

ASSESSMENT OF TWO CHEAP CLOSE-RANGE FEATURE EXTRACTION SYSTEMS

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ABSTRACT

The use of non-metric cameras in photogrammetric applications is considered under very strict constraints due to their instability and lack of fiducial coordinate system. Architectural building documentation, monuments registration, and monitoring structure deformations are very essential close-range photogrammetric applications that require high accuracy and quick data acquisition. Using metric cameras, in such situations, is quite uneconomic and non-metric cameras are in favor. In order to accelerate the processing time of analyzing non-metric cameras digital techniques are preferred.

The aim of this research is to investigate the use of two inexpensive techniques for object reconstruction using digital images produced by non-metric cameras. The first technique employs an inexpensive 35mm camera and a cheap scanner, while a low-cost digital camera is used in the second technique. Both techniques are thoroughly evaluated and the RMS errors are investigated. Results show that the 6-parameter transformation model is the best model to handle geometric errors introduced by scanners. The object reconstruction process results show that sub millimeter accuracy, in object coordinates, can be achieved if systematic errors are considered.

1. INTRODUCTION

The basic task of many photogrammetric systems is to derive object space coordinates from 2D images. Analog, semi-analytical, and analytical techniques have been employed for a long period of time in photogrammetry to extract ground coordinates of objects from hardcopy images. In recent years, digital techniques are implemented in photogrammetric applications. The advantages of using digital techniques are: the ease and speed of data acquisition, the inherent on-line and real-time capabilities, and the high degree of automation. Acquiring digital images is done either by scanning hardcopy images or by capturing the photographs directly in digital format using digital sensors.

The aim of this paper is to investigate the process of capturing ground features digitally through one of the following schemes: scanning hardcopy images produced by non-metric 35mm cameras or acquiring digital images directly using non-metric digital cameras. Each technique is evaluated and analyzed using a number of mathematical models that relate image space coordinates with ground space coordinates. The implemented mathematical models were adapted to handle the systematic errors produced by non-metric cameras.

2. PREVIOUS WORK

In (Boron, 1996) the accuracy of the UMAX 1200 scanner is investigated; the correction method he proposed reduces the scanning errors from ± 5 pixels to ± 0.15 pixels. The correction is executed in two stages. First order corrections are found for each point in the scanner plate first then the second order corrections for each run are determined. In (Bolte *et al.*, 1996) both the geometric and radiometric properties of the scanners were studied. The RM-1 scanner was used and it was found that its accuracy is equivalent to the analytical plotter.

In (Karras and Mavrommati, 2001) the effects of the radial distortions in the 35mm cameras is studied. A number of approaches, ranging from the utilization of linear features to the rectification of regular grids, were used. It was shown that ignoring the radial lens distortion increases the RMS errors dramatically. In (Cruz *et al.*, 2000) the inner orientation of non-metric cameras was investigated. The 35mm camera images were scanned at 600 dpi and 1200 dpi. A comparison between the 6-parameters and 4-parameters coordinate transformation models showed that the former transformation model is better than the later.

In (Seedahmed and Schenk, 1998) a bundle adjustment with self-calibration scheme is presented for calibrating a high accuracy CCD digital camera. An extended version of the collinearity equations was implemented with corrections for the symmetric distortion, the decentering distortion, the image plane unflatness, and the in-plane image distortion. The results showed the necessity to correct systematic errors. In (Zolfaghari and Malian, 2000) non-metric cameras are used to record architectural and historical buildings. The work shows the effectiveness of using non-metric cameras for capturing this type of features.

Section 2 presents the calibration process of flatbed scanners. Section 3 summarize the mathematical models used to transfer image coordinates to ground coordinates. The object reconstruction process is presented in section 4. Conclusions are discussed in section 5.

2. GEOMETRIC CALIBRATION OF FLATBED SCANNERS

During the scanning process, the positions of the scanned features are corrupted causing the distances between them to change. For cheap scanners, the distortions increase due to the bad functioning of the mechanical, optical, and electronic

parts of the scanner. In this section different mathematical models are used to handle the geometric errors introduced by the scanners, the performance of each model is evaluated and the best model is remarked.

2.1 Two-Dimensions Coordinate Transformations

In order to study and compensate the introduced geometrical distortions in the scanning process we employed four 2D coordinate transformation models.

