SIMULATION AND ANALYSIS OF SATELLITE SMART AGILITY IMAGING SYSTEM

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KEY WORDS: Smart Agility Imaging Mode, Attitudes Alter Dynamically, Errors Simulation and Analysis, Geometric Correction.

ABSTRACT: High resolution satellite imagery has been widely used in surveying, mapping, and environmental monitoring, etc. It could truly record the ground scenes and provide large amount of earth surface information. However, satellite's orbit is always fixed and stable, and the scan direction is usually parallel to the orbit. Therefore, sometimes high resolution satellite's images won't cover the regions which we have interest in. In that case, we might need to mosaic several images from different orbits into a new one, and this causes lots of problems such as geometric correction and color balancing.

Smart Agility Imaging Mode (SAIM) which was proposed by NSPO can alter satellite's attitudes dynamically during image acquisition. With this mode, satellite's scan direction and orbit can be unparallel. In the same period of satellite's movement, the region of image can be different. If this mode can be used wisely, satellite image's acquisition and application should be more flexible and effective.

In this study, the characteristics and the mechanism of SAIM are firstly introduced. The orbits and possible imaging regions are simulated according to the dynamically varying attitudes of satellites. Finally, the surface images are simulated and possible errors are analyzed for further applications.

1. INTRODUCTION

High resolution satellite imagery has been widely used in surveying, mapping, and environmental monitoring, etc. The characteristic of satellite image is that satellite's orbit is always fixed and stable, and the arrangement of image acquisition is relatively simple. However, since the satellite's orbit is fixed, the region of satellite image affect by the scan direction. Most satellite's scan direction is usually parallel to the orbit; therefore the image acquisition and usage have many limitations. Smart agility imaging mode was proposed by National Space Organization, which can alter satellite's attitudes dynamically during image acquisition; hence the scan direction and orbit can be unparallel. With this mode, users can obtain different region of image according to their own needs more immediately.

2. SMART AGILITY IMAGING MODE

Smart agility imaging mode is a concept which proposed by NSPO. The definition from NSPO is that satellite takes the picture and alters attitudes simultaneously, and can take the pictures thru specific direction on the ground. In this situation, satellite is capable of asynchronous imaging. In order to fulfill the purpose of smart agility imaging mode, satellite sensor alters attitudes in LVLH coordinate system with linear function of time during image acquisition. (Huang and Liu, 2009)

The attitudes alter of the satellite sensor can split to 3 axes: pitch, roll and yaw. Pitch is the angle which sensor rotates along the linear sensor axis. When pitch alters, the ground distance between two adjacent image lines would change, and affect the continuity of image. The region of image could prolong or abbreviate along the orbit direction.

Roll is the angle which sensor rotates along the orbit direction. When roll alter, the region of image could be unparalleled to the orbit, and fulfill the demand of smart agility imaging mode's character. It means in the same period of image acquisition, the region of image could turn left or right.

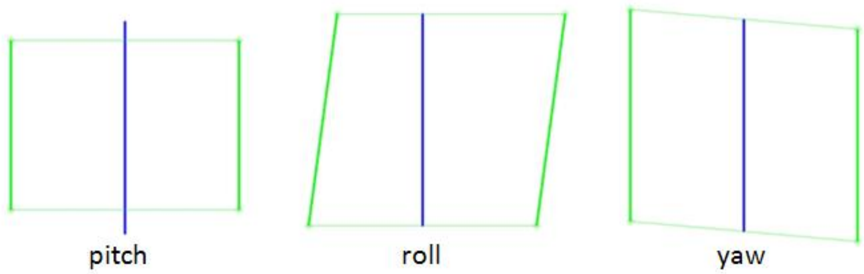

Fig1. Ground region change while attitudes alter

Yaw is the angle between linear sensor direction and orbit direction. When yaw alter, the region of image would rotate along ground surface. In TDI (time delay and integration) sensor, in order to promote the collection of light energy, the sensor and orbits should keep vertical during image acquisition, this needs yaw to control. (Liu et al, 2008) The change of the ground region while attitudes alter is shown in figure1.

