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Target Object Detection using Homographic Transformation

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Abstract

Background/Objectives: It is important to detect target objects in complicated environments without particular limits. This paper proposes a new method of detecting a target object in various circumstances with reflection. **Methods/Statistical Analysis**: The proposed method uses a stereo camera to capture a target object and then extracts the characteristics of the lines and corners that present the object well. After that, homographic transformation is applied to effectively remove unreal reflected characteristics from the extracted characteristics of the captured left and right images. Lastly, the real characteristics without reflected ones are clustered, and a target object is detected robustly. **Findings**: The test results of this paper reveal that the proposed algorithm detected a target object in the natural environment with reflection more accurately than an existing algorithm. For comparative evaluation of the performance of the proposed object detection algorithm, this paper uses as an experimental image the multiple scenes captured by a stereo camera in the general circumstance that has much reflection and no constraints. In particular, as an experimental image, the inside of an elevator comprised of steel walls with much mirror reflection was captured. This paper clustered real features and split them in the unit of object. To measure the performance of the target detection algorithm proposed in this paper, accuracy measure was used. As shown in the performance evaluation, the conventional algorithm tries to detect a target object without any removal of reflected features so that it has relatively lower accuracy than the proposed method. The proposed algorithm tries to detect a target object after removing unreal reflected features so as to detect a target object relatively reliably. **Improvements/Applications**: We expect that the proposed technique of detecting target objects in reflection environments will be utilized in various types of real application areas related to multimedia contents.

Keywords: Corner, Homography, Object Detection, Performance Evaluation, Stereo Camera, Virtual Feature

1. Introduction

In the 2D or 3D image processing and computer vision field, it is very fundamental and important to detect a target object accurately in a user's image[1–7].

There are a variety of target object detection techniques, such as differential image-based technique, motion information-based technique, model-based technique, and prediction-based technique. Object detection techniques are usefully applied to various areas, including mobile object tracking, traffic analysis, security, object modeling, and service robot[8–12].

Generally, a target object is present in a complicated cluttered environment that is greatly influenced by

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external factors such as lighting and reflection[13]. The object detection techniques applying the effect of lighting are found in previous literature[14]. However, it is hard to find studies on target object detection in the environment with reflection. In particular, in the environment of walls with severe mirror-like reflection, it has been known to be very difficult to detect a target object that a user wants. Until now, no particular solution has been suggested.

Therefore, this paper proposes a technique of detecting a target object robustly in the natural environment with reflection. Figure 1 illustrates the overview of the robust technique of detecting a target object in mirror-reflection circumstance. As shown in Figure 1, the proposed technique receives a stereo input image and then extracts main features representing a target object. After that, homographic transformation is applied to remove the features created by reflection from the extracted ones. Lastly, real features are used in order to recognize a target object robustly.

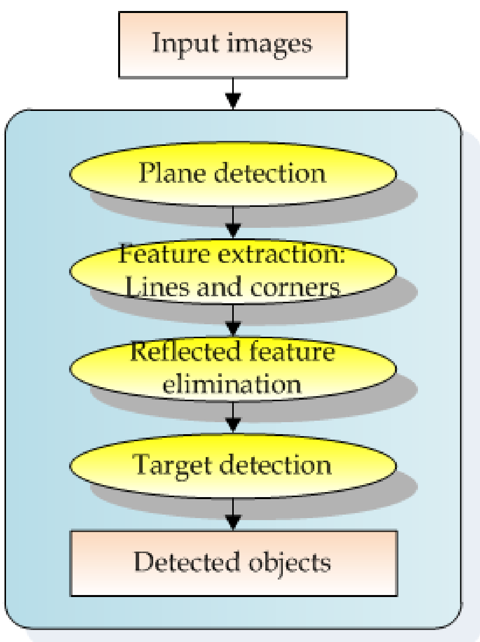

Figure 1. Overview of the proposed technique.

2. Feature Extraction

This paper uses lines and corners as the main features representing a target object. First, this paper extracts Canny edge-based 2D lines which are used as the first characteristics of objection detection[15–17]. The line detection used in this paper is comprised of an edge detection step and a straight line detection step.

As for edge detection, Canny edge known as the best edge detector is used. Generally, an edge image created by an edge operator shows a very different result depending on a degree of smoothing. An edge image created in the way of applying a proper threshold to an edge size also has a very different shape depending on the threshold value. In a boundary of an area, a user wants to make edge points with the thickness of one pixel, but there are many cases with different results. Therefore, Canny edge operator was designed to overcome the problems.

The Canny edge operator used in this paper removes small edges in the procedure of applying Gaussian smoothing to remove noise, calculating an edge size and direction with the use of Sobel operator, and tracking an edge with the use of dual threshold[18].

As for straight line detection, edges are connected and then the connected edges with a small number of edges are removed. If the edge most distant away from the straight line created in the connection between the start edge and the end edge of the connected edges exceeds a threshold, the process of splitting a connected edge from the most distant edge is repeated until the final line is detected. Usually, Canny edge operator has a different image depending on a threshold. Therefore, repeated test is conducted to determine a threshold suitable to a relevant domain.

