# A STUDY ON THE DEVELOPMENT OF SEMI-METRIC CAMERA FOR VERY CLOSE-RANGE PHOTOGRAMMETRY

W.J. Oh
Dept. of Cadastral College of Chungcheong
Cheongjoo, 363-890, Seoul, Korea

S.H. Han
Dept. of Civil Engineering
Cheonan National Technical College
Cheonan, 303-240, Seoul, Korea

S.H. Song, S.H. Bae, H.S. Lee
Dept. of Civil Engineering
Chungnam National University
Taejeon, 305-764, Seoul, Korea

Commission V, WG 2

KEY WORDS: Metric, Non-Metric, Camera, Calibration, Very Close-Range Photogrammetry, Bundle Adjustment

## ABSTRACT

As for the non-metric camera, the control of focal length is free, and it is free from restraint about minimum object distance. So, if the inner orientation parameter is solved, prompt photogrammetry will be able to be possible.

In this study, this researcher obtained the inner orientation parameter of non-metric camera by means of collimator method. And this researcher calculated with bundle adjustment, by photographing the small size object with very close range. And, then, this researcher tries to suggest the optimum photography condition of very close-range photogrammetry, by analyzing the feature of r.m.s.e based on the change of convergent angle, control point and number of photographs etc. In addition, this researcher tries to solve the difficult problem of control surveying, by devising and applying the self-control point system.

As the result of study, as the superiority of very close-range photogrammetry by non-metric camera and the applicability of self-control point system could be proved, the utilization is expected for the precise measurement of small size object.

## 1. INTRODUCTION

As the metric camera is expensive, it is difficult to compose the multi-synchro shutter system. And, as it is heavy, the treatment is inconvenient. Besides, as the focal length is being fixed with several units, it is restricted about minimum object distance. Thus, there is the limit in the very close-range photogrammetry. However, as for the non-metric camera, the price is cheap, the treatment is easy, the control of focal length is free, and the limit about minimum object distance is small, in comparison with metric camera(Fraser1982, Fryer1985, Hatzopoulos,1985). So, it is suitable for the very close-range photogrammetry, if one executes the lens calibration. As for the metric camera, the distortion is small, and the inner orientation parameter is offered. So, the precise 3-D measurement from camera is possible. But, as there is not the inner orientation parameter in non-metric camera, the study for solving the point at issue efficiently must precede(Fioretti,1985, Light, 1991, Fryer, 1992).

In this study, this researcher tries to develop the non-metric camera into semi-metric camera, by manufacturing and installing the glass plate fiducial mark in the mount of non-metric camera and extracting the principal point of autocollimation, the principal point of symmetry, and the equivalent focal length, the calibrated focal length and the lens distortion coefficients etc., by collimator method. By applying this to the practical experiment, this researcher tries to examine the usefulness of semi-metric camera through the r.m.s.e analysis based on number of photographs and convergent angle, convergent angle and number of control point, and object distance and number of photographs and to solve the difficult problem of control surveying by self-control point system.

## 2. COLLIMATION TEST

As there is not the fiducial mark in non-metric camera, this researcher manufactured the glass plate fiducial mark so as to obtain the exact photo coordinate(Fig. 1). This researcher attached the manufactured glass plate fiducial mark to the mount of non-metric camera, so that the central fiducial mark of it may be situated at the principal point.

