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TILTED WINDOW DETECTION FOR GONDOLA-TYPED FACADE ROBOT

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ABSTRACT

Working on building façade is dangerous. Many accidents have occurred, and many workers have lost their lives. We have researched to apply robot systems to prevent these accidents. In this paper, we purposed an algorithm for sensor system of a gondola-typed building façade maintenance robot. The robot system moves on the building façade autonomously, or by remote control. Therefore, window area detection is important for painting of the gondola system. For robust and accurate detection, the proposed algorithm was designed for tilted windows.

KEYWORDS

gondola robot, building facade, window detection

1. INTRODUCTION

We have researched a robot system that works on high-rise building facade. As cities have expanded, the high-rise buildings have increased. For example, they are the Marina Sands By hotel in Singapore and Empire State Building in New York. Their maintenance has been arisen as an annual task. Our robot system targets on it. Maintenance by human labours is executed by workers hanged on a couple of ropes. There have been a lot of safety accidents that many people lost their lives all over the world. Therefore, building facade workers are under great stress. Only few people want to work there. Hiring them becomes trouble, and labour cost arises. Automated or remotely controlled robot system can solve such problems.

There are four types of climbing robots on building facade. They are vacuum suckers, negative pressure, propellers, and grasping grippers [1]. Robot systems using suction pads are appropriate for glass-wall high-rise building maintenance [1, 2]. In order to navigate on reinforced concrete building that has concrete ribs, negative pressure or propeller system may have more adaptability [3].

Many robots accept hanging mechanism like a gondola system to lighten the weight burden [2]. The strong point of this approach is that other actuators except for rope winders are free from system own weight. Using built-in guide rail is another approach to solve weight burden and navigation [4]. This system navigates on rails that established when the building is under construction.

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We have researched sensor and control systems for gondola-typed robot system [5-7]. Especially, pose and location control is essential for our autonomous and remotely controlled system [5, 6]. The main task using our system is to paint on reinforced concrete walls. Therefore, additionally to pose and location control, we have researched on window detection [7].

In this paper, we will suggest a window detection methodology that upgrades the algorithm shown in [7]. It is a reaction algorithm for tilt window detected during the gondola robot system navigation. In Chapter 2, detailed introduction for our system is shown, and the meaning of window detection for painting robot will be discussed. In Chapter 3, our suggested methodology for tilt window detection will be described. Experimental result and relevant discussion are in Chapter 4.

2. AUTONOMOUS WALL PAINTING ROBOT

Our robot system focuses on painting at building facade. The main targets are RC (Reinforced Concrete) wall. As shown in Fig. 1, our system keeps contact on the wall using four propelling fans. Two endless winders control the movement of this gondola-typed robot system. An ARS (Attitude Reference System) sensor is applied to pose control, and a range sensor is used for location control [2]. An array of spray nozzles are attached horizontally and abreast.

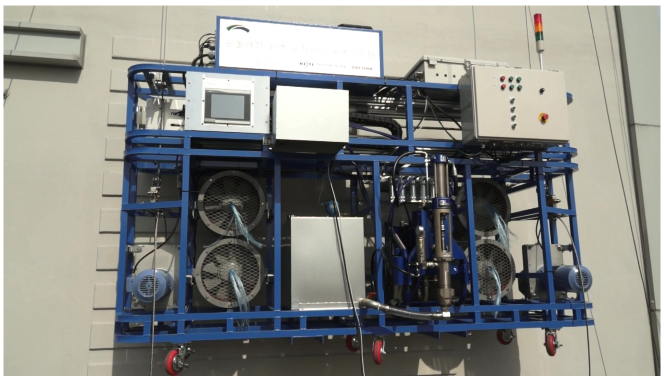


Figure 1. Gondola-typed robot system

2.1. Strategies for Operation

With above system, an operational strategy is that painting is executed from top to down. As step by step, the first operational phase is that the gondola system is set up at bottom of the wall. Second, wire rope, power cable, and communication cable are hooked up to the gondola. Third, initial check is conducted. Forth, the gondola system goes to the top of the wall. Finally, the gondola goes down to the bottom while the painting task is executed.

