

Study on Geometric Correction for FY-2 S-VISSR Data

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ABSTRACT

FY-2 is the first generation of Chinese geostationary meteorological satellite. This paper proposes a simple and effective geometric correction method for FY-2 S-VISSR data. In this method, FY-2 normalized projective latitude and longitude comparison table (NPLLCT) is used as the reference image; FY-2 S-VISSR data is used as the input image. Firstly, 25×25 line-pixel coordinates of the input image is obtained from simplified mapping grid data of S-VISSR data. Secondly, the 625 corresponding points are found in NPLLCT according to latitude and longitude of the grid data. As a result, these corresponding point pairs are used as control points (CPs) for image correction. Finally, polynomial and projective transform models are used for geometric correction of FY-2 S-VISSR data, and then make a comparative analysis for accuracy of these models. Experiment demonstrates that fifth-order polynomial performs best among these models.

Keywords: FY-2, geometric correction, Mathematical models, accuracy analysis

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1 Introduction

FY-2 is the first generation of Chinese geostationary meteorological satellite. It can be used for continuous real-time observation on the variation of weather over China and her surrounding area, and plays an important in medium and long term weather forecast accurately [1]. FY-2C and FY-2D launched successfully in Oct 2004 and in Dec 2006 that means tow geostationary meteorological satellites locating west and east over China. Image correction is not only key technology of geosynchronous meteorological but also the basis of satellite quantitative product development and application [2]. In order to utilize FY-2 data to the time series analysis, the geometric correction with high-speed and high accuracy is needed. At present, there are two kinds of geometric correction methods for FY-2 S-VISSR data: one is to use the simplified mapping grid data, which obtains latitude and longitude by interpolating within grid points [3]. But, as the latitude and longitude in each grid cell varies greatly, the result of correction may include some errors [4]. Another is the systematic geometric correction using orbit and attitude information, which can transform map coordinate into image coordinate and transform image coordinate into map coordinate. However, In the case of FY-2, the methods of correction using orbit and attitude information has not been published in detail so far. Moreover, it may take long processing time for generating geometrically corrected image because the method is complex processing [5]. In this paper, we try to find a simple and effective geometric correction method for FY-2 image. Polynomial and projective transformation models are used for geometric correction of FY-2 image, and the best model is identified base on the accuracy from these models.

2 Data

2.1 FY-2 S-VISSR data

FY-2 is a spin stabilized geosynchronous meteorological satellites. It carries the stretched Visible Infrared Spin Scan Radiometer (S-VISSR), which has five channels, namely long wave infrared (IR1, 10.3~11.3 μm , IR2 11.5~12.5 μm), water vapor (IR3, 6.5~7.0 μm), medium wave infrared (IR4, 3.5~4.0), visible (VIS, 0.55~0.90) channels. FY-2 satellites are located on the geostationary orbit on the equator of 105°E (FY-2C) and 86.5°E (FY-2D). In an ideal condition, the orbit of the satellite should be in the equatorial plane; the axes of the satellite and the earth should be parallel [6]. But, in practice, the orbit of the satellite is not in the equatorial plane, and there are some geometric deformations in the S-VISSR data due to the changing of the satellite attitude (yaw, pitch and roll) [7]. As illustrated in Figure 1 which is exaggerated for clarity, these image deformations appear as vertical compression and expansion of the image, non-vertical alignment of the North and South Poles.

