FORMOSAT-2 GAIN MAP

Shih-Chieh Chou [*a] , Kuo-Hsien Hsu[b] and An-Ming Wu [c]

[a] Assistant Researcher, National Space Organization, 8F, 9 Prosperity 1st Road, Science Park, Hsinchu 30078, Taiwan; Tel: + 886-3-5784208#1729;

E-mail: jay@nspo.narl.org.tw

[b] Assistant Researcher, National Space Organization, 8F, 9 Prosperity 1st Road, Science Park, Hsinchu 30078, Taiwan ; Tel: + 886-3-5784208#1082;

E-mail: khhsu@nspo.narl.org.tw

[c] Senior Researcher, National Space Organization, 8F, 9 Prosperity 1st Road, Science Park, Hsinchu 30078, Taiwan; Tel: + 886-3-5784208#1033;

E-mail: amwu@nspo.narl.org.tw

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ABSTRACT: Since the FORMOSAT-2 satellite was launched in 2004, it has conducted the mission for 7 years, and has imaged over the most areas around the world. Although the gain selection is according to the gain map of the SPOT satellites, it is sometimes modified for acquiring clear images. In this paper, we plot the FORMOSAT-2 gain map of four seasons from the gain selection for the imaged areas, and investigate the evolution of the radiometric characteristics in 7 years. Being different from SPOT satellite based on the grid, we mark on targets with colors corresponding to the gain values from 1 to 10 to form a map. This approach is more suitable for FORMOSAT-2, since its imaging not according to the grid, and there is only target information in the database.

FORMOSAT-2 gain map can be used to improve the image quality, and can be also used as references of gain selection for the future FORMOSAT-5 mission. We propose an interpolation algorithm with arbitrary number of points, which is the least-squares rational polynomial interpolation of one point using the neighboring points in a rectangle. This algorithm is easily to determine the neighboring points, allows non-uniform distribution of the known points, and is adaptive to a large range of numbers of points. If there are enough neighboring points, we can even screen out some points according to the attributes, for example, city, forest, desert, or ocean.

1. Introduction

FORMOSAT-2 satellite was launched on May 20, 2004, and is operated on a Sun-synchronous orbit of 14 rev/day. It is currently the only one satellite with daily revisit and global coverage, since it possesses features of daily repeat, high altitude, and large field of regard. The image taken by the remote sensing instrument (RSI) on board is in the nadir direction with a swath width of 24 km and is with a field of regard of ±45 deg for along-track and cross-track viewing. RSI provides images for 2 m ground sampling distance (GSD) in panchromatic band and 8 m GSD in four multispectral bands. The satellite images with duty cycle of 8% in every orbit period of 102.9 minutes. FORMOSAT-2 is able to quickly and intensively respond to take images for 14 strips of worldwide areas, and is also able to periodically generate the whole Taiwan image map in one season to satisfy the various needs.

The satellite possesses the features of daily repeat, high altitude, and large field of regard, and has demonstrated that it is currently the only high-resolution satellite having capabilities to daily image anywhere worldwide. The daily repeat of FORMOSAT-2 simplifies operations, scheduling, and processing. Furthermore, the users can easily request imaging for urgent needs.[A.M.Wu 2010]

FORMOSAT-2 has taken the first images and is continuously monitoring after large disasters over the world to support the aftermath relief and precaution of secondary disasters. For example, the southern Asia tsunami on 2004.12.26, the Wilkins Ice Shelf disintegration on 2008.2.28, the Sichuan earthquake on 2008.5.12, the typhoon Morakot over Taiwan on 2009.8.8, the Haiti earthquake on 2010.1.12, the Chile earthquake on 2010.2.27, and the Japan tsunami on 2011.3.11.Since the satellite was launched in 2004, it has imaged over the most areas around the world. Although the gain selection is according to the gain map of the SPOT satellites, it is sometimes modified for acquiring clear images. In this paper, we plot the FORMOSAT-2 gain maps of twelve months in one year from the gain selection for the imaged areas, and investigate the evolution of the radiometric characteristics in 7 years. The gain maps can be used to improve the image quality, and is aimed to be used in the gain selection for the future FORMOSAT-5 mission.

