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Detecting Falling Rocks by Estimating Excavation Points Using Single Color Markers

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Abstract

Tunnels have been constructed in various places for transportation and lifelines. During tunnel construction, the industrial accidents have occurred due to falling rocks from the tunnel face. A large amount of falling rocks is confirmed in the precursor of tunnel collapse. Therefore, it is necessary to detect falling rocks to prevent industrial accidents and to grasp of the situation on tunnel face. As conventional methods, the inter-frame difference method and the laser measurement method were proposed. However, those methods were difficult to monitor the entire tunnel face and detected moving objects other than falling rocks. In this paper, we propose a falling rocks detection method that combines the moving object detection method on the tunnel face and the estimation method of excavation points using single color markers. It was confirmed that only falling rocks were detected during excavation experiment.

Introduction

Tunnels have been constructed in various places for transportation and lifelines. Especially in Japan, the mountain tunnel method accounts for over 50% of number of constructions per year [1]. During tunnel construction, industrial accidents often occur due to falling rocks from the tunnel face. A large amount of falling rocks is confirmed in the precursor of tunnel collapse. Therefore, it is necessary to detect falling rocks to prevent industrial accidents and to grasp of the situation on tunnel face [2]. As a conventional method, the detection method using the inter-frame difference was proposed [3]. A camera is used to capture a tunnel face, and moving objects are extracted using the inter-frame difference method. The objects that move in the vertical direction over multiple frames are detected as falling rocks. However, the parts of heavy machines and the people who move in the vertical direction are erroneously detected as falling rocks. The detection method using a line laser rangefinder was proposed [4]. A line laser rangefinder is used to constantly measure the top of the tunnel face. When the depth change exceeds a preset threshold, it is detected falling rocks. However, measurement of the entire tunnel face is difficult. The detection method using the inter-frame difference method of depth images was proposed [5]. The method detects falling rocks based on the inter-frame difference method using values of depth images captured by a depth camera. However, in the inter-frame difference method, the depth data is normalized to a 256-gradation image and converted into an 8-bit depth image. As a result, the depth resolution per gradation changes depending on the distance between the camera and the tunnel face.

Focusing on falling rocks occurs from tunnel face, we proposed a falling rocks detection method by combining the mask image generation method of only the tunnel face using depth image and the inter-frame difference method using RGB image [6]. It was confirmed that the falling rocks can be detected on the entire tunnel face. However, it has the problem of detecting excavated soil generated on the tunnel face during breaker excavation operations.

In this study, in order to eliminate the false detection of excavated soil, we propose a falling rocks detection method that combines the estimation of excavation points using single color markers installed at the breaker of excavating heavy machines and the detection of moving object on tunnel face.

Method

First, two single color markers for estimation of the excavation position are installed in advance on the breaker portion of the excavation heavy machine. In addition, the center of gravity of the single color markers is aligned with the tip portion. An installation example of single color markers is shown in Fig. 1. As shown in fig. 2, the distance between the marker and the breaker is measured in advance. The distance Z_1 is between the center of gravity of the marker near the tip and the tip of the breaker. The distance Z_2 is between the centers of gravity of two markers.

Figure. 1 Installation example of markers

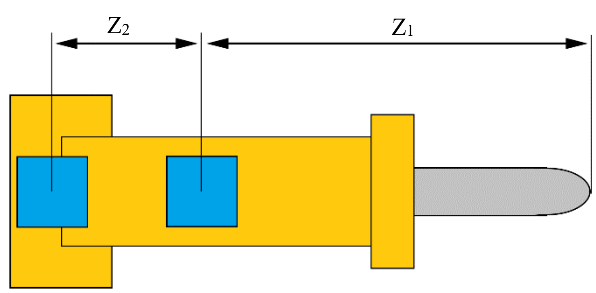

Figure. 2 Illustration of the measurement position

When generating the tunnel face mask image to be used in the detecting of moving object on tunnel face, it is necessary to identify the tunnel face in captured image. Therefore, the three-dimensional point cloud corresponding to the tunnel face in the RGB image is extracted in advance from the depth data obtained from the RGB-D camera. Since the tunnel face can be approximated to a plane, the planar equation is obtained using the extracted three-dimensional point cloud. A three-dimensional point cloud that satisfies the obtained plane equation can be determined as the point cloud on the tunnel face.

