격자형 선폭들의 투영변화비를 이용한 카메라 교정 파라메터 추정

Camera calibration parameters estimation using perspective variation ratio of grid type line widths

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Abstract - With 3-D vision measuring, camera calibration is necessary to calculate parameters accurately. Camera calibration was developed widely in two categories. The first establishes reference points in space, and the second uses a grid type frame and statistical method. But, the former has difficulty to setup reference points and the latter has low accuracy. In this paper we present an algorithm for camera calibration using perspective ratio of the grid type frame with different line widths. It can easily estimate camera calibration parameters such as lens distortion, focal length, scale factor, pose, orientations, and distance. The advantage of this algorithm is that it can estimate the distance of the object. Also, the proposed camera calibration method is possible estimate distance in dynamic environment such as autonomous navigation. To validate proposed method, we set up the experiments with a frame on rotator at a distance of 1, 2, 3, 4[m] from camera and rotate the frame from -60 to 60 degrees. Both computer simulation and real data have been used to test the proposed method and very good results have been obtained. We have investigated the distance error affected by scale factor or different line widths and experimentally found an average scale factor that includes the least distance error with each image. The average scale factor tends to fluctuate with small variation and makes distance error decrease. Compared with classical methods that use stereo camera or two or three orthogonal planes, the proposed method is easy to use and flexible. It advances camera calibration one more step from static environments to real world such as autonomous land vehicle use.

Key Words : camera calibration, perspective ratio, difference line width, focal length, lens distortion

1. Introduction

Generally, a vision system can be used in quality control for identification of a part's location, for orientation, sorting, verification, and dimensional measurements. In order to use it for precision measurement, the camera calibration is a crucial problem for many industrial applications that incorporate visual sensing.

Physical camera parameters are commonly divided into intrinsic and extrinsic parameters. The former gives information about the optical and geometrical camera characteristics such as focal length, scale factor, and lens distortion. The latter gives information about the position and orientation of the camera frame relative to a world coordinate system such as rotation and translation. There are many different methods for camera calibration. In general, existing camera calibration techniques can be classified into two types: linear calibration using reference points and nonlinear calibration with large points. Linear calibration techniques[1,2]using reference points involve the determination of transformation parameters by solving linear equations with known reference parameters. The algorithms are fast and accurate, but reference points are hard to set in the world coordinate system. Nonlinear calibration techniques[3]use a large number of unknowns and a large-scale nonlinear optimization. These models are more accurate, but computationally more expensive and hard to process in real time.

In this paper, to complement these calibration methods, we propose a camera calibration technique which estimates iteratively real world coordinates using the projective fluctuation ratio of line widths in the image plane.

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2.The Camera Model

In this section the basic principles and notations used in the rest of the paper are introduced. Fig. 1 shows a camera model based on the pinhole model. Let $P_w= [x_w\ y_w\ z_w]^T$ is in space, measured in millimetres, $P_c=[x_c, y_c, z_c]^T$ is the camera coordinate system(CCS) which is also measured in millimetres and $P_i=[x_i, y_i]^T$ is the image plane which is parallel with the x-y plane of CCS, and optical axis (established by the center of the lens) along the z-axis and be its coordinates. Thus, the center of the lens is at the origin, and the center of the image plane is at coordinates (0, 0, f).

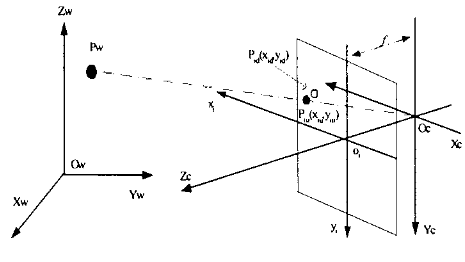

Fig. 1. Camera geometry of perspective projection and radial lens distortion

Here, f is the effective focal length of the lens. (x_u, y_u) are the image coordinates of (x_c, y_c, z_c) if a perfect pin hole camera model is used. (x_d, y_d) are the actual image coordinates which differ from (x_u, y_u) due to lens distortion. The relationship between a 3D point P_w and its image projection P_i(in pixels) is given by

$$P_i = MRP_W + T \quad (1)$$

where R and T, called the extrinsic parameters is the rotation and translation which relates the world coordinate system to the camera coordinate system, and M is called the camera perspective projection matrix. Without loss of generality, we assume the object plane is on z_w=0 of the world coordinate system. Equation (2) shows a perspective projection between the image coordinate system and the camera coordinate system.