3. SMART AGILITY IMAGE SIMULATION METHOD

3.1 Collinear Equation

Most satellite sensors are linear sensor, collinear equation can express the relationship between object and image.

$$x = -f\frac{m_{11}(X - X_L) + m_{12}(Y - Y_L) + m_{13}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)} \tag{1}$$

$$y = 0 = -f\frac{m_{21}(X - X_L) + m_{22}(Y - Y_L) + m_{23}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)} \tag{2}$$

In order to calculate the ground coordinates, modify equation 1 and 2 to equation 3 and 4.

$$X = X_L + (Z - Z_L)\frac{m_{11}(x) + m_{21}(y) + m_{31}(-f)}{m_{13}(x) + m_{23}(y) + m_{33}(-f)} \tag{3}$$

$$Y = Y_L + (Z - Z_L)\frac{m_{12}(x) + m_{22}(y) + m_{32}(-f)}{m_{13}(x) + m_{23}(y) + m_{33}(-f)} \tag{4}$$

In smart agility imaging mode, satellite sensor alters attitudes with linear function of time during image acquisition.

$$\omega = \omega_0 + \omega_1 t \tag{5}$$

$$\phi = \phi_0 + \phi_1 t \tag{6}$$

$$\kappa = \kappa_0 + \kappa_1 t \tag{7}$$

Where:
(x,y) are image coordinates; m is rotation matrix; ω is pitch; ϕ is roll; κ is yaw; (X,Y,Z) are objects coordinates; (X_L,Y_L,Z_L) is the coordinate of perspective center.

3.2 Image Simulation

By giving different functions of attitudes alter and using collinear equation, the region's ground coordinates could be calculated. However, the ground coordinates which calculated by the current exterior parameter not necessary is integer on the basic image, which we used to provide color information; therefore the simulation image needs to resample. There are many methods to resample: nearest-neighbor, bilinear interpolation and cubic resampling.

In our research, we used WorldView-2 high resolution satellite image as our basic image, the ground resolution of image is 0.5 meter, and the simulation image ground resolution is 2 meter. In this case, one pixel of simulation image may contain several pixels in basic image, as shown in figure 2. The color information of simulation image is provided by its corresponding pixel occupied ratio in basic image and calculated with linear combination.

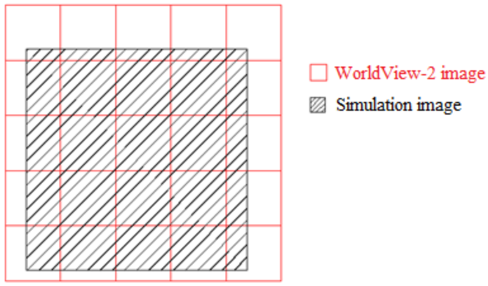

Fig2. Image simulation

4. IMAGE SIMULATION AND ANLYSIS

4.1 Experiment Purpose

This research is intend to understand the characteristic of smart agility imaging mode, including image simulation and analyzing the effect from smart agility imaging mode to ground sample distance(GSD).

4.2 Experiment 1: Smart Agility Image Simulation

The basic image is a WorldView-2 high resolution satellite image, covering Taipei city, with 0.5 meter ground resolution. The original image and partial enlarge image is shown in figure 3. The simulation image has size 6000*6000pixel, with 2 meter ground resolution.

4.2.1 Attitude unchanged

In order to verify the correctness of simulation method and algorithm, and compare to attitude alter images which simulate late, first we simulate attitude unchanged image. The region of image is shown in figure 4, and simulation image is shown in figure 5. Comparing from simulation image to original image, there’s no obvious deform between two images. However, if enlarge simulation image, the ground resolution image is worse than original image.

