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MATHEMATICAL MODEL FOR COORDINATE ATTACHMENT AND RECTIFICATION OF SPACE IMAGES WITH HIGH RESOLUTION

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Abstract

In the paper, a strict method for georeference of high-resolution (1 - 3 m) space images is suggested, through determination of the coordinates of GCPs of the earth cover using GPS measurements. As a projection plane a reference (earth) ellipsoid is assumed and the ellipsoid heights of the identifies GCPs of the cover are accounted for. Determining the scale between the identified points provides for precise rectification of the space images.

1. Introduction

In the last decade, high-resolution space images became quite topical in the communities dealing with large scale mapping and remote sensing of the Earth. Research in this specific area gained a tremendous impetus after the first satellite images of the Earth with resolution from 1.0 to 3.0 m were received. The process of rapid improvement of space cameras and scanner systems [1,5], as well as of their carriers - Space Flying Apparata (SFA) was triggered. Nowadays, cameras of the type *KVR-1000* with focal distance $f = 10\ m$, flying at height $h = 220\ km$ (Fig.1) are used. They provide resolution of 2.0 *m*. Camera *KFA-3000* (f = 3.0 m; H = 270 km) provides resolution of $2-3\ m$. The results provided by the scanner systems *QuickBird, EROS-B, IKONOS1*, orbiting at heights of 600 *km* to 680 *km* and featuring an image resolution of 1 m. are similar. When the scanner systems are launched to higher orbits, lenses are used to insure long focal distances f = 10 m as is the case with *IKONOS*.

The current state-of-the-art with satellite images provides real opportunities for large scale mapping, upgrading of available maps, monitoring of the Earth scene and other practical and research tasks necessitating great precision in determining the mutual position of individual discrete points or contours in some particular region.

To accomplish these tasks it is necessary to refer the image coordinates to some identified ground control points (GCP) of the scene [2,3,4,5].

The various companies and corporations make efforts to supply the users with adequate software to solve this problem. It is of great importance to know the geometrical characteristics of the various types of satellite images (scenes). Users have to take them into consideration when choosing the program packages for processing of these images.

Prof. Gordon Petrie from the Glasgow University pays special attention to this problem [1]. He makes the conclusion that most of the users are aware that the greater part of the program packages for satellite image processing are unable to handle geometrical configurations.

This was confirmed by the distributor of the American-Israeli group IAI/Core of the *EROS* satellite on a conference organized by the Ministry of Defence of the Republic of Bulgaria in October, 2001. He stated that, with immediate determining of the GCP coordinates of the scene by GPS measurements, precision increases 3 to 4 times. Actually, this corresponds to the resolution of the satellite image.

As for remote sensing software, a lot of packages can only provide a very simple geometrical model of the images. Often, satellite images are treated in a 2D-coordinate system (the case with aerial photography), making no lieu with their real geometry, possible relief shift or image slope. In the last case, rectification is made using the method of the "rubber sheet". It is based on calculation of polynomials, aiming to make the image generally coincide with the referent coordinate system of the map, not removing the scene's geometrical deformations.

To fulfill its modern functions: small scale topographic mapping, revision of maps, monitoring of the environment, keeping a precise track of land scene changes etc., satellite images with high resolution have to undergo some preliminary processing [2,3,5,6]:

- high-precision coordinate reference of GCPs by GPS measurements;
- image rectification, accounting for changes in scale coefficients and relief pattern;
- using the Earth (referent) ellipsoid as a projection plane;
- taking into consideration ellipsoid heights;

- using strict methods for processing and evaluation of the results.

Under these condition we will have results precise enough to correspond to the aims of objectives of these modern satellite images.

2. New mathematical model for coordinate connection of the ground control points from the satellite image

The information which is received and used at satellite images is versatile with respect to both the determined elements and their location in time and space. For this reason, the coordinates of the determined values refer to different orthogonal coordinate systems, as follows:

- The coordinates of GCP X_j, Y_j, Z_j, $(j = 1,2,...,n)$ from the real earth scene refer to the **Greenwich equatorial geocentric coordinate system** X, Y, Z, having its origin O in the Earth's mass center, axis Z pointing to the central pole, and axis X pointing to the cross point of the Equator and the Greenwich meridian (Fig. 1).