A corner is used as the second characteristic. Generally, edge detection is often used to solve the problem of computer vision. However, the definition of edge is obscure, and it is not easy to develop the operator to detect an edge perfectly. On contrary, a corner point is defined relatively clearly, and thereby is used as a useful characteristic in object detection process[19–21].

For the corner characteristic, this paper uses Harris corner detector proposed by Harris[22–25]. The basic formula to induce Harris corner detector is written as in the Formula (1).

$$E(x,y;\Delta x,\Delta y)=\sum_{(u,v)\in(x,y)} w(u,v)\big(f(u+\Delta x,v+\Delta y)-f(u,v)\big)^2 \quad (1)$$

In other words, after an image is moved as many as Δx in the x direction and as many as Δy in the y direction, the sum of the difference from the pixel value of an original image is calculated. In this case, the sum of the difference is calculated within the window function w(x, y) with a relatively small size. Now, a corner point can be determined in the way of moving the window to calculate the sum of the difference and finding a position of the window in which the sum of the difference is a large value. The window used in this paper is Gaussian window with a small size as shown in the Formula (2).

$$w(u,v) = \exp\left(\frac{(u-x)^2+(v-y)^2}{2\sigma^2}\right) \tag{2}$$

3. Removal of Reflected Features

The line and Harris corner features extracted from left and right stereo images include the unreal reflected features through mirror reflection. Therefore, this paper applies homographic transformation[26–29] to remove the virtual features created by reflection and select real features.

To remove mirror-reflected features effectively, this paper uses the distance information on the plane between a camera and a target object. In other words, if the 3D distance between a stereo camera and an extracted random feature is equal to the distance between the camera and an object, the feature is judged to be real. Otherwise, it is judged to be the feature created by mirror reflection.

To detect a plane where an object is present, this paper attaches a chessboard marker to the plane. The corners present in the chessboard marker are then extracted from left and right stereo images, and the left and right matching of the extracted corners are made to extract 3D coordinates. The extracted 3D coordinates are used to calculate the solutions of the Formula (3) for a plane where a target object is present.

$$ax + by + cz + d = 0 \tag{3}$$

In the Formula (3), a, b, c, and d are constants. In this paper, the coordinates of 16 corners present in the chessboard marker are extracted, and then singular value decomposition (SVD) is applied for calculation in the plane equation[30,31].

After the equation of a plane of an object, planar homography generated in the plane and left and right stereo images is applied to remove the virtual features created by mirror reflection. Generally, homography is widely used for camera calibration, stereo matching, and 3D image reconstruction. The perspective projected points on 2D image for the points over the same plane of 3D space can be expressed with 3×3 homography matrix.

The corresponding relationship between the perspectively projected points on 2D stereo image for the points over the same 3D plane is expressed as shown in the Formula (4). In the formula, x means the point where the point x_π over the plane π is projected on the left image, and x' the point projected on the right image. H represents homography matrix present in two images that satisfies the Formula (4). It is found that the coordinate x' is the mapping of the coordinate by the homography H in the Formula (4). x and x' are homogeneous coordinates in the Formula (4).

$$x' = Hx \tag{4}$$

$$\begin{bmatrix} x' \\ y' \\ w' \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ w \end{bmatrix}$$

In the Formula (4), the 3×3 homography matrix H is expressed as shown in the Formula (5). In the Formula (5), K and K' mean the compensation matrix of left and right cameras, respectively. R is 3×3 matrix representing a degree of rotation of the left and right cameras. T is 3×1 translation matrix representing a degree of translation of the left and right cameras. In this paper, the stereo camera distant as many as the base line t_x only in the x-axis direction is used. n means normal vector of the 3D plane. v means the distance between the camera and the plane π.

$$H = K'\left(R - \frac{T \times n^T}{v}\right)K^{-1}$$
$$where \begin{cases} K = K' = \begin{bmatrix} f & 0 & p_x \\ 0 & f & p_y \\ 0 & 0 & 1 \end{bmatrix},\ T = \begin{bmatrix} t_x \\ 0 \\ 0 \end{bmatrix},\ R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \\ n = [a\ b\ c] \\ v = \dfrac{|d|}{\sqrt{a^2+b^2+c^2}} \end{cases} \tag{5}$$

Once the homography matrix H is calculated, the Formula (4) is applied to map the line and corner characteristics extracted from the left image to the right image. After that, the mapping dissimilarity function Φ, and the defined Formulae (8) and (9) are applied to remove the virtual features created by mirror reflection.