In the first model, Equation (1), three parameters are used to represent two shifts and a rotation angle between the hardcopy coordinate system and the scanner coordinate system. In the second model one more parameter is added to consider the uniform scale between the two systems, Equation (2). The third model represents the 4parameter transformation model. Six parameters are used to represent two translations, the rotation angle between the two systems, two different scaling factors, and a skew factor, Equation (3). The fourth model is the 8parameter transformation model, Equation (4). A complete study on the 2D transformation models is discussed in (Mikhail *et. al.*, 2001).

$$\begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} = \begin{bmatrix} \cos q & -\sin q \\ \sin q & \cos q \end{bmatrix} \begin{bmatrix} X_1 \\ Y_1 \end{bmatrix} + \begin{bmatrix} X_o \\ Y_o \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} = S * \begin{bmatrix} \cos q & -\sin q \\ \sin q & \cos q \end{bmatrix} \begin{bmatrix} X_1 \\ Y_1 \end{bmatrix} + \begin{bmatrix} X_o \\ Y_o \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} = \begin{bmatrix} \cos q & -\sin q \\ \sin q & \cos q \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \mathbf{a} & 1 \end{bmatrix} \begin{bmatrix} S_x & 0 \\ 0 & S_y \end{bmatrix} \begin{bmatrix} X_1 \\ Y_1 \end{bmatrix} + \begin{bmatrix} X_o \\ Y_o \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} = \begin{bmatrix} \frac{a_1 X_1 + b_1 Y_1 + c_1}{a_o X_1 + b_o Y_1 + 1} \\ \frac{a_2 X_1 + b_2 Y_1 + c_2}{a_o X_1 + b_o Y_1 + 1} \end{bmatrix} \quad (4)$$

Where X_1, Y_1 = hardcopy coordinates,
 X_2, Y_2 = scanner coordinates,
 X_o, Y_o = shift parameters,
 q = rotation angle,
 S = uniform scale factor,
 S_x, S_y = non uniform scale factors
 \mathbf{a} = skew factor, and
 $a_1, a_2, a_o, b_1, b_2, b_o, c_1, c_2$ = the 8parameter transformation model parameters.

2.2 Experiment Setup

Some experiments are performed to evaluate the scanning process as well as to choose the most appropriate model that minimizes the produced geometric distortions. The process is based on scanning a precise hardcopy image of known and accurate point coordinates, Figure 1. The measured coordinates are used as the reference coordinates for the hardcopy points. The experiment is performed with a

4400CSE Howled Packard scanner. Two scanning resolutions were used (2400dpi, and 600dpi).

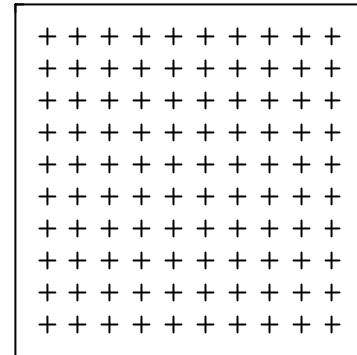


Figure 1. Configuration of Reference Image

The calibration process is summarized in three steps. First the scanned coordinates of all points are measured digitally. The points are divided to control points and check points. The control point coordinates are used to estimate the 2D transformation parameters for each 2D transformation model. Then the estimated parameters are used to convert the scanned coordinates of the check points to the hardcopy coordinate system. The RMS errors are calculated for each model and are shown in Figures 2. The Y direction represents the scanning direction. The results show that the 6-parameter transformation model is the best model to recompense the geometric errors introduced by the scanners.

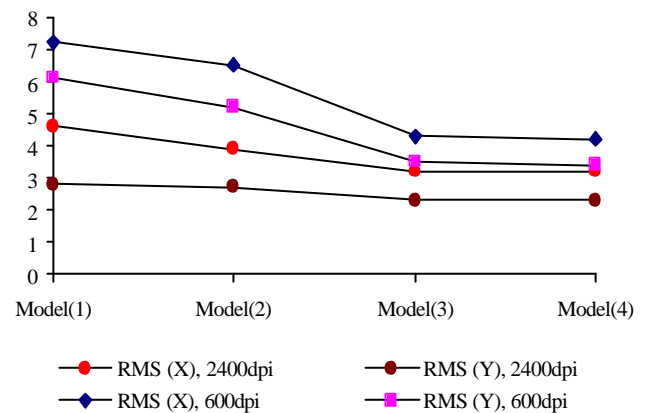


Figure 2. RMS Errors for the Scanning Process (Pixels)

