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Construction of SLAM Algorithm for Window Cleaning Robot Moving Along Window Frame

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Abstract. The purpose of this study is to build SLAM algorithm for window cleaning robot which move along window frame. Automation of window cleaning in skyscraper by a robot is desired. It's necessary for cleaning to the corner of window that the robot which move on the windowpane wall recognizes shape of the window frame and to estimations self-localization on the windowpane wall. However, since it is difficult to detect the glass surface directly with a non-contact sensor, it is not possible to acquire the features necessary for SLAM. Therefore, the window frame is detected as a feature point by the RGB-D sensor, and the SLAM algorithm on the windowpane wall is constructed using the detected feature value. In this paper, various window frame shapes are prepared, distance information from the RGB-D sensor to the window frame is acquired, and the results obtained as 3D information and the feature value acquisition results by image processing are described.

1. Introduction

It is necessary to automate window cleaning in high-rise buildings with robots. High-rise buildings with various window glass shapes have been constructed by improving window cleaning construction technology. On the other hand, the outer walls of high-rise buildings have been cleaned by human power, and serious accidents related to human lives such as fall accidents occur every year [1]. In order to reduce human-related accidents, it is necessary to be able to clean up in dangerous places instead of people. Therefore, automation of window cleaning is required.

In the 2010s, many window cleaning robots for high-rise buildings have been developed to automate window cleaning [2]. Conventionally, there are robots that hang cleaning units from the rooftop and clean windows while moving along installed guide rails. However, every time it is cleaned, it is necessary to install a large device on the roof to suspend the unit, which requires enormous costs. To solve this problem, research on window cleaning by small self-propelled robots has been conducted [3]. By moving the window glass while attracting it with a magnet, it is possible to clean the window at a low cost. In addition, it can detect the dirt on the window glass after the robot passes and clean it until the dirt disappears. However, since the robot is operated with a cleaning algorithm that assumes that the window shape is a rectangle, it is difficult to clean up the edge of the window on a glass surface with a complicated window frame shape. Also, it cannot move over the window frame onto another window glass surface. In order to solve this problem, it is necessary to make the robot move along the window frame and move through obstacles.

Nansai et al. Proposed a cleaning algorithm for complex window glass shapes using a walking robot while overcoming obstacles such as window frames [4] [5]. When the robot moves, it is necessary for the robot to grasp its own position with respect to the surrounding environment. In general, non-contact sensors such as cameras and laser sensors are used to recognize the self-position in the surrounding environment, but it is difficult to detect the glass shape directly from the glass surface with a non-contact sensor. In this paper, we describe a method for recognizing the window glass shape from the window frame shape and estimating the position of the robot on the glass surface from the positional relationship between the window frame and the robot.

2. System Configuration

In this chapter, we describe system configuration of the mobile robot to estimate positional relationship between window frame and the robot. In section 2.1, we describe configuration of mobile robot. In section 2.2, we describe Simultaneous Localization And Mapping (SLAM) system which performs map generation and self-location estimation simultaneously. Then, we describe a feature extraction method necessary for SLAM system.

2.1. Robot's Configuration of System

In this study, we use two-wheeled vehicle robot which is possible to move on the glass surface to verify whether self-position estimation is possible on the glass surface. This is because the self-position estimation can be simplified by acquiring the wheel rotation angle of the robot with an encoder. When generating surrounding terrain information as map information, non-contact sensors such as laser sensors and camera sensors which acquire surrounding information are used. When mobile robot moves on the glass wall of skyscrapers, it is difficult to acquire surrounding information because of window frame position. Therefore we use camera sensor that can acquire feature points as secondary current status. In addition, it is difficult to obtain color images and infrared images on the walls of high-rise buildings, which are real environments, because they are easily affected by sunlight. Therefore, an RGB-D sensor with an infrared filter is used. Figure 1 shows the robot system configuration that satisfies the above system. The robot has a RaspberryPi3 as a computer, an encoder that can acquire wheel angle information, an RGB-D sensor RealSense D435i that generates a distance image from a stereo infrared sensor through an infrared filter, and the angle information acquired from the encoder is sent to RaspberryPi3 via Arduino Equipped with OpenCR.