2. RSI Radiometric model

The Formosat-2 RSI radiometric model is described as follows (Astrium 2001) :

$$C(b,p,G(b,j),R(b)) = A(b,p,G(b,j)) \cdot R(b) + N(b,p,G(b,j),R(b)) + C(b,p,G(b,j),0) \qquad (1)$$

where b = 0 for panchromatic band and b = 1, 2, 3, 4 for multispectral bands; p ranges from 1 to 12000 for panchromatic band and p ranges from 1 to 3000 for multispectral bands; $G(b,j)$ is the user selectable gains for the spectral band b

$$G(b,j) = \left(\sqrt{2}\right)^{j-1} \qquad (2)$$

Gain number, j, ranges from 1 to 10; $R(b)$ is the mean radiance level of the scene in the b spectral band in the unit of $Wm^{-2}sr^{-1}m^{-1}$; $C(b,p,G(b,j),R(b))$ is the 8-bit output signal; $A(b,p,G(b,j))$ is the overall conversion factor from the input radiance to the output signal code; $N(b,p,G(b,j),R(b))$ is 8-bit detected noise. $C(b,p,G(b,j),0)$ corresponds to the offset of the output code. It is obtained by averaging over a large number of lines (typically 500 consecutive lines), which is recorded in darkness ($R(b)$=0) for each gain $G(b,j)$ without the noise term. $A(b,p,G(b,j))$ can be expressed as:

$$A(b,p,G(b,j)) = \rho(b,p) \cdot K(b) \cdot G(b,j)\,. \qquad (3)$$

where $K(b)$ is the mean conversion factor over the whole set of pixels of that band; (b,p) is the relative response of each pixel compared to $K(b)$. Except for gain number, j, all parameters of RSI radiometric model are directly derived according to RSI characteristics performed by regular RSI radiometric calibration. Gain number, j, is controlled by the concept of database, which is called gain map. In the next subsection, we describe the operation and maintenance of the gain map briefly.

3. Gain Map Operation and maintenance

To obtain optimal output signal of FORMOSAT-2 RSI radiometric model, a proper gain number need being provided accordingly. French space agency CNES derives such number by using the BDHS (Base de Données des Histogrammes SPOT) which is a database stores the histogram of all cloud-free images taken by SPOT satellites. The database is operationally used to deduce the satellite programming gains, depending on the date and the location of target. Furthermore, a specific conversion method to generate FORMOSAT-2 gain map from BDHS was described (CNES 2007) mainly by considering the difference between visible and near infra-red spectral bands as well asthe orbit characteristics between Formosat-2 and SPOT satellites. Figure 1 shows that the comparison of FORMOSAT-2 and SPOT5 bands (CNES 2007). The reflectance of each FORMOSAT-2 spectral was considered to be composed of SPOT5 bands with different weighting factors. Then the Top of Atmosphere radiance observed by FORMOSAT-2 could be estimated according to lambertian model. The optimum gain number could be determined by radiometric model.

