ORTHORECTIFICATION OF MONOSCOPIC BILSAT IMAGES BY A NEW DIFFERENTIAL IMAGE RECTIFICATION METHOD

Abstract

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Abstract — A new rectification method is implemented for the generation of orthoimages of the earth surface from monoscopic digital images. In the rectification procedure Bilsat images are used by taking into account the camera calibration parameters of Bilsat and atmospheric corrections. The new method maps every pixel vertically along the surface normal onto a curved surface of reference frame WGS84 directly under the condition that a precise enough surface elevation model is available. The ellipsoidal coordinates (latitude, longitude and height) of each pixel calculated are then transformed into isothermal coordinates i.e. the UTM projection coordinates. Resampling of the Bilsat images is accomplished on the basis of the transformation result between ellipsoidal geodetic coordinates and isothermal coordinates.

1. Introduction

Global Positioning System (GPS) and star tracker on board Bilsat are used to find the position and attitude (orientation) of the CCD images to be rectified. Orthorectification procedures are usually accomplished by projecting the image to the flat earth surface, where the earth curvature can be corrected explicitly [2]. However, the new method projects the images directly on to the ellipsoid and corrects the relief displacements from height information extracted from a Digital Elevation Model (DEM) taking into account atmospheric refraction as well[7].

2. Application of the Method to BILSAT Images

Required parameters for the orthorectification method i.e. (position, attitude) are obtained from the Bilsat telemetry file of the corresponding epoch while atmospheric parameters are obtained from the meteorological stations of the region. Additionally SRTM DEM [1] is used in 3 arc second intervals for relief displacement corrections.

Differential image rectification methods rectify the image pixel by pixel. For this reason rectification of the 2048 x 2048 pixels Bilsat images are computationally very demanding. Resection algorithm can be illustrated by a flow chart step by step as in Figure 1.

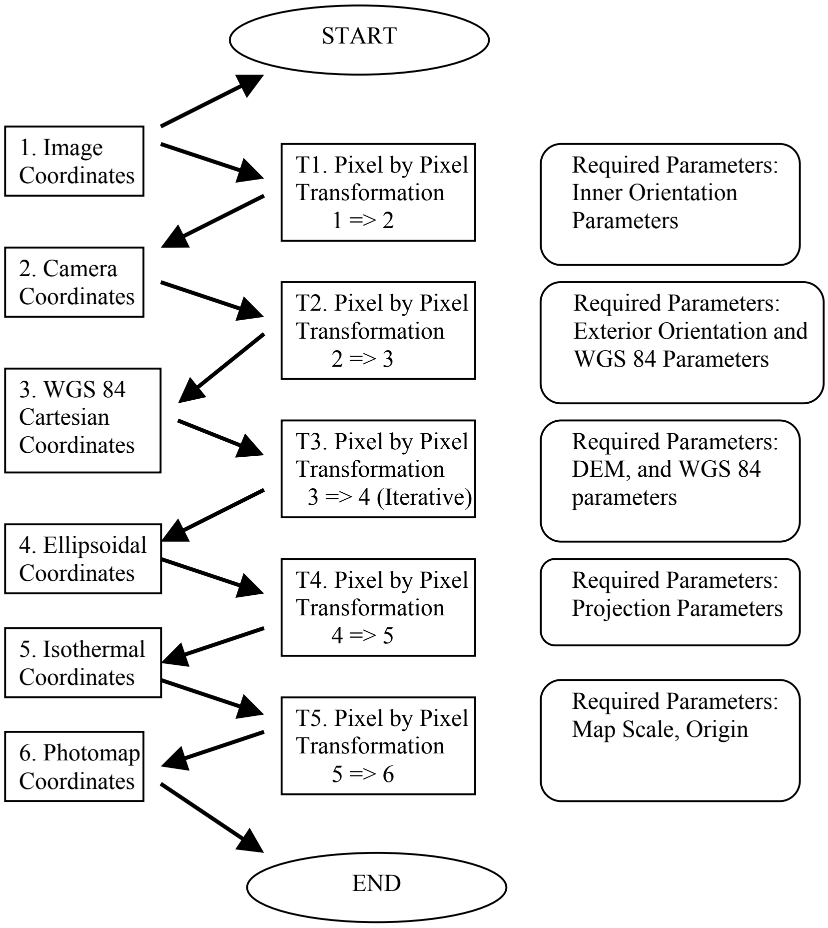

Figure 1. Flowchart for image rectification and mapping with transformations T1–T5.