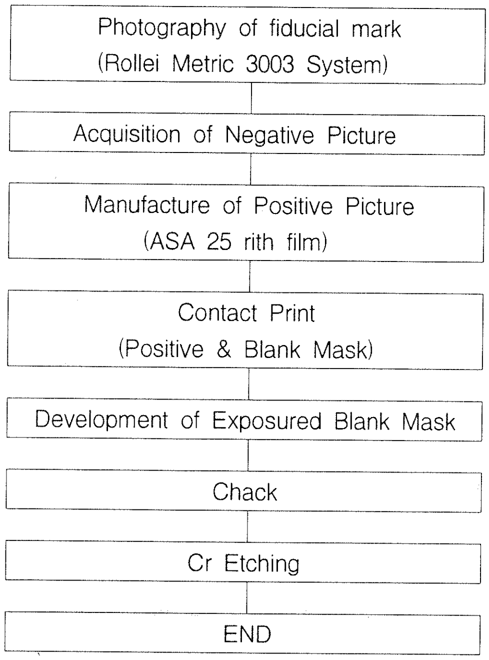



Fig. 1. Manufacture of glass plate fiducial mark

## 2.1 PPS and PPA

In case of correction about the lens distortion, one must know the exact radial distance. Radial distance is not the distance from the origin of photo coordinate, but it is defined as the distance from the PPS(principal point of symmetry) of lens distortion to the image point. So, one may correct the distortion, only in case that one knows the principal point of symmetry. As for the view angle of NIKON F-801 non-metric camera(f-35 mm), the horizontal direction was about 50° , and the vertical direction was about 33° . Therefore, this researcher photographed 9 units of collimator images respectively, by revolving the collimator by 6° toward horizontal direction and by 4° toward vertical direction(Fig. 2). This researcher obtained the principal point of symmetry by averaging the difference of radial distance about horizontal direction and vertical direction(Fig. 3).

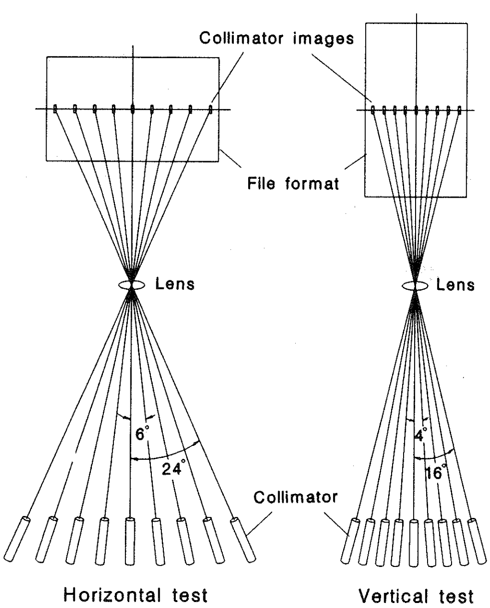



Fig. 2. Calibration of lens by collimator

In installing the lens in camera, the center of lens and center of photo is not coincident. So, one must make the correction about this. As for the displacement amount, this researcher obtained the PPA(principal point of autocollimation) by observing the radial distance to each collimator image and observing the displacement amount of 0° collimator image about central fiducial mark, in the collimation test(Fig. 4).

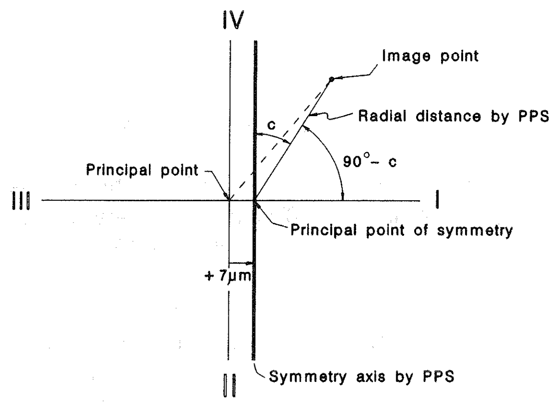



Fig. 3. Principal point of symmetry

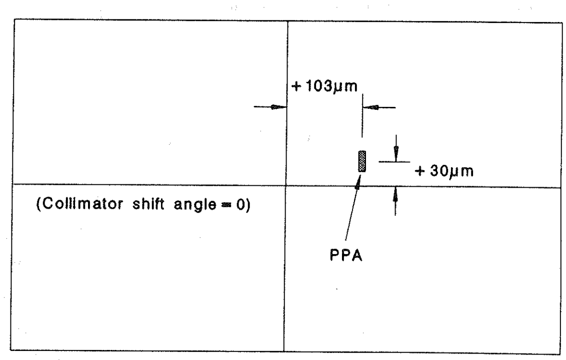



Fig. 4. Principal point of autocollimation

## 2.2 EFL and CFL

As for the EFL(equivalent focal length), we obtained 36.266mm by $EFL = \dfrac{(\mathrm{I}_{r1} + \mathrm{II}_{r1} + \mathrm{III}_{r1} + \mathrm{IV}_{r1})}{\tan\theta}$, as one assumes that there is not the distortion around the central part of lens generally(Fig. 5). If one knows the equivalent focal length, one may calculate the theoretical radial distance that the collimator image illuminated from collimator. So, one may obtain the radial lens distortion by comparing with the practically photographed radial distance(Kang,1992).

