SATELLITE ATTITUDE OFFSET ESTIMATION FOR KOMPSAT-6

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ABSTRACT: We present a Kompsat-6 (K6) satellite attitude offset estimation method from Doppler Centroid (DC) information, and validate its reliability by using simulated SAR images generated with K6 Image Chain Analysis Software (ICAS) and actual Kompsat-5 (K5) images. For the verification test, we simulate SAR images by intentionally applying the satellite attitude offset using ICAS system, and then re-estimate the satellite attitude offset from the DC information of simulated SAR images. The original satellite attitude offset was able to be recovered very closely by using the suggested K6 attitude offset estimation method. In addition, the K5 satellite attitude offset is estimated from K5 Amazon images using the suggested method, and is compare to the attitude offset from calibration activity during K5 Launch and Early Orbit Phase (LEOP). The difference of the offset values is 0.007 degree in yaw and 0.002 degree in pitch. After compensating K5 satellite attitude with the newly estimated offset value replacing the offset from K5 calibration activity, the difference between DC from geometry information and DC from image was reduced by 15%.

1. INTRODUCTION

Kompsat-6 (K6) satellite equipped with Synthetic Aperture Radar (SAR) with sub-meter resolution will be launched in November 2021. Attitude of the K6 will be controlled in yaw and pitch directions for accurate Zero-Doppler steering along the satellite orbit pass. The accuracy of the attitude measurements from the K6 attitude and orbit control system (AOCS) is directly related to the beam pointing accuracy, and hence to the quality of K6 SAR images.

In order to ensure the beam pointing accuracy of K6 SAR system, a dedicated beam pointing calibration activity will be performed during K6 Launch and Early Orbit Phase (LEOP) by estimating and correcting the offset in the satellite attitude measurements. The attitude offset is calculated by comparing the measured attitude provided by the K6 AOCS and the estimated attitude directly from the SAR image. To do that, the Doppler Centroids (DCs) are calculated from the SAR imaging geometry including satellite attitude and from the SAR images over homogeneous areas such as Amazon Rainforest. The DC reflects beam pointing in SAR azimuth direction and is related to satellite attitude especially in yaw and pitch axis directions.

In this paper, we describe a method and procedure for predicting K6 satellite attitude offset in the yaw and pitch directions using the differences in DCs obtained from imaging geometry and from image data, respectively.

2. METHOD

In order to estimate the satellite attitude offset from DC difference, the relation between satellite attitude coordinate transformation and DC variation should be clearly explained (Knut 1994). The variation of beam pointing direction ($\vec{r}$) due to satellite attitude rotation can be described through coordinate transformation as in Figure 1.

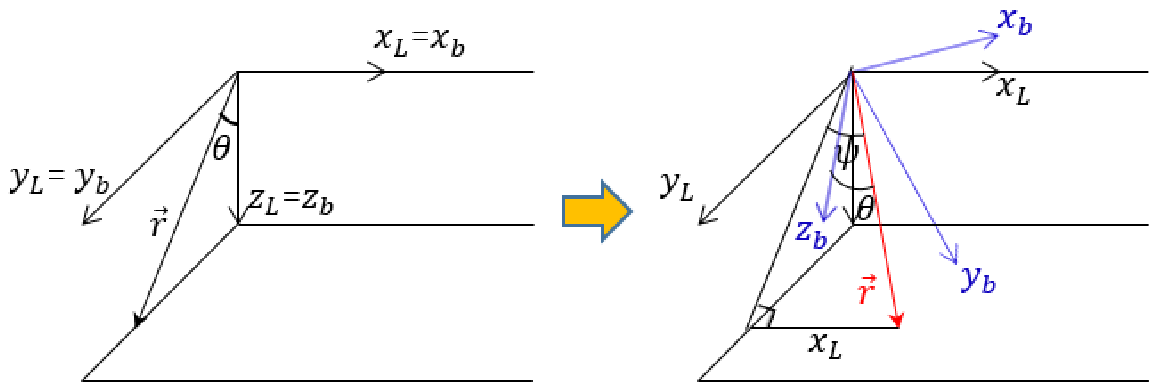

Figure 1 Variation of beam pointing geometry due to satellite attitude rotation

The satellite attitude coordinate system (or body frame) should be coincided with Zero-Doppler orbit frame ($\vec{X}_L = [x_L, y_L, z_L]$) due to Zero-Doppler steering maneuver over a satellite pass. However, body frame ($\vec{X}_b = [x_b, y_b, z_b]$) becomes slightly off from the orbit frame due to actual small attitude rotation. The beam pointing ($\vec{r} = [0, rsin\theta, rcos\theta)$ in body frame becomes change due to attitude rotation when it is expressed in the orbit frame. The beam pointing component in satellite azimuth direction (x_L) and the squint angle (ψ) are directly related to DC. Under the roll(R)-pitch(P)-yaw(Y) rotation sequence (1-2-3)* and small angle assumption, x_L and ψ can be expressed with yaw and pitch angles as follow.

$$\sin\psi = {}^{x_L}/_{r} = [-\mathrm{Y}\sin\theta + \mathrm{P}\cos\theta] \tag{1}$$

The relation between the azimuth squint angle (ψ) and DC (f) can be expressed as in Equation (2) based on the SAR imaging geometry of Figure 2.

