FORMOSAT-2 IMAGING SIMULATION AND GEOMETRIC ERROR ANALYSIS

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ABSTRACT: FORMOSAT-2 satellite has the capability of daily revisit and global coverage, and provides images with a panchromatic band resolution of 2 m and multispectral band resolution of 8 m. Since its launch in 2004, the satellite has taken first-time images and provided continuous monitoring for many large events around the world. To provide a quick response to support disaster relief operations, the FORMOSAT-2 team began, in 2010, to deliver image products in KML format for GoogleEarth overlay. Since the geometric data of the FORMOSAT-2 image is calculated from the orbit, the attitude and the camera model, misregistration often occurs when overlaid, thus requiring a further geometric correction. In this study, we take the images over the duration of one day and collate them into one strip. Further this is repeated so that we have 14 image strips for 14 orbits around the world. When one image is overlaid in GoogleEarth, we read two sets of coordinates of four landmarks, and find the least-squares affine transformation from FORMOSAT-2 image to the GoogleEarth image. We calculate the coordinates of the four vertices in GoogleEarth as references, and denote the average of the errors of the four vertices as the processing error. From the distribution of the errors of the 14 images, we can then estimate the systematic error and random error. Furthermore, we simulate the FORMOSAT-2 imaging geometry using Satellite Tool Kit Software (STK) with high precision orbit propagator (HPOP), and obtain the simulation errors when compared with the GoogleEarth. The vector correlation coefficients are calculated for the processing and simulation errors. The sufficient accuracy of STK simulation in the orbit, the attitude, and the projection shows that the method can further be used to calibrate the camera model.

1. INTRODUCTION

FORMOSAT-2 Earth observation satellite is currently heading in its eighth year of service. The high inclination and high altitude orbital radius, coupled with a high resolution remote sensing instrument providing panchromatic band resolution of 2 m and multispectral band resolution of 8 m endows the mission with the capability of daily revisit, polar area imaging and global coverage. Since its launch in 2004, the satellite has provided extensive amount of images which include many of the first-time response and continuous monitoring for many events around the world [1]. Two typical images taken from FORMOSAT-2 are presented below where Figure 1 is the image of Christchurch taken just one day after the New Zealand earthquake of September 2010 and Figure 2 are images of Sendai Airport which presents features before and after the earthquake and tsunami that hit north-east Japan in March 2011.

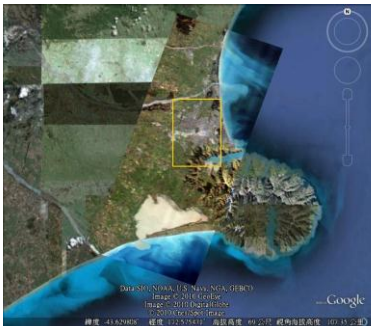

Figure 1 FORMOSAT-2 image of Christchurch on 2010.9.5 following 2010.9.4 earthquake in New Zealand

Figure 2 FORMOSAT-2 images o f Sendai Airport taken before (2011.3.11) and after (2011.3.13) Japan tsunami and earthquake (2011.3.11)

In order to provide images in a more efficient way, the image processing system (IPS) of Taiwan's National Space Organisation (NSPO) commenced last year to apply GoogleEarth map as the medium to provide images for end users. This is achieved through the function of KML image overlay, thus the information of the images can be easily presented on GoogleEarth. The objective of this study is to understand the relation of geometric error between FORMOSAT-2 images and STK simulation when both of them are analysed based on the GoogleEarth coordinates. Through the application of least-square affine transformation, from the shift of certain obvious landmarks we can find the transformation between the images and GoogleEarth system and further define the misregistration. Having obtained these two results, we implemented correlation analysis to understand whether there exists any event that results in the misregistration.

The paper is presented in the following order. Imaging processing case will be examined first; this includes the introduction of IPS operations, affine transformation and the image overlay on GoogleEarth which are followed by the obtained error results. Then, we discuss STK simulation case which starts from a brief STK overview and then presents the simulation result which are displayed on STK 2D Graphics and then outline the error result. Finally, the numerical analysis of error correlation is performed.

2. IMAGING PROCESSING

IPS has been implemented by NSPO to handle imaging scheduling, data ingestion, data processing, and data management. After receiving requests from the end-users, the system generates the tasking schedules according to the area to be viewed, and informs the Multi-Mission Centre (MMC) to command the satellite for imaging and downloading the payload data. The data are ingested as raw images, and radiometrically and geometrically corrected to generate the standard products, which can be accessed by the users through the management web site.

