SLAC-TN-10-016

Calibration of the Nikon D200 for Close Range Photogrammetry

Lassana Sheriff
Office of Science, Science Undergraduate Laboratory Internship Program

City College of New York, New York NY

SLAC National Accelerator Laboratory
Menlo Park, California

August 14, 2009

Prepared in partial fulfillment of the requirement of the Office of Science, Department of Energy’s Science Undergraduate Laboratory Internship under the direction of Brian Fuss in the Metrology Department, Alignment Engineering Group of the Stanford Linear Accelerator Center.

Participant: ______________________________
Signature

Research Advisor: ______________________________
Signature

Work supported in part by US Department of Energy contract DE-AC02-76SF00515.

Table of Contents

ABSTRACT

Calibration of the Nikon D200 for Close Range Photogrammetry. LASSANA SHERIFF (City College of New York, New York, New York, 10031) BRIAN FUSS (Stanford Linear Accelerator Center, Menlo Park, CA 94025).

The overall objective of this project is to study the stability and reproducibility of the calibration parameters of the Nikon D200 camera with a Nikkor 20 mm lens for close-range photogrammetric surveys. The well known “central perspective projection” model is used to determine the camera parameters for interior orientation. The Brown model extends it with the introduction of radial distortion and other less critical variables. The calibration process requires a dense network of targets to be photographed at different angles. For faster processing, reflective coded targets are chosen. Two scenarios have been used to check the reproducibility of the parameters. The first one is using a flat 2D wall with 141 coded targets and 12 custom targets that were previously measured with a laser tracker. The second one is a 3D Unistrut structure with a combination of coded targets and 3D reflective spheres. The study has shown that this set-up is only stable during a short period of time. In conclusion, this camera is acceptable when calibrated before each use. Future work should include actual field tests and possible mechanical improvements, such as securing the lens to the camera body.

1. INTRODUCTION

The Alignment Engineering Group (AEG) and Metrology Department are responsible for precisely measuring and aligning various objects and components on the site. This project involves working on a photogrammetric system that they are developing. Photogrammetry is one technique to measure geometrical information on items such as electromagnets which are used in physics experiments. A photogrammetry software package called Australis is being used where I have to photograph and process images to measure 3D objects. This program generates parameters that can then be used to significantly improve the accuracy of the system.

Photogrammetry stands for "photographic metrology [5]." The technique works in much the same way as human stereo vision, where depth is perceived partially as a function of the angle of two intersecting light rays running from the point of interest to your two eyes. With photogrammetry the intersection of all light rays from several images yields the required XYZ coordinates for a point via a mathematical reconstruction of 3-D shape from the multiple 2-D images. Therefore the model requires a calibrated camera in order to accurately compare these coordinates.

There are two types of photogrammetry; one of which is *close-range* that I have been investigating. The other one is aerial or space borne. Close-range photogrammetry is used to describe the technique when the extent of the object to be measured is less that about 100 meters and cameras are positioned close to it [3]. Photos of specially coded retro-reflective targets from different angles are made and then these photos are loaded [1] into Australis for processing. The results include a well known 10 parameter correction model defined as follows:

- Camera interior orientation: c, xp, yp
- Radial distortion parameters: $k1$, $k2$, $k3$
- Decentering (aka tangential) distortion parameters: $p1$, $p2$
- Linear distortion (aka shearing) parameters: $b1$, $b2$

These are corrections that simulate the ideal “central perspective model” discussed in section 2.

Upon using the Australis program [2] to perform fully automatic measurements, certain requirements need to be met. Every targeted object point must appear in two or more images that provide good ray intersection geometry. There needs to be a sufficient number of coded targets and the camera must be rotated or rolled approximately ninety degrees between images to distribute where the target image falls on the CCD. Once these requirements are met and the images are loaded into the project, the network of coded targets is automatically measured to provide the camera self-calibration.

A stable relatively flat wall is being used in the Alignment Engineering Group’s Sector 10 Calibration Laboratory. A pattern of coded retro-reflective targets is used to study the effect of the camera and target position and the effect of the addition of a scale bar to the model. A 3D structure was added to the project to compare with the flat wall. The results of these two calibration techniques are compared.

2. METHODS

The camera used in this project is a commercially available Nikon D200 SLR with a regular lens and built-in flash. The camera is a DX format of 23.7 mm x 15.7mm. It is about 10.2 megapixels (3872 x 2592); and the lens is a wide angle Nikkor of 20mm. The pictures are taken with “Manual” mode option and the settings in Table 1.

Nikon D200 SLC Camera Settings	
Option	Setting
Aperture	f = 11
Distance	Between 2m and ∞
ISO	100
Speed	1/250
Flash Exposure	Compensated to -3.0 (and paper filter)

Table 1. Camera Settings

Software Targets:

Australis is a photogrametry program used to make automatic 3D measurements of an array of specially coded or uncoded targets placed on or an object of interest. Basic targets are flat circular objects made of gray retro-reflective material. They come in different diameters usually being at least 1/100th of the object size. They start losing their reflective property when viewed from an angle greater than 60 degrees off-axis. Coded targets are automatically detected, identified and measured by the software. For Australis, the coded targets are made of an arrangement of dots. The central dot gives the position of the target and the pattern of dots is the key to the target's identification. The spacing of the dots can also be used for scale determination. Retro-reflective targets can be mounted onto spheres and these may be interchanged with other spheres that survey instruments such as laser trackers can measure.