Basically, all the painting operations are executed only when the gondola contacts on the wall firmly because the painting sprays are optimised on fixed distance to the wall. Wind is another condition for the gondola operation. For industrial safety, many regulars and laws prohibit building facade tasks when wind speed is over regulations. Based on these conditions, we can assume that the gondola keeps contact to the wall and moves down smoothly.

2.2. Window Detection

On the building facade, there are some areas that should not be painted. Window is a typical obstacle for painting. Therefore, while the sensor system of the gondola robot scans the building facade, the windows should be detected. When the painting nozzles come close to the windows, they should be turned off. After the gondola gets off the window area, the painting task resumes. Because we use the array of paint spray nozzles, there are dead zone around the window [7]. This dead zone is to prepare for sudden gust disturbing paint spray, and originated from gap of spray installation points. Additionally, it helps the painting tool system adapt various two-dimensional and three-dimensional shapes of windows. Painting the dead zone is conducted by human labours through the window or hanging rope.

As sensor of window detection, we used a visual sensor. At [7], we suggested two approaches. First, we used the blob labelling algorithm for the window frame colour [8]. Predefined size was applied to select window blobs. Second, after converted to binary image, width histogram and height histogram of the image were analyzed to extract window corners. 3D scanner such as Microsoft Kinect[1] and ToF (Time-of-Flight) camera is another good sensor for our proposed algorithm. After 3D data is converted to 2D data that shows whether a pixel is the wall or not in binary image type, we can find out shapes of window.

3. TILTED WINDOW DETECTION

3.1. Reason for Tilted Window

While moving downward, the gondola system is sometimes tilted. For example, after the gondola overcomes some obstacles such as concrete ribs and only left side of the gondola passes through it, the lengths between each endless winder and each rope cart on the roof are different. Additionally, if accidental gust pushes the gondola, the window on the gondola camera should be tilted temporary even though the gondola pose is controlled by our task manager controller. In summary, the tilted window means the window area estimated by the gondola sensor system.

3.2. Algorithm for Tilted Window Detection

As many smart devices such as smart phones and tablet PCs have been spread, 2D barcode has been used a lot. The 2D barcode is similar with the window area on the building façade because both of them have square frame. Therefore, the 2D barcode detectors extract four lines on the square frame after binary image is grabbed and edge detection algorithm is conducted [9, 10].

However, the window detection for the gondola robot system cannot adapt this approach because the silhouette is not such solid line [7]. If there is sealant around window frames, the measured binary image would reflect shape and colour of the sealant. Abrasion of concrete area holding window frame is another reason. Because the window frame is shining, visual sensors are disturbed its reflection. Accessories for windows such as a safety grille and a balcony for flower pots also prohibit the silhouette of the window area having an exact rectangular shape. Therefore, for window detection, an algorithm for noise corrupted rectangular is required.

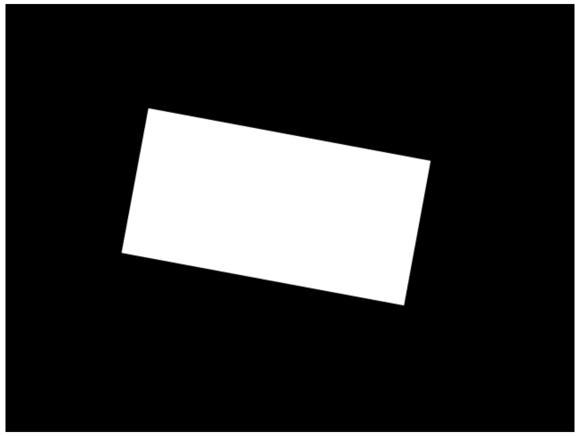


Figure 1. White area is a window area on building façade.

In order to introduce the suggested algorithm easily, we used a simple rectangular in Fig. 1. The white rectangular is a window area measured by the gondola sensor system. Note that we will not use the edge detection on this rectangular. As start of the algorithm, the input is converted to width histogram and height histogram. The width histogram bar means that occurrence of the white pixels on width axis, so number of white pixels in column direction is counted. The height histogram is produced in similar method.

