On Spaceborne Synthetic Aperture Radar (SAR) Systems in China

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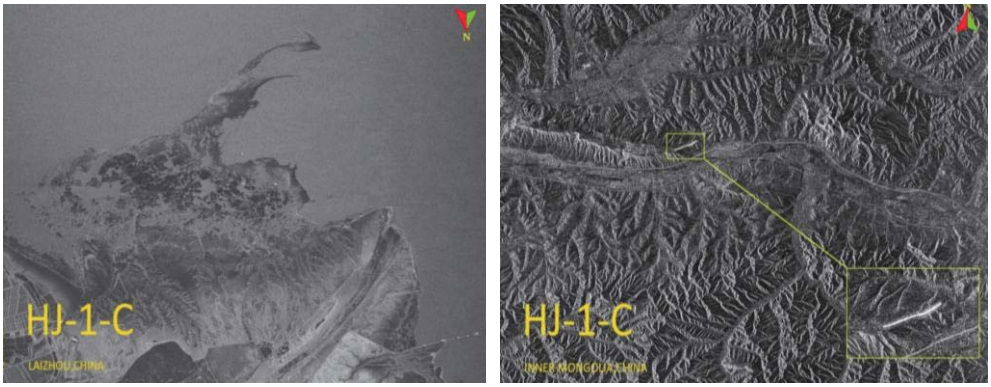
1. Introduction

The Synthetic aperture radar (SAR) technology has been developed in China since 1970s, and the first airborne SAR system was established in 1979 and obtained multiple SAR images. Although the spaceborne SAR technology started later in China, advanced concepts and key techniques of spaceborne SAR systems were proposed and investigated in recent twenty years. In 2006, the first satellite SAR in China was launched and obtained mount of detailed SAR images of the Earth's surface. The advanced SAR satellite named HJ-1-C for geosciences and climate change research, environmental and Earth system monitoring was launched on November 19, 2012. Furthermore, several new spaceborne SAR concepts and techniques to support the next China spaceborne SAR systems were studied, and their corresponding airborne experiments are carried out.

2. Development of the SAR technology in China

2.1 HJ-1-C Satellite SAR

HJ-1-C is a China Radar Earth-observation satellite in a polar orbit at an altitude of 500km, and has been launched on November 19, 2012. It is S-band SAR sensor using light-weight distributed-centralized reflector antenna. It offers high-quality SAR images of down to five meters with a swath of 40km, regardless of weather conditions, cloud coverage and availability of daylight. It acquitted the first image on 9 December 2012. The objective of the mission is to provide value-added SAR data in the S-band, for the dynamic monitoring of the ecological environment and disaster as well as timely assessment of disaster and trend forecast. The SAR system has been developed by Institute of Electronics, Chinese Academy of Sciences (IECAS). Fig. 1 shows SAR images obtained by HJ-1-C.



(a) (b)

Fig. 1. HJ-1-C SAR images (Stripmap Mode, 5 m Resolution, VV Polarization, Provided by IECAS) (a) Laizhou, China, and (b) Inner Mongolia, China.

2.2 Trend of China spaceborne SAR systems

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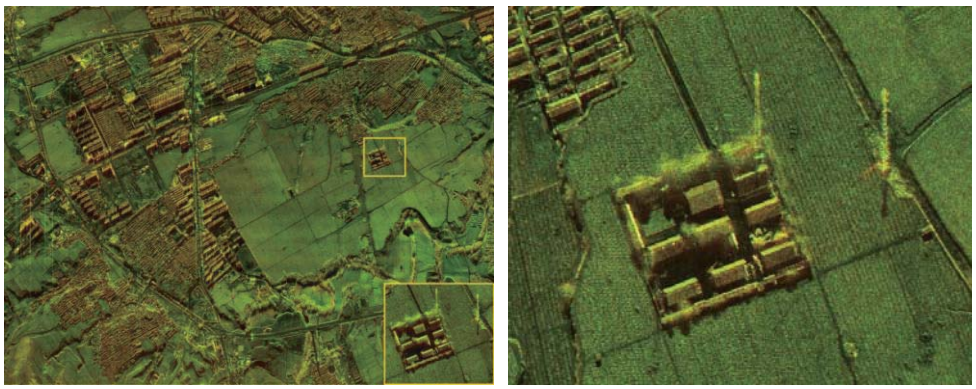
2.2.1 High resolution imaging

