SCIENCE CHINA
Information Sciences

• LETTER •

December 2016, Vol. 59 129302:1–129302:3
doi: 10.1007/s11432-016-5524-x

Feasibility study of inclined geosynchronous SAR focusing using Beidou IGSO signals

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Received October 18, 2015; accepted December 1, 2015; published online April 22, 2016

Citation Dong X C, Hu C, Tian W M, et al. Feasibility study of inclined geosynchronous SAR focusing using Beidou IGSO signals. Sci China Inf Sci, 2016, 59(12): 129302, doi: 10.1007/s11432-016-5524-x

Dear editor,

Geosynchronous synthetic aperture radar (GEO SAR) [1,2] has an inclined geosynchronous orbit of around 36000 km, which leads to its short revisit time of around 24 hours and a wide coverage of up to approximately one third of the Earth surface. Its long integration time guarantees the fine resolution. Thus, GEO SAR owns the promising capability of providing images with the high resolution, wide swath and frequent revisit time. This ensures its overwhelming advantages for monitoring hazards and disasters compared with low earth orbit SAR (LEO SAR). Currently, many studies [3, 4] have been concentrated on system design and performance analysis, imaging algorithms, along with non-ideal influences, including atmospheric effects and orbital perturbations. But on the contrary, these multiple non-ideal influences will accumulate during this long period, which would lead to the degradation and even the failure of GEO SAR focusing. Thus, suspects of whether GEO SAR can really image exist since it was first proposed. Many scholars [5–7] have contributed to the theoretical studies on these influences. But an experiment demonstration is essential for validating the feasibility of GEO SAR focusing, and it is also a significant supplement to the current theoretical analysis.

In this letter, an experiment is presented to study the feasibility of GEO SAR focusing under the long integration time of around several hundreds to even thousands of seconds. The experiment is configured as a space-surface bistatic SAR (SS-BISAR), employing the Chinese Beidou inclined geosynchronous satellite orbit (IGSO) navigation satellites as illuminator of opportunity. The Beidou IGSO orbit is one of the 3 kinds of Beidou satellite orbits, of which the other two are the geostationary orbit and the medium Earth orbit. The satellites in geosynchronous and geostationary orbits are used for enhancing regional positioning. The Beidou IGSO satellites have the similar 'figure-8' nadir tracks as the inclined GEO SAR. This makes it a natural way to verify the feasibility of GEO SAR focusing through the employment of Beidou IGSO satellites as illuminator of opportunity in the SS-BISAR configuration. The Beidou IGSO has the similar orbit parameters as GEO SAR (see Figure 1(a)). They both run on the inclined geosynchronous orbit with the similar orbit parameters of eccentricity, inclination of orbit and argument of perigee.

The experiment was carried out in a park in Changshu in southern China in July, 2013. In the SS-BISAR configuration, the bistatic angle is set to be less than 90° in order to achieve a backscat-

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The authors declare that they have no conflict of interest.

Parameter	Semi-major axis (km)	Eccentricity	Inclination (°)	Argument of perigee (°)	Bandwidth (MHz)	Frequency (GHz)
Beidou IGSO	≈42161	≈0.002	≈54.8	≈178	20	1.268
GEO SAR	42164	0.07	53	178	20	1.25

(a)

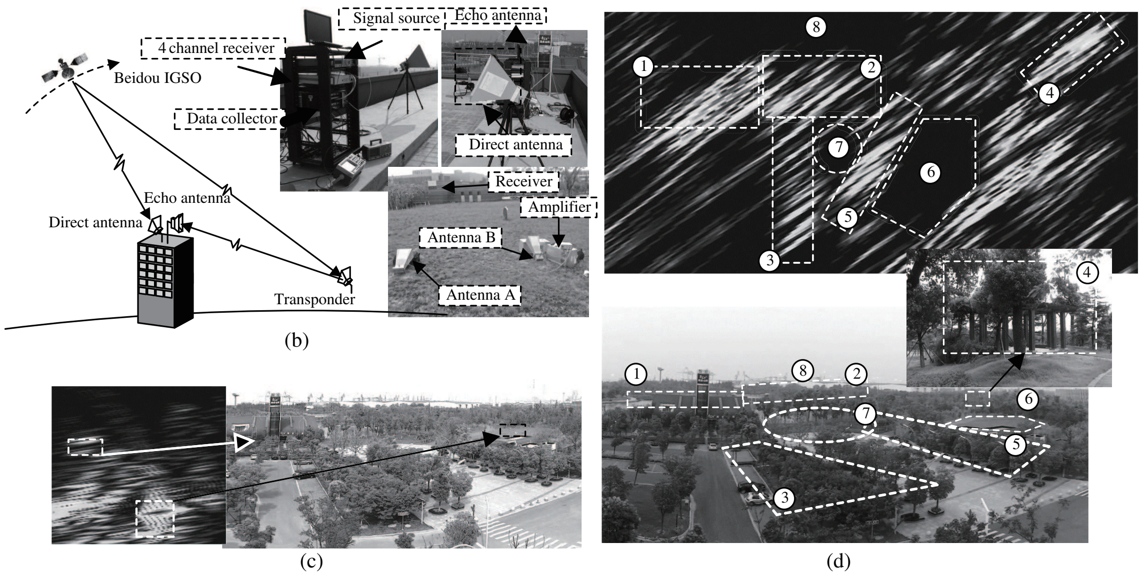

Figure 1 (a) Beidou IGSO and GEO SAR system parameters; (b) experimental topology with Beidou IGSO and the corresponding equipment; (c) the imaging results of the transponder; (d) the natural scene compared with optical photos.