The algorithm of the proposed method will be described. The flowchart is shown in fig. 3.

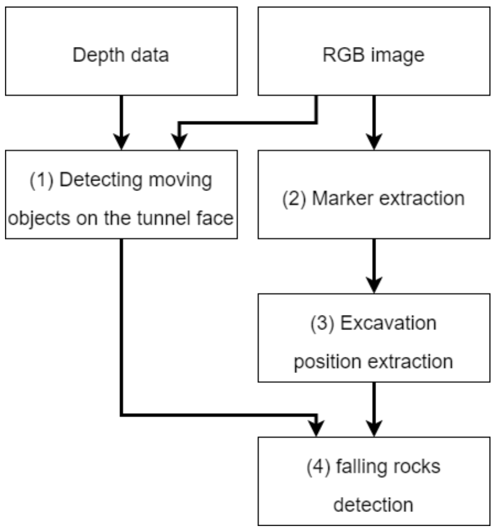

Figure. 3 Flowchart of the proposed method

We explain (1) detecting moving object on tunnel face in Fig. 3. The coordinates of the RGB image and the depth data correspond to each other. A mask image that cuts out the tunnel face of the RGB image is generated using the depth data that satisfies the planar equation calculated in advance. Next, the moving object is extracted by applying the inter-frame difference method using RGB images. By taking the logical product of the extracted moving object and the mask image, it becomes detecting moving objects on the tunnel face. It is falling rocks and excavated soil.

Next, we explain (2) Marker extraction. In order to extract single color markers from RGB image, HSV color space used. The hue (H) in the HSV color space represents colors in a hue circle ranging from 0° to 360°. Therefore, by extracting the hue value of single color markers as the threshold, pixels of the single color markers can be extracted in RGB image. The RGB color space of an RGB image is converted to the HSV color space. Equation (1) shows the equation for converting each pixel in an RGB image to a hue (H) in HSV color space.

$$H = \begin{cases} undefined(MIN = MAX) \\ 60 \times \dfrac{G-R}{MAX-MIN} + 60(MAX = B) \\ 60 \times \dfrac{B-G}{MAX-MIN} + 120(MAX = R) \\ 60 \times \dfrac{R-B}{MAX-MIN} + 180(MAX = G) \end{cases} \quad (1)$$

$$MAX = MAX(R,G,B), MIN = MIN(R,G,B)$$

We explain (3) Excavation position estimation. Labeling of four connected components is performed on the mask image from which the single color marker is extracted. The area of each labeled component is calculated. Of the areas calculated, the element with the largest value and the next largest value corresponds to single color markers in the RGB image. The center of gravity of these two elements is calculated from each element. The coordinates of the center of gravity of the largest area are expressed as (x_1, y_1). The coordinates of the center of gravity of the area with the next largest value are expressed as (x_2, y_2). Next, we check the positioning of the markers. From the planar equation of the tunnel face calculated in advance, it is possible to confirm what angle the camera has with respect to the tunnel face. For example, the camera is angled to the right against the tunnel face. Figure. 4 shows Illustration image of the image taken in this case.

