Artículo de investigación

Simplified method of linking raster image points of Earth remote sensing satellites to geographical coordinates

Упрощенный метод привязки точек растрового изображения спутников дистанционного зондирования Земли к географическим координатам

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Abstract

In article the simplified method of definition of a binding pixels raster picture to geographical coordinates in multichannel satellite imageries of the remote sensing (RS) of Earth is described. It is assumed that the picture is a rectangular raster with dimensions of the coating area on the surface of the Earth within the limits of the first hundred kilometers, obtained when the direction of shooting is deviated from nadir within the limits of the first degrees. At the same time the corner points of the screen have reference to geographical coordinates of sufficient accuracy. It is required to bind each raster pixel to a point on the Earth's surface, that is, to constrain the column and row of the raster pixel to the geographical latitude and longitude of the corresponding point. This paper proposes a simplified universal method, without some of the disadvantages inherent in standard methods of solving the problem. It is based on considering the geometric features raster and the area of the Earth surface covers it.

Keywords: Eco-monitoring, geolocation, multichannel satellite imagery, remote sensing of the Earth, satellite imagery.

Аннотация

В статье описан упрощённый метод определения привязки точек растрового снимка к географическим координатам в многоканальных снимках спутников дистанционного зондирования Земли (ДЗЗ). Предполагается, что снимок представляет из себя прямоугольный растр с размерами зоны покрытия на поверхности Земли в пределах первых сотен километров, полученный при отклонении направления съёмки от надира в пределах первых градусов. При этом угловые точки растра имеют привязку к географическим координатам достаточной точности. Требуется реализовать привязку каждой точки растра к точке на поверхности Земли, то есть установить зависимость между столбцом и строкой точки растра и географическими широтой и долготой соответствующей точки на поверхности Земли. В данной работе предлагается упрощённый универсальный метод, лишённый некоторых недостатков, присущих стандартным способам решения задачи. Он основан на учёте геометрических особенностей взаимного расположения растра и покрываемого им участка Земной поверхности.

Ключевые слова: дистанционное зондирование земли, космоснимки, многоканальные спутниковые снимки, привязка, экомониторинг.

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Introduction

Multichannel satellite imagery is increasingly used in environmental monitoring, forest fire detection, control of the use of vast land, mapping, meteorology, etc (Bakhtin, Omelyanchuk, Semenova, 2017).

In particular, State Oceanographic Institute named after N.N. Zubov carries out regular environmental monitoring of the Volga-Akhtuba floodplain, for which it is necessary to analyze quantitative indicators reflecting the state of wetlands and associated vegetation on areas of ten thousand square kilometers (Kozlov, Kozlova, Skorik, 2016). Field studies and aerial photography also remain important aspects of these studies, but they do not technically provide coverage for the entire area required. At the same time, a characteristic feature of the plant communities of arid wetlands characteristic of the Volga-Akhtuba floodplain is their significant variability both in time and in space. This fact leads to the need to process a large number of high-resolution of satellite imagery (Kozlov, Kozlova, Skorik, Sharonov, 2017).

For example, Landsat 7 satellite has a return period of 16 days and a span of about 200 kilometers (Zanter, 2018). Its raster imagery has nine (by the number of registered sub-ranges of electromagnetic radiation) matrices with a resolution of 30 meters per pixel. The scene metadata contains information about the geographical coordinates at the four corners of the imagery that correspond to the matrix elements, for example, (0, 0), (0, 8361), (7751, 0), (7751, 8361), but there is no binding for each matrix element to the coordinate. Thus, for automatic processing of a large number of images, it is necessary to implement the simplest possible method of converting the coordinates of the raster points to geographic coordinates and back based on the available data. First, let us consider the imageries from the flat terrain (for example, in the Volga-Akhtuba floodplain), where the height difference between the points of the imagery is small. Under the above conditions, when determining geographical coordinates, the convexity of the Earth's surface can be neglected and the surface of the scene can be flat.