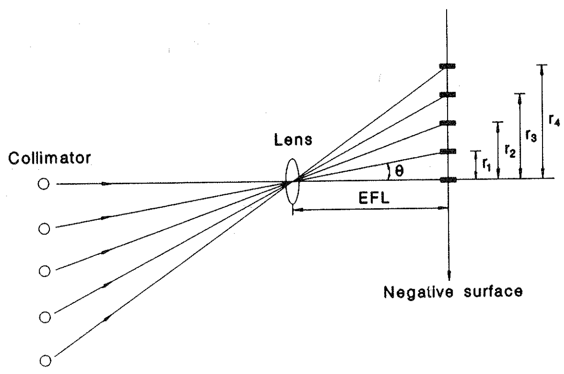



Fig. 5. Principal of calculation of equivalent focal length

As for the CFL(calibrated focal length) of lens, this researcher obtained 36.079mm, by averaging all the focal length of radial direction(Karren,1967, Wolf,1983). In case of applying the equivalent focal length, the distortion of lens of horizontal appeared as 9㎛~-144㎛. But, in case of applying the calibrated focal length, 4㎛~-51㎛ that about 64% was reduced appeared by being distributed evenly. In case of vertical direction also, the reduction of about 76% appeared from 5㎛~53㎛ to 6㎛~19㎛. So, in the photogrammetry, it is considered desirable to apply the calibrated focal length.

If one knows the radial lens distortion, one may obtain the coefficient of radial lens distortion from correction polynomial(Kang,1992).

## 3. APPLICATION

After choosing the small-size stone lantern(tower to light a candle or to keep sarira in Buddhist temple) which is suitable for very close-range photogrammetry as the object, this researcher arranged 28 unknown points on the surface of object equally. After attaching the calibrated square, so that it may be the axis of X, Y of coordinate system, this researcher utilized the scale of this square as the self-control point. This researcher took total 60 sheets of photographs by 15 sheets respectively, by changing the rotation angle with 10 interal at the object distance, 0.45m, 0.67m, 1.0m and 1.4m by means of NIKON F-801 non-metric camera (f=35mm) in this study. At this time, this researcher made f-stop as 22 by considering the circle of confusion, and photographed with indirect illumination so as to prevent the halation. About the triangulation, we executed with Kern DKM 2-A(1″ reading) theodolite. And, about the observation of baseline, we corrected the systematic error after observing with the calibrated steel tape over several times repeatedly. And about the comparator coordinate, we used the photo densitometer that the observation to 1$\mu$m is possible. This researcher decided the exterior orientation parameter and the 3-D coordinates of unknown point simultaneously, by executing space resection and space intersection with the bundle adjustment based on collinearity condition (Kang,1989, Kang,1990).

In the photogrammetry science to calculate 3-D coordinates of object from the projection relation of object and camera, the geometrical conditions such as photographing position, direction and arrangement of control point etc. are important. Therefore, this researcher examined as to which influence the change of object distance, convergent angle, numbers of control point, and number of photographs etc. has on 3-D coordinates of object.