Scale Bar:

To scale a photogrammetric measurement, at least one known distance is needed. If the actual coordinates of some targeted points are known beforehand, the distances between these points is computed and used to scale the measurement. Another possibility is to use a fixture such as a bar with targets on it and measure this along with the object. The distance between the targets on the bar is known (it had been measured on a Coordinate Measuring Machine) and can be used to scale the measurement. Such fixtures are commonly called scale bars [3].

Camera Parameters and Model:

Data for the focal length and the principal point of the camera: c, xp, and yp, radial distortion, k1, k2, and k3 will be analyzed. These parameters are compared in both 2D and 3D targets set-ups (figures 11 and 12). By analyzing these six key parameters with a statically significant number of samples, an assessment of the camera's stability can be determined. Figure 1 illustrates an ideal basic photogrammetry model. This is known as the "central perspective projection". Geometrically it is a 3D similarity transformation between 2 coordinate systems. The first coordinate system is positioned arbitrarily and is generally characteristic of an object being measured. It is noted: (X, Y, Z). The second coordinate system is linked to the camera position: its origin is at the perspective camera center C, its z-axis coincides with the principal axis of the camera. The image plane is at $z = -c$.

This central perspective model is only an idealization of the real optical geometry of a camera [4]. The major differences come from the stability of the interior parameters, the lens distortion and the Charge Coupled Device (CCD) flatness and regularity. The camera interior orientation is as follows c, xp, and yp; where c is the focal length of the camera. xp and yp are the coordinates of the principal point and they are often called principal position offsets. These form the camera interior parameters. The camera perspective center C has the coordinates (Xc, Yc, Zc) in the object system. Let M be a point in the space and m its image. The coordinates of M in the object space are (X_M, Y_M, Z_M). Its image m has the coordinate (x_M, y_M, $-c$) in the camera system.

The transformation between the 2 systems can be written:

$$\begin{bmatrix} x_M \\ y_M \\ -c \end{bmatrix} = \lambda \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \begin{bmatrix} X_M & - & X_c \\ Y_M & - & Y_c \\ Z_M & - & Z_c \end{bmatrix}$$

The perspective center the image point and the object point are required to lie along one straight line. The above 3 equations can be combined into 2 to eliminate the scale factor:

$$x_M = -c\frac{r_{11}\left(X_M - X_c\right) + r_{12}\left(Y_M - Y_c\right) + r_{13}\left(Z_M - Z_c\right)}{r_{31}\left(X_M - X_c\right) + r_{32}\left(Y_M - Y_M\right) + r_{33}\left(Z_M - Z_c\right)}$$

$$y_M = -c\frac{r_{21}\left(X_M - X_c\right) + r_{22}\left(Y_M - Y_c\right) + r_{23}\left(Z_M - Z_c\right)}{r_{31}\left(X_M - X_c\right) + r_{32}\left(Y_M - Y_c\right) + r_{33}\left(Z_M - Z_c\right)}$$

The equations are known as the collinearity equations.

A 2D coordinate system represents the projection plane of the camera which also is the CCD. Its origin is at the center of the CCD. Components of r (*d*x and *d*y) are part of the Brown [1] model and are computed as follows:

$$dx = \bar{x}dr + p_1(r^2 + 2\bar{x}^2) + 2p_2\overline{xy} + b_1\bar{x} + b_2\bar{y}$$

$$dy = \bar{y}dr + p_2(r^2 + 2\bar{y}^2) + 2p_1\overline{xy}$$

where:

$$\bar{x} = x_M - x_p \qquad \bar{y} = y_M - y_p$$

$$r^2 = \bar{x}^2 + \bar{y}^2 \qquad dr = k_1r^2 + k_2r^4 + k_3r^6$$

These can be added to the basic collinearity equations to give:

$$x_M = x_p - c\frac{r_{11}(X_M - X_C) + r_{12}(Y_M - Y_C) + r_{13}(Z_M - Z_C)}{r_{31}(X_M - X_C) + r_{32}(Y_M - Y_C) + r_{33}(Z_M - Z_C)} + dx$$

$$y_M = y_p - c\frac{r_{21}(X_M - X_C) + r_{22}(Y_M - Y_C) + r_{23}(Z_M - Z_C)}{r_{31}(X_M - X_C) + r_{32}(Y_M - Y_C) + r_{33}(Z_M - Z_C)} + dy$$

3. ANALYSIS

To study the interior parameters of the camera two graph types were used, line graphs and histograms. The line graphs have the date on the x-axis and the value of the parameter is on the y-axis. The purpose of this graph is to check for any trends in the data. The histograms are used to study the distribution of the parameters. As the number of observations grows, it is expected that the histogram should look like those with a normal distribution [4].

