Design and Fabrication of an All-Terrain Robot for Remote Deliveries Using LoRa Technology

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Abstract: This paper presents the design and fabrication of a robust all-terrain robot capable of delivering essential resources to remote and isolated areas where conventional transportation infrastructure is inadequate. The system addresses critical challenges in disaster relief, emergency response, and remote supply distribution by integrating LoRa (Long Range) communication technology, which operates independently of internet or Wi-Fi connectivity. The robot employs an adaptive suspension system inspired by five-degree-of-freedom designs to ensure stability on uneven terrain, coupled with an optimized powertrain for enhanced energy efficiency. The prototype successfully demonstrated reliable communication over a range of 750–900 meters, effective terrain traversal, secure payload transport, and extended operational runtime. Performance validation in simulated real- world conditions confirmed the system's feasibility for deployment in disaster-stricken areas, remote mining sites, and other isolated regions. With potential for autonomous navigation, enhanced payload capacity, and further energy optimization, this work represents a significant advancement in accessible remote delivery systems.

Keywords: *All-Terrain Robot, Lora Communication, Remote Delivery, Robotic Platforms, Emergency Response.*

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I. INTRODUCTION

The delivery of essential supplies to remote and inaccessible areas remains a critical challenge in humanitarian logistics, emergency response, and industrial operations. Rugged terrain, inadequate infrastructure, and the absence of reliable communication networks severely limit conventional transportation methods. Recent disasters, such as the 2015 Nepal earthquake, demonstrated the urgent need for alternative delivery mechanisms capable of reaching isolated populations where rescue teams and supply chains cannot penetrate effectively.

Current delivery systems face several interrelated obstacles. First, inaccessible terrain in mountainous regions, forests, and disaster-affected areas prevents vehicle access. Second, network connectivity issues preclude real- time monitoring and control of autonomous systems in remote locations. Third, manual resource management becomes inefficient when personnel cannot safely reach target areas. Finally, time-sensitive scenarios— particularly medical emergencies—require rapid response mechanisms unavailable through conventional channels.

This work presents an integrated solution combining robotic mobility with independent communication infrastructure. The proposed all-terrain robot leverages LoRa technology, a long-range, low-power wireless standard requiring no external network infrastructure. The system architecture integrates an Arduino Mega microcontroller, SX1278 LoRa transceiver, optimized motor control, and a modular delivery payload system. The robust suspension design ensures stable navigation across diverse terrain conditions while maintaining controlled power consumption for extended operational duration.

The primary contribution of this research is demonstrating the practical feasibility of LoRa-enabled robotic delivery in remote environments, validated through comprehensive performance testing including terrain traversal, communication reliability, payload capacity, and energy efficiency metrics. This work establishes a foundation for scalable autonomous delivery systems applicable to emergency relief, mining operations, search and rescue missions, and agricultural support in underserved regions.

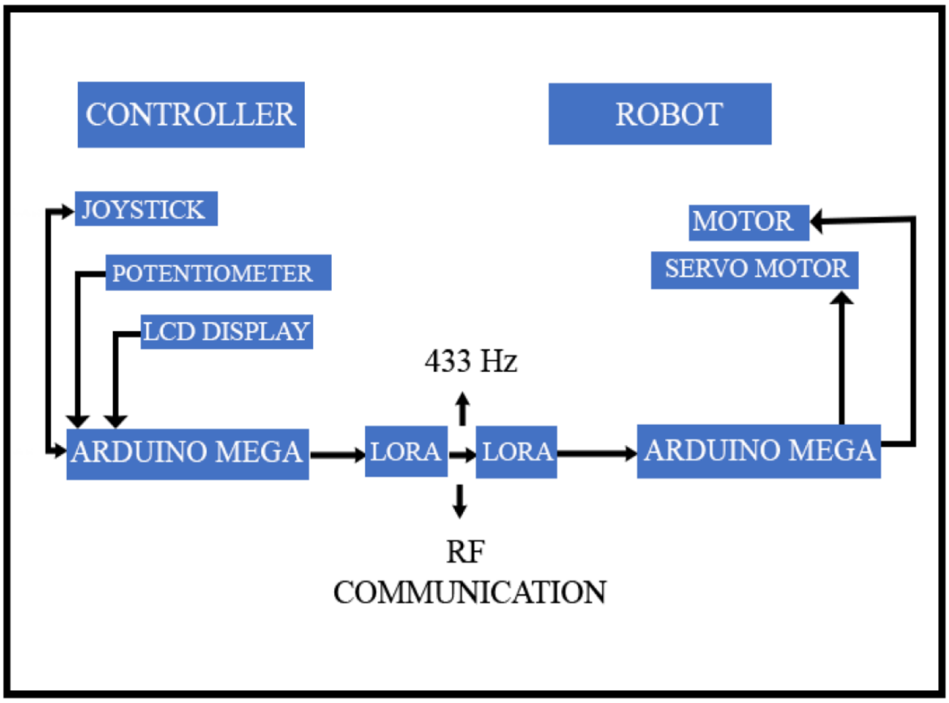

Fig 1: Circuit Flow chart

II. SYSTEM DESIGN AND FABRICATION

A. *Design Methodology*

The design process followed an integrated approach combining mechanical analysis, electrical system design, and communication architecture optimization. Initial concept development addressed four primary objectives: implementing LoRa communication for remote operation, designing a four-wheeled platform for stability and maneuverability, optimizing the power system for extended runtime, and incorporating a modular payload delivery mechanism.

