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# INTRINSIC PARAMETER CALIBRATION PROCEDURE FOR A (HIGH-DISTORTION) FISH-EYE LENS CAMERA WITH DISTORTION MODEL AND ACCURACY ESTIMATION*

SHISHIR SHAH and J. K. AGGARWAL

Computer and Vision Research Center, Department of Electrical and Computer Engineering, ENS 522, The University of Texas at Austin, Austin, TX 78712-1084, U.S.A.

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**Abstract**—This paper presents a calibration procedure for a fish-eye lens (a high-distortion lens) mounted on a CCD TV camera. The method is designed to account for the differences in images acquired via a distortion-free lens camera setup and the images obtained by a fish-eye lens camera. The calibration procedure essentially defines a mapping between points in the world coordinate system and their corresponding point locations in the image plane. This step is important for applications in computer vision which involve quantitative measurements. The objective of this mapping is to estimate the internal parameters of the camera, including the effective focal length, one-pixel width on the image plane, image distortion center, and distortion coefficients. The number of parameters to be calibrated is reduced by using a calibration pattern with equally spaced dots and assuming a pin-hole model camera behavior for the image center, thus assuming negligible distortion at the image distortion center. Our method employs a non-linear transformation between points in the world coordinate system and their corresponding location on the image plane. A Lagrangian minimization method is used to determine the coefficients of the transformation. The validity and effectiveness of our calibration and distortion correction procedure are confirmed by application of this procedure on real images. Copyright © 1996 Pattern Recognition Society. Published by Elsevier Science Ltd.

Camera calibration  Lens distortion  Intrinsic camera parameters  Fish-eye lens  Optimization

## 1. INTRODUCTION

Accurate calibration of an imaging device is of utmost importance in computer vision. Precise camera calibration is needed in various applications which involve quantitative measurements, such as stereo vision, robot navigation, inspection and automated assembly, and robot vision. An important aspect of calibration is estimating the internal or intrinsic parameters of the camera. These parameters determine how the image coordinates of any point may be computed, given the three-dimensional (3-D) position of the point with respect to the camera. The estimation of the geometric relation between the camera and the scene is also an important aspect of the calibration procedure, and the parameters which characterize this relation are termed the external or extrinsic parameters. The estimation of extrinsic parameters has been well studied in the past and will not be detailed in this paper. On the other hand, researchers have neglected the estimation of intrinsic parameters, which in fact are crucial to a precise quantitative analysis.

Most cameras are not perfect and tend to show a variety of distortions and aberrations. For geometric measurements, the most important issue is the distortion that the camera exhibits. The cameras most commonly used have off-the-shelf lenses that exhibit a substantial amount of distortion. The camera assembly is often misaligned internally, and the CCD sensing array may not be orthogonal to the optical axis of the lens. Similar characteristics are inherent to the fish-eye lens camera, thus making it important to establish an efficient method of calibration before determining the camera distortion coefficients. The fish-eye lens proves to be useful where a large field of view is required, since it provides a field of view which is approximately 180°. When the distance between the lens and the object is small, a fish-eye lens can provide a full view of the object where other lenses fail to do so. To obtain accurate quantitative measurements from fish-eye lens images, we have to calibrate certain camera parameters so that we can accurately transform the image plane coordinates of the object into the 3-D world coordinates.

Although fish-eye lenses provide for a large field of view ($\sim 180°$), they introduce significant distortion in the image, as seen by comparing Figs 1 and 2.

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## 6. CONCLUSION

In this paper, we have presented a simple but effective procedure for the calibration of a high distortion lens. The determination of intrinsic parameters using a simple calibration procedure is addressed. The parameters calibrated include the distortion coefficients, the optical center, the effective focal length, and the one pixel width on the image plane. A camera model for fish-eye lenses is presented and the distortion characteristics are analysed. In the calibration procedure, the polynomial transformation is calculated for a camera which has two components of distortion, radial and tangential. The polynomial is calculated using Lagrange minimization and the coefficients are further optimized using *a priori* information. The technique of inverse mapping is used to account for the blank areas in the undistorted image and to recover a complete gray-level image. The calibration procedure is successfully applied to real world images acquired using the fish-eye lens, and the accuracy of the correction is established.

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**About the Author**—J. K. AGGARWAL has served on the faculty of The University of Texas at Austin College of Engineering since 1964 and is currently the Cullen Professor of Electrical and Computer Engineering and Director of the Computer and Vision Research Center. His research fields include computer vision, parallel processing of images, and pattern recognition. He has been a Fellow of IEEE since 1976. In 1992, he received the Senior Research Award of the American Society of Engineering Education. Dr Aggarwal is author or editor of seven books and 31 book chapters; author of over 160 journal papers, as well as numerous proceedings papers, and technical reports. He has served as Chairman of the IEEE Computer Society Technical Committee on Pattern Analysis and Machine Intelligence (1987–1989); Director of the NATO Advanced Research Workshop on Multisensor Fusion for Computer Vision, Grenoble, France (1989); and Chairman of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition (1993). He currently serves as IEEE Computer Society representative to the International Association for Pattern Recognition, is Past President of the International Association for Pattern Recognition, and is an Editor of IEEE *Transactions on Parallel and Distributed Systems.*

**About the Author**—SHISHIR SHAH received the B.S. degree in mechanical engineering in 1994, and the M.S. degree in electrical engineering in 1995 from The University of Texas at Austin. He is presently working toward the Ph.D degree at the Computer and Vision Research Center, The University of Texas at Austin. His research interests include mobile robots, computer vision, and pattern recognition. Mr Shah is a student member of the IEEE Computer Society.