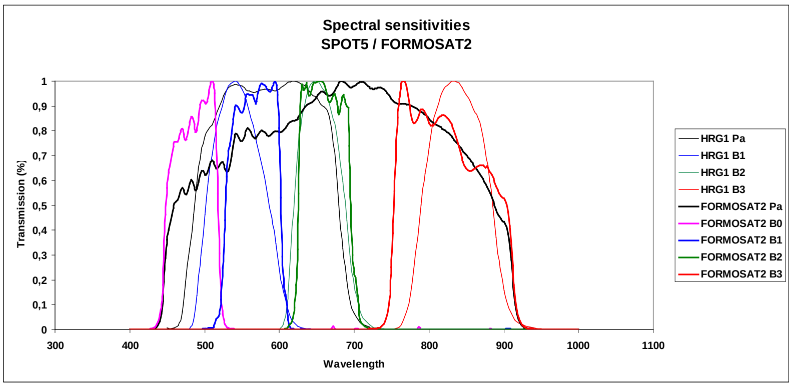

Figure 1 Comparison of SPOT5 and FORMOSAT2 spectral sensitivities

Currently, the gain file was provided the optimum gain for 60 km grid elements and there are more than 140 thousands gain numbers (grids) distributed on the worldwide basis with monthly variation as shown in the Figure 2. However, due to insufficient global SPOT BDHS data, gain numbers over some regions are derived by using interpolation methods.

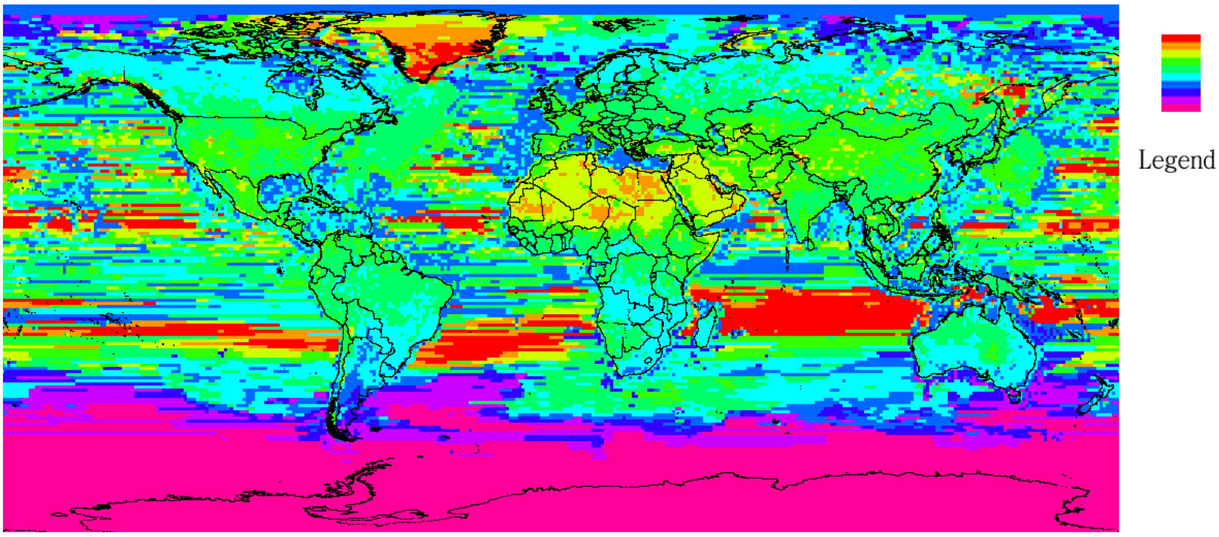

Figure2 . Contour plot of Gain Map of August

Figure 3 present the general procedure of gain number adjustment, for current FORMOSAT-2 gain map operation, the gain value is generated depending on the scheduled acquisition date, location of interesting area and satellite programming parameter. Then the image quality will be examined. Finally, the gain value will be modified if necessarily. In order to trace the correctness of predicted gain number for FORMOSAT-2 images, all images of each spectral bands are finally examined by analyzing the histogram distribution. The histogram distributions of example images are shown in Figure 4. The whole image was partitioned into different sub-image according to ground feature. Then by analyzing the dynamic range of the histogram, a proper gain value will be evaluated.

