

Development of a 4-Wheel Elevated Mobile Robot for High-Position Valve Manipulation

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1. Introduction

Wheel valves installed at elevated locations in nuclear power plants require frequent operation and maintenance. However, direct human access is often restricted due to densely packed equipment, confined spaces, uneven floors with steps and debris, and the potential risk of coolant leakage or radioactive contamination. Consequently, there is an increasing demand for robotic platforms capable of stable mobility and task execution in hazardous high-elevation environments.

The previously proposed TeLoS, a three-wheeled omni-wheel-based elevated work robot, demonstrated excellent maneuverability on flat indoor surfaces. Nevertheless, its ability to overcome steps and rough terrain typically encountered in nuclear facilities was limited. In addition, due to the inherent characteristics of omni-wheels, ground traction was restricted, and structural reinforcement was required to reliably withstand lateral reaction forces generated during wheel valve manipulation.

To address these limitations, this study proposes a high-elevation robotic platform adopting a four-wheel independent steering and driving configuration combined with conventional pneumatic tires. Pneumatic tires provide a high friction coefficient and a large contact area, enabling stable locomotion on rough surfaces. The four-wheel configuration distributes the load more effectively, thereby enhancing structural stability against reaction forces during manipulation tasks. Furthermore, four multi-stage telescopic lifts are independently controlled to actively maintain the horizontal alignment of the upper working platform and to improve overall structural stiffness.

A precision-controlled collaborative manipulator is mounted on the upper platform to enable accurate operation of wheel valves installed at complex and elevated positions. Through this integrated design, the proposed system achieves enhanced mobility, structural robustness, and precise manipulation capability, functioning as a practical robotic solution for high-risk elevated operations in nuclear facilities.

2. Mechanical Design of the 4-Wheel Elevated Mobile Robot

The proposed 4-wheel elevated mobile robot is designed based on a telescopic lift mechanism for stable vertical elevation of the upper working platform and an

independent four-wheel steering and driving system for high maneuverability. As shown in Fig. 1, the overall structure adopts a four-point support configuration, in which a 3-stage telescopic linear lift is installed at each supporting leg to enable vertical extension and retraction of the upper platform.

The telescopic structure consists of multiple nested sections, allowing the robot to maintain a minimized overall height when fully retracted for passing through doorways, while providing sufficient elevation height during operation.

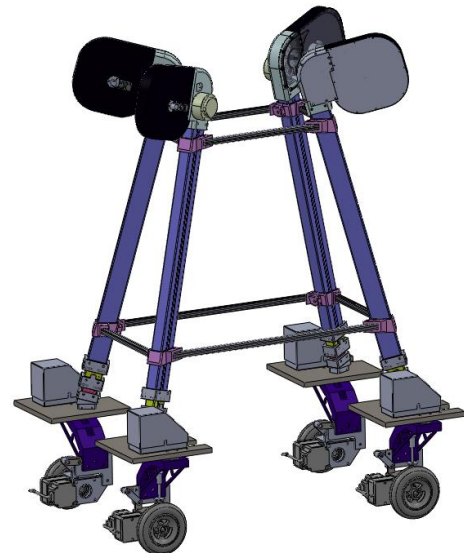


Fig. 1. Overall design of the proposed 4-wheel elevated mobile robot

The vertical motion of each telescopic lift is achieved through a motor-driven chain transmission mechanism, as illustrated in Fig. 2.

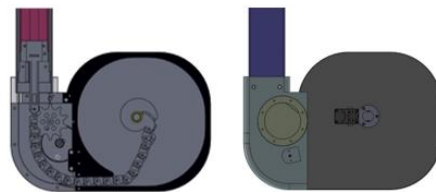


Fig. 2. Front and rear views of the chain-driven telescopic lift mechanism

A motor mounted within the lift module drives a sprocket connected to a block chain, which converts rotational motion into linear displacement. By controlling the motor direction, the chain either pulls or pushes the nested telescopic sections, enabling extension and retraction of the lift.

This configuration allows stable and synchronized vertical motion while maintaining a compact internal structure. The chain-based transmission provides sufficient force transmission capability to support the upper platform load during elevation and lowering operations.

Table I: Geometric and Physical Characteristics of the 4-Wheel Elevated Mobile Robot

Parameter	Value
Total Mass	80 kg
Wheel Module Mass	10 kg (each)
Telescopic Lift Mass	10 kg (each)
Lift Structure	3-stage telescopic
Minimum Height	1700 mm
Maximum Height	3550 mm
L × W at Min. Height	1000mm x 780mm
L × W at Max. Height	2000mm x 1380mm
Drive Configuration	Independent steer/drive

Table I summarizes the key geometric and structural specifications of the proposed platform, including its overall mass, elevation range, drive configuration, and overall dimensions at both Min. Height and Max. Height. These values indicate the maximum overall length and width of the platform in the fully retracted and fully elevated states, respectively. In particular, the compact footprint at Min. Height allows the robot to pass through standard doorways commonly found in typical indoor industrial environments. The system provides a wide vertical operating range through a 3-stage telescopic lift while maintaining a compact form factor in the retracted state. The four-wheel independent steering and driving system ensures high maneuverability and stable support, particularly during elevated operation.

