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Virtual camera calibration and stereo correspondence of single-lens bi-prism stereovision system using geometrical approach

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ABSTRACT

This paper proposes a simple geometrical ray approach to calibrate the extrinsic parameters of the virtual cameras and solve the stereo correspondence problem of the single-lens bi-prism stereovision system. Each images captured using this system can be divided into two sub-images which are generated by two virtual cameras due to the refraction through the bi-prism. This stereovision system is equivalent to the conventional two camera system and the two captured sub-images provide disparity which can be used for depth recovery. The virtual cameras will be calibrated geometrically and the correspondence problem of this system will be solved by applying epipolar geometry constraint on the generated virtual cameras instead of the real CCD camera. Experiments are conducted to validate the proposed method and the results are compared to the conventional approach to confirm its accuracy and effectiveness.

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1. Introduction

Conventional stereovision camera system requires two or more cameras to capture the same scene from different position or orientation in order to obtain disparity. Using this disparity together with the information of the extrinsic and intrinsic parameters of the cameras, the 3D views of the scene can be reconstructed. However, there are some difficulties in employing such system which include necessitates fastidious synchronization of two cameras, there are many system parameters and the cost could be high in medical application as two high resolution cameras are required. For example, a typical high resolution surgical microscope costs more than 50 thousands dollar. Thus, there are a lot of studies ([14–19]) to develop a single-lens stereovision system to replace the conventional two camera system to overcome the above difficulties. The single-lens prism based system studied in this paper is shown in Fig. 6. Although the system looks bulky, the design of the system can be improved by miniaturizing the prism and fixing it inside the lens or camera. Besides, this system can be easily generalized to a multi-faced prism system which is equivalent to a multi-view system. This will further reduce the cost and occupy less space as only one camera is required even for a multi-view system. In short, this single-lens system retains all the advantages of the current two-camera system such as high resolution, simple design and easy interface but at the same time much cheaper, potentially occupy less space and simpler hardware design.

In this paper, we will propose a geometrical approach to calibrate the extrinsic parameters of the virtual cameras and solve the stereo correspondence problem of the single-lens bi-prism stereovision system. This single-lens stereovision system is described in Fig. 2. By placing a two-faced prism in

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front of a CCD camera, two sub-images of the same scene is captured on the left and right image plane of the camera. These images are equivalent to two images taken using two-camera system with different orientation and position. Fig. 2 also shows the formation of the virtual cameras which are generated by the bi-prism. This system potentially overcomes the aforementioned problems of the conventional two camera system.

Theoretically, most of the previous algorithms in stereovision can be applied on this system if the single image captured treated as two images obtained from two cameras. However, due to the concern that the two cameras are virtual with very small baseline, a geometrical approach is proposed and customized for this system to model the two virtual cameras and to solve the correspondence problem. The results obtained using the proposed method is compared with other conventional algorithms. The experimental results showed that the proposed approach is much simpler and more effective for this particular system as compared to the conventional methods.

This paper is structured as follows: Section 2 will review the previous development of single-lens stereovision system and stereo matching technique; in Section 3, both the methods used for virtual camera modeling are discussed; the proposed stereo matching technique is described in Section 4 and the results are compared to the conventional calibration approach and last but not least the conclusion is done in Section 5.

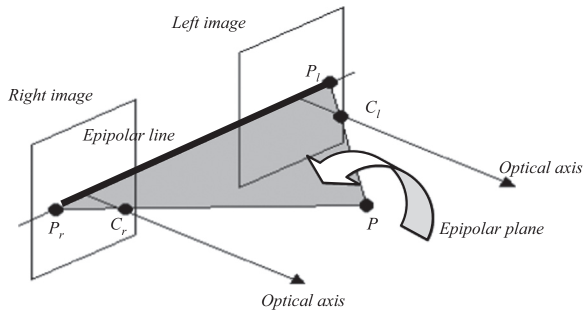

Fig. 1. Definition of epipolar plane.

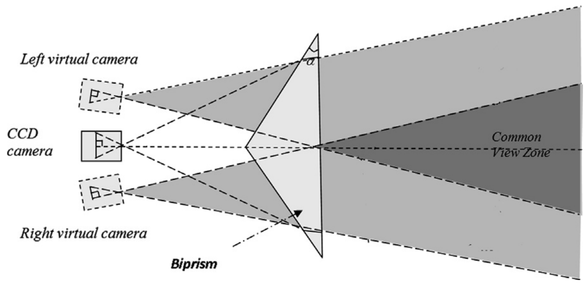

Fig. 2. Single-lens bi-prism stereovision system.

2. Literature review

Stereo correspondence problem is always the key problem in stereovision system. Correspondence points are the projected 3-dimensional point on the camera image plane. By obtaining these points and calculating the disparity (difference in positions on their respective image plane), the depth of the point in 3D space can be recovered. The main purpose of stereo matching algorithm is to find the best matching point accurately and effectively. In general, stereo matching algorithm can be categorized into three main groups which are pixel-based matching; feature based matching and global matching. Pixel-based matching such as correlation approach measures the similarity between two windows on the two images. A higher correlation number means a greater similarity. This algorithm is able to find the depth map of the object but it has poor effect on texture less images. Feature based matching can match some of the features or scene accurately and quickly but perform poorly when feature extraction is not possible. The last algorithm which is the global matching technique such as graph cuts and dynamic programming converts stereo matching problem to energy minimization problem. This method yield high accuracy but computation time is costly. There have been a lot of improvement and development on this area to address additional problem such as occlusions and reducing the computational time. More details can be found in [20,21].

Furthermore, additional constraint using epipolar geometry [3,6,7,10] can be applied on the stereovision system to reduce the searching and matching time. Referring to Fig. 1, a point in the 3D space together with the two optical centers of the cameras forms a plane which is called epipolar plane. The intersection between the epipolar plane and the image planes is called epipolar line. By constructing the epipolar line, the stereo correspondence searching is reduced to a 2-dimensional search along the epipolar line [3].

Conventional stereovision system requires two or more cameras capturing scene from different orientations to obtain disparity for depth recovery. In the past few decades, there was various single-lens stereovision system proposed to potentially replace the conventional two camera system with some significant advantages mentioned. Single-lens stereovision system with optical devices was first proposed by Nishimoto and Shirai [13]. They proposed a single-lens system with a glass plate which is positioned in front of a camera. The rotation of the glass plate causes deviation of the camera′s optical axis due to reflection which produces a pair of stereo images. The main disadvantage of this method is the disparities between the image pairs are small. Teoh and Zhang [11] further improved the idea of the single-lens stereovision camera with the aid of three mirrors. Two of the mirrors are fixed at 45 degrees at the top and bottom and the third mirror is rotated freely at the middle. Two shots will be taken with the third mirror aligned to be parallel to the fixed mirrors. Francois et al. [5] further refined the concepts of stereovision from a single perspective to a mirror symmetric scene and concluded that a mirror symmetric scene is equivalent to observing scene with two cameras and all traditional analysis tools of binocular stereovision can be applied. The main problem of mirror based single-lens system is its application only limited to static scene as

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