3D Reconstruction through the Ray Calibration of an Optically Distorted Stereo-photogrammetric System

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Even coupled with the standard image distortion corrections, the popular method of Zhang Camera Calibration still fails to produce accurate image based stereo 3D reconstructions in the presence of strong optical distortion effects. Considering a generalized imaging model, the technique of Ray-Based Camera Calibration is demonstrated to enable 3D reconstruction despite these effects.

1 Introduction

One of the ways to achieve three dimensional surface reconstruction of an object is through stereoscopic imaging. Imaging an object from two different views provides a means to triangulate the 3D coordinates of any point. Triangulation requires the directional behavior of all light rays originating from the object towards the camera sensor. This information is determined through camera calibration. A popular method of camera calibration developed by Zhang [1] is most commonly performed to obtain the camera's intrinsic parameters and distortion coefficients so that light ray direction can be recovered. Zhang calibration is then performed in conjunction with Hartley's 8-point algorithm [2] to extract the relational geometry between the two cameras by determining the Fundamental Matrix. Große [3] improved camera parameter estimation by displaying a sequence of statistical band-limited patterns (BLPs) on a TFT monitor as a means of temporally encoding each TFT pixel. This produced a dense and accurate set of corresponding points between the world and image coordinates, resulting in up to a four times improvement in camera parameter precision. With increased parameter precision comes increased surface reconstruction precision.

These methods however rely on the assumption that the cameras operate under classical perspective projection. They are susceptible to imaging systems that violate perspective projection such as fish-eye or wide angle lens attachments that introduce a strong optical distortion effect into the image. Applying the standard distortion correction [4] to the images still fails to result in an accurate reconstruction. To overcome this, a generalized imaging model introduced by Grossberg [5] is used as a means to directly map a light ray to each individual image sensor pixel in a technique known as Ray-Based Calibration.

2 Experimental Setup

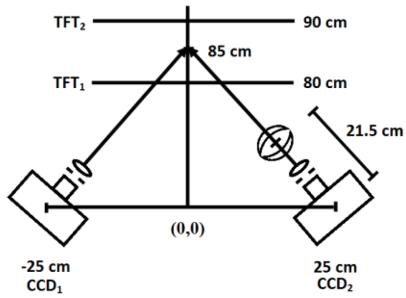

Fig. 1: *Stereo imaging setup with distorting lens*

The stereo imaging setup was created as shown in Fig.1 with a total measurement volume of 10×10×7 cm^3. To obtain a directional vector for each camera pixel in Ray-Based Calibration, a TFT monitor is imaged in two different positions. The TFT displays a sequence of BLPs such that it is possible to determine which camera pixel is the corresponding projection of which TFT pixel through temporal coding. With this, two points lying along the same light ray are obtained, allowing for the calculation of a vector. The rotation and translation of the second TFT position (TFT_2) must be known with respect to the first TFT position (TFT_1) as only the local TFT coordinates (i.e. TFT pixel) are determined. In this study, to simplify the Ray-Based Calibration process, TFT_2 was not rotated with respect to TFT_1 and its translation was fixed along the z-axis. To introduce a strong distortion effect into one of the camera images, a barrel distorting doublet lens was placed 21.5 cm in front of one of the cameras. A total of ten Ray-Based Calibration samples were taken such that TFT_1 was randomly placed within a ±2.5 cm range from the 80 cm position so as to emulate the natural variation in placing the TFT at its nominal positions.

To perform Zhang Calibration, the TFT was placed in 20 random orientations within the 80-90 cm range from the camera baseline in order to obtain the camera's intrinsic parameters and the distortion

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coefficients for image correction. To determine the stereo geometry, a sequence of BLPs is then projected onto a calibrated object so that the Fundamental Matrix can be determined through the 8-point algorithm using corresponding points between the two views. A total of ten Zhang Calibration samples were taken.

Reconstructions were performed using the setup with and without the distorting lens such that the performance of Ray-Based and Zhang Calibration can be compared under distorted and non-distorted imaging conditions.

3 Reconstruction Results

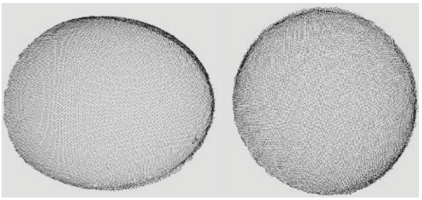

***Fig. 2**: Sphere reconstruction produced by Zhang Calibration (left) and Ray-Based Calibration (right) under strong image distortion*

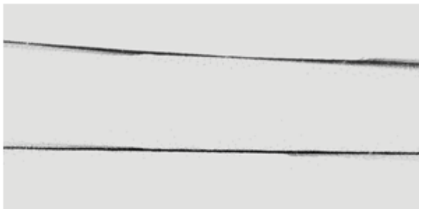

***Fig. 3**: Top-wise view of plane reconstruction produced by Zhang Calibration (top) and Ray-Based Calibration (bottom) under strong image distortion*

A calibrated sphere and plane were placed in positions within the measurement volume according to the standard VDI 2634 [6]. Shown in Fig. 2 and Fig. 3 are their reconstructions produced under distorted imaging conditions. In both cases, it can be seen that Zhang Calibration is unable to reproduce the object geometry accurately while Ray-Based Calibration is still able.

4 Discussion

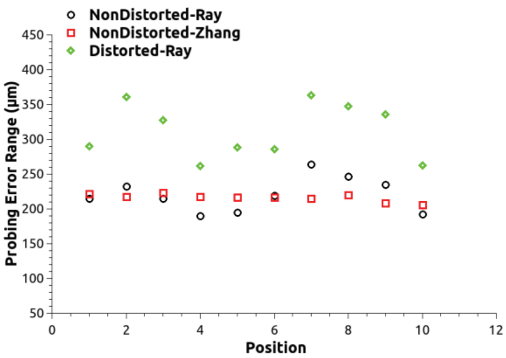

***Fig. 4**: Plot of peak-to-valley error in sphere surface reconstruction known as the Probing Error Range*

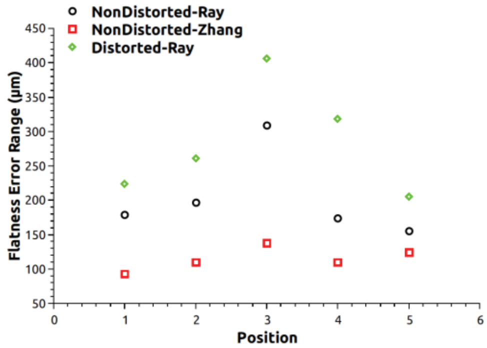

***Fig. 5**: Plot of peak-to-valley error in plane surface reconstruction known as the Flatness Error Range*

Fig. 4 and 5 show the mean Probing Error and the mean Flatness Error for each position in the measurement volume calculated from the ten samples of each camera calibration method. It can be seen that under non-distorted imaging conditions, Zhang Calibration has superior performance compared to Ray-Based Calibration as the mean error for both the sphere and plane reconstruction is lower and more consistent. Under distorted imaging conditions where Zhang Calibration fails, Ray-Based Calibration is still able to reconstruct but its performance becomes degraded by up to 150 μm.

5 Conclusion

It has been shown that even with the standard image correction technique applied, Zhang Calibration in conjunction with Hartley's 8-point algorithm is unable to perform 3D surface reconstruction under the presence of strong distortion effects. Ray-Based Calibration on the other hand is still able, but its performance becomes degraded compared to non-distorted conditions.

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