THE INVESTIGATION OF VIEWING ANGLE EFFECTS ON GROUND SAMPLING DISTANCE OF THAICHOTE SATELLITE IMAGERY

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ABSTRACT

Thaichote satellite has the ability to rotate itself for imaging. The effect of increased viewing angle is described in terms of Ground Sampling Distance (GSD). Consequently, spatial resolution is varied with respect to the viewing angle. We apply the Spherical Laws of Cosines formula in order to calculate distance on earth while the distance on image can be tested by applying the Pythagorean theory. The result clearly demonstrates that the imaging at each increased viewing angle has insignificant impact on along-track GSD on the image but across-track one. The comparison of Across-Track GSD between Pitch and Roll angle effects that it is increased from 1.87 to 2.78 and 4.42 meters for 30 and 45 degrees of roll angle respectively. Besides, it is increased to 2.20 and 2.85 meters for 30 and 40 degrees of pitch angle. It can be concluded that roll angle has more impact on GSD rather than pitch angle.

Keywords: Thaichote satellite image, viewing angle, spatial resolution, ground sampling distance

INTRODUCTION

Thaichote, a.k.a. THEOS, is the first Thailand Earth Observation Satellite. It was launched on 1st October 2008. Thaichote has a panchromatic product 2 meters of resolution using its spatial resolution for visual interpretation with a capability of attitude maneuver for imaging at different angles. Such ability allows to image the specified area within a short period of time and increase the opportunity for data acquisition. Nevertheless, it casts an impact on image spatial resolution, causing quality to drop. The spatial resolution is the minimum ground area observed by the instrument of satellite that also known as Ground Sampling Distance (GSD) which is a function of satellite viewing angles. The GSD is the distance between the centers of adjacent pixels measured on ground. Which is a measure of one limitation to image resolution, as a major influence on data quality of satellite images. We are interested in the effect of viewing angles which are left-right (Roll) and forward-backward (Pitch) angles. In this study of real GSD on original image, we used panchromatic level 1A as there were no resampling on the image of geometric correction in level 2A process. Even though the level 2A product has 2 meters of resolution from resampling according to standard product, this does not mean the GSD is 2 meters. We can compute the GSD by the ratio of distance on earth per distance on image. We applied the Spherical Laws of Cosines formula in order to calculate distance on earth while the distance on image can be tested by applying the Pythagorean theory which is computed to measure the distance between reference points on earth and image. For this reason, the study can be used for calibrating the GSD on image from characteristic of Thaichote satellite. Understanding the characteristic of satellite image leads to the proper selection of right data for each application and it can also be used as a reference for mission planning to optimize the quality and acquisition period bringing about a greater benefit for end-user.

MATERIALS AND METHODS / EXPERIMENTAL

From the characteristic of Thaichote satellite, the focal length is 2.89 meter, pixel size is 0.65 ×0.65 µm and altitude 822 km. Which can be compute the GSD at off-nadir of panchromatic image is 1.85 meter. following the equation 1.

$$GSD_{nadir} = \frac{\text{Pixel size} \times \text{Altitude}}{\text{Focal lenght}} \quad (1)$$

Ground sampling distance (GSD)

In practical imaging, the viewing angle is generally non-nadir depending on area of interest resulting in change of GSD which can be computed alternatively from image. We applied The Spherical Laws of Cosines and the Pythagorean theory to compute and demonstrate the GSD of satellite image. Based on the assumption that Earth is a spheroid, we measured the distance between 2 obvious reference points in both along-track and across-track on the image and ground. In this study, we used panchromatic level 1A, which has not been geometrically corrected for testing. The GSD at different angles can be obtained by equation 2.

$$GSD = \frac{D_{real}}{D_{image}} \quad (2)$$

D_{real} : Distance between 2 reference points on earth (km).
D_{image} : Distance between 2 reference points on the image (pixel).