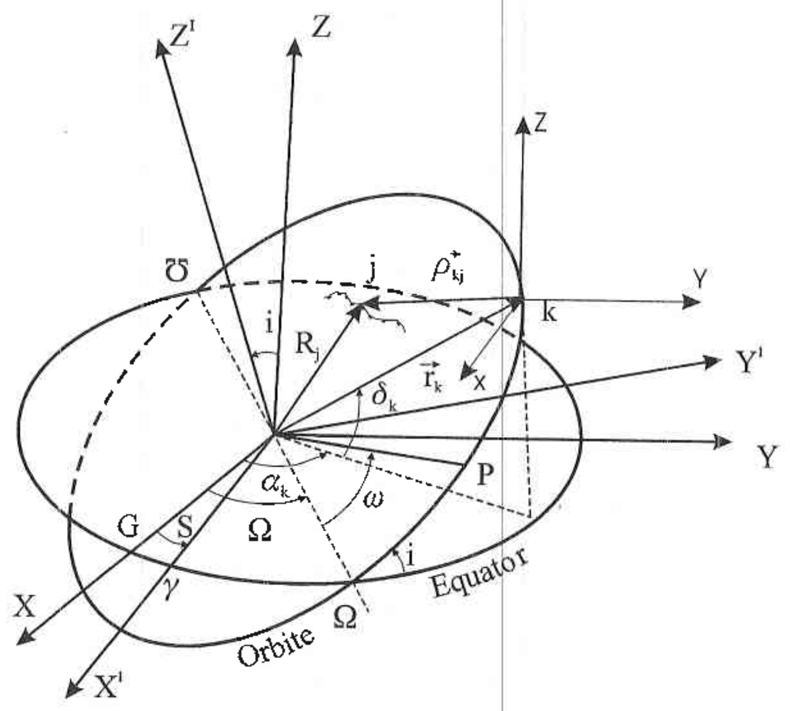

Fig. 1

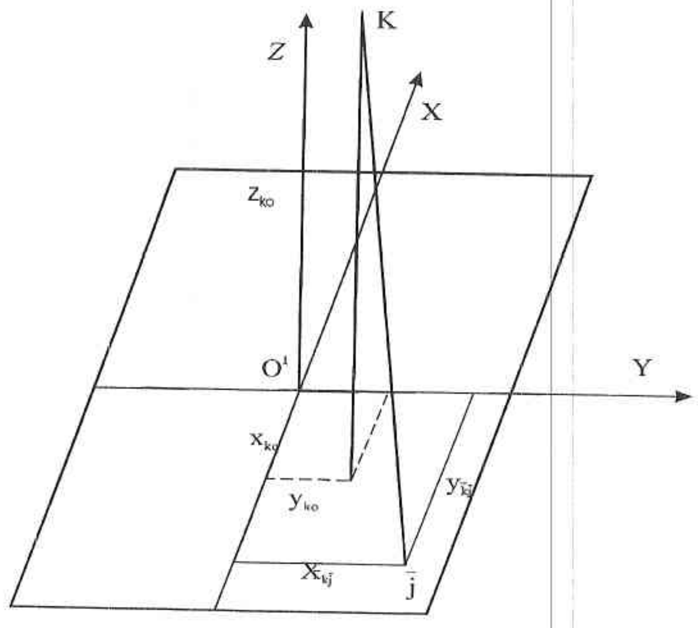

Fig. 2

- The coordinates of the satellite - X_k', Y_k', Z_k', *(k*=1, 2,..., *m)* are determined in the ***inertial equatorial geocentric coordinate system*** X', Y', Z' (Fig. 1).

- The coordinates of the images $\bar{j}$ $(x, y, z)_{k\bar{j}}$ of the GCPs are in the ***centric- satellite inertial coordinate system*** x, y, z (Fig. 2).

Quite often, in mathematical processing and evaluation of the precision of coordinate reference and rectification of the scenes, formulae are used where only the x_j and y_j coordinates of the GCPs images are determined, thereby actually handling the image in a 2D coordinate system. As stated and substantiated above, these equations, deprived of scale coefficients, do not provide a clear and accurate idea of the geometrical configuration of the image.

