

Design of an autonomous stair traversal method for a tracked mobile robot in nuclear power plants

Wonseo Lee^{a,*}, Seungjun Lee^{a,b}, Dongseok Ryu^a, Sungmoon Joo^a, and Jonghwan Lee^a

^aExtreme Robotics Team, Korea Atomic Energy Research Institute (KAERI), Daejeon, Republic of Korea, 34057

^bDepartment of Robotics, Hanyang University, Ansan, Republic of Korea, 15588

*Corresponding author: wonseo@kaeri.re.kr

***Keywords :** autonomous stair traversal, nuclear power plant, tracked mobile robot

1. Introduction

Robots can be an effective means of reducing radiation exposure to human workers when inspection and response operations are required in high-radiation areas or environments where radiation conditions have not yet been characterized. Accordingly, various studies have investigated the use of robots for monitoring and response operations in nuclear facilities including nuclear power plants (NPPs).

Following the Fukushima Daiichi accident in 2011, PackBot (Endeavor Robotics, USA) was deployed and entered the Unit 2 reactor building to monitor environmental conditions, including radiation levels, temperature, humidity, and gas concentrations [1]. West *et al.* introduced a radiation mapping framework using a mobile robot to remotely characterize spatial radiation distributions [2]. Ryu *et al.* developed an unmanned ground vehicle for radiation monitoring in nuclear facilities by remotely collecting radiation data in outdoor environments [3]. Lee *et al.* proposed a tracked mobile platform equipped with four independently controlled flipper tracks, enabling the robot to overcome various types of stairs and steps inside NPPs [4]. However, the robots in the conventional studies were primarily operated via teleoperation, in which a human operator directly controls the robot based on real-time visual images. This teleoperation-based approach results in several critical limitations from a practical perspective. First, the operational range of a teleoperated robot can be severely limited, because it is difficult to ensure sufficient performance and reliability of communication, which is necessary for real-time teleoperation, throughout complex indoor structures of NPPs. Second, when the robot moves through complex environments such as stairs, the operator may need to repeatedly adjust the robot motions through trial and error, which can lead to longer operation time and an increased risk of operational errors.

In this paper, we propose an autonomous stair traversal method for a tracked mobile robot to overcome the limitations of teleoperation. Among various types of mobile robots, tracked mobile robots are particularly suitable for response operations in NPPs because of their high payload-carrying capability, which enables them to carry high-payload manipulators and other equipment. For autonomous monitoring and

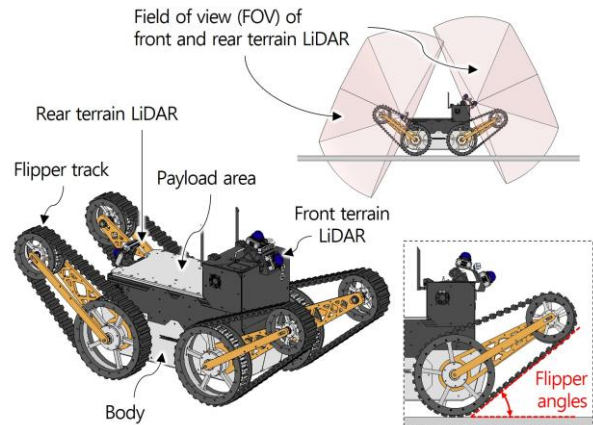


Fig. 1. Structure of TALON and FOV of equipped LiDARs.

response operations in multi-floor NPP environments, reliable autonomous stair traversal is one of the most important capabilities required to reduce dependence on teleoperation and enable autonomous mobility. The proposed stair traversal method divides the traversal procedure into multiple phases and utilizes sensor information to estimate the progress of each phase. We designed the traversal phases, the driving conditions for each phase, and the transition conditions between phases based on the characteristics of the tracked mobile robot. Both stair ascent and descent were considered, and the proposed method was validated in a simulation environment replicating the actual test facility.

