A Study on the Improvement of Accuracy of Very Close-Range Photogrammetry by Using Non-metric Camera

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ABSTRACT

To monitor the precision machine parts, we made and set the fiducial glass plate on a non-metric camera (Nikon F801,f=35mm) format and obtained PPS, PPA, EFL,and CFL of the lens and the radial lens distortion coefficients for each side through the collimator test. In addition,using analytical plumb line method, radial and tangential lens distortion coefficients were obtained and then systematic errors were corrected.

As the results of we excuted the simulation test with this calibrated non-metric camera, we could obtain high accuracy in monitoring the thickness of the ship screw,one of precision machine parts. In this application self-control points are used to resolve the difficulties of control surveying and tie points are used to analyze simultaneously front and rear sides of the screw. In the case of very close range photogrammetry,it was found out that this calibrated camera is more efficient than the metric camera with a limited focal length.

Keyword : Calibrated Non-metric Camera, Collimator Test, Plumb line Method,Close-Range Photogrammetry, Monitoring Precision Machine parts.

INTRODUCTION

The application of a non-metric camera to the purpose of measurements has been often tried previously (Kang,Oh,1990). In this study, in order to develop the camera which has the system similar to metric camera ,the fiducial glass plate, which is made by the means of chrome etching technique, is set on the Nikon F801(f=35mm) camera. EFL, CFL, PPA, PPS, and radial lens distortion coefficients for each side were calibrated by laboratory method using a single collimator. In addition, radial and tangential lens distortion coefficients were derived by the analytical plumb line method from film format taken by double exposure (Brown, 1971).

To estimate the application propriety of the calibrated camera, 35 targets were attached to a wall and 9 photos were taken ; 3 photos at 0.5m, 1.0m,and 2.0m respectively. Data reduction is performed by bundle adjustment (Fig.4).

To monitor thickness, one of important factors of screw , it is necessary to analayze simultaneously front and rear sides of screw with one strip. For it, tie points were set up around object (Photo 1).

FIDUCIAL GLASS PLATE

Transparent positive mask is obtained from negative film which is imaged the fiducial marks of Rollei 3003 metric camera (Fig.1). Then fiducial glass plate is made by chrome etching technique as following procedure (Fig.2).

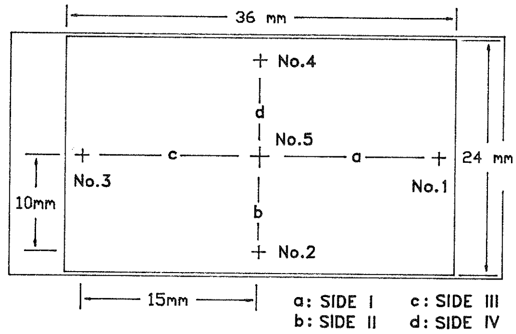


Fig.1 Fiducial Mark of Glass Plate.

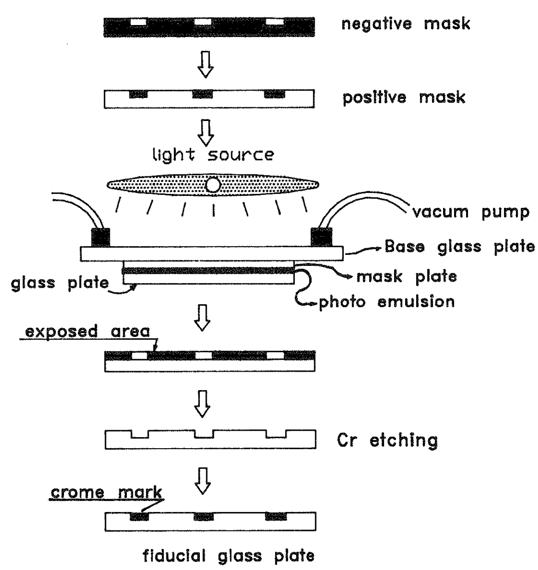


Fig.2 The Process of Cr Etching for Glass Plate.

measuring the difference between No.5 fiducial mark and the center of central slit of collimator.

Radial lens distortion coefficients : Total 18 slits were imaged as shifting and rotating the single collimator with 6° incresement from 0° to ±24° successively to horizontal direction, with 4° incresement from 0° to ±16° to the vertical direction for obtaining the radial lens distortion coefficients. Collimator rotation angle (minimum 1/1000sec) was controlled by computer. And then we measured the distance between slits on the developed negative film (Table 1).

