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Single-image calibration method for multiple virtual binocular vision system

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ABSTRACT

The virtual binocular vision system (VBVS) based on single camera and mirrors has been paid increasing attention, with the advantages of high flexibility and compactness. However, in its calibration process, the conventional methods require several images and obtain different intrinsic parameters, which should be identical between different virtual cameras. To simplify the calibration process and obtain identical intrinsic parameters, a single-image calibration method for the VBVS based on one camera and mirrors is proposed. Through the single image including multiple sub-images of the calibration planes, the intrinsic parameters and distortion coefficients can be obtained. Then, the global calibration of multiple virtual binocular structures can be performed efficiently. To test the performance of the proposed approach, a VBVS composed of four pairs of virtual binocular structures was designed and the calibration experiments were performed using an artificial three-dimensional calibration target. Moreover, an accuracy comparison with the conventional method was carried out. The results exhibited the feasibility of this method and proved its accuracy.

Keywords: virtual camera, calibration, stereovision, vision measurement

1. Introduction

In the field of machine vision, with the practical requirements of diversification and miniaturization, the virtual binocular vision system (VBVS) based on single camera and catoptric mirrors has become an attractive research orientation in recent years [1–5], for its potential prospect in the areas of inner surface inspection, machine navigation, and visual obstacle avoidance. The main advantages generated by catoptric virtual binocular structure are due to its identical camera parameters, compact structure, and perfect synchronization. Currently, various catoptric mirrors have been designed for the VBVS [6–8]. The main challenges of these vision systems are due to inherent distortion of curved mirrors, inconsistent image resolution, and complex calibration model. To simplify structure model and avoid curved mirrors distortion influence, a vision sensor based on multiple virtual binocular structures was designed by ZHOU [9], which could capture images conforming to the perspective projection invariance [10]. More important, the measurement accuracy of the sensor can maintain at the same level of traditional binocular stereo vision, and the traditional binocular model can still be used to some extent [11, 12].

However, different from traditional multi-camera binocular structure [13, 14], each pair of virtual cameras will be generated by the catoptric imaging structure and all the virtual cameras have identical intrinsic parameters. For calibrating the vision system precisely, using the conventional two-step method [15], the intrinsic parameters of the single camera and the structure parameters of the vision system are calibrated separately [16]. Its main disadvantages for the VBVS are the complicated process and need to remove the catoptric mirrors in the process of calibrating intrinsic parameters [17].

To simplify the calibration process and integrate conventional two-step method, a novel calibration method based on one single image of a 3D calibration target is proposed. The 3D calibration target is composed of steel support and multiple calibration planes with the same parameters [18], which are symmetrically installed toward multiple directions. Any two calibration planes of the 3D target have been confirmed their transformation relationship, which can be measured easily by a precisely calibrated traditional two-camera system [19]. Thus, one single image of the 3D calibration target includes multiple calibration planes and structure information of all pairs of virtual cameras. In the calibration process, the local calibrations of each virtual binocular structure [20] and the global calibrations between different pairs of virtual cameras [21] can be performed using the same single image. This paper starts with the VBVS and imaging principle, followed by the local and global calibration models. In the final, real comparison experiments and analysis were performed to verify the performance of the proposed method.