2. Autonomous stair traversal method for a tracked mobile robot

The stair traversal method was designed for TALON, a tracked mobile robot consisting of a body and four independently controllable flippers [4]. The four flippers are covered by tracks as shown in Fig. 1, and TALON can generate various body postures by adjusting the flipper angles. The flipper angle was defined as the angle between the horizontal plane and the lower track surface of the flipper, as illustrated in the subfigure of Fig. 1. Since there are no supporting tracks on the bottom of the body, the flipper posture should be configured to prevent direct contact between

the body and protruding features such as stair edges. TALON is equipped with front- and rear-mounted LiDAR sensors (MID-360, Livox, China) to obtain local terrain information and an inertial measurement unit (IMU) at the center of the body for feedback during stair traversal. The mounting angle between the bottom surface of each LiDAR and the that of the robot body was set to 65 degrees for sufficient coverage of stair edges during both ascent and descent.

The autonomous stair traversal method consists of the following six phases: READY, APPROACH, ENTRY TRANSITION, STAIR TRAVERSAL, EXIT TRANSITION, and ESCAPE. The linear velocity and desired flipper angles were specified for each phase, as summarized in Table I. The linear velocity of track is categorized to STOP, LOW, and MEDIUM, and the flipper angle command is categorized to DEFAULT, ADJUST, and SUPPORT. DEFAULT and SUPPORT correspond to flipper angles of 50 degrees and -40 degrees, respectively, where the flipper angle is defined as the angle between bottom surfaces of the flipper track and the robot body. The SUPPORT angle was selected to prevent direct contact between the body and stair edges during the EXIT TRANSITION phase. ADJUST is determined by the relative angle (θ_{ADJUST}) between the robot body and the target stair slope. As shown in Eq. (1), θ_{ADJUST} is calculated from the stair slope angle (θ_{stair}) and the body pitch angle (θ_{body}).

$$\theta_{\text{ADJUST}} = \theta_{\text{stair}} + \theta_{\text{body}} \quad (1)$$

Since the two angles have opposite signs under the z-up coordinate convention used in this study, their sum represents the angular difference between the robot body and the stair slope. The stair slope angle was assumed to be known in this study to focus on the phase design and transitions of the stair traversal phases.

The phase transition conditions were defined based on the body pitch angle measured by the IMU, the flipper angles obtained from encoder feedback, and a pointcloud data acquired by either the front or rear LiDAR sensor depending on the moving direction. The detailed transition conditions for each phase are summarized in Table 1. Pointcloud data are used only during STAIR TRAVERSAL phase to detect the adjacent floor, indicating that the robot is approaching the end of the staircase. Floor detection is performed through the following process: (1) cropping points outside the region of interest (ROI), (2) voxel from APPROACH to ESCAPE downsampling, (3) transformation to the global coordinate frame, (4) height-based filtering to retain relevant points, (5) plane detection using a constrained random sample consensus (RANSAC) algorithm and tracking the maximum number of inliers among detected planes, and (6) activation of the floor-detection flag when the maximum number of inliers exceeds 1.5 times the moving average over the latest 10 values.

To verify the proposed autonomous stair traversal method, a simulation environment was constructed. A simulation environment replicating the actual test

Table I: Driving conditions and phase transition conditions for each phase of the stair traversal method (θ_{tol} : tolerance angle ≈ 2 degrees, ¹⁾Ascent case and ²⁾descent case)

Phase	Linear velocity	Front flipper	Rear flipper	Transition conditions
READY	STOP	DEFAULT	DEFAULT	Command received
APPROACH	LOW	ADJUST	ADJUST	$\theta_{\text{body}} > \theta_{\text{tol}}$
ENTRY TRANSITION	LOW	ADJUST ¹⁾ SUPPORT ²⁾	ADJUST	$\theta_{\text{ADJUST}} < \theta_{\text{tol}}$
STAIR TRAVERSAL	MEDIUM	ADJUST	ADJUST	Floor detected & $\theta_{\text{ADJUST}} > \theta_{\text{tol}}$
EXIT TRANSITION	LOW	ADJUST	SUPPORT ¹⁾ ADJUST ²⁾	$\theta_{\text{body}} < \theta_{\text{tol}}$
ESCAPE	LOW	DEFAULT	DEFAULT	All flippers reach target position