Common ways to solve this problem have some disadvantages:

- The simplest linear transformations of coordinates on the imageries of the considered size may have errors of hundreds of meters;
- Polynomial approximation of the dependence between the coordinates for a degree higher than the first is impossible under the conditions under consideration, since the polynomial of two variables contains six unknown coefficients, but the known coordinates of the corner points allow making only four equations on them; thus, polynomials of the second degree and higher require more reference points;
- When using local coordinate systems for the projection of RS imageries onto the Earth's surface, it is necessary to attract additional information that is different for different parts of the Earth; so, an additional problem of choosing the parameters of the local coordinate system arises; if automation of processing a large number of images is necessary, this task is difficult;
- Use of the UTM coordinate system (Universal Transverse Mercator) (Stott, 1977) is fraught with certain difficulties due to a variable scale factor, variations of which within each cartographic area of the order of 800 kilometers must be considered to obtain coordinates more accurately than about 100-300 meters, and also because of the need for special calculations in the circumpolar regions.

Theoretical basis

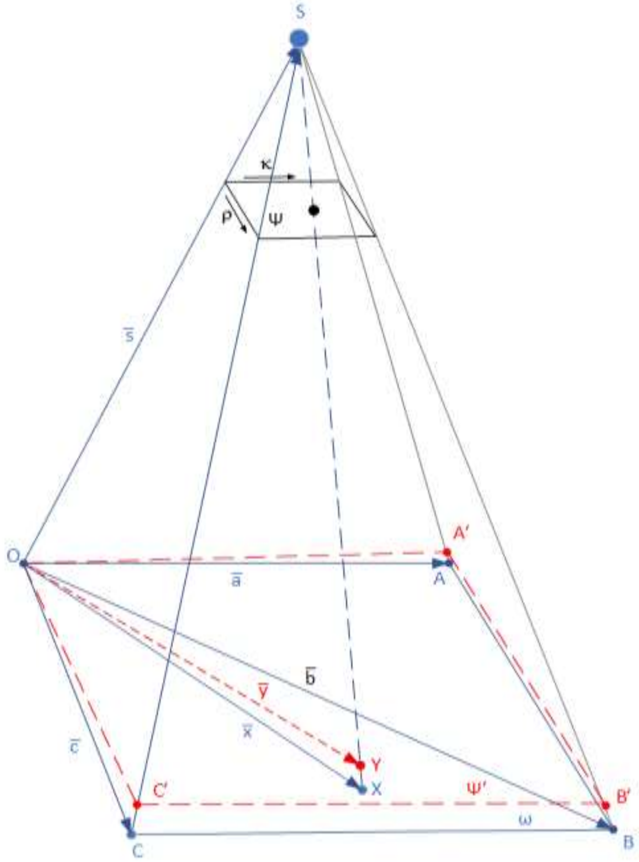

Figure 1. Demonstration of the imagery scene plane, sensor plane, imaginary scene plane and point projections on them

ω is the true plane of scene;
ψ is the sensor plane;
O, A, B, C are the angle points of the imagery scene (top left, top right, bottom right, bottom left accordingly);

O is the anchor point of the scene, top left corner;
ψ' is the plane parallel to the sensor plane and passing through the reference point of the scene;

$\overline{c}$ is the vector OC;

$\overline{a}$ is the vector OA;

$\overline{б}$ is the vector OB;

X is the desired point in the plane ω
Y is the corresponding point on the line of sight in the plane ψ'
$\overline{x}$ is the radius vector of the desired point in the plane ω;

$\overline{y}$ is the radius vector of the corresponding point in the plane ψ;
$\kappa, \rho \in [0,1]$ are the normalized pixel coordinates in the raster;

$\alpha, \beta, \gamma \in [0,1]$ are the normalized vector coordinates when expanding in basis vectors $\overline{a}$ and $\overline{c}$ in scene planes for points A, B, C accordingly;

μ, ν, σ are the nadir parameters characterizing the deviation of the scene plane from the sensor plane, defined as:

$$\begin{cases} \mu = \dfrac{AA'}{AS'}, \\ \nu = \dfrac{CC'}{CS'}, \\ \sigma = \dfrac{BB'}{BS'}, \end{cases}$$

$\eta_{A,B,C}$ are the rectangular Earth-centered, Earth-fixed (ECEF) of the corresponding points;
φ, λ, h are the geographic coordinates of points (north latitude, east longitude and height relative

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to the model ellipsoid of the Earth); S is the satellite location.