Looking at the line graphs of the D200's interior orientation (figures 2 through 7), as expected, there seems to be no trend as the data is fairly scattered. For example for *c*, the focal length of the camera, most of the data are within a narrow band, but some points were far off the average for reasons that are likely due to camera transportation and handling. The data shows that photo sets taken within a short period of time showed positive results as the values were close together. The histograms for the principal point positions *x*p and *y*p (figures 9 and 10) are almost similar and not normally distributed. The focal length data looks more like a normal distribution but it isn't as good as expected (figure 8).

The data for the 2D wall and 3D structure have been kept separate. The number of observations for the 3D structure is minimal but they agree with the 2D data showing the same pattern. Further studies will be needed to evaluate if changing the types of camera angles to the 3D structure will give different results.

For the 2D study, 13 points were precisely measured with a laser tracker. The photogrammetric coordinates were transformed to the laser tracker coordinate system within the Australis program. The quality of the survey can be judged by the global RMS from each transformation. The average global RMS is 0.143 mm and 0.030 mm standard deviation. Values less than 100 micrometers were expected. Some commercial systems can achieve accuracies as good as 50 micrometers [4].

4. CONCLUSION

Not all parameters show a normal distribution. This suggests that the camera can be used for photogrammetric measurements only if calibrated before each use. Testing in the future should include field tests and possible mechanical improvement to the camera such as securing the lens to the camera body. Future tests should be also include more observations of the 3D structure with more photos from many more angles to get true 360 degree coverage..

5. ACKNOWLEDGEMENTS

The Science Undergraduate Laboratory Internship SULI program wouldn't have been possible without the funding of the Department of Energy DOE here at Stanford Linear Accelerator Center SLAC. Special acknowledgment goes to my mentor BRIAN FUSS for his diligent guidance and support. I would like to acknowledge CATHERINE LECOCQ for her resilient work and direction in the entire project. And finally acknowledgement to BRENDAN DIX for his participation in building the 3D structure; and to the rest of the members of Alignment Engineering Group for their support.

6. REFERENCES

[1] Brown, D.C.,. "Close-Range Camera Calibration". PE&RS, Vol. 37(8), (1971): 855-866.

[2] User Manual for *Australis*:
http://www.photometrix.com.au/downloads/australis/Australis7_Users_Guide.pdf

[3] The Basics of Photogrammetry:
http://www.geodetic.com/Downloadfiles/Basics%20of%20Photogrammetry.pdf

[4] LeCocq, C. Internal notes. SLAC (2009).

[5] Atkinson, K.B. "Close Range Phptogrammerty and Machine Vision". (1996)

