HIGH ACCURATE GEOMETRIC CORRECTION FOR NOAA AVHRR DATA CONSIDERING THE IMPACT OF ELEVATION ON ERROR

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ABSTRACT: NOAA images have been provided very useful environmental information from all over the world. In order to use NOAA images, they need to be transformed from image into map. This paper proposes a method that corrects the errors caused by this transformation. First, elevation errors are calculated and corrected based on elevation values, which are read from GTOPO30 database. These elevation values are also verified to divide data into flat and rough blocks. Next, GCP template matching is used to calculate the residual errors for the blocks that match GCP templates. Reference data is referred in case the number of GCP templates is not enough. Based on the blocks which match GCP templates, the residual errors of other flat and rough blocks are calculated by Affine and Radial Basic Function transformation respectively. According to residual errors, all points in the image are moved to their correct positions. Finally, data is transformed from image into map by bilinear interpolation. With proposed method, because the relationship between the error and the variation of elevation is controlled better, residual errors are corrected more accurately and the errors of bilinear interpolation are smaller. As a result, the error after correction is considerably reduced. This method was applied to correct the errors for NOAA images receiving in Tokyo, Bangkok and Ulaanbaatar. The results proved that this is a high accurate geometric correction method.

1. INTRODUCTION

NOAA images have been provided very useful environmental information from all over the world. Recently, precise geometric correction method (Ono, 2001; Takagi, 2003; Yasukawa, 2004) for NOAA AHVRR data, which uses GCP template matching and considers elevation effect, has obtained accurate results by considering residual errors and elevation effect. Though the precision of this method is high, there are still errors in the rough regions, where the difference of elevation among the points is big. In order to improve the precision of precise geometric correction method, this paper proposes a high accurate geometric correction method considering the variation of elevation. With proposed method, since the relationship between the error and the variation of elevation is considered in more detail, the error after correction is considerably reduced.

2. ELEVATION ERROR

Figure 1 (Ono, 2001) is an example of elevation error. There is a mountain at A with the height H. The top of the mountain D is observed from the satellite C seems to be from A'. In this case, the difference of the scan angles ($\theta_2 - \theta_1$) is directly proportional to the elevation error. The elevation error is calculated as (1) and (2), where *RE*=6387.14km is the Radius of Earth, *r*=7228km is the radius of the satellite, and the scan angle of AVHRR sensor is ± 55.4 deg.

$$\theta_2 = \theta_1 \cos^{-1}[DC^2 + r^2 - DCr(RE + H)^2 / 2] \quad (1)$$

$$Elevation\ error = (\theta_2 - \theta_1) * 1024 / 55.4 \qquad (2)$$

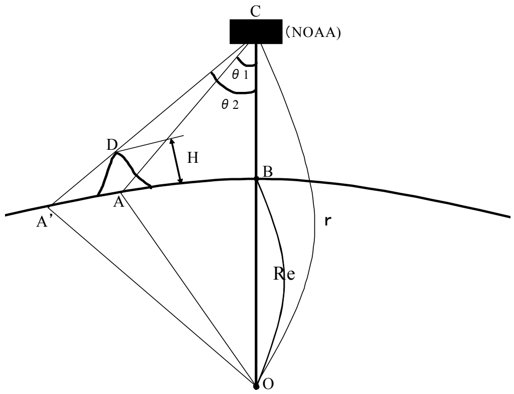


Figure 1. Elevation Error

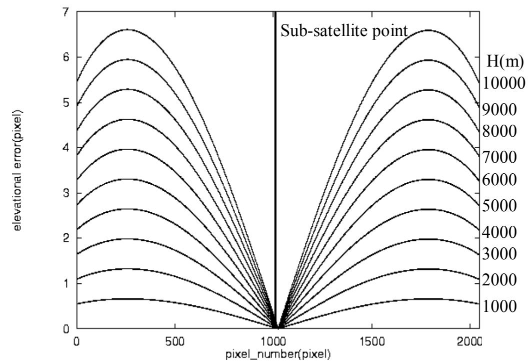


Figure 2. Elevation and Elevation Error

Elevation errors are in the longitude direction in map coordinate system, which corresponds to the pixel direction in image coordinate system. The elevation data is read from GTOPO30 dataset. Figure 2 (Ono, 2001) shows the relationship between elevation and elevation error.

3. PRECISE GEOMETRIC CORRECTION

In the precise geometric correction method, because the correction result in image coordinate system is more accurate than the one in map coordinate system (Ono, 2001; Takagi, 2003), NOAA data is corrected in image coordinate system before transformation into map coordinate system. Figure 3 shows the steps of this method.