Distance on image (D_{image})

We selected Thaichote images of test site such as Barcelona, Los Angeles because these are the test site of Thaichote geometric calibration/validation. The images of each area were taken at different according to test conditions. In order to determine the distance between 2 points on an image in both directions as across and along track as possible as following figure 1. We have to define the coordinates of our reference points pixel column (X) and line (Y) these can be obtained from reference points. We simply use the Pythagorean theory to calculate the distance on image by equation 3.

$$D_{image} = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \quad (3)$$

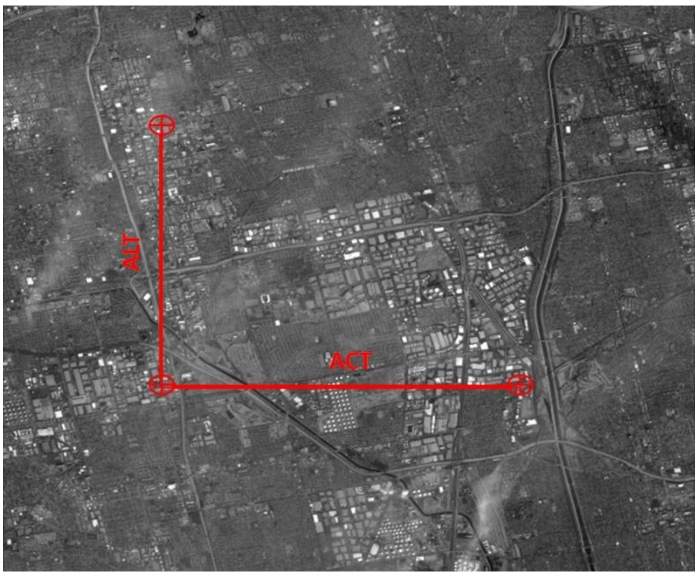

Figure 1. Direction of measurement on image

Distance on earth (D_{real})

In reality, The Earth sphere is almost spherical. The real distance between 2 points on earth is, as a result, a curve which is calculable by equation 4.

$$D_{real} = R_{mean} \times \theta_C \quad (4)$$

R_{mean} is the Radius measured from center of earth (km.) at the average latitude location of 2 reference points in Figure 2. Which can be measured and obtained the coordinate from Ground Control Point (GCP) or other geodetic reference such as Google Earth with equation 5.

$$R_{mean} = \sqrt{(RE\cos(\theta_{lat})^2 + RP\sin(\theta_{lat})^2} \quad (5)$$

θ_{lat} : Mean latitude of 2 reference points (degree)
RE : Equatorial Earth Radius (km)
RP : Pole Earth Radius (km)

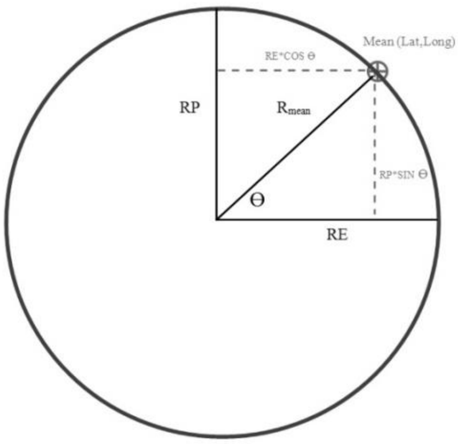

Figure 2. Radius from center of the Earth

From the equation 4, θ_c is the angle that support the real distance on earth (radian). When the Spherical Laws of cosines is applied, the relationship between the sides and angles of a triangles. with all 3 sides are the arcs of the sphere [2][4], We can create a triangle with all 3 sides of the arc on the sphere connected by the 3 points on the sphere; A, B and C. The length of 3 arcs refer to a, b and c which can be define the opposite corner of the arc a is A. The relationship of the rules circular Cosine can be presented in equation 6.

$$COS(c) = COS(b)COS(a) + SIN(b)SIN(a)COS(C) \quad (6)$$

From the Spherical Laws of cosines, it is evident that there must be a reference point among all 3 points. In this case, we chose the polar (90°) as a reference point C as it is generally used in Figure 3. in order to calculate the angle in radians between the other 2 points as illustrated in the equation 7.

$$\theta_c = COS^{-1}((90° - Lat.A) \times COS(90° - Lat.B) + \ldots$$
$$SIN(30° - Lat.A) \times SIN(30° - Lat.B) \times COS(Long.B_{coreccted} - Long.A)) \quad (7)$$