4.2.2 Pitch Alter

When pitch alters, the image region changed along the orbit direction. In same period of satellite movement, longer or shorter region could be obtained, as shown in figure 6 and figure 8. However, the number of sensor array is fixed, simulation image on sensor direction remain unchanged. When the region expand, simulation image reduced, it’s because there might have some ground region not been taken between two adjacent image lines. On the other hand, when the region reduced, simulation expend, it’s because some ground region have been taken repeatedly between two adjacent image lines. The ground resolution remained the same. The simulation image is shown in figure 7 and figure 9.

4.2.3 Roll Alter

When roll alters, the image region could be unparalleled to the orbit direction, and fulfill the demand of smart agility imaging mode. In same period of satellite movement, the region could turn left or right. Take figure 10 as example, the region could turn right, and simulation image is shown in figure 11, the image deform to left.

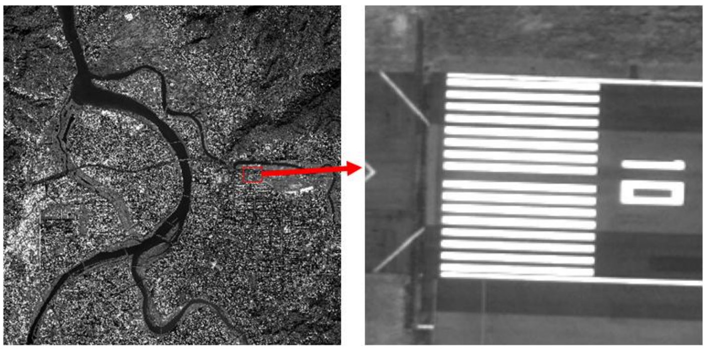

Fig3. Original image

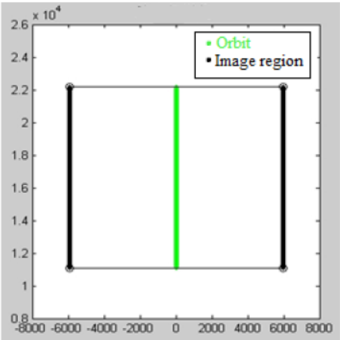

Fig4. Attitude unchanged region

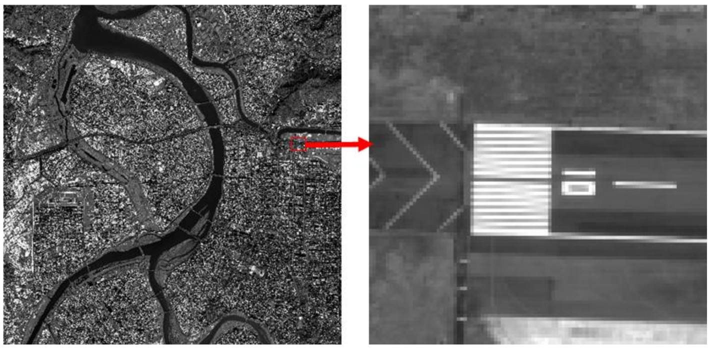

Fig5. Simulation image—attitude unchanged

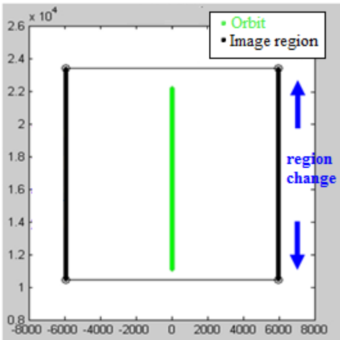

Fig6.Pitch alters region(longer)

