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Stereo camera calibration with fluorescent spherical marker and laser interferometer

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Abstract

Stereo vision is an image measurement system that acquire three-dimensional information of a target without contact. One of the most important applications of stereo vision is a motion capture system measuring three-dimensional positions of multiple moving targets. In this presentation, we propose a calibrator with fluorescent spherical marker and laser interferometer for improving accuracy of stereo vision system. In conventional calibration of stereo camera, check pattern on a plane is usually used as a calibrator. The conventional calibrator has relative accuracy of about 10^{-3} to its size and can be detected in a captured image with accuracy of about 0.1 pixels. In contrast, the proposed calibrator has relative accuracy of about 10^{-6} and can be detected in a captured image with accuracy of about 0.001 pixels. In displacement measurement of 180 mm with fluorescent spherical marker as a measuring target, RMSE of the proposed and conventional methods were 1.57 µm and 232.84 µm respectively. The standard deviation of both methods was 0.45 µm. These results show the proposed method improved trueness of stereo vision system about 100 times higher than the conventional one.

Fluorescence, Spherical Marker, Calibration, Stereo Camera

1. Introduction

Stereo camera systems are calibrated with geometrical information obtained from a calibrator. The most famous calibrator is two-dimensional grid pattern on a plane like a chessboard [1-4]. In this calibrator, control points are expressed as corner points [1, 2] or circle centers [3, 4] and can be detected in a captured images with about 0.1 pixel precision. Relative shape accuracy of this calibrator to its size is about 10^{-3}.

A sphere is used as three-dimensional stereo vision calibrator [5, 6]. Retroreflective spherical markers are widely used in a motion capture system and are installed on a calibrator. This marker can be detected in a captured images with about 0.01 pixel precision [6, 7]. Fluorescent spherical markers can be detected more precisely than the retroreflective ones [8, 9].

In this paper, we propose a stereo vision calibration with fluorescent spherical marker and laser interferometer for high-accuracy image measurements. The proposed method improves the camera parameters obtained from a conventional calibration method.

2. Stereo camera calibration

2.1. Fluorescent spherical marker

Fluorescent spherical markers are optical ones for precise image measurement [8, 9]. Precision of the marker detection is about 0.001 pixels, which is milli-pixel marker detection. This marker has a potential of improving stereo camera calibration.

Fluorescent spherical markers excited by a UV light are captured by a camera with UV-cut filter. This leads to high contrast between the marker and background in the captured image. Image edges on the high contrast contour can be detected precisely. The position of this marker is calculated as a center of the circle fitting to the edges [8, 9].

2.2. Calibrator with fluorescent spherical marker and laser interferometer

In this paper, we propose a calibrator for stereo camera calibration with a fluorescent spherical marker and laser interferometer as shown in Figure 1. The fluorescent spherical marker is installed on a moving stage and captured by a stereo camera system for calibration. Relative accuracy of displacement measurement by the laser interferometer is about 10^{-6}.

Displacement of the marker is measured by both of the stereo camera system and the laser interferometer. Parameters of the stereo camera system are estimated as minimizing the difference between these measured displacements by Levenberg-Marquardt algorithm:

$$\boldsymbol{p}^* = \operatorname*{argmin}_{\boldsymbol{p}} \sum_{i=1}^{n} \left(x_{\mathrm{C},i}(\boldsymbol{p}) - x_{\mathrm{L},i}\right)^2,$$

where $\boldsymbol{p}$ is the vector of camera parameters which are same as described in [1], x_{C} is measured displacement by the stereo camera, x_{L} is measured displacement by the laser interferometer, and n is the number of calibration data.

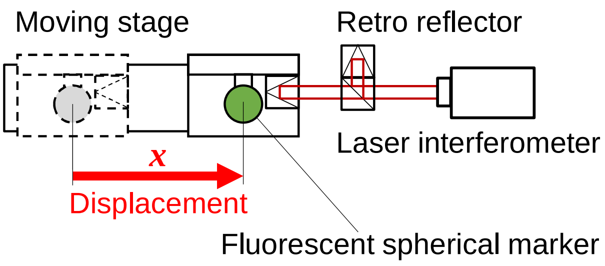

Figure 1. Proposed calibrator with fluorescent spherical marker and laser interferometer.

2.3. Calibration procedure

The proposed calibration method consists of two-step calibrations. The first step is conventional calibration using grid-pattern calibrator [1], which is pre-calibration. The second step is calibration with the proposed calibrator.

The purpose of the second step is to improve the camera parameters. In the calculation of the second step, camera parameters estimated in the first step are used as a initial values in optimization of the second step.

