

A Mobile Robot for Extreme Environments with Wireless Teleoperation and Autonomous Environmental Perception

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Abstract—This paper presents a mobile robot designed for task execution in extreme disaster environments, integrating wireless teleoperation with autonomous environment perception. The robot employs wheel-equipped, 3-DoF legs that switch locomotion modes and traverse diverse terrains. A ROS 2–based architecture enables remote operation, and a perception pipeline that fuses 4D LiDAR and a depth camera provides accurate environmental estimation in complex scenes. Using these capabilities, the robot autonomously measures ground geometry and forward free space and performs terrain traversal in extreme environments.

Keywords—*extreme environment, mobile robot, teleoperation, ROS 2, environment perception system*

I. INTRODUCTION

Disaster sites constitute extreme environments with multiple hazards. Human operators performing exploration, transport, or rescue under such conditions face a high risk of secondary incidents and injuries. Moreover, missions such as victim rescue and goods delivery are time-critical, demanding rapid mobility.

Robots that can be deployed in unstructured environments on behalf of humans are therefore needed. To assess feasibility, we analyzed mobile robots with a focus on locomotion performance. Conventional single-mode platforms include wheeled and legged robots. Wheeled robots offer high speed but struggle on rough terrain; legged robots provide terrain adaptability but suffer from lower mobility and energy efficiency. Each mode has strengths but also clear weaknesses; while acceptable in structured settings, they are difficult to deploy in extreme,

unstructured environments. To address the limitations of single-mode locomotion, transformable (hybrid) robots that combine modes have been explored.

Wheel-transforming mobile robots [1]–[3] travel quickly in a wheel mode and overcome obstacles by transforming the wheels, yielding simple control and energy benefits. However, because transformation typically scales from the wheel size, they encounter difficulties with obstacles taller than the wheel, discontinuous footholds, and other nonuniform terrain.

In addition, operation in unstructured environments demands an appropriate control system. A review of control approaches for disaster-response robots [4]–[7] shows that robust behavior is commonly achieved by fusing multiple sensors in real time to obtain reliable state and terrain information, thereby stabilizing control. Such multi-sensor control architectures increase the trustworthiness of terrain perception and the robustness of locomotion in unstructured settings.

Consequently, executing missions in unpredictable mixed terrains requires: (i) high agility, (ii) robust adaptation and traversal across diverse terrain types, (iii) remote monitoring and control from a safe standoff position, and (iv) autonomous perception when the operator cannot reliably assess the terrain.

We therefore propose a mobile robot for extreme environments that combines wireless teleoperation with autonomous environmental perception. The robot uses wheel-equipped, transformable legs to adapt to terrain features and move efficiently. IP-based wireless communication (Wi-Fi) supports

operation from a safe location, and the perception stack enables the robot to recognize and traverse difficult terrain, achieving fast and stable mission execution.

II. MAIN RESULTS

A. Robot Overview

Fig. 1 shows the proposed robot. It combines wheels with articulated legs so that both locomotion modes can be exploited. A forward-looking monitoring camera and perception sensors are mounted at the front of the robot.

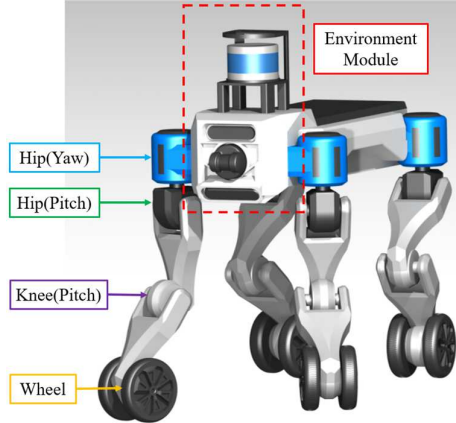


Fig. 1. Prototype of the mobile robot for extreme environments.

B. Wheel-Equipped Articulated Legs

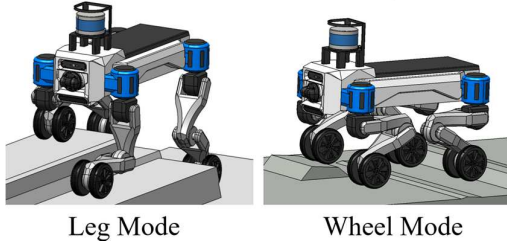


Fig. 2. Locomotion using wheel-equipped, articulated legs.

