Recent Progress of ISAR Imaging Algorithms

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Abstract. Inverse synthetic aperture radar (ISAR) has the characteristics of all-day, all-weather and long-range imaging. It realizes the imaging and recognition of noncooperative targets and has a wide range of applications in military and civilian fields. In this paper, the range Doppler (RD) algorithm, range-instantaneous Doppler (RID) algorithm, compressive sensing (CS) theory-based ISAR imaging algorithm, as well as three-dimensional interferometric inverse synthetic aperture radar (3-D InISAR) imaging algorithm are introduced. The prospect of ISAR imaging technology is given.

Keywords: ISAR · RD algorithm · RID algorithm · CS-based ISAR imaging · 3-D InISAR imaging

1 Introduction

With the development of signal processing [1, 2] and broadband radar technology, radar imaging has made breakthroughs, which carries out two-dimensional or even three-dimensional high-resolution imaging of long-range moving targets despite the time and weather. As a result, it has broad applications in the fields of military and civilian. Typically, the radar imaging algorithms include synthetic aperture radar (SAR) imaging and inverse synthetic aperture radar (ISAR) imaging [3, 4], and these two algorithms have similar imaging principles. The main difference between them is that SAR uses the motion of the radar to form a synthetic aperture to image fixed targets, while ISAR uses the motion of the target to form a large synthetic aperture for imaging. Therefore, compared with SAR imaging of fixed targets, ISAR imaging can effectively achieve imaging of noncooperative targets.

In this paper, we first give several imaging algorithms of ISAR and then propose the corresponding prospect of ISAR imaging. Specifically, range Doppler (RD) algorithm is a typical ISAR imaging algorithm, which is suitable for imaging stationary moving targets. When the target is non-stationary, the imaging result obtained by range-instantaneous Doppler (RID) algorithm is better than that of the RD algorithm [5, 6]. ISAR imaging based on compressive sensing (CS) theory [7] can effectively reduce

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the sampling rate, and improve the resolution as well as the two-dimensional imaging quality. In order to obtain the three-dimensional information of the target, three-dimensional imaging algorithm is proposed. Three-dimensional interferometric inverse synthetic aperture radar (3-D InISAR) imaging algorithm combines ISAR imaging with interference technology to achieve 3-D imaging of noncooperative targets [8]. As a result, 3-D InISAR can obtain more information of the target, which is of great significance for extracting the feature information of the target.

This paper is organized as follows. In Sect. 2, several ISAR imaging algorithms are introduced. In Sect. 3, the prospect of ISAR imaging technology is given. Finally, conclusion is given in Sect. 4.

2 ISAR Imaging Algorithms

RD algorithm is a classical ISAR imaging algorithm, and it decomposes the radar imaging process into a matching filtering process in the range and azimuth direction, respectively. The range direction achieves high resolution through pulse compression, and the azimuth direction achieves high resolution by Doppler. It contains the following four steps. Firstly, the received radar data is pulse-compressed in the range direction to obtain a one-dimensional range image of the target. Secondly, the range cell migration correction (RCMC) is performed after the azimuth FFT is performed on the range image. Thirdly, pulse compression is carried out in the azimuth direction. Finally, IFFT is performed in the azimuth direction to obtain the final imaging. The flowchart of RD algorithm is shown in Fig. 1.

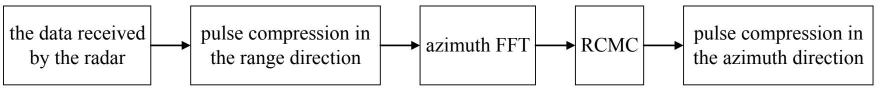

Fig. 1 RD algorithm flowchart

Generally, when the target is moving at a steady and uniform speed, the imaging results of RD algorithm are acceptable. However, the movement of the target is usually unstable, and due to the time-varying characteristics of Doppler [5], the RD algorithm is not applicable. The resulted images may suffer from defocus phenomenon in the azimuth direction or even result in false targets. To achieve the non-stationary moving target imaging, the RID algorithm is proposed, which applies the time–frequency analysis method to replace the azimuth FFT of RD algorithm [6, 9]. Chen et al. [10] employ the joint time–frequency analysis method to image the non-stationary moving targets, and the imaging quality is improved.