### 3.1 Self-Control Point System

Table 1. Comparison of calculation of results by theodolite and self-control point ($\mu$m)

| # of photos | $T_{0.45}$ | $T_{0.67}$ | $T_{1.0}$ | $T_{1.4}$ | $S_{0.45}$ | $S_{0.67}$ | $S_{1.0}$ | $S_{1.4}$ |
|---|---|---|---|---|---|---|---|---|
| 2 | 46 | 74 | 115 | 164 | 45 | 66 | 99 | 137 |
| 4 | 34 | 55 | 82 | 115 | 33 | 48 | 71 | 99 |
| 8 | 25 | 38 | 58 | 80 | 25 | 34 | 50 | 72 |
| 15 | 18 | 28 | 43 | 58 | 18 | 25 | 37 | 50 |

Table 1 is what showed the r.m.s.e calculated by using the result of control surveying based on theodolite and the self-control point. T means the result of control surveying by theodolite, S is the result of self-control point, and the subscript is object distance(meter). In case that the number of photographs changes into 2 sheets, 4 sheets, 8 sheets and 15 sheets at the object distance, 0.45m, the r.m.s.e based on the result of self-control point is 45$\mu$m, 33$\mu$m, 25$\mu$m, and 18$\mu$m, and the r.m.s.e based on the result of control surveying by theodolite is 46$\mu$m, 34$\mu$m, 25$\mu$m and 18$\mu$m. So, it can be known that the case to have calculated by using the result of control surveying based on theodolite and the result to have calculated by using the result of self-control point are very similar. Thus, it is expected that one will be able to solve the difficult problem about the manufacture and installation of control point, observation of angle and baseline which is raised at the time of control surveying of small size object efficiently, if one uses the self-control point.

### 3.2 Object Distance and Number of Sheet of Photos

Fig. 6 is what illustrated the r.m.s.e based on the change of object distance and number of photographs, which was calculated by using the result of self-control point. According as the object distance changes from 1.4m to 1.0m, 0.67m and 0.45m, r.m.s.e reduces to 28%, 50% and 60% or so. respectively. And if the number of photographs increases from 2 sheets to 4 sheets, 8 sheets and 15 sheets, r.m.s.e was reduced to

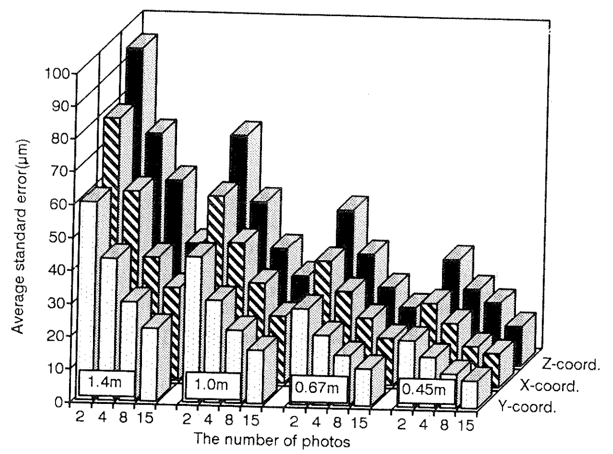



Fig. 6 R.m.s.e based on the change of object distance and number of photographs

30%, 50% and 65% or so. respectively. So, it can be seen that number of photographs and object distance are very important elements, in 3-D coordinates measurement of object.

### 3.3 Convergent Angle and Number of Control Point

Fig. 7 is what showed the r.m.s.e of X, Y and Z which is based on the change of convergent angle and number of control point. In case that the convergent angle is same, if one changes the number of control point from 15 units to 3 units with even density, the r.m.s.e increased, with about 70% about X, Y, and with 89%~101% or so. about Z. In case that the number of control point is same and that the convergent angle changes from 20° to 120°, X coordinates increased with 88%, and Y coordinates is not being influenced, but the r.m.s.e of Z coordinates was reduced with about 78%.

