

Optimal Antenna Pattern Design For Synthetic Aperture Radar Using Particle Swarm Intelligence

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1. Introduction

Active phased array SAR(Synthetic Aperture Radar) system requires a variety of operational modes based on the mission requirements. According to the complex system operation concepts, SAR requires the various antenna patterns in order to meet the system performance such as range ambiguity. An antenna pattern optimization method for improvement of the range ambiguity in the synthetic aperture radar is presented. To determine the amplitude and phase excitations of the active phased array SAR antenna, the particle swarm method is applied to the antenna elevation pattern optimization based on the cost functions, which are derived from the system configuration, operation concept and requirements.

In this paper, we propose a novel beam synthesis technique using the particle swarm optimization in order to obtain the optimal range ambiguity ratio with the shaped antenna pattern.

2. Antenna pattern and cost function

Range ambiguity often degrades the image quality acquired from SAR antenna pattern [1]. Therefore, the ambiguous signals must be effectively controlled by the shaped antenna pattern. The suppression of range ambiguity in wide-swath space-borne SAR would permit a much larger swath. There are several techniques such as waveform diversity or antenna diversity for suppression of range ambiguity [2].

Many optimization techniques are widely used to make the antenna beam pattern fit into its mask templates. The SAR system with active phased array antenna has a great flexibility to achieve a multiple of missions, by adjusting amplitude and phase settings in the transmit/receive modules. In order to optimize the antenna pattern based on the system requirements, antenna peak gain, mainlobe gain slope, and sidelobe level should be considered, each of which is closely related to SAR performances such as the noise equivalent sigma zero, radiometric accuracy and range ambiguity ratio.

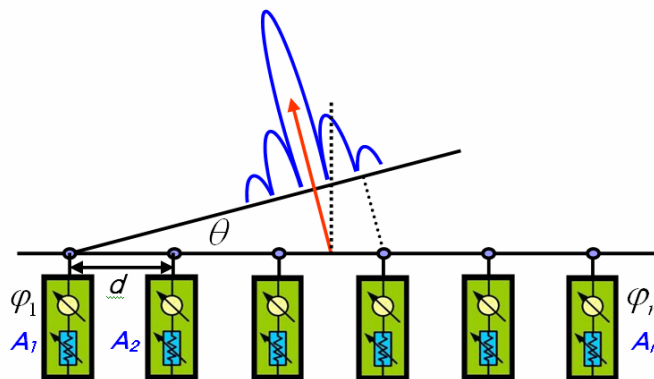


Figure 1: Active phased array SAR configuration

Active synthetic aperture radar has an N-element array which consists of T/R modules and radiators. Fig. 1 shows the active phased array radar configuration utilizing the T/R module to set up the amplitude and phase excitations. The normalized array factor $E(\theta)$ for an N-element array is defined as following.

$$E(\theta) = \sum_{n=0}^{N-1} A_n \cdot \exp(-j \cdot k \cdot d \cdot n \cdot \sin \theta_n + j \cdot \varphi_n) \quad (1)$$

where A_n , φ_n , k and d are each element's amplitude, phase, wave number and the inter-element's distance. Active phased array SAR has a capability to electrically steer the antenna beam by changing the phase slope and also synthesize the antenna pattern by adjusting each T/R module's amplitude and phase value. By adjusting the directivity, gain ripple and sidelobe level of antenna pattern using T/R module's amplitude and phase value, active synthetic aperture radar could meet the system requirements such as range ambiguity ratio, $NE\sigma_0$ (Noise Equivalent sigma zero) and radiometric accuracy.