ω = 0.1-0.01t

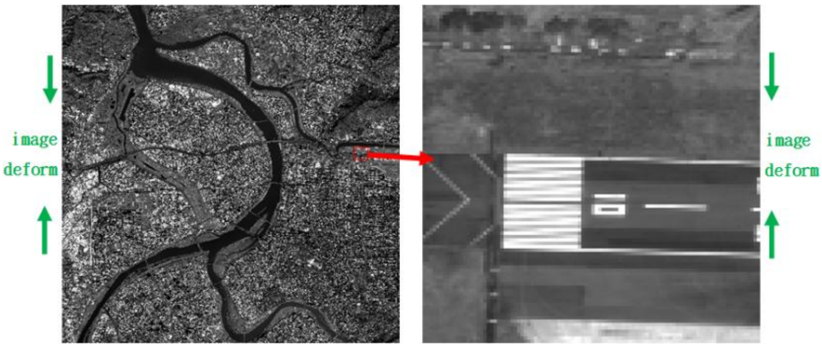

Fig7. Simulation image—pitch alters(longer region)

ω = 0.1-0.01t

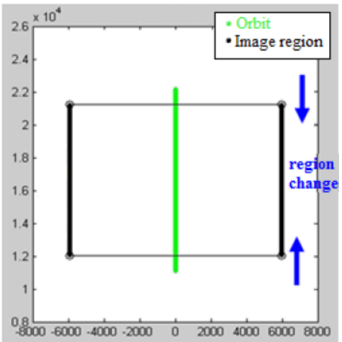

Fig8. Pitch alters region(shorter)

ω=-0.0755+0.01t

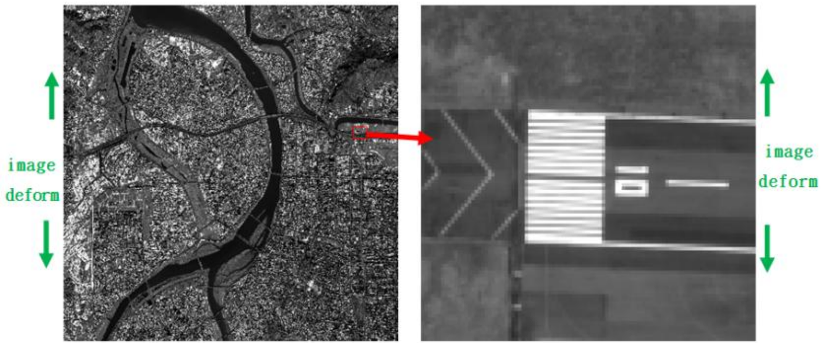

Fig9. Simulation image—pitch alters (shorter region)

ω=-0.0755+0.01t

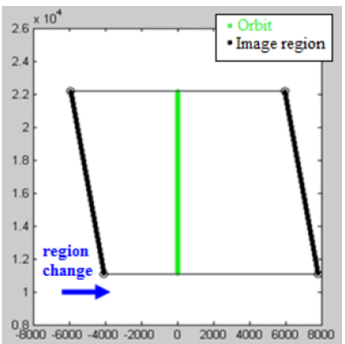

Fig10. Roll alters region

φ = 0-0.01t

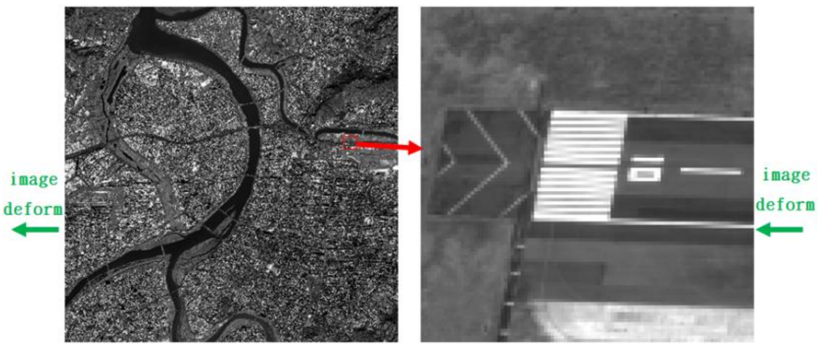

Fig11. Simulation image—roll alters

φ = 0-0.01t

4.3 Smart Agility Imaging System and Ground Sample Distance

During satellite image acquisition, attitude alter would follow ground sample distance (GSD) changed. In a single image, different image lines or even in the same image line, GSD might be different. In smart agility imaging mode, the attitudes alter during image acquisition, so it's necessary to figure out the effect caused by attitude change. In the following experiment, every pixel in first image line GSD is 2 meter both horizontal and vertical.

