

# RECTIFICATION OF DIGITAL CLOSE RANGE IMAGES: SENSOR MODELS, GEOMETRIC IMAGE TRANSFORMATIONS AND RESAMPLING

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## ABSTRACT:

Rectification may be considered as the transformation process of digital images carried out to obtain distortion free versions of the images. Transformation parameters are obtained by using ground control points (GCP) on the uncorrected raw image and their corresponding points on the map or on an ortho-rectified image. At the end of the geometric transformation, to obtain the pixel values of the new image a radiometric resampling is required. For this purpose, interpolation techniques are used. In this paper, in order to perform rectification issues, we used Restore 1.0 software which we developed for rectification of digital images, in Borland C++ Builder platform.

## 1. INTRODUCTION

In the recent years, with the developments on both technology and photogrammetry, the accuracy of the information obtained with the photogrammetric techniques, have been increasing rapidly. Development of computational tools and sensor systems together has been brought the expectation of high accuracy especially from the side of close range photogrammetric systems. Although these developments, images, which are the basic elements of photogrammetry are naturally effected by some distortions caused by sensor systems' insufficient capacity, sampling interval, atmospheric effects, etc, and these distortions must be eliminated to achieve high accuracy from photogrammetric data.

A digital image is basically a two dimensional array of pixels having both radiometric characteristics and spatial components (Fogel, 1997). The close range digital images obtained via sensor arrays, are charged with errors (distortions). These errors arise from the capacity of sensors, atmospheric conditions and the geometry of projection. These errors effect energy values of electro magnetic waves measured by sensors. Additionally they effect the spatial arrangement of object details which corresponds to the sensor arrays. In accordance with the above arguments, these effects may be categorized in two main groups called radiometric and geometric errors respectively. The images should be purified from these errors. Result products and expected accuracies are important to decide the mathematical models of restoration which are to be performed before extraction of geometric and semantic knowledge from images. Processes which are performed to correct the geometric errors of digital images are generally called as rectification. There are three commonly used approaches to perform rectification process. These methods are polynomial, projective, and differential rectifications. At the end of the geometric transformation, to obtain the pixel values (gray level values, intensities or color values) of the new image a radiometric resampling (gray level resampling) is required. For this purpose, interpolation techniques are used.

We give a sample application performed with both real and synthetic images. In order to test the algorithm has been implemented, non-metric digital camera was used. Control points of the test area are measured by geodetic methods and images of the test area have been taken from several projection stations. After the implementation the models, rectified images and final results of application are given and discussed. In this paper, in order to perform rectification issues, we used Restore 1.0 software which we developed (developed by Temiz, M.S. and Dogan, S.) for rectification of digital images, in Borland C++ Builder platform. Restore 1.0 software can perform, image band operations, mathematical image calculations, bundle adjustment with self calibration, image transformations, image enhancement, filter operations and rectification of any digital image.

## 2. SENSORS AND ADDITIONAL PARAMETERS

The close range digital images obtained via sensor arrays, are charged with errors (distortions). These errors arise from the capacity of sensors, atmospheric conditions and the geometry of projection. These errors affect energy values of electro magnetic waves measured by sensors. These errors must be modeled and the images should have to be purified from these errors.

The additional parameters model the geometric effects of the deviation of the physical reality from perspective geometry, called systematic errors (Beyer, 1992).

In order to model the deviation of the physical reality from the perspective geometry, we investigate sensor models in this paper. Before any camera system is used for photogrammetry, these deviations should either be known or compensated for subsequent computations. For this purpose calibration techniques are used. Calibration involves the establishment of the parameters which can best describe the performance of the camera system. Camera models used in digital close range photogrammetry are usually based on the co-linearity

conditions and on a number of additional parameters modelling the interior orientation, lens and further distortions (Remondino, 2000). These parameters show changes according to sensor specifications. In this study we investigate parameters for only matrix array sensors. There are several calibration methods exist. Some of these are laboratory calibration, test range calibration, self calibration and analytical plumb-line calibration etc. These methods are analyzed and in this study, we have used one of the best technique which is bundle adjustment with self-calibration parameters. The internal orientation and systematic errors due to lens distortions and CCD (Charged Coupled Device) lines rotations are estimated with self-calibration. The aim of self-calibration is to estimate additional parameters which model the systematic errors due to changes in the interior orientation (principal point position and focal length), lens distortions and CCD line rotation in the focal plane (Temiz and Doğan, 2005).