According to Fig. 1, we can draw the following coordinate relation between the centric-satellite vector-radius $\vec{\rho}_{kj}$, geocentric vector-radius $\vec{r}_k$ and topocentric vector-radius $\vec{R}_{kj}$, referred to the inertial geocentric systems, namely:

(1) $$\vec{\rho}_{kj} = (\vec{R}_j - \vec{r}_k) = \begin{vmatrix} X'_j - X'_k \\ Y'_j - Y'_k \\ Z'_j - Z'_k \end{vmatrix} = \rho_{kj} \begin{vmatrix} \cos\alpha_k \cos\delta_k \\ \sin\alpha_k \cos\delta_k \\ \sin\delta_k \end{vmatrix} = \rho_{kj} \begin{vmatrix} \xi_{kj} \\ \eta_{kj} \\ \zeta_{kj} \end{vmatrix},$$

where:

$\xi_{kj}{}^2 + \eta^2{}_{kj} + \zeta^2{}_{kj} = 1$

α_{kj} and δ_{kj} are the satellite's rectascensia and declination, accordingly.

$\vec{R}_j = (X', Y', Z')_j^T$ - coordinates of GCP - j in inertial coordinate system

$\vec{r}_k = (X', Y', Z')_k^T$ - coordinates of satellite in inertial coordinate system

Let us assume that vector $\vec{D}_{k\bar{j}}$ of the image $\bar{j}$ on the space image (Fig.2) of ground point j in a *centric-satellite inertial coordinate system* is as follows:

(2) $$\vec{D}_{kj} = \begin{vmatrix} x_{k\bar{j}} - x_{ko} \\ y_{k\bar{j}} - y_{ko} \\ z_{k\bar{j}} - z_{kj} \end{vmatrix} = D_{k\bar{j}} \begin{vmatrix} \xi_{kj} \\ \eta_{kj} \\ \zeta_{kj} \end{vmatrix},$$

where:

(3) $$D_{k\bar{j}} = \sqrt{(x_{k\bar{j}} - x_{ko})^2 + (y_{k\bar{j}} - y_{ko})^2 + (z_{k\bar{j}} - z_{ko})^2}$$

$(x, y, z)_{kj}$ - coordinates of the image of GCP - j on the satellite image;

$(x, y, z)_{ko}$ - coordinates of the main point of the scene O, obtained from the perpendicular drawn from the hind point of the lens's focal plane.

In reality, the main point does not coincide with the origin of the coordinate system O on the satellite image (Fig. 2). From (2), we receive the unit vector $\vec{D}^o{}_{k\bar{j}}$, whereas equation (3) will be uses as a norm factor:

(4) $$\vec{D}^{o}_{k\bar{j}} = \frac{1}{D_{kj}} \begin{vmatrix} x_{k\bar{j}} - x_{ko} \\ y_{k\bar{j}} - y_{ko} \\ z_{k\bar{j}} - z_{ko} \end{vmatrix} = \begin{vmatrix} \xi_{kj} \\ \eta_{kj} \\ \zeta_{kj} \end{vmatrix}$$

Formulae (1)-(4) provide the opportunity to define the point from the satellite image in a *centric-satellite inertial coordinate system.* But the coordinate reference of the images suggests that this be done in the *Greenwich system* defined above, in which the centric-satellite vector-radius is as follows:

(5) $$\vec{\rho}_{kj} = \rho_{kj} \begin{vmatrix} \cos(\alpha_{kj} - S_k)\cos\delta_{kj} \\ \sin(\alpha_{kj} - S_k)\cos\delta_{kj} \\ \sin\delta_{kj} \end{vmatrix} = \rho_{kj} \begin{vmatrix} \xi_{kj} \\ \eta_{kj} \\ \zeta_{kj} \end{vmatrix} = - \begin{vmatrix} X_k - X_j \\ Y_k - Y_j \\ Z_k - Z_j \end{vmatrix},$$

where:

(6) $$\rho_{kj} = \sqrt{(X_j - X_k)^2 + (Y_j - Y_k)^2 + (Z_j - Z_k)^2},$$

- S_k is the star time at Greenwich, corresponding to the moment t_k of receiving of the satellite image. The coordinates of *KJIA*- $(X,Y,Z)_k$ and of the GCP - $(X,Y,Z)_j$ are in *the Greenwich coordinate system.*

Using the operator $\vec{P}_o$, we can obtain the unit vector $\vec{D}_{kj}{}^{o}$, which points to *GCP- j from the scene* in the *Greenwich geocentric system,* namely:

(7) $$\vec{D}_{kj}{}^{o} = \vec{P}_o \begin{bmatrix} \xi_{kj} \\ \eta_{kj} \\ \zeta_{kj} \end{bmatrix} = \frac{1}{D_{kj}} \vec{P}_o \begin{bmatrix} x_{k\bar{j}} - x_{ko} \\ y_{k\bar{j}} - y_{ko} \\ z_{k\bar{j}} - z_{ko} \end{bmatrix}$$

From formulate (5) and (7) we obtain the following equation:

(8) $$\vec{\rho}_{kj} = \rho_{kj} \begin{bmatrix} \xi_{kj} \\ \eta_{kj} \\ \zeta_{kj} \end{bmatrix} = \frac{1}{D_{kj}} \rho_{kj} \vec{P}_o \begin{bmatrix} x_{k\bar{j}} - x_{ko} \\ y_{k\bar{j}} - y_{ko} \\ z_{k\bar{j}} - z_{ko} \end{bmatrix} = \begin{bmatrix} X_j - X_k \\ Y_j - Y_k \\ Z_j - Z_k \end{bmatrix}$$

or we can draw the following relation:

$$(9)\qquad \begin{bmatrix} x_{kj} - x_{ko} \\ y_{kj} - y_{ko} \\ z_{kj} - z_{ko} \end{bmatrix} = \frac{D_{kj}}{\rho_{kj}} \vec{P}_o^T \begin{bmatrix} X_j - X_k \\ Y_j - Y_k \\ Z_j - Z_k \end{bmatrix} = m\vec{P}_k \begin{bmatrix} X_j - X_k \\ Y_j - Y_k \\ Z_j - Z_k \end{bmatrix},$$

where:

$$(10)\qquad m_{kj} = \frac{D_{kj}}{\rho_{kj}}$$ - scale coefficient

$$(11)\qquad \vec{P}_k = \vec{P}_o^T = \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix}$$

The operator $\vec{P}_k = \vec{P}_o^T$ is an orthogonal matrix accomplishing the transition from *the Greenwich coordinate system* to the *satellite-centric coordinate system.*

a_i, b_i and c_i, $i = 1,2,3$ are elements of the matrix $\vec{P}_k$, which are function of the Euler angles (Fig.1): Ω - length of the ascending knot; w - argument of the pericenter; i - orbit slope have the following form:

$$(12)\begin{cases} a_1 = \cos w \cos\Omega - \sin w \sin\Omega \cos i, & b_1 = -\sin w \cos\Omega - \cos w \sin\Omega \cos i, \\ a_2 = \cos w \sin\Omega + \sin w \cos\Omega \cos i, & b_2 = \sin w \sin\Omega + \cos w \cos\Omega \cos i, \\ a_3 = \sin w \sin i, & b_3 = \cos w \sin i, \\ c_1 = \sin\Omega \sin i, \quad c_2 = \cos\Omega \sin i, & c_3 = \cos i \end{cases}$$

From formulae (9), substituting (10) and (11), we can obtain:

$$(13)\qquad \begin{bmatrix} x_{kj} - x_{ko} \\ y_{kj} - y_{ko} \\ z_{kj} - z_{ko} \end{bmatrix} = m_{kj} \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} \begin{bmatrix} X_j - X_k \\ Y_j - Y_k \\ Z_j - Z_k \end{bmatrix}$$

From equations (13) we obtain a system of linear equations to determine the coordinates of the GCPs of the image.

From equation (13) we obtain the linear equations:

$$(14) \qquad \begin{cases} x_{k\bar{j}} - x_{ko} = m_{kj}[a_1(X_j - X_k) + a_2(Y_j - Y_k) + a_3(Z_j - Z_k)] \\ y_{k\bar{j}} - y_{ko} = m_{kj}[b_1(X_j - X_k) + b_2(Y_j - Y_k) + b_3(Z_j - Z_k)] \\ z_{k\bar{j}} - z_{ko} = m_{kj}[c_1(X_j - X_k) + c_2(Y_j - Y_k) + c_3(Z_j - Z_k)] \end{cases}$$

