An improved BP Algorithm in Geosynchronous SAR

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Abstract

In Geosynchronous SAR (GEO SAR),because of the orbit determination error, the imaging quality of the back Propagation (BP) algorithm is greatly affected. In order to solve this problem, This paper presents a searching method based on the principles of optimization. Firstly, using the coordinate rotation method to search the two order term and the above parameters of the true slant histories. Then, using the Traversal method to search the Constant term. Finally, the simulation results show that the improved BP algorithm can realize the orbit determination error correction.
Index Terms—CS algorithm, GEO SAR, the orbit determination error, searching method

1. Introduction

The current spaceborne SAR orbital altitude usually in 500 km to 800 km, due to the restrictions of orbital altitude, Small covering area, narrow swath and long repeat observation period Restrict its application to a large extent. Geosynchronous SAR(GEO SAR) orbit located at an elevation of about 36000 km distance from the surface of the earth. In the revisit cycle, coverage, and other aspects, it has an LEO SAR incomparable advantages and a good applied prospects in military and civilian, therefore it become a new research hot spot for spaceborne SAR system at home and abroad in recent years[1-4].

Due to high orbital altitude ,long synthetic aperture time, low satellite speed and the more serious influence of earth rotation, the GEO SAR trajectory shall be regarded as variable speed curve model, the conventional SAR imaging algorithm is no longer applicable. At present the studies in GEO SAR imaging algorithm mainly concentrated in the frequency domain， that has high computational efficiency. But the true slant histories is generally fourth order, the high order parameter estimation has not related research, and azimuth degeneration remains to be further research. Without any assumption, the back Propagation (BP) algorithm based on time domain applicable to arbitrary trajectories, there is no the azimuth degeneration problem. But it needs to know the platform flight parameters accurately, The current orbit determination method is not precise enough that affects the imaging quality.

BP algorithm is the coherent accumulation in time domain, if there is no orbit determination error, the true slant histories is correct and the accumulative energy value is the largest. Therefore, to correct the orbit determination error, the accumulative energy maximum principle can be used to search the slant histories parameters. Finally, simulation results are given a set of optimized search results and the simulation of point targets at perigee, that proves the effectiveness and correctness of the proposed algorithm.

2. GEO SAR BP algorithm and Parameter Searching Method

The basic thoughts of BP algorithm is to calculate the round-trip delay between every point on imaging area and antenna, then coherent accumulate the echo signal along the corresponding time delay curve. It makes the echo signal of the pixels in phase, so the energy strengthened. And the echo signal phase from other points is different, so the energy is weak. Thus, the overlapping results realize the focus imaging of the entire area [5]. Use the formula can be expressed as

$$f\left(x_i, y_j\right) = \int_{\eta} S_M\left(\tau_{ij} = \frac{2R(\eta)}{c}, \eta\right) d\eta \qquad \text{* MERGEFORMAT (1)}$$

Where the $S_M(\tau,\eta)$ means the results of echo signal range compression, τ and η are range and azimuth time, $R(\eta)$ are the range from radar to target $\left(x_i, y_j\right)$, the literature [7] shows that the geosynchronous orbit SAR shall be the fourth order slant histories. Therefore, $R(\eta)$ can be written as

$$R(\eta) = R_0 + V\eta + A\eta^2 + B\eta^3 + C\eta^4 \qquad \text{* MERGEFORMAT (2)}$$

Where the R_0 is the constant term parameters, V , A , B and C are corresponding to one, two, three and four order parameters.

The geometric relationship of the precise orbit and the orbit with determination error can be shown in the figure 1

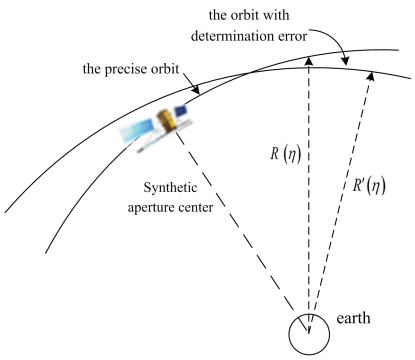


Fig 1 orbit geometry relationship

When the satellite position exists orbit determination error,the slant histories shall be introduce the error term.Now the slant histories orbit determination error can be written as

$$R'(\eta) = R(\eta) + R_{error}(\eta) = R_0' + V'\eta + A'\eta^2 + B'\eta^3 + C'\eta^4$$

* MERGEFORMAT (3)

Where the $R_0^{'}$ is the constant term parameters, $V^{'}$, $A^{'}$, $B^{'}$ and $C^{'}$ are corresponding to one, two, three and four order parameters.

BP algorithm is the coherent accumulation in time domain, if there is no orbit determination error, the true slant histories is correct and the accumulative energy value is the largest. Thus the accumulative energy maximum principle can be used to search the slant histories parameters $R_0^{'}$, $V^{'}$, $A^{'}$, $B^{'}$ and $C^{'}$. The energy accumulative formula is as follows

$$S_{img} = \sum_n S_M\left(\tau = \frac{2R(\eta_i)}{c}, \eta_i\right) \exp\left(j4\pi R(\eta_i)/\lambda\right) \qquad \text{* MERGEFORMAT (4)}$$

GEO SAR orbit determination error is in meters, far longer than the wavelength. As can be seen from the (4), if searching the constant terms parameter with the others together, it will create the problems of phase winding to make the searching result totally wrong. Thus, one, two, three and four order parameters V , A , B and C should be search firstly to let the (2) and (4) differ only in constant, then, searching the constant terms parameter only.

