HexaRover: A Six-Wheeled Bot for Critical Rescue Missions

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Abstract - *Disaster response and relief efforts are often hindered by unpredictable terrain, hazardous conditions, and limited accessibility to affected areas. Traditional human-led search and rescue missions face significant risks and delays due to unstable structures, debris, and environmental hazards. The HexaRover is designed to address these challenges by providing an advanced, autonomous six-wheeled robotic system tailored for critical rescue missions. HexaRover integrates a robust six-wheel drive system to maximize terrain adaptability and maneuverability, enabling seamless navigation over rough, debris-filled, and unstable surfaces. Equipped with an array of state-of-the-art sensors, including LiDAR, ultrasonic sensors, infrared thermal imaging, and environmental sensors, HexaRover enhances the detection and identification of survivors in disaster-stricken zones. Furthermore, it employs machine learning-based obstacle avoidance and GPS-guided autonomous navigation to ensure efficient path planning and movement in dynamically changing environments. The robot features a multi-modal communication system comprising GSM, IoT cloud networking, and a real-time data transmission module that allows rescue teams to remotely monitor and control the rover from a central command station. Its AI-driven decision-making algorithms process sensory inputs to optimize search.*

***Key Words*: Disaster Response, Autonomous Robotics, HexaRover, Obstacle Avoidance, Terrain Adaptability, Machine Learning Navigation, and Real-time Data Transmission**

1.INTRODUCTION

Disasters, both natural and man-made, pose a significant threat to human life, infrastructure, and economic stability. Earthquakes, floods, hurricanes, wildfires, and industrial accidents frequently leave behind devastated regions where timely search and rescue (SAR) operations are critical. Traditional SAR operations rely heavily on human responders, who must navigate treacherous conditions, often placing their own lives at risk. Despite technological advancements, response times in such scenarios remain slow due to logistical challenges, terrain limitations, and the sheer scale of destruction. Autonomous robotic systems offer a promising solution to mitigate these risks. Over the past two decades, robotics has revolutionized multiple industries, from manufacturing to space exploration, and its application in disaster management has grown exponentially. Search and rescue robots are designed to traverse complex environments, detect survivors, and relay critical data to rescue teams, ensuring that first responders can focus on high-priority areas. Among these, wheeled robots provide a balance of mobility, payload capacity, and cost effectiveness. However, traditional wheeled robots often struggle with unstable terrain, a crucial factor in disaster zones.

1.1 Motivation for the Study

The primary motivation behind the development of HexaRover stems from the need for a highly mobile, intelligent, and autonomous system capable of providing real-time situational awareness in disaster-stricken areas. Some of the key challenges in SAR missions that HexaRover aims to address include:

1. Terrain Navigation – Disaster zones are filled with obstacles such as rubble, uneven ground, and unstable structures. HexaRover's six-wheeled design, along with advanced suspension systems, ensures it can traverse difficult terrain without tipping over or losing traction.
2. Survivor Detection – Efficient identification of survivors trapped under debris is crucial. HexaRover integrates LiDAR, infrared thermal cameras, and acoustic sensors to enhance its ability to detect life signals.
3. Real-Time Communication – A key limitation in current SAR operations is the delay in relaying information between response teams and robotic systems. HexaRover leverages GSM and IoT-based cloud connectivity to enable real-time data transmission, ensuring that rescuers have immediate access to critical insights.
4. Autonomy and AI-Driven Decision Making – Many existing robotic solutions require direct human intervention for operation. HexaRover implements AI-driven path planning, obstacle avoidance, and collaborative decision-making algorithms, reducing

human workload while increasing operational efficiency.

1.2 Objectives of the Study

- Design and Development of a Highly Mobile Robotic Platform: Implement a six-wheeled system that optimizes stability and manoeuvrability in rugged conditions.
- Integration of Multi-Sensor Data Processing: Employ LiDAR, infrared, ultrasonic, and environmental sensors for comprehensive data collection.
- Implementation of AI-Based Navigation and Obstacle Avoidance: Develop machine learning algorithms for intelligent decision-making and efficient route planning.
- Enhancing Communication Systems: Ensure reliable real-time data transmission using GSM, IoT networking, and cloud-based monitoring.
- Experimental Validation in Simulated Environments: Conduct field tests to assess navigation accuracy, battery performance, and environmental adaptability.
- Developing a Swarm Intelligence Framework: Enable multiple HexaRovers to coordinate in large-scale rescue missions.

2. SYSTEM DESIGN & METHODOLOGY

The HexaRover is designed to be a robust, autonomous, and adaptable search-and-rescue robot that can navigate hazardous terrains and relay critical information to human responders. Its system design integrates multiple subsystems, including locomotion, sensing, navigation, communication, power management, and AI-driven decision-making. Each subsystem is optimized for reliability and efficiency to ensure high performance in disaster scenarios.

2.1 Mechanical Structure & Locomotion System

1. Chassis and Structural Design

   The chassis of HexaRover is built from high-strength aluminum alloy with reinforced joints to withstand impacts and harsh environmental conditions. The frame is lightweight yet durable, ensuring the robot's mobility without compromising structural integrity. Additional shock-absorbing components have been integrated to reduce vibrations caused by rough terrains.

2. Six-Wheel Drive Mechanism

   HexaRover utilizes a six-wheel independent suspension system, allowing each wheel to adjust dynamically to terrain variations. The primary advantages of this system include:

   - Enhanced Stability: Reduces the risk of toppling on uneven surfaces.
   - Improved Traction: Enables movement across loose soil, gravel, and rocky landscapes.
   - Obstacle Handling: Facilitates climbing over debris and small obstacles up to 20 cm in height.