The upper platform is designed with a modular mounting interface, enabling the integration of a manipulator, collaborative robot, or other task-specific equipment. Therefore, the proposed system serves as a reconfigurable elevated mobile platform capable of accommodating various robotic modules depending on the intended application..

3. Wheel Valve Operation on an Elevated Mobile Platform

Wheel valve manipulation is performed after the platform reaches the required working height. First, all four telescopic legs are fully extended to secure sufficient vertical reach. As the footprint of the base increases when the legs are extended, the front two legs

are then slightly retracted to generate a small forward tilt of the platform. This adjustment allows the upper structure to approach the wall more closely while maintaining four-point support, thereby reducing the distance between the robot base and the wheel valve.

After positioning, the end-effector is aligned with the valve center and commanded to follow a circular trajectory around the valve axis. The desired Cartesian position is defined as in (1).

$$P_d(t) = P_c + \begin{bmatrix} 0 \\ r \cos \theta(t) \\ r \sin \theta(t) \end{bmatrix}, \theta(t) = \frac{2\pi}{T} t \quad (1)$$

Where P_c denotes the valve center position, r is the rotation radius, and T is the period of one revolution. The target position $P_d(t)$ is updated in real time, and inverse kinematics is used to compute the corresponding joint configuration. The previous joint solution is used as the initial seed to ensure continuity, and joint velocity limits are applied to maintain smooth motion. Through this trajectory-based control, the end-effector continuously tracks the circular path, enabling stable rotation of the wheel valve while the elevated platform maintains structural support.

4. Experiments and Results

To verify the feasibility of high-position valve manipulation, a simulation experiment was conducted in Isaac Sim. As shown in Fig. 3, a wheel valve located at a height of 3.6 m was modeled in the virtual environment. The valve was assumed to be fixed in space, and its center position relative to the robot base frame was set to (0.7, 0.0, 0.5) m. The physical valve radius was defined as 0.125 m.

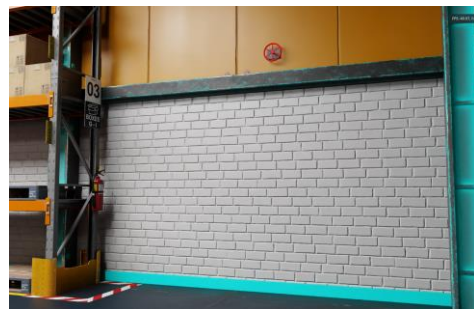


Fig. 3. High-position wheel valve in the simulation environment

As shown in Fig. 4, the platform was fully elevated and slightly tilted forward by retracting the front legs, allowing the manipulator to reach the valve. The end-effector then followed the circular trajectory to rotate the high-position wheel valve in simulation.

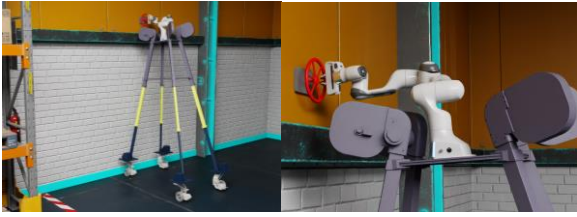


Fig. 4. Simulation of the elevated mobile robot manipulating a high-position wheel valve

The 3D trajectory of the end-effector consists of an initial approach phase followed by a circular motion around the valve center. The approach path was designed to prevent contact with the outer surface of the valve, allowing a smooth transition into the rotation phase. After reaching the desired contact radius, the end-effector accurately follows the predefined circular trajectory, demonstrating stable and consistent valve rotation.

As shown in Fig. 5, the generated path avoids collision with the valve structure and clearly forms a circular motion around the target center.

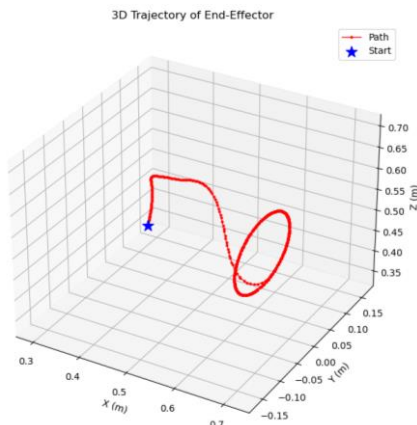


Fig. 5. 3D trajectory of the end-effector during wheel valve manipulation

5. Conclusion and Future Work

In this study, the proposed elevated mobile robot successfully demonstrated the capability to manipulate a wheel valve located at a high and fixed position. The platform was able to elevate to the required height, adjust its posture, and enable stable valve rotation using the manipulator. The simulation results confirmed the feasibility of performing high-position valve operation with the integrated elevated mobile system.

For future work, a vision-based perception system will be incorporated to enhance autonomy. By integrating RGB and depth cameras, the robot will be able to detect and localize wheel valves in various positions within the environment. This will enable the system to recognize valve locations automatically and perform manipulation tasks without relying on predefined coordinates, improving adaptability to real-world scenarios.

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