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Elevator-Based Multi-Story Navigation for Personal Mobility Systems

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1 Introduction

Personal mobility is a promising application area of mobile robot technologies. Personal mobility system can support the elderly and disabled in moving through human-populated environments and non-public spaces where public transportation is not readily available. Such a system should have intelligent functions to guide and carry a person from one place to another by automatically choosing an appropriate route. In indoor navigation, multi-story navigation using elevators is sometimes necessary. This paper describes a prototype system for multi-story navigation. The system uses the Whill electric wheelchair model CR as a base, equipped with a 3D LiDAR and a camera. We assume that the user riding the system will operate the elevator buttons.

One of the issues in using elevators is safety; that is, personal mobility systems must be aware of surrounding people to avoid obstructing or harming them. To this end, we developed a people detection method for narrow areas, such as inside an elevator, using a spherical camera. We also analyze the people flow around the elevator to choose the waiting position of the system.

2 Prototype System

The developed system performs multi-story navigation in the following four steps (see Fig. 1): (1) autonomous navigation from the starting point on a floor to an elevator, (2) taking an elevator to the destination floor, (3) exiting the elevator, and (4) autonomous navigation from the elevator to the destination. In steps (1) and (4), we use 3D LiDAR-based mapping and localization [1] with the move_base package [2] of ROS.

We detail step (2) as follows: The system first moves to a position where the user can press the elevator button. Next, it moves to a waiting position determined by considering the flow of people departing from the elevator. After detecting the door opening, it recognizes people inside the elevator and determines whether it can create a clear path for entry. If so, it enters the elevator. We use TEB (Timed Elastic Band) local planner [3] for entering and departing motions.

Fig. 2 shows a heatmap depicting the entry and exit paths of 53 people around an elevator (25 for entering and 28 for departing), measured by a depth camera-based person tracker. Based on this data, we determined the waiting position as shown. Note that the paths toward (1.0, -3.5) represent movements toward the camera by curious individuals and are not expected in real-world scenarios.

Most existing visual and LiDAR-based human trackers suffer from a limited field of view and an inability to track in very close proximity [4, 5]. We therefore developed a vision system with a spherical camera (Theta-V by Ricoh) that enables recognition of people even in narrow spaces. The vision system uses trt_pose [6] and UKF for detection and tracking, with people height estimation using the neck and ankle as feature points (see Fig. 3). Since the person model was trained on perspective images, we do not process the panoramic image directly. Instead, we divide it into four 90-degree segments and process each one separately.

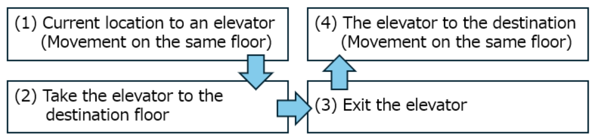
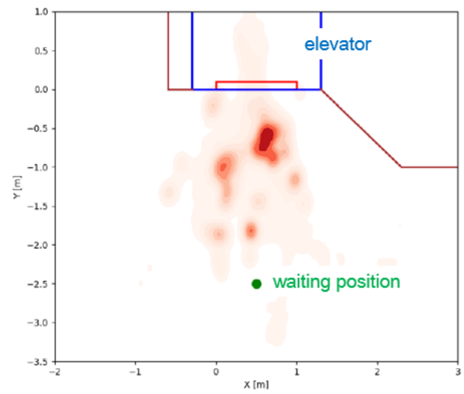
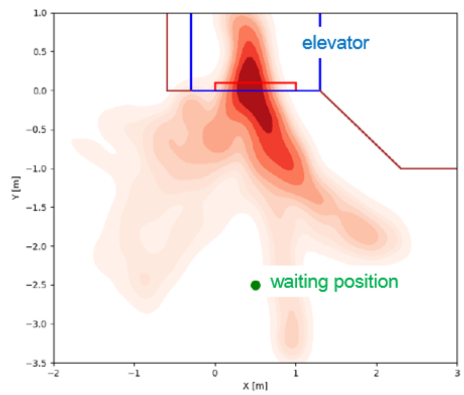


Fig. 1 Four steps for multi-story navigation.



(a) Heatmap of entering trajectories.



(b) Heatmap of departing trajectories.

Fig. 2 Heatmap of entering and departing paths and robot's waiting position.