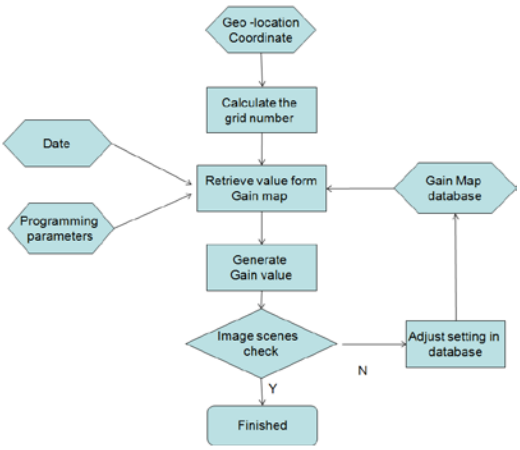

Figure 3. Flowchart of FORMOSAT-2 gain map operation

Obviously, a better histogram distribution of image is observed if gain number is selected properly. Improper gain number of an image is immediately adjusted for next acquisition. The adjustment of gain number is processed according to the performance of histogram distribution and customers' requests. The performance of histogram distribution strongly depends on situations such as practical weather (seasonal) effect, cloud coverage, and improper default gain number, etc. However, an improper default gain number sometimes provides a very good reference for adjustment. Since 2004, FORMOSAT-2 has been imaged the land areas more then 800 million square kilometers of earth surface. Gain numbers of those imaged areas also have been properly validated and updated for next acquisition. In other words, the cost of labor-intensive procedure for gain number adjustment has been decreased gradually as more lands have been imaged.

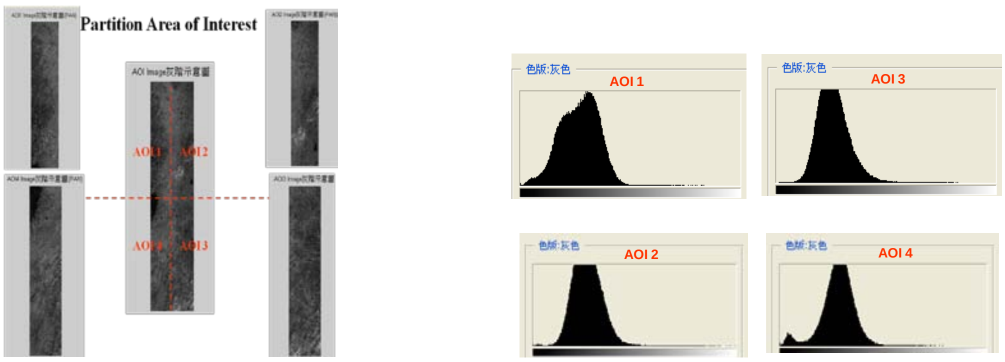

Figure 4(a) Quick-look Image of Panchromatic (b) Histogram distribution of Image

4. FORMOSAT-2 Gain Map.

4.1 Gain map Distribution

According to the experience of FORMOSAT-2 satellite operation over seven years, NSPO not only built the knowledge of histogram according to the ground feature, solar elevation and satellite programming parameters but also obtained the abundant feedback from the end-user of various applications. The proper gain value database has been established gradually by utilizing could-free and wide dynamic range image data. Each value of different spectral band is associated with a geographic coordinate, a date of month and a satellite viewing angle. The geographic distribution is non-uniform and the value is unequally spaces of each other. During seven years mission period, there are more than 13,722 acquisitions of image have been taking into account by now. In general, the higher value density of distribution, the more knowledge information of image radiometric prosperities. Furthermore, a total of more than 1,200,000 square kilometers in the Polar Region had been imaged by FORMOSAT-2, therefore, the gain value of high latitude, which do not exist in the CNES histogram database, was also established. The world wide distribution of gain value for panchromatic band in whole year was shown in the Figure 5. It shows that the gain value geographic shifts gradually according with the season.

