Rectification Y-Coordinate of Epipolar Geometry in Calibration of Binocular Eye System

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Abstract

This paper presents a modest calibration method for binocular eye system use in humanoid robot vision. The method focuses on rectification Y-coordinate of epipolar geometry to correct an image seen at the left eye is exactly the same as seen at the right eye. A set of stereo camera is installed on the custom mount of tripod in order to represent a prototype robot vision system. Furthermore, a 2D pattern chessboard was selected as object in this calibration test. The calibration process starts with capturing the images of the chessboard pattern by posing the chessboard at different angles in front of the cameras. In addition, a new program algorithm is developed to correct the distort geometry and execute the rectification process. Finally, this paper presents the calibration result called disparity map which is presenting both of images pixel positions of the undistorted and the rectified image of the chessboard.

Keywords: Binocular eye system, calibration, rectification, epipolar geometry, disparity maps.

1. Introduction

Binocular vision system in humanoid robot plays an important role to acts as human eye in order to enable them to assist and imitate human work. That artificial eye allowing the robot to locate, measure, inspect and identify any object position in front of it. The information data will be processed at first before the robot can gain sufficient information, thus giving it the ability to execute the command given. But before those works can be applied, the camera vision itself needs to undergo calibration process so that the data result received is constant and acceptable according to the application. However, in the binocular vision sensor field, there are many methods of calibration process, so it is important to understand and make sure to select the most suitable approach according to the desired...
output. This is because different methods have its own process of implementation advantage and limitation. At the end, calibration is the crucial step in artificial vision before proceed to another stage because it will determine the accuracy and correctness of the data gathered from both of the cameras for future development. The objective of this project is to calibrate two separate cameras into producing a single image with the aid of program algorithm that use rectification on Y-coordinate of epipolar geometry. Furthermore this paper presents reprojection error occurred that affected the result of the calibration due to the parameters and set up of the system. Figure 1 shows the experimental set-up of stereo camera used in this project to represent the prototype of robot binocular vision system.

2. Epipolar Geometry

Generally, there are two types of parameters involved in reconstructing the 3D structure of a scene from the pixel coordinates of its image points. Firstly, the extrinsic parameter. This type of parameter define the location and orientation of the camera reference frame, with respect to a defined world reference frame [1]. Furthermore, it also includes the translational and rotational feature of the image, that produce at one image with its pair so that both of its pixel rows perfectly align to each other as shown in Fig. 2.

The second parameter, termed as intrinsic, is the parameter that is responsible to link the pixel coordinates of the image point with the corresponding coordinate in the camera reference frame [1]. This type of parameter includes the focal length, the transformation between image planes coordinates and pixel coordinates, as well as the geometric distortion (radial and tangential) introduced by the optics.

There are a number of geometric relations between the 3D points and their respective projections onto the 2D images (epipolar geometry) when two cameras view a 3D scene from two different positions that will lead to some constraints between the image points [3]. These relations were derived based on the assumption that the cameras can be approximated as a pinhole camera model. For each pixel in the source image, its corresponding epipolar line in the search image must be calculated. This is where the rectification processes take place to transform the images in a condition where the epipolar lines are parallel and horizontal. Figure 3 below shows the steps involved in a stereo camera calibration, from its raw images to its final calibrated ones. The calibrated images were then cropped to examine its positional error.
3. Rectification Process

Figure 4 demonstrates the process of rectification. \( W \) represents the point in 3D space, \( C_1 \) and \( C_2 \) represent the camera focal points, \( M_1 \) and \( M_2 \) are the projections of \( W \) on the retinal planes of the cameras and \( R_1 \) and \( R_2 \) are the retinal planes of the cameras. In the left image, the points \( E_1 \) and \( E_2 \) represent the epipolar points of both images. In the right view, these points lie at infinity. After rectification, the epipolar lines are colinear and horizontal [4]. The points \( E_L \) and \( E_R \) are called the epipolar points of both images. All epipolar lines intersect the epipolar point of a given image. However, when the rectification process was done, the epipolar points move to infinity and the epipolar lines in one image become parallel to one another [5].

4. Calibration Process

The pattern used was chessboard (Fig. 5. raw stereo image) and the calibration process is consisting of undistortion process, rectification and disparity map. All the test were set with different test setup in term of its mounting alignment, and optic center of the camera alignment. The unit of average error is in pixels. All the image paired were captured correspond with the real time of every test. Every set of the test consist of 19 images in pairs and the size of the picture taken is 640 x 480 pixels. The command given by the algorithm is to detect 9 horizontals and 6 verticals of each edge. The step involve in calibration process are as follows:
a) Set up the individual test parameter position of stereo camera on its mounting.
b) Take a picture of the chessboard via left and right camera.
c) Save the image set consist of 19 pair of images with different pose.
d) Run the algorithm of Stereo Calibration.
e) Summoning set of file saved.
f) Process distortion images.
g) Process rectification (Y-coordinate of epipolar geometry)
h) Show the processed information data.

![Fig. 5. Captured raw image from (a) left camera and (b) right camera.](image)

![Fig. 6. Reprojection error correspond to number of image use](image)
5. Calibration Result

The calibration result was obtained from 2 sets of test. The information data on reprojection error correspond to number of image use is shows in Fig. 6. From the graph, the number of the error obtained from Test 1 was increase and decrease from number of image 4 to 13 and from number of image 16 to 19 respectively. Moreover graph Test 2 shows the error slightly decrease from image 4 to 7 but greatly increase from image 10 to 16. This shows us the reprojection error is not affected by the number of the image used.

Table 1 shows the coordinates from both of the images as a result from the rectification and distortion process. By refering the Fig. 7, green lines presenting the epipolar lines and all points on the image from both cameras will be situated at the same lines. From the Table 1, the Y-coordinates shows all the same colored point are on the same axis. Such as points Red and Red' having coordinates of 5. Whereas, at x-coordinates shows the coordinates of the colored points with a different origin. As a result, the coordinate at x-axis is not same for all the colored point. This result shows us that rectification process is a process of transforming the epipolar line of the left image and the right image become horizontal and parallel to each other, thus make the object seen at left image is exactly at the right image to the binocular eye system.

<table>
<thead>
<tr>
<th>Point</th>
<th>X-Coordinates</th>
<th>Y-Coordinates</th>
<th>X-Coordinates</th>
<th>Y-Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>1.2</td>
<td>5</td>
<td>5.2</td>
<td>5</td>
</tr>
<tr>
<td>Yellow</td>
<td>1.7</td>
<td>7</td>
<td>5.8</td>
<td>7</td>
</tr>
<tr>
<td>Orange</td>
<td>3.4</td>
<td>2</td>
<td>7.2</td>
<td>2</td>
</tr>
<tr>
<td>Blue</td>
<td>3.3</td>
<td>8.33</td>
<td>7.2</td>
<td>8.33</td>
</tr>
<tr>
<td>Purple</td>
<td>4.6</td>
<td>6.33</td>
<td>8.4</td>
<td>6.33</td>
</tr>
<tr>
<td>Green</td>
<td>2.9</td>
<td>3</td>
<td>6.9</td>
<td>3</td>
</tr>
</tbody>
</table>

Fig. 7. The chessboard is undergoing the stereo calibration method on detecting chessboard corner.
5. Conclusion

From the result of the experiment of the stereo calibration, the calibration process is executed and the reprojection error obtained is low, with a small gap between the reprojection error obtained which is 0.569. Besides, the implementation of the new algorithm is able to get the result and can be used for further development and research. Furthermore, this research able to identify the error occurred from the image captured and under the calibration of undistortion and rectification error and distortion map.

References

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