The collinearity equation between the camera center, CCD array and the corresponding ground point can be written as;

$$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} = \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} + s \begin{bmatrix} \mathbf{r}_\mathbf{x} \\ \mathbf{r}_\mathbf{y} \\ \mathbf{r}_\mathbf{z} \end{bmatrix} \quad (1)$$

In this equation X_0, Y_0 and Z_0 are the coordinates of the corresponding point on the earth surface. X_c, Y_c and Z_c are the coordinates of the camera. s is the distance between the ground point and the camera. **r** is the direction vector between camera center, corresponding sensor and the ground point. Both the position and the direction vectors are measured in earth fixed reference frame. To represent the direction vector in earth fixed reference frame consecutive rotations are needed.

First step is to transform the each pixel from image coordinates to camera coordinates. The unit of the pixels is converted from pixel value to mm by using the size of the one sensor in the CCD array and the coordinates of the principal point of the CCD. The next step is the application of lens distortion corrections to pixel positions by using the lens distortion parameters of the on board camera of Bilsat. Lens distortion effect is modeled by 4 parameters, 2 for the radial lens distortion and 2 for the tangential asymmetric lens distortion.

By using the corrected pixel coordinates the direction vector (unit vector) ${}^{C}\mathbf{r}$, of each pixel is computed with respect to camera coordinate system, S_C.

$$
{}^{C}\mathbf{r} = [x, y, z]' / \sqrt{x^2 + y^2 + z^2} \tag{2}
$$

where x, y and z are the corrected pixel coordinates in photo coordinate system in mm.

The next step is to transform the direction vector ${}^{C}\mathbf{r}$, from camera coordinate system to the Earth Centered Earth Fixed reference frame, S_E:

$$
{}^{E}\mathbf{r} = {}^{E}\mathbf{R}_C \, {}^{C}\mathbf{r} \tag{3}
$$

where ${}^{E}\mathbf{R}_C$ consists of following consecutive rotation matrixes [3]

$$
{}^{E}\mathbf{R}_C = {}^{E}\mathbf{R}_I \, {}^{I}\mathbf{R}_O \, {}^{O}\mathbf{R}_B \, {}^{B}\mathbf{R}_C \; . \tag{4}
$$

In Eq. (4) ${}^{B}\mathbf{R}_C$ is the fixed rotation matrix from camera coordinate system to body fixed reference system. ${}^{O}\mathbf{R}_B$ is the rotation matrix from body fixed reference frame to orbital reference frame is calculated in terms of quaternions on the basis of the observed star coordinates delivered by the high precision star tracker onboard the satellite (Strikwerda and Junkins [4]). ${}^{I}\mathbf{R}_O$ is the rotation matrix from orbital coordinate system to inertial reference system formed by using the position and velocity vector of the satellite while ${}^{E}\mathbf{R}_I$ gives the rotation matrix from inertial reference system to earth fixed reference system. During these two rotations precession, nutation and polar motion are taken into account.

The next step is to compute the coordinates of the intersection points of the direction vectors with the earth surface. To achieve this, colinearity equation and the equation of a point on the ellipsoidal surface are used so that the direct projection of the image coordinates onto the surface of the ellipsoid can be accomplished. Equation of an ellipsoid of revolution is:

$$
\frac{X_0^2 + Y_0^2}{a^2} + \frac{Z_0^2}{b^2} = 1 \tag{5}
$$

where a and b are the semimajor and semiminor axes and X_o, Y_o and Z_o are the Cartesian coordinates of the point on the ellipsoidal surface. WGS 84 reference ellipsoid is used as Earth model. After substitution of Eq. (5) into Eq. (1), the following colinearity equation is obtained:

$$
\left[\frac{S_{Ex}^{\;2} + S_{Ey}^{\;2}}{a^2} + \frac{S_{Ez}^{\;2}}{b^2} \right] * s^2 + 2 * \left[\frac{S_{Ex} * X_{cam} + S_{Ey} * Y_{cam}}{a^2} + \frac{S_{Ez} * Z_{cam}}{b^2} \right] * s + \frac{X_{cam}^{\;2} + Y_{cam}^{\;2}}{a^2} + \frac{Z_{cam}^{\;2}}{b^2} - 1 = 0 \tag{6}
$$

Eq (6) is a quadratic equation, for this reason two solutions for s are available. The smaller root is the correct solution because the larger s will give the distance between the camera and the other side of the ellipsoid. Substituting smaller s in Eq (1) gives the Cartesian coordinates of the intersection point. After computing the intersection point, atmospheric refraction correction is applied by computing the zenith angle and its correction with atmospheric parameters.