### 2.1 Radial and Decentering Lens Distortion

Close range photogrammetry uses digital cameras. These are generally non-metric digital cameras. But all cameras, whether metric or non-metric, change the direction of light path, since at least the existence of the optical systems. In photogrammetry, these aberrations reduce the image quality by affecting the image coordinates. The aberrations, known as radial and decentering distortion, affect the location of positions in an image. Radial lens distortion can be modelled from figure 1;

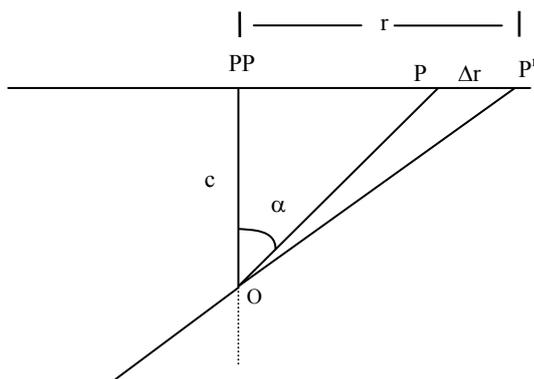


Figure 1. Radial lens distortion

$$\Delta r = r - c \cdot \tan \alpha \quad (1)$$

Radial distortion can be represented by a polynomial series of odd powered terms;

$$dr = K_1 r^3 + K_2 r^5 + K_3 r^7 + \dots \quad (2)$$

$$\Delta x_r = K_1 r^3 + K_2 r^5 + K_3 r^7 \quad (3)$$

$$\Delta y_r = K_1 r^3 + K_2 r^5 + K_3 r^7$$

K's are the coefficients of radial distortion corresponding to infinity focus, dr is in  $\mu\text{m}$ , and;

$$r^2 = (x - x_0)^2 + (y - y_0)^2 \quad (4)$$

where x,y, are the coordinates of points on the image,  $x_0$  and  $y_0$  are displacements between the Principal Point (PP) and the origin of the measured coordinates.

Decentering distortion is caused by slight misalignments of lens components during manufacturing. Decentering distortion has both radial and tangential components. They can be modelled as;

$$\Delta x_d = (r^2 + 2\bar{x}^2)P_1 + 2\bar{x}\bar{y}P_2 \quad (5)$$

$$\Delta y_d = 2\bar{x}\bar{y}P_1 + (r^2 + 2\bar{y}^2)P_2$$

where,

$$\bar{x} = (x - x_0) \text{ and } \bar{y} = (y - y_0)$$

### 2.2 Distortion of Sensor Plane

The in-plane distortion parameters are empirical in nature and modeled by a polynomial. For digital cameras the total number of parameters is reduced from 12 to a sub-set of 2, which are the "scale", parameter b1 and the "shear", parameter b2:

$$\Delta x_f = b_1 \bar{x} + b_2 \bar{y} \text{ and } \Delta y_f = 0 \quad (6)$$

(Dörtsel et al., 2003)

## 3. RECTIFICATION

Rectification may be considered as a transformation process of digital images carried out to obtain distortion free versions of the images. Transformation parameters are obtained by using ground control points (GCP) on the uncorrected raw image and their corresponding points on the map or on an ortho-rectified image. There are three commonly used approaches to perform rectification process. These methods are polynomial, projective, and differential rectifications. First two methods are approximate solutions but the last one models the physical reality of the imaging process by means of co-linearity equations and it corrects relief displacements and it is also known as ortho-rectification. Polynomial and projective rectification methods can not correct relief displacements, since no information concerning the ground control points (GCP) is used.

At the end of the geometric transformation, to obtain the pixel values (gray level values, intensities or color values) of the new image, a radiometric resampling (gray level resampling) is required. For this purpose, interpolation techniques are used. Gray level interpolation is important, because it directly effects the image quality. Interpolation method also effects the result accuracy. There are three commonly used approaches for radiometric resampling. These are nearest neighbor (with one pixel), bi-linear (with 4 pixels) and bi-cubic interpolations (with 16 pixels). These methods are also analyzed and compared in this paper.

### 3.1 Polynomial Rectification

Because of we perform transformation on digital images, it is sufficient to use two dimensional transformation functions.

$$x' = \sum_{r=0}^m \sum_{k=0}^{m-r} a_{rk} x^r y^k \quad \text{and} \quad y' = \sum_{r=0}^m \sum_{k=0}^{m-r} b_{rk} x^r y^k \quad (7)$$

If the polynomial (7) is developed;

$$\begin{aligned} x' &= a_{00} + a_{01}y + a_{10}x + a_{11}xy + a_{02}y^2 + a_{20}x^2 + a_{12}xy^2 + a_{21}x^2y + \dots \\ & \quad (8) \\ y' &= b_{00} + b_{01}y + b_{10}x + b_{11}xy + b_{02}y^2 + b_{20}x^2 + b_{12}xy^2 + b_{21}x^2y + \dots \end{aligned}$$

(8) is obtained (Monti et al., 1999).

