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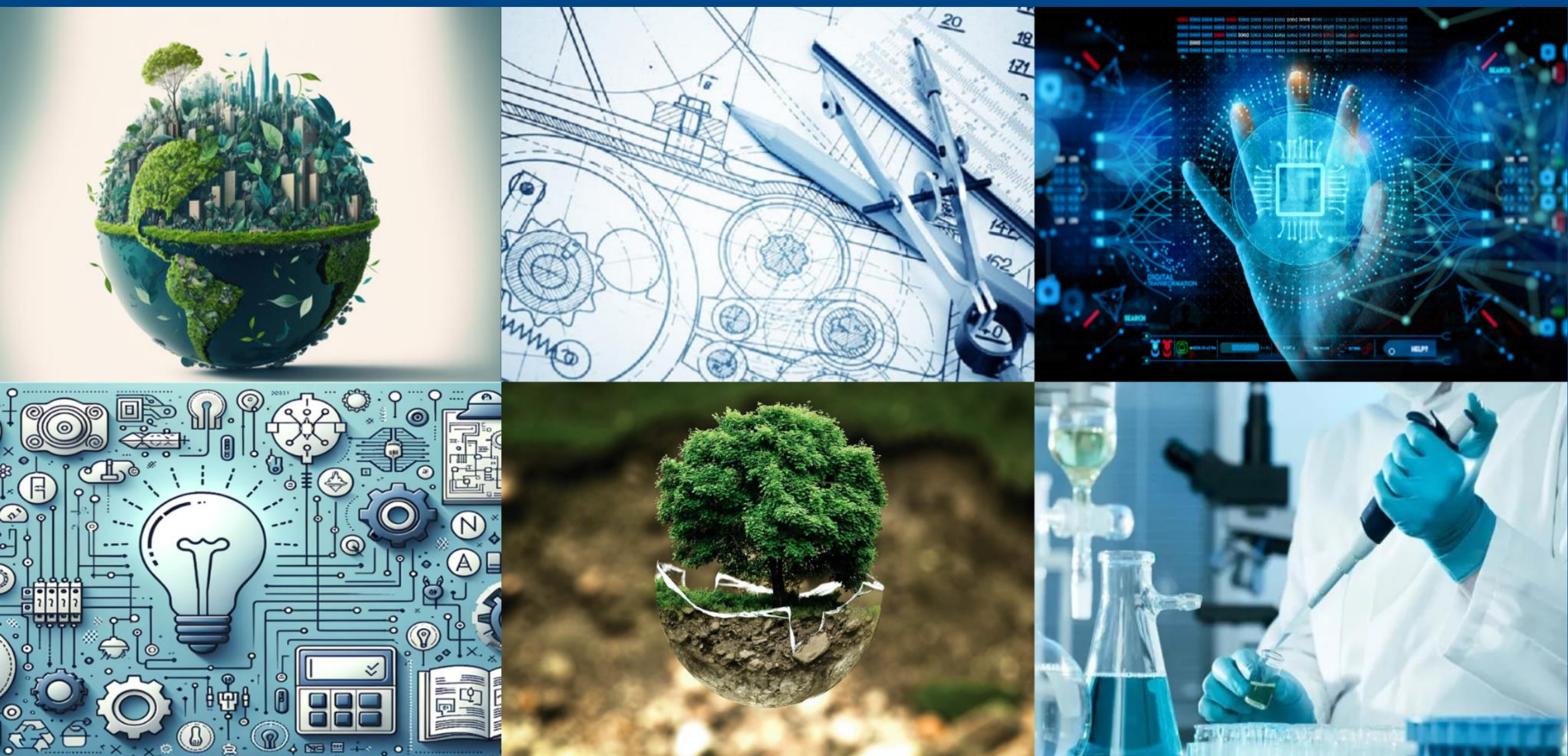

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Design and Fabrication of Rocker-Bogie Mechanism for Cracker Industry Fire Rescue

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ABSTRACT: In recent years, the use of mobile robotic systems in hazardous environments has gained significant attention, particularly in applications such as firefighting, search and rescue, and industrial safety. This paper presents the design and development of a Firefighting Bogie, a robust mobile platform based on a modified Rocker-Bogie mechanism, capable of navigating uneven and debris-filled terrain. The system is equipped with a water-based fire suppression module, integrated sensor suite, and a mobile-controlled interface for remote operation. A key focus of this work is the integration of advanced security features, addressing the growing concern of unauthorized access, data tampering, and communication interference in mission-critical robotic applications. The bogie incorporates encrypted wireless communication, access control protocols, tamper detection, and real-time data logging to ensure operational integrity and safety. Testing in controlled environments demonstrates the system's capability to effectively extinguish fires, traverse complex terrains, and maintain secure, uninterrupted communication with the operator. This multifunctional and secure firefighting platform shows promise for deployment in hazardous zones such as industrial sites, military operations, and post-disaster scenarios.