Cartesian coordinates of the intersection point on the reference ellipsoid are converted to geodetic coordinates. The transformation to compute the ellipsoidal longitude and latitude (iterative) of is given by [5, p. 199]. But the geodetic coordinates are not the exact coordinates because the ellipsoidal height of a point is a very rare case to be exactly zero. For this reason ellipsoidal height of that point is extracted from DEM and an iterative procedure starts which corrects the geodetic coordinates of the point by using the elevation differences of the elevations. The elevations are obtained from DEM both for the previous and the current iteration steps. The iteration steps can be explained as:

First, direction vector measured in earth fixed coordinates should be converted into local ellipsoidal coordinates by the rotation matrix

$$R = \boldsymbol{Q}_1 \boldsymbol{R}_2(90 - \varphi)\boldsymbol{R}_3(\lambda) \tag{7}$$

where $\boldsymbol{Q}_1$ is a reflection matrix, ϕ and λ are the geodetic or ellipsoidal coordinates in terms of latitude and longitude.

And then, initial height of the intersection point, $h_0(\lambda_0, \phi_0)$ is computed as zero. The corresponding ellipsoidal height of that point is obtained from DEM and by using the zenith angle, z the absolute value of the relief displacement, d_n is computed. By using the ellipsoidal parameters V, c and the azimuth angle, α changes in the geodetic coordinates are computed and the geodetic coordinates are corrected. The new ellipsoidal height of the corrected coordinates is obtained from the DEM and the difference between the two heights, Δh_n is compared with the threshold value and the iteration continues until the required accuracy is reached. This procedure is explained in Eq (8) and Fig. 2.

$$\Delta h_n = h_n(\lambda_{n-1}, \phi_{n-1}) - h_{n-1}(\lambda_{n-1}, \phi_{n-1}) \tag{8a}$$

$$d_n = \Delta h_n \tan(z) \tag{8b}$$

$$\lambda_n = \lambda_{n-1} + d_n \sin(\alpha) * \left(\frac{V}{c}\right)_{n-1} \left(\frac{1}{\cos(\phi_{n-1})}\right) \tag{8c}$$

$$\phi_n = \phi_{n-1} + d_n \cos(\alpha_{n-1}) * \left(\frac{V^3}{c}\right)_{n-1} \quad \text{Where;} \tag{8d}$$

$$c = \frac{a^2}{b}, \qquad V_n = \sqrt{1 - \frac{a^2 - b^2}{b^2} \cos^2(\phi_0)_n} \tag{8e}$$

[4, p. 105]

The threshold value to be satisfied is $|\Delta h_n| < \varepsilon$, finally

$\lambda_a = \lambda_n, \quad \phi_a = \phi_n, \quad h_a = h_n$.

