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Disaster Surveillance Robotic Vehicle

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Abstract
In recent years, the frequency of natural and human-induced disasters, including earthquakes, fires, and floods, has significantly increased, creating major challenges for search, rescue, and disaster management operations. Deploying human personnel in such hazardous environments is often dangerous, time-consuming, and resource-intensive. This project presents the design and development of an IoT-enabled robotic vehicle for disaster surveillance and real-time monitoring. The proposed robotic system is capable of remote operation through wireless communication, allowing rescue personnel to monitor disaster-affected areas from a safe distance. An ultrasonic sensor is integrated for obstacle detection and collision avoidance, ensuring safe navigation in complex environments. A thermal sensor is employed to detect abnormal heat signatures that may indicate the presence of survivors or fire hazards. A GPS module provides real-time location tracking of the robotic vehicle, while an ESP32-CAM module enables live video streaming for continuous visual monitoring. The entire system is controlled by an Arduino microcontroller, which coordinates the operation of sensors, communication modules, and actuators to ensure reliable performance. Experimental evaluation demonstrates that the proposed system effectively performs surveillance, obstacle avoidance, live monitoring, and location tracking, thereby assisting rescue teams in improving situational awareness, minimizing human exposure to dangerous conditions, and enhancing the overall efficiency of disaster response operations.

Keywords*—Disaster Surveillance, Internet of Things (IoT), Robotic Vehicle, Arduino Uno, ESP32-CAM, Ultrasonic Sensor, Thermal Sensor, GPS Tracking, Wireless Communication, Search and Rescue.*

Introduction

Natural and human-induced disasters such as earthquakes, floods, fires, landslides, and industrial accidents have become increasingly frequent, resulting in significant loss of life, damage to infrastructure, and environmental destruction. Conducting rescue and surveillance operations in disaster-affected areas is often challenging due to unstable structures, hazardous conditions, and limited accessibility. In many situations, deploying human rescue personnel directly into these environments exposes them to considerable risks and delays emergency response. Therefore, the use of robotic systems and Internet of Things (IoT) technologies has emerged as an effective approach to improving disaster management and search-and-rescue operations.

This project presents the design and development of an IoT-enabled Disaster Surveillance Robotic Vehicle capable of remotely monitoring disaster-affected regions in real time. The proposed system integrates multiple sensors and communication modules to enhance situational awareness and support rescue teams during emergency operations. An ultrasonic sensor is employed for obstacle detection and collision avoidance, enabling safe navigation through hazardous environments. A thermal sensor detects abnormal heat signatures that may indicate the presence of survivors or fire hazards. A GPS module provides accurate real-time location tracking of the robotic vehicle, while an ESP32-CAM module streams live video to a remote monitoring station, allowing rescue personnel to assess the disaster site without entering dangerous areas. The entire system is controlled by an Arduino microcontroller, which coordinates the operation of all sensors and actuators to ensure reliable and efficient performance. By combining robotics, IoT, and real-time monitoring technologies, the proposed system enhances disaster surveillance, reduces risks to rescue personnel, and improves the effectiveness and speed of emergency response operations.

Literature Survey

Several research studies have contributed to the development of robotic surveillance systems for disaster management by integrating advanced sensing, navigation, and communication technologies. Mittal *et al.* (2025) proposed a modular robotic platform with a lightweight 3D-printed structure that incorporates GPS-based navigation and a "Return-to-Home" safety mechanism, improving the reliability of robotic operations in hazardous environments. Gholami *et al.* (2025) demonstrated the effectiveness of the YOLO deep learning framework for near real-time human detection during search and rescue missions. Although the system achieved high detection accuracy, it required powerful computing hardware, making it less suitable for low-cost embedded applications.

Papanashi *et al.* (2026) investigated the use of low-resolution thermal sensors for human detection and tracking, showing that thermal imaging provides energy-efficient operation while maintaining user privacy compared to conventional RGB cameras. Brenner *et al.* (2023) reviewed hybrid sensing techniques that combine RGB and thermal imaging, concluding that sensor fusion significantly improves human detection accuracy in low-light and smoke-filled disaster environments. Abdelnabi and Rabadi (2024) analyzed sensor technologies for Search and Rescue (SAR) missions and identified thermal imaging as one of the most effective methods for the rapid detection of survivors trapped under debris or operating in hazardous conditions. These studies demonstrate that integrating robotics, IoT, thermal sensing, GPS, and real-time communication technologies can significantly enhance disaster surveillance systems and improve the effectiveness of emergency response operations.