Coefficients  $a_{rk}$  and  $b_{rk}$  must be known to perform transformation. If they are not known as prior, to find their values corresponding points on both images may be used.

If the geometric transformation does not change rapidly depending on position in the image, low order approximating polynomials can give good results. If the transformation is position-sensitive, i.e. changes rapidly with position, low order polynomial approximation will fail. In this case, the approximation requires a higher order terms of the polynomial. The higher the degree of the approximating polynomial, the more sensitive to the distribution of the pairs of corresponding points the geometric transformation (Zhang, 2001).

#### 3.1.1 Two Dimensional Similarity Transformation

Two dimensional similarity transformation functions are defined with two shifts, one scale and one rotation.

$$x' = a_{00} + a_{01}y + a_{10}x \quad \text{and} \quad y' = b_{00} - a_{10}y + a_{01}x \quad (9)$$

with constraints  $a_{01} = b_{10}$  and  $a_{10} = -b_{01}$ , the similarity transformation is obtained by the first 3 terms of equations (8).

#### 3.1.2 Affine Transformation

In equations (8), without any constraint, with the first 3 terms, affine transformation is obtained.

$$x' = a_{00} + a_{01}y + a_{10}x \quad \text{and} \quad y' = b_{00} + b_{01}y + b_{10}x \quad (10)$$

To perform the transformation, we need at least 3 corresponding points on both images.

#### 3.1.3 Bi- Linear Transformation

In practice, the geometric image transformations are usually approximated by the bilinear transformation. 4 pairs of corresponding points are sufficient to find the transformation (Zhang, 2001).

$$x' = a_{00} + a_{01}y + a_{10}x + a_{11}yx \quad (11)$$

$$y' = b_{00} + b_{01}y + b_{10}x + b_{11}yx$$

Although polynomials are very easy to use for rectifications, they can cause problems and errors in the transformed image. They do not adequately correct relief displacements, nor do they consider the special geometry of the imaging system. For the inexperienced user, a high-order polynomial may seem to provide a perfect fit at the reference points, as the residuals are small; however, due to undulations between the reference points large errors could be created (Novak, 1992).

Sample application on polynomial transformation is given in figure 2.



Figure 2. Original and distorted images.

Original image in figure 2 has been distorted synthetically and second image has been obtained. Unknown transformation parameters have been computed by using corresponding corner points of images. Finally the image in figure 3 which has been rectified with affine transformation has been obtained.



Figure 3. Rectified image with Restore 1.0

At the end of the geometric transformation, to obtain the pixel values of the new image, bi-cubic interpolation technique has been used. As seen in figure 3, distorted image has been corrected in an adequate amount. Histogram of difference image between original and corrected image is seen in figure 4. All pixels values of expected difference image must be zero (black) but because of resampling and rolling ups precisions occurred during calculations, it is impossible to be all zero.

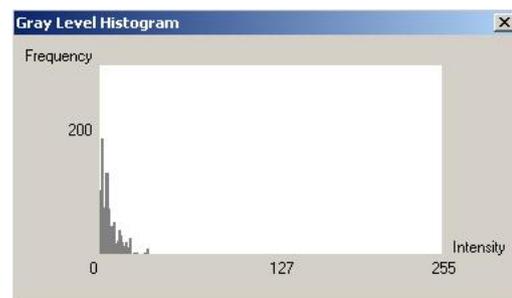


Figure 4. Histogram of the difference image

Rectification residuals can be seen in histograms of original and rectified image. Figure 5 and figure 6 illustrate histograms.

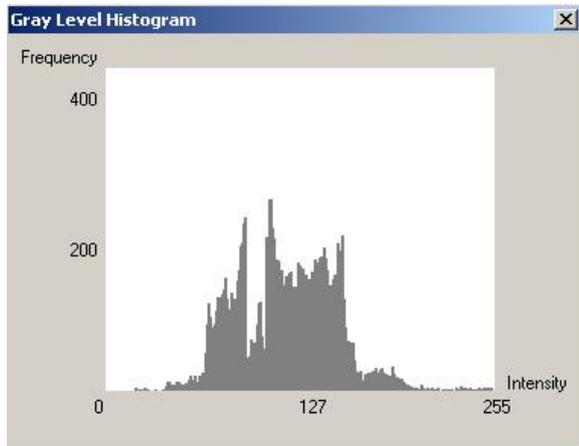


Figure 5. Histogram of the original image.