Resolution is a key parameter for SAR system design, as higher resolution enables more image details. To acquire high azimuth resolution, spotlight SAR is developed via steering the radar antenna beam to always illuminate the same area during the data acquisition interval. A mixture between spotlight SAR and stripmap SAR is the sliding spotlight SAR, where the antenna beam simultaneously slides and steers. On the other hand, to realize high range resolution, multiple subbands SAR, where stepped frequency chirps and synthetic bandwidth technique are employed, comes into being. The problems should be taken into consideration for high resolution SAR are much more than low resolution SAR. As a result, the investigation and settlement of these technique difficulties are of great significance. Fig. 2 shows airborne SAR images of the high resolution sliding spotlight mode, and the resolution of the following SAR image is 0.15m.

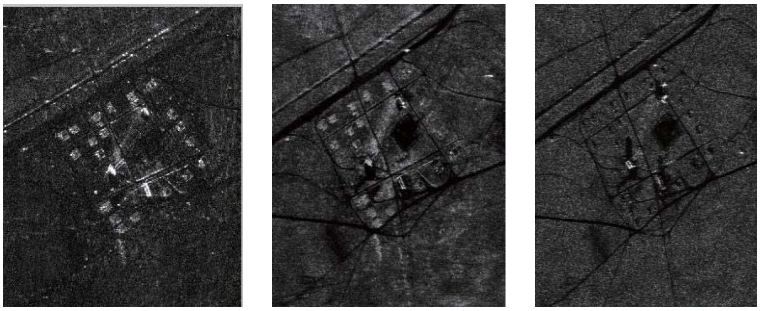


(a) (b)

Fig. 2. X-band airborne SAR image with resolution of 0.15m (sliding spotlight mode, provided by IECAS)

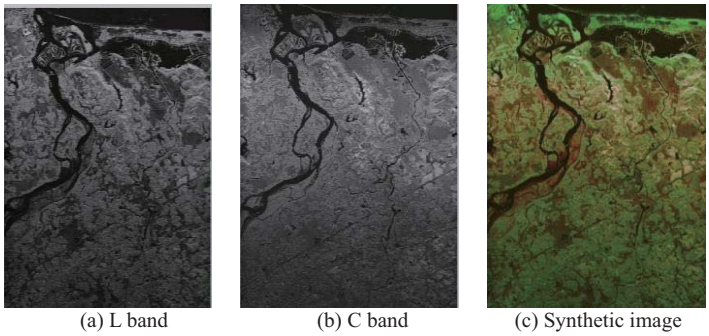
2.2.2 Multi-band imaging

Across the range of common SAR frequencies (P-band to Ku-band, 0.5-13GHz), in general it can be said that electromagnetic wave with lower frequency is of stronger penetration capability but weaker reflection capability than that with higher frequency. Therefore, for the same target illuminated by different wave-bands, it appears differently in the SAR images and then shows different information. Fig. 3 shows SAR images of the same imaged area with different range frequencies. Furthermore, combining the information provided by different wave-bands can improve the vegetation classification accuracy in agriculture, the soil moisture inversion accuracy in hydrology, and shrub identification accuracy in forestry. Moreover, in oceanographic observation and geological hazard monitoring, the employment of multi-bands can provide more comprehensive features. Consequently, the research on multi-band SAR is of great value for the world. Fig. 4 shows the synthetic SAR image with the L-band and the C-Band.