7. FIGURES

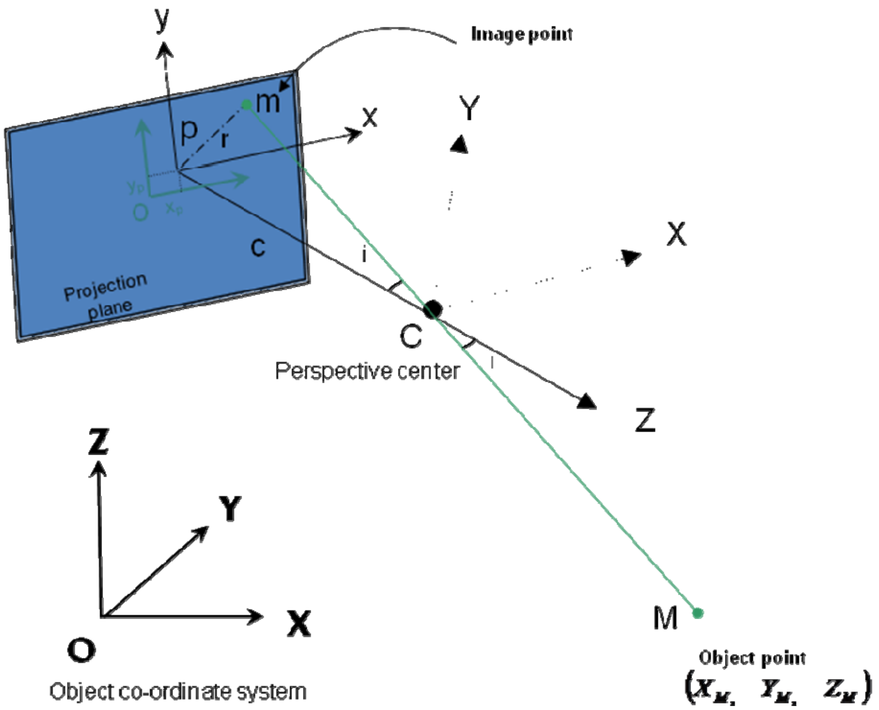

Figure 1. The central perspective model

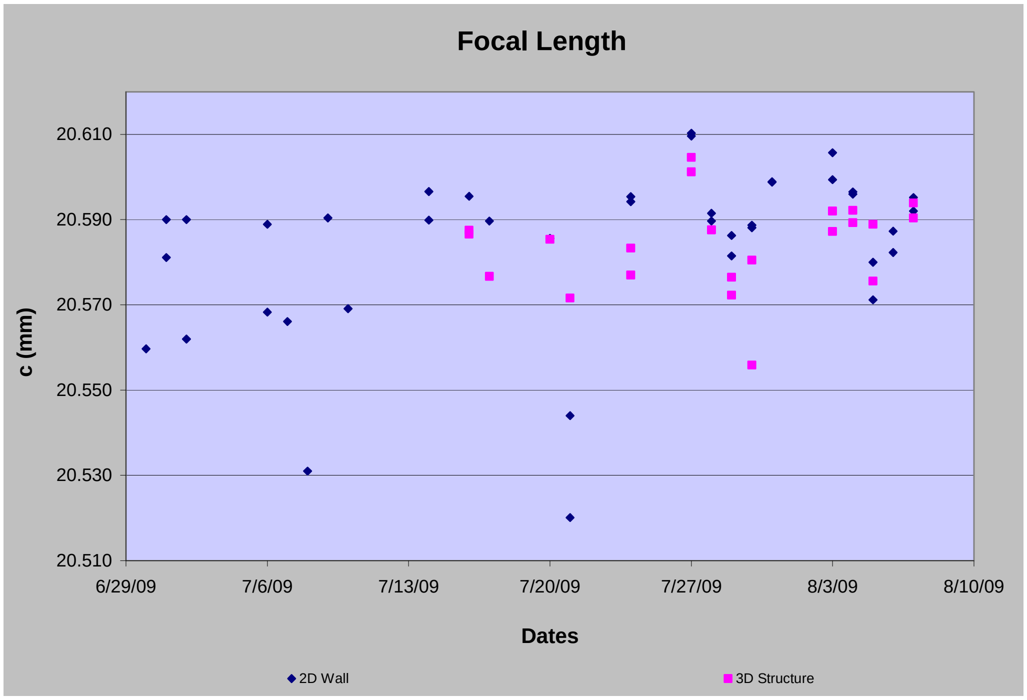

Figure 2. Nikon D200 focal length parameter measured over time

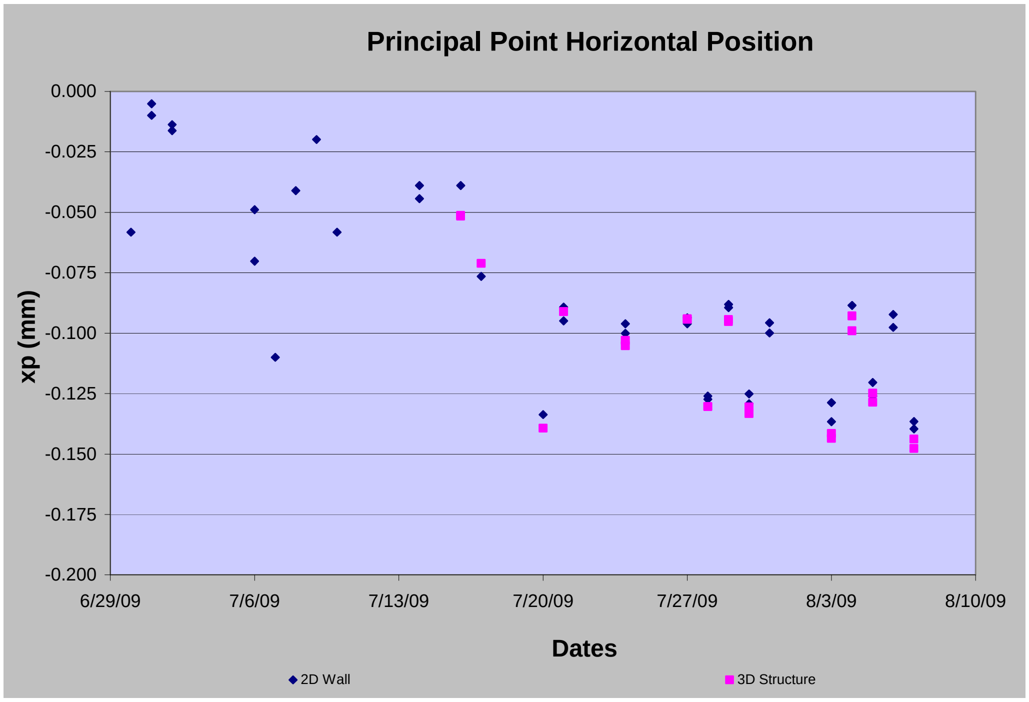