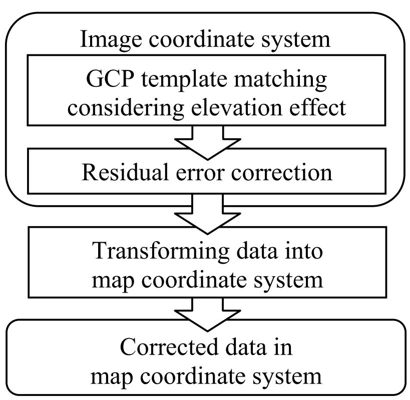


Figure 3. Precise geometric correction

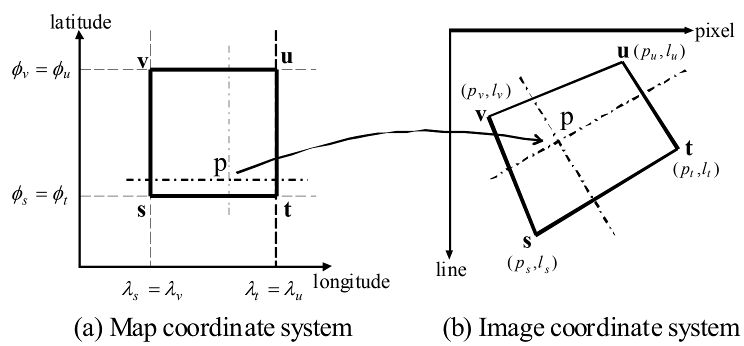


Figure 4. Bilinear interpolation

In the first step, residual errors are measured by GCP template matching. The information about GCP templates is stored in the Digital Chart of the World. First, GCP templates are transformed from map into image coordinate system and their elevation errors are corrected. GCP templates and NOAA image are matched by SSDA (Takagi, 2003) to find out the residual error vectors. In the second step, affine transformation is used to calculate the residual error vectors for the rest points of image. Based on the error vectors, all points in the image are moved to their correct positions. In the third step, NOAA data in image coordinate system is transformed into map coordinate system. To speed up this transformation, the data in map coordinate system is divided into the blocks of 16 x 16 points. The image positions of four corner points in each block are precisely calculated based on the parameters of the satellite and earth's location. The image positions of the other points in the block are specified from the positions of the four corner points by bilinear interpolation. In figure 4, the image position of the point p is interpolated from four corner points s, t, u and v by (3), with E_s, E_t, E_u, E_v are the elevation errors of s, t, u, v, correspondingly. After calculating image positions from the given map positions, the data in the image are assigned to the correct positions in the map.

$$\begin{cases} l_p = \dfrac{\begin{array}{l}(\phi_v-\phi_p)(\lambda_t-\lambda_p)l_s \\ +(\phi_p-\phi_s)(\lambda_t-\lambda_p)l_t \\ +(\phi_v-\phi_p)(\lambda_p-\lambda_s)l_u \\ +(\phi_p-\phi_s)(\lambda_p-\lambda_s)l_v\end{array}}{(\phi_v-\phi_s)(\lambda_t-\lambda_s)} \\ p_p = \dfrac{\begin{array}{l}(\phi_v-\phi_p)(\lambda_t-\lambda_p)(p_s+E_s) \\ +(\phi_p-\phi_s)(\lambda_t-\lambda_p)(p_t+E_t) \\ +(\phi_v-\phi_p)(\lambda_p-\lambda_s)(p_u+E_u) \\ +(\phi_p-\phi_s)(\lambda_p-\lambda_s)(p_v+E_v)\end{array}}{(\phi_v-\phi_s)(\lambda_t-\lambda_s)} \end{cases} \tag{3}$$

According to the correction process, because affine transformation is applied to calculate error vectors, the variation of elevation is considered as a linear variation on all regions. However, in fact, the variation of elevation on rough regions is complicated; therefore, affine transformation will produce wrong correction results, especially on the rough regions. Furthermore, referred to (3), the elevation errors of the points in a block are interpolated from the elevation errors of only four corner points. For this reason, (3) will give correct result on only the flat blocks. It will be wrong on the rough blocks, where the variation of elevation is big.

4. PROPOSED METHOD

In order to improve the result of the precise geometric correction method, a new correction method is proposed. The steps of the proposed method are shown in Figure 5.