(a) L band (b) C band (c) X band

Fig. 3. SAR images of the same area with different frequency bands (Provided by IECAS)

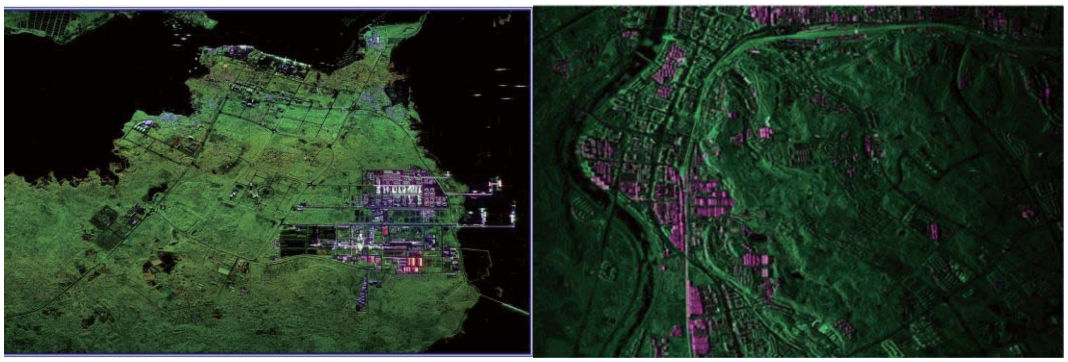


(a) L band (b) C band (c) Synthetic image

Fig. 4. Combining SAR images with different frequency bands together (Provided by IECAS)

2.2.3 Full polarization imaging

SAR polarimetry is a widely used technique for the derivation of qualitative and quantitative physical information for land, snow and ice, ocean and urban applications based on the measurement and exploration of the polarimetric properties of man-made and natural scatterers. Measuring the full scattering matrix allows to build up a powerful observation space sensitive to shape, orientation and dielectric properties of the scatterers and allows the development of physical models for the identification and/or separation of scattering mechanisms occurring inside the same resolution cell. Fig. 5 shows full polarization SAR images.

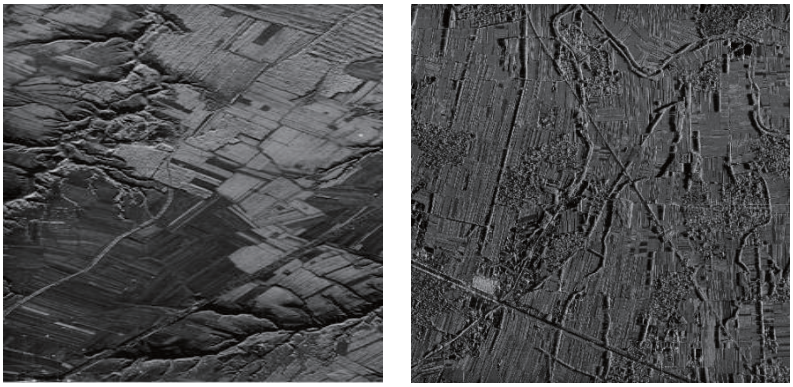


(a) (b)

Fig. 5. Full polarization SAR images (Provided by IECAS)