Figure 3. Nikon D200 horizontal position for the principal point

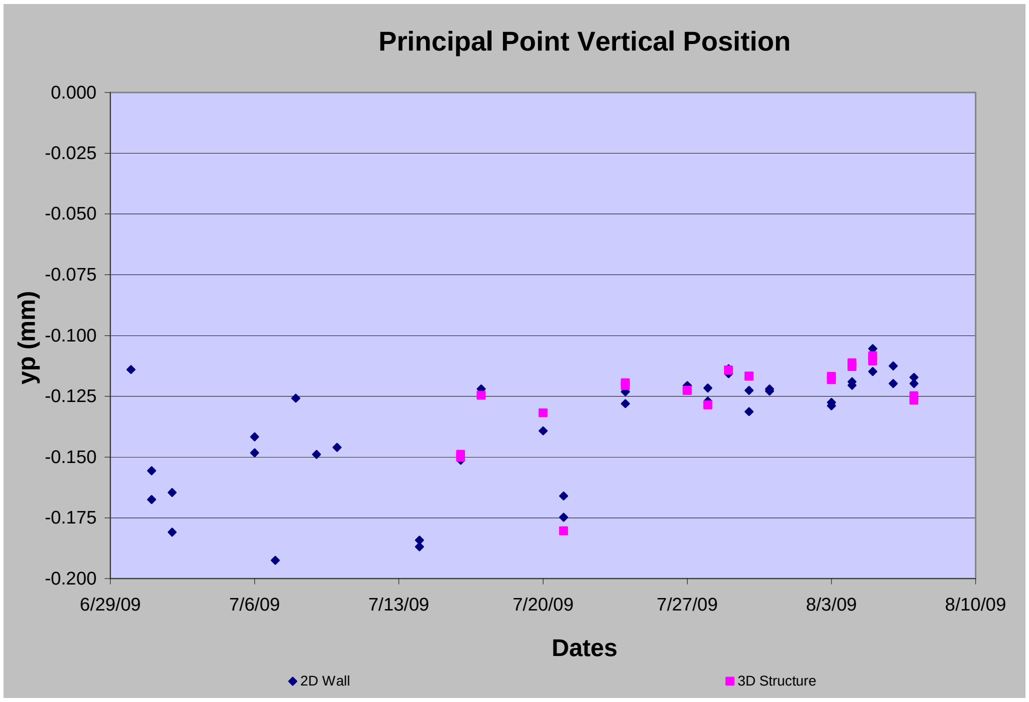

Figure 4. Nikon D200 vertical position for the principal point

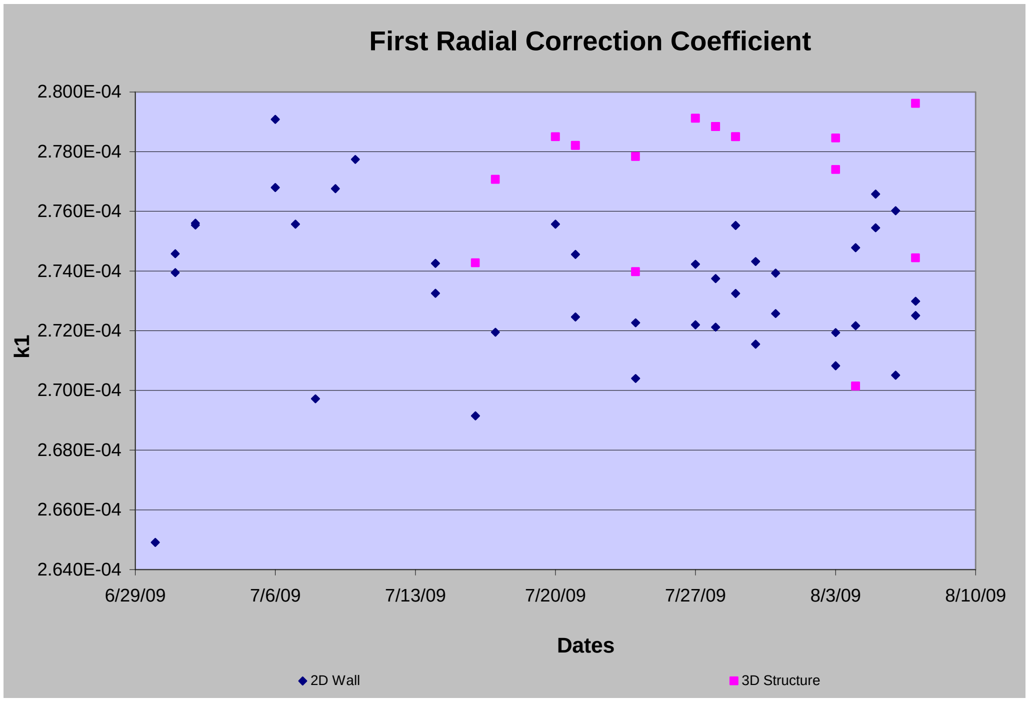

Figure 5. Nikon D200 first radial correction coefficient