4.3.1 Pitch and GSD

If the first image line with pitch equals to 0°, after taken 12000 image lines with pitch alter, the final image line horizontal and vertical GSD value is shown in table 1 and figure 14, with pitch equals 0°,10°,20°,30°,40°,50°,60°. When pitch alter to 60°, the final line horizontal GSD reach 4 meter, twice as first image line. On the other hand, when pitch alter to 50°, the final line vertical GSD exceed 4 meter. Figure 12 shows when pitch alters from 0° to 60°, horizontal GSD change result, and figure 13 shows vertical GSD change result.

Table1. Pitch alter and GSD

	0	10	20	30	40	50	60
Final line horizontal GSD（m）	2.0000	2.0309	2.1338	2.3094	2.5957	3.1376	4.0000
Final line vertical GSD（m）	2.0000	2.0622	2.2650	2.6668	3.4084	4.4808	8.0005

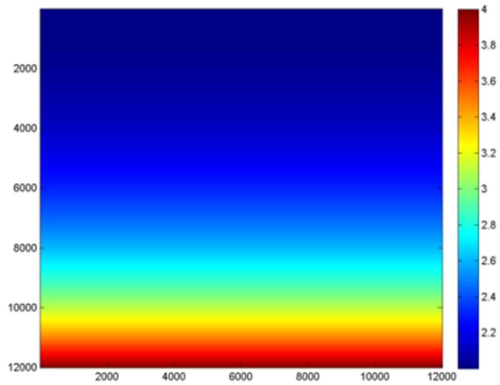
Fig12. Pitch alter horizontal GSD change

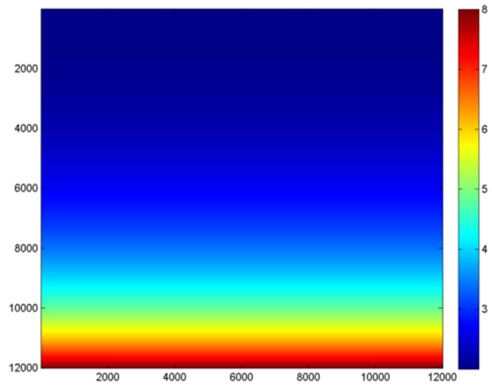
Fig13. Pitch alter vertical GSD change

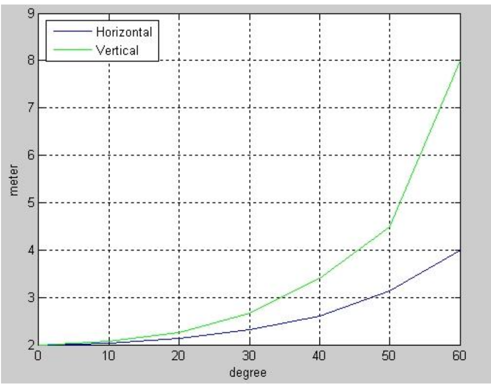

Fig14. Pitch alter and GSD

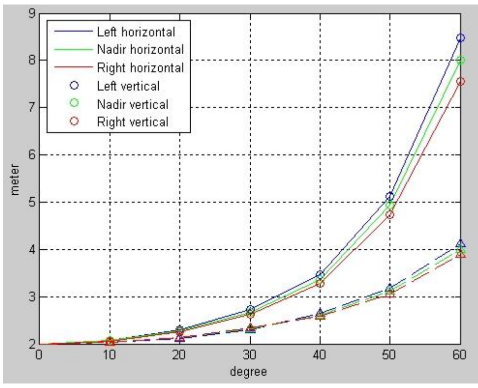

Fig15. Roll alter and GSD

4.3.2 Roll and GSD

If the first image line with roll equals to 0°, after taken 12000 image lines with roll alter, the final image line horizontal and vertical GSD value is shown in table 2 and figure 15, with roll equals 0°, 10°,20°,30°,40°,50°,60°. Unlike pitch alter, roll alter might caused in same image line, left, nadir and right side GSD could be different, because the different side of sensor have different altitude from ground. Table3 shows horizontal GSD difference between left and right side when roll alter. When roll alter to 60°, the difference between two sides reach 1 meter.