A number of antenna pattern optimization methods have been studied [3]. In this paper, particle swarm optimization algorithm as one of the evolutionary algorithms was applied to synthesize both the antenna mainlobe and sidelobe level within the specified pattern mask. The cost function is defined to optimize the antenna pattern in terms of range ambiguity ratio. In particular, the effectively well synthesized antenna pattern is allowed to minimize the ambiguous echoes reflected from sidelobes. In order to search for Tx and Rx's amplitude and/or phase excitations of aperture based on antenna mask templates, the cost function $G(\theta)$ for mainlobe and sidelobes is defined as follows.

$$\text{Min}\{G(\theta)\} = W_m \cdot \sum_{\theta} (M_{\theta} - \widetilde{M}_{\theta}) + \sum_{\theta} W_{s\theta} \cdot (S_{\theta} - \widetilde{S}_{\theta}) \quad (2)$$

where $\text{Min}\{\cdot\}$ represents the minimum value of argument, W_m and $W_{s\theta}$ are the weighting function for the directivity of mainlobe and sidelobes, respectively. Its value is heuristically determined with respect to the optimization priority. M_{θ} and S_{θ} represent the desired directivity for mainlobe and sidelobes. \widetilde{M}_{θ} and \widetilde{S}_{θ} represent the synthesized mainlobe and sidelobes pattern at a specific observation angle θ . The cost function is composed of the summations of the cost functions of mainlobe and sidelobes. The cost function for sidelobes consists of the sum of a series of the difference between the desired pattern and the synthesized pattern. Each sidelobe is multiplied by the weighting functions $W_{s\theta}$, which is based on the echo return time, signal strength, and geometrical configuration.

3. PSO simulation

Particle swarm optimization is a sort of evolutionary algorithm utilizing swarm intelligence to achieve the goal of optimizing a specific fitness function, and it operates on a model of social interaction between independent particles [3]. The position X and velocity V of the particles are updated each iteration according to the velocity and position update equations given by [4].

$$\mathbf{V} = \mathbf{V}_p + W_1 \cdot \xi_1 \cdot (\mathbf{L} - \mathbf{X}) + W_2 \cdot \xi_2 \cdot (\mathbf{G} - \mathbf{X}) \quad (3)$$

$$\mathbf{X} = \mathbf{X}_p + \mathbf{V} \quad (4)$$

where X and V are the position and velocity vectors and L and G represent the local and global best position in the swarm. $\xi_{1,2}$ is the random variable between 0 and 1 and $W_{1,2}$ is the optimization parameter which is dependent on the particle's movement. p denotes the previous state of the particle. The position and velocity of a particle is a function of the distance from its current position to the previous local and global best. Table 1 represents the SAR system simulation parameter for optimal antenna pattern design. Initial aperture distribution and particle velocity are given by Taylor plus random variable. Updating the particle's position and velocity continually, SAR antenna patterns have been effectively synthesized by particle swarm optimization with the antenna mask

pattern given by the range ambiguity performance. In this letter, active antenna is assumed to have 24 T/R modules in the elevation plane, each of which has a 6 bits phase shifter and a 5 bits digital controlled attenuator.

Table 1: SAR Simulation Parameters

SAR Parameter	Value
Frequency	X-band
PRF	3 kHz
Altitude	600 km
Look Angle(near, far)	25.6 ~ 28.7 deg
Elevation/Azimuth Distance	0.74 / 0.68 λ
Gain / Phase Step	0.5 dB / 5.625 deg
Minimum Gain	45 dB
Initial Aperture distribution	Taylor + Random[0, 1]
Initial Particle Velocity(V1, V2)	Random[-1, 1]

A particle has 96 dimensions, each of which consists of Tx amplitudes(24), Tx phases(24), Rx amplitudes(24), and Rx phases(24). Total number of particles is chosen to 10 by considering a trade-off between the optimization efficiency and the computational speed. Tx and Rx patterns are simultaneously synthesized in 96 dimensions. Fig. 2 represents the optimized antenna gain pattern based on the mask template.