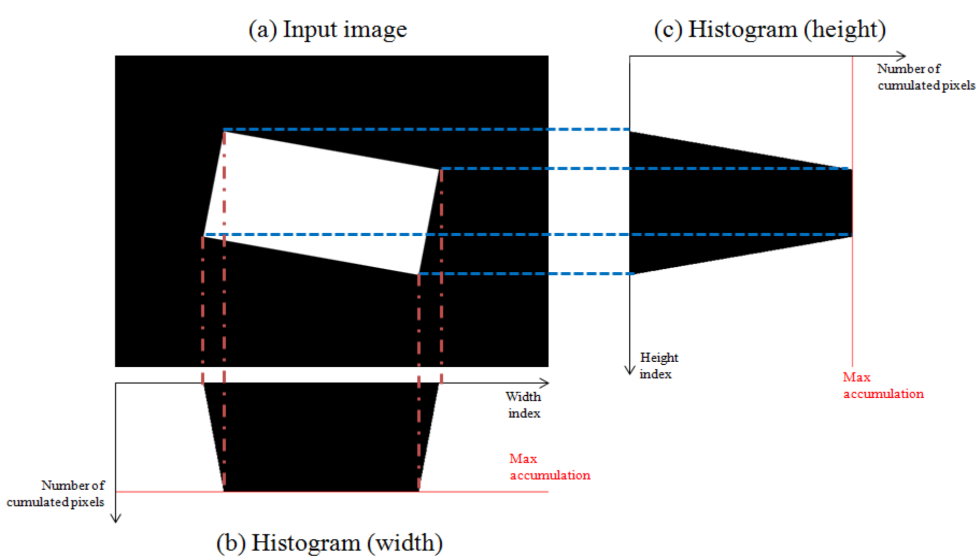


Figure 2. (a) Distinguished points on width and height histograms are mapped on tilted window area (b) Distinguished points on histogram are the start and end of histogram and its max area. (c) Distinguished points in height histogram.

As shown in Fig. 2, distinguished points are mapped on corners of window areas. To specify the window area, eight values for width and height axis are required. On width histogram, the start point of histogram (leftmost point) is mapped to width index of left-bottom point of the window

area. The end point is mapped to width index of right-top point of the window.
Note that width and height histograms are trapezoidal because tilt of the gondola system is limited. Therefore, start and end points of max bar of width histogram are mapped to width indices left-top and right-bottom points, respectively.

The height histogram is similar. Start and end point of histogram are mapped to height indices of left-top and right-bottom points. Height indices of right-top and left-bottom are mapped to start and end point of max bars of height histogram.

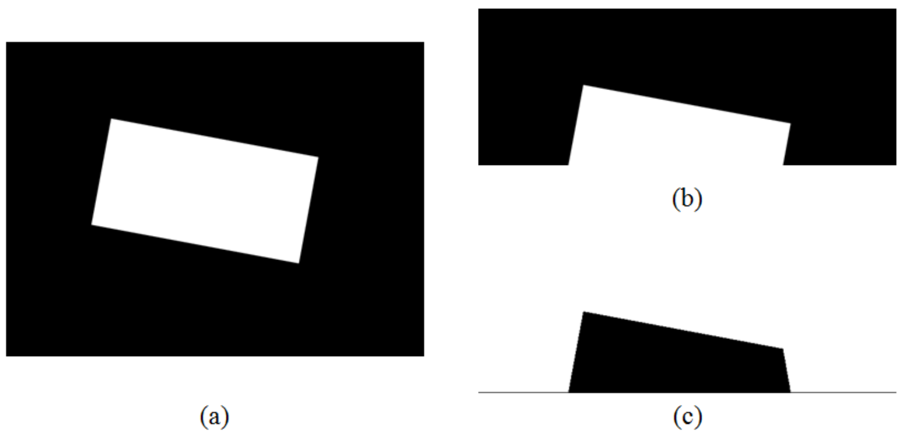


Figure 3. Method for tilt direction decision. (a) Input image. (b) Half-top of input image. (c) Width histogram of half-top of input image

However, the mapping table for above algorithm depends on tilt direction of window area (i.e., tilt of the gondola system). Above example is for CW (Clockwise) direction. To select the mapping table, the algorithm need identify the tilt direction. Fig. 3 shows the concept for the identification. Half-top of input image as shown in Fig. 3 (b) is converted to width histogram. At Fig. 3 (c), the max histogram bar is in left side, and it means that this window area is tilted in CW direction.