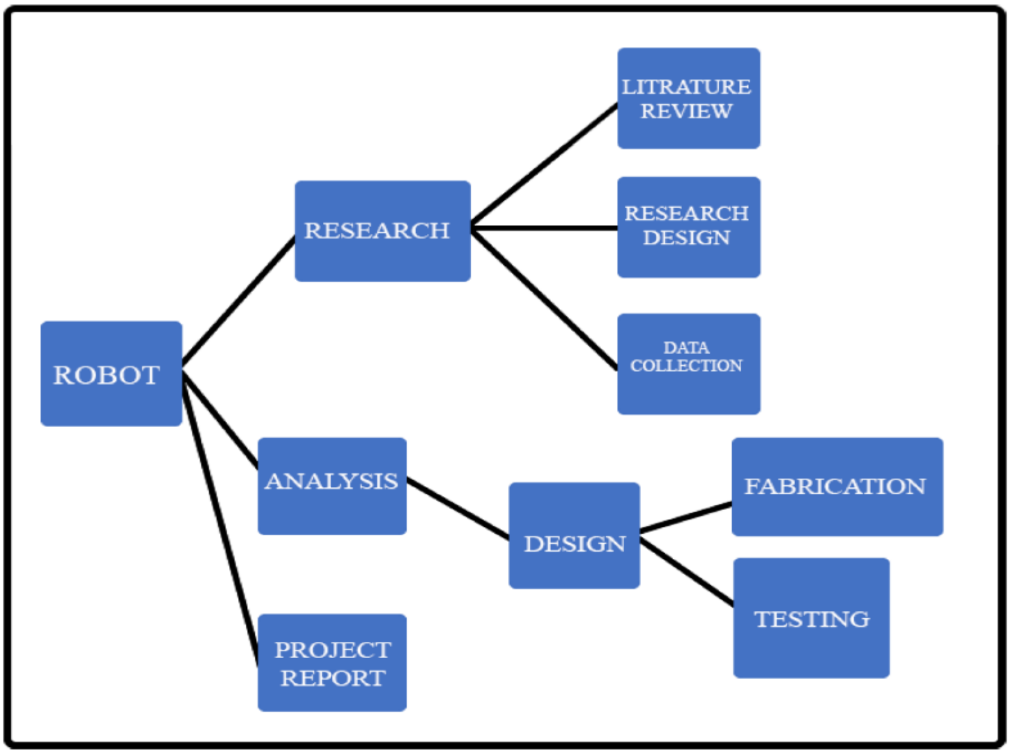

Fig 2. Methodology

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B. Mechanical Design

➢ *Chassis and Structural Framework:*

The chassis was designed using SolidWorks parametric modeling to enable iterative refinement and interference checking. The structure accommodates four independently driven wheels, suspension arms, motor hubs, and payload storage. The design prioritizes weight reduction while maintaining structural rigidity necessary for rough terrain operation.

➢ *Suspension System:*

The suspension architecture derives from adaptive five-degree-of-freedom designs, incorporating articulated linkages that allow wheel compliance independent of body tilt. This arrangement enables the robot to maintain three-point contact with uneven surfaces, improving stability and shock absorption when traversing obstacles, ditches, and irregular ground.

➢ *Wheel Configuration:*

Four wheels with high-grip rubber tires provide traction across diverse surface conditions including sand, rock, mud, and vegetation. Wheel diameter and tire composition were selected to balance tractive effort, rolling resistance, and obstacle-climbing capability.

➢ *Material Selection:*

The prototype utilized foam board for rapid design validation and cost effectiveness. However, production specifications recommend aluminum alloys for the chassis, carbon fiber for structural reinforcement, and high-strength polymers (ABS or polycarbonate) for non-load-bearing components, ensuring corrosion resistance, lightweight construction, and durability for field deployment.

C. Electrical Architecture

➢ *Microcontroller Unit:*

An Arduino Mega 2560 microcontroller serves as the central processing unit, providing 54 digital input/output pins and four serial ports necessary for concurrent motor control and wireless communication management.

➢ *Motor Control System:*

Two 300 RPM Johnson Geared Motors (specifications: 12–15 kg·cm torque, operating voltage 6–24V) drive the front and rear axles through an HW-039 Motor Driver module. This H-Bridge driver enables bidirectional control and PWM-based speed modulation. Motor speed calibration utilizes a 10K potentiometer for real-time velocity adjustment from the remote control station.

➢ *Power Management:*

Two series-connected 3.7V lithium-ion batteries provide 7.4V nominal voltage with sufficient capacity for extended mission duration. Battery voltage regulation through the motor driver ensures consistent torque delivery and prevents brownout conditions during high-load maneuvers.