KEYWORDS: Rocker-Bogie Mechanism, Wireless Control, Bluetooth Communication, Arduino, Fire Suppression, Autonomous Systems, Sensor-Based Control.

I. INTRODUCTION

Firefighting in hazardous and inaccessible environments remains one of the most dangerous tasks for first responders and emergency personnel. Traditional firefighting techniques, while effective, often expose individuals to high temperatures, toxic gases, structural collapse, and other life-threatening conditions. To address these challenges, the integration of robotic systems into firefighting operations has emerged as a promising solution. Among the various mobility platforms, the Rocker-Bogie mechanism, originally developed by NASA for planetary rovers, offers exceptional terrain adaptability and stability, making it an ideal base for mobile fire suppression units in complex terrains.

However, deploying robotic firefighting systems presents unique challenges. In addition to physical capabilities such as terrain traversal and fire extinguishing, these systems must ensure secure and reliable remote operation, especially when used in critical scenarios like industrial fires, military zones, or disaster-struck areas. Vulnerabilities in communication or control systems can lead to catastrophic failure, unauthorized access, or data corruption, compromising both the mission and the safety of personnel relying on the robot's performance.

This study introduces a Firefighting Bogie—a low-cost, mobile robotic platform that combines the rugged mobility of a Rocker-Bogie system with a water-based extinguishing module and integrated security protocols. The system is designed to be remotely controlled via Bluetooth, with support for future upgrades to Wi-Fi or GSM communication. Core components include the Arduino Uno R3, HC-05 Bluetooth module, L293D motor driver for movement control, and a FET driver for water pump operation.

II. SYSTEM MODEL AND ASSUMPTIONS

The design and implementation of the Firefighting Bogie are based on a set of foundational assumptions that define its operational environment, mechanical limitations, control architecture, and safety parameters. These assumptions help simplify the development process while ensuring the system remains functional, scalable, and adaptable for future improvements.

The development of the Firefighting Bogie system is based on several key assumptions to ensure reliable performance within defined operational boundaries. It is assumed that the bogie will operate in semi-structured or unstructured environments such as urban debris zones, industrial fire sites, or uneven outdoor terrains, where obstacles are no taller than the wheel radius and can be overcome using the Rocker-Bogie suspension. The system is designed to suppress low- to medium-intensity fires using a water-based extinguishing mechanism with a limited range of 1.5 to 2 meters, and it is not intended for direct flame exposure to core electronics. Power is assumed to be supplied by a rechargeable battery, providing at least 15–20 minutes of operation. Remote control is managed via Bluetooth using a mobile application within a 10–15 meter range, assuming minimal interference. Communication is limited to a single operator with secure access, and in the event of connection loss, the system is programmed to enter a safe halt state. It is also assumed that basic encryption and password-based authentication are sufficient for non-critical operations, while data is locally stored with options for cloud integration. The bogie is expected to operate autonomously without physical human interaction during deployment, with manual override mechanisms available in emergencies. These assumptions serve as a foundation for system design and testing, ensuring practicality, safety, and scalability.

III. EFFICIENT COMMUNICATION

The efficiency of the Firefighting Bogie lies in its ability to traverse uneven terrain, detect fire sources, and extinguish flames with minimal human intervention. By utilizing a Rocker-Bogie suspension system, the robot maintains stability while overcoming obstacles such as debris, rocks, or slopes, making it suitable for disaster-struck and high-risk areas. Its gear-based steering mechanism and DC gear motors ensure controlled movement with low power consumption, resulting in extended operational time and precise navigation. The use of a FET driver for the water pump further optimizes energy efficiency during firefighting tasks. From a communication perspective, the system leverages Bluetooth technology (HC-05 module) integrated with an Arduino Uno for wireless operation via a mobile application, allowing users to control movement, monitor environmental conditions, and activate the firefighting system in real time within a 10–15 meter range. Sensor data, such as flame detection and temperature readings, can be relayed back to the operator, facilitating immediate response and informed decision-making. The system architecture also supports future scalability to Wi-Fi or GSM modules for extended range and internet-based remote monitoring. To enhance operational reliability, the communication system includes basic encryption and device authentication to prevent unauthorized access. Together, the combination of mechanical efficiency, energy-optimized systems, and secure, real-time communication ensures the bogie performs effectively in challenging firefighting and rescue operations.