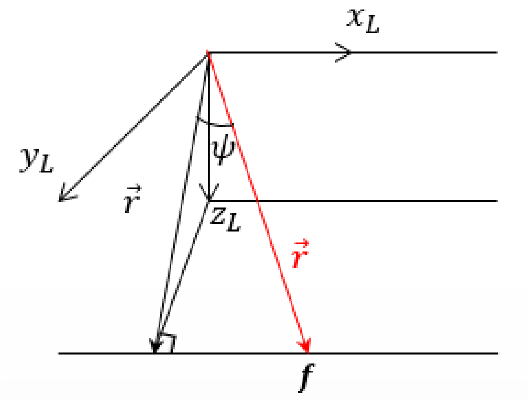

Figure 2 Doppler centroid and azimuth squint angle

$$\mathrm{f} = -\frac{2}{\lambda}|v_{st} - v_T|\sin\psi \tag{2}$$

Where λ is wavelength, v_{st} is satellite velocity, and v_T is target velocity. In order to accurately estimate satellite attitude (yaw and pitch) using Equation (1) and (2), DC (f) measurements should be provided along wide elevation angle (θ) range to increase the sensitivity of estimation in the Least Square sense.

The procedure for estimating the satellite attitude offset is as follows.
Step 1: Calculate DC from geometry by extracting geometric information (orbit, attitude, beam steering, antenna misalignments, etc.) from Amazon SAR images.
Step 2: Calculate DC from image using the phase information of the same Amazon images.
Step 3: Calculate the DC difference (delta DC) between DC from geometry and DC from image.
Step 4: Repeat step 1 through step 3 over wide beam elevation angle range.
Step 5: Estimate the satellite yaw and pitch offsets using the delta DC measurements via Equation (1) and (2) in the Least Square optimization sense.
Step 6: Re-calculate DC from geometry using the updated satellite attitude after compensating the estimated attitude offset, and calculate the delta DC statistics.

3. TEST RESULT

3.1 ICAS Data

K6 satellite attitude offset estimation algorithm is tested with K6 ICAS (Image Chain Analysis Software) Data. Standard (ST) mode data are simulated by intentionally applying a satellite attitude offset (yaw: 0.007 degree, pitch: -0.014 degree) to attitude measurements from attitude control system. The DCs are estimated from the beam imaging geometry including satellite attitude information and from the image phase information, respectively. The DC difference values are 117.5 Hz (RMSE) and are represented in Table 1. The satellite attitude offset is estimated using the suggested algorithm expressed in Equation (1) and (2). The original satellite attitude offset is recovered very closely. After compensating the satellite attitude information with the estimated offset, the DC is re-calculated from the updated satellite attitude and compared to the DC from the image. The DC difference values are reduced dramatically to 4.5 Hz (RMSE). This result shows that the error in the satellite attitude is correctly compensated through the suggested satellite attitude offset estimation algorithm.

Table 1 Doppler Centroid measurements from K6 ICAS data

Image Name	**DC from Geometry with offset (Yaw=0.007,**	**DC from Image**	**ΔDC without offset correction**	**ΔDC with offset correction**

* Rotation sequence does not matter under small angle assumption.

	Pitch=-0.014)			
ST-01	-1603.1	-1506.85	96.25	-3.85
ST-10	-1338.9	-1216.55	122.35	-4.55
ST-19	-1102.3	-971.14	131.17	-4.93
RMSE			**117.5 Hz**	**4.5 Hz**

3.2 Kompsat-5 Data

The satellite attitude offset is calculated from the K5 Amazon rainforest data, which have homogeneous radar backscattering characteristics and are optimal for DC estimation. The ST mode data in the wide range of beam elevation angles are selected for the DC estimation process and the list of data is shown in Table 2. The estimated satellite offset from the selected K5 data set is 0.007 degree in yaw axis and -0.014 degree in pitch axis. [*]On the other hand, the previously estimated satellite offset during K5 LEOP calibration period was 0.0 degree in yaw and -0.012 degree in pitch. To compare the effectiveness of the two different offset values, the DC difference from geometry and SAR image is calculated after updating K5 satellite attitude offsets, respectively. The RMSE of the DC difference is 19.4 Hz with the satellite offset from K5 LEOP and 16.6 Hz with the newly estimated offset. There is 15% increase in the satellite attitude estimation accuracy and it shows the validity of the suggested algorithm.

Table 2 Doppler Centroid measurements from K5 Amazon data

Image Name	DC from Image (Hz)	DC Geometry (Y=0, P=-0.012)	DC Geometry (Y=0.007, P=-0.014)	ΔDC LEOP	ΔDC New
ES_01_HH	-395.4	-394.7	-396	-0.7	0.6
ES_01_VV	-710.6	-709.5	-710.8	-1.1	0.2
ES_09_HH	188.4	174.1	154.3	14.3	34.1
ST_03_HH	221.1	202.8	196.5	18.3	24.6
ES_05_HH	405.6	422.1	411.4	-16.5	-5.8
ST_16_HH	-9.9	32.4	3.1	-42.3	-13
ES_19_HH	-23.7	0.3	-31.8	-24	8.1
ST_08_HH	-491.5	-480.2	-497.5	-11.3	6
ES_16_HH	29.8	39	9.7	-9.2	20.1
RMSE				**19.4 Hz**	**16.6 Hz**

4. CONCLUSIONS

An algorithm and procedure for estimating the satellite attitude offset for Kompsat-6 are presented and tested using K6 simulation data and K5 Amazon data. As a result, the proposed algorithm was able to accurately estimate the satellite attitude offset in both the simulation data and the K5 actual data. After compensating for the estimated satellite attitude offsets, the difference between DC calculated using geometry information and DC calculated using images has been greatly reduced for both simulated and actual data.

References

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[*] The K5 satellite attitude estimation method was developed by TAS-I, Italy, and is not open to public.