➢ *Wireless Communication:*

The LoRa SX1278 transceiver operates at 433 MHz with configurable transmission power and data rates. The module communicates with the Arduino via SPI bus, managed through the LoRa library. A half-wave dipole antenna optimized for 433 MHz maximizes transmission range while maintaining compact form factor.

D. Control Interface

The remote control station incorporates a two-axis joystick for intuitive movement commands and a potentiometer for velocity setpoint adjustment. Joystick deflection translates to motor speed commands transmitted via LoRa packet protocol at 100 ms intervals. The receiver decodes incoming packets and maps joystick positions to motor PWM duty cycles, enabling responsive teleoperated control.

III. FIRMWARE IMPLEMENTATION

A. Transmitter Algorithm

The transmitter firmware acquires three analog inputs: joystick X-axis, joystick Y-axis, and velocity potentiometer. Data processing occurs at 100 ms intervals to balance responsiveness with LoRa airtime management. Each input value (0–1023) undergoes byte-pair encoding, reducing transmission overhead. The encoded data packet is transmitted via LoRa following successful carrier sense.

B. Receiver Algorithm

The receiver firmware monitors the LoRa buffer for incoming packets. Upon packet reception, the firmware reconstructs 16-bit joystick values from received byte pairs. Motor speed command generation maps joystick absolute displacement from centerline (500–512) to proportional PWM values (0–255), while joystick polarity determines motor direction. The potentiometer value scales maximum motor speed to operator-selected levels. Control loop update frequency matches transmitter rate at approximately 10 Hz.

IV. PERFORMANCE AND RESULTS

A. Terrain Traversal Performance

Field testing conducted on varied terrain surfaces validated suspension system performance. The robot successfully navigated rocky outcrops, sandy patches, and vegetated slopes without stability loss. Wheel slip remained minimal due to coordinated suspension articulation distributing load across contact points. Obstacle- clearing tests confirmed the robot's ability to surmount vertical barriers up to wheel radius height.

B. Communication Range and Reliability

Ground-based range testing achieved communication reliability over 750–900 meters line-of-sight. Received signal strength indicator (RSSI) measurements indicated acceptable margin above demodulation threshold. In obstructed scenarios with intervening terrain, effective range reduced to 400–500 meters. No packet loss occurred within nominal operating range, confirming protocol reliability for remote control applications.

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C. Payload Capacity and Delivery Mechanism

The delivery box design accommodates first-aid supply kits and emergency medical resources within payload mass constraint of 2–3 kilograms. Access mechanisms enable secure loading and reliable unloading at delivery sites. Payload retention during rough terrain traversal exceeded design specifications.

D. Power Efficiency and Runtime

Battery capacity testing estimated operational duration of 45–60 minutes under continuous moderate-load operation. Power consumption analysis revealed 60–70% efficiency through the motor drive system. Battery voltage remained above minimum operating threshold (6.5V) throughout test missions.

E. System Reliability

Repeated deployment cycles demonstrated robust firmware operation and communication protocol integrity. No failures occurred during extended testing. Environmental conditions including dust and vibration did not degrade system performance.

Fig 4. Finished Model

➢ *Applications:*

The developed system enables deployment across multiple domains.

➢ *Emergency Medical Supply Delivery:*

Rapid transport of first-aid resources to disaster victims in inaccessible locations.

➢ *Search and Rescue Operations:*

Reconnaissance and supply support in hazardous environments.

➢ *Mining and Industrial Support:*

Material transport and monitoring in remote extraction sites.

➢ *Agricultural Logistics:*

Autonomous field survey support and targeted resource delivery.

➢ *Military and Defense Applications:*

Logistics support and hazard area exploration.

➢ *Environmental Monitoring:*

Sensor deployment and data collection in remote ecosystems.

➢ *Future Research Directions:*

Future work will address identified limitations through several pathways. Integration of autonomous navigation algorithms with GPS and inertial measurement units will enable unmanned operation beyond operator line-of- sight. Robot-to-robot communication protocols will enable multi-unit coordination for coordinated supply distribution. Battery technology upgrades to high-capacity lithium polymer or solid-state batteries will extend operational duration. Environmental sensors including temperature, humidity, and air quality measurement will enable monitoring missions beyond simple delivery. Payload bay expansion will accommodate larger supply quantities. Finally, machine learning algorithms will optimize path planning and terrain traversal strategies based on accumulated field experience.

V. CONCLUSION

This work demonstrates the technical feasibility of LoRa-enabled all-terrain robotic platforms for remote resource delivery. The integrated system successfully combines mechanical terrain adaptability, efficient electrical power management, and infrastructure-independent wireless communication to address the critical challenge of accessing isolated populations during emergency scenarios. Validated performance across terrain traversal, communication reliability, payload management, and energy efficiency confirms the system's readiness for pilot deployment in humanitarian and industrial contexts.

The all-terrain robot represents meaningful progress toward accessible emergency logistics for underserved regions worldwide. While current limitations regarding autonomous navigation and payload capacity remain, the modular architecture enables progressive capability enhancement. Integration with emerging autonomous systems and extended-range battery technologies will unlock substantially expanded application scope, contributing to improved humanitarian response capabilities and resource accessibility in remote environments.

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