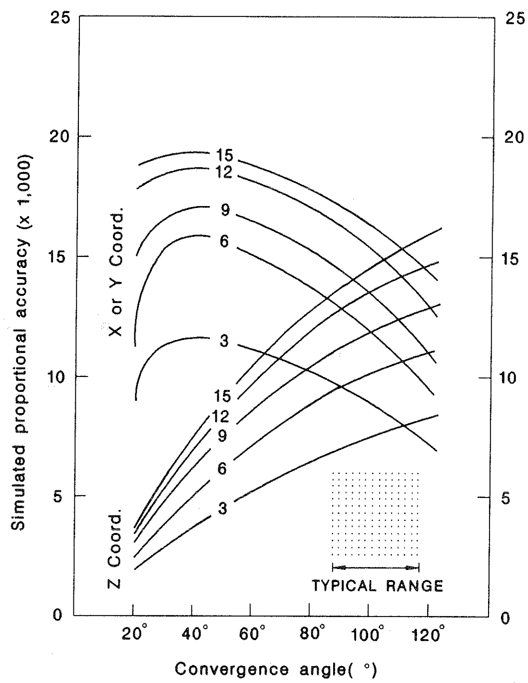
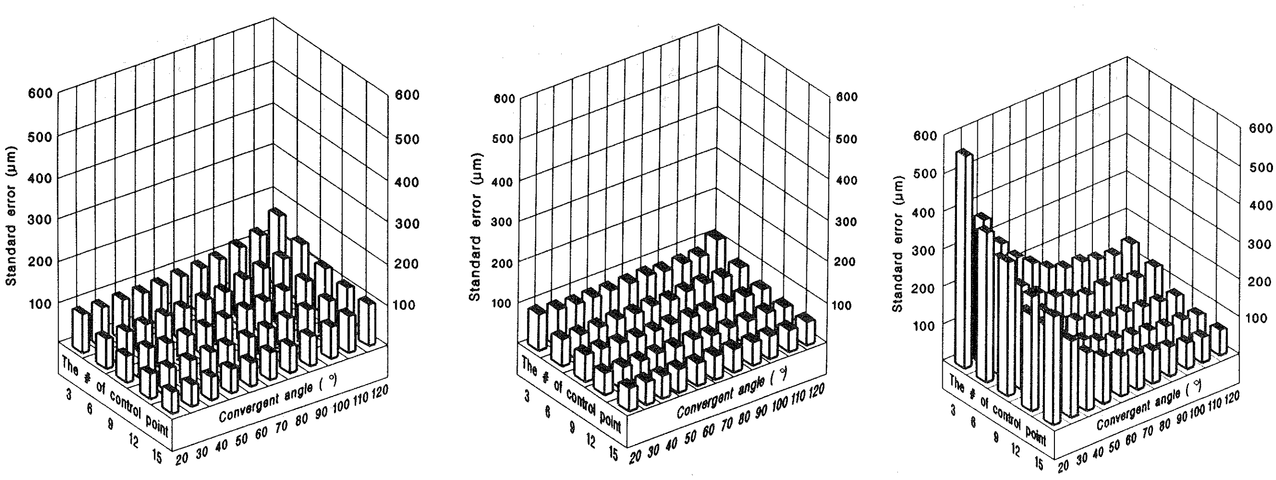



Fig. 8 Proportional accuracy of X, Y and Z coordinates based on the change of convergent angle and number of control point




X coord. Y coord. Z coord.

Fig. 7 R.m.s.e of X, Y and Z coordinates based on the change of convergent angle and number of control point

Fig. 8 is what showed the proportional accuracy of X, Y and Z coordinates which is based on the change of convergent angle and number of control point(object distance, 1.0m). If the number of control point gets to be many, the accuracy gets to be improved, but the rate is reduced gradually. So, the number of control point which is suitable for the condition of object is required. When the convergent angle changes from 20° to 120°, the accuracy of X, Y coordinates is highest at 40° ~50°, and than it is reduced gradually, but the accuracy of Z coordinates was improved in proportion to the size of convergent angle.

Fig. 9 is what illustrated the r.m.s.e of X, Y and Z coordinates based on the change of number of photographs and convergent angle. According as the number of photographs increases into 2 sheets, 4 sheets, 6 sheets and 8 sheets, the r.m.s.e of X, Y and Z coordinates is being reduced remarkably. In addition, if the convergent angle changes from 20° to 140°, the r.m.s.e of X coordinates increases suddenly, and the r.m.s.e of Z coordinates reduces suddenly, but the r.m.s.e of Y coordinates is showing almost constant aspect. So, it can be seen that the r.m.s.e of Y coordinates is not influenced by the change of convergent angle.