3. Displacement measurement by calibrated stereo vision

Accuracy of calibrated stereo camera system was evaluated in displacement measurement as shown in Figure 2. Measurement error was calculated by subtracting displacement measured by a laser interferometer from one measured by the camera system. Measured errors were compared between conventional (1-step) and proposed (2-step) calibrations.

3.1. Experimental equipment

Two cameras of AVT Prosilica GX6600 with lens of AI AF Nikkor 50mm f/1.8D were placed on a vibration-isolated table. The optical axes were parallel, and the baseline was 125 mm.

A fluorescent spherical marker of 25.4 mm diameter was installed on a moving stage. Distance between the moving axis and optical centers of the camera system was 800 mm.

UV-ring lights were placed in front of the camera system. The peak wavelength of the lights was 375 nm. The fluorescent spherical marker was excited by the lights and captured by the camera system with UV-cut filter of 410 nm cut-off wavelengths.

A laser interferometer of Renishaw XL-80 measured displacement of the moving marker as ground truth.

3.2. Stereo camera calibration

As the first step calibration, the stereo camera system was calibrated by conventional method [1] with grid pattern shown in Figure 3. The number of stereo image pairs for this calibration was 20. Estimated camera parameters were used as the initial values in optimization calculation of the second step calibration.

In the second step calibration, the fluorescent spherical marker was moved 180 mm in 20 mm steps. At the each position, the marker was captured 30 times by the stereo camera system as calibration data.

3.3. Displacement measurement

The fluorescent spherical marker was moved 200 mm in 20 mm steps. At each position, the marker was captured 5 times by the stereo camera system as evaluation data.

Figure 4 shows the comparison of measurement error between conventional (1-step) and proposed (2-step) calibrations. The proposed calibration reduced the RMS error of measured displacement by more than 99%. Relative accuracy and precision of the proposed method was 7.9×10^{-6} and 2.3×10^{-6}, respectively.

4. Conclusion

This paper proposes a stereo calibration method with fluorescent spherical marker and laser interferometer. In displacement measurement of 200 mm, RMS error of displacement measured by calibrated stereo camera system was reduced by more than 99% compared with conventional calibration method.

Acknowledgment

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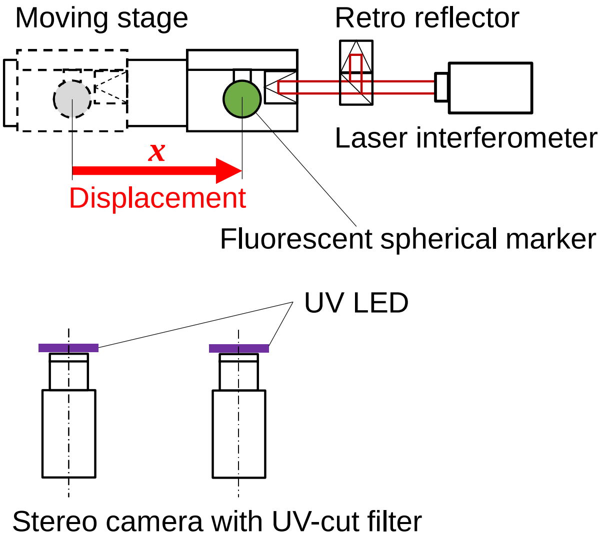

Figure 2. Experimental setup for displacement measurement by stereo camera system with a fluorescent spherical marker.

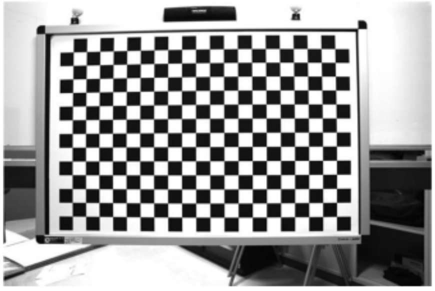

Figure 3. Grid pattern for conventional camera calibration.

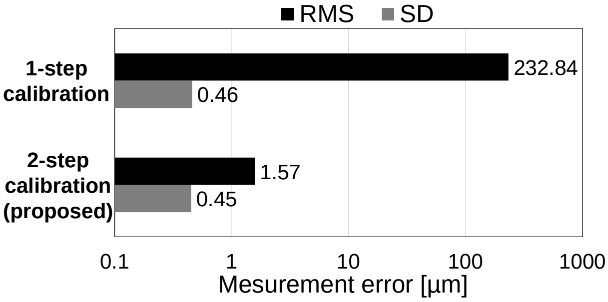

Figure 4. Comparison of measurement error between conventional and proposed calibration methods.

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