Working of Disaster Surveillance Robotic Vehicle

The Disaster Surveillance Robotic Vehicle is an IoT-enabled embedded system designed to support disaster monitoring, surveillance, and rescue operations in hazardous environments where human intervention is difficult or unsafe. The proposed system integrates an Arduino UNO microcontroller with multiple sensors and communication modules to perform real-time monitoring and navigation. An ultrasonic sensor is used to detect obstacles and prevent collisions during movement, while a thermal sensor monitors heat signatures that may indicate the presence of survivors or fire hazards. A GPS module continuously tracks the robot's location and provides real-time positioning information. The system also incorporates Bluetooth communication for local wireless control and an ESP8266 Wi-Fi module for remote monitoring through a web-based dashboard. In addition, an ESP32-CAM module provides live video streaming, enabling rescue teams to observe disaster-affected areas remotely. The robotic vehicle is powered by a regulated battery supply, and its movement is controlled using an L298N motor driver and DC motors. By integrating sensing, communication, and surveillance technologies, the system provides an effective and reliable solution for disaster management applications.

Existing System

Several disaster surveillance and search-and-rescue systems have been developed using robotics, artificial intelligence, and Internet of Things (IoT) technologies. AI-based robotic systems commonly employ cameras and deep learning algorithms such as YOLO for human detection and object recognition. IoT-enabled monitoring systems facilitate remote data transmission and environmental monitoring, while thermal imaging systems are widely used for detecting survivors in low-light or smoke-filled environments. Unmanned Aerial Vehicles (UAVs) are frequently deployed for aerial surveillance and rapid assessment of disaster-affected regions. In addition, sensor fusion techniques that combine RGB cameras and thermal imaging have been introduced to improve detection accuracy under challenging environmental conditions. Although these systems provide advanced monitoring capabilities, many are expensive, computationally intensive, and dependent on aerial platforms or high-performance processors, limiting their practicality for low-cost ground-based rescue operations.

Limitations of Existing System

Despite significant advancements in disaster surveillance technologies, existing systems have several limitations. Rescue personnel are often required to enter hazardous environments, exposing them to fire, toxic gases, collapsed structures, and other life-threatening conditions. Many surveillance systems have limited accessibility and cannot effectively navigate narrow passages, debris-filled areas, or blocked pathways. Some systems do not provide continuous real-time monitoring or live video transmission, reducing the effectiveness of emergency response. In addition, conventional disaster monitoring solutions often lack reliable wireless communication for remote operation and monitoring. Many existing platforms also integrate only a limited number of sensors, making it difficult to simultaneously monitor obstacles, environmental temperature, location, and visual information, thereby reducing overall system performance.

Proposed System

The proposed Disaster Surveillance Robotic Vehicle integrates sensing, communication, navigation, and surveillance technologies into a single embedded platform. The system employs an Arduino UNO as the central controller to coordinate the operation of all hardware components. An ultrasonic sensor detects obstacles and assists in safe navigation, while a thermal sensor identifies abnormal heat signatures that may indicate survivors or fire hazards. A GPS module continuously provides real-time location information, allowing rescue teams to accurately track the robot's position. Bluetooth communication enables local wireless control, whereas the ESP8266 Wi-Fi module facilitates remote monitoring and control through a web dashboard. An ESP32-CAM module streams live video from the disaster site, enabling rescue personnel to monitor hazardous environments without direct exposure. The robot's movement is controlled using an L298N motor driver and DC motors, allowing efficient navigation across difficult terrain. By combining these technologies, the proposed system provides a cost-effective, reliable, and efficient solution for disaster surveillance and emergency response.