   Each wheel is powered by a high-torque Johnson DC motor (12V, 300 RPM) controlled by BTS7960 motor drivers, ensuring smooth speed adjustments and torque efficiency.

3. Adaptive Suspension System

   The rover employs a semi-active suspension system controlled by microcontrollers. This system dynamically adjusts the damping characteristics based on terrain feedback from onboard sensors, significantly improving shock absorption and stability in disaster environments.

2.2 Sensor Integration & Perception System

HexaRover incorporates a diverse set of sensors to enhance environmental perception and obstacle detection. These include:

1. LiDAR-Based Mapping & Object Detection
   - Model Used: RPLIDAR A2M8
   - Function: Real-time 2D mapping of surroundings and obstacle detection.
   - Range: 12 meters, 360-degree field of view.
   - Integration: Works in combination with ultrasonic and IR sensors for precise localization.
2. Ultrasonic & Infrared Sensors for Proximity Sensing
   - Model: HC-SR04 (ultrasonic), IR proximity sensors.
   - Function: Short-range obstacle detection.
   - Application: Enhances obstacle avoidance capabilities in cluttered environments.
3. Thermal & Infrared Imaging for Survivor Detection
   - Model: FLIR Lepton 3.5
   - Function: Identifies heat signatures of survivors trapped under debris.
   - Application: Facilitates AI-driven victim localization.
4. Environmental Sensors for Hazard Detection
   - Model: MQ-135 (gas detection), DHT22 (temperature & humidity sensor).

- Function: Detects hazardous gases and environmental conditions.
- Application: Helps assess air quality in collapsed structures.

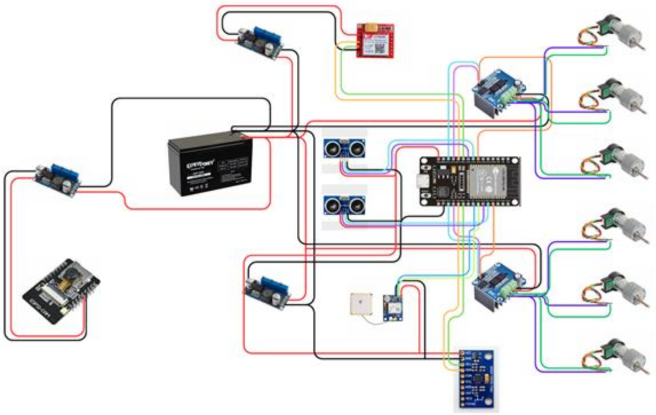

Fig -1: Circuit Diagram

2.3 Navigation & Path Planning Algorithms

HexaRover's movement is controlled using a combination of GPS-based localization, LiDAR-assisted SLAM (Simultaneous Localization and Mapping), and AI-powered path planning algorithms.

1. GPS-Based Navigation System
   - Module: NEO-6M GPS.
   - Function: Provides real-time location tracking with ±2.5m accuracy.
   - Application: Ensures HexaRover remains on a pre-defined search grid.
2. SLAM for Dynamic Mapping
   - Technology: Simultaneous Localization and Mapping (SLAM).
   - Function: Generates real-time environmental maps, continuously updating as HexaRover moves.
   - Application: Crucial for navigating unknown disaster zones.
3. AI-Powered Obstacle Avoidance
   - Algorithm Used: Deep Reinforcement Learning.
   - Training Data: Pre-trained on datasets of various terrains and obstacles.
   - Function: Enables real-time adaptive movement decisions.

Fig -2: HexaRover Deployed in Real-World Conditions

2.4 Communication & Data Transmission System

1. GSM & IoT Connectivity
   - Module: SIM800L.
   - Function: Sends telemetry data to cloud servers for real-time monitoring.
2. Wireless Video Streaming
   - Module: ESP32-CAM.
   - Function: Streams live video to rescue teams.
3. Multi-Robot Coordination
   - Protocol: MQTT-based communication.
   - Function: Enables multiple HexaRovers to share mapping data.

2.5 Power Management & Battery Optimization

1. Power Supply & Battery System
   - Battery Used: 12V 20Ah Li-ion battery.
   - Backup System: Solar charging for extended operations.
2. Energy Optimization Strategies
   - Sleep mode activation in low-energy states.
   - Intelligent load balancing of power-consuming components.

2.6 Software Implementation & AI Integration

1. Machine Learning Models: CNN for object detection.
2. Robotic Operating System (ROS): Framework used for motion planning.
3. Cloud Data Processing: Stores maps and sensor data in real-time for rescue coordination.

Fig -3: Structural and Electronic Assembly of HexaRover

3. CONCLUSIONS

The HexaRover project marks a significant leap in autonomous search and rescue (SAR) robotics, demonstrating its effectiveness in disaster response through enhanced mobility, survivor detection, and real-time communication. With its six-wheeled drive and adaptive suspension, HexaRover navigates rough terrains seamlessly, while thermal imaging and acoustic sensors improve survivor identification. IoT and GSM-based networking ensure reliable data transmission, and AI-driven navigation reduces human intervention. Additionally, solar-assisted charging extends operational efficiency for prolonged missions. By integrating advanced sensor fusion, artificial intelligence, and multi-agent coordination, HexaRover emerges as a scalable and efficient solution for disaster-prone regions, minimizing risks for human rescuers and improving response time.

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