Equation (14) can be also presented in the form:

$$(15) \qquad \begin{cases} x_{k\bar{j}} = m_{kj}[a_1\Delta X_{kj} + a_2\Delta Y_{kj} + a_3\Delta Z_{kj}] + x_{ko} = m_{kj}\overline{N}_{kj} + x_{ko} \\ y_{k\bar{j}} = m_{kj}[b_1\Delta X_{kj} + b_2\Delta Y_{kj} + b_3\Delta Z_{kj}] + y_{ko} = m_{kj}\overline{P}_{kj} + y_{ko} \\ z_{k\bar{j}} = m_{kj}[c_1\Delta X_{kj} + c_2\Delta Y_{kj} + c_3\Delta Z_{kj}] + z_{ko} = m_{kj}\overline{Q}_{kj} + z_{ko} \end{cases},$$

where, according to (14), we have:

$$(16) \qquad \Delta X_{kj} = X_j - X_k, \quad \Delta Y_{kj} = Y_j - Y_k \quad и \quad \Delta Z_{kj} = Z_j - Z_k$$

x_{kj}, y_{kj}, z_{kj} - the definable coordinates of the images of the GCPs on the satellite image;

x_{ko}, y_{ko}, z_{ko} - the coordinates of the main point of the satellite image;

X_j, Y_j, Z_j - geocentric Greenwich coordinates of a GCP from the earth cover;

X_k, Y_k, Z_k - geocentric Greenwich coordinates of the "hind" lens point;

a_i, b_i, c_i, $i = 1,2,3$ - elements of the orthogonal matrix

$\vec{P}_k$ - function of the Euler angles Ω, w, i.

3. Determination of the correction equations

For every point $\bar{j}$ from the satellite image, which turns to be image of GCP-j from the earth scene, we have twelve unknown quantities according to equations (14), accordingly (15).

$$(17) \qquad X_j,\ Y_j,\ Z_j,\ X_k,\ Y_k,\ Z_k,\ \Omega_k,\ w_k,\ i_k,\ x_{ko},\ y_{ko},\ z_{ko}$$

whereas their approximately values will be denoted by:

(18) $$X_j^{\circ}, Y_j^{\circ}, Z_j^{\circ}, X_k^{\circ}, Y_k^{\circ}, Z_k^{\circ}, \Omega_k^{\circ}, w_k^{\circ}, i_k^{\circ}, x_{ko}^{\circ}, y_{ko}^{\circ}, z_{ko}^{\circ}$$

Linearizing equations (14), accordingly (15), for each support point j from the scene of the space image with coordinates $\bar{j} = (x \quad y \quad z)^T_{kj}$,yields correction equation:

(19) $$\vec{V}_{U_{kj}} = \begin{pmatrix} \vec{A}_k & \vec{B}_k & \vec{C}_j & \vec{D}_{ko} \end{pmatrix} \begin{pmatrix} d_k \vec{S}_k \\ d\vec{r}_k \\ d\vec{R}_j \\ d\vec{n}_{ko} \end{pmatrix} + \vec{L}_{kj} ; \qquad P_{kj}$$

P_{kj} - weight coefficient

The values $\vec{A}_k, \vec{B}_k, \vec{C}_j, \vec{D}_{ko}$ in correction equation (19) should be considered as partial derivatives of the coordinates x_{kj}, y_{kj}, z_{kj} , namely

(20) $$\vec{A}_k = \frac{\partial(x, y, z)_{kj}}{\partial(\Omega, w, i)_{kj}}$$

(21) $$\vec{B}_k = \frac{\partial(x, y, z)_{kj}}{\partial(X, Y, Z)_{k(j)}} ,$$

whereas $\vec{B}_k = -\vec{C}_j$, the index "k" is differentiation along the coordinates of satellite, and the index "j" - differentiation along the coordinates of the GCPs of the scene.

(22) $$\vec{D}_{ko} = \frac{\partial(x, y, z)_{kj}}{\partial(x, y, z)_{ko}}$$

The correction vectors $d\vec{S}_k, d\vec{r}_k, d\vec{R}_j, d\vec{n}_{ko}$ of the unknown values (17) for the approximate values of (18) have the form:

(23)
$$\begin{cases} \vec{V}_{U_{kj}} = \begin{pmatrix} v_x & v_y & v_z \end{pmatrix}_{kj}^T \\ d\vec{S}_k = \begin{pmatrix} d\Omega & dw & di \end{pmatrix}_k^T \\ d\vec{r}_j = \begin{pmatrix} dX & dY & dZ \end{pmatrix}_k^T \\ d\vec{R}_j = \begin{pmatrix} dX & dY & dZ \end{pmatrix}_j^T \\ d\vec{n}_{ko} = \begin{pmatrix} dx & dy & dz \end{pmatrix}_{ko}^T \end{cases}$$