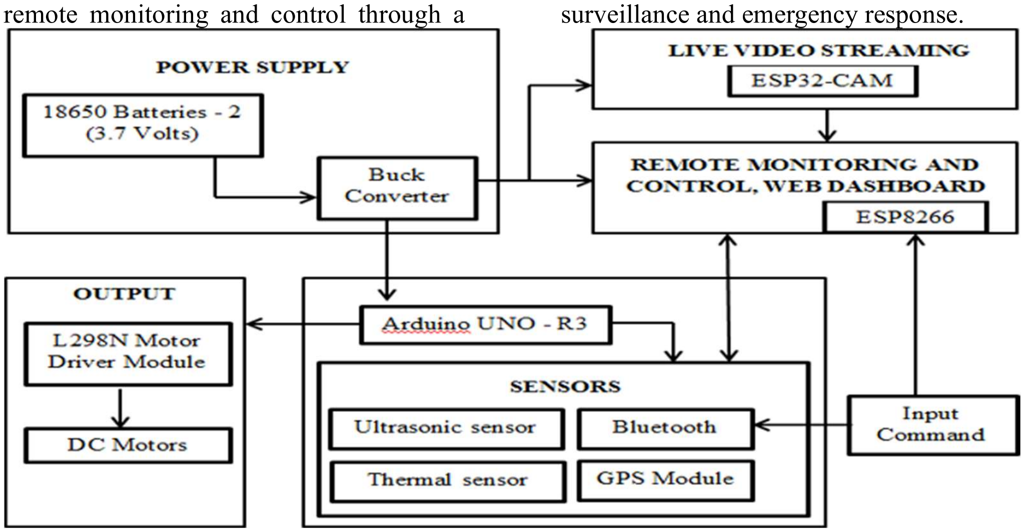

Fig. 1; Working of Disaster Surveillance Robotic Vehicle

Working Process of Disaster Surveillance Robotic Vehicle

The operation of the Disaster Surveillance Robotic Vehicle begins with the power supply unit, where rechargeable batteries provide the required electrical energy to the system. A buck converter regulates the input voltage to ensure stable and safe operation of all electronic components. The Arduino UNO functions as the central controller, receiving data from various sensors and coordinating the operation of communication modules and motor drivers. The ultrasonic sensor continuously detects obstacles to prevent collisions during navigation, while the thermal sensor monitors surrounding temperatures and detects abnormal heat signatures that may indicate survivors or fire sources. Simultaneously, the GPS module acquires real-time location coordinates for accurate tracking of the robotic vehicle.

The collected sensor data is processed by the Arduino UNO to make navigation and control decisions. Bluetooth communication enables nearby users to operate the robot wirelessly, whereas the ESP8266 Wi-Fi module transmits sensor information to a web-based dashboard for remote monitoring and control over the Internet. The ESP32-CAM captures and streams live video, allowing rescue teams to visually inspect disaster-affected areas in real time. Based on sensor inputs and user commands, the Arduino sends control signals to the L298N motor driver, which drives the DC motors to move the robotic vehicle safely through hazardous environments. This integrated operation enables efficient surveillance, obstacle avoidance, real-time monitoring, and communication, making the system highly effective for disaster management and search-and-rescue applications.

Results and Discussion

The Disaster Surveillance Robotic Vehicle (DSRV) was developed to assist rescue teams in monitoring hazardous and disaster-affected environments without exposing personnel to unnecessary risks. The system integrates multiple sensors and IoT technologies to provide real-time environmental information, including obstacle detection through an ultrasonic sensor, temperature monitoring using a thermal sensor, location tracking with a GPS module, and live video streaming via the ESP32-CAM module. The robotic vehicle can be remotely controlled using Bluetooth and IoT platforms, enabling users to navigate the robot efficiently while continuously monitoring the disaster site from a safe location. The integration of these technologies improves situational awareness and supports faster and more effective disaster response operations.

Result

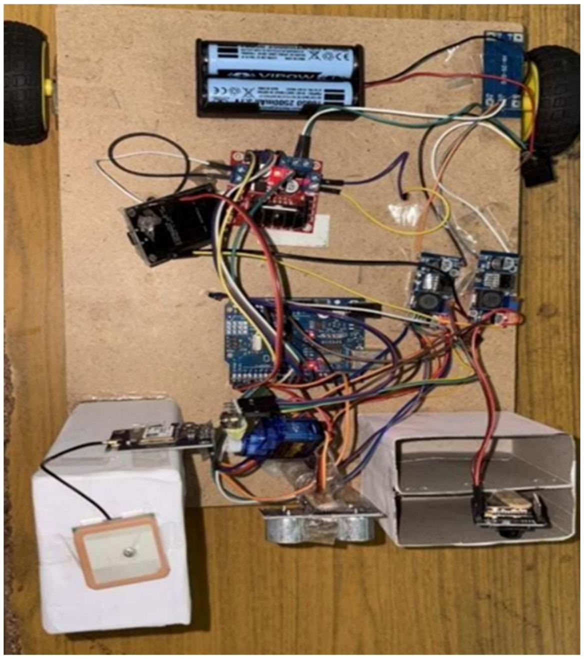

Fig. 2 Top View of DSRV

Figure 2 illustrates the top view of the Disaster Surveillance Robotic Vehicle, showing the arrangement of major hardware components, including the Arduino UNO, ESP communication modules, sensors, motor driver, battery, and interconnecting circuitry. The compact layout demonstrates efficient hardware integration, ensuring reliable communication among all modules while maintaining a lightweight and portable design suitable for disaster surveillance applications.

