PRIMARY STUDY OF GEOMETRIC ACCURACY FOR SAR SATELLITE

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ABSTRACT: Synthetic Aperture Radar (SAR) is an imaging radar with high resolution. SAR systems can operate on all-weather to in extensive area imaging, which are suitable for the climate of Taiwan. The radar can be carried by aircrafts or satellites to support disaster survey and rescue, scientific research, and environmental monitoring.

SAR system has various kind of specification such as resolution, swath and so on. Geometric accuracy is one of them, which is the known as pixel localization accuracy, has to be determined using the range-Doppler equations. It is one of the important specifications for SAR satellite because SAR is the imaging sensor. especially for the analysis using more than two SAR image such as interferometry because two SAR images can’t be compared if geometric accuracy is not good enough. Therefore, the error cause of geometric accuracy is researched in this study.

First step is the extraction of error cause of geometric accuracy. Five types of error cause is extracted. Second step is the evaluation of these error cause. The impact is evaluated and also discussed about how to compensate them. The requirement to achieve the high-quality geometric accuracy is proposed from this discussion.

1. INTRODUCTION

1.1 Synthetic aperture radar

The space-borne X-band SAR system is intended to produce high resolution radar images for a broad range of applications and purposes. Normally SAR system is designed to operate in three different modes, stripmap, ScanSAR and spotlight mode, where the latter should provide image data suitable for image products of up to one meter resolution. There are various kind of analysis methods. The interferometry is the one of them. This geodetic method uses two or more SAR images to generate maps of surface deformation or digital elevation, using differences in the phase of the waves returning to the satellite. The geometric accuracy is one of the important specifications when the two image are compared. The geometric error makes it difficult to extract the phase difference from SAR image.

A study is carried out to understand the cause of geometric error and estimate the error budget for the geometric accuracy.

1.2 System condition

The antenna of the space-borne SAR has mainly two types, one is the reflector type, another one is the Active phased array antenna (APAA) type. APAA has the unique ability to change the shape and direction of the radiation pattern without physically moving the antenna. Elements in an antenna array are placed in such a way that the signals transmitted by individual antennas sum up and provide better gain, directivity and performance in a particular direction. The APAA type is discussed in this paper.

2. ERROR PARAMETERS

2.1 Orbit accuracy

Radar system is the system to measure the distance from the system to target. Therefore, the accuracy of the satellite position affect to the geometric accuracy. This error depends on the orbit accuracy. Satellite uses the GPS signal to measure the satellite position. The GPS signal is affected by the ionosphere because it is L band signal. The dual frequency receiver system is currently utilized to compensate the influence of ionospheric.

The orbit accuracy between the real time orbit on the space and the analysed one on the ground system. SAR data is going to process on the ground system using orbit data, therefore the precise orbit data is available.
The accuracy of the orbit depends on the satellite system specification. The requirement of the orbit accuracy for the a SAR satellite is about 2m for the standard, 0.2m for the precise respectively[1].

2.2 Datum shift

Normally satellite system utilize WGS84 (World Geodetic System) coordinate, which defines an Earth-centered, Earth-fixed coordinate system and a geodetic datum, and also describes the associated Earth Gravitational Model (EGM) and World Magnetic Model (WMM). The standard is published and maintained by the United States National Geospatial-Intelligence Agency. On the other hand, the local area has their own coordinate system. Their ellipsoid reference which are semi-major axis a, semi-minor axis b, and inverse flattening is different. The SAR data normally use WGS84, therefore it needs to convert to project on the local map. Datum shift is the conversion error from global map to local map. Error amount depends on the definition of the local map. The definition of the local map of Taiwan is almost same as WGS84, therefore there is no error for the datum shift.

2.3 Ortho-refraction

Radar system transmit the signal from the space and receive the signal from the target. the slant range which is the distance between the SAR system and the target can be calculated by measuring the propagating time between the transmitting and the receiving signal. Ground range which is the distance on the surface is converted from the slant range. The slant range is same when the target has the height even the ground range is different. Fig.1 shows the schematic of the ortho-refraction. The geometric error doesn’t happen at flat area. The geometric accuracy normally measures at the flat area to avoid the ortho-refraction.