There are four variables need to be searched for the first time, which belong to the multivariable parameter optimization problem. The coordinate rotation method can be used here, that each search allows only one variable changes, letting the rest of variable remain unchanged, and take turns to search in sequence. So it make a much more complex variable searching into a simple single variable

searching. The search steps are as follows:

Step one:Define the slant histories parameters as the initial searching value x_0 , so $x_0 = [V' \quad A' \quad B' \quad C']$, according to the error conditions set search cycles N_{um} ,Step length $step = [V_{step} \quad A_{step} \quad B_{step} \quad C_{step}]$, and precision $\varepsilon = [\varepsilon_V \quad \varepsilon_A \quad \varepsilon_B \quad \varepsilon_C]$.

Step two: Start from the initial value x_0, every time V is the first searching.

If meeting the decision conditions $S_{img}(V_k + V_{step}) > S_{img}(V_k)$

$V_{k+1} = V_k + V_{step}$, $k = 0,1,\ldots,N_{um} - 1$

Otherwise, $V_{k+1} = V_k - V_{step}$, $k = 0,1,\ldots,N_{um} - 1$

According to the above steps again，search A , B and C along the sequence.

Step three:If meeting the decision conditions $S_{img}(V_{k+1}, A_{k+1}, B_{k+1}, C_{k+1}) > S_{img}(V_k, A_k, B_k, C_k)$

$x_{k+1} = [V_{k+1} \quad A_{k+1} \quad B_{k+1} \quad C_{k+1}]$, $k = k+1$, $k = 1,2,\ldots,N_{um}$

Otherwise, $x_{k+1} = [V_k \quad A_k \quad B_k \quad C_k]$, $k = k+1$, $step = step/2$, $k = 1,2,\ldots,N_{um}$

Step four: Inspecte the number of iterations and the accuracy.

If meeting the decision conditions $k < N_{um}$ and $step > \varepsilon$

Return to step 2, continue to search. Otherwise, terminate the searching, and the searching value is $x_{k+1} = [V_{k+1} \quad A_{k+1} \quad B_{k+1} \quad C_{k+1}]$, that will be the The optimal approximate solution of V , A , B and C .Now the searching for V , A , B and C is finished.

The constant term parameter can be searched by the traversing method, that take the constant term parameter R_0' as the center, within the scope of the orbit determination error and the step that less than $\lambda/4$, find out all the accumulative energy S_{img} , the constant term parameter that correspond to the maximum vaule is the approximate solution. The specific steps are as follows:

3. Simulation Rsults

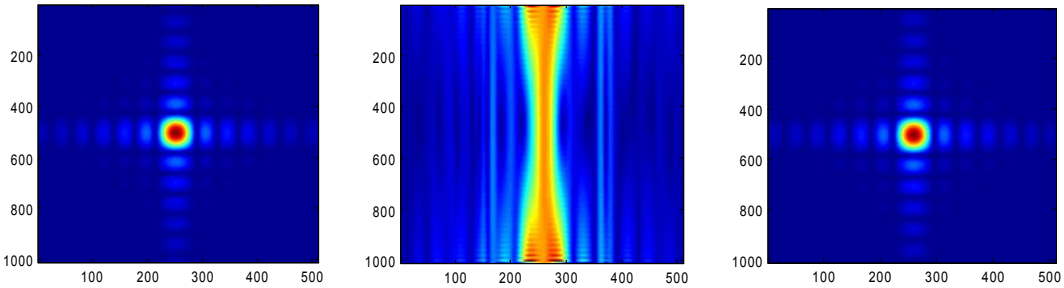
In order to verify the correctness of the proposed imaging method. Some simulation results based on the parameters of the “water drop shape ” orbit will be given in this section.

The orbit parameters are as follows: orbital inclination is 16 degree, eccentricity ratio is 0.05, perigee argument is 90degree, right ascension is 110 degree, off-nadir angle is 3.5 degree. In the table I, I, II and III respectively stand for the sumulation results that correspond to perigee 0 time, 3 times and 6 times as the center, with the ten minutes of synthetic aperture time. We can see that the searching method makes the parameters error decreased obviously from the table I.

TABLE I parameter comparison between the initial error and the error after searching

Point target			1	2	3
Traversing method	Distance(m)	Initial error	0.9426	-0.7264	-0.9999
		Searching error	-0.0374	-0.0064	7.9364×10^{-5}
Coordinate transformation method	Velocity(m/s)	Initial error	-1.7043×10^{-4}	3.5083×10^{-4}	-6.4286×10^{-6}
		Searching error	1.9973×10^{7}	-2.8422×10^{-14}	-1.2556×10^{-8}
	Accelerated velocity (m/s^2)	Initial error	1.2277×10^{-7}	1.0141×10^{-7}	1.3026×10^{-7}
		Searching error	-9.9033×10^{-9}	9.4611×10^{-8}	8.6503×10^{-9}
	Second acceleration (m/s^3)	Initial error	7.4667×10^{11}	-3.0404×10^{-11}	3.9395×10^{-13}
		Searching error	1.4917×10^{-12}	-1.5202×10^{-11}	5.8744×10^{-13}
	Three acceleration (m/s^4)	Initial error	3.5054×10^{-15}	-1.7059×10^{-15}	-4.0577×10^{-13}
		Searching error	1.1904×10^{-15}	-1.1656×10^{-15}	-2.6109×10^{-15}

The figure 2 is respectively the point target simulation results that are with no error, with the orbit determination error and using searching method to correct. We can clearly see from the figures that the orbit determination error will cause the defocused point targets, and the searching method can get the good focusing point target.



(a) (b) (c)

Fig 2 Imaging result with (a)no error, (b) error, (c) using the searching method to correct error

4. Conclusion

Because of the orbit determination error, the GEO SAR imaging quality of the back Propagation (BP) algorithm is greatly affected. This paper presents a searching method based on the principles of optimization to solve the above problem. And the simulation results prove the effectiveness and correctness of the searching method.

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