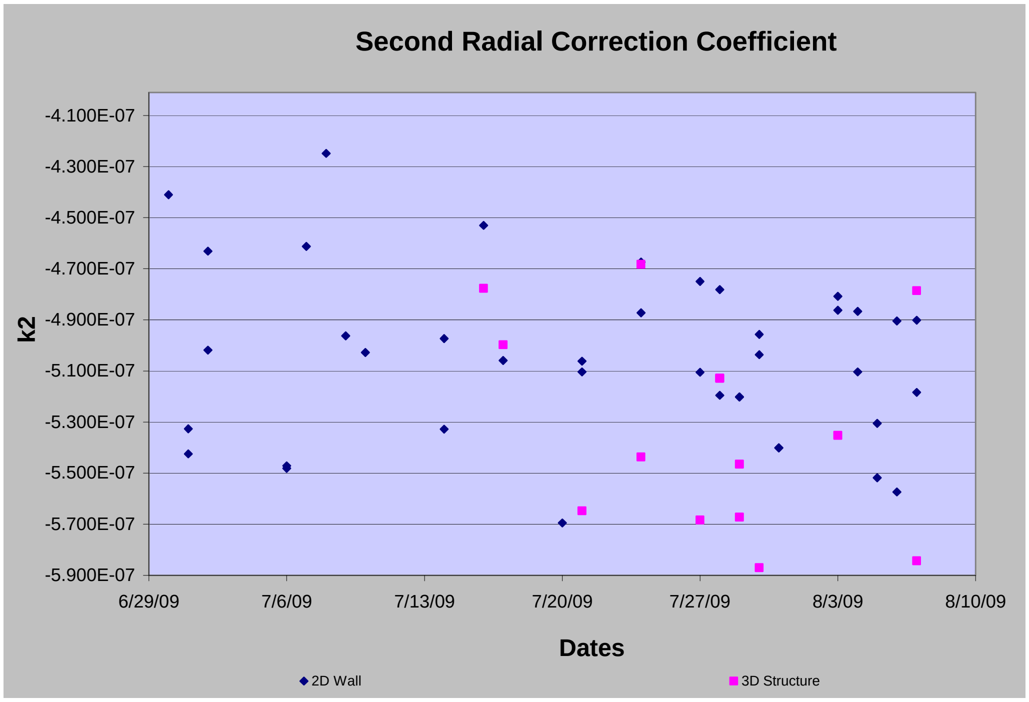

Figure 6. Nikon D200 second radial correction coefficient

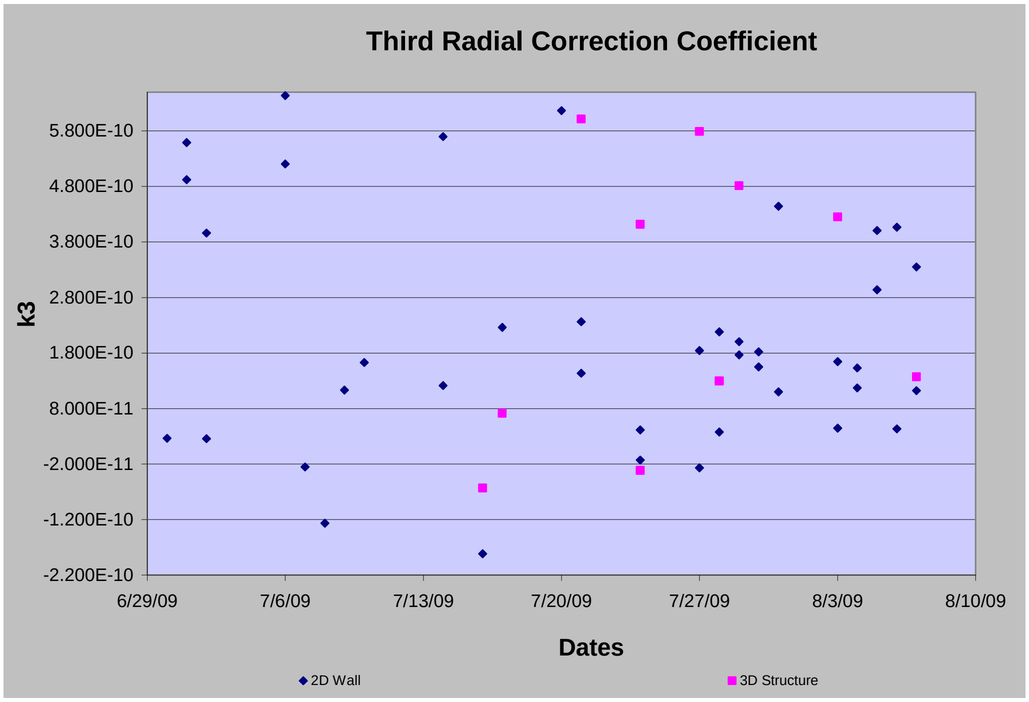

Figure 7. Nikon D200 third radial correction coefficient

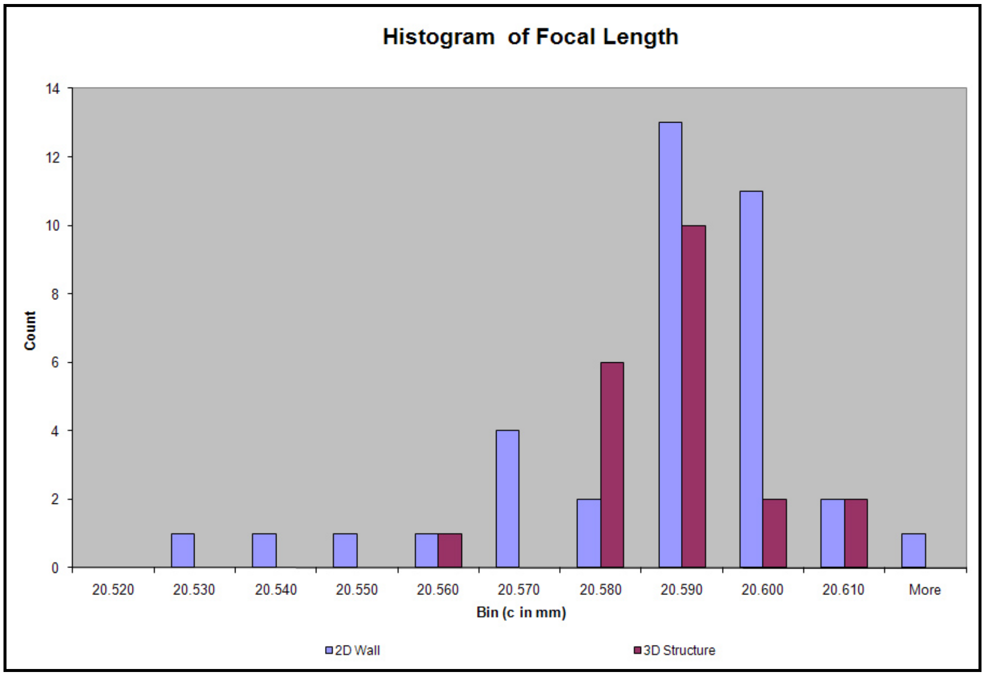