Fig. 10 is what showed the proportional accuracy of X, Y and Z coordinates based on the change of number of photograph, and convergent angle. If the convergent

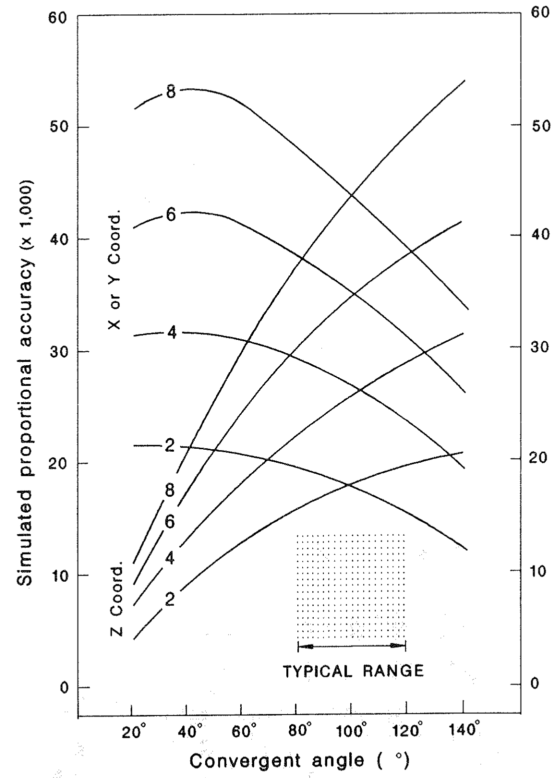



Fig. 10 Proportional accuracy of X, Y and Z coordinates which is based on the change of number of sheets of photos and convergent angle.

### 3.4 Convergent Angle and Number of Sheets of Photos

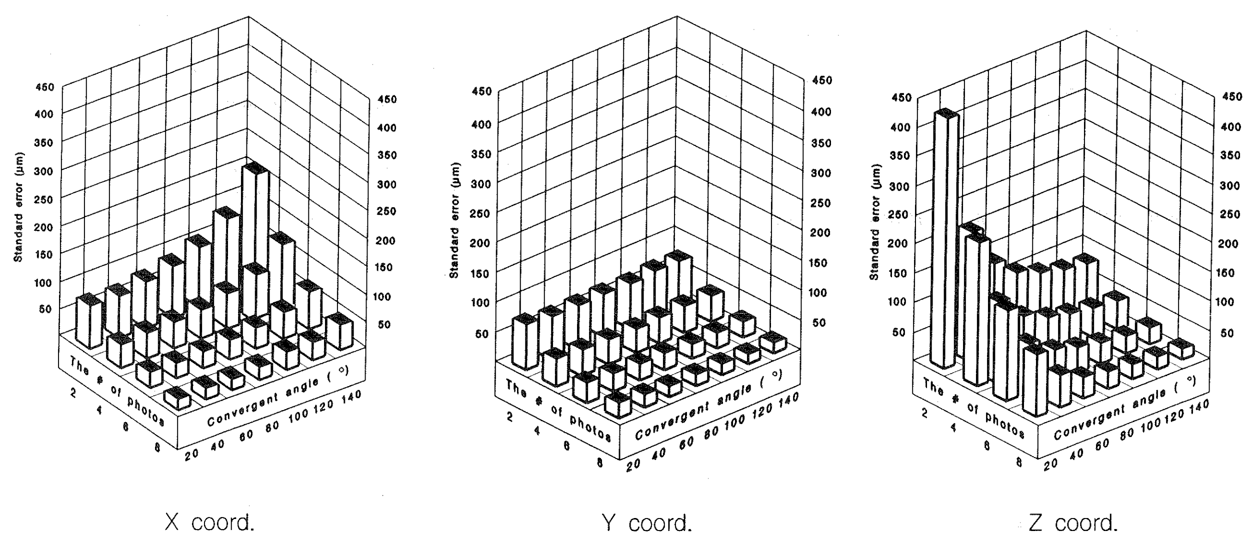



Fig. 9 R.m.s.e of X, Y and Z coordinates which is based on the change of number of sheets of photos and convergent angle.

angle gets to be large, the accuracy of Z coordinates is improved suddenly. But, the accuracy of X, Y coordinates is being reduced gradually, while it shows the highest state at 40°. Thus, it can be seen that the optimum condition of convergent angle that the proportional accuracy of X, Y and Z coordinates is appearing most satisfactory is 80° ~ 120°.

