REAL-TIME FLOOR RECOGNITION IN INDOOR ENVIRONMENTS USING TOF CAMERA

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ABSTRACT: Navigation in public spaces is an essential technique for pedestrian guidance and autonomous robot assistance. Navigation systems mainly consist of positioning systems, maps, route finding, and a user interface. Image acquisition or 3D sensing is also required to recognize the unknown environment around a pedestrian or robot. Therefore, we aim to develop a sense-and-avoid application for pedestrians and autonomous robots. We propose a real-time methodology to recognize the mobility area in an indoor environment using an active depth imager. In our experiments, we used a handheld time-of-flight (TOF) camera. We selected corridors, stairs, large rooms, and our laboratory in our campus as study areas. These areas consist of walls, glass walls, steps, and gaping holes. These objects were recognized with online processing, and notification for obstacle avoidance was issued after object recognition. Our experiments confirmed that our approach can process 3D measurements, classify objects, and notify for obstacle avoidance in real time.

1. INTRODUCTION

Advanced public facilities and navigation are required to provide safe and convenient public spaces. Navigation is an essential technique for pedestrian guidance and autonomous robot assistance in public spaces in both normal times and emergencies (Zlatanova et al. 2013). Navigation systems mainly consist of positioning systems, maps, route finding, and a user interface. For indoor or outdoor seamless navigation, positioning systems are required to combine global navigation satellite systems with inertial sensors, while indoor positioning systems may use Wi-Fi, Indoor Messaging Systems, and iBeacon. Image acquisition or 3D sensing is also required to recognize the unknown environment around a pedestrian for evacuation in a dark environment or to assist a blind pedestrian. Passive cameras and scanners have the advantage of low cost. On the other hand, active cameras and scanners, such as LiDAR, have the advantage of robustness against illumination changes. In this research, we aim to develop a sense-and-avoid application for pedestrians and autonomous robots. We also propose a real-time recognition methodology for a mobility area in an indoor environment using an active sensor.

2. METHODOLOGY

The main components of our methodology are the measurement part, the object classification part, and the navigation part, as shown in Figure 1. In the measurement part, range images, such as depth and point cloud data, are acquired using an active depth imager with approximate 45° downwards viewing direction and 40° horizontal viewing angle, as shown in Figure 2. We assume that these restrictions in 3D measurement using the active depth imager are based on imaging and scanning from wearable devices and autonomous robots. In the object classification part, walkable floor surfaces and unwalkable surfaces are classified. Figure 2 shows how visible flat surfaces from the imager are recorded in acquired range images. These include floor surfaces, wall surfaces, gap surfaces and object surfaces. Moreover, the nearest surface from the imager can be assumed to be the walkable floor surfaces. On the other hand, unwalkable surfaces exist further away than the walkable floor surfaces. Based on this knowledge, walkable floor surfaces are distinguished from unwalkable surfaces in the range images. Next, extracted unwalkable surfaces are classified into horizontal surfaces and vertical surfaces. The horizontal surfaces include gaping holes and stairs (up or down). The vertical surfaces include walls, boxes, and moving objects, such as pedestrians. These objects and obstacles are estimated through a region classification using depth edges and normal vectors (Nakagawa et al. 2015) of the extracted unwalkable surfaces. The navigation part sends alerts and notifications to the user with sound or voice navigation. Several types of alerts and notifications are prepared as a dataset in advance, and a suitable alert or notification for a situation is selected from the dataset. The alert or notification is selected according to the distance from the imager to the obstacle and the recognized type of the object or obstacle. For example, when a floor surface continues in front of an imager or user, the navigator part indicates that the user is in a walkable area. When obstacles exist within 2 m of the imager or user, the navigator part provides an alert and sound guidance to avoid the obstacles. The measurement, classification, and navigation are conducted for every range image. These procedures are iterated for navigation in real time.

