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First three-dimensional imaging experiment of Chinese commercial SAR satellite Fucheng-1

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Three-dimensional (3D) spaceborne synthetic aperture radar (SAR) imaging [1] holds significant importance in various fields such as urban mapping [2] and disaster monitoring [3], as it provides a comprehensive view of the spatial scattering structure of objects and landscapes. The increasing complexity of urban environments and the growing requirements for precise and detailed spatial data have made advanced 3D imaging techniques more essential than ever. Due to the high cost, technical complexity, and insufficient commercial market demand in the early stage of development, SAR satellites were initially used in the field of civil remote sensing monitoring. Fucheng-1 is the first commercial SAR satellite of China with interferometric capability, which is significant for exploring its multi-dimensional imaging potential. In this study, a data processing framework for urban 3D super-resolution tomographic SAR (TomoSAR) inversion based on Fucheng-1 is developed, achieving the first successful 3D reconstruction of large-scale urban areas using a Chinese commercial SAR satellite. The reconstruction results lay the foundation for further multi-dimensional research on this satellite.

Brief introduction of Fucheng-1 SAR satellite. Fucheng-1 is the first SAR satellite with interferometric capability, independently designed, developed, and tested by Spacety Aerospace Company Limited. As the inaugural satellite of the Mianyang constellation, Fucheng-1 meets advanced international standards and utilizes an active phased array antenna for C-band SAR remote sensing. It features long time-series interferometry capabilities, with satellite data offering advantages of high revisit frequency, high resolution, and high coherence, enabling the monitoring of ground surface deformation at the millimeter level. The acquired information can be globally utilized across various fields, including urban infrastructure monitoring and geological disaster detection.

Overview of 3D imaging. The 3D imaging process based on the Fucheng-1 SAR dataset is introduced below.

(1) Datasets. The dataset used in this study includes both ascending and descending orbit data. The ascending orbit data consists of 14 scenes collected from January 7, 2024, to June 20, 2024, with a baseline length of 252 m and an elevation resolution of 64.7 m. The descending orbit data consists of 15 scenes collected from January 18, 2024, to June 20, 2024, with a baseline length of 171 m and an elevation resolution of 97.4 m. This study focuses on the compressive sensing (CS)-TomoSAR 3D reconstruction of urban architecture [4]. The densely built near the University of Magdeburg is selected as the experimental site.

(2) 3D imaging framework and results. Ascending and descending single look complex (SLC) image datasets are input separately and preprocessed for 3D imaging. The TomoSAR imaging results obtained from the ascending and descending orbits data using the CS-based method are shown in Figures 1(a) and (b). These figures show the TomoSAR results superimposed on the SAR images, with the color representing the height. The 3D point clouds of ascending and descending orbits show different building facades. Then, the whole 3D building structure is demonstrated in the fused 3D result (Figure 1(c)). In order to more accurately match the true geographic location of the buildings, this study selects the footprints downloaded from open street map (OSM) as the reference for the actual geographic coordinates of the buildings. The used OSM data includes the latitude and longitude coordinates of buildings and highways. Since the highway footprints are clearer than the building ones, we chose the highway coordinates as the reference to verify the accuracy of the coordinate transformation. Figures 1(d) and (e) show the SAR images of ascending and descending orbit data after a coordinate transformation, where the green lines represent the highway footprints. It is found

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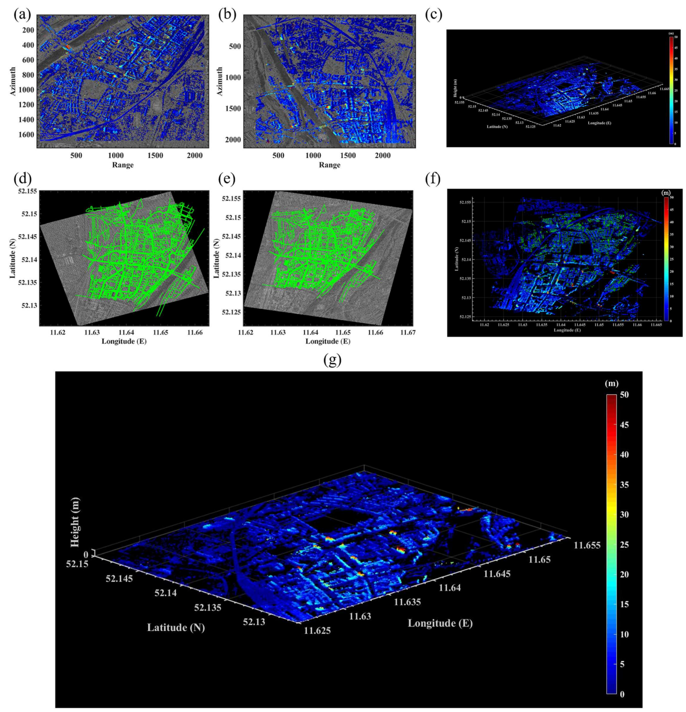

Figure 1 (Color online) Processing results of the proposed method. (a) TomoSAR imaging results of ascending orbit data; (b) TomoSAR imaging results of descending orbit data; (c) point cloud after fusion of ascending and descending orbits; (d) SAR image of ascending orbit data after coordinate transformation; (e) SAR image of descending orbit data after coordinate transformation; (f) point cloud and building footprint of the University of Magdeburg area; (g) point cloud after optimization of the University of Magdeburg area.

that the coordinates transformation almost fits the highway footprints. Besides, by integrating the building footprint information from OSM, this study introduces an additional layer of validation to filter out inaccuracies and outliers in the point cloud. Utilizing building footprints is a crucial step in optimizing the point cloud. These footprints provide a reliable reference to correct bias and ensure that points accurately represent the physical environment. The match between the building footprint and the point cloud is shown in Figure 1(f), illustrating the alignment and integration of these two data sources, with the green lines representing the building footprints. The method filters points outside the footprint while preserving the point cloud inside the footprint. Subsequently, Figure 1(g) displays the refined 3D point cloud, with the color representing the height. The point cloud has been adjusted to the building footprint constraints to provide a more clear and accurate representation of the target distribution. This process not only improves the fidelity of the point clouds but also enhances its utility for further applications such as urban planning, navigation, and environmental monitoring.

Conclusion. In this study, the first urban 3D point cloud from the Fucheng-1 SAR satellite was obtained. The interference and tomographic inversion abilities of this satellite are successfully verified. In addition, this study also introduces an advanced Fucheng-1 processing framework for deriving 3D point clouds based on TomoSAR technology. Although the elevation resolution of the used dataset is up to fifty meters, 14 ascending orbit images and 15 descending orbit images were utilized to achieve high-precision 3D imaging of Magdeburg through a super-resolution imaging algorithm. Based on the current research, the future study aims to further explore the application potential of Chinese commercial SAR satellites, including the development of large-area differential tomography imaging for high-precision deformation monitoring. Besides, the proposed framework will also be extended to the vast mountains and forest areas.

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