A NOVEL PROPOSAL OF GAOFEN-3 SATELLITE CONSTELLATION FOR MULTI-APPLICATIONS

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ABSTRACT:

Gaofen-3 is the first C-band fully polarimetric SAR satellite in China, which is widely used in various fields such as ocean monitoring, disaster reduction and so on. In this paper, a new satellite constellation is proposed based on the orbit of Gaofen-3 satellite. The constellation includes Gaofen-3 and other two duplicates. It is able to do repeat-pass interferometry, repeat-pass differential interferometry, along-track interferometry and stereo measurement. With these abilities, it can generate the earth DEM without ground control points and have better performance in moving target identification and monitoring. The performance and the system requirements are analysed, which provides a good reference for the design of spaceborne SAR constellation.

1. INTRODUCTION

Gaofen-3 is the first C band fully polarimetric SAR satellite in China. It can work in twelve different modes, in which the highest resolution reaches 1 meter. It also is the first Chinese dual-channel spaceborne SAR, which has the ability of along-track interferometry. Gaofen-3 was launched in August 2016, and was officially put into operation in January 2017. Now Gaofen-3 is widely used in various fields such as ocean monitoring, disaster reduction, water conservancy and so on.

However, single low-orbit SAR satellite observation has its limitations, such as a long revisit cycle, bad performance in low or high speed moving target monitoring. So, a number of SAR constellations are proposed and established. For example, the Sentinel-1 A/B constellation (Ramón Torres, 2016), the COSMO-SkyMed constellation (D. O. Nitti, 2009) and the proposed RADARSAT Constellation Mission (RCM) (Sergey Samsonov, 2016), which all aim at a shorter revisit period, so the satellites in each constellation are in the same orbit with different true anomalies. The SAR-lupe constellation, which has three different orbits, can achieve both a short revisit period and different observation directions. The Tandem-X constellation (Manfred Zink, 2016) has a HELIX satellite formation, which aims at high-quality interferometry to get high-quality DEM. Besides, it is able to do SAR-GMTI with the along-track baseline (Stefan. V, 2011). Moreover, the interferometric Cartwheel (R. Fjortoft, 2004) and the BISSAT mission (A. Moccia, 2002) are proposed, which have bistatic SAR imaging mode. However, all these constellations above are some kind of single-functional in our opinion. Except for the bistatic SAR constellations, the cooperation of the satellites in a constellation is not very close.

In this paper, a new multi- functional constellation is proposed based on the Gaofen-3 orbit. The main orbital elements are given and the orbits are demonstrated. Furthermore, the work modes and the multi-applications are analysed and simulated. Also, the requirements about the SAR systems to fulfill these applications are given, which provides a good reference for spaceborne SAR constellation design.

2. DESIGN OF THE GAOFEN-3 CONSTELLATION

The Gaofen-3 satellite flies in a sun-synchronous orbit. The orbit radius is about 710 km and the inclination is about 98 degrees. With such an orbit, the satellite revisit period is about 29 days. In order to make an extension of the observation ability of Gaofen-3, a constellation including Gaofen-3 and other two duplicates is designed. The following table shows the orbit difference between Gaofen-3 and the other two satellites. In this constellation, satellite-2 flies in the same orbit of Gaofen-3, with about 2.6 degree true anomaly departure, which takes about 44.8 seconds for satellite-2 to fly to the same position as Gaofen-3 in the earth coordination. Satellite-3 flies in an orbit close to the Gaofen-3 orbit, with a 0.007 degree ascending node difference and 2.6 degree true anomaly difference. Satellite-3 keeps ahead of Gaofen-3, the along-track baseline is about 326 km while the cross-track baseline is about 500 m. According to Gaofen-3 repeat-pass InSAR processing results, a 500 m cross-track baseline can guarantee good coherence, the coherent coefficient is around 0.8 and can reach 0.88 in some cases (Tao Zhang, 2017).