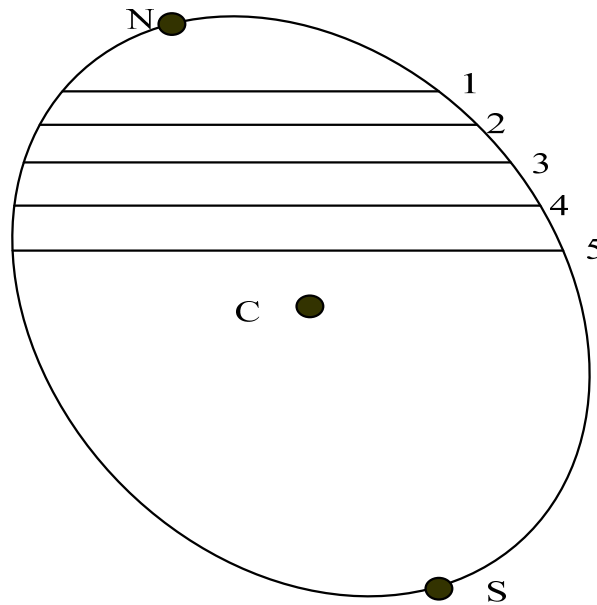


Figure 1. Exaggerated VISSR Image of Earth

These distortions may well be explained by considering Figure 2 which illustrates the same scan-lines on the projection plane of the earth. Again, for clarity, these scan-lines are depicted to be non-parallel and unevenly spaced to a degree more so than the realistic cases.

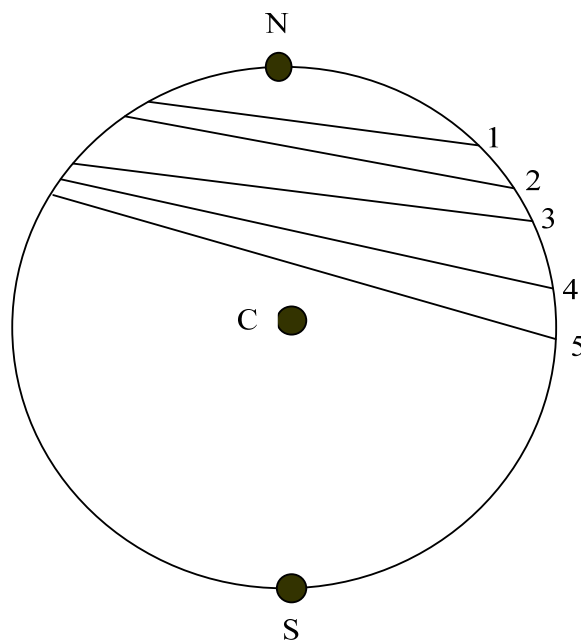


Figure 2. Projection Plane Image of Earth

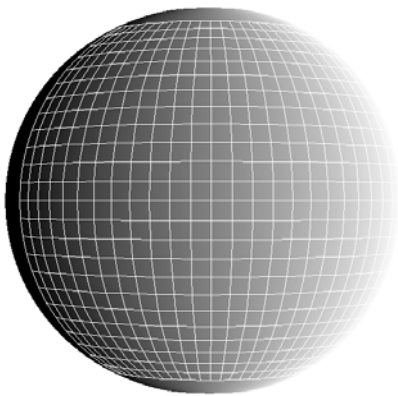
The geometric correction is applied to S-VISSR data, and geometrically corrected image on map coordinate is generated. As the map coordinate, there are the projections such as Mercator and polar-stereo. But, normalized projection, which will be describe in the following, is adopted as map coordinate for FY-2, because it is flexible and easy to transform into other projection.

2.2 Normalized projection

In an idea condition, FY-2C is located on the geostationary orbit on 104.5°E, 0°N; the axes of the satellite and the earth should be parallel, and scanning radiometer works without mismatch. At this time, the scanned image becomes NOM image, and the projection is called as normalized projection [8]. In practice, in order to facilitate users, FY-2 S-VISSR data is usually projected onto normalized projection. Normalized projection longitude and latitude comparison table (NPLLCT) and normalized projective image is one-to-one Correspondence, and provide the longitude and latitude of each pixel of normalized projective image. In this paper, NPLLCT is used as the reference image, and FY-2 S-VISSR data is used as the input image.

2.3 Simplified mapping grid data

FY-2 S-VISSR provides the simplified mapping grid data, which contains a part of list which indicates the mapping information between pixel coordinates and geographical coordinates. The mapping values indicate line numbers and pixel numbers of 25×25 grid points on an image, which correspond to the points on geographical coordinates of every 5 degrees between 60 degrees north and 60 degrees south of latitude and 45 degrees east and 165 degrees east of longitude. The simplified mapping grid data is shown in Figure 3.