In this study, we took the scheduled imaging data on 2011.06.08, one clear image was chosen as the sample object from each of the 14 orbits, shown in Figure 3. And the details of the 14 selected images are highlighted in Table 1.

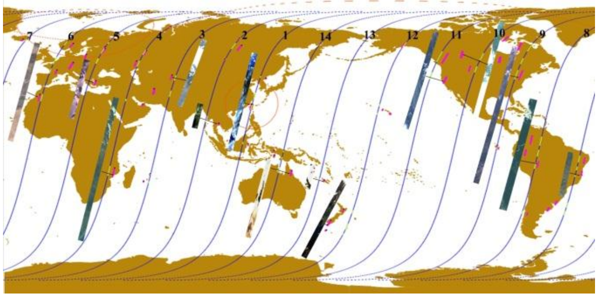

Figure 3 Schematic of selected images distribution

To define the differences between the real images and the relative positions on GoogleEarth [2], we first applied images overlay. Figure 4 below shows an example of image overlay and if we zoom in to inspect in more detailed, as highlighted in Figure 5 and Figure 6 which are the southwest coast of image in Figure 4, we can see that there is an apparent displacement of the cape. We marked the location on GoogleEarth as G tag and the location on FORMOSAT-2 image as F tag respectively.

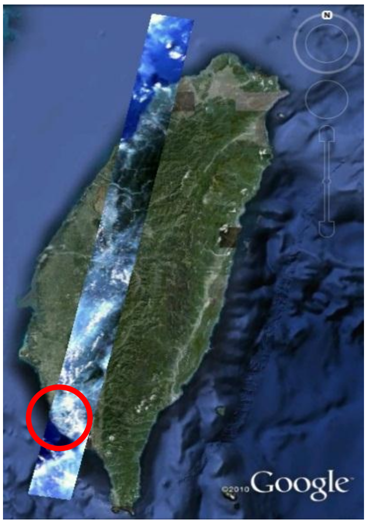

Figure 4 GoogleEarth overlay of orbit 1 FORMOSAT-2

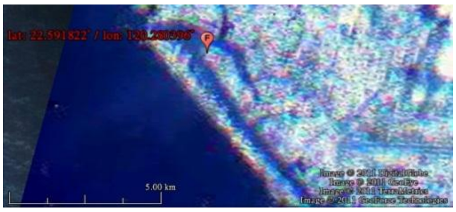

Figure 5 FORMOSAT-2 image - southwest coast of Figure 4

Figure 6 GoogleEarth image - southwest coast of Figure 4

Table 1 Selected Schedule on 2011.06.08

Orbit	**Target**	**Imaging Time (UTC)**	**Imaging Duration (Sec)**	**Yaw Angle (˚)**	**Pitch Angle (˚)**	**Roll Angle (˚)**
1	Taiwan3	01:58:30	65	0	37.875446	-3.12387
2	Si Racha, Thailand	03:45:58	21	0	3.748508	42.527849
3	Kygyztan_48_57	05:21:10	50	0	-1.801095	-12.066185
4	Mozambique_408_429	07:19:48	97	0	1.460434	19.55637
5	Mithatpasa Mh, Turkey	08:47:26	45	0	1.398563	20.517447
6	Ksar of Ait-Ben-Haddou, Morocco	10:33:02	70	0	-0.549214	-8.36816
7	Southern Bahia_51_56, Brazil	12:28:29	33	0	12.183608	20.79662
8	Amazon basin_1515_1533	14:10:38	60	0	-8.83802	11.088886

9	Casselman(Ontario), Canada	15:37:23	95	0	-3.757393	14.280342
10	Fort McMurray, Canada	17:17:15	70	0	-1.647853	-39.576615
11	Hackamore, USA	19:03:32	70	0	2.542473	39.36926
12	Arrowtown, New Zealand	21:12:44	60	0	-1.511585	-40.67255
13	Hienghene (New Caledonia), France	22:47:37	21	0	1.298051	19.691995
14	York Cape Peninula_443_454, Australia	+1 00:28:34	57	0	3.225547	40.325169

As marked in Figure 5 and Figure 6, we look for four set of landmarks in total on each image, as showed in Figure 7, and tag them separately to read their coordinates.