There being considered distortion free around center of lens at range of ±6° in horizontal and +4° in vertical, EFL(Equivalent Focal Length) was computed as 36.266mm in case of ±4° among exposed slits. (radial distance / tan θ°) Theoretical values of radial distance to slits,which have to be imaged from collimator, were deducted from the calculated EFL and the values were compared with the radial distance to slits imaged actually and the calaulated radial distortion is shown in Table 2.

Radial distortion coefficients in each side were obtained by Brown polynomial based on distortion data taken from Table 2 (Brown,1971).

CFL : With the CFL(Calibrated Focal Length), we took an average on the amount of horizontal distortion on side I and III by the formula (ri-CFL * tan θi) + (rj - CFL * tan θj) = 0 and maximum and minimum values. We obtained a 36.079mm average value from 36.131mm and 36.027mm on vertical direction side II and IV .

The amounts of distortion in horizontal dir-ection range from 0.009 to -0.144mm in case of application of EFL while range from 0.004 to -0.051mm in case of application of CFL and then decrease by 64% than in case of EFL. The amounts of distortion in vertical direction range from 0.005mm to -0.053mm in case of application of EFL while range from 0.019 to -0.006mm in case of application of CFL and then decrease by 76% than in case of EFL. Consequently we recognized that CFL is to be applicated.

Table 1 Collimator shift angle versus radial distance. (Direction to horizontal & vertical)

H	angle	+24°	+18°	+12°	+6°	0°	- 6°	-12°	-18°	-24°
	dist.	-16.003	-11.718	-7.696	-3.810	0	3.821	7.704	11.735	16.020
V	angle	+16°	+12°	+8°	+4°	0°	-4°	-8°	-12°	-16°
	dist.	-10.356	-7.691	-5.086	-2.531	0	2.541	5.093	7.684	10.346

CALIBRATION TEST

Collimator method

PPA and PPS : Setting up the fiducial glass plate on camera mount, We found out PPA ($\Delta x = 103\mu m$, $\Delta y = 30\mu m$) and PPS($\Delta x = 7\mu m$, $y = 0\mu m$) through

Table 2 The radial lens distortion for each side vs. collimator shift angle. (by EFL)

shift angle		radial lens distortion(mm)			
H	V	SIDE I	SIDE II	SIDE III	SIDE IV
± 6°	± 4°	0.009	0.005	-0.002	-0.005
± 12°	± 8°	-0.005	-0.004	-0.013	-0.011
± 18°	±12°	-0.049	-0.025	-0.066	-0.018
± 24°	±16°	-0.127	-0.053	-0.144	-0.043

Table 3 The coefficients of radial lens distortion in each side obtained by collimator test. (×E-3)

coeff.	SIDE I	SIDE II	SIDE III	SIDE IV
K_1	0.003546	0.003174	0.001178	0.004410
K_2	-8.552213E-5	-1.996202E-4	-4.344807E-5	-4.285227E-4
K_3	2.773137E-7	2.024559E-6	-1.133125E-7	7.853835E-6
K_4	-4.608873E-10	-8.256863E-9	4.990564E-10	-4.291548E-8

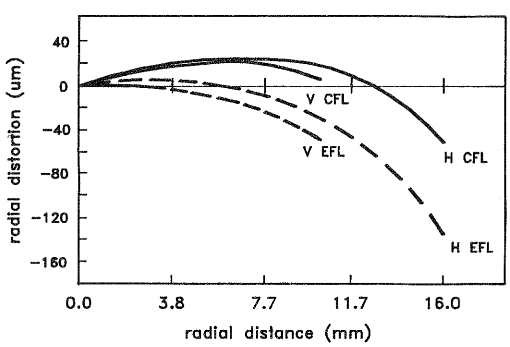


Fig.3 Radial lens distrotionby EFL and CFL

Table 4 Lens distortion coefficient of Nikon 801 non-metric camera.(× E-6)

Distance (m)	radial distortion coeff.		
	K_1	K_2	K_3
0.5	43.82876730	-0.03626487	-0.00000921
1.0	53.17592457	-0.07958205	-0.00005170
1.8	42.51753570	-0.03721015	-0.00001845
Distance (m)	**tangential distortion coeff.**		
	P_1	P_2	P_3
0.5	-30.87500896	-17.43285964	-0.74695714
1.0	-20.93058837	7.74351767	-0.01338893
1.8	9.84737198	25.69442983	-0.28874270

Analytical Plumb Line Method

Grid images are obtained by wide angle lens with 35mm focal length through double exposures. 10 plumb lines are imaged in first exposure and 7 plumb lines in second exposure. We obtained radial and tangential lens distortion coefficients of Nikon F801 non-metric camera.