$$x_i = fx_c/z_c \qquad y_i = fy_c/z_c \qquad z_i = f \quad (2)$$

Radial lens distortion, modeled with a 2^{nd} order polynomial (3):

$$x_u = x_d(1+k\rho^2),\ y_u = y_d(1+k\rho^2),\ \rho^2 = \sqrt{x_d^2 + y_d^2} \quad (3)$$

Let's denote the column scale factor of the image coordinate system by Sx, and row scale factor of it by Syand image center (Cx, Cy). Real image coordinate (x_d, y_d) to computer image (frame buffer) coordinate (x_f, y_f) or (x', y')(used later as abbreviation) conversion is

$$x' = x_f = x_d S_x + C_x, \quad y' = y_f = y_d S_y + C_y \quad (4)$$

3. Projection of Line Widths

Fig. 2 shows line widths of a line. We divide a line horizontally or vertically into many line widths with which two points are composed p_m and p_n. Solving for a line width in the image coordinate

$$W'_{mn} = \sqrt{(x'_m - x'_n)^2 + (y'_m - y'_n)^2} \quad (5)$$

According to the equation (5), the object coordinate is accomplished by using the image coordinate. And, equation (6) shows a line width with which two points are composed, p_m and p_n, in the camera coordinate.

$$W_{mn} = \frac{1}{f}\sqrt{(z_n x'_n - z_m x'_m)^2 + (z_n y'_n - z_m y'_m)^2 + f^2(z_m - z_n)^2} \quad (6)$$

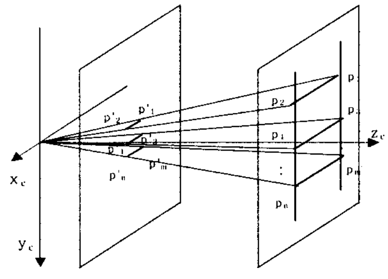

Fig. 2. Perspective of line widths

If the x-y plane of the camera coordinate system and the object coordinate system are parallel, all line widths Win the object are same position of z. Then line widths are equally projected by equation (7).

$$\frac{z_{mn}}{f} W'_{mn} = W_{mn} \quad (7)$$

When the object coordinate rotate about each axis, each line widths are projected by a z coordinate of each two points which construct a line width. Equation (8) shows this relation. By the movement of z like this, in Fig. 3, the projection ratio cannot have a constant value, the change occurs.

$$\frac{z_{mn}}{f} W'_{mn} = \zeta_{mn} W_{mn} \quad (8)$$

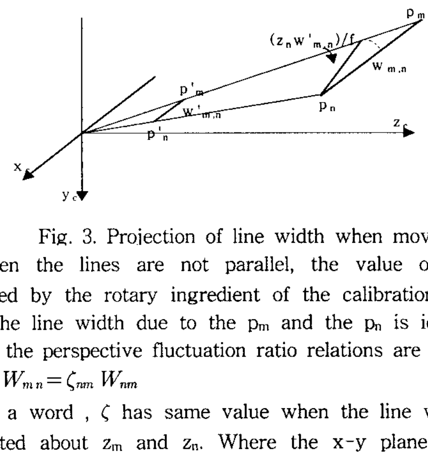

Fig. 3. Projection of line width when moved

When the lines are not parallel, the value of ζ be changed by the rotary ingredient of the calibration panel. But, the line width due to the p_m and the p_n is identical. Thus, the perspective fluctuation ratio relations are

$$\zeta_{mn} W_{mn} = \zeta_{nm} W_{nm} \quad (9)$$

In a word , ζ has same value when the line width is projected about z_m and z_n. Where the x-y plane of the camera coordinate system and the object coordinate system are parallel, in this case, the value of ζ is 1.