Figure 1. Configuration of System

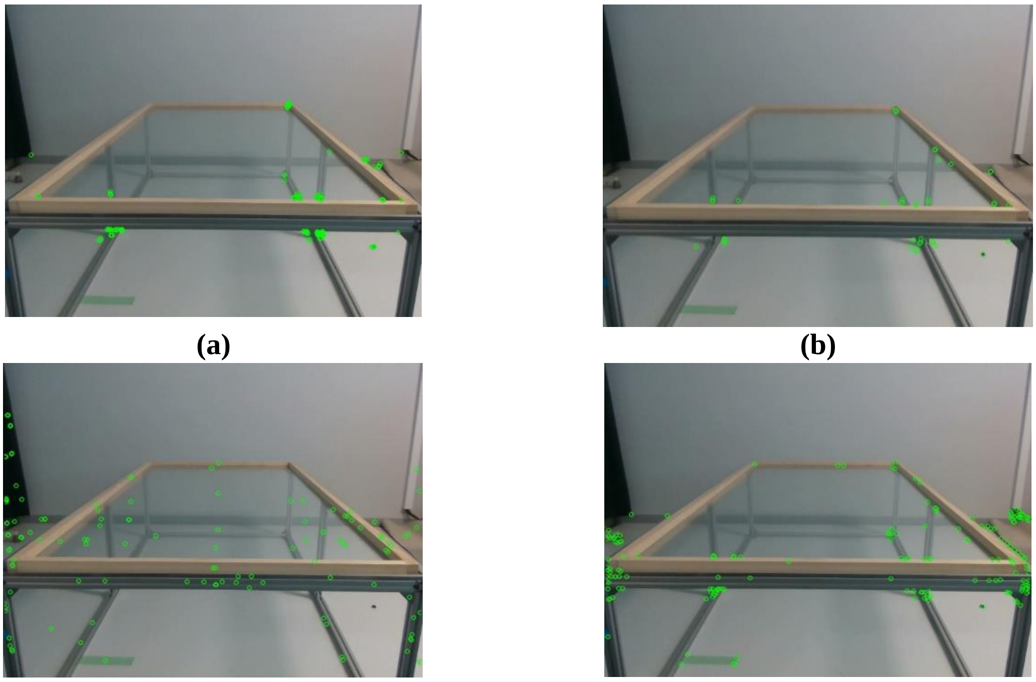
2.2. SLAM and Feature extraction method

In order to estimate the position of the mobile robot on the window glass wall, map information of the surrounding environment is required. However, in order to acquire the map information of the surrounding environment by the robot, it is necessary to acquire the distance information from the robot body, but the position information of the robot is required. Therefore, Simultaneous Localization And Mapping (SLAM) that can acquire map information and location information at the same time is used. SLAM can measure the landmarks in the map information acquired by the sensor and measure the distance and direction from the sensor to the landmark for each frame, thereby acquiring the map information and the sensor position on the map.

In order to detect landmarks, it is necessary to extract features from map information. The feature quantity depends on the type of sensor used. In this research, it is necessary to detect the window frame in the image obtained by the RGB-D sensor as a feature point. There is ORB-SLAM that uses Oriented FAST and Rotated BRIEF (ORB) as a feature point detection method. ORB is a technique for detecting feature points by generating binary code by comparing two pixel values. In SLAM, three threads of Tracking, Local mapping, and Loop closing are executed in parallel, a map is created from the points obtained by Tracking and KeyFrames information, and a location recognition database for Relocalization and Loop Closing is created. ORB is used to estimate the self-position relative to the landmark by judging whether the landmarks reflected in each frame match.

3. Feature point extraction accuracy comparison experiment

This paper describes an experiment to verify the accuracy of distance information to feature points detected using ORB with an RGB-D sensor. Verify that the window frame can be detected as a feature point with the RealSenseD435i RGB-D sensor fixed. In addition, whether distance information to the feature point can be obtained correctly is verified by comparison with actual measurement values. To prepare multiple window frame installation patterns, and verify the accuracy of the value estimated from the distance image by using the tape measure to measure the distance from the camera to each point of the frame in each pattern. Figure 2 shows the positional relationship between RealSenseD435i and window frames installed in multiple patterns. Table 1 shows the number of feature points detected when each feature point extraction method is applied to the same image. As a result, (a) was 136, (b) was 41, (c) was 121, and (d) was 169. Since SLAM requires a calculation cost for each number of landmarks, it is better to use fewer feature points in SLAM. Comparing Table 1, AKAZE in (b) extracted feature points with a smaller number than the other three. However, the pixel value of the feature point acquired by the extraction method and the location that becomes the feature of the window frame is different. It seems that there is a problem in accuracy when applied to SLAM. At the next point in time, the MER of (c) with a small number of feature points is not suitable for landmark detection because the locations that can be feature points have not been determined. The ORB in (a) confirms that the correct Kayo is recognized because the feature points converge. AGAST in (d) is thought to be computationally expensive due to the large number of feature points. Therefore, in the feature point detection, ORB is considered to be appropriate among the four feature point extraction methods.



(a) **(b)** **(c)** **(d)**

Figure 2. (a) ORB, (b) AKAZE, (c) MSER, (d) AGAST

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Table 1. A number of feature points

