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The Coordinate Conversion Method of Digital Topographical Map Data for Real Estate Management

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The great leader Comrade Kim Il Sung said:

"If you are to manage land and natural resources, buildings and facilities in cities and in the countryside well, you should make a register and regularly investigate and enter in it the relevant conditions of immovable state properties so as to know them like the palm of your hand."

Digital topographical map data – a kind of the spatial information infrastructures – are very important foundational data of GIS.

There is certain difference between the geodetic coordinate system for topographical maps in our country and ITRF geodetic coordinate system. GRS－80 coordinate system is convenient for the acquisition, maintenance and management of spatial data, and can ensure higher accuracy than previous coordinate systems.

Therefore, we carried out research into the conversion of topographical maps using the traditional coordinate systems such as 1∶1000, 1∶10,000, 1∶25,000, 1∶50,000 etc. to those using the GRS－80 coordinate system.

1. The Coordinate System Conversion Method of Digital Topographical Map Data

There are two methods of converting the coordinate system of the digital topographical map data; one is to convert the geodetic coordinate system to GRS－80 coordinate system and another is to convert the rectangular plane coordinate system to the GRS－80 coordinate system.

Coordinate system conversion procedure includes setting-up of GCPs necessary for conversion, and the conversion to GRS－80 coordinate system.

1.1. Setting-up of GCPs

It is common to set up GCPs in the topographical map and in high resolution satellite images etc, and to use the geodetic and GRS－80 coordinate values for the points as the sample data. In other case, the GCPs are set up in topographical maps and high resolution satellite images for the uniform distribution throughout the country.

As it is impossible to guarantee the accuracy in the digital topographical map with only the main conversion arising from the features of the GCPs used in its first making, it is important to first convert them to GRS-80 coordinate system and correct the distortions, for position accuracy.

The distortion here means the difference between the GRS-80 coordinate system data when the existing geodetic data of the GCPs have been converted through the coordinate conversion procedure and the GRS-80 coordinate system data from the GPS observation.

Modeling and correction of the distortion include reducing the accidental error in the GCPs and the errors that are caused by the mathematical limitations in the conversion of the coordinate system. This is done to enhance the accuracy of the converted topographical maps.

The following corrections are made to the distortion:

First, the distortions (△X, △Y) which are the difference on the axes X and Y of the rectangular plane coordinates of the GRS-80 coordinate system and the rectangular plane coordinates of the converted images are calculated respectively.

Next, in order to ensure the accuracy of the parameters used for the conversion and the reliability of the conversion, the distortions of all the GCPs are evaluated and GCPs with large distortions are removed. The reduction should be done by analyzing axis by axis and if the distortion of a point goes beyond the accuracy standard even on one axis, that point is removed. When reducing the GCPs with large distortions, the statistical confidence interval is set and the GCPs the distortion value of which goes beyond the confidence interval are removed. In this article, to be specific, reduction was done for the GCPs whose distortion values are larger than the standard accuracy.

The calculation process of $\triangle X$, $\triangle Y$ is as follows.

$$\overline{X_1}=\frac{1}{n}\sum_{i=1}^{n}X_{1i},\ \overline{Y_1}=\frac{1}{n}\sum_{i=1}^{n}Y_{1i},\ \ \overline{X_2}=\frac{1}{n}\sum_{i=1}^{n}X_{2i},\ \overline{Y_2}=\frac{1}{n}\sum_{i=1}^{n}Y_{2i}$$

$$X_{1i}^{/}=X_{1i}-\overline{X_1},\ \ Y_{1i}^{/}=Y_{1i}-\overline{Y_1},\ \ X_{2i}^{/}=X_{2i}-\overline{X_2},\ \ Y_{2i}^{/}=Y_{2i}-\overline{Y_2},\ \ \Delta X=X_{1i}^{/}-X_{2i}^{/},\ \ \Delta Y=Y_{1i}^{/}-Y_{2i}^{/}$$

It is a rule to set the GCPs equidistantly; however, there are some exceptions. If the points are not set evenly, deviated points are removed to prevent the conversion errors caused by them. Here, only the points whose distance from the neighboring points are in a certain limit are selected.