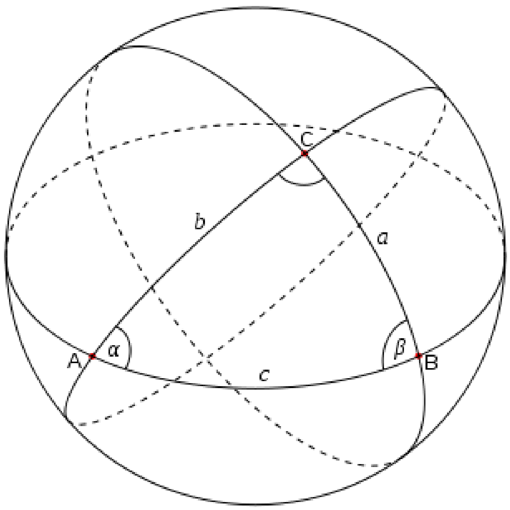

Figure 3. The Spherical Laws of cosines [3]

Thaichote has the Pushbroom imaging that acquires one line of image at a time, the whole image is consisted of several consecutive exposures [1]. Therefore, before using the equation 7, We have to re-calculate Long.B from the reference point B based on the Earth rotation and motion of satellite during imaging as figure 4. Therefore, it must be calculated which can be computed in the equation 8.

$$\text{Long.B}_{\text{corrected}} = \text{Long.B} + (Y_2 - Y_1) \times \text{Sampling time (ms)} \times \text{Earth rotation speed } (°/s) \qquad (8)$$

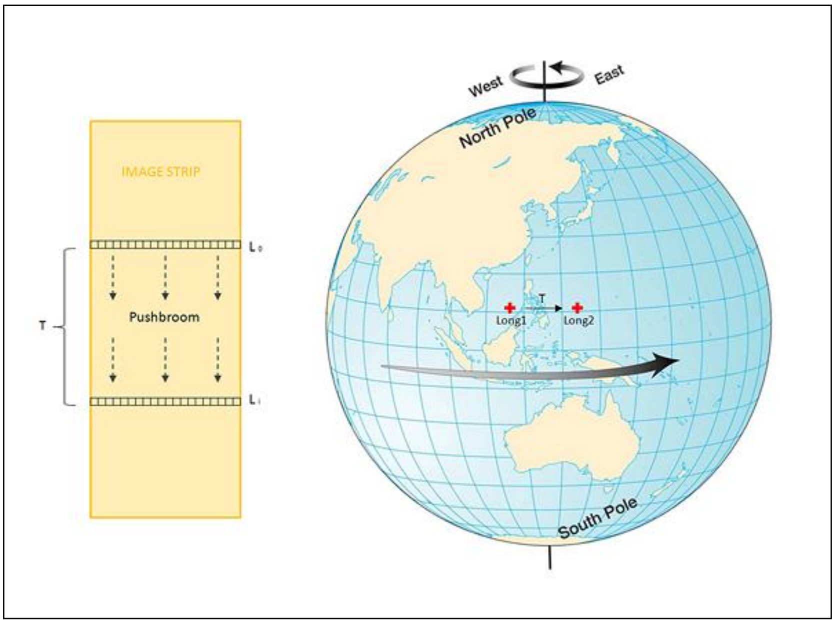

Figure 4. Relationship between pushbroom imaging and Earth rotation

Swath width

Thaichote panchromatic sensor has 12000 pixels in array, which can be computed the primary swath width by multiplication between the GSD and pixel in array as the following equation 9.

$$\text{Swath width} = \text{GSD} \times \text{Pixels in array} \qquad (9)$$

RESULTS AND DISCUSSION

The result was determined with the test conditions which were set by fixing either pitch or roll angle at near off-nadir as the another is varied to full angle at every 5 degrees to determine the effect of roll and pitch variation to GSD. The varied for both directions according to table 1-2.