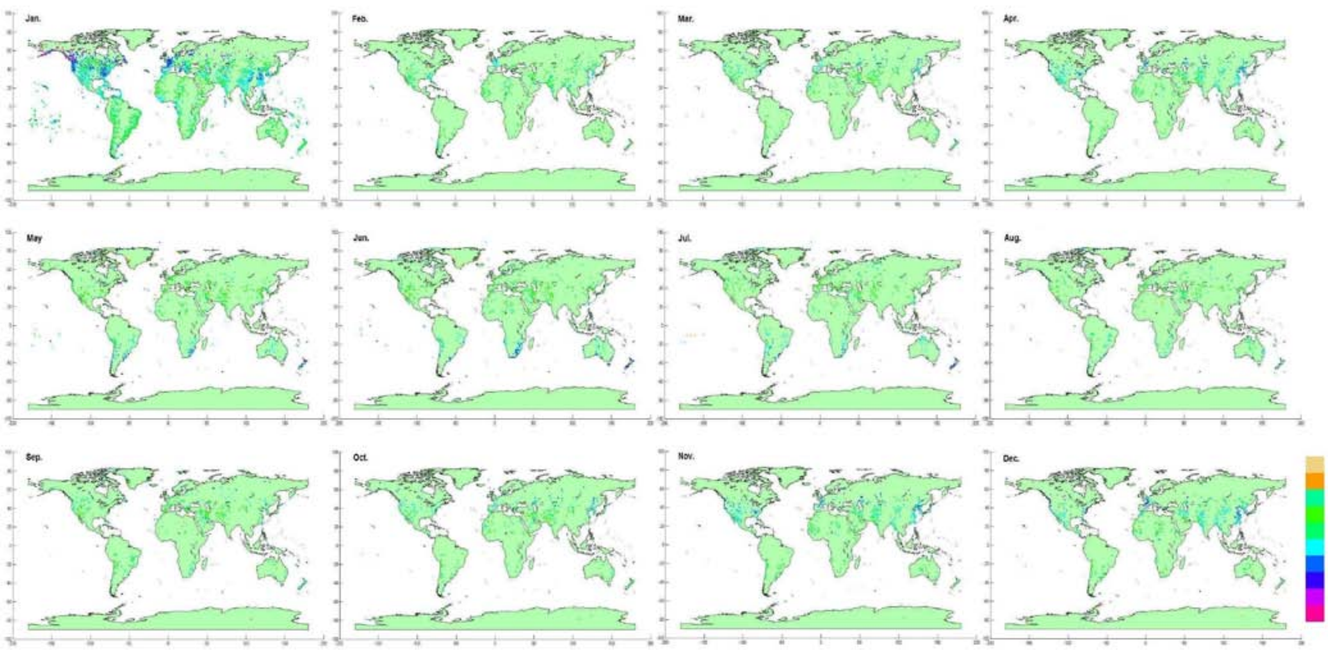

Figure 5 the FORMOSAT-2 Gain map variation for panchromatic band during 12 month

4.2 **Interpolation algorithm**

Based on the record of FORMOSAT-2 acquisition over 7 years, NSPO has built its own gain value database around the world. These data randomly distribute around the world according to the FORMOSAT-2 activity. Unlike the concept of CNES gain map which provides cell dataset with equally spacing between cells, we derive the value according to an irregular spacing dataset. Beside the characteristics of RSI, a proper gain value also depends on ground feature, illumination and weather condition. Therefore, we assume that the gain value of specific area is highly correlated with the geo-location area of the neighbor because they have similar exterior condition. The gain value function, which varies with geo-location, could be described as a smooth surface. We develop a procedure of determining such function that takes on specific gain-value at given location.