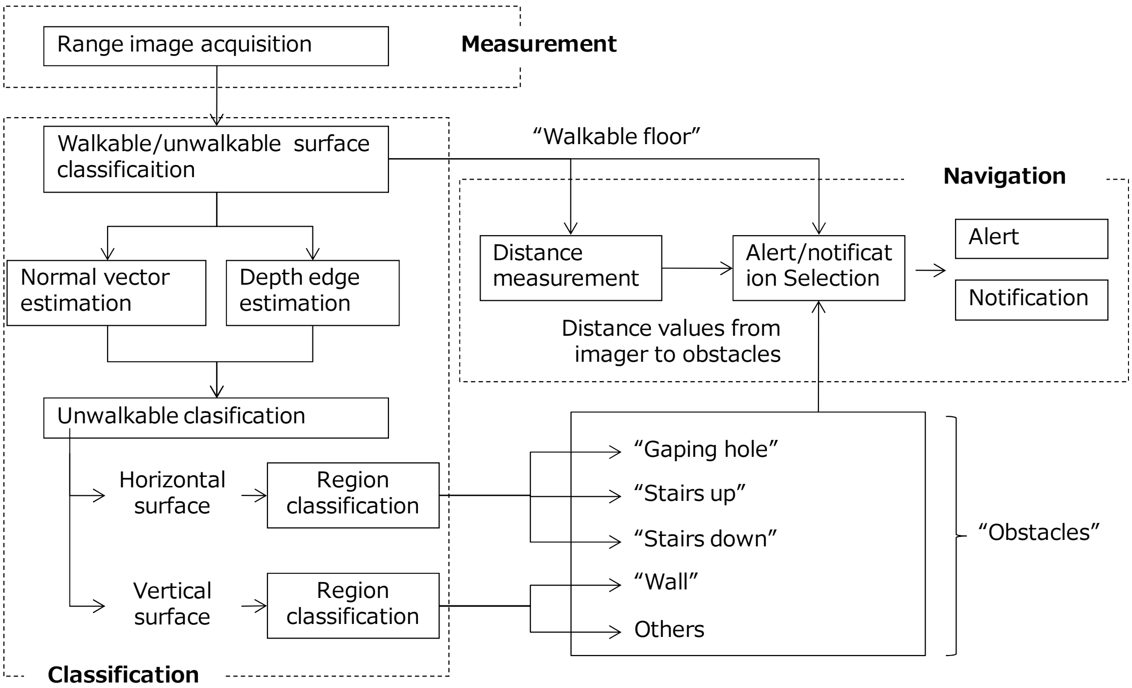


Figure 1. Methodology

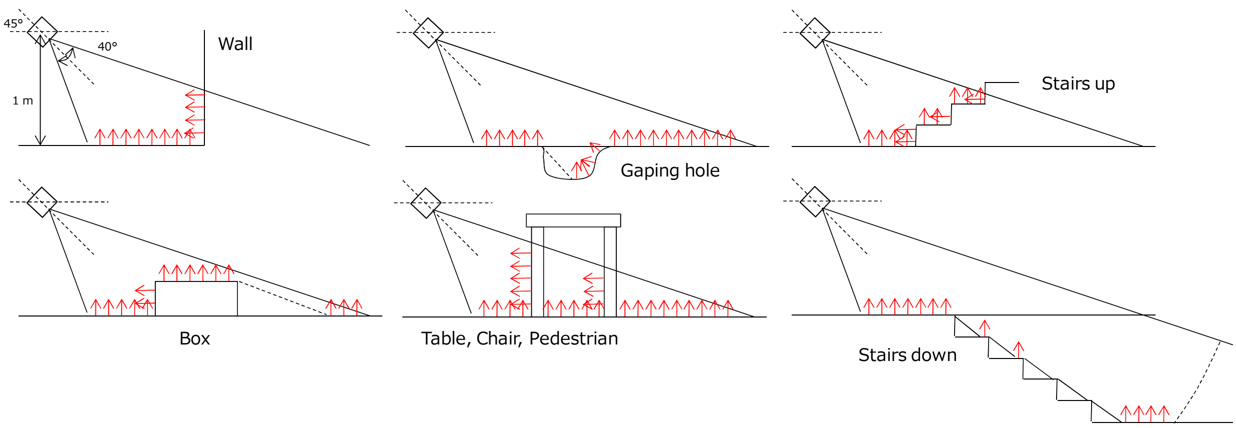
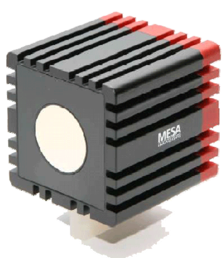


Figure 2. Restrictions on 3D measurements using an active depth imager for real-time object recognition

3. EXPERIMENTS

In our experiments, we used a handheld time-of-flight (TOF) camera (SwissRanger SR4000, MESA) as an active depth imager, as shown in Figure 3.