(a) The simplified mapping grid

位置	类型	内容
1~2	1*2	60°N, 45°E 行号
3~4	1*2	60°N, 45°E 列号
5~6	1*2	60°N, 50°E 行号
7~8	1*2	60°N, 50°E 列号
...
101~102	1*2	55°N, 45°E 行号
103~104	1*2	55°N, 45°E 列号
105~106	1*2	55°N, 50°E 行号
107~108	1*2	55°N, 50°E 列号
...
2493~2494	1*2	60°S, 160°E 行号
2495~2496	1*2	60°S, 160°E 列号
2497~2498	1*2	60°S, 165°E 行号
2499~2500	1*2	60°S, 165°E 列号

(b) The format of the simplified mapping grid data

Figure 3. The simplified mapping grid data

3 Mathematical models

Mathematically, the correction process of satellite image is transformation problem. Many transformation models can be used, such as polynomial, affine, projective models and Rational Function Model. In this paper, Geometric Correction of FY-2 S-VISSR data do not consider the Elevation due to its low resolution. Two kinds of models were utilized due to their simplicity and availability within most of remote sensing software packages. These mathematical models include polynomials and projective models.

3.1 Polynomial models

Polynomial models usually can be used in the transformation between image coordinates and object coordinates. The needed transformation can be expressed in different orders of the polynomials based on the distortion of the image, the number of GCPs and terrain type [9]. A first-order transformation is a linear transformation, which can change location, scale, skew, and rotation, and transformations of the second-order or higher are nonlinear transformations that can be used to correct nonlinear distortions such as Earth curvature, camera lens distortion. The following equations are used to express the general form of the polynomial [10]:

$$\begin{aligned}x &= \sum_{i=0}^t \sum_{j=0}^i a_k \times X^{i-j} \times Y^j \\y &= \sum_{i=0}^t \sum_{j=0}^i b_k \times X^{i-j} \times Y^j\end{aligned}\quad (1)$$

Where, (x, y) is the input image coordinate and (X, Y) is the reference image coordinate; $k = \frac{i \times i + j}{2} + j$, t is order of the polynomials.

3.2 Projective models

Projective model express the relationship between two spaces based on perspective projection concepts. The basic elements of the perspective projection consist of the point of perspective center, bundle of arrays through this point and two different planes cut the bundle of arrays and do not contain perspective center. Projective model is expressed as follows:

10-parameter transformation model:

$$\begin{aligned}x &= \frac{a_0 + a_1 X + a_2 Y}{1 + a_3 X + a_4 Y} \\y &= \frac{b_0 + b_1 X + b_2 Y}{1 + b_3 X + b_4 Y}\end{aligned}\quad (2)$$

22-parameter transformation model:

$$\begin{aligned}x &= \frac{a_0 + a_1 X + a_2 Y + a_3 XY + a_4 X^2 + a_5 Y^2}{1 + a_6 X + a_7 Y + a_8 XY + a_9 X^2 + a_{10} Y^2} \\y &= \frac{b_0 + b_1 X + b_2 Y + b_3 XY + b_4 X^2 + b_5 Y^2}{1 + b_6 X + b_7 Y + b_8 XY + b_9 X^2 + b_{10} Y^2}\end{aligned}\quad (3)$$

38-parameter transformation model:

$$\begin{aligned}x &= \frac{a_0 + a_1 X + a_2 Y + a_3 XY + a_4 X^2 + a_5 Y^2 + a_6 X^2 Y + a_7 XY^2 + a_8 X^3 + a_9 Y^3}{1 + a_{10} X + a_{11} Y + a_{12} XY + a_{13} X^2 + a_{14} Y^2 + a_{15} X^2 Y + a_{16} XY^2 + a_{17} X^3 + a_{18} Y^3} \\y &= \frac{b_0 + b_1 X + b_2 Y + b_3 XY + b_4 X^2 + b_5 Y^2 + b_6 X^2 Y + b_7 XY^2 + b_8 X^3 + b_9 Y^3}{1 + b_{10} X + b_{11} Y + b_{12} XY + b_{13} X^2 + b_{14} Y^2 + b_{15} X^2 Y + b_{16} XY^2 + b_{17} X^3 + b_{18} Y^3}\end{aligned}\quad (4)$$

Where, (x, y) is the input image coordinate and (X, Y) is the reference image coordinate.