	ORB	AKAZE	MSER	AGAST
Points	136	41	121	169

4. Distance information acquisition accuracy verification experiment

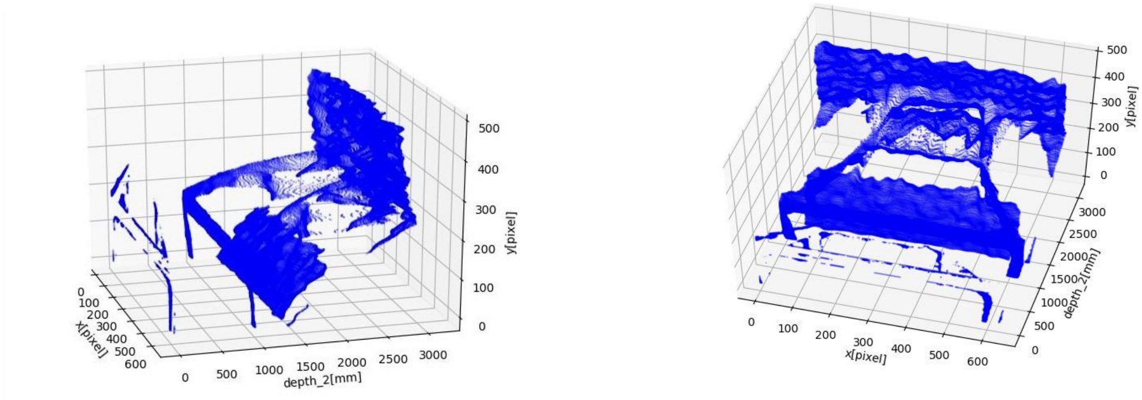
It is necessary to verify whether the distance information to the feature point acquired from the image can be acquired accurately. For this purpose, the distance information obtained from the depth image is generated as 3D map information. Several window frame installation patterns are prepared, and each window frame pattern is estimated from the distance image. Figure 3 shows the positional relationship between RealSenseD435i and the window frame installed in multiple patterns. Pattern 1 is an outer frame only, Pattern 2 is a horizontal partition, Pattern 3 is a vertical partition, Pattern 4 is a cross-shaped partition, and Pattern 5 is a frame that is shifted. Prepare a partition.

(a) **(b)** **(c)** **(d)** **(e)**

Figure 3. (a) pattern 1, (b) pattern 2, (c) pattern 3, (d) pattern 4, (e) pattern 5

5. Experimental results

Figure 4 shows a 3D graph of the distance information acquired for the window frame frames from patterns 1 to 5 using RGB-D sensors from the depth image. Based on the distance information of each pattern, it can be expressed as 3D information as shown in Figure 4 In the future, we will verify the accuracy of this 3D map information.



(a) (b)

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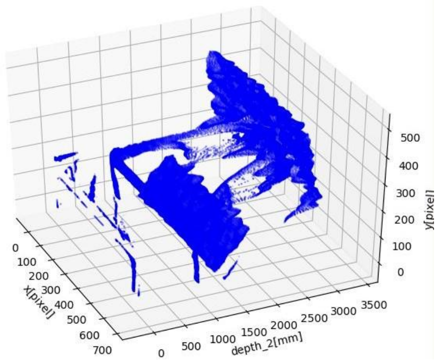
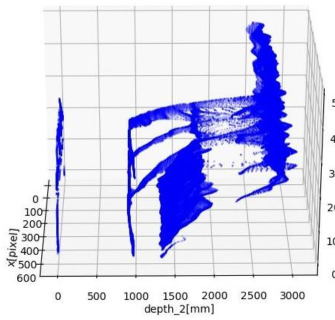
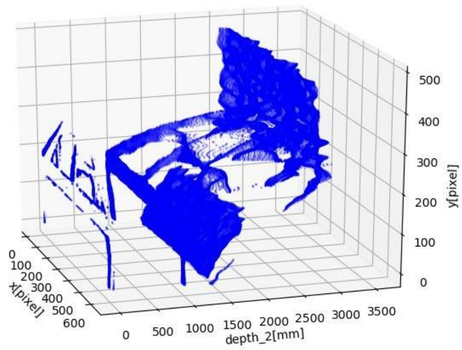


(c)



(d)



(e)

Figure 4. (a) 3D information with pattern 1 (b) 3D information with pattern 2 (c) 3D information with pattern 3 (d) 3D information with pattern 4 (e) 3D information with pattern 5

6. Conclusion

The purpose of this paper is to construct a SLAM algorithm for a window cleaning robot that moves along a window frame. The window frame shape reflected in the Color image is extracted as a feature point, and based on the obtained feature point, the distance information obtained from the Depth image is obtained to estimate the self-position of the window cleaning robot on the window glass. The technique to do was described. We proposed applying ORB to Color images as a method for extracting feature points. Furthermore, it was described that the distance information from the camera to the window frame shape detected as the feature point can be obtained by applying the pixel value of the feature point detected by ORB to the distance image. In order to verify whether the proposed method can be applied to SLAM, we tried several feature point detection methods for color images of window frame frames and compared feature extraction methods suitable for SLAM systems. When four feature extraction methods ORB, AKAZE, MSER, and AGAST are used for a color image in which a window frame is reflected, the ORB is found to be appropriate based on the number of feature points acquired and the degree of coincidence of the recognized feature points. Thought. In SLAM, it was confirmed that the window frame can be detected as a feature point by using the feature point extraction ORB. In addition, the distance information estimated from the depth image was obtained as 3D information map information. As a future plan, the distance information to the feature point is acquired by referring to the pixel value acquired by ORB for the acquired 3D information, and the accuracy for the true value is verified. In addition, in order to bring the experimental environment closer to the conditions of the real environment, an environment using infrared light and white light is prepared, and the effect on the RGB-D sensor in that environment is investigated. Furthermore, we will conduct a self-position estimation accuracy verification experiment when the mobile robot is actually running on the window glass wall and ORB-SLAM is applied.

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