SIMULATION TEST

Using the coefficients obtained by the camera calibration, we performed the simulation test to examine the accuracy of results through the error correction.

The 35 targets arrayed on the plane wall were photographed with 9 photos obtained at 0.5m, 1.0m, 2.0m with the convergent angle 30° and normal case. The targets were rearranged for each object distance in order to be covered uniformly on the full film area.

The standard deviations of results of two casese were compared between systematic error to be corrected and not to be through plumb line method and collimator method (Fig.5). It is noted that compared with uncorrected case, both methods have 20%-30% decrease of standard deviations.

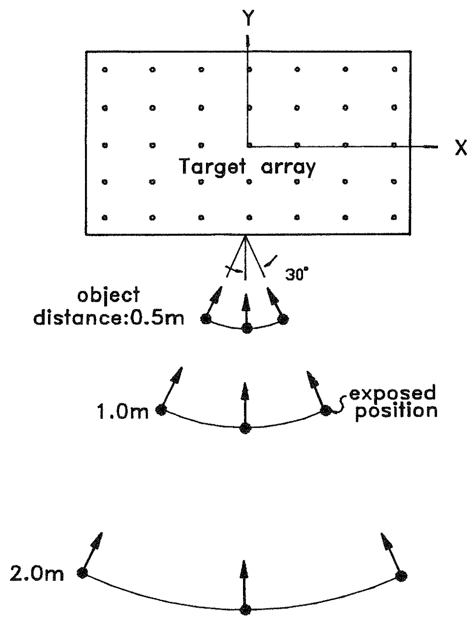
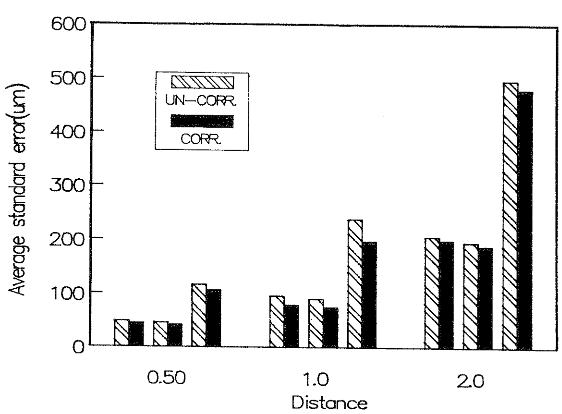
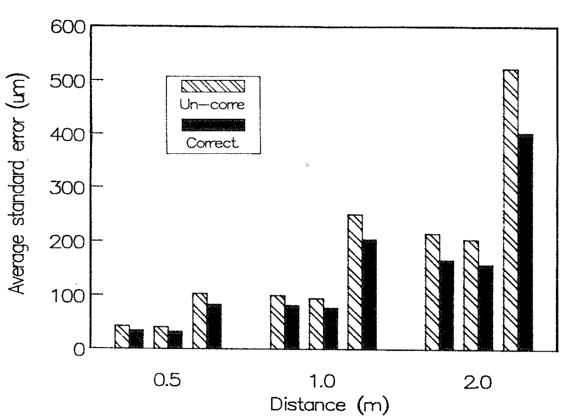


Fig.4 Test Field of Simulation Test.



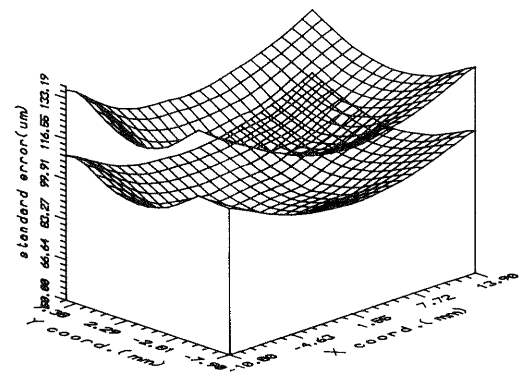
a) Plumb line method



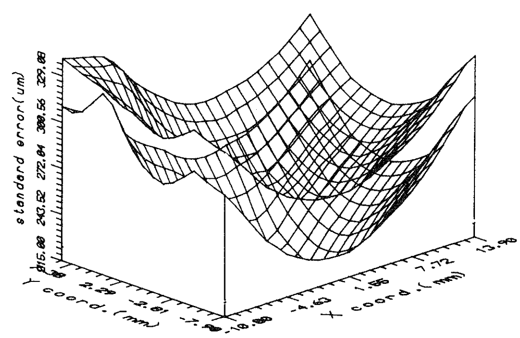
b) Collimator method

Fig.5 Comparison of the Standard Deviation vs. the Uncorrected Case and the Corrected Case.