4 Methodology

The systematic geometric correction using orbit and attitude information can correct FY-2 S-VISSR data into map coordinate. But, it has not been published in detail so far, and it may take long processing time for generating geometrically corrected image [2]. In this paper, we try to find a simple and effective geometric correction method for FY-2 S-VISSR data. In our experiment, FY-2 NPLLCCT is used as the reference image; FY-2 S-VISSR data is used as the input image (Figure 4).

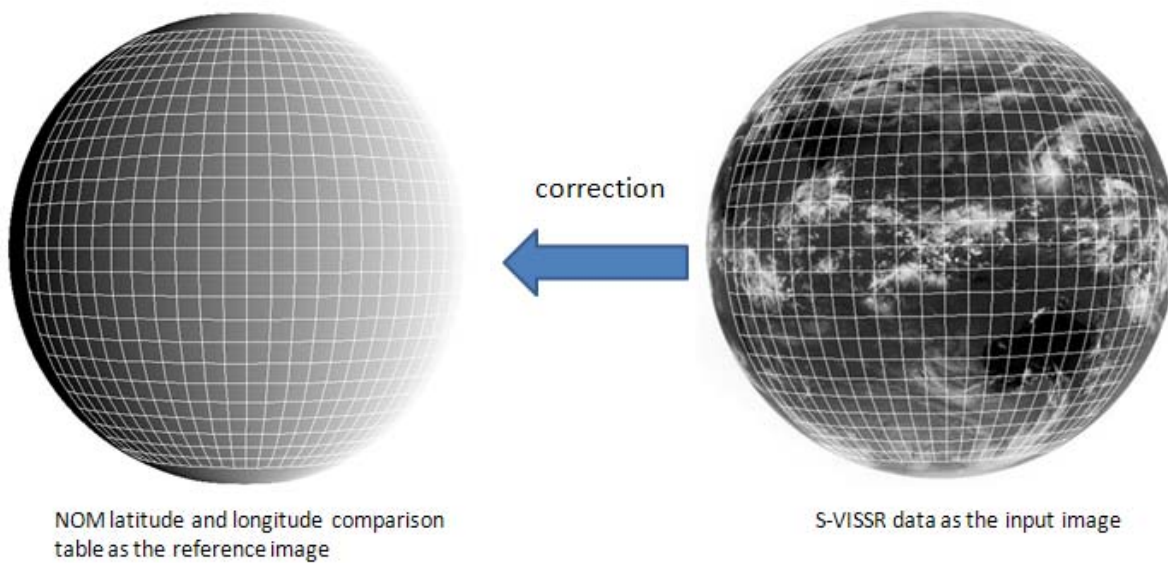


Figure 4. The principle of FY-2 S-VISSR data correction

Firstly, 25×25 pixel coordinates of the input image is obtained from simplified mapping grid data of S-VISSR. Secondly, the 625 corresponding points are found in NPLLCCT according to latitude and longitude of grid data. As a result, these corresponding point pairs are used as control points (CPs) for image correction. Finally, various kinds of mathematical models are used for geometric correction of FY-2 S-VISSR data, and then make a comparative analysis for accuracy of these models. The correction processing is shown in Figure 5.