3 Experimental Results

We first compare 3D LiDAR-based people tracking [1] with the proposed spherical camera-based method. Fig. 4 shows the trajectories of one person walking around the sensors. In both cases, we placed the LiDAR and the spherical camera at the origin (0.0). The proposed system exhibits compara-

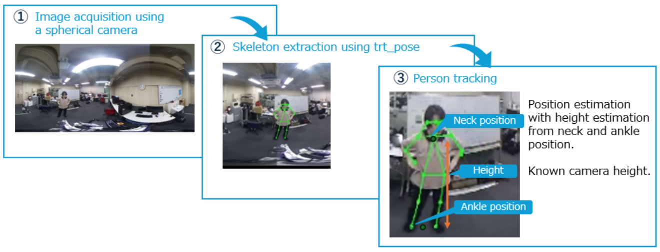


Fig. 3 Steps for people detection and tracking using spherical camera.

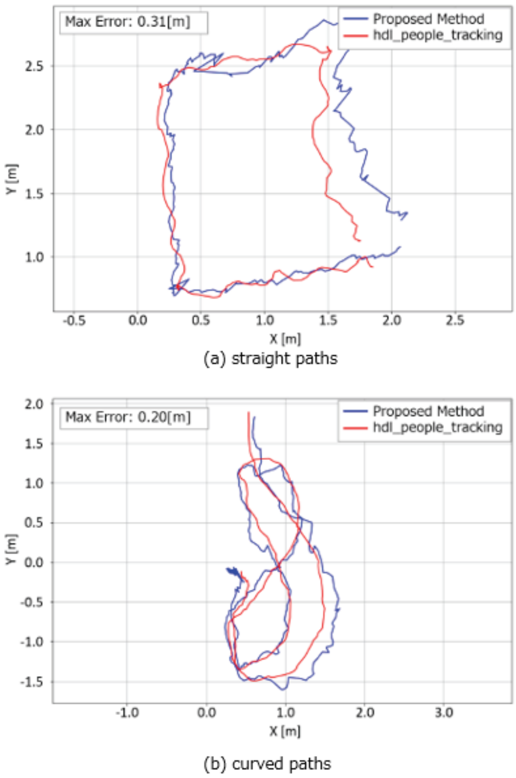


Fig. 4 Comparison of people tracking results between the proposed (spherical camera) and 3D LiDAR.

ble performance to the LiDAR-based one, especially in the vicinity of the sensors.

We then examine how well the system can take elevators, irrespective of the person's position inside the elevator. Fig. 5 shows three cases where the system successfully entered the elevator by adjusting the path depending on the person's position. Fig. 6 shows the person detection and local mapping result for Fig. 5(c). When the system could not generate a safe path for entry, it successfully moved back to the waiting position.

We then conducted multi-story navigation experiments in the buildings on our campus. We set two locations: one on the fifth floor of a building and the other on the second floor of another building. The distance between the elevators used is about 100m. We tested this navigation task ten times, and the system was able to complete it every time. We encountered false people detection due to certain lighting conditions and reflections in the elevator. Although such false detections

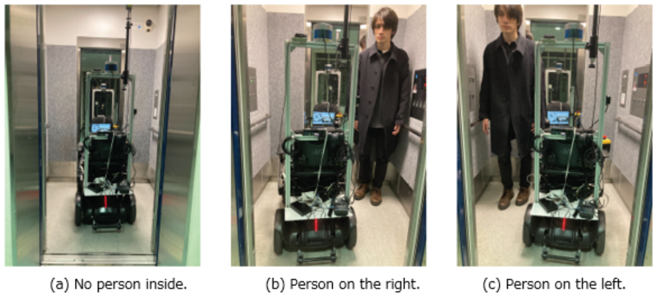


Fig. 5 The system's actions to take an elevaotr.

Fig. 6 Person detection and mapping result.

occurred on a small number of occasions and did not cause the navigation to fail, they affected the smoothness of the system's navigation.

4 Summary

We developed a personal mobility prototype capable of performing elevator-based multi-story navigation. To ensure safe elevator usage, we developed a spherical camera-based people detection and tracking method and analyzed the flow of people exntering and departing the elevator to determine the system's waiting position. Preliminary navigation experiments demonstrate the potential feasibility of the developed system. Future plans include enhancing the robustness of people recognition and testing in more realistic, sometimes congested environments with various types of elevators.

Acknowledgment

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