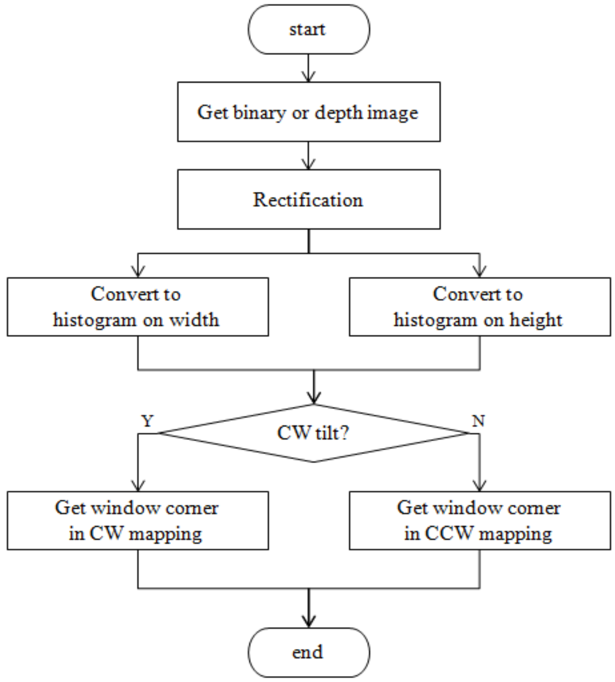


Figure 4. Flow chart for tilted window detection

Fig. 4 is a flow chart for tilted window detection. After getting input image and rectifying it, width and height histograms are converted. With decision algorithm shown in Fig. 3, appropriate mapping table is input for distinguished points in histograms. Finally, we can specify the tilted window area that the autonomous or remote-controlled gondola system should not paint on.

4. EXPERIMENTAL RESULT

The proposed algorithm in Chapter 3 was tested with an exact rectangular with solid edges. However, the real window is different because of characteristic of construction as mentioned above. At this experiment, we applied a real input image used in [7].

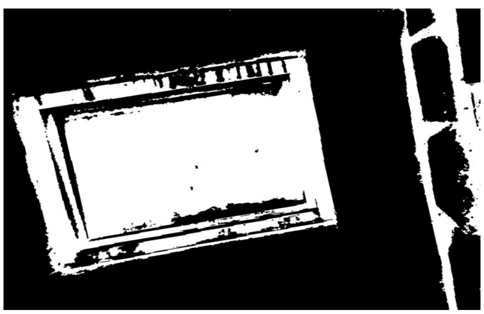


Figure 5. Binary image of tilted real window

Fig. 5 is a binary image of a real window. Even though the window is rectangular, its edges are not straight. The reason is that the shape comes from window frame sealant. Additionally, inside of the window is not homogeneous. There are a lot of black pixels in the window area. At right side, there are white pixels come from non-window area.

Figure 6. Rectification of input image

In order to use this input image for the proposed algorithm, it needed to be rectified. First, unintended white pixels at right side were filtered out with blob labelling. After applying blob labelling, predefined window sizes and ratios were compared with blobs. Because the right side of the input image does not have window ratio, it was eliminated. Second, another blob labelling was executed to pick up background black pixels. The other pixels are deleted from the input image. Finally, we got a rectified image that has only the window area and its inside is filled with white pixels, as shown in Fig. 6.