Table 1. The table presents ACT, ALT GSD and swath width with fixed Pitch angle at near off-nadir in variation of Roll angle

Roll angles (°)	ACT GSD (meter)	ALT GSD (meter)	Swath width (kilometer)
0	1.87	2.01	22.39
5	1.89	2.00	22.64
10	1.97	1.97	23.62
15	2.07	1.95	24.86
20	2.26	1.92	27.12
25	2.53	1.90	30.36
30	2.78	1.88	33.31
35	3.17	1.96	37.99
40	3.81	2.09	45.71
45	4.42	2.09	53.02

Table 2. The table presents ACT, ALT GSD and swath width with fixed Roll angle at near off-nadir in variation of Pitch angle

Pitch angles (°)	ACT GSD (meter)	ALT GSD (meter)	Swath width (kilometer)
0	1.85	2.02	22.25
5	1.86	2.04	22.35
10	1.90	2.03	22.80
15	1.93	2.03	22.80
20	1.99	2.05	23.88
25	2.09	2.02	25.06
30	2.20	2.03	26.34
35	2.38	2.05	28.60
40*	-	-	-
45	2.85	2.03	34.14

**Notice: There is no data for 40 degrees due to unavailability of image for this condition.*

The average GSD have been obviously changed for non-nadir angles. The comparison between the impact from pitch and roll angle demonstrate that the roll angle is more responsible for the ACT GSD variation than the pitch angle as illustrated in the following figure 5. However, there is no significant effect on ALT GSD according to figure 6. Furthermore, because the ACT GSD is increased for the more viewing angle, the swath width gets consequently wider as Figure 7.

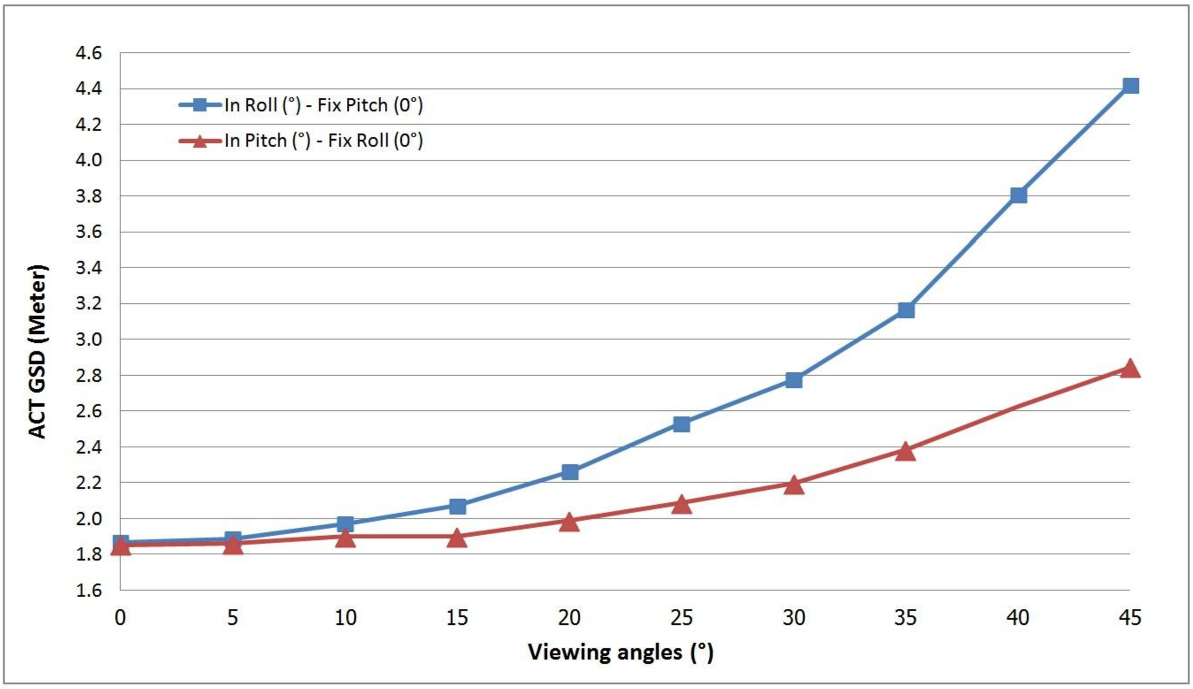

Figure 5. Compare the impact from the variation of pitch and roll angles on ACT GSD