Methodology. Defining nadir parameters

Let the geographical coordinates of the corners of the scene be given O, A, B, C. Using them, we determine the parameters of the nadir μ, ν. When working with the geographic coordinates of the angles of the imagery, we convert them into ECEF ones (Vavilova, Golovan, Parusnikov, Trubnikov, 2009):

$$\varphi_O, \lambda_O, h_O \to \eta_O;$$
$$\varphi_A, \lambda_A, h_A \to \eta_A;$$
$$\varphi_B, \lambda_B, h_B \to \eta_B;$$
$$\varphi_C, \lambda_C, h_C \to \eta_C.$$

Thus, we are able to express the vectors:

$$\bar{a} = \overline{\eta_O} - \overline{\eta_A};$$
$$\bar{b} = \overline{\eta_O} - \overline{\eta_B};$$
$$\bar{c} = \overline{\eta_O} - \overline{\eta_C}.$$

The nadir parameters μ, ν, σ determine the deviation of the sensor plane from the scene plane, for example, when the planes are parallel, $\mu = \nu = \sigma = 0$. Wherein $\mu, \nu, \sigma \ll 1$, since it is assumed that the deviation of the sensor from the nadir is small. By definition μ, ν and σ:

$$\overline{A'A} = \mu(\bar{a} - \bar{s});$$
$$\overline{C'C} = \nu(\bar{c} - \bar{s});$$
$$\overline{B'B} = \sigma(\bar{b} - \bar{s}).$$

Since $OA'B'C'$ by construction it is a rectangle, the direction of shooting perpendicular to the rectangle of the imagery raster, which is provided technologically by the sensor RS (Storey, 2006), so:

$$\overline{OA'} + \overline{OC'} = \overline{OB'}$$
$$\overline{OA'} + \overline{A'A} = \bar{a}, \quad \overline{OB'} + \overline{B'B} = \bar{b}, \quad \overline{OC'} + \overline{C'C} = \bar{c}.$$
$$\bar{a} - \mu(\bar{a} - \bar{s}) + \bar{c} - \nu(\bar{c} - \bar{s}) = \bar{b} - \sigma(\bar{b} - \bar{s}),$$
$$\mu(\bar{a} - \bar{s}) + \nu(\bar{c} - \bar{s}) - \sigma(\bar{b} - \bar{s}) = \bar{a} + \bar{c} - \bar{b} \tag{1}$$

Since $\mu, \nu, \sigma \ll 1$, then instead of unknown true coordinates $\bar{s}$ it is permissible to use their estimate:

$$\tilde{s} = \frac{1}{2}(\bar{a} + \bar{c}) + \frac{\bar{a} \times \bar{c}}{\|\bar{a} \times \bar{c}\|} H \tag{2}$$

where H is the satellite orbit height RS. The error of this approximation will be equal in (1) to $(\mu + \nu - \sigma)(s - \bar{s})$, which can be neglected.

Vector equation (1) is a system of three linear equations with three unknowns μ, ν, σ, there are estimates of the nadir parameters $\tilde{\mu}, \tilde{\nu}$ there:

$$\begin{bmatrix} \tilde{\mu} \\ \tilde{\nu} \\ \tilde{\sigma} \end{bmatrix} = \left[\bar{a} - \bar{s}\bar{c} - \bar{s} \quad -(\bar{b} - \bar{s})\right]^{-1} (\bar{a} + \bar{c} - \bar{b}) \tag{3}$$

Determining the coordinates of a pixel by the geographical coordinates of a point

Let it be required to obtain the coordinates κ, ρ of the pixel in the raster, having the geographical coordinates of the point $\varphi_x, \lambda_x, h_x$. To do this, we convert these geographical coordinates into rectangular ECEF, using, as earlier, the formulas (3):

$$\varphi_x, \lambda_x, h_x \to \eta_x,$$
vector $\bar{x}$ is:
$$\bar{x} = \overline{\eta_x} - \overline{\eta_O}.$$

From the Figure 1 it follows that:

$$\bar{x} = \bar{s} + \|SX\|,$$
where $\|SX\| = \|SY\|(1 + \varepsilon)$,
$$\varepsilon = \frac{\|SY\|}{\|SX\|},$$
$$SY = \|\bar{y} - \bar{s}\|.$$
$$\bar{x} = (1 + \varepsilon)y - \varepsilon s$$