tering geometric relationship. The acquisition time should be specifically determined according to the position and trajectory of IGSO satellites to achieve the required resolution performance. In the experiment, the acquisition time is set as 1800 s and thus an azimuth resolution is obtained as around 2 m. Figure 1(b) shows the experimental topology and the equipment. The receiver is placed on a high building and consists of a direct antenna for receiving the direct IGSO signals and an echo antenna for collecting the echoes backscattered from the natural scene. Under the assumption that the non-ideal influences are spatial invariant within the small imaging scene (smaller than 1 km × 1 km), the employment of the direct signals as reference is able to compensate the non-ideal factors in focusing the natural echoes. A transponder is set as a strong target in the natural scene and located about 150 m from the receiver. The transponder is composed of 2 antennas and an amplifier, which will receive and transmit the Beidou IGSO signals. One antenna is employed to receive the direct signal; the amplifier amplifies the signals and then transmits it to the echo antenna via the other antenna which is oriented to the receiver. In this way, a strong point can be constructed and can be used for the focusing capability validation and the resolution evaluation.

The equipment used in the experiment is listed in Figure 1(b). A 4-channel receiver is used to record the direct signals (I & Q channels) and echoes reflected from the transponder or natural scene (I & Q channels, too), respectively. The signal source provides reference clock to guarantee the coherence between the 4-channel receiver and the data collector. A high stable oscillator (atomic clock) in receiver is used as the frequency and phase benchmark, in order to solve the synchronization problem.

The recorded signal from IGSO has a special signal format. It should be pre-processed before it is used to generate SAR images. Firstly, the direct signals were recorded and tracked in order to locate the initial position of the C/A code. The ephemeris information could be extracted from the navigation message. The satellite positions were calculated from the satellite ephemeris and the timing information. Together with the receiver antenna phase center, the slant range history could be retrieved. Then the initial position of the C/A code is used to estimate the time synchronization while the frequency synchronization is carried out using the Doppler phase history. Finally, the echo data were pre-processed by the navigation phase removal and the following synchronization using the information retrieved from direct signals. The synchronized echoes could then be focused [8] and the back projection algorithm is employed. During the processing, the non-ideal influences have been removed along with the time-frequency synchronization errors. This is because of the assumption that these non-ideal influences have the identical effects for the echoes and the direct signals used as reference.

The imaging results of the transponder and the natural scene are presented in Figure 1(c) and (d), respectively. For the result of the transponder, the theoretical and experimental resolutions are evaluated. The theoretical resolution is not derived by formulae. Instead, it is obtained by evaluating the point spread function (PSF) of the ideally simulated signals. The simulation employs the ephemeris of Beidou IGSO satellite (refer to parameters in Figure 1(a) and the integration time is 1800 s) and the geometry of the transponder, and the echoes are generated by simulation. The experimental resolution is obtained by focusing the echoes backscattered from the transponder. The theoretical and experimental resolutions are 17.77 m and 19.09 m in range, and 1.73 m and 1.75 m in azimuth. The deviations are probable to be induced by the multi-path effects and locate within 10% which are acceptable. The consistence between the two resolutions presents a strong validation of the GEO SAR imaging capability.

Figure 1(d) gives the imaging result of a natural scene and the corresponding details of the interpretation of the SAR images compared with the optical photos. The targets of 1–5 are strong stable targets, such as buildings and shelters, while the numbered 6–8 targets are lawn and lakes which backscatter weakly in the SS-BISAR configuration in this experiment. The imaging results demonstrate that the strong stable targets in the natural scene can be focused well in GEO SAR with the long integration time. In the experiment, it benefits from the direct path information as all the nondeal factors can be retrieved and compensated as they are underlying in the direct signal. Though in real GEO SAR cases such direct path information is absent, the experiment can still deliver the demonstration validation that in GEO SAR the strong stable targets can be well focused if the multiple influences are compensated. In real cases, the errors from curved trajectories, perturbations and atmosphere are expected to be compensated individually [3] and the image will be focused well. Nonetheless we also have to accept sub-optimum images if the residual errors exist, and it is sure that the autofocus techniques are needed in the further study.

Acknowledgements This work was supported by National Natural Science Foundation of China (Grant Nos. 61225005, 61501032, 61120106004).

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