Optimum Design of Antenna Pattern for Spaceborne SAR Performance Using Improved NSGA-II

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Introduction

In order to map earth's surface with a synthetic aperture radar (SAR), the antenna radiation pattern plays an important role in determining the performance. The inevitable sidelobes in the antenna pattern cause the received signal containing undesired ambiguous signal, then decreasing imaging quality. A quantitative measure of the SAR performance degradations, depending on these ambiguous contributions, can be evaluated by the ambiguity-to-signal ratio (ASR). The parameter expresses the capability of the antenna to reject signal returning from regions of the earth's surface outside the imaging swath [1,2].

The antenna pattern design technique for spaceborne SAR optimizing the ASR and gain is proposed in this paper. It takes into account the ground reflectivity and the viewing geometry. The proposed technique allows the achievement of better performance compared to the uniform weighted value. In particular, it allows the system designer to relax the choice of the pulse repetition frequency (PRF), which is an over-constrained parameter, from the ASR constraint, kept under control by a proper design of the antenna radiation pattern.

Description of the problem

In the conventional SAR system, the PRF must satisfy a number of constraints such as the range and Doppler ambiguities, and the signal-to-noise ratio (SNR). In practice, its value must result from a trade off among different and contrasting considerations in order to meet as much as possible the user's requirements, the swath width and image quality. The presence of ambiguities in the SAR process and the consequent need to maintain the ASR below a certain level. The choice of the PRF is often imposed by the ASR constraint and therefore the corresponding value may be quite different from the best one for user. The reason for this is that ambiguities are usually kept under control by the system designer by acting on the PRF, which therefore becomes an overconstrained parameter. For overcoming some of the problems due to the number of constraints affecting the choice of the PRF, in this work an evolutionary algorithm synthesis method is proposed, which consists in designing the antenna radiation pattern in order to get the minimum ASR and maximization of antenna radiation directivity, whatever the PRF value. In this way the choice of the PRF is less constrained by the ASR, and therefore its value can be chosen in order to satisfy other user requirements such as swath width or SNR.

The ambiguity problem in a SAR system has been already considered in the literature [1,2]. Given a certain PRF and some parameter, the ASR can be written as

$$ASR(\tau) = \frac{\sum_{m,n=-\infty}^{\infty} \int_{-B/2}^{B/2} S(f_d + mPRF, \tau + n/PRF)df_d - \int_{-B/2}^{B/2} S(f_d, \tau + n/PRF)df_d}{\int_{-B/2}^{B/2} S(f_d, \tau + n/PRF)df_d}$$

Where B is the bandwidth of the linear frequency modulation signal, τ is the time delay, f_d is the Doppler frequency.S(.)is the return signal power and can be rewritten as

$$S(f_d, \tau) = k\frac{G^2(f_d, \tau).\sigma_0(f_d, \tau).A(f_d, \tau)}{R^4(f_d, \tau)}$$

Where G(.) is the antenna power gain,R(.)is the slant distance, σ_o(.) is the cross section of the cell, A(.) is the reflectivity area. The G(.) can be cut into two plane: range plane G_θ(.) and azimuth plane $G_\varphi(.)$ independently, so the ASR's can be defined in time and frequency, respectively:

$$ASR_T(\tau) = \frac{\sum_{n=-\infty}^{\infty} S_T(\tau + n/PRF) - S_T(\tau)}{S_T(\tau)}$$

$$= \frac{\sum_{n}\sum_{m=\pm1,\pm2} G^1(\frac{2R_n}{c} + m/PRF)\sigma(\frac{2R_n}{c} + m/PRF)/(R_n + m/PRF)^1 \sin\theta(\frac{2R_n}{c} + m/PRF)}{\sum_n G^1(\frac{2R_n}{c})\sigma(\frac{2R_n}{c})/R_n^1 \sin\theta(\frac{2R_n}{c})}$$

$$ASR_F = \frac{\sum_{m=-\infty}^{\infty} \int_{-B/2}^{B/2} S(f_d + mPRF)df_d - \int_{-B/2}^{B/2} S(f_d)df_d}{\int_{-B/2}^{B/2} S(f_d)df_d}$$

Then overall ASR(τ) is approximately equal to the sum of two ASR's:

$$ASR(\tau) = [ASR_T(\tau) + 1](ASR_F + 1) - 1 \approx ASR_T(\tau) + ASR_F$$

Where c is the light speed, n is the sample number in the range plane; R_n is the sample position's slant distance. θ is the incidence angle of EM wave of position R_n..

In the following the time ambiguity in the range plane $ASR_T(\tau)$ is our studied problem, Because the dependence of time ambiguity on the ground reflectivity and distance is more significant than fro the Doppler ambiguity. Next the optimization of antenna radiation pattern in the range plane using the improved NSGA-II method which minimizes the time ambiguity and maximization of the antenna radiation directivity. The problem will be given in the section 4.

The improved NSGA-II theory

Non-dominated sorting genetic algorithm (NSGA-II), a popularly used algorithm proposed by Deb et al [4], offers schemes to deal with multi-objective optimization problem. This algorithm is an improvement over the original algorithm proposed by Srinivas and Deb [3]. There are two key