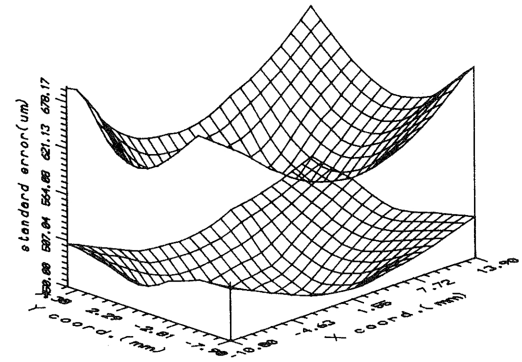
Three dimensional position errors illustrated in Fig.6 show that the more targets place at fringe of film, the more errors increase gradually. Also, the case that systematic errors were corrected was distributed lowly by about 30~40μm in comparison with uncorrected case. Thus it is proved that calibration by collimator method or plumb line method is effective considerably.



(a) 0.5m



(b) 1.0m



(c) 2.0m

Fig.6 Comparison of Errors vs. the Uncorrecte Distortion and the Corrected Distortion by Collimator Method.

APPLICATION

Monitoring of Screw

The 9 exposure stations were placed at the 0.3m with a changing every 10 ° from +140° to -140°, for 7 exposure stations placed toward the center of object with the cone type changing and at same distance and 7 stations placed with the cone type at the 0.4m object distance. So all 23 exposure stations were placed in the front side (SIDE I) of the screw. At the rear side (SIDE II) of the screw, 23 exposure points were placed in the same manner. All 46 exposure points were planned to be placed. To analyze simultaneously both sides of the screw, we have arrayed tie points (Photo 1).

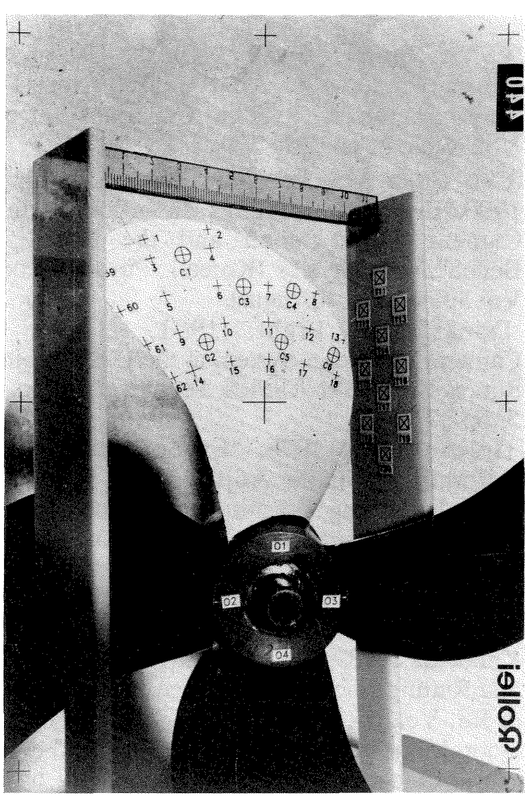
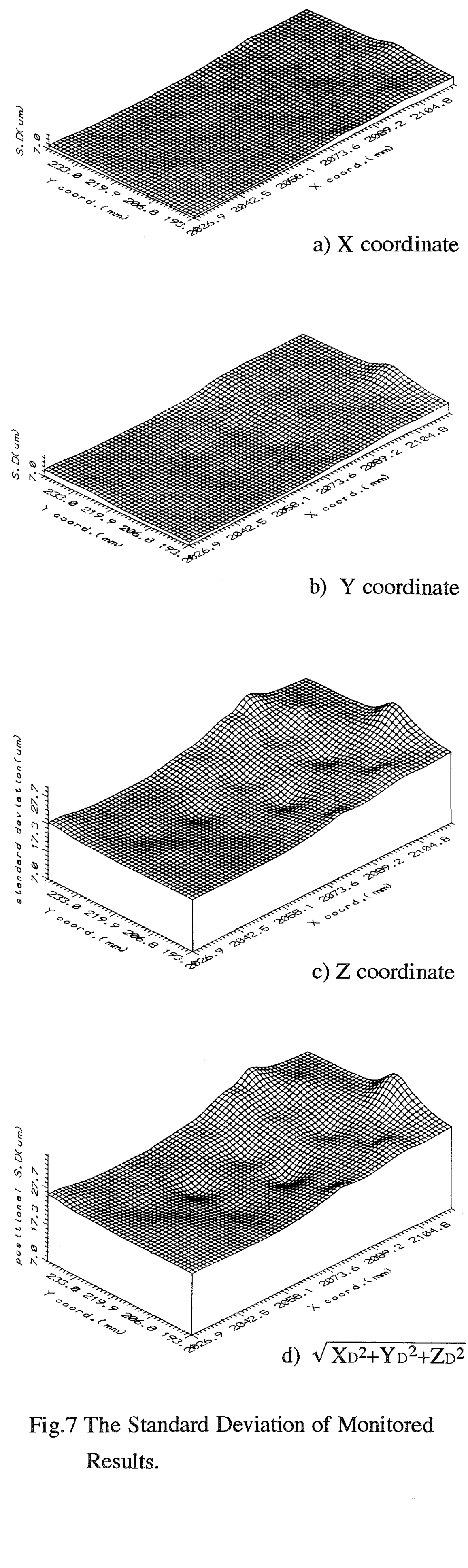


