CCD Camera Calibration Using Planer Constraint”, presented in the Close-Range Techniques and Machine Vision Symposium

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CCD CAMERA CALIBRATION USING PLANAR CONSTRAINT

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Abstract:

A method has been developed for the calibration of CCD cameras using a planar object as control field. A stereo pair of images of a planar object must be acquired using the camera to be calibrated. The condition of spatial intersection of the two bundles of rays provides the geometric constraint to determine image distortions in the direction perpendicular to the scan lines. The planar object provides the additional constraint that all the conjugate pairs of rays must intersect at points located on the plane, thus permitting the determination of image distortions along the direction of the scan lines. Experimental tests using a brick wall as control field and manual matching of conjugate image points resulted in image residuals (1 σ) of ± 0.3 pixel.

INTRODUCTION

Proper calibration of the interior geometry of CCD cameras is the key to computer vision metrology. Laboratory calibration using three-dimensional test fields had clearly demonstrated the potential geometric accuracy of computer vision systems (Wiley and Wong, 1992). However, it is technically difficult to establish and maintain a three-dimensional test field consisting of thirty or more targets whose coordinates must be determined to an accuracy better than ±0.1 mm. For the calibration of zoom lenses, more than fifty control targets will be needed to provide a sufficiently large number of targets at the full range of focal settings. In practice, such calibration facilities are available only in a few research laboratories.

There is a need to develop a method of geometric calibration that can be easily performed by users of CCD vision systems for metric measurement. The method should require no special calibration facility or accurately surveyed three-dimensional control points. This paper reports on the successful development of such a method based on the principle of planar constraint.

THE ALGORITHM

The method requires that two images of a planar object, such as a brick wall, be acquired with the camera that is to be calibrated. The two images should provide a stereo coverage of the planar object. In the complete absence of geometric distortions, the two bundles of rays, representing the two images, would intersect perfectly in space. Thus, the condition of spatial intersection provides the geometric condition to determine geometric distortions in the direction perpendicular to the scan lines; i.e. in the column direction. The planar object provides the additional constraint that all the conjugate pairs of rays must intersect at points located in a plane. This second condition provides the geometric constraint to determine the geometric distortions along the direction of the scan lines; i.e. along the row direction. Figure 1 illustrates the basic principle of the method.

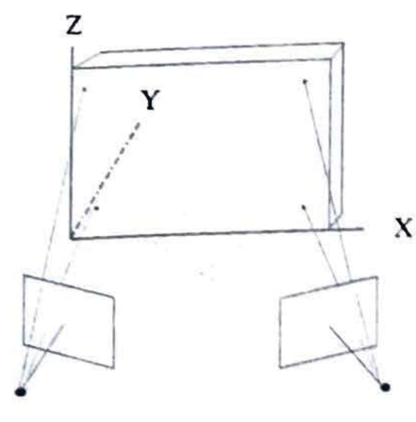

Figure 1. Stereo intersection with planar constraint

The general equation for a plane is as follows:

$$A\,X_j + B\,Y_j + C\,Z_j = 1 \qquad (1)$$

where X_j, Y_j, and Z_j represent the object-space coordinates of any point j located on the plane. Based on the projective transformation geometry, the coordinates (X_j, Y_j, and Z_j) can be expressed as functions of the image coordinates and interior and exterior orientation parameters of the two images. After substituting these functions into Equation 1 and linearizing by Newton's first order approximation, the resulting equation is expressed as follows:

$$\begin{aligned} & a_1 V_{xlj} + a_2 V_{ylj} + a_3 V_{xrj} + a_4 V_{yrj} \\ & + a_5 \Delta X_l^c + a_6 \Delta Y_l^c + a_7 \Delta Z_l^c \\ & + a_8 \Delta \omega_l + a_9 \Delta \phi_l + a_{10} \Delta \kappa_l \\ & + a_{11} \Delta X_r^c + a_{12} \Delta Y_r^c + a_{13} \Delta Z_r^c \\ & + a_{14} \Delta \omega_r + a_{15} \Delta \phi_r + a_{16} \Delta \kappa_r \\ & + a_{17} \Delta x_p + a_{18} \Delta y_p \\ & + a_{19} \Delta k + a_{20} \Delta l_1 + a_{21} \Delta l_2 \\ & + a_{22} \Delta p_1 + a_{23} \Delta p_2 + a_{24} \Delta p_3 \\ & + a_{25} \Delta A + a_{26} \Delta B + a_{27} \Delta C + a_{28} = 0 \end{aligned} \qquad (2)$$

where the Δ-terms are the corrections to the exterior orientation parameters (X_l^c, Y_l^c, Z_l^c, ω_l, φ_l, κ_l, X_r^c, Y_r^c, Z_r^c, ω_r, φ_r, and κ_r) of the left and right images; the coordinates of the principal point (x_p, y_p); the scale distortion parameter (k); the lens distortion parameters (l_1, l_2, p_1, p_2, and p_3); and the parameters (A, B, and C) defining the plane. Equations for the distortion model can be found in (Wiley and Wong,, 1992).