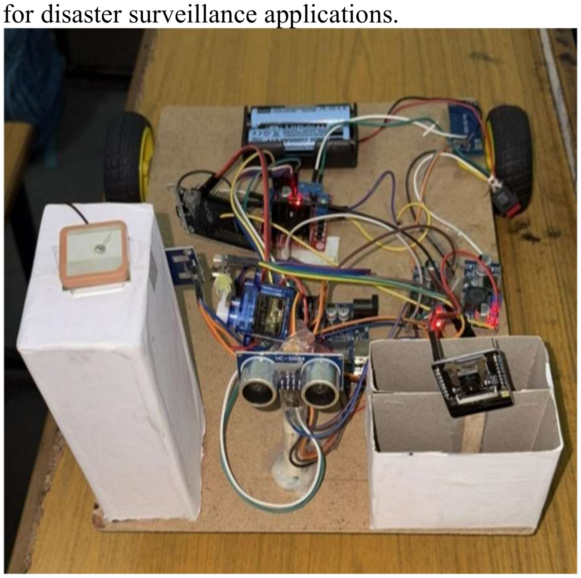

Fig 3 ; Front View of DSRV

Figure 3 presents the front view of the robotic vehicle, highlighting the placement of the ultrasonic sensor and the ESP32-CAM module. The ultrasonic sensor is positioned to detect obstacles in the robot's path and prevent collisions during navigation, while the camera module provides live video streaming for continuous visual monitoring of disaster-affected areas. This arrangement enables efficient navigation and real-time surveillance in hazardous environments.

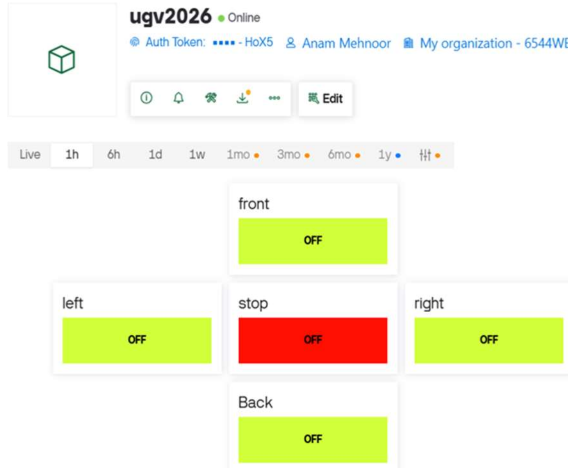

Fig. 4; Blynk Dashboard

Figure 4 shows the Blynk IoT dashboard used for remotely controlling and monitoring the robotic vehicle. The dashboard provides user-friendly control buttons for robot movement, including forward, backward, left, right, and stop functions. It also enables remote monitoring of sensor data and system status through a mobile device or web interface, allowing rescue personnel to operate the robot from a safe distance.

The experimental results demonstrate that the Disaster Surveillance Robotic Vehicle performs effectively in disaster monitoring and surveillance applications. The robot responded accurately to movement commands received through Bluetooth and IoT communication, enabling smooth and reliable navigation in different directions. The ultrasonic sensor successfully detected obstacles and prevented collisions, ensuring safe movement even in complex environments. The thermal sensor effectively detected variations in temperature, providing valuable information that can assist in identifying possible human presence or fire hazards, particularly in low-visibility conditions. Furthermore, the GPS module continuously provided real-time location data, allowing rescue teams to track the robot throughout its operation. The ESP32-CAM module delivered uninterrupted live video streaming, enabling remote visual inspection of disaster sites. All sensor data and control functions were successfully integrated into the Blynk IoT dashboard, facilitating efficient monitoring and decision-making. Overall, the proposed system demonstrated reliable performance and proved to be an effective, low-cost solution for disaster surveillance and emergency response support.