$$
\begin{aligned}
& IF\ \left(\Phi\left(L'_{left}, L_{right}\right) \leq TH_{line}\right)\ THEN \\
& \quad L_{left}\ \ and\ \ L_{right}\ \ are\ \ real \\
& ELSE\ \ L_{left}\ \ and\ \ L_{right}\ \ are\ \ virtual
\end{aligned} \tag{6}
$$

$$
\begin{aligned}
& IF\ \left(\Phi\left(P'_{left}, P_{right}\right) \leq TH_{corner}\right)\ THEN \\
& \quad P_{left}\ \ and\ \ P_{right}\ \ are\ \ real \\
& ELSE\ \ P_{left}\ \ and\ \ P_{right}\ \ are\ \ virtual
\end{aligned} \tag{7}
$$

$$\Phi\left(L'_{left}, L_{right}\right) = \sqrt{(x_l^{1'} - x_r^{1})^2 + (y_l^{1'} - y_r^{1})^2} + \sqrt{(x_l^{2'} - x_r^{2})^2 + (y_l^{2'} - y_r^{2})^2} \tag{8}$$

$$\Phi\left(P'_{left}, P_{right}\right) = \sqrt{(x'_l - x_r)^2 + (y'_l - y_r)^2} \tag{9}$$

The Formula (8) is mapping dissimilarity function of the line L_{left}' mapped to the right image of the line L_{left} extracted from the left image, and the line L_{right} extracted from the right image.

The Formula (9) is mapping dissimilarity function of the corner P_{left}' mapped to the right image of the corner P_{left} extracted from the left image, and the corner P_{right} extracted from the right image. In the formula (6) and the Formula (7), TH_{line} and TH_{corner} are thresholds applied to the mapping dissimilarity functions of line and corner. They are determined experimentally in this paper.

4. Detection of Target Object

This paper applies a clustering algorithm in order to remove the virtual features created by mirror reflection with the use of planar homography and to make use of real line and corner features to detect a target object robustly[32–36].

As a clustering algorithm, this paper uses ISODATA clustering algorithm which is one of unsupervised classification techniques for grouping, although it is impossible to find the number of clusters in advance[37,38]. The input data of ISODATA clustering algorithm are the line and corner characteristics of an object which are judged to be real.

Generally, ISODATA clustering algorithm is an improved k-means clustering method. The similar feature of ISODATA clustering algorithm and k-means clustering method is to allocate samples to the closest cluster to minimize a distance error[39]. The different one is that k-means clustering method creates a fixed number of clusters and ISODATA clustering algorithm can create up to the number of clusters including the number of clusters specified by a user. If clusters are too many or are too close, they are merged. If clusters are too small or have different types of samples, they are split.

5. Experimental Results

For comparative evaluation of the performance of the proposed object detection algorithm, this paper uses as an experimental image the multiple scenes captured by Bumblebee stereo camera in the general circumstance that has much reflection and no constraints. In particular, as an experimental image, the inside of an elevator comprised of steel walls with much mirror reflection was captured.

This paper clustered real features and split them in the unit of object. To measure quantitatively the performance of the robust target object detection algorithm proposed in this paper, accuracy measure was used as shown in the Formula (10), where the scale D_{rate} is the percentage of the number of accurately detected target objects and the total of target objects present in the image.

$$D_{rate} = \frac{NO_{detected\_objects}}{NO_{total\_objects}} \times 100\ (\%) \tag{10}$$

Figure 2 shows the graphs of the performance measurement results between the conventional clustering algorithm-based object detection algorithm without any removal of reflected features, and the proposed object detection algorithm with removal of reflected features.

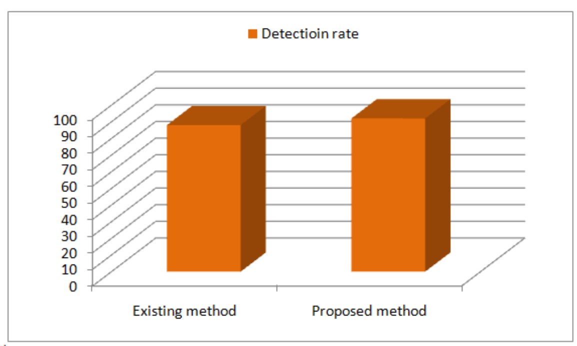

Figure 2. Detection accuracy.

As shown in the performance evaluation in Figure 2, the conventional algorithm tries to detect a target object without any removal of reflected features so that it has relatively lower accuracy than the proposed method. The algorithm proposed in this paper tries to detect a target object after removing unreal reflected features so as to detect a target object relatively reliably.

6. Conclusions

This paper newly proposed an algorithm of detecting robustly a target object that a user wants in the natural environment with mirror reflection. The proposed algorithm captured a target object with a stereo camera and then extracted the features representing the target object. After that, homographic transformation was applied to remove the virtual features created by mirror reflection and select real features. Lastly, the real features were clustered in order to detect a target object robustly. In an experiment, it was found that the proposed method detected an object more accurately than an existing method without any removal of any reflected features.

In the future, it is planned to complexly apply other representative features than the ones used already so as to improve accuracy of target objection detection. In addition, the types of a target object to detect will be diversified.

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