After rectification histograms of original and corrected images must be same. As mentioned above, these differences occurred because of resampling and rolling ups during calculations.

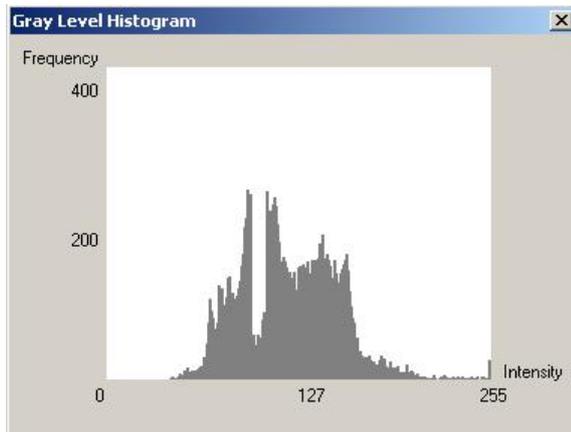


Figure 6. Histogram of the rectified image.

### 3.2 Projective Transformations

Projective transformation defines the relationship between two planes. It is defined by eight parameters (equation 12), which can be derived from four object points lying in a plane and their corresponding image coordinates. The elements of exterior and interior orientations are not necessary, as they are implicit in these parameters (Novak, 1992).

$$x = \frac{a_1x' + a_2y' + a_3}{c_1x' + c_2y' + 1} = f_x(x', y')$$

$$y = \frac{b_1x' + b_2y' + b_3}{c_1x' + c_2y' + 1} = f_y(x', y')$$

(12)

Equation (12) can be derived from co-linearity equations by setting  $Z=0$  and dividing the right side of co-linearity equations with  $(-r_{33}.c)$ , where  $c$  is principal distance and  $r_{33}$  is an element of rotation matrix. Thus with these constraints, equation (12) is obtained.

This method is typically used to rectify aerial photographs of flat terrain or images of facades of buildings (Novak, 1992).

Figure 7 shows a three dimensional test field with 60 control points. We measured three dimensional coordinates of the control points with geodetic techniques by using a theodolite.

At first, unknown transformation parameters must be determined for rectification of image. For this purpose, the bundle adjustment with self-calibration has been performed with Restore 1.0 software. At the end of the adjustment, unknown exterior and interior orientation parameters and additional parameters have been obtained. Then transformation parameters have been obtained. Rectified image in figure 8 has been obtained after transformation with these parameters.

The original image in figure 7 has been corrected in an adequate amount as seen in figure 8. But it has still some distortions, because of relief displacements. Digital differential rectification must be performed to correct these distortions.



Figure 7. Test field.



Figure 8. Rectified image.

### 3.3 Digital Differential Rectification

The term differential rectification has its origin in the approach of rectifying small parts as of a photograph at a time.

Conventional analog or analytical ortho-projectors do this by optical image transfer. For digital differential rectification, each pixel is separately transferred from the original image to the resulting image (Novak, 1992). Differential rectification is generally called as ortho-rectification in literature.

Elements of exterior and interior orientations and digital elevation model of the stereo model area are required to perform the transformation. Additional parameters which are modelled to correct errors of the sensors may be added to equation (13) to increase the precision and accuracy of the transformation.

$$x = x_0 - c \frac{r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} = f_x(x', y') \quad (13)$$

$$y = y_0 - c \frac{r_{21}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} = f_y(x', y')$$

Polynomials cannot correct relief displacements, because no information concerning the height of the ground control points are used (Rocchini, 2004). Digital differential rectification is the best rectification technique which corrects all distortions caused by sensors and others. The disadvantage of this technique is, it requires too many priory data for transformation.

#### 4. CONCLUSIONS

Polynomial transformations may be used to eliminate the geometrical distortions of images. They can be preferred for rectification of satellite images which have low geometric resolution. Projective transformations may be used for rectification of aerial photographs of approximately flat terrain or for rectification of close range photographs of building facades. Relief displacements must be corrected for more precise applications. For the gray level resampling which was performed after geometric transformations, we found that bi-cubic interpolation is the best method which gives the highest quality.

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