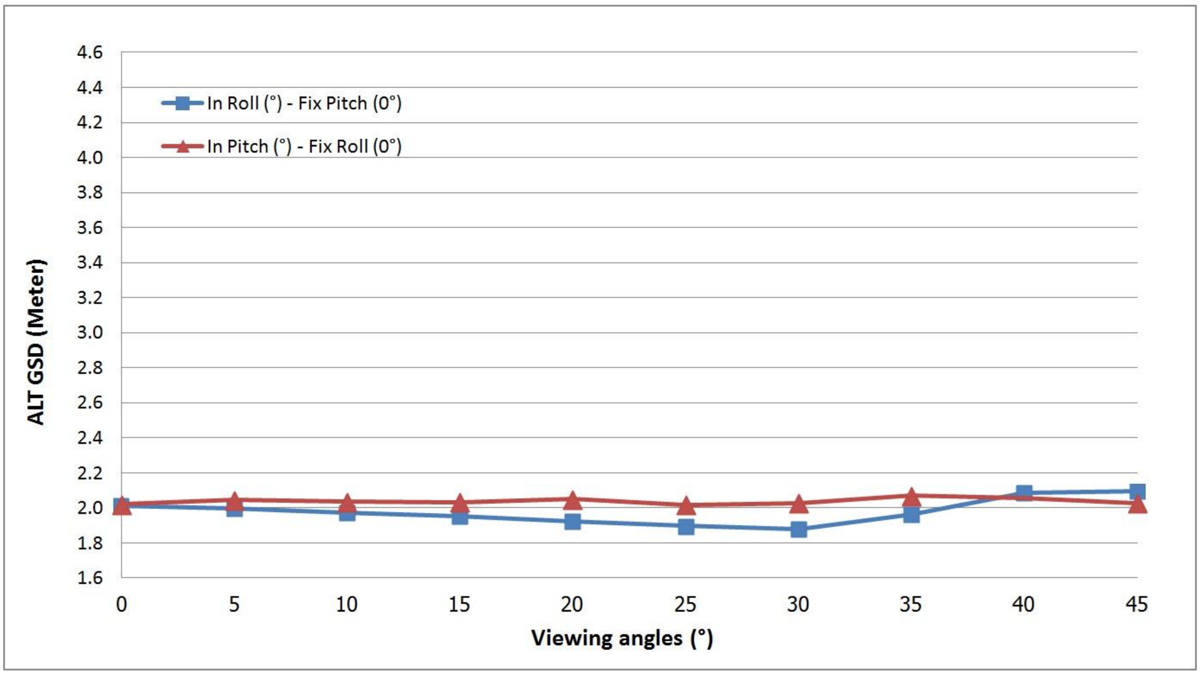

Figure 6. Compare the impact from the variation of pitch and roll angles on ALT GSD