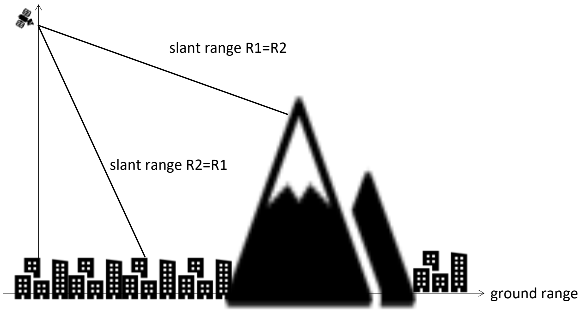

Figure 1 schematic of the ortho-refraction

The DEM (Digital Elevation Model) is utilized to compensate the ortho-refraction. The error of the DEM data also makes the geometric error. Two types of DEM data are normally utilized which is SRTM DEM (Space Shuttle Radar Topography Mission) and ASTER DEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer). The error of DEM is about 6m at flat area and about 15m at mountain area. The research said the ortho-refraction error is about up to 28m at mountain area, it depends on the location though [2].

2.4 Ionospheric delay

The ionosphere is the ionized part of the upper atmosphere of Earth, from about 48 km to 965 km above sea level. The propagation speed of the electromagnetic signals in the ionosphere is changed slower compared with vacuum. Therefore, it needs to be compensated before processing. The speed of propagation depends on its electron density. The equation of the ionospheric delay is flowing [2]:

$$\Delta r = \frac{40.3TEC}{f^2}$$

Figure 2 shows the ionospheric delay at X band. This electron density has the distribution and it changes every moment. Taiwan has the map of the distribution. This error can be compensated less than 0.3m with the electron density distribution data which is provided.

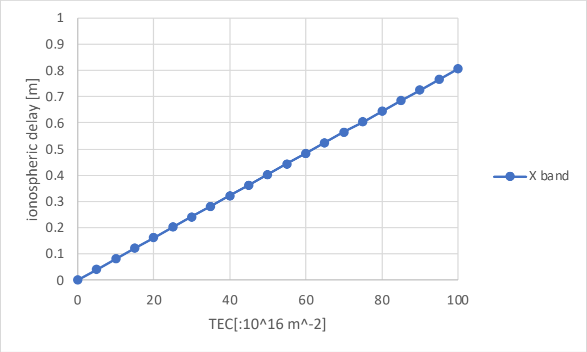

Figure 2 ionospheric delay

2.5 Tropospheric delay

Troposphere is the atmospheric layer placed between earth's surface and an altitude of about 60 km. The troposphere is refractive, its refraction of signal is not related to its frequency. The refraction is tantamount to a delay in the arrival of signal. The effect of the troposphere on the signals appears as an extra delay in the measurement of the signal traveling from the satellite to receiver. The tropospheric delay is usually divided into hydrostatic, wet and liquid components[4].

$$\Delta r_{tropo} = \Delta r_{hyd} + \Delta r_{wet} + \Delta r_{liq}$$

The contribution of liquid components is small such as mm order, so it is usually neglected for SAR path delay estimates. The hydrostatic component in the nadir direction can be written by

$$\Delta_{hyd} = 10^{-6} k_1 \frac{R_d}{g_m} P_0$$

Where g_m is the acceleration due to local gravity, k_1=77.6 $[\frac{K}{mbar}]$ is a refractive constant, and R_d=287 $[\frac{J}{K \cdot kg}]$ is the ideal gas constant, P_0 is the air pressure of surface [hPa].
The wet delay is written by

$$\Psi_{wet} = 10^{-6} \left(\frac{(k_2' T_m + k_3) R_d e_0}{T_0 (g_m (\lambda + 1) - \beta R_d)} \right) \cdot \kappa_{wet}$$

$$\kappa_{wet} = \left(1 - \frac{\beta h}{T_0} \right)^{\frac{(\lambda+1) g_m}{R_d \beta} - 1}$$