Rational Polynomial Function

By utilizing the gain database with irregular spacing between each other, we develop the procedure of using known data values to estimate unknown data values. A straightforward method requires knowledge of the points in the certain extent In general, polynomial function is the most convenient approach for numerical efficiency. In order to evaluate the function involving the polynomial approximation, the state-of-the-art methods are using rational function. It performs the transformation between geodetic coordinate and gain-value through the ratio of two polynomials. The general form of second order polynomial is

$$g = \frac{a_{00} + a_{10}x + a_{01}y + a_{20}x^2 + a_{02}y^2 + a_{11}xy}{1 + b_{10}x + b_{01}y + b_{20}x^2 + b_{02}y^2 + b_{11}xy} \qquad (4)$$

which is called Rational Polynomial Function (Tao), where x and y are the longitude and latitude coordinate on the earth; g is the gain value and a_{ij}, b_{ij} are the polynomial coefficients. In this model, there are 11 terms, including 6 terms in the numerator and 5 terms and 1 constant in the denominator. In order to solve the coefficients, at least 11 geo-positions are required.

Given known coordinates x_n, y_n (n >11) of geo-location and the corresponding gain-value, the unknown coefficients can be expressed as a linear equation. This over-determined system could be solved by least-squares estimation.

The normal equation is

$$A \bullet \theta = G$$

Where

$$A = \begin{bmatrix} 1 & x_1 & -gx_1 & y_1 & -gy_1 & x_1y_1 & -gx_1y_1 & x_1^2 & -gx_1^2 & y_1^2 & -gy_1^2 \\ 1 & x_2 & -gx_2 & y_2 & -gy_2 & x_2y_2 & -gx_2y_2 & x_2^2 & -gx_2^2 & y_2^2 & -gy_2^2 \\ . & . & . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . & . \\ 1 & x_n & -gx_n & y_n & -gy_n & x_ny_n & -gx_ny_n & x_n^2 & -gx_n^2 & y_n^2 & -gy_n^2 \end{bmatrix} \quad \theta = \begin{bmatrix} a_{00} \\ a_{10} \\ b_{10} \\ a_{01} \\ b_{01} \\ a_{11} \\ b_{11} \\ a_{20} \\ b_{20} \\ a_{02} \\ b_{02} \end{bmatrix} \quad G = \begin{bmatrix} g_1 \\ g_2 \\ g_3 \\ g_4 \\ g_5 \\ g_6 \\ g_7 \\ g_8 \\ g_9 \\ g_{10} \\ g_{11} \end{bmatrix}$$

The Least square estimator is $\theta = (A^T A)^{-1} A^T G$ (5)

The Figure 6 shows that the general procedure of determining the gain value from non-uniform distribution points for the arbitrary geo-location points by using the second order Rational polynomial function.

The Figure7 present the illustration of interpolation method, if we want to estimate the gain value in the geographic coordinate of longitude = 121.48 and latitude = 31.20 , there are 18 targets within radius of 2.539 radian. By using equation (5), we could obtain θ, which is the coefficient of both numerator and denominator in equation (4). The gain value is calculated according to equation (4).

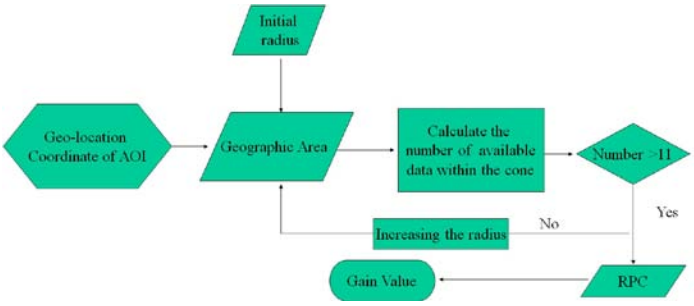

Figure 6 Procedure of determining Gain Value

Figure 7 Illustration of interpolation method

5. Conclusions

We describe the development of FORMOSAT2 gain map and current status of gain map operation. Meanwhile, we also propose an interpolation algorithm used to predict the gain value base on the information in the neighborhood. Up till now, there are more than 13,000 cloud-free images available to taken into account to estimate unknown gain value for given specific geographic coordinate. It is expected that the amount of data in gain value database will increase with ongoing FORMOSAT-2 missions. Those data not only improve the image quality but also provide a good reference for future FORMOSAT-5 missions.

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