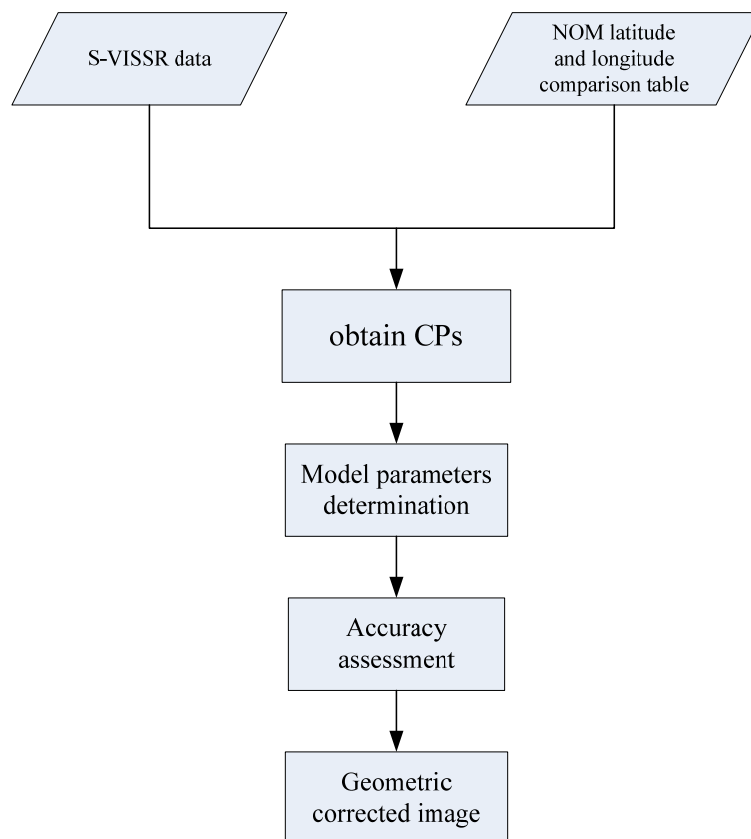


Figure 5. A flow of geometric correction for FY-2 S-VISSR data

4.1 Obtain CPs

The simplified mapping grid data of S-VISSR data provides 25×25 line-pixel coordinates of the input image corresponding Latitude and longitude grid points. We can calculate the line-pixel coordinates of corresponding points in the reference image by using Latitude and longitude of grid points in NPLLCT. As a result, 625 corresponding points are obtained between the input image and the reference image, and these corresponding points are used as the CPs for geometric correction.

4.2 Model parameters determination

In the proposed method, various kinds of mathematical models are used for geometric correction of FY-2 S-VISSR data. These mathematical models include first- to seventh-order polynomials and 10-parameter to 38-parameter projective model, and the parameters are determinate by least-squares method.

4.3 Accuracy assessment

After model parameters determination is completed, check points will be obtained for accuracy assessment. The root mean-square error (RMSE) between CPs after the transformation provides a measure of correction accuracy and is defined as :

$$RMSE = \sqrt{\frac{\sum_{n=1}^N ((x_{r,n} - x_{i,n})^2 + (y_{r,n} - y_{i,n})^2)}{N}} \quad (5)$$

Where, $x_{r,n}, y_{r,n}$ is the reference image coordinate and $x_{i,n}, y_{i,n}$ is the corrected image coordinate, N is number of CPs.

5 Experiment

In this study case, a FY-2C S-VIRRS data named FY2C_2009_10_09_06_01.vsr was used as the input image. Using the method present, 625 CPs were obtained between S-VIRRS and NPLLCT, then polynomial and projective transformation models were used for geometric correction. In order to assess the accuracy, we made a new image by resampling from global 1KM DEM data according to NPLLCT. The coastline of the new image and NOM image should overlap completely, so 20 check points were derived from the coastline of the new image (Figure 6). Table 1 shows the result for each mathematical model.