## 4. CONCLUSION

As the result to have tested the non-metric camera as collimator and to have applied this for observing the small size object more precisely, this researcher drew the following conclusion.

This researcher could develop the semi-metric camera, by extracting the coefficient of radial lens distortion, the principal point of symmetry, the principal point of autocollimation, the equivalent focal length, and the value of calibrated focal length, through the calibration about non-metric camera.

At the time of photogrammetry of small size object, the result to have calculated by using the self-control point was satisfactory. So, this researcher could solve the difficult problems of control surveying such as the manufacture, installation and observation etc. of control point.

If one changes the control point from 3 units to 15 units, the proportional accuracy of X, Y and Z coordinates is improved largely. So, it can be seen that the number of control point is very important element for 3-D coordinates measurement of object.

If one changes the convergent angle from 20° to 140°, the proportional accuracy of X, Y coordinates is satisfactory at 40°. And, according as the convergent angle increases, it is reduced gradually. But, the proportional accuracy of Z coordinates is improved remarkably in proportion to the size of convergent angle. So, it could be seen that the optimum convergent angle about 3-D coordinates of X, Y and Z is 80° ~ 120°.

## ACKNOWLEDGMENTS

" This paper was supported (in part) by NON DIRECTED RESEARCH FUND, Korea Research Foundation "

## REFERENCES

Fioretti, S., Germani, A. & Leo, T., 1985, Stereometry in very close-range stereophotogrammetry with non-metric cameras for human movement analysis, Journal of Biomechanics, Vol. 18, No. 11, pp. 831-842.

Fraser, C. S., 1982, On the use of non metric cameras in analytical close-range photogrammetry, The Canadian Surveyor, Vol. 36, No. 3, pp. 259-279.

Fryer, J. G., 1985, Non-metric photogrammetry and surveyors, The Australian Surveyor, Vol. 32, No. 5, pp. 330-341.

Fryer, J. G., 1992, Resent developments in camera calibration for close-range application, in : International Archives of Photogrammetry and Remote Sensing, Washington, D.C., America, Vol. XXIX, Part B5, pp. 594-599.

Hatzopoulos, J. N., 1985, An Analytical system for close-range photogrammetry, PE & RS, Vol. 51, No.10, pp.1583-1588.

Kang, J. M., Oh, W. J. & Han, S. H., 1992, A study on the improvement of accuracy of very close-range photogrammetry by using non-metric camera, in : International Archives of Photogrammetry and Remote Sensing, Washington, D.C., America, Vol. XXIX, Part B5, pp. 203-208.

Kang, J. M., Hintz, R. J. & Karakadas, C., 1989, Analysis of pavement cracking and rutting using close-range photography, PE & RS, Vol. 55, No. 2, pp. 217-221.

Kang, J. M., Oh, W. J. & Hintz, R. J., 1990, Analysis of very close-range photogrammetry by using non-metric camera, Korean Society of Geodesy, Photogrammetry and Cartography, Vol. 8, No. 2, pp 23 - 29.

Karren, R. J., 1967, Camera calibration by the multicollimator method, PE & RS, Vol. 33, pp 706-719.

Light, D. L., 1991, The new camera calibration system at the U.S. geological survey, ACSM-ASPRS Technical Papers, Vol. 5, pp 237-250.

Shih, T. Y., 1996, A photogrammetric simulator for close-range applications, PE & RS, Vol. 62, No. 1, pp. 89-92.

Wolf, P. R., 1983, Element of Photogrammetry, 2/e, McGraw-Hill, pp. 74-83.