After n iterations final position of the point becomes λ_n, ϕ_n and h_n

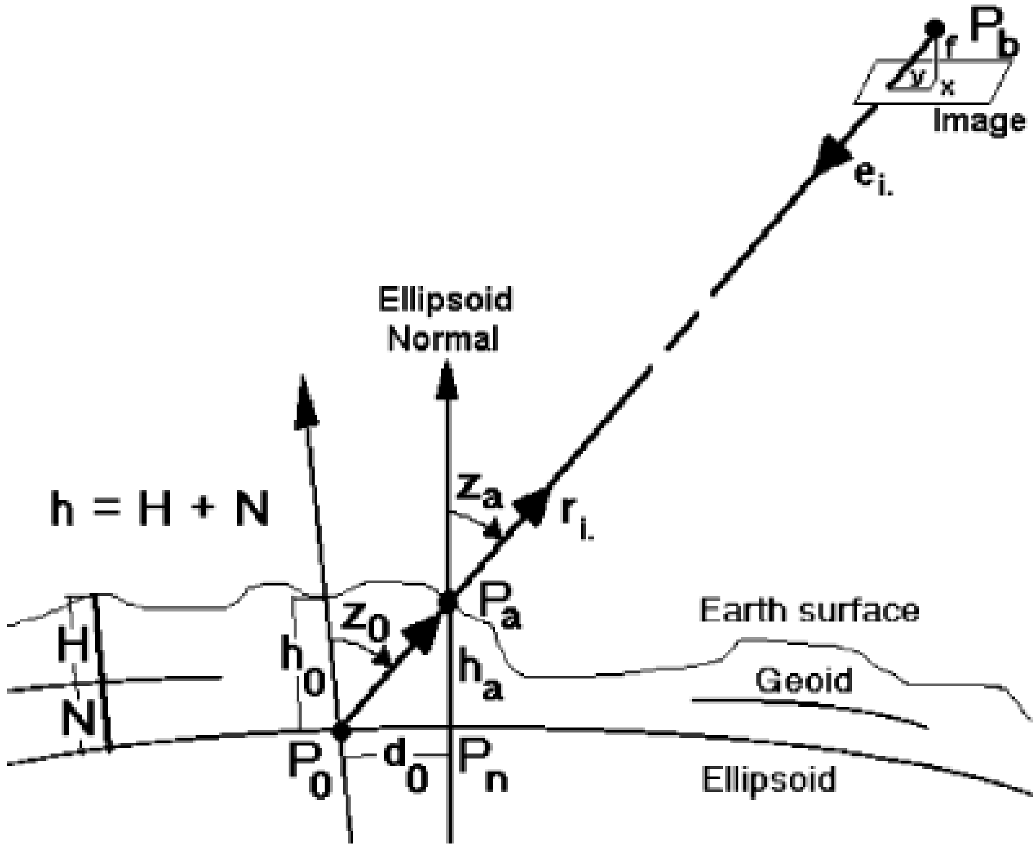

Figure 2. Illustration of the colinearity equation and the iterative solution for the relief displacement correction.

The geodetic coordinates are converted to isothermal coordinates in terms of UTM coordinates [5].

At final stage, after computing the map coordinates of each pixel the image is resampled in order to compute the brightness values of map coordinate grids. Among the resampling algorithms, nearest neighborhood method is used in order to conserve the original brightness values of the pixels[6].

3. Implementation Of the Method

The new differential image rectification method is implemented on Matlab software. The software reads the attitude and position data at the time of exposure of the image from a file and computes the velocity of the satellite. Furthermore the software requires the camera's inner and outer orientation parameters and atmosphere parameters from the user. The software eliminates the relief displacements by corresponding DEM and converts the ellipsoidal coordinates to UTM map coordinates. The algorithm is implemented by the images supplemented by Bilten. The raw and rectified images of Ankara are shown in Fig.3-4.

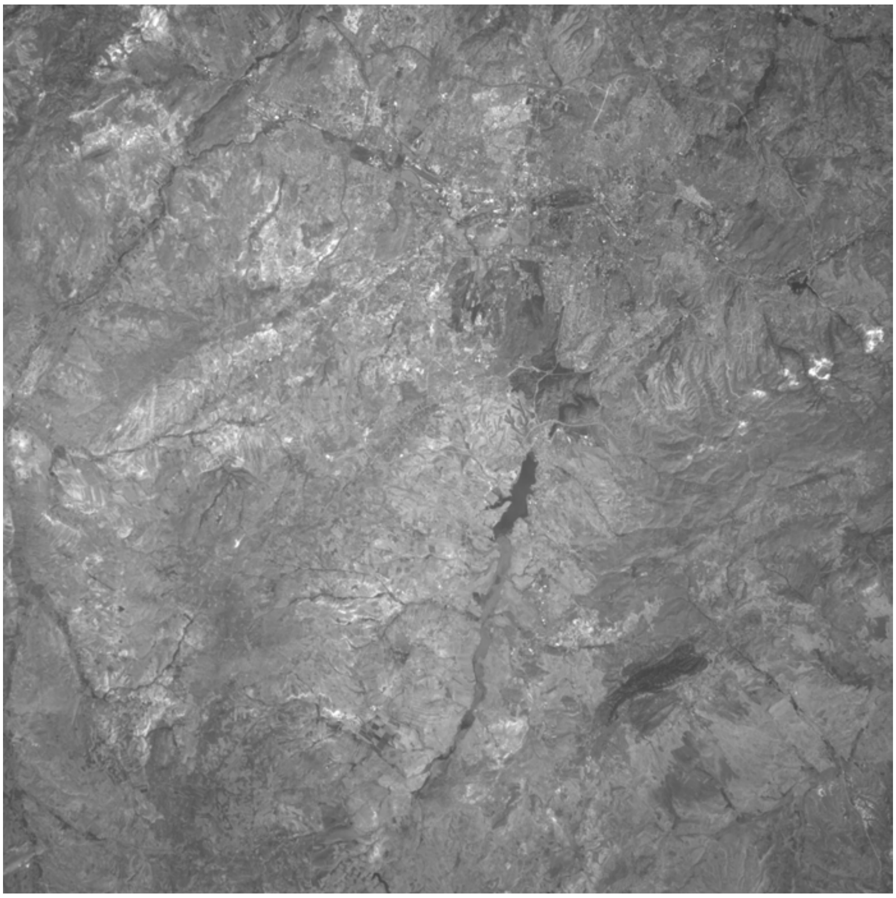

Fig. 3 Raw image of Ankara.