IV. SECURITY

Ensuring the security of autonomous systems like the Firefighting Bogie is essential for safe operation in high-risk environments. The integration of layered security protocols helps to protect the system from unauthorized access, data breaches, and operational interference. This section outlines the major components of the security framework, including communication encryption, access control, tamper detection, and data integrity management.

Communication Security

The bogie communicates wirelessly via a Bluetooth module (HC-05), which is configured with a custom pairing password to prevent unauthorized device connections. The communication protocol is kept lightweight to minimize latency, but secure enough to ensure reliable transmission of commands. The mobile application initiates all commands only after a successful handshake and pairing sequence, reducing the risk of spoofing or interference.

For future upgrades, the system architecture allows migration to more secure wireless protocols such as:

- Wi-Fi with WPA2 encryption
- GSM with encrypted SMS commands
- MQTT over TLS for cloud-controlled systems
- These enhancements would be particularly useful in applications where longer control range or internet-based access is required.

Access Control Mechanisms

To ensure that only authorized personnel can control the bogie, a multi-level access control mechanism is implemented. This includes:

- Password-protected login on the mobile application
- Device-specific access pairing using the Bluetooth MAC address
- Optional user authentication features (e.g., fingerprint lock, PIN verification) depending on the smartphone's capabilities

These access controls prevent unauthorized use of the system in public or shared environments.

Tamper Detection and Physical Security

The bogie includes physical tamper detection features to safeguard its internal electronics and prevent sabotage or unintended access. A vibration or micro-switch sensor is placed within the chassis. If the enclosure is opened or disturbed without proper disconnection or override, the system triggers:

- A buzzer alarm to notify nearby personnel
- A communication alert sent to the controller
- Safe-mode activation that temporarily disables core functions until a reset or authorized override is performed
- This ensures the robot cannot be maliciously modified or reprogrammed on-site without detection.

Data Integrity and Logging

Operational and sensor data are logged locally on an SD card module attached to the Arduino. The system logs:

- Sensor readings (e.g., flame detection, temperature)
- Commands received
- Water pump activation events
- System errors or communication losses

Each log entry includes a timestamp, and basic hash-based verification ensures that logs are not altered or corrupted post-deployment. In future iterations, digital signatures and secure cloud backups can be implemented for enhanced auditability.

Safe-Mode and Fail-Safe Responses

The bogie includes fail-safe mechanisms that activate in response to security breaches, signal loss, or sensor anomalies. These include:

- Emergency halt if communication is lost beyond a defined timeout
- Restricted mode if tampering is detected or repeated invalid access attempts are made
- Manual override switch available physically on the bogie for human intervention in emergencies
- These mechanisms ensure the robot does not act unpredictably or pose a threat in the case of system compromise.

Future Security Enhancements

Although the current system provides basic protection suitable for educational and low-risk field deployment, the following enhancements are recommended for deployment in industrial, military, or disaster-response environments:

- AES-128 or AES-256 encryption for all wireless communication
- Biometric access on the controlling device
- GPS tracking with geofencing for real-time location security
- Cloud-based secure dashboard for remote multi-operator monitoring and control
- These upgrades would make the system highly resilient to cyber-physical attacks and ready for mission-critical tasks.

