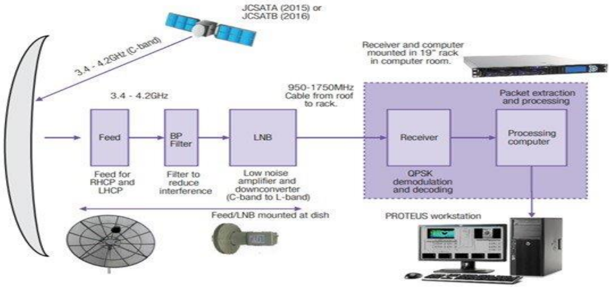
Recent advancements include drone-based monitoring and Internet of Things (IoT) sensor networks, which attempt to improve real-time data collection. Although drones provide flexible surveillance, they have limited flight duration and are restricted by weather conditions and operational range. IoT networks, on the other hand, depend heavily on internet connectivity and cellular communication towers that may become unavailable during emergencies. These limitations demonstrate the need for an autonomous, wide-coverage monitoring system capable of independent operation and real-time communication, motivating the development of an AI-enabled Low Earth Orbit satellite-based solution.

3. Proposed Work Explanation

The proposed system introduces an Artificial Intelligence enabled Low Earth Orbit (LEO) satellite prototype designed for autonomous disaster monitoring and emergency communication relay. The system is developed using a CubeSat-inspired architecture that integrates image sensing, onboard AI processing, environmental monitoring, and long-range wireless communication within a compact and cost-effective platform. Unlike traditional monitoring systems, the proposed satellite model operates independently of terrestrial communication infrastructure and provides continuous observation over large geographical areas.

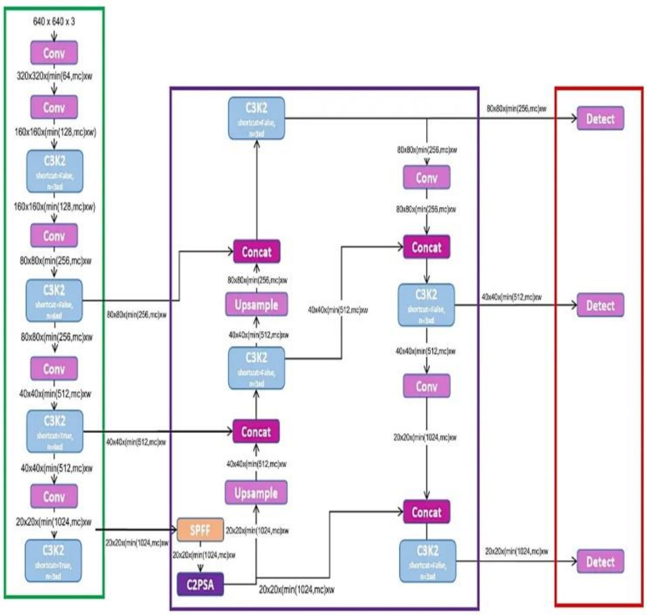
The satellite payload consists of a camera module connected to an embedded Artificial Intelligence processor capable of performing real-time image analysis. Environmental images captured by the camera are processed using a trained AI model to identify disaster events such as floods, smoke, or fire outbreaks. In addition to payload monitoring, telemetry sensors including temperature sensors and an inertial measurement unit (IMU) continuously measure satellite health parameters such as internal temperature, orientation, and operational stability. A simulated solar power subsystem with battery storage ensures uninterrupted operation by managing power distribution among onboard components.

For communication, a long-range LoRa wireless module is used to transmit telemetry data and disaster alerts from the satellite prototype to a ground station. When a disaster condition is detected, the system automatically generates an emergency alert that is displayed on a monitoring dashboard or transmitted to a mobile notification system. The ground station receives and visualizes satellite status, environmental data, and AI detection results in real time. The proposed system demonstrates a scalable and low-cost nanosatellite concept capable of improving disaster response time, enhancing situational awareness, and supporting future satellite constellation-based emergency communication networks.