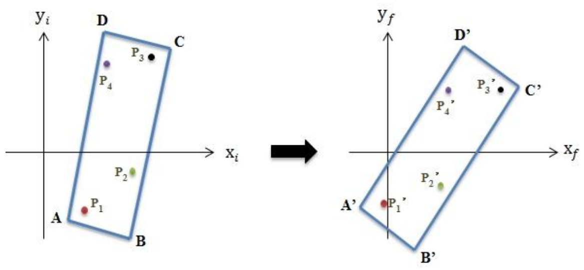

Figure 7 Schematic of image adjustment

The data are then considered as two groups of givens which can be substituted to find the least-square affine transformation from FORMOSAT-2 images to GoogleEarth images as following form [3].

$$\begin{cases} x_f = ax_i + by_i + c \\ y_f = \alpha x_i + \beta y_i + \gamma \end{cases} \tag{1}$$

Using Matlab software [4], we repeated this process for every selected sample to obtain the transformation and further to find the four relative vertices coordinates of the images on GoogleEarth. The image after adjustment is presented in Figure 8. The mean error can then be computed and if we plotted the data into vector form, the result is presented in Figure 9 below where a significant large error value on Orbit 10 can be distinguished.

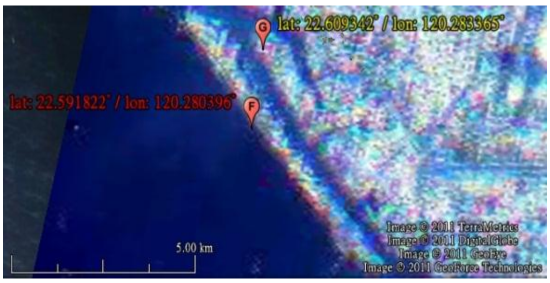

Figure 8 Image after affine transformation

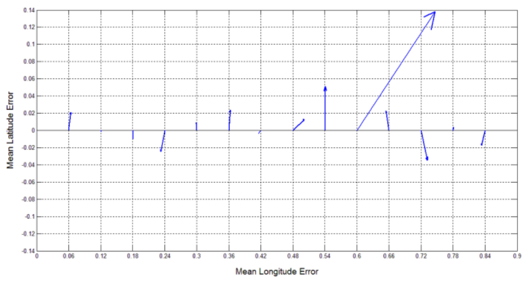

Figure 9 Error vectors of image processing case

3. STK SIMULATION

STK [5] is an off the shelf software product developed by Analytical Graphics, Inc., which can be applied to model the system, analyse mission application and provide customisable report and data for space mission design, military defence and intelligence engineering. In this research, we applied STK to produce another set of comparison. The HPOP model is applied to run the computation and the VVLH coordinate is selected when assigning attitude data. The simulation obtained is shown in Figure 10, where the black sections show the periods when the satellite performs an attitude change to record ground images while the red areas correspond to the scheduled targets to be monitored. We export the swath points to obtain the four corner coordinates of each sensing area. The mean errors can then be computed again and are plotted in Figure 11. Each error data presents slight different on size and direction from the error vectors in previous case but the error at orbit 10 remains larger than others.

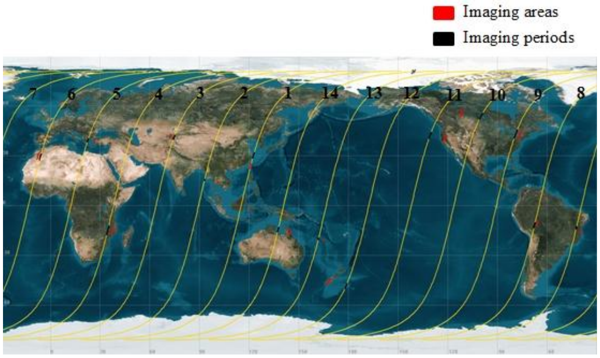

Figure 10 STK simulations of selected imaging events

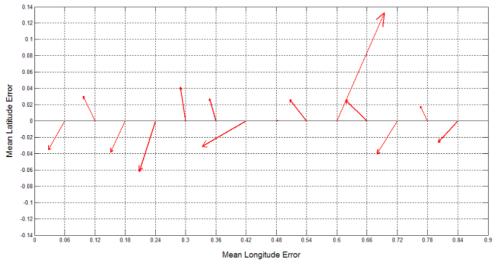

Figure 11 Error vectors of STK simulation

4. ERROR ANALYSIS

Two errors are plotted together in Figure 12.