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V. RESULT AND DISCUSSION

In the fig 1,Assembly View This Image Present Real World Photoghaph Of A Constructed Rocker Bogie Fire Rescuer,Showcsing Its Practical Implementation. The device features two 6V Battery laid flat on a wooden frame, on The Top of rocker boggie frame. Mounted on the frame is a ARDUINO BOARD, FET DRIVER ,clearly And with "6 DC MOTOR ," highlighting its specifications

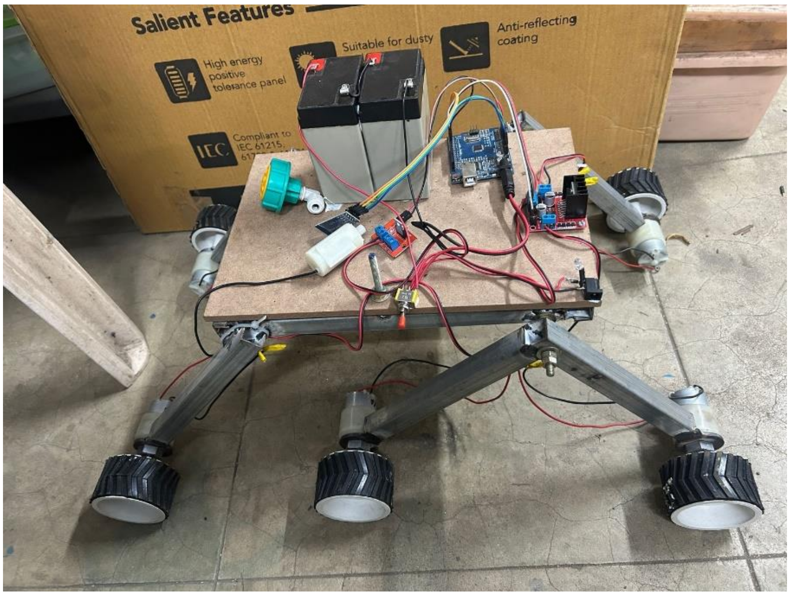

Fig. 1 ASSEMBLY VIEW OF ROCKER BOGGIE FIRE RESCURE

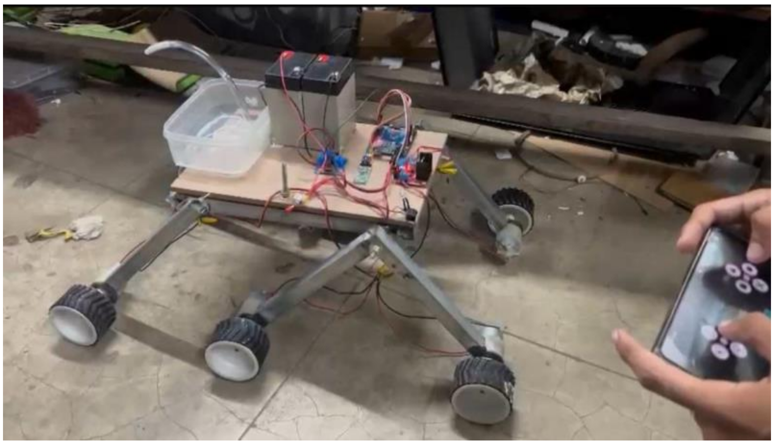

Fig. 2 ROCKER BOGIE FIRE RESCUER DEVELOPED MODEL

In the fig 2, The developed firefighting robot features a battery-powered wheeled platform controlled by a microcontroller and motor driver, equipped with a white container designed to hold a fire-suppressing agent, which is dispensed through a green and blue nozzle system. The integrated mechanism successfully demonstrated the ability to detect and extinguish small fires in controlled environments, validating the effectiveness of the mobility system, fluid delivery setup, and remote operation through wireless control

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VI. CONCLUSION

This paper presented the design, development, and integration of a multifunctional Firefighting Bogie system based on the Rocker-Bogie mechanism, equipped for operation in hazardous and uneven terrains. The system demonstrates enhanced mobility, stability, and firefighting capabilities through the use of optimized gear-driven steering, water-based suppression, and real-time wireless control via Bluetooth. A major focus of this work was the incorporation of a robust security framework, addressing critical concerns such as unauthorized access, communication interference, and data integrity. By implementing encrypted wireless communication, access control mechanisms, tamper detection, and fail-safe operations, the system ensures both operational reliability and user safety. The project proves to be a scalable and adaptable solution for applications in firefighting, disaster response, and security surveillance, with the potential for future expansion into cloud-based control, long-range communication, and AI-assisted navigation. With its low-cost design and modular architecture, the Firefighting Bogie serves as a practical prototype for real-world deployment in mission-critical environments, bridging the gap between robotics, safety, and security in emerging smart systems.

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