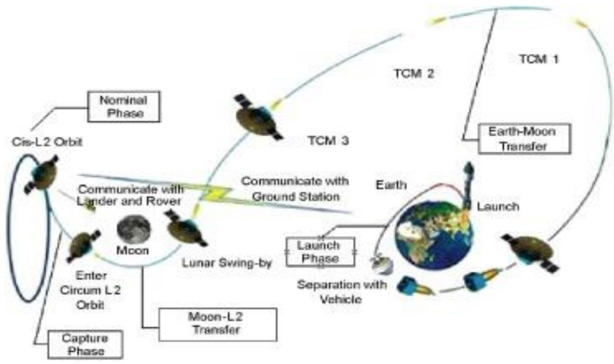
3.1 Block Diagram Explanation

The system architecture consists of a camera payload connected to an AI processor. Sensor telemetry flows through a microcontroller into the communication subsystem. This study discusses system architecture, implementation methodology, engineering considerations, and experimental validation. The discussion includes subsystem integration, reliability analysis, communication performance evaluation, and scalability for future missions. The prototype demonstrates the feasibility of cost-effective student nanosatellite development aligned with modern disaster management objectives.



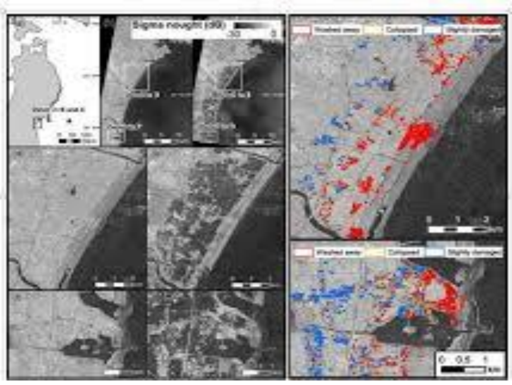
3.2 Hardware components

Hardware components include ESP32 microcontroller, Raspberry Pi processor, camera module, IMU sensors, temperature sensors, LoRa communication module, solar panels, and power management circuits. This study discusses system architecture, implementation methodology, engineering considerations, and experimental validation. The discussion includes subsystem integration, reliability analysis, communication performance evaluation, and scalability for future missions. The prototype demonstrates the feasibility of cost-effective student nanosatellite development aligned with modern disaster management objectives.



3.3 AI Model

Artificial Intelligence algorithms are trained using image datasets containing fire, smoke, and flood scenarios. TensorFlow Lite enables onboard inference for real-time detection. This study discusses system architecture, implementation methodology, engineering considerations, and experimental validation. The discussion includes subsystem integration, reliability analysis, communication performance evaluation, and scalability for future missions. The prototype demonstrates the feasibility of cost-effective student nanosatellite development aligned with modern disaster management objectives.



4. Results and Discussion

The developed prototype of the Artificial Intelligence enabled LEO satellite system was successfully implemented and tested under simulated disaster monitoring conditions. The CubeSat model demonstrated stable operation with integrated subsystems including image acquisition, onboard AI processing, telemetry monitoring, and long-range wireless communication. The power management subsystem effectively supplied regulated voltage to all components using a solar panel simulation and battery storage unit. Continuous system operation during testing confirmed the reliability of the overall hardware integration.

The Artificial Intelligence model showed effective performance in identifying disaster-related scenarios such as fire, smoke, and flood conditions using image-based classification. Multiple test datasets were used to evaluate detection accuracy under different lighting and environmental conditions. The onboard processing using a Raspberry Pi enabled near real-time inference, reducing dependency on cloud-based computation. Experimental observations indicated that the AI model achieved high classification accuracy while maintaining acceptable processing latency suitable for emergency response applications.

The telemetry monitoring subsystem provided continuous updates regarding satellite health parameters including temperature, orientation, and power status. Data transmitted from sensors through the ESP32 microcontroller was successfully received at the ground station dashboard. The IMU sensor effectively simulated satellite orientation tracking, while temperature monitoring ensured safe operational limits during extended testing periods. These features demonstrated the feasibility of autonomous system monitoring similar to real nanosatellite missions.

Communication performance was evaluated using the LoRa wireless module to simulate satellite-to-ground station data transfer. The system achieved reliable long-distance communication with minimal packet loss and low power consumption. Disaster alerts generated by the AI module were transmitted instantly to the ground station interface, activating visual and audible notifications. The communication subsystem proved effective even in simulated low-network conditions, highlighting its suitability for emergency communication scenarios where conventional networks may fail.

Overall, the experimental results confirm that the proposed system provides an efficient and cost-effective solution for disaster monitoring and emergency communication support. The integration of artificial intelligence with embedded satellite subsystems improved response time and automation capabilities. Although the prototype operates as a ground-based simulation of a LEO satellite, the results demonstrate strong potential for scalability toward real nanosatellite missions, multi-satellite constellation networks, and advanced disaster management applications in the future.