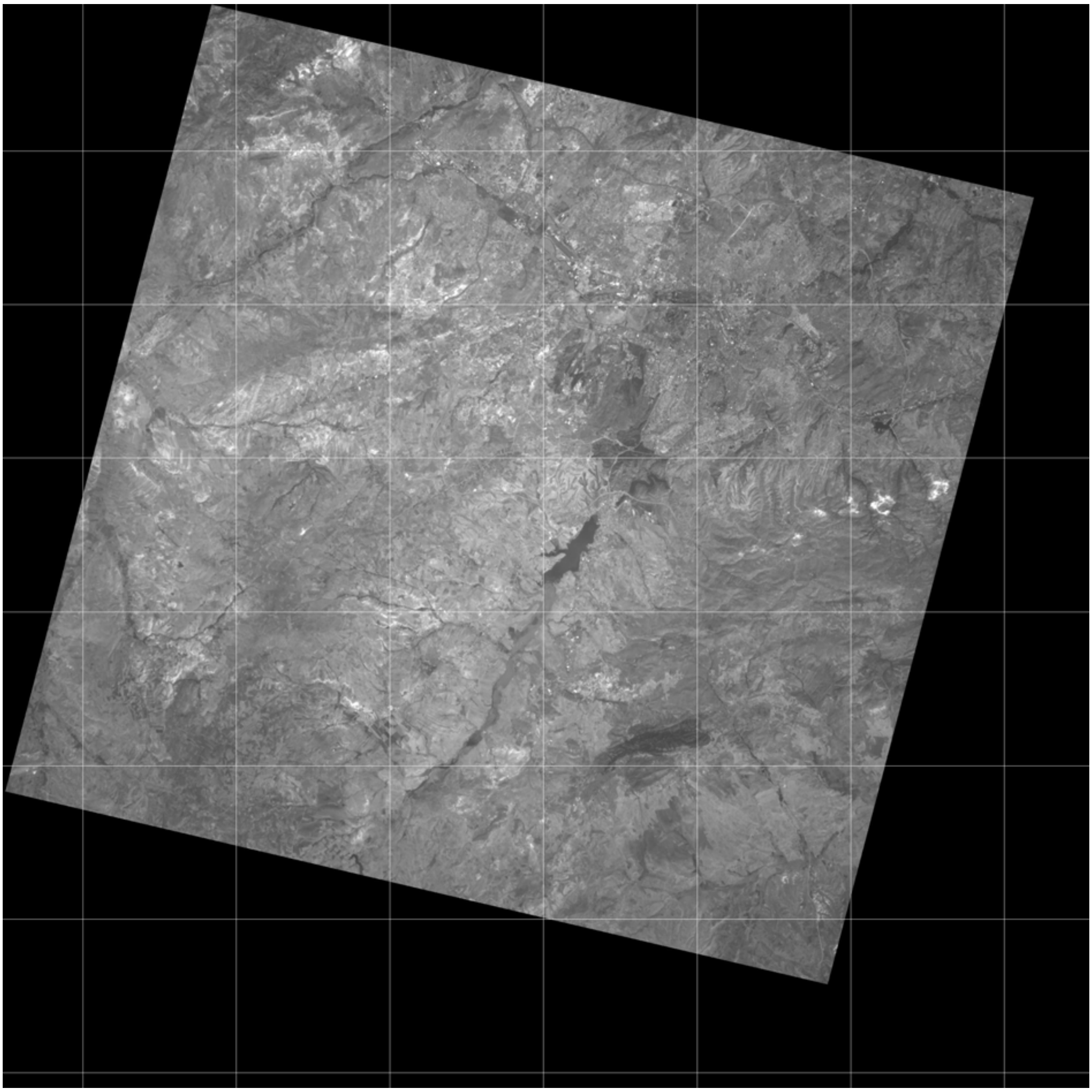

Fig. 4 Orthorectified image of Ankara.

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