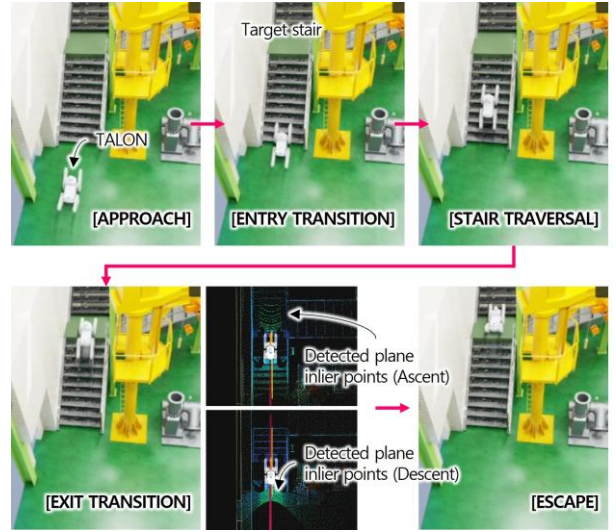


Fig. 2. Autonomous stair ascent traversal sequence from APPROACH to ESCAPE in the Isaac Sim environment.

facility was constructed in Isaac Sim, and a virtual model of TALON was equipped with the sensors provided by Isaac Sim. The virtual LiDAR sensors were configured by modifying the RTX LiDAR preset to match the characteristics of the actual MID-360 sensors, and all virtual sensors, including IMU, were mounted according to the extrinsic parameters of the real robot. As shown in Fig. 2, the proposed method executed all phases and phase transitions as designed, and TALON successfully traversed the target stair autonomously in both ascent and descent directions.

3. Conclusions

In this study, we proposed an autonomous stair traversal method for TALON, a tracked mobile robot, to enable multi-floor mobility in NPP environments. The proposed method consists of six phases, with the driving conditions for each phase and the phase transition conditions based on the characteristics of the tracked mobile robot. Both stair ascent and descent were validated in a simulation environment replicating the actual test facility and robot, and TALON successfully completed autonomous stair traversal using

the proposed method. In future work, the proposed method will be implemented on the actual robot and verified in the test facility using real sensor data. Furthermore, the stair traversal method will be extended to cases that prior stair information, such as the stair location and slope angle, is not provided.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government (MSIT) (No. RS-2022-00144385).

REFERENCES

- [1] T. Trainer, "Deployment of unmanned systems after March 2011 incident," *Journal of the Robotics Society of Japan*, vol. 32, no. 2, pp. 133-136, 2014.
- [2] A. West, I. Tsitsimpelis, M. Licata, A. Jazbec, L. Snoj, M. J. Joyce, and B. Lennox, "Use of Gaussian process regression for radiation mapping of a nuclear reactor with a mobile robot," *Scientific Reports*, vol. 11, no. 1, 2021.
- [3] D. Ryu, W. Lee, S. Shim, Y. Cho, and H. Shin, "Development of an unmanned ground vehicle for prevention of radioactive disasters by providing outdoor radiation information in nuclear facility," *Korean Nuclear Society Autumn Meeting*, October 30-31, 2025, Changwon, Korea.
- [4] W. Lee, J. Park, D. Hyun, and D. Ryu, "Development of a tracked mobile platform with adaptive locomotion capability for operations in nuclear power plants," *Korean Nuclear Society Spring Meeting*, May 7-8, 2026, Jeju, Korea.