Where $k_2' = 23.3[\frac{K}{mbar}]$, $k_3 = 3.75 \cdot 10^5 [\frac{K^2}{mbar}]$ are refractive constants, β $[K/m]$ is the temperature lapse rate, T_0 [K] the temperature, e_0 [hPa] the water vapour pressure above sea level, T_m [K] the mean temperature of water vapour, h is the target height and λ [unitless] the average water vapour decrease. These parameters are modeled at each latitude. Figure 3 is the tropospheric delay at the latitude of Taiwan. The tropospheric delay can be compensated within 1m error by utilizing DEM data.

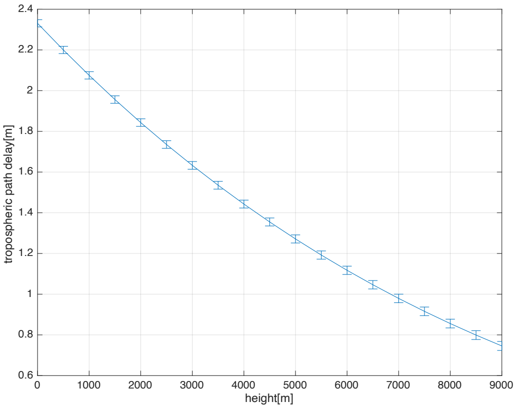

Figure 2 tropospheric delay

2.6 Doppler Center Frequency Error

SAR system utilize the doppler signal for the high resolution to azimuth direction. SAR system correct the doppler data during moving to the azimuth direction. The high azimuth resolution can be achieved by the signal processing on the ground. The doppler center frequency is corresponding to the focus point, so the error of the doppler frequency effect geometric accuracy. The geometric error of doppler center frequency can be written by following:

$$\Delta r_{dop} = -\frac{\lambda R_0}{2V}\Delta f$$

Where h is the wavelength, R_0 is the slant range, V is the speed of the satellite and Δf is the error of doppler center frequency. Doppler center frequency error of 1 Hz leads to a maximal error of 1.4 m in case of forward geocoding. Normally the goal of the doppler center frequency is within 1 Hz.

2.7 Sampling Window Start Time Error

SAR system measure the propagating time of the electromagnetic signal for the range direction. the speed of the electromagnetic is same as the speed of the light. Therefore, the time management of the transmitting and receiving is important. The sampling window start time error means the timing error of the transmitting and receiving signal. The sampling frequency of the X band SAR system is a few hundred MHz which clock time is a few ns. Therefore, the error of the sampling window can be within 0.5 m maximum.

3. CONCLUSION

The SAR system is planning in Taiwan. The geometric accuracy is one of the important parameters. The error cause of the geometric accuracy is extracted and evaluated to estimate the goal of the specification in this paper. The geometric accuracy is estimated about 1.8 m at the flat area with RSS (root some square) evaluation, it depends on the compensation method though. The measurement result of the geometric accuracy for the current SAR satellite system is mostly less than 1.0 m. It seems to be possible to achieve this goal in that reason.

4. REFERENCE

[1] Takashi, N., 2016. Evaluation of relative geometric accuracy of TerraSAR-X by pixel matching methodology. *JSPRS*, XLI-B7, pp. 859-864.

[2] Takashi, N., 2015. Application of the geometric accuracy estimation model of the terrain corrected data to TerraSAR-X data. *JSPRS*, 53(6), pp. 242-249.

[3] Otsuka, Y., 2002. A new technique for map- ping of total electron content using GPS network in Japan. *Earth Planets Space*, 54(1), pp. 63-70.

[4] Michael, J., 2008. Estimation of atmospheric path delay in TerraSAR-X data using models vs. measurement. *Sensors*, 8, pp. 8479-8491.