Figure 8. Nikon D200 focal length distribution

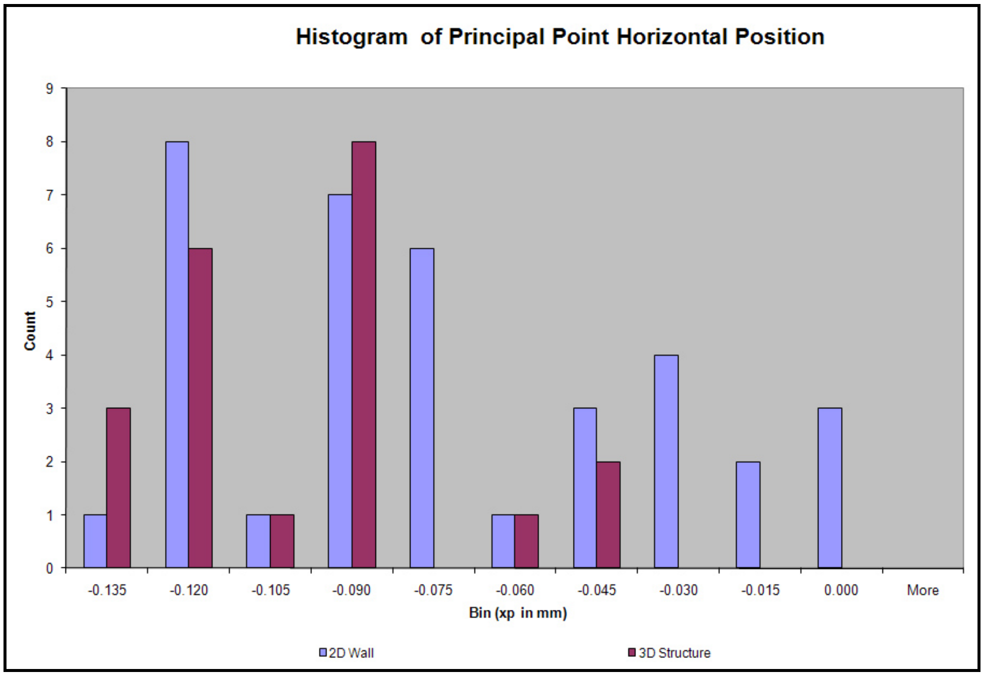

Figure 9. Nikon D200 horizontal principal point distribution

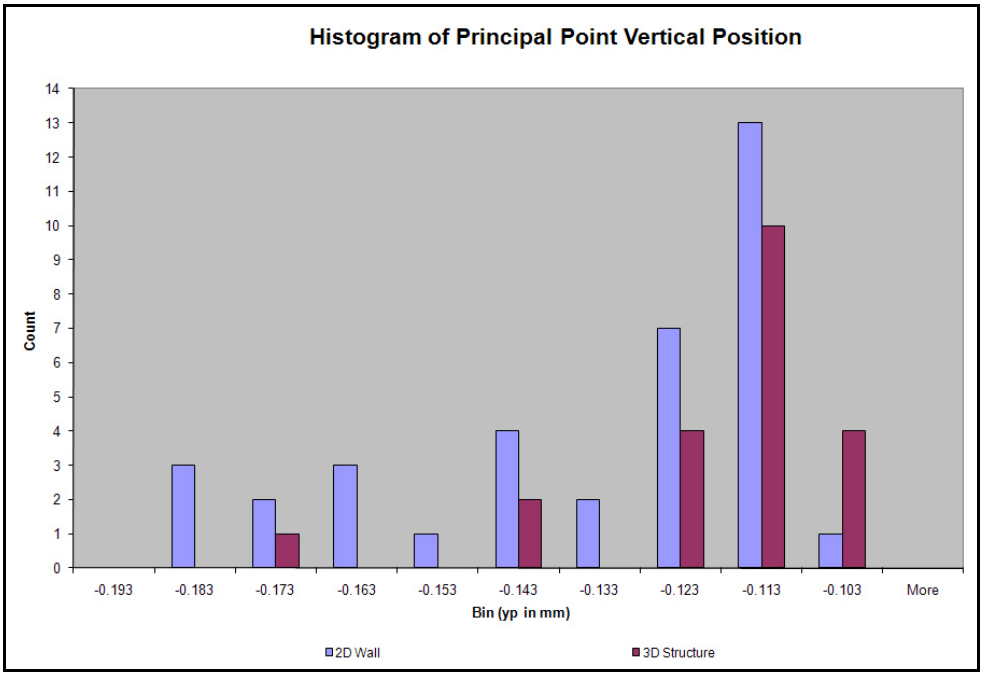

Figure 10. Nikon D200 vertical principal point distribution