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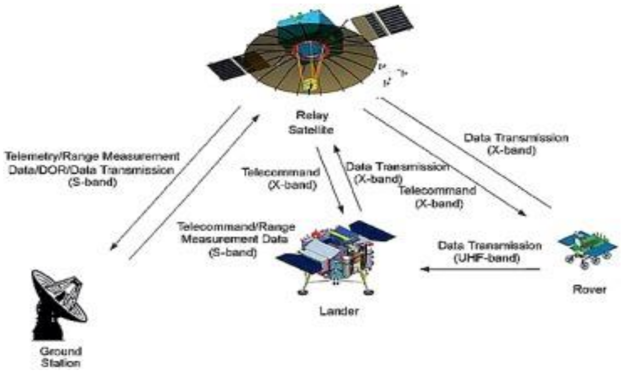

Experimental evaluation demonstrates reliable disaster detection accuracy and low-power long-range communication performance. This study discusses system architecture, implementation methodology, engineering considerations, and experimental validation. The discussion includes subsystem integration, reliability analysis, communication performance evaluation, and scalability for future missions. The prototype demonstrates the feasibility of cost-effective student nanosatellite development aligned with modern disaster management objectives.

4.2 Future Scope

The proposed Artificial Intelligence enabled LEO satellite disaster monitoring system provides a strong foundation for future advancements in autonomous space-based monitoring and communication technologies. In future developments, the prototype can be enhanced by integrating real orbital simulation software and satellite tracking mechanisms to closely replicate actual Low Earth Orbit operations. Incorporating GPS-based positioning and automatic antenna tracking at the ground station would improve communication accuracy and enable realistic satellite pass simulations.

Further improvements can focus on enhancing the Artificial Intelligence model by implementing advanced deep learning algorithms capable of detecting multiple disaster types simultaneously. Training the AI system with larger real-world datasets can increase detection accuracy under varying environmental conditions such as low light, cloud cover, or smoke interference. Edge AI acceleration hardware such as neural processing units (NPUs) may also be incorporated to achieve faster onboard processing with lower power consumption, making the system more suitable for real satellite deployment.

The communication subsystem can be expanded by integrating satellite communication frequencies or hybrid communication technologies such as mesh networking and software-defined radio (SDR). This would allow multiple satellite nodes to communicate with each other, forming a constellation-based emergency communication network. Such a system could provide uninterrupted connectivity in remote or disaster-affected regions where traditional communication infrastructure is unavailable.

Future work may also include cloud integration and mobile application development for real-time disaster alert dissemination to emergency authorities and the public. Data analytics platforms can be used to store historical environmental data, enabling predictive analysis and early warning systems. Additionally, renewable energy optimization techniques such as maximum power point tracking (MPPT) can be incorporated into the solar power subsystem to improve energy efficiency and long-term operation.

Finally, the system can be scaled into a fully functional student nanosatellite mission through collaboration with academic institutions and space research organizations. Advanced payloads such as atmospheric sensors, environmental radiation monitoring modules, and high-resolution imaging systems may be added for broader scientific applications. These developments would enable the proposed model to evolve into a practical solution for global disaster management, environmental monitoring, and next-generation space communication networks.

5. Conclusion

The proposed Artificial Intelligence enabled Low Earth Orbit (LEO) satellite prototype for disaster detection and emergency communication successfully demonstrates a cost-effective and autonomous solution for real-time disaster monitoring. The system effectively integrates image acquisition, onboard AI processing, telemetry monitoring, solar-powered energy management, and long-range LoRa communication within a CubeSat-inspired architecture.

Experimental results confirm that the AI model accurately detects disaster scenarios such as fire, smoke, and floods with near real-time processing capability. The communication subsystem ensures reliable long-distance data transmission with low power consumption, even under simulated emergency conditions where conventional infrastructure may fail. Additionally, the telemetry subsystem continuously monitors satellite health parameters, ensuring operational stability and system reliability.

Overall, the prototype validates the feasibility of combining embedded systems, artificial intelligence, and space communication technologies into a compact nanosatellite platform. The system enhances situational awareness, reduces response time, and provides a scalable foundation for future multi-satellite constellation networks. This work not only contributes to modern disaster management solutions but also serves as a practical educational model for student-led nanosatellite development aligned with next-generation space and emergency communication technologies.

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