Using (5)-(9), we obtain the ratio of real line width to projected line width equation as

$$\frac{W_{mn}}{W'_{nm}} = \frac{1}{f}\frac{z_n}{\zeta_{mn}} = \frac{1}{f}\frac{z_m}{\zeta_{nm}} \quad (10)$$

If we know two point of a line width, n and m, the value of ζ can be estimated by equation (10), because we know the line width on the object. Using this estimated value of ζ, we assume focal lengths which are satisfied ζ =1 through changing of f. When the calibration panel consists with difference line width rotate each x, y, z axis separately. The value of ζ related with angles (α, β, γ, ϕ, θ, ψ) and T. Instead of mathematical solution, we estimate these parameters to change f and ζ iteratively.

$$P_i = MR(z, y, z; \alpha, \beta, \gamma)R(x, y, z; \phi, \theta, \psi)P_W + T \quad (11)$$

4. Experimental Results

The proposed algorithm has been tested on real data. With a camera which is resolution 682(H)×492(V)[pixels] in CCD array area 6.4(H)×4.8(V)[mm],and mounted with WV-LZ62/2 Panasonic TV lens, we set up the experiments with a frame on rotator at a distance of 1,200[mm] from the camera and rotate the frame from -60 to 60 degrees.

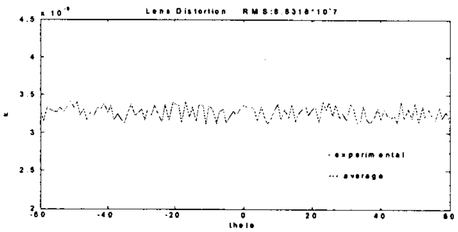

Fig. 4. Lens distortion coefficient k and RMS error

Fig. 4 shows a result of estimated lens distortion coefficient k. to estimate k, we use proposing method by Moumen T. Ahmed[4] and the result of root mean square(RMS) is 8.83×10^{-7}. Fig. 5 shows a result of estimated scale factor ratio that is cause by the CCD array. Compare with camera specification and experimental result, estimated error is approximately 1%.

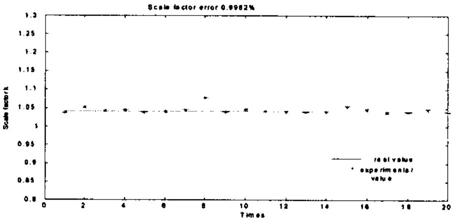

Fig. 5. Scale factor errors

Fig. 6 shows errors of estimated focal length when a calibration panel rotates counter clockwise from 0 to 60 degrees. To investigate focal length estimation correctly, it is necessary to measure the distance the motor uses between CCD array and lens. But, using average value of the focal lengths which are presumed, the error ratio appeared under 2%. The distance from the center of the lens to intersection which intersects the optical axis and the calibration plane surface show the results in Fig. 7. Ideally, since the calibration panel rotates on the rotator, the distance must be constant. But, experimental results show that the distance varied. The reason for this change is that the calibration panel was shaking when rotating, and also, the rotor center of the rotator, the optical axis, and the center of the calibration panel didn't accurately align.

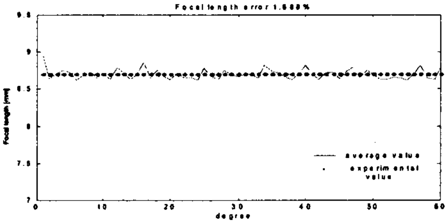

Fig. 6. Estimation errors of focal length

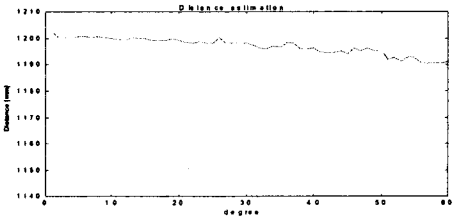

Fig. 7. Estimation errors of distance

5. Conclusions

In this paper, we present an algorithm for camera calibration using perspective ratio of a grid type frame with different line widths. If we know the line widths of the calibration panel, the proposed algorithm can estimate camera calibration parameters that include the errors on the focal length, scale factor, pose, orientation, and distance by 1%, 1.7%, 4%, ± 2 degrees, and 3%, respectively.

Further improvements can be obtained adopting more accurate inner parameters and using more stable and higher resolution CCDcameras. More effective edge detection and segmentation techniques must be studied and applied to this approach as well as the extension of the model to use linear features. We also plan to investigate techniques to make the procedure more flexible and useful for autonomous land vehicle, by recognizing number panels of a car for measuring the distance.

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