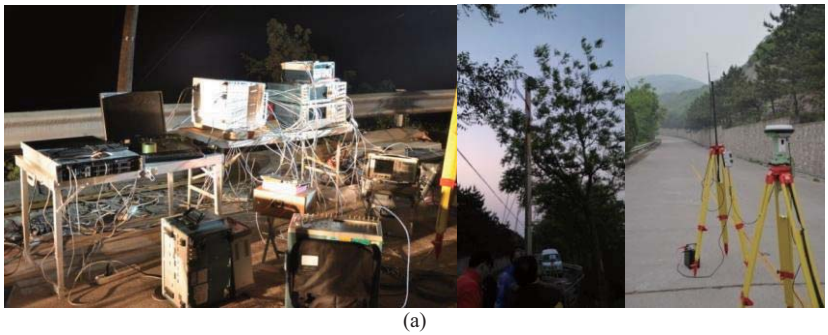
2.2.4 Wide swath imaging

Future spaceborne SAR systems require the high resolution wide swath imaging capacity. The high geometric azimuth resolution and the wide swath pose different pulse repetition pulse frequency (PRF) requirement, this contradiction could be overcome by the displaced phase center multiple azimuth beams (DPCMAB) technique, which introduces additional spatial samples to reduce the PRF requirement. In addition to overcoming the contradictive PRF requirement, improving the signal to noise ratio (SNR) and suppress the range ambiguity are also very important for spaceborne high resolution wide swath imaging. To improve the SNR and suppress the range ambiguity, a large size of the receive antenna is adopted. Furthermore, the large receive antenna is divided into multiple sub-apertures in elevation, and echoes of the whole imaged swath are individually received and sampled by each sub-aperture. Afterwards, echoes from all sub-apertures are combined together by a digital beamforming (DBF) processor. This DBF on receive scheme is to form a narrow sharp receive beam which follows the radar pulse as it travels on the ground. As a result, the DPCMAB technique combined with DBF on receive in elevation would be adopted for future high resolution wide swath imaging. Fig. 6 shows SAR images of the airborne SAR systems with six azimuth channels. Fig. 7 shows the ground-based DBF on receive experiment.

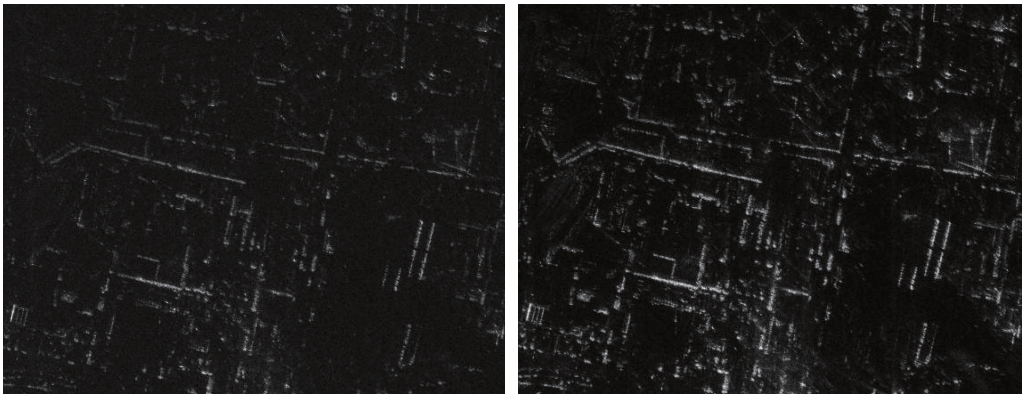


(a) (b)

Fig. 6. Azimuth multichannel SAR images (Provided by IECAS) (a) SAR image of the azimuth multichannel stripmap mode with the resolution of 0.3m, and (b) SAR image of the azimuth multichannel stripmap mode with the resolution of 0.5m.



(a)



(b) (c)

Fig. 7. Results of the ground-based DBF on receive experiment (Provided by IECAS) (a) Equipments for the ground-based DBF on receive experiment, (b) SAR image of a single channel, and (c) SAR image after multichannel DBF processing.

3. Conclusion

In a changing and dynamic world, high-resolution and timely geospatial information with global access and coverage becomes increasingly important. Constellations of SAR satellites will play a major role in remote sensing, since spaceborne SAR is the only sensor that has all-weather, day-and-night, high-resolution imaging capability. From the first China's satellite SAR launched in 2006 to the recent HJ-1-C, the China's spaceborne SAR systems show the powerful capacity in microwave remote sensing, which provid a complementary and useful addition to optical remote sensing. However, with the fast increasing user requirements, spaceborne SAR systems should obtain more detailed information of the Earth's surface. As a result, multiple new concepts and techniques especially for high resolution, frequency multi-band, full polarization and high-resolution wide-swath imaging would be adopted in future China spaceborne SAR missions. Furthermore, mount of airborne SAR experiments had been carried out to support these new concepts and techniques.