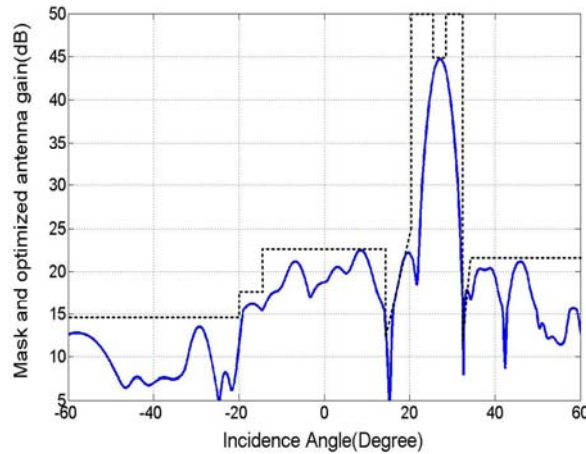


Figure 2: Mask and optimized antenna gain
(..... mask template , — optimized antenna gain)

10 particles have either a Taylor or uniform distribution as an initial setting mixed with random position in a 96-dimensional space, constrained between zero and one in each dimension. The velocity for each particle is randomly initialized between -1 and 1. To successfully achieve antenna sidelobes suppression in Eq. 2, the weighting function W_{st} is applied to the first and third sidelobes according to the geometrical configuration between antenna beam pointing and the distributed ground targets. Fig. 3 shows the convergence speed between genetic algorithm and particle swarm optimization. In the case of genetic algorithm, only mutation technique was applied to get the optimal aperture distribution. To search for 10 particles' optimal amplitude and phase values to fit antenna pattern into the antenna templates, iteration numbers are progressed to 2000, as shown in Fig. 3.

The range ambiguity ratios calculated from the optimized aperture distribution and Taylor distribution are presented, as shown in Fig. 4. The range ambiguity suppression is about 7 ~ 27 dB better within the defined swath. This is due to the effective optimization results over the critical sidelobes. As a result, by using particle swarm optimization, SAR antenna patterns are effectively synthesized to satisfy the mask requirements and RAR is also greatly improved over the range aperture.

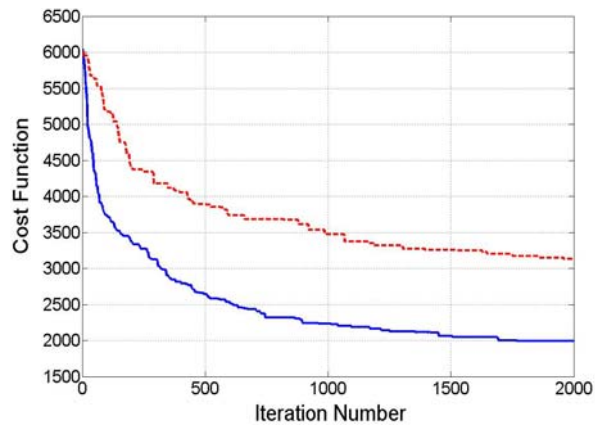


Figure 3: Convergence Speed Comparison between GA and PSO
(..... Genetic Algorithm, — Particle Swarm Algorithm)

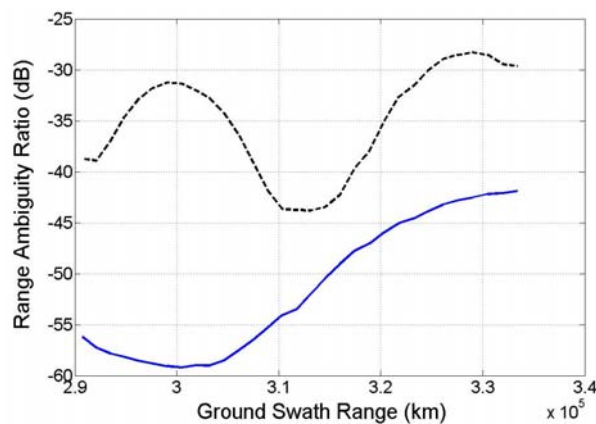


Figure 2: Range ambiguity ratio in swath region
(..... Taylor distribution, — Optimized distribution)

4. Conculsion

Optimal antenna pattern synthesis technique using a particle swarm intelligence has been proposed and simulated for the optimal range ambiguity ratio with the shaped antenna pattern. Using the proposed synthesis method, the performance of SAR can be easily optimized for various antenna patterns. The range ambiguity ratio is improved about 7 ~ 27 dB within the swath due to the effective optimization results for antenna pattern.

Acknowledgments

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