Advantages

The proposed Disaster Surveillance Robotic Vehicle offers several advantages for disaster management applications. It significantly improves the safety of rescue personnel by allowing surveillance in hazardous areas such as collapsed buildings, fire zones, and toxic environments without direct human intervention. The integration of live video streaming, thermal sensing, GPS tracking, and obstacle detection provides comprehensive real-time monitoring, enabling rescue teams to make faster and more informed decisions. Remote operation through Bluetooth and IoT platforms allows users to control the robot safely from distant locations. The combination of multiple sensors enhances the accuracy and reliability of environmental monitoring, while the use of low-cost components such as the Arduino UNO, ESP modules, and standard sensors makes the system economical, easy to develop, and suitable for both academic research and practical disaster management applications.

Limitations

Despite its effective performance, the proposed system has certain limitations. The accuracy of the sensors may decrease under extreme environmental conditions such as dense smoke, heavy rainfall, excessive heat, or severe weather, which can affect overall system performance. Remote monitoring and live video streaming depend on stable wireless or internet connectivity, which may not always be available in disaster-affected regions. The robot is powered by rechargeable batteries, limiting its operating time and requiring periodic recharging during extended missions. In addition, the thermal sensor detects heat sources but cannot independently confirm the presence of human survivors under all circumstances. Finally, the system is designed primarily for surveillance and monitoring purposes and does not possess the capability to perform physical rescue operations such as removing debris, transporting supplies, or assisting victims directly.

Conclusion and Future Scope

Conclusion

The Disaster Surveillance Robotic Vehicle successfully demonstrates an effective and practical solution for improving disaster management and search-and-rescue operations through the integration of robotics, embedded systems, and Internet of Things (IoT) technologies. The developed system enables real-time surveillance, remote operation, obstacle detection, environmental monitoring, and live video streaming, thereby reducing the risks associated with human intervention in hazardous environments. The ultrasonic sensor ensures safe navigation by detecting obstacles and preventing collisions, while the thermal sensor assists in identifying abnormal heat signatures that may indicate the presence of survivors or fire hazards. The GPS module provides accurate real-time location tracking, enabling rescue teams to monitor the robot's position during operations. Furthermore, the ESP32-CAM module offers continuous live video streaming, improving situational awareness and supporting informed decision-making. The Arduino-based control system effectively coordinates all sensors, communication modules, and actuators to ensure reliable system performance. Overall, the proposed system demonstrates that low-cost hardware integrated with IoT technologies can provide an efficient, reliable, and scalable solution for disaster surveillance, reducing human risk, improving response time, and enhancing the effectiveness of emergency rescue operations.

Future Scope

The proposed Disaster Surveillance Robotic Vehicle can be further enhanced by incorporating advanced sensing, navigation, communication, and artificial intelligence technologies to improve its operational capabilities. Future versions of the system can integrate LiDAR and RADAR sensors to generate high-resolution, 360-degree environmental maps for accurate navigation in both indoor and outdoor disaster environments. The use of depth cameras and three-dimensional vision systems can further improve obstacle detection by accurately estimating the size, shape, and distance of surrounding objects. Artificial intelligence and machine learning algorithms can be incorporated to classify detected obstacles, distinguish between survivors, debris, and hazardous objects, and automatically determine the most appropriate navigation strategy.

Sensor fusion techniques can be implemented to combine information from ultrasonic, thermal, camera, GPS, and LiDAR sensors, thereby improving detection accuracy and reducing false alarms. High-precision GPS with Real-Time Kinematics (RTK) technology can provide centimeter-level positioning accuracy for outdoor rescue missions. Simultaneous Localization and Mapping (SLAM) algorithms can be integrated to enable autonomous navigation in unknown environments by creating real-time maps while continuously tracking the robot's location. Neural network-based path planning algorithms can further optimize navigation by learning from previous missions and selecting the safest and shortest routes under changing environmental conditions.

Future enhancements may also include voice-based command systems for dynamic route planning and hands-free robot control during rescue operations. Mechanical improvements, such as caterpillar tracks, adaptive suspension systems, or hybrid wheel-leg mechanisms, can increase mobility over rough terrain, debris, stairs, and uneven surfaces commonly found in disaster zones. In addition, bio-inspired robotic designs based on the locomotion of insects or geckos may enhance climbing and maneuverability in challenging environments. The integration of renewable energy sources, long-range wireless communication technologies, cloud-based data analytics, and swarm robotics can further extend the system's operational range, reliability, and effectiveness, making it a comprehensive intelligent platform for future disaster surveillance and emergency response applications.

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