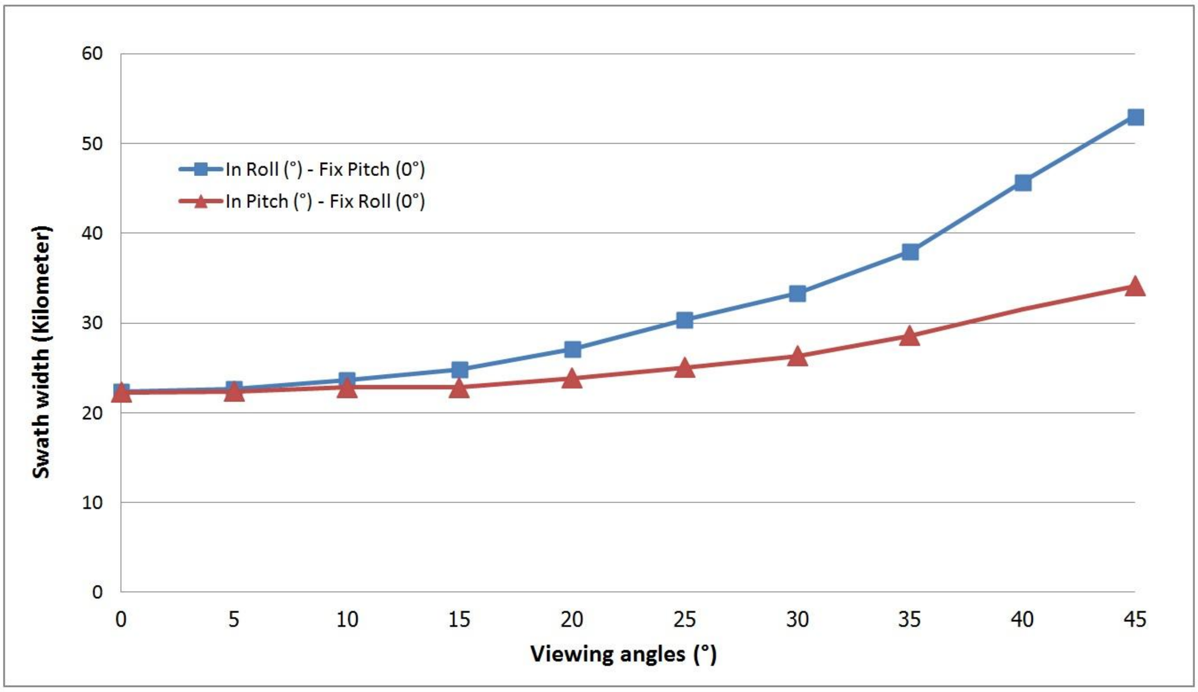

Figure 7. Compare swath width from the variation of pitch and roll angles

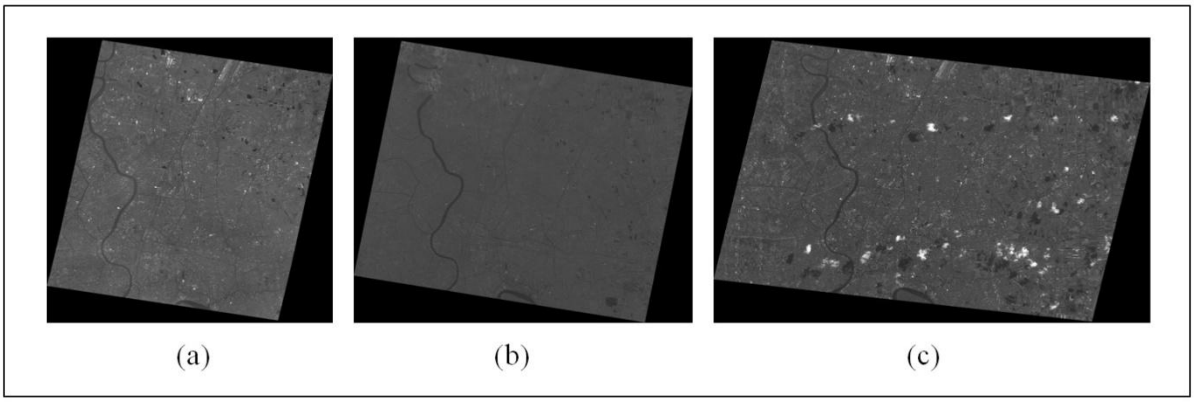

Figure 8. Thaichote level 2A Panchromatic compare with different viewing angles, (a) Near off nadir, (b) 30 degree, (c) 45 degree

CONCLUSION

The result clearly demonstrates that the imaging at each increased viewing angle has insignificant impact on along-track GSD on the image but across-track one. At 30 degrees, GSD is increased by 1.5 and 1.19 times owing to roll and pitch angles respectively. Likewise, at the full angle, 45 degrees, GSD is increased by 2.36 and 1.54 times due to roll pitch angle consequently. Nevertheless, an increase of viewing angle from nadir leads to an extension of swath width. For this reason, the impact that end-user of Thaichote imagery must take into consideration is the effect of viewing angle upon a product. Such an impact on product resolution can be estimated through the relationship as stated.

ACKNOWLEDGMENT

We would like to express our special appreciation and thanks to Thaichote Cal/Val team who has tremendously supported our study. We would also like to thank Thaichote IGS members for irreplaceable cooperation and encouragement to overcome every obstacle during this research.

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