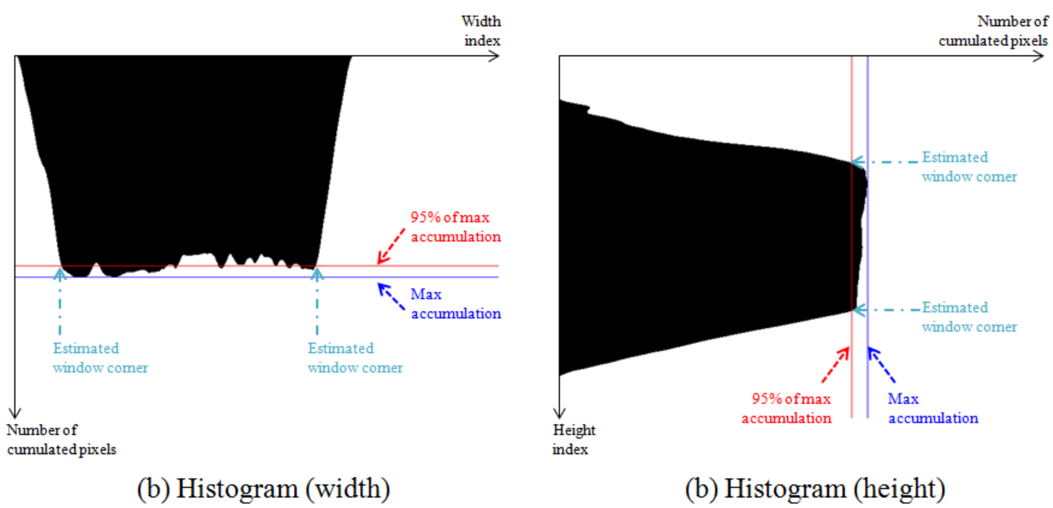
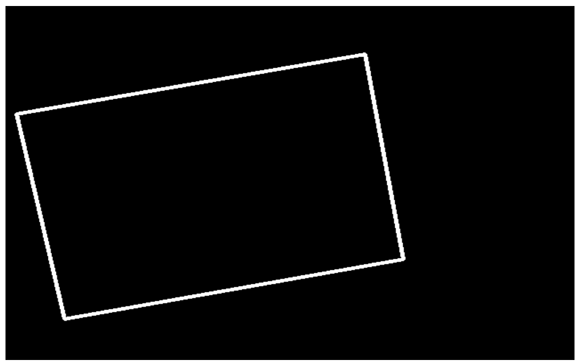
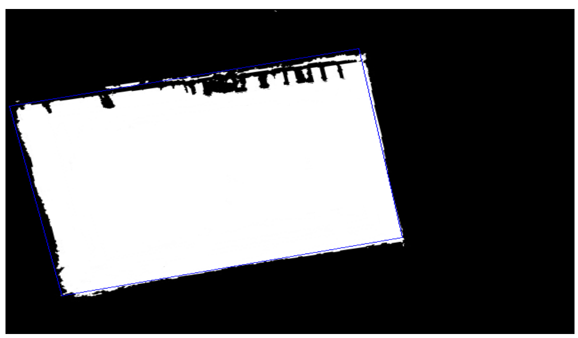


Figure 7. (a) Width histogram of the rectified image
(b) Its height histogram

With Fig. 6, the proposed algorithm was converted to width and height histogram. Selecting start and end points of histograms is identical with above example in Chapter 3. However, max histogram bar area fluctuated because there were some error pixels. In other words, the histograms are not trapezoid with straight edges. In order to select start and end point of max histogram bars, we set a threshold with 95% value of the maximum value of each histogram. First and last points which are over the threshold were selected as start and end point of histogram max area. Therefore, eight values for specifying window area were selected.



(a)



(b)

Figure 8. Detected area of tilted window

Fig. 8 (a) is the detected window area, and Fig. 8 (b) is the overlaid image of the input image and detected window. There are some white pixels at out of detected window area noted with blue lines. However, they are acceptable. With our strategies of operations, there are 20 cm safety zone around each window.

5. CONCLUSIONS

Many sensor systems are needed for an automated or remote-controlled gondola system. We have researched window detection algorithms as one of their job. In this paper, we focused an algorithm for tilted window detection. With width and height histograms, distinguished points were selected and mapped to corners of window area. In order to apply to real input image, some tips were used to overcome noise pixels.

The purpose of this algorithm is to provide basic data for painting tool system for the gondola robot. As future work, we are working on controlling painting tools with these data.

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