According to the CS theory, if the signal is compressible or sparse in a known transform domain, then it can be sampled with a sample rate that much lower than the Nyquist frequency, and it can be reconstructed by a signal reconstruction method [7]. In ISAR imaging under far-field conditions, the target is generally composed of strong scattering points, which are sparsely distributed in the imaging area. Applying the CS theory to ISAR imaging not only reduces the amount of data processing and sampling rate, but also improves the imaging resolution as well as the imaging quality. In the recent literature, Raghu et al. [11] model the ISAR imaging problem in the sea clutter as a convex optimization problem that can be solved by CS theory. Thus, the CS-based ISAR imaging has received extensive attention. Both domestic and foreign researchers have conducted a great deal of research on the CS-based ISAR imaging.

In recent years, 3-D InISAR imaging algorithm has become a research hotspot in the field of radar imaging. InISAR achieves 3-D imaging of noncooperative targets by combining ISAR imaging with interference technology [8, 12]. It arranges multiple antennas in the horizontal and vertical directions, and emits large bandwidth signals to obtain high resolution of distances. Then, the phase difference is calculated in each distance unit to obtain the azimuth and height information relative to the baseline of the scattering points, which are in the different distance units on the target. 3-D image of the target is obtained by adding the distance information of the target. Assuming that the three antennas are A, B and C, then the three-antenna InISAR three-dimensional imaging flowchart is given in Fig. 2.

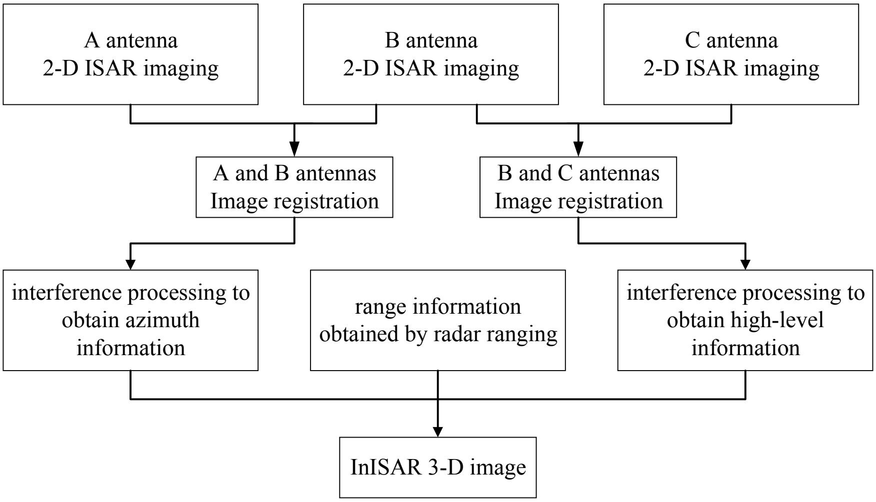

Fig. 2 Three-antenna InISAR 3-D imaging flowchart

Compared with the 2-D ISAR imaging results, 3-D InISAR imaging of the target can obtain more feature information. It not only directly reflects the 3-D shape and structure of the target, but also is less affected by the target's movement and posture changes. It is conducive to realize more accurate imaging and recognition of the target, and of great significance to improve the target feature extraction ability.

3 Prospect

With the increasing complexity of ISAR application scenarios, the requirements for the resolution and quality of ISAR imaging are becoming increasingly high. As a result, ISAR imaging algorithms require further studies. The research directions of ISAR imaging can be concluded as follows.

Firstly, as the target observed by radar becomes more diversified, few researches are focused on ISAR imaging algorithms for close-range micro-moving targets. Secondly, ISAR imaging algorithms for the long-range targets with low signal-to-noise ratio are worthy of further studies. Last but not least, 3-D ISAR imaging technology can be combined with optical image to obtain more target information, which is of great significance for the improvement of target recognition and classification.

4 Conclusion

In this paper, we concluded the RD algorithm, RID algorithm, CS-based ISAR imaging algorithm and 3-D InISAR imaging algorithm. However, with the increasing requirements of the imaging resolution, the imaging results obtained by the existing imaging algorithms may not be satisfactory. Therefore, it is necessary to combine the practical requirements and radar system design so as to enrich the applications of the ISAR imaging.

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