Photo 1 Design of Tie Points.

As the results of monitoring, standard deviation in X is 7.0μm ~ 13.0μm m with the average 8.2μm, that in Y is 7.0μm ~ 11.0μm with the average 7.7μm and that in Z is 19.0μm ~ 33.0μm with the average 22.7μm. As the positional error range from 21.0μm to 37.0μm, the accuracy of results is satisfied with monitoring the screw. Also in monitoring the small precision part, we found that the accuracy depend on the arrangement of control points, distribution of object points and tie points and depth of field.



a) X coordinate

b) Y coordinate

c) Z coordinate

d) $\sqrt{X_D^2+Y_D^2+Z_D^2}$

Fig.7 The Standard Deviation of Monitored Results.

We compared the measured results with the design values regarding the thickness of screw (Fig.7). Measurement values corrected systematic errors and design values consistently is approached with each other and the difference between both is 0.011mm~0.189mm at an average 0.093mm at any object point. This difference is rather great in some sense, but it is estimated that the error is due to the difference between the point marked by the dimension gridgage and the point arrayed for the photogrammetry.

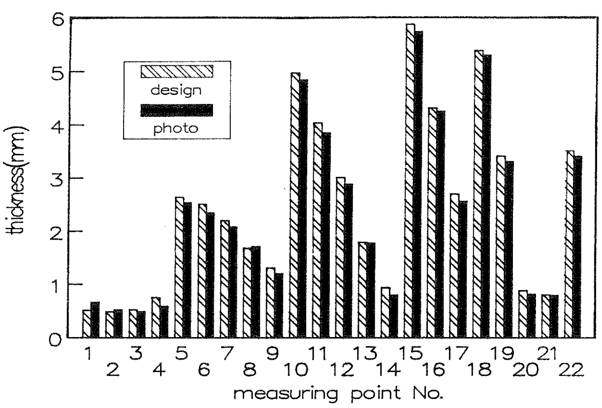


Fig.8 The Results of Monitoring.

CONCLUSIONS

To measure precisely a small object with the non-metric camera, we calibrated the camera for the purpose of measurement and monitored the precision mechanical part. We concluded the following.

To develop a non-metric camera into metric camera, we produced the fiducial marks by chrome etching method and found out the PPS, PPA,EFL,and CFL value by collimator method. In very close-range photogrammetry, it is desirable to use CFL as amount of distortion is considerably decreasing with applying the CFL.

Radial and tangential lens distortion coefficients according to the object distance were derived by analytical plumb line method. The correction for lens distortion results in the reduction of about 20-30% of X,Y,Z positional error. In the precise measurement by non-metric camera, therefore the correction of systematic errors is important.

In monitoring of screw,in order to solve the diffcult problem of finding blade tortion, thickness, non-linear section and overlap of blade, it is important that accurate marking of monitoring points, camera's depth of field and arrangement of tie points and control points have to be planned carefully.

As the result that we analyzed the precision mechanical parts with very close photos obtained with the calibrated non-metric camera, average standard deviation result in 7.1 μm in X, 6.9 μm in Y and 21.3 μm in Z. Conclusively, with free-focus non-metric camera the monitoring of precision mechanical parts could be performed effectively and successfully.

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