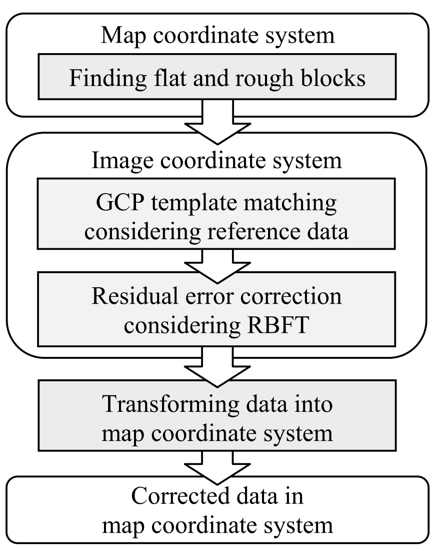


Figure 5. Steps of the proposed method

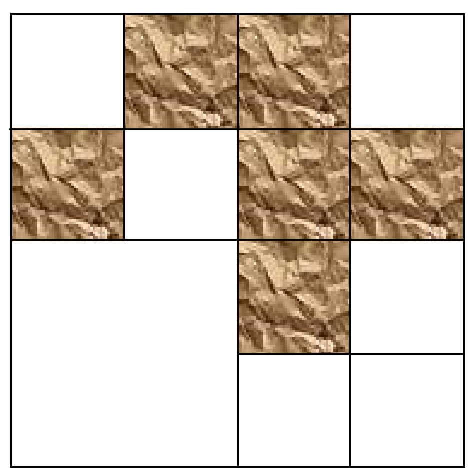


Figure 6. Flat and rough blocks

4.1 Finding flat and rough blocks

The purpose of this step is to monitor the variation of elevation. Map data is divided into blocks of 16x16 points. The elevation data of every point in each block are read from GTOPO30 dataset. The highest and lowest points in each block are compared to decide if it is flat or rough block. If a block is rough, it will be divided into four smaller blocks with the same size. The dividing process will repeat for rough blocks until the sizes of all rough blocks are 4x4 points. Figure 6 is an example of the flat and rough blocks. An original block (16x16 points) is divided into 7 flat blocks (white blocks) and 6 rough blocks (brown blocks).

4.2 GCP template matching considering reference data

In some cases, the number of GCP templates inside the correcting region is not enough to calculate residual errors accurately. In proposed method, reference data from surrounding regions is used to solve this problem. If the surrounding regions are in the same NOAA image as the correcting region, NOAA data and GCP templates on these regions will be used to calculate residual errors. If the surrounding regions are outside the current image, other NOAA images in the same orbit as the current image will be referred. First, the images are stitched based on the name of the image and the time codes of the lines in each image (Van, 2007). GCP templates and coast line data on the reference images are then generated. Finally, GCP template matching is applied as in the precise geometric correction method.

4.3 Residual error correction considering Radial Basic Function Transformation

In the proposed method, residual errors are corrected by using both affine transformation and Radial Basic Function Transformation (RBFT). On the flat blocks, because the elevation errors of all points are same, affine transformation is applied. Obviously, a residual error vector of a point will be affected by the residual error vectors of its surrounding points. The further the surrounding point is, the less influence the point is affected by them. Therefore, on the rough blocks, RBFT with radial basic function $g(t) = e^{-kt}$ is applied for the rough blocks. Figure 7 is an example of residual error correction using RBFT.

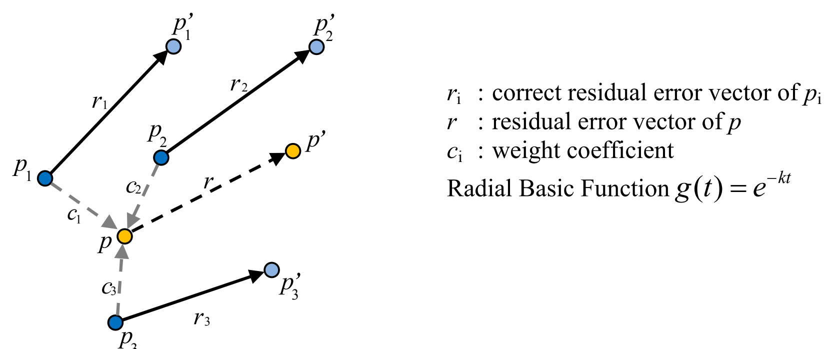


Figure 7. Example of RBFT

Supposed that there are N residual error vectors r_i which are specified by GCP template matching. RBFT will be used to find the residual error vector r of the point p based on r_i. Because residual error vectors r_i are already known, the weight coefficients c_i are found by (4). Based on c_i, residual error vector r is calculated as (5).

$$r_i = \sum_{j=1}^{N} c_j g(\|p_i - p_j\|) \tag{4}$$

$$r = \sum_{i=1}^{N} c_i g(\|p - p_i\|) \tag{5}$$

With RBFT, both direction and magnitude of the residual error vector of a point is specified based on the directions and magnitudes of the residual errors vectors of other points, whose residual error vectors are calculated accurately by GCP template matching. Therefore, on the rough regions, where the elevation errors and residual errors of the points are quite different, residual error vectors will be calculated more precisely.