Initial approximations must be generated for the above 17 parameters. In order to facilitate the generation of these approximations, as well as to arbitrarily fix the exterior orientation of the left image with respect to the plane, the approximate object-space coordinates of four points lying on the plane need to be known. The coordinates of these four points are used to compute the exterior orientation parameters of the two images by spatial resection, and the plane parameters (A, B, and C). The computed exterior orientation parameters for the left image are then held fixed in the solution. The scale and lens distortion parameters can be assumed to be zero as initial approximation.

For scale control within the stereo model, at least one length must be known on the plane. The length constraint between points i and j on the plane is expressed as follows:

$$(X_j - X_i)^2 + (Y_j - Y_i)^2 + (Z_j - Z_i)^2 = S_{ij}^2 \qquad (3)$$

The algorithm assumes that the focal length is known. It is the only interior orientation parameter that can not be recovered using this method. This should not a serious limitation. In practical applications, the approximate value of the focal length can usually be determined from markings on the lens housing or computed from a measured distance of the camera from the plane.

CALIBRATION TEST

The algorithm was used to calibrate a SONY CCD-F55 video camcorder, which was equipped with an 8.5-68 mm zoom lens. The focal plane of the camcorder consisted of 250,000 effective pixels, and measured 16.9 mm along the diagonal.

A brick wall was used as planar control. Stereo images of the brick wall was acquired with focal settings of 10, 12, 16, 22.5, and 32 mm. The camera stations were located at a distance of 7.8 m from the wall, and the base distance between the two stations were 1.7 m for all focal settings. The camera was warmed up for 30 minutes prior to image capture. The images were recorded on standard 8-mm video tapes. Figure 2 shows an image of the brick wall.

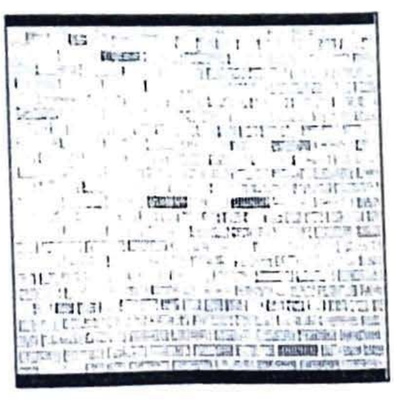

Figure2. Calibration image of a brick wall

An EPIC frame grabber, installed in a 486-PC, was used to capture individual frames from the video recording. The resulting images consisted of 512(H) x 512(V) pixels and 256 gray levels.

A software package, called DRSTEREO (Wong and Obaidat, 1993), was used to manually measure image coordinates of conjugate points in a pair of stereo images. The corners of the individual bricks and the mortar joints provided a large number of well defined points throughout the stereo pair of images at all of the focal settings. Between 35 and 39 data points were measured in each stereo pair. DRSTEREO provided the means to measure the image coordinates to a least count of 0.17 pixel.

Within each stereo pair, four points on the brick walls were chosen as control points. The object-space coordinates of the four points were computed from the nominal dimensions of the bricks and mortar joints.

The focal length was held fixed at the nominal values obtained from makings on the lens housing.

TEST RESULTS

Tabulated in Table 1 are the computed root-mean-square (RMS) errors of the x- (row) and y- (column) coordinates for the stereo pairs of images from five focal settings. In all cases, the RMS errors were less than ± 0.3 pixel in x and ± 0.01 pixel in y. Figures 3 and 4 shows the changes in the interior orientation parameters with the five different focal settings.

Table 1. RMS errors of image residuals from calibration

Focal Length (mm)	RMS error in x-coord. (pixel)	RMS error in y-coord. (pixel)
10	± 0.17	± 0.01
12	0.25	0.006
16	0.16	0.003
22.5	0.21	0.005
32	0.21	0.005

DISCUSSIONS

Accuracy of the planar constraint algorithm is limited by several factors, including: 1) base/height ratio of the stereo model, 2) unflatness of the planar object, and 3) accuracy with which the image coordinates of the conjugate image points can be matched and measured.

The calibration test was intended to illustrate the practicality of the approach. Brick walls are commonly available, and they provide a large number of well defined points at any focal settings within the available zoom range of a camcorder. No attempt was made to measure the unflatness of the wall. Yet the tests consistently resulted in image residual RMS errors better than ± 0.3 pixel. Other commonly available flat objects that may be used using this approach include concrete block walls, large glass windows and steel plates.

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