3. MATHEMATICAL MODELS FOR CLOSE RANGE PHOTOGRAMMETRY

Due to the wider use of non-metric cameras for different photogrammetric purposes such as in registering archeological buildings, documenting historical writings, and recording historical buildings, there has been an increasing demand to calibrate non-metric cameras. Using non-metric cameras incorporate many problems, including:

- 1-Non-metric cameras lack a stable inner orientation technique and irregular methods of calibration.
- 2-Most non-metric cameras have neither a reseau plate nor fiducial coordinate system to act as a reference for photographic measurements.

Due to these two disadvantages, the use of non-metric cameras in photogrammetric applications is considered under very strict constraints. However if non-metric cameras are calibrated properly they could be used in more applications. In section 3.1 a brief summary of the systematic errors introduced by the non-metric cameras is presented. Section 3.2 describes the mathematical models employed to transform image space coordinates to the object space coordinates taking into account the effect of the systematic errors.

3.1 Systematic Errors Introduced By Non-Metric Cameras

“Systematic errors in non-metric cameras are the deviation of the physical imaging event from the projection mathematical model”, Karara (1989). There are two types of systematic errors; the external systematic errors, and the internal systematic errors. The sources of the external systematic errors are: the atmospheric refraction and the comparator errors. However, according to (Marzan and Karara, 1976) the atmospheric refraction errors are neglected for object distances less than 300 meters. The causes of the internal systematic errors are: the lens distortion, the film deformation, and film unflatness.

Lens distortion is considered as the major source of errors for the non-metric cameras. Lens distortion is introduced by two components: symmetric lens distortion and asymmetric lens distortion. The adopted mathematical model for symmetric lens distortion according to (Brown, 1971) is given by Equation (5).

$$\Delta r = k_1 r^3 + k_2 r^5 + k_3 r^7 + \dots \quad (5)$$

Where $k_1, k_2, k_3 =$ constants,

$r =$ radial distance from the point of symmetry, and
 $\Delta r =$ symmetric lens correction in the radial direction

The asymmetrical lens distortion is due to the lenses decentering. We employed the correction model presented by (Faig and Moniwa, 1972), Equations (6).

$$\begin{aligned} \Delta x &= b_1(r^2 + 2x^2) + 2b_2xy \\ \Delta y &= b_2(r^2 + 2y^2) + 2b_1xy \end{aligned} \quad (6)$$

Where $b_1, b_2 =$ constants,

$r =$ radial distance from the point of symmetry,
 $x, y =$ point coordinates in image space, and
 $\Delta x, \Delta y =$ symmetric lens corrections

The film deformation inside the camera is caused by bad flatness of the film. The film deformation outside the camera is due to lack of control over temperature, and the humidity during processing and storage of non-metric films. In (Robson, 1992) the 6-paramer transformation model is used to model the total film deformation.

3.2 Transformation Between Image Coordinates and Ground Coordinates

We employed four models to transform the image coordinates and the object coordinates. The first model is the

collinearity representation with no systematic error correction parameters. Nine transformation parameters are included in this model. The second model is a modified version of the collinearity representation, 6 more parameters are added to handle the systematic errors, Equation (7). The third model is the DLT representation, (Abdel-Aziz and Karara, 1971). The fourth model is an adapted form of the DLT representation, Equation (8). The DLT is a linear treatment of a non-linear problem so its results are approximate.

$$\begin{aligned} a_o + a_1x + a_2y + k_1xr^2 &= \\ -f \frac{m_{11}(X - X_c) + m_{12}(Y - Y_c) + m_{13}(Z - Z_c)}{m_{31}(X - X_c) + m_{32}(Y - Y_c) + m_{33}(Z - Z_c)} & \quad (7) \\ b_o + b_1x + b_2y + k_2yr^2 &= \\ -f \frac{m_{21}(X - X_c) + m_{22}(Y - Y_c) + m_{23}(Z - Z_c)}{m_{31}(X - X_c) + m_{32}(Y - Y_c) + m_{33}(Z - Z_c)} & \end{aligned}$$