4.4 Transforming data into map coordinate system

In the final step, data is transformed into map coordinate system. With the flat blocks, data is transformed by using bilinear interpolation as it is done in the precise geometric correction method. With the rough blocks, because the elevation values are quite different among the points in each block, the image positions of all points are found by using the satellite's parameters and earth's location. With this transformation, because bilinear interpolation is applied only on the flat blocks, where the evelation errors of all points are fairly same, the error of bilinear interpolation is reduced. Furthermore, since satellite's parameters and earth's location are used to transform data on the rough regions, the precision of transformation on the rough regions is high.

5. RESULT

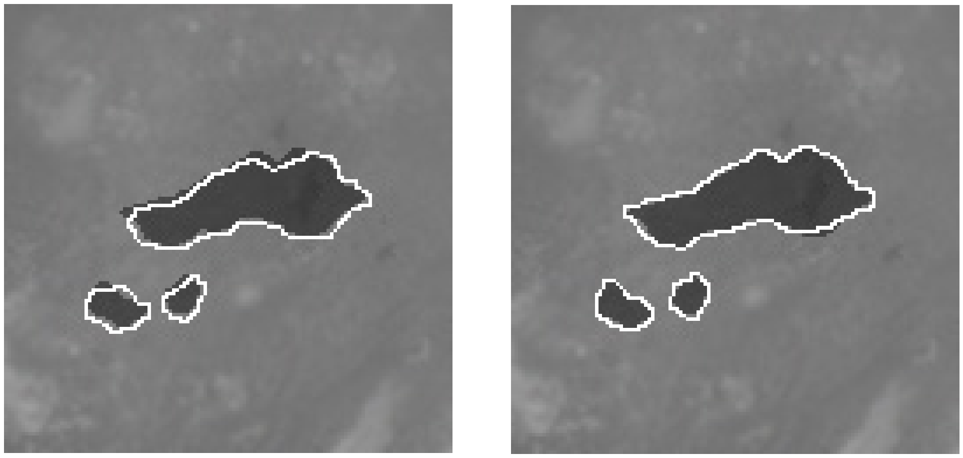
The proposed method was applied to correct geometric error for NOAA images receiving in Tokyo (Japan), Bangkok (Thailand) and Ulaanbaatar (Mongolia). In order to evaluate the precision of the proposed method, the residual errors after correction are acquired. First, NOAA images are corrected by precise geometric correction method. They are then corrected by proposed method. During correction process, only 9/10 number of GCPs are used. After correction, the rest 1/10 number of GCPs is used to acquire residual errors by GCP template matching.

Image	**Value**	**Precise Method**		**Proposed Method**	
		Latitude	***Longitude***	***Latitude***	***Longitude***
AH14060402222944	Average	0.52	0.64	0.31	0.35
	Maximum	1.00	1.00	1.00	1.00
	Mininum	0.00	0.00	0.00	0.00
AH16110602044118	Average	0.31	0.61	0.23	0.28
	Maximum	1.00	2.00	1.00	1.00
	Mininum	0.00	0.00	0.00	0.00
AH16110702183721	Average	0.38	0.42	0.21	0.26
	Maximum	1.00	2.00	1.00	2.00
	Mininum	0.00	0.00	0.00	0.00
200 NOAA images	Avarage	0.42	0.49	0.24	0.29

Table 1. Errors after correction (unit: pixel).

Table 1 shows the residual errors after correction. The average, maximum and minimum values of the residual errors in latitude and longitude direction are recorded. In this table, the values in the longitude direction are greater than the one in the latitude direction because the elevation errors are in longitude direction. Both methods give high accurate correction results, but the residual errors after correction of the proposed method are smaller than the one of the precise geometric correction method. The smaller residual error values after correction proved that the proposed method is more accurate than the precise geometric correction method.

Figure 8 shows the correction result on a region of China where the elevation is 4831m. In this figure, the border of the black objects is found by precise geometric correction method and proposed method. The white border in the image corrected by the proposed method is more accurate than the one of the precise geometric correction method.



Precise method Altitude: 4831m Proposed method

Figure 8. Correction result

6. CONLUSION

A new geometric correction method considering the variation of elevation effect is proposed. The data in map coordinate system is divided into flat and rough blocks in order to identify the variation of elevation. Residual errors are specified in image coordinate system by GCP template matching and they are corrected based on the variation of elevation. Reference data can be used to calculate residual errors. Affine and RBFT is used to correct the residual errors on flat rough blocks respectively. For this reason, residual errors are corrected more precsisely. When transforming data into map coordinate system, bilinear interpolation is applied only on the flat blocks; satellite's parameters and earth's location are used to transform data on rough blocks. Therefore, the precision of this transformation process is higher.

The correction results of proposed method show that there are still errors after correction. In order to minimize these errors, elevation errors and residual errors need to be specified more precisely. In order to improve the correction result, a better method to specify and correct residual errors should be proposed.

7. REFERENCES

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