Orbital elements	Gaofen-3	Satellite-2	Satellite-3
Radius (km)	713		
Eccentricity	0.0014		
Inclination (degree)	98.3		
Perigee (degree)	100.7		
Ascending node (degree)	A	A	A-0.007
True anomaly (degree)	T	T-2.6	T+2.6

Table 1. Orbit elements of the constellation

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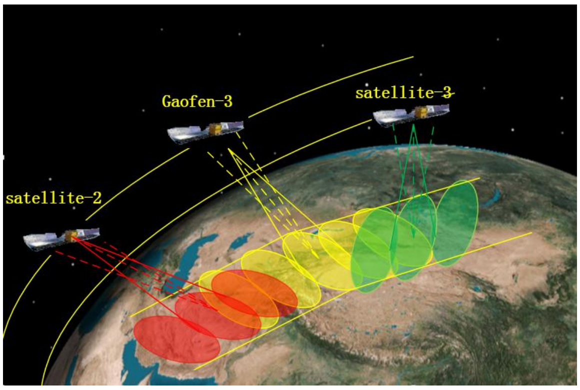

Figure 7. Moving target monitoring mode illustration

In this mode, each SAR works in the dual-receiving channel (DRC) mode, while Gaofen-3 is side-looking, satellite-2 and satellite-3 are forward-looking and backward-looking. The SAR antenna of Gaofen-3 is 7.5m in azimuth direction as shown in Figure 8. While working in the DRC mode, the receive centers have a distance of 3.75 m. With such an along-track baseline, the maximum unambiguous radial velocity $v_{r\max}$ can be calculated by the following equation

$$v_{r\max} \approx \frac{\lambda v_s}{2d}, \tag{2}$$

where

λ is the wavelength,

v_s is the ground velocity of the satellite,

d equals 3.75m here.

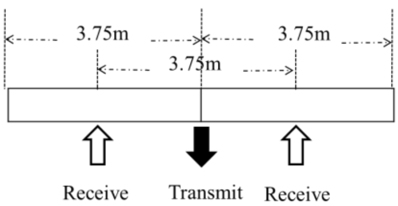

Figure 8. Illustration of the Gaofen-3 DRC mode

So $v_{r\max}$ is about 48 m/s, which is quite a high speed and is almost enough for most of the ground and ocean moving targets. However, the along-track interference for a single SAR only can get the radial velocity. We do not know the true moving direction and the true velocity amplitude. In this constellation, the true velocity of moving targets can be estimated by two or three satellites (Paco Lopez-Dekker, 2014). Because satellite-2 and satellite-3 can get their radial velocities, while the radial directions are different from Gaofen-3. The relationship between the true velocity vector and the radial velocities is shown in Figure 9. Then the velocity amplitude v_{real} and the direction angle ϕ_v can be solved by the following equations

$$v_{ri} = v_{real} \cos\theta_i \cos(\phi_i - \phi_v), \quad i = 1,2,3 \tag{3}$$

where θ_i is the incidence angle, and ϕ_i is the ground squint angle.

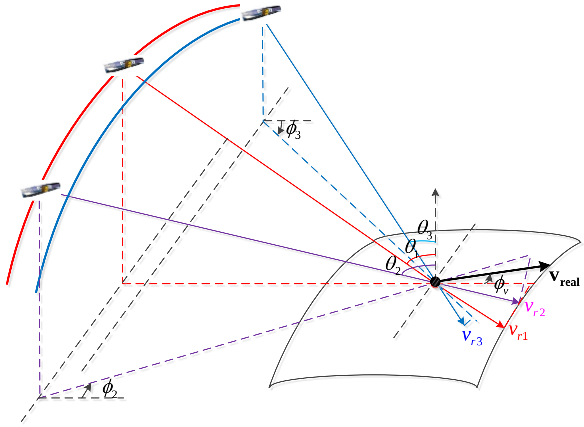

Figure 9 Illustration of the relationship between the true velocity and the radial velocity of a moving target