Where $f =$ camera interior parameters,

$X_c, Y_c, Z_c =$ exposure station coordinates,

$x, y =$ image space coordinates,

$X, Y, Z =$ object space coordinates,

m_{11} through $m_{33} =$ rotation matrix elements,

$r =$ radial distance from the point of symmetry, and

$k_1, k_2, b_o, b_1, b_2, a_o, a_1, a_2 =$ systematic error correction parameters

$$\begin{aligned} x + l_1X + l_2Y + l_3Z + l_4 + l_9xX + l_{10}xY + l_{11}xZ + k_1xr^2 &= 0 \\ y + l_5X + l_6Y + l_7Z + l_8 + l_9xX + l_{10}xY + l_{11}xZ + k_2yr^2 &= 0 \end{aligned} \quad (8)$$

Where $x, y =$ image space coordinates,

$X, Y, Z =$ object space coordinates,

l_1 through $l_{11} =$ DLT parameters,

$r =$ radial distance from the point of symmetry, and

$k_1, k_2 =$ systematic error correction parameters

4. DIGITAL APPROACH FOR OBJECT SPACE RECONSTRUCTION

Two object space reconstruction systems are presented in this paper. The first system employs a cheap 35mm camera, Zenit E, and an inexpensive flatbed scanner, while the second system uses only a low-resolution digital camera, Casio QV-A10. First 50 target points are fixed as shown in Figure 3. The points are fixed on wood plates with different thickness varying from 5 mm to 10cm. A theodolite and a total station are employed to find the reference ground coordinates of the target points.

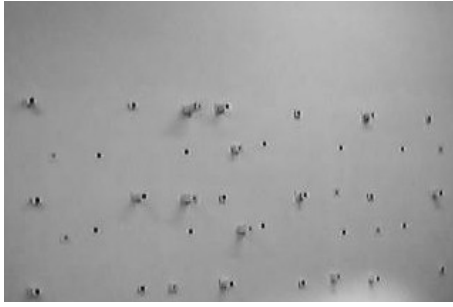


Figure 1. Test Area Configuration

4.1 Acquisition of Digital images from the 35mm camera and the scanner

In this section the analog camera, Zenit E, was used together with the HP scanner to produce the digital images. First the camera was used to collect a number of image pairs with different B/H ratio, and these images are scanned with different resolutions. Sixteen well-distributed control points were chosen to solve the resection problem for each image. The intersection process is used to evaluate the experiments. Table 1 shows the different combinations of the B/H ratios and the used resolutions. Figure 3-a, b, and c show the RMS errors for the different experiments.

Case	H (m)	B (m)	B/H	Scanning Resolution (dpi)
1	4	1	0.25	1200
2	4	1	0.25	300
3	4	3.9	0.97	1200
4	5	3	0.6	1200