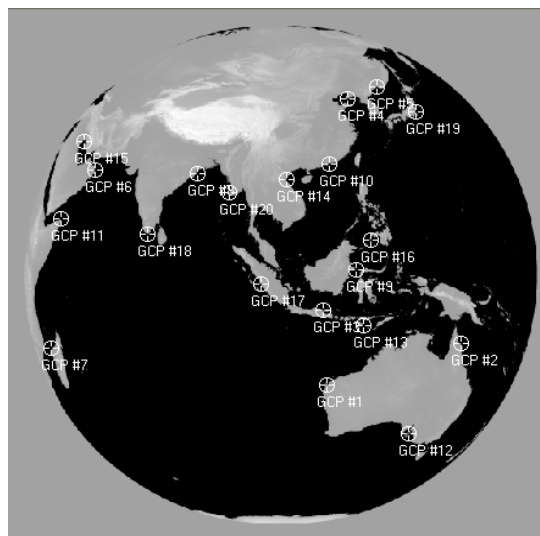


Figure 6 Check points

Table 1. The results from the mathematical models

Mathematical model	Control points (625)		Check points(20)	
	Maximum residual (pixel)	RMSE(pixel)	Maximum residual (pixel)	RMSE(pixel)
first-order polynomials	13.38	6.05	11.48	7.42
second-order polynomials	4.24	1.24	3.40	1.80
third-order polynomials	3.93	1.15	2.53	1.56
fourth-order polynomials	2.14	0.67	1.65	1.15
fifth-order polynomials	2.21	0.59	1.55	1.08
Sixth-order polynomials	1.46	0.50	1.52	1.07
seventh-order polynomials	1.48	0.48	1.53	1.07
10-parameter projective transformation	9.14	4.19	7.10	4.83
22-parameter projective transformation	9.96	4.19	6.57	3.43
38-parameter projective transformation	21.97	8.76	11.54	6.68

From the results obtained, it was found that the correction accuracy of polynomials were better than projective transformation. The correction accuracy had some improvement with the order of polynomials increasing. However, when the order of polynomials was more than 4, there was little improvement of the correction accuracy. Moreover, the higher the order of polynomials is, the more time the process need. Taking into account the accuracy and rate of the image correction, fifth-order polynomial performs best among these models. The RMSE of fifth-order polynomial achieved 1.07 pixels, and the processing time was about 1minute. The used computer was Dell OptiPlex 755 (CPU : E6550 2.33GH, Memory: 2GB). Figure 7 shows contrasts between the uncorrected image and corrected image.

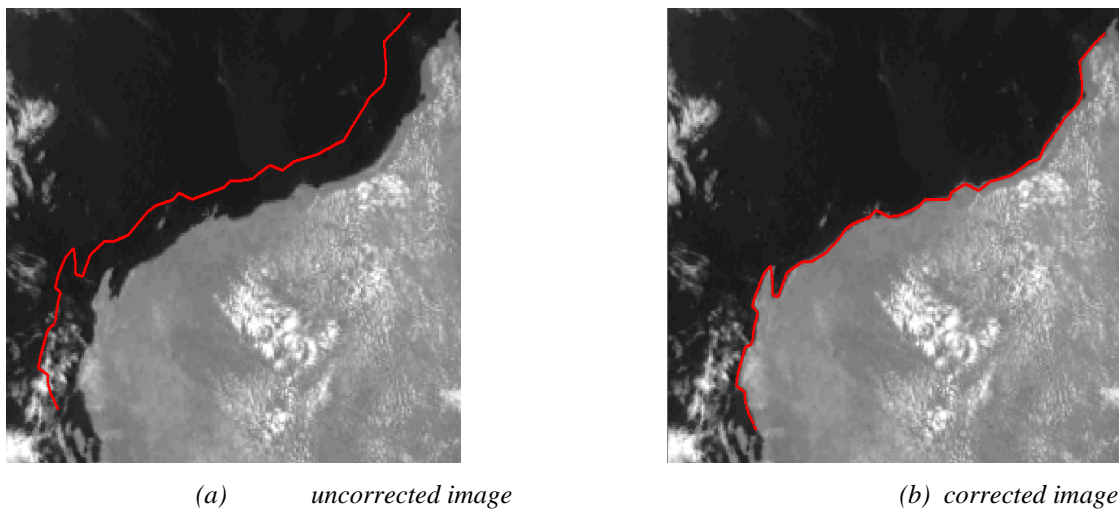


Figure 7. The contrasts between the uncorrected image and corrected image

6 Conclusion

In order to generate geometrically corrected image with the time series, this paper proposed a sample and effective geometric correction method. The main principle of the proposed method was that FY-2 S-VISSR data was corrected to normalized projective by using NPLLCT as the reference image. This paper presented an experimental assessment of various transformation models for FY-2 S-VISSR data. The assessment includes identifying the most suitable transformation modes for image correction. According to the experiments in this study, the result showed that the correction accuracy of polynomials were better than projective transformation, and Taking into account the accuracy and rate of the image correction, fifth-order polynomial gave the best image correction results (RMSE is 1.07 pixels).

In the future, the more precise correction will be carried out by using ground control points (GCPs). Moreover, the geometric correction considering the elevation will be developed and useful for land area.

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