As to the minimum detectable velocity and the precision of the velocity estimation, it can be estimated by the following equation,

$$v_{r\min} = \frac{\lambda v_s}{4\pi d}\phi_{d\min} \tag{4}$$

Where $\phi_{d\min}$ is the phase threshold, which is affected by the noise and clutter. For example, if $\phi_{d\min} = 30^\circ$, then $v_{r\min}$ is about 4 m/s for Gaofen-3, which means the precision of the velocity estimation is limited to this level.

Because the moving target will appear at different position in each SAR image of the image sequence, the velocity also can be confirmed by this information. The time interval of these images can be more than 10 s, and the target differential position extraction precision is on the resolution level, so the velocity estimated using the image sequence can reach a better precision on the decimetre per second level. As a result, the constellation can do the moving target identification work using the DRC mode on-board each satellite, and then estimate the true velocities of moving targets from the image sequence, so as to get better performance in moving target monitoring.

4. CONCLUSION

In this paper, a new multi-application SAR constellation is proposed. The designed constellation can do stereo measurement combined with InSAR and DInSAR, and is able to monitor the moving targets and get their velocity with amplitude and direction. The orbits and the collaboration working modes for the constellation are designed, concerning the Chinese Gaofen-3 satellite. Furthermore, the performances, such as stereo SAR measurement, are analysed theoretically and by simulations. This constellation concept and the performance analysis results provide good references for SAR constellation design of multi-applications.

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REFERENCES

Ramón Torres, et al, 2016, Sentinel-1B LEOP and commissioning, *In 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, Beijing, China, pp. 3877 – 3881

D. O. Nitti, et al, 2009, Quantitative analysis of stripmap and spotlight SAR interferometry with COSMO-SkyMed constellation, *In 2009 IEEE International Geoscience and Remote Sensing Symposium*, pp. II-925 - II-928

Sergey Samsonov, et al, 2016, RADARSAT constellation mission for monitoring ground deformation in Alberta's oil sands, *In 2016 IEEE 17th Annual Wireless and Microwave Technology Conference (WAMICON)*, pp. 1-4

Manfred Zink, et al, 2016, TanDEM-X mission status: The complete new topography of the Earth, *In IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, Beijing, China, pp. 317 – 320

Stefan V, et al, 2011, Large along-track baseline SAR-GMTI: First results with the TerraSAR-X/TanDEM-X satellite constellation, *In 2011 IEEE International Geoscience and Remote Sensing Symposium*, pp.1319-1322

R. Fjortoft, et al, 2004, Impact of ambiguities in multistatic SAR: some specificities of an L-band interferometric cartwheel, *In 2004 IEEE International Geoscience and Remote Sensing Symposium*, pp 1754 – 1757

A. Moccia, et al, 2002, BISSAT: a bistatic SAR for Earth observation, *In IEEE International Geoscience and Remote Sensing Symposium*, pp. 2628-2630

Paco Lopez-Dekker, et al, 2014, Experimental Bidirectional SAR ATI acquisitions of the ocean surface with TanDEM-X, *In 10th European Conference on Synthetic Aperture Radar*, pp.1-4

Chibiao Ding, et al, 2017, Preliminary Exploration of Systematic Geolocation Accuracy of GF-3 SAR Satellite System, *Journal of Radars*, 2017. 6 (1), pp.11-16.

Tao Zhang, et al, 2017, Repeat-pass SAR Interferometry Experiments with Gaofen-3: A Case Study of Ningbo Area, http://lanl.arxiv.org/abs/1704.01067

Michael Eineder, et al, 2011, Imaging Geodesy – Toward Centimenter-Level Range Accuracy With TerraSAR-X, *IEEE Transactions on Geoscience and Remote Sensing*, 2011,49(2), pp 661-671