When roll alter to 50°, the final line horizontal GSD exceed 4 meter, twice as first image line. On the other hand, when roll alter to 60°, the final line vertical GSD exceed 4 meter. Figure 16 shows when roll alters from 0° to 60°, horizontal GSD change result, and figure 17 shows vertical GSD change result.

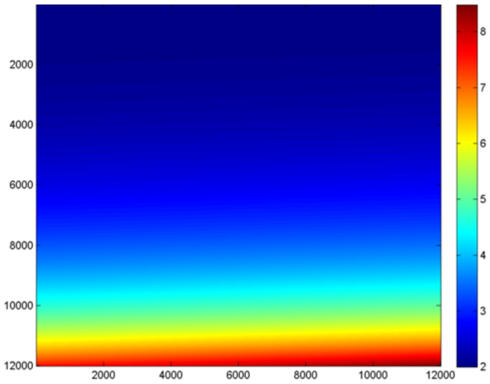

Fig16. Roll alter horizontal GSD change

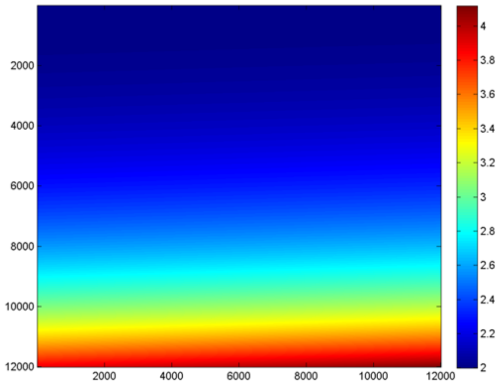

Fig17. Roll alter vertical GSD change

Table2. Roll alter and GSD

	0	10	20	30	40	50	60
Left side final line horizontal GSD（m）	2.0000	2.0501	2.2487	2.6161	3.2778	4.7299	7.5574
Nadir side final line horizontal GSD（m）	2.0000	2.0622	2.2766	2.6667	3.3699	4.9293	8.0000
Right side final line horizontal GSD（m）	2.0000	2.0744	2.3051	2.7187	3.4636	5.1268	8.4826
Left side final line vertical GSD（m）	2.0000	2.0249	2.1414	2.3319	2.5748	3.0509	3.8878
Nadir side final line vertical GSD（m）	2.0000	2.0309	2.1284	2.3094	2.6108	3.1115	4.0000
Right side final line vertical GSD（m）	2.0000	2.0369	2.1155	2.2874	2.6479	3.1745	4.1189

Table3. The difference between left and right side horizontal GSD when roll alter.

	0	10	20	30	40	50	60
GSD difference between left and right side (m)	0.0000	0.0243	0.0564	0.1026	0.1858	0.3969	0.9252

5. CONCLUSION

1. With smart agility image mode, satellite's scan direction and orbit can be unparallel. In the same period of satellite's movement, the region of image can be different. If this mode can be used wisely, satellite image's acquisition and application should be more flexible and effective.

2. Pitch and roll would affect GSD, yaw wouldn't. When pitch alters, the influence on vertical GSD is bigger than horizontal GSD. When roll alters, the influence on horizontal GSD is bigger than vertical GSD.

3. In horizontal GSD analysis, when pitch alter to 60°, or roll alter to 50°, the final image line horizontal GSD exceed 4 meter, twice as first image line.

4. In vertical GSD analysis, when pitch alter to 50°, or roll alter to 60°, the final image line vertical GSD exceed 4 meter, twice as first image line.

6. REFERENCE

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