For the vector of the free term $\vec{L}_{kj}$ we have:

(24)
$$\vec{L}_{kj} = \vec{U}_{kj} - \vec{U}'_{kj} = \begin{vmatrix} x_{kj} - x'_{kj} \\ y_{kj} - y'_{kj} \\ z_{kj} - z'_{kj} \end{vmatrix},$$

where:

$\vec{U}_{kj} = \begin{pmatrix} x & y & z \end{pmatrix}_{kj}^T$ - the defined values of the coordinates x_{kj}, y_{kj}, z_{kj} along (14), accordingly (15);

$\vec{U}'_{kj} = \begin{pmatrix} x' & y' & z' \end{pmatrix}_{kj}^T$ - the measured coordinates of the space image

4. Obtaining equations to determine the values $\vec{A}_k, \vec{B}_k, \vec{C}_j$

To obtain the partial derivatives, constituting elements of the matrix (20), (21) and (22), it is necessary to successively differentiate the coordinates x_{kj}, y_{kj}, z_{kj} in relation to the Euler angles (Ω, w, i), the space coordinates of the ground points GCP - j $\begin{pmatrix} X & Y & Z \end{pmatrix}_j$, the Greenwich coordinates of *КЛА*-$\begin{pmatrix} X & Y & Z \end{pmatrix}_k$ and to coordinates $\begin{pmatrix} x & y & z \end{pmatrix}_{ko}$.

4.1. Partial derivatives of the value $\vec{A}_k$

According to equation (22), it is necessary to differentiate the image coordinates from (14), accordingly (12), in relation to (Ω, w, i). But since only values $a_i, b_i, c_i, (i = 1,2,3)$ are function of the Euler angles, it is necessary to differentiate $\overline{N}_{kj}$, $\overline{P}_{kj}$, $\overline{Q}_{kj}$, according to the equations:

$$
(26)\quad \begin{cases}
\dfrac{\partial x_{kj}}{\partial(\Omega,w,i)_k} = \dfrac{\partial(m_{kj}\overline{N}_{kj})}{\partial(\Omega,w,i)_k} = m_{kj}\dfrac{\partial(\overline{N}_{kj})}{\partial(\Omega,w,i)_k} \\
\dfrac{\partial y_{kj}}{\partial(\Omega,w,i)_k} = \dfrac{\partial(m_{kj}\overline{P}_{kj})}{\partial(\Omega,w,i)_k} = m_{kj}\dfrac{\partial(\overline{P}_{kj})}{\partial(\Omega,w,i)_k} \\
\dfrac{\partial z_{kj}}{\partial(\Omega,w,i)_k} = \dfrac{\partial(m_{kj}\overline{Q}_{kj})}{\partial(\Omega,w,i)_k} = m_{kj}\dfrac{\partial(\overline{Q}_{kj})}{\partial(\Omega,w,i)_k}
\end{cases}
$$

4.2. Partial derivatives of the values $\vec{B}_k = -\vec{C}_j$

As stated above, to obtain the derivatives of the reflectance coordinates from $(x,y,z)_{kj}$ in relation to $(X \quad Y \quad Z)_k^T$ and $(X \quad Y \quad Z)_j^T$, equations (14), accordingly (15), should be used, which means both the scale $m_{kj} = \dfrac{D_{kj}}{\rho_{kj}}$, following formula (10), and $\overline{N}_{kj}, \overline{P}_{kj}, \overline{Q}_{kj}$ are function of the Greenwich coordinates. Having in mind this fact, we will differentiate, using equations:

$$
(27)\begin{cases}
\dfrac{\partial x_{kj}}{\partial(X,Y,Z)_{k(j)}} = \dfrac{\partial(m_{kj}\overline{N}_{kj})}{\partial(X,Y,Z)_{k(j)}} = \dfrac{\partial(m_{kj})}{\partial(X,Y,Z)_{k(j)}}\overline{N}_{kj} + m_{kj}\dfrac{\partial(\overline{N}_{kj})}{\partial(X,Y,Z)_{k(j)}} \\
\dfrac{\partial y_{kj}}{\partial(X,Y,Z)_{k(j)}} = \dfrac{\partial(m_{kj}\overline{P}_{kj})}{\partial(X,Y,Z)_{k(j)}} = \dfrac{\partial(m_{kj})}{\partial(X,Y,Z)_{k(j)}}\overline{P}_{kj} + m_{kj}\dfrac{\partial(\overline{P}_{kj})}{\partial(X,Y,Z)_{k(j)}} \\
\dfrac{\partial z_{kj}}{\partial(X,Y,Z)_{k(j)}} = \dfrac{\partial(m_{kj}\overline{Q}_{kj})}{\partial(X,Y,Z)_{k(j)}} = \dfrac{\partial(m_{kj})}{\partial(X,Y,Z)_{k(j)}}\overline{Q}_{kj} + m_{kj}\dfrac{\partial(\overline{Q}_{kj})}{\partial(X,Y,Z)_{k(j)}}
\end{cases}
$$

The essential thing here is that the scale coefficient m_{kj} is calculated for each available *GCP* from the cover, with the obtained deformations of the image between each determined reflectance point and the origin of the coordinate system.

4.3. Equation to determine the derivatives $(x,y,z)_{kj}$ in relation to $(x,y,z)_{ko}$

Following equation (22) and the system of linear equations (14), accordingly (15), and having in mind that, according to equation (10), in determining m_{kj}, the distance D_{kj} of the image is used, formula (3), which is a function of the coordinates of the main point x_{ko}, y_{ko}, z_{ko} on picture O. Based on this, we have the following meanings for the matrix D_{ko}:

$$(28) \qquad \vec{D}_{ko} = \begin{vmatrix} \frac{(x_{kj}-x_{ko})^2}{D^2{}_{ko}} & 0 & 0 \\ 0 & \frac{(y_{kj}-y_{ko})^2}{D^2{}_{ko}} & 0 \\ 0 & 0 & \frac{(z_{kj}-z_{ko})^2}{D^2{}_{ko}} \end{vmatrix}$$

The essential thing here is that the scale coefficient m_{kj} is calculated for each available *GCP* from the cover, with the obtained deformations of the image between each determined reflectance point and the origin of the coordinate system.

Correction equation (19) has the form:

$$(29) \qquad \vec{V}_{U_{kj}} = \vec{A}_k d\vec{S}_k + \vec{B}_k d\vec{r}_k + \vec{C}_j d\vec{R}_j + \vec{D}_{ko} d\vec{n}_{ko} + \vec{L}_{kj}; \qquad P_{kj}$$

6.Conclusion

As a conclusion we will note that the developed mathematical model provides the opportunity for georectification of the images of GCPs from the cover in a 3D satellite-centric coordinate system $(x, y, z)_{kj}$ having its origin O in the lens's hind point, thereby obtaining a 3D model of the image. Usually, in the program packages used in remote sensing of the Earth, the images of the GCPs are rectified in a ground coordinate system $(x, y)_{kj}$. The essential point here is that we obtain the real geometry of the image and it is possible to determine the shift of the projected GCP as a result of the cover pattern and slope.

In the obtained equations, the scale coefficient $m = \frac{D_{kj}}{\rho_{kj}}$ is also included,which provides the opportunity to determine the geometric deformation of the scenes and to perform a precise rectification of the space images, accordingly.

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МАТЕМАТИЧЕСКИ МОДЕЛ ЗА ПРИВЪРЗВАНЕ НА КОСМИЧЕСКИ ИЗОБРАЖЕНИЯ С ВИСОКА РАЗДЕЛИТЕЛНА СПОСОБНОСТ ЧРЕЗ ОПРЕДЕЛЯНЕ НА КООРДИНАТИТЕ НА ОПОРНИ ТОЧКИ С GPS ИЗМЕРВАНИЯ

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Резюме

В статията се предлага строг метод за привързване на космически изображения с голяма разделителна способност от 1 - 3 м, чрез определяне координатите на опорните точки (ОТ) от физическата земна повърхност с помощта на GPS измервания.За проекционна повърхнина се приема референтен (земен) елипсоид и съответно се отчитат елипсоидните височини на идентифицираните от терена. Определянето на мащабите между идентифицираните точки дава възможност за прецизна ректификация на космическото изображения.