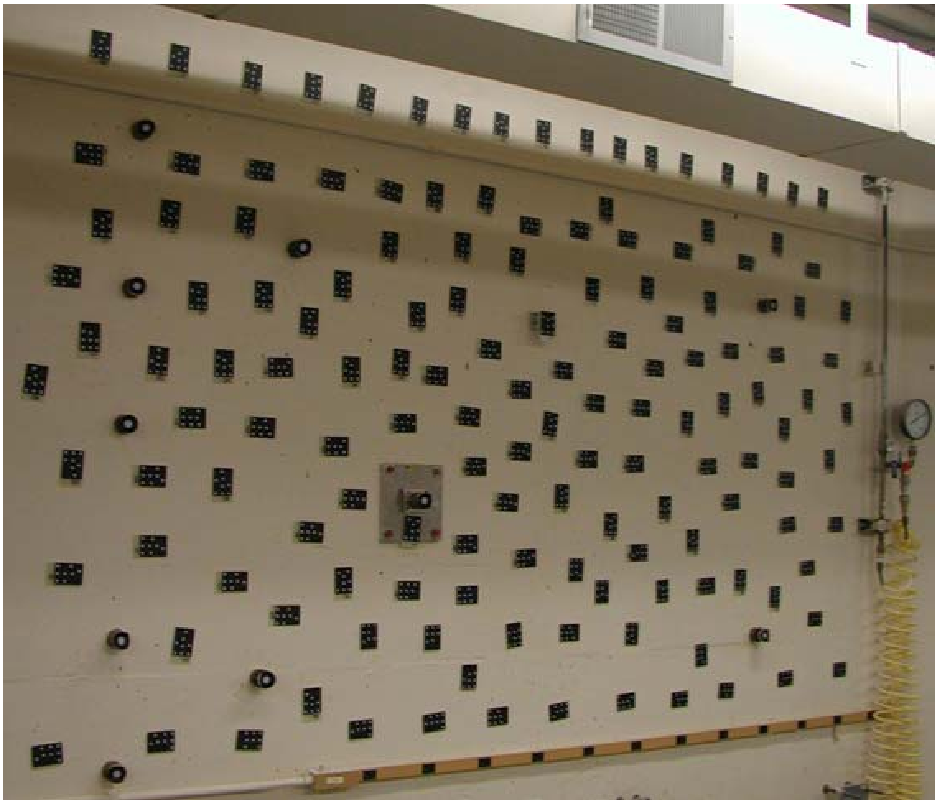

Figure 11. Wall test structure for camera calibration (2D Wall)

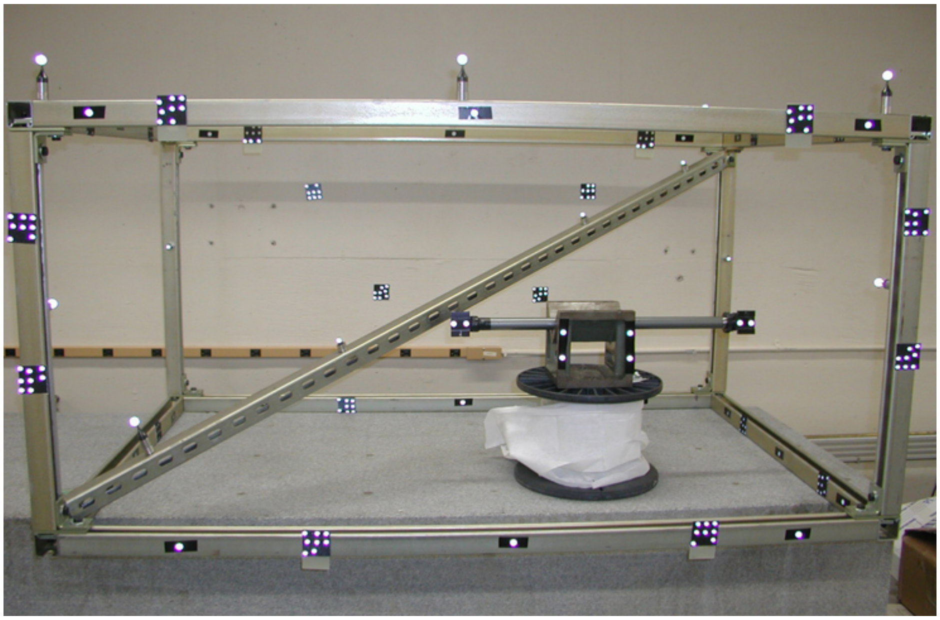

Figure 12. 3D Structure test for camera calibration (with scale bar)