Pixel array	176 (h) by 144 (v)
Wavelength	850 nm
Angle of view	43.6° (h) by 34.6° (v)
Measurable range	5.0 m (@ 30 MHz)
Frame rate	up to 50 fps
Frequency	30 MHz

Figure 3. SwissRanger SR4000 (MESA)

The TOF camera is a range imaging camera that acquires depth images and point cloud data with distance measurements based on the speed of light. The TOF camera is more robust than optical stereo cameras against illumination changes in indoor environments. However, the measurable distance is shorter than that with an optical stereo camera. Therefore, the TOF camera is suitable for measurement in narrow indoor spaces (Nakagawa et al. 2013).
We selected stairs, corridors, large rooms, and our laboratory on our campus as a study areas, as shown in Table 1. These areas consist of walls, glass walls, steps, and gaping holes as fundamental features in mobility assistance and evacuation guidance.

Table 1. Measured objects

Measured objects	Notes
Wall	Includes curved walls
Stairs up	Navigation tiles in front of the stairs for blind people not included
Stairs down	Navigation tiles in front of the stairs for blind people not included
Gaping holes	Assumed floor destruction after disasters
Glass wall	Glass is installed from floor height

4. RESULTS

The results of our experiments are shown in Figure 4. The top row shows intensity images in five scenes: 1) wall, including a fire extinguisher, 2) stairs (up), 3) stairs (down), 4) gaping holes, and 5) glass wall. The middle row shows object recognition results overlaid on the intensity images. Each colored area indicates an obstacle. The bottom row shows object recognition results overlaid on point clouds. Walls, steps, and gaping holes were stably extracted from point cloud data acquired with the TOF camera. These objects were recognized within 12 fps with online processing (Core i7-4500U 1.8 GHz, MATLAB), as shown in Figure 5. Moreover, notifications for obstacle avoidance were issued after the object recognition. However, although objects through glass walls were recognized, the glass walls could not be extracted from point cloud data.

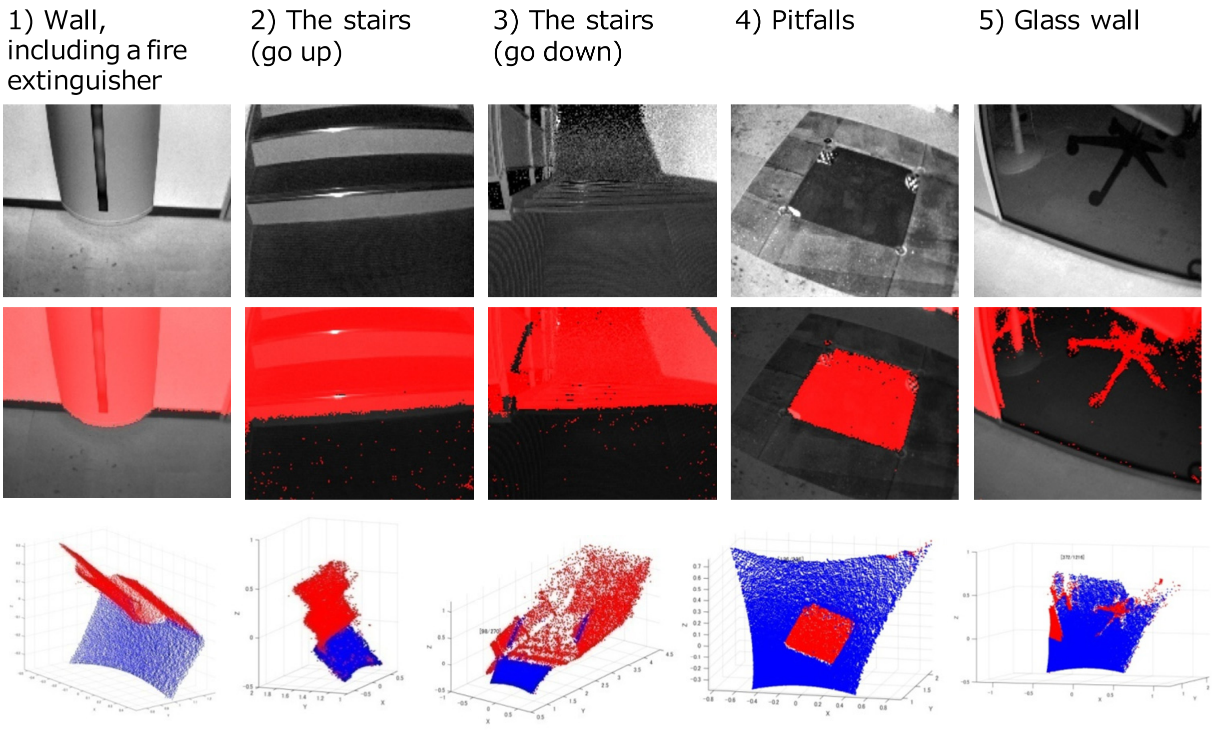


Figure 4. Object recognition results (top row: intensity images, center row: object recognition results overlaid on intensity images, bottom row: object recognition results overlaid on point clouds)