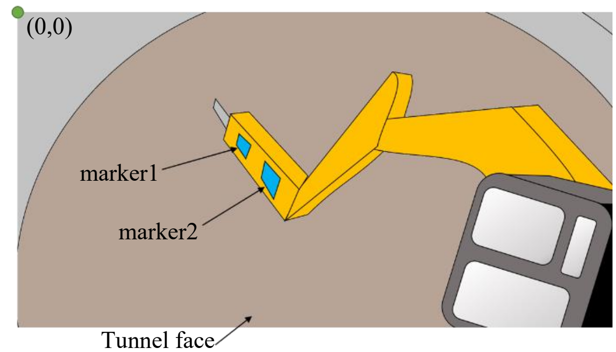

Figure. 4 Illustration image when the camera inclines to the right, captured image

When the marker farther from the breaker tip in the image (marker2) is used as a reference, the marker closer to the breaker tip (marker1) will always exist on the left side even if the breaker is shaken. The green point in fig 4 is the origin (0,0) of the image coordinate system. The single color maker whose x-axis direction is close to 0 is maker1.If the horizontal angle is set to the left, the marker closer to the tip will be on the right. In other words, the correspondence is reversed. Moreover, the tip of the breaker is on a straight line of the center of gravity of the two markers. Therefore, the coordinates (x, y) of the tip of the breaker can be calculated by the ratio of the measured z_1 and z_2 to the absolute value of the difference between the center of gravity of the two markers. The calculation formula is shown in Equation 2. Right capture in Equation 2 is used when the camera is angled to the right of the tunnel face, and left capture is used when the camera is angled to the left.

$$x = \begin{cases} x[x\_min\_idx] - |x_1 - x_2| \times \dfrac{z_1}{z_2} \text{(Right capture)} \\ x[x\_max\_idx] - |x_1 - x_2| \times \dfrac{z_1}{z_2} \text{(Left capture)} \end{cases}$$

$$y = \begin{cases} y[x\_min\_idx] + (y[x\_min\_idx] - y[x\_max\_idx]) \times \dfrac{z_1}{z_2} \\ \text{(Right capture)} \\ y[x\_max\_idx] + (y[x\_max\_idx] - y[x\_min\_idx]) \times \dfrac{z_1}{z_2} \\ \text{(Left capture)} \end{cases} \quad (2)$$

$$x[i] = \{x_1, x_2\}, y[i] = \{y_1, y_2\},$$

$$x\_min\_idx = \arg\min(x_1, x_2), x\_max\_idx = \arg\min(x_1, x_2)$$

We explain (4) falling rocks detection. The items extracted by (1) detecting moving object on tunnel face are falling rocks and excavated soil. Based on the calculated excavation position coordinates, it is specified a range in which the excavated soil can be masked from the extracted results. Therefore, the excavated soil is removed from the items. This makes it possible to detect only falling rocks.

Experiment and Result

An experiment was conducted to conformed if it is possible to detect falling rocks during excavation of 9m wide and 8m high with double track railroad tunnel under construction. For the experiment, we used an intel RealSense D455 as RGB-D camera with a resolution of 1280×720pixels at 30fps.

1. Conventional method

The results of processing by the conventional method of detecting of moving object on tunnel face are shown in this subsection. Figure. 5 shows the RGB image acquired one frame ago. Figure. 6 shows the RGB image acquired in the current frame. Figure. 7 shows the resultant image that detected pixels as falling rocks are colored red by using Figs. 5 and 6. And the yellow frame in Figs. 5 and 6 shows the enlarged area where the falling rocks occurred. And the yellow frame in Fig. 7 shows the enlarged area where detected falling rocks.

Figure. 5 One frame ago image

Figure. 6 Current frame image

Figure. 7 Result image of the conventional method

2. Proposed method

The processing result to which the proposed method is applied is shown in this subsection. Figure. 8 shows an image in which the result of estimating the excavation site is marked with a green point and center of gravity of two marker with a red point using Fig. 5. Figure 9 shows the image colored in the same way as in Figure 8 using Figure 6. Figure. 10 shows the resultant image that detected pixels as falling rocks are colored red by using Figs. 5 and 6. The yellow frame in Figs. 8 and 9 shows the enlarged area where markers. The yellow frame in Fig. 10 shows the enlarged area where detected falling rocks . Table 1 shows the processing time from the acquisition of the RGB image and depth data from the RGB-D camera to the generation of the result image shown in Fig 10. Table 2 shows the computer specifications used in the process.