Table 1. First System Configuration

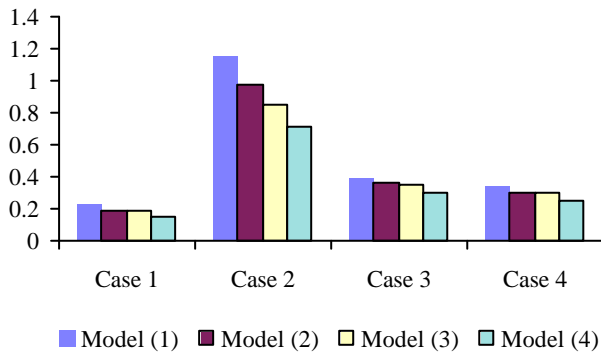


Figure 3-a. First System RMS Errors (mm), X Direction

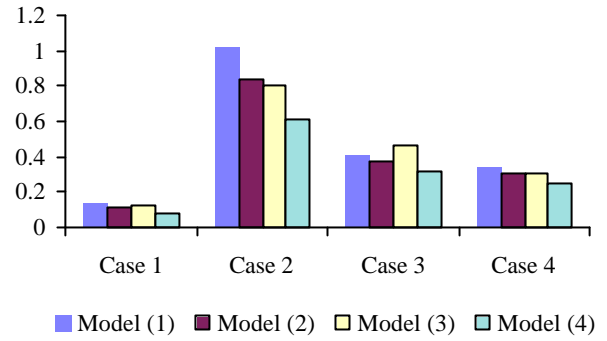


Figure 3-b. First System RMS Errors (mm), Y Direction

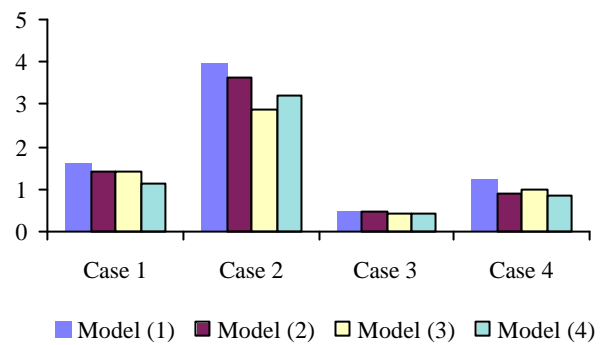


Figure 3-c. First System RMS Errors (mm), Z Direction

4.2 Acquisition of Digital Images Using The Digital Camera

The digital camera was used to produce the digital images directly. The images were taken with B/H ratios shown in Table 3. The resection and intersection processes were applied to solve for the camera parameters and the ground coordinates of the target points. Figure 4-a, b, and c show the RMS errors for the different experiments using the digital camera.

Case	H (m)	B (m)	B/H
1	4	1	0.25
2	5	3	0.60
3	4	3.9	0.97

Table 3. Second System Configuration

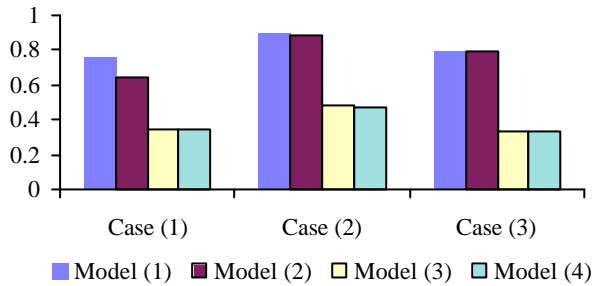


Figure 4-a. Second System RMS Errors (mm), X Direction

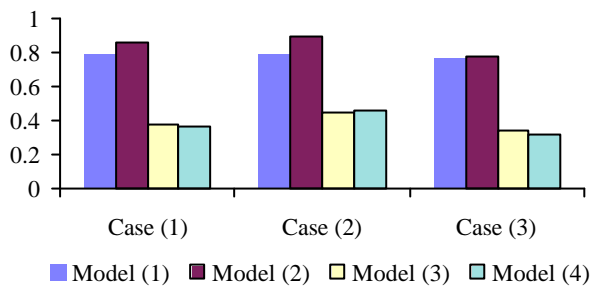


Figure 4-b. Second System RMS Errors (mm), Y Direction

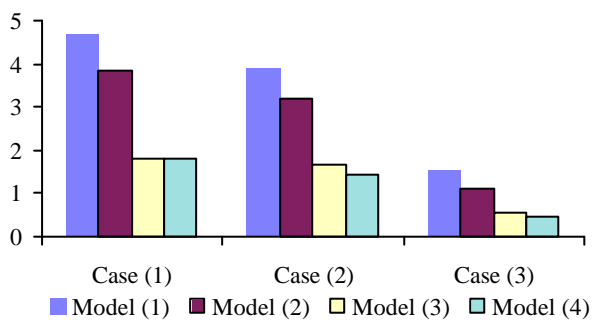


Figure 4-c. Second System RMS Errors (mm), Z Direction

5. CONCLUSIONS

- 1- The best mathematical model for the treatment of the geometric errors introduced during the scanning process is 6-paramters transformation model.
- 2- The (B/H) ratio must be considered during the imaging process in order to achieve similar accuracy in the X,Y,Z ground coordinates.
- 3- The accuracy of the ground coordinates extracted from the digital images captured by scanning hardcopy images could reach sub millimeter accuracy with high quality scanning resolution (1200dpi) and good (B/H) ratio.
- 4- The accuracy of the low resolution digital cameras could reach sub millimeter with good (B/H) ratio.

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