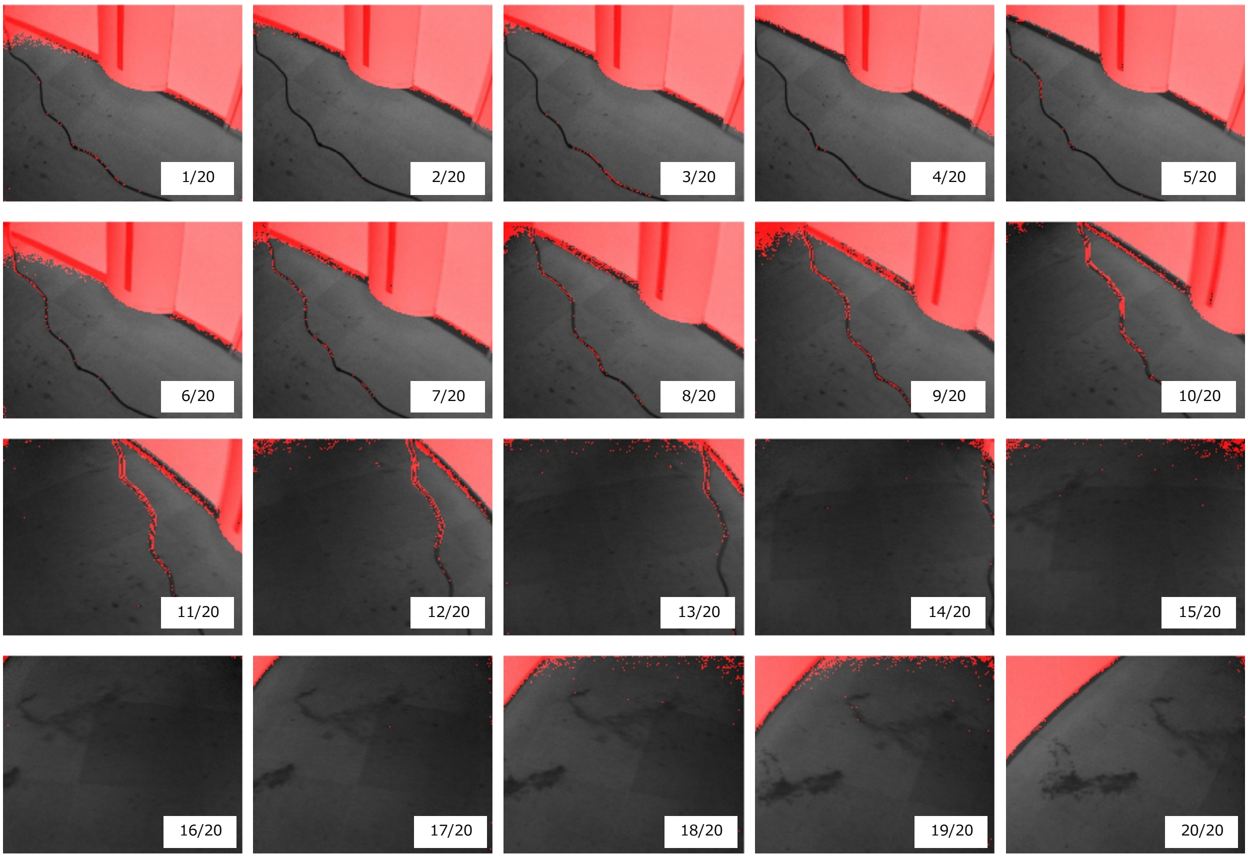


Figure 5. Sequence results in obstacle recognition

5. SUMMARY

We have proposed a sense-and-avoid application using an active camera with some restrictions for pedestrian and autonomous robots. We have also proposed a real-time recognition methodology for mobility areas in indoor environments using an active sensor. In our experiments, walls, steps, and gaping holes were stably extracted and recognized using a TOF camera within 12 fps with online processing, and notifications for obstacle avoidance were issued after object recognition. Our experiments have confirmed that our approach can process 3D measurements, classify objects, and notify of obstacles for avoidance in real time.

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