1.2. Conversion to GRS－80 coordinate system

When it is possible to get some data that are calculated using two different geodetic coordinate systems, i.e., when the digital topographical map data on the reduced scales of 1: 25,000 and 1: 50,000 and high resolution satellite images are available, the geodetic coordinate system is converted to the GRS-80 coordinate system.

Conversion to GRS－80 coordinate system means coordinates conversion of the traditional geodetic system to GRS－80 coordinates. This includes the following procedure:

① Determination of 7 parameters by GCPs

GCPs are selected according to the way of setting up the GCPs mentioned above.

The conversion of the longitude and latitude of the geodetic coordinate system to its 3D geocentric rectangular coordinate system is done with the following formula:

$$\left.\begin{aligned} X_{gk} &= (N_k + H_k)\cos B_k \cos L_k \\ Y_{gk} &= (N_k + H_k)\cos B_k \sin L_k \\ Z_{gk} &= [N_k(1-e_k{}^2) + H_k]\sin B_k \end{aligned}\right\} \tag{1}$$

The conversion of the longitude and latitude of the GRS-80 coordinate system to its 3D geocentric rectangular coordinate system is done with the following formula:

$$\left.\begin{aligned} X_{gw} &= (N_w + H_w)\cos B_w \cos L_w \\ Y_{gw} &= (N_w + H_w)\cos B_w \sin L_w \\ Z_{gw} &= [N_w(1-e_G{}^2) + H_w]\sin B_w \end{aligned}\right\} \tag{2}$$

where $N_k = \dfrac{a_k}{\sqrt{1-e_k{}^2\sin B_k}}$, $N_w = \dfrac{a_G}{\sqrt{1-e_G{}^2\sin B_w}}$, $e_k{}^2 = \dfrac{a_k{}^2 - b_k{}^2}{a_k{}^2}$, $e_G{}^2 = \dfrac{a_G{}^2 - b_G{}^2}{a_G{}^2}$, a_G =6 378 137m, b_G =6 356 752.314m, a_k =6 378 245.000 00m, b_k = 6 356 863.018 77m.

The determination of 7 parameters by the GCPs is done as follows.

$$\begin{bmatrix} X_{gw} \\ Y_{gw} \\ Z_{gw} \end{bmatrix} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + \begin{bmatrix} X_k \\ Y_k \\ Z_k \end{bmatrix} + S\begin{bmatrix} X_k \\ Y_k \\ Z_k \end{bmatrix} + \begin{bmatrix} 0 & Z_{gk} & -Y_{gk} \\ -Z_{gk} & 0 & X_{gk} \\ Y_{gk} & -X_{gk} & 0 \end{bmatrix}\begin{bmatrix} \gamma_X \\ \gamma_Y \\ \gamma_Z \end{bmatrix} \tag{3}$$

where $\Delta X, \Delta Y, \Delta Z$ are line elements, $\gamma_X, \gamma_Y, \gamma_Z$ are angle elements, and S is a scale element.

The coefficient matrix for one GCPs is made as follows.

$$\begin{pmatrix} 1 & 0 & 0 & 0 & Z_{gk} & -Y_{gk} & X_{gk} & X_{gw} - X_{gk} \\ 0 & 1 & 0 & -Z_{gk} & 0 & X_{gk} & Y_{gk} & Y_{gw} - Y_{gk} \\ 0 & 0 & 1 & Y_{gk} & -X_{gk} & 0 & Z_{gk} & Z_{gw} - Z_{gk} \end{pmatrix}$$

The standard equation is made with this coefficient matrix and we can get the value for the 7 parameters.