Each leg is a 3-DoF serial chain Hip(Yaw)–Hip(Pitch)–Knee(Pitch) with an additional wheel rolling DoF at the tip for propulsion. The robot uses wheels for high-speed travel on flat or continuous terrain and legs for traversal on complex, discontinuous terrain.

C. Teleoperation (ROS2)

To enable remote operation, the robot carries an onboard Wi-Fi router, forming a wireless link to the operator station as shown in Fig. 3. Both endpoints run Ubuntu 22.04 and communicate via ROS 2. Sensor data and robot states are transmitted on the uplink, while control commands are sent on the downlink.

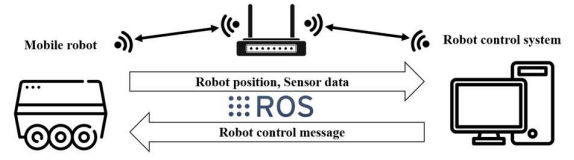


Fig. 3. Operator station for the extreme-environment mobile robot.

D. Autonomous Environment Perception System

We developed an autonomous perception system that uses both a 4D LiDAR and a depth camera mounted at the front of the robot. The complementary strengths—long-range, vertical-structure sensitivity of the LiDAR and high-resolution, near-field ground sensing of the depth camera—yield robust and precise perception by compensating for each other’s weaknesses. The two sensors are extrinsically calibrated to a common frame, and ROS 2 fuses the streams into a single point cloud. State estimation is performed with Point-LIO (LiDAR–IMU fusion) to produce odometry and map frames (Fig. 4).

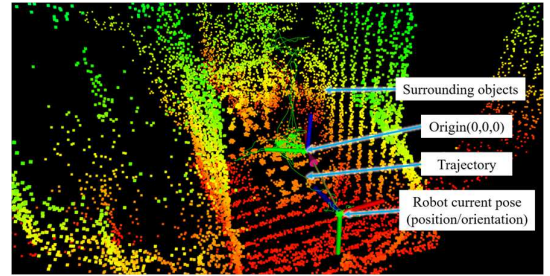


Fig. 4. SLAM based on LiDAR-IMU fusion.

Using this reference frame, we estimate the ground plane and segment step planes ahead to compute step height and horizontal distance. We also estimate corridor width from the fused cloud by detecting two vertical planes (left/right walls) and measuring the passage width. Fig. 5 illustrates the integrated perception system. Fig. 6 shows a narrow corridor without steps: the left wall (blue) and right wall (magenta) are detected, while no step (red) is found, indicating correct operation. Thus, by recognizing ground and free-space geometry and extracting key metrics, the robot can autonomously assess the environment.

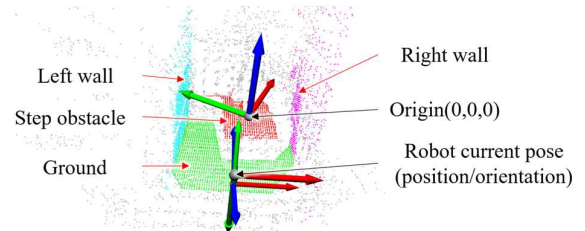


Fig. 5. Integrated autonomous perception system.

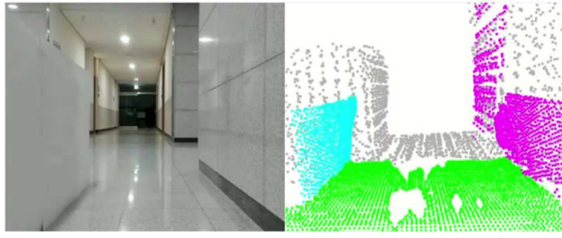


Fig. 6. Spatial perception experiments.

III. SUMMARY

We presented a prototype mobile robot for extreme environments that integrates wireless teleoperation with autonomous perception. The platform combines wheels with 3-DoF legs, enabling fast travel and rough-terrain traversal via locomotion-mode switching. A ROS 2 teleoperation stack was implemented, and 4D LiDAR–depth fusion allows the robot to perceive and estimate ground and free-space geometry for decision-making.

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