Also, vector $\bar{y}$ is:

$$\bar{y} = \kappa(\bar{a} + \mu(\bar{a} - \bar{s})) + \rho(\bar{c} + \nu(\bar{c} - \bar{s})),$$
$$where\ \mu, \nu \ll 1.$$

Let us substitute in (3)

$$\bar{x} = (1 + \varepsilon)\Big(\kappa(\bar{a} + \mu(\bar{a} - \bar{s})) + \rho(\bar{c} + \nu(\bar{c} - \bar{s}))\Big) - \varepsilon\bar{s},$$
$$\frac{\bar{x} + \varepsilon\bar{s}}{1 + \varepsilon} = \kappa(\bar{a} + \mu(\bar{a} - \bar{s})) + \rho(\bar{c} + \nu(\bar{c} - \bar{s})),$$
$$\bar{x} = \kappa(\bar{a} + \mu(\bar{a} - \bar{s})) + \rho(\bar{c} + \nu(\bar{c} - \bar{s})) + \varepsilon(\bar{x} - \bar{s}).$$

This vector equation is a system of three linear equations, from which, with the nadir parameters μ and ν known from (3) can get the desired κ and ρ.

Determining geographical coordinates of point by the pixel coordinate

Now it is required to have geographical coordinates $\varphi_z, \lambda_z, h_z$, corresponding to the specified normalized pixel coordinates in the raster κ, ñ.

From equation (3) y is:

$$y = \kappa(\overline{a} + \mu(\overline{a} - \overline{s})) + \rho(\overline{c} + \nu(\overline{c} - \overline{s}))$$
$$(1 + \varepsilon)y - \varepsilon\tilde{s} = б\overline{a} + \gamma\overline{c}$$
$$y = á\overline{a} + \gamma\overline{c} + \varepsilon(\tilde{s} - y),$$

where $\tilde{s}$ is from the formula (2).

With the parameters of the nadir μ and ν, we solve a system of equations of three linear equations, substituting the vectors $\overline{a}$, $\overline{c}$. Calculated α and γ are used to obtain the desired coordinates:

$$\overline{\eta_z} = \overline{\eta_O} + \alpha\overline{a} + \gamma\overline{c}.$$

Thus, we obtain the desired geographical coordinates (Vavilova, Golovan, Parusnikov, Trubnikov, 2009):

$$\overline{\eta_z} \rightarrow \varphi_z, \lambda_z, h_z.$$

Evaluation of result and accuracy of transformations

The accuracy of the conversion of the pixel coordinates into geographical coordinates was assessed using a set of points that have explicit visual landmarks and are linked to geographical coordinates in an existing GIS (Geographic Information System) Google Earth (https://www.google.com/intl/ru/earth/). For example, we consider the end of the runway of the airfield in the Landsat 7 imagery with the identifier LE71700271999223EDC00 (Figure 2, point 1). The picture has dimensions [7231, 7931] and geographical coordinates of the corners according to the Table 1.

Table 1. Geographic coordinates of the imagery corners LE71700271999223EDC00

Line	Column	Longitude	Latitude
0	0	44.98107°	48.43994°
0	7931	48.19513°	48.39556°
7231	0	44.98176°	46.48827°
7231	7931	48.07923°	46.44680°

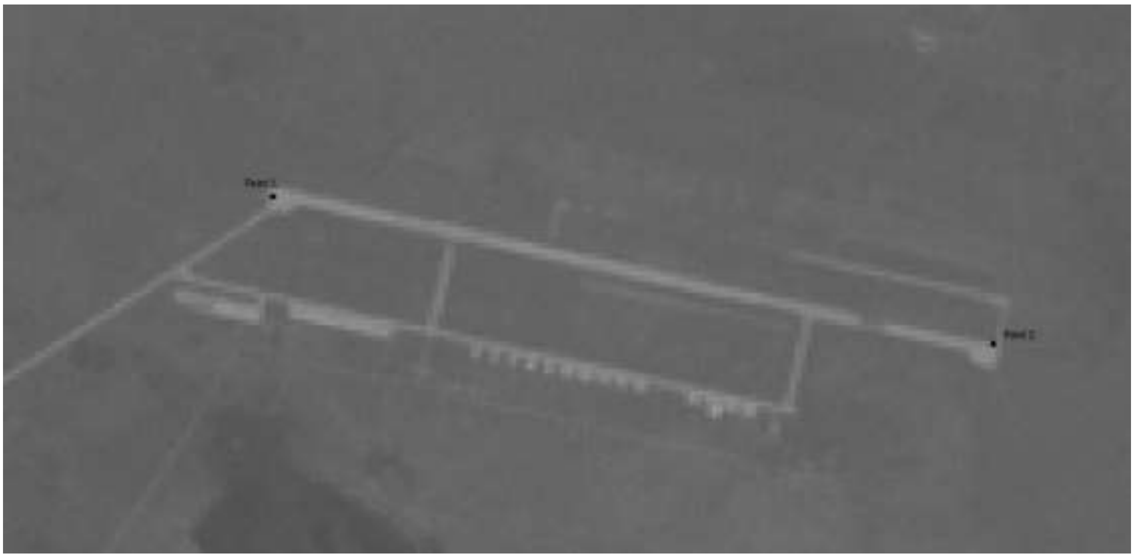

Figure 2. Searched points 1 and 2 on the scene of imagery

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In this example, the coordinates of the pixel in the raster for the considered point 1 (Figure 2) are 428, 3133. Using the algorithm described above, we obtain the geographical coordinates of this point in the imagery, and compare them with the desired point in GIS Google Earth (Figure 3).

Figure 3. Searched points 1 and 2 on Google Earth maps

The accuracy of the conversion of the geographical coordinate to the pixel coordinates in the raster is evaluated in a similar way, but in the reverse order. Let us choose the opposite end of the runway as a point for searching on the stage (point 2, Figure 3), with geographic coordinates 46.301408°, 48.309579°.

Using the algorithm described in the article, the coordinates of the pixel in the raster for this point are [456, 3263] (point 2, Figure 2).

In this case, the conversion error is not more than the size of one pixel (30 meters for the Landsat 7 imagery used in the example). This accuracy assessment method was applied for 30 points in different parts of Landsat 7 imageries.

Table 2. Pixel observational errors for imagery LE71700271999223EDC00

№ of point	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Observational error	1	0	1	2	0	0	1	1	0	1
№ of point	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Observational error	0	0	1	1	0	0	0	0	1	2
№ of point	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Observational error	1	0	1	1	1	0	1	1	1	1

The average error is 0.7 pixels, i.e., about 20 meters.

Conclusion

The simplified algorithm described in this article for linking the raster imagery points of Earth remote sensing satellites to the geographical coordinates is suitable for the tasks of automatic imagery processing with a resolution of 30 meters per pixel or more, where an accuracy of about one pixel is sufficient.

References

Bakhtin A.A., Omelyanchuk E.V., Semenova A.Yu. (2017). Analysis of the modern possibilities of organizing ultra-high-speed satellite radio links. Proceedings of Moscow Aviation Institute. 96.

Kozlov A.V., Kozlova M.V., Skorik N.A. (2016). Simple Harmonic Model for FAPAR Temporal Dynamics in the Wetlands of the Volga-Akhtuba Floodplain. Remote Sens. 8(9), 762/

Kozlov A.V., Kozlova M.V., Skorik N.A., Sharonov A.V. (2017). Use of multichannel satellite imagery to analyze the annual dynamics of vegetative activity, Proceedings of Moscow Aviation Institute. 96.

Zanter K. (2018) Landsat 7 (L7), Data users handbook. Sioux Falls: EROS.

Stott P.H. (1977). The UTM Grid Reference System. Journal of the Society for Industrial Archeology. 3(1), 1-14.

Vavilova N.B., Golovan A.A., Parusnikov N.A., Trubnikov S. A. (2009). Mathematical models and measurement processing algorithms for GPS satellite navigation system. Standard mode. Moscow: MSU Publishing House.

Storey J. (2006). Landsat 7 (L7), Image assessment system (IAS), Geometric algorithm theoretical basis document (GTBD). Sioux Falls: EROS.

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