② Conversion of the data for a region by the 7 parameters

The conversion of the 3D geocentric rectangular coordinates to the longitude and the latitude of the GRS coordinate system is done with the following formula:

$$\left.\begin{aligned} B_G &= \arctan\left(\frac{Z_G + e_G'^2 b_G \sin^3\theta}{P - e_G^2 a_G \cos^2\theta}\right) \\ L_G &= \arctan\left(\frac{Y_G}{X_G}\right) \\ H_G &= \left(\frac{P}{\cos B_G} - N_G\right) \end{aligned}\right\} \tag{4}$$

where $P = \sqrt{(X_G{}^2 + Y_G{}^2)}$, $\theta = \arctan\left(\dfrac{Z_G a_G}{P b_G}\right)$, $e_G'^2 = \dfrac{a^2 - b^2}{b^2}$.

When the data can only be calculated based on the traditional geodetic coordinate system, i.e., the digital topographical map data on the reduced scale of 1: 10,000 and high resolution satellite images are available, the rectangular plane coordinate system is converted to the GRS-80 coordinate system.

The GCPs are selected according to the set-up method of the GCPs mentioned above and the longitude and the latitude of the GRS-80 coordinate system are converted to the rectangular plane coordinate data of the GRS-80 coordinate system.

And the rectangular plane coordinate data of the GRS-80 coordinate system is converted to the coordinate data of the reduced map on the scale of 1:10,000 with the affine conversion method, i.e. the quadratic polynomial conversion method; after this, the coordinate values are matched.

$$\left.\begin{aligned} X_2 &= a_0 + a_1 X_1 + a_2 Y_1 + a_3 X_1{}^2 + a_4 X_1 Y_1 + a_5 Y_1{}^2 \\ Y_2 &= b_0 + b_1 X_1 + b_2 Y_Y + b_3 X_1{}^2 + b_4 X_1 Y_1 + b_5 Y_1{}^2 \end{aligned}\right\} \tag{5}$$

A coefficient matrix is as follows when there are 6 GCPs:

$$\begin{pmatrix} 1 & X_{11} & Y_{11} & X_{11}{}^2 & X_{11}Y_{11} & Y_{11}{}^2 & X_{21} \\ 1 & X_{12} & Y_{12} & X_{12}{}^2 & X_{12}Y_{12} & Y_{12}{}^2 & X_{22} \\ 1 & X_{13} & Y_{13} & X_{13}{}^2 & X_{13}Y_{13} & Y_{13}{}^2 & X_{23} \\ 1 & X_{14} & Y_{14} & X_{14}{}^2 & X_{14}Y_{14} & Y_{14}{}^2 & X_{24} \\ 1 & X_{15} & Y_{15} & X_{15}{}^2 & X_{15}Y_{15} & Y_{15}{}^2 & X_{25} \\ 1 & X_{16} & Y_{16} & X_{16}{}^2 & X_{16}Y_{16} & Y_{16}{}^2 & X_{26} \end{pmatrix}$$

A standard equation is made with the coefficient matrix and the values of the 12 coefficients are calculated. After this, the rectangular plane coordinate data of the geodetic maps are converted to the rectangular coordinate data of the GRS-80 coordinate system.

Finally, the rectangular plane coordinates are converted to the longitude and the latitude of the GRS-80 coordinate system.

2. Accuracy Estimation

Accuracy estimation means setting up some checkpoints on a digital topographical map, measuring some values for the points and estimating the accuracy of the map. This is to check if the converted digital map is accurate enough.

It is essential that the converted digital topographical maps are accurate enough; therefore, we should do the accuracy estimation of the converted maps with the GRS-80 coordinate system and the converted values should be within the accuracy tolerance range. If the map is not accurate enough, another way of making digital topographical maps should be considered.

A traditional way of accuracy estimation is to select some points on the map that can be clearly measured, and field measuring is done in those places.

Preparing this article, we measured the data of the GRS-80 coordinate system and the converted digital topographical map data with the difference between the values and we estimated the accuracy of the map, because the field measuring was not available.

The accuracy error in the converted digital topographical map was ±4m for maps on the scale of 1:10,000 and ±10m for maps on the scale of 1:25,000. The result shows that the converted data are within the tolerance range.

Conclusion

In order to reduce errors in the conversion as much as possible and improve the accuracy of the converted digital topographical maps, we should introduce a better way of modeling and correcting the distortion, thus further deepening the research on the conversion of digital topographical maps.

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