Figure. 8 Marker detection and excavation point using Fig. 5

Figure. 9 Marker detection and excavation point using Fig. 6

Figure. 10 Detection result of the proposed method

Table 1. Processing time

Item	Time
average processing time	15.4 ms
Maximum processing time	32 ms

Table 2. Computer specifications

Item	Specs
OS	Windows 10 pro
CPU	Intel core i7-10750H
Memory	32GB

Discussion

In conventional method, comparing falling rocks detection area in Fig. 7 and falling rocks occurrence area in Figs. 5 and 6, it can be confirmed that falling rocks can be detected. However, it can be confirmed that the excavated soil is also detected.

From Figs. 8 and 9 of the proposed method, it can be confirmed that the marker detection is performed properly, and the green circle of the estimated excavation point roughly coincides with the tip of breaker. In addition, it can be confirmed from fig. 10 that only falling rocks are detected. From the results in Table 1, it was confirmed that the maximum processing time was completed by 32 ms and real-time processing was realized. This means that the proposed method can detect only falling rocks during excavation with heavy machines and various moving objects.

Conclusions

Tunnels have been constructed in various places for transportation and lifelines. During tunnel construction, the industrial accidents have occurred due to falling rocks from the tunnel face. A large amount of falling rocks is confirmed in the precursor of tunnel collapse. Therefore, it is necessary to detect falling rocks to prevent industrial accidents and to grasp of the situation on tunnel face. As conventional methods, the inter-frame difference method and the laser measurement method were proposed. However, those methods were difficult to monitor the entire tunnel face and detected moving objects other than falling rocks. Focusing on falling rocks occurs from tunnel face, we proposed a falling rocks detection method by combining the mask image generation method of only the tunnel face using depth image and the inter-frame difference method using RGB image. It was confirmed that the falling rocks can be detected on the entire tunnel face. However, it has the problem of detecting excavated soil generated on the tunnel face during breaker excavation operations. In this study, in order to eliminate the false detection of excavated soil, we propose a falling rocks detection method that combines the estimation of excavation points using single color markers installed at the breaker of excavating heavy machines and the detection of moving object on tunnel face. From the experimental results, it was confirmed that the tip of breaker was properly estimated by the marker and only falling rocks was detected. In the future, by conducting experiments to see if the proposed method can be applied to various work environments, we want to detect falling rocks during the entire construction process.

References

[1] Japan Tunnelling Association, Annual Report on Tunnels 2020, (2019).

[2] Naotaka Kikkawa, Kazuya Itoh, Yasuo Toyosawa, et al," Analysis of Labour Accidents due to Rock Fall Events at the Cutting Face in Tunnels and Proposals for Prevention Measures", National Institute of Occupational Safety and Health in Japan, JNIOSH-TD-No.2 (2012).

[3] Yositaka Koga, Takuya Tani, Toshiaki Sudo, et al,"Development of a device for instant detection and warning of falling rocks in tunnel faces", JSCE 73th Annual Academic Lecture VI-019 (2018)

[4] Akio itikawa, Hironori Sato, et al,"New monitoring technology to notify the displacement situation of the tunnel face", Tunnels and Underground Cities: Engineering and Innovation meet Archaeology,Architecture and Art, p7 (2019).

[5] Takahumi Nakamura, Taiga Ukezeki, Masando Shiozaki, et al,"Basic research on the development of a tunnel face monitoring system using a depth camera", JSCE 74th Annual Academic Lecture VI-735 (2019).

[6] Rei Kobayashi, Masaya Miura, Jun Mitsuo, Yue Bao," Detecting Rock Falls on Tunnel Face using RGB-D camera", JSCE 75th Annual Academic Lecture VI-678 (2020).

Author Biography

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