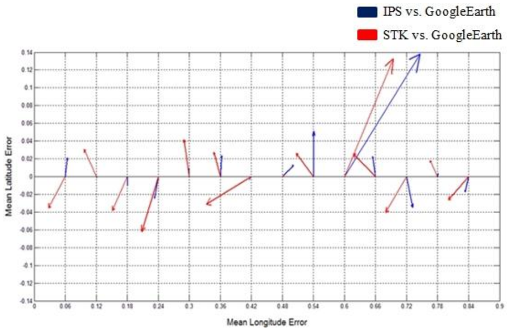

Figure 12 Error vectors plot

To discuss the correlation [6], we investigate the means, the variances, the covariances and the correlation coefficients of the two types of the errors. Assume:

$$W_1 = \begin{bmatrix} u_1 \\ v_1 \end{bmatrix}; \quad W_2 = \begin{bmatrix} u_2 \\ v_2 \end{bmatrix} \tag{2}$$

W_1 is composed of two mean errors of case 1 while W_2 is the same data of case 2.

The Vector Correlation Matrix $\Sigma_{W_1W_2}$ is defined and evaluated as follows.

$$\sum_{W_1W_2} = \begin{bmatrix} \sum_{11} & \sum_{12} \\ \sum_{21} & \sum_{22} \end{bmatrix} = \begin{bmatrix} \sigma_{u_1u_1} & \sigma_{u_1v_1} & \sigma_{u_1u_2} & \sigma_{u_1v_2} \\ \sigma_{v_1u_1} & \sigma_{v_1v_1} & \sigma_{v_1u_2} & \sigma_{v_1v_2} \\ \sigma_{u_2u_1} & \sigma_{u_2v_1} & \sigma_{u_2u_2} & \sigma_{u_2v_2} \\ \sigma_{v_2u_1} & \sigma_{v_2v_1} & \sigma_{v_2u_2} & \sigma_{v_2v_2} \end{bmatrix} = \begin{bmatrix} 0.00157 & 0.00140 & 0.00138 & 0.00145 \\ 0.00140 & 0.00178 & 0.00130 & 0.00181 \\ 0.00138 & 0.00130 & 0.00155 & 0.00153 \\ 0.00145 & 0.00181 & 0.00153 & 0.00249 \end{bmatrix} \tag{3}$$

Where $$\mu_v \equiv \frac{1}{n}\sum_{i=1}^{n} u_i; \quad \mu = M = Mean$$

$$\sigma_{uu} = \sigma_u \equiv \frac{1}{n-1}(u_i - \mu_u)^2; \quad \sigma_{uu} = Variance\ of\ u \quad and \quad \sigma_{uv} \equiv \frac{1}{n-1}(u_i - \mu_u)(v_i - \mu_v); \quad \sigma_{uv} = Covariance\ of\ u\ and\ v$$

As for correlation coefficient, two kinds of definitions are available for data in vector form and the values are:

$$\rho^2_D = \frac{Tr(\sum_{12})^2}{Tr(\sum_{11})\,Tr(\sum_{22})} = 0.7527 \tag{4}$$

$$\rho^2_v = Tr(\sum_{11}^{-1}\sum_{12}\sum_{22}^{-1}\sum_{21}) = 1.6409 \quad (5)$$

According to the definition of these two coefficients, the parameter $\rho_D{}^2$ is a normalised number which ranges from 0.0 to 1.0; therefore, to compute ρ_D, we simply do the square root of $\rho_D{}^2$; however, $\rho_v{}^2$ has not been normalised and the range of its value is between 0.0 and 2.0. So when finding ρ_v, we need to first divide $\rho_v{}^2$ by 2 and then take its square root. Following these calculations, ρ_D and ρ_v turn out to be: $\rho_D = 0.8676$ $\rho_v = 0.9058$

Table 2 Properties of Correlation

Parameter	**IPS**	**STK**
LonMeans μ_u	0.011842	-0.021444
LatMeans μ_v	0.013530	0.005034
LonVariance σ_{uu}	0.00157	0.00155
LatVariance σ_{vv}	0.00178	0.00249
ρ_D	0.8676	
ρ_v	0.9058	

It can be seen that both of the values are quite close to 1.0 where larger value indicates the more coincident for two sets of data. The second coefficient ρ_v is greater due to its extensive characteristic as it is invariant under rotation and scaling effects.

5. CONCLUSION

The terrain model is not considered in this paper. The large values of the orbit 10 image are probably due to a lack of accuracy there in GoogleEarth. Rational polynomial function can be applied to obtain a better solution [7,8]. From the obtained correlation coefficients, the larger value of the second coefficient indicates that the errors in the STK simulation are result from rotation or scaling which may be caused by the neglect of the effect of camera model. Therefore, sufficient accuracy in the orbit, the attitude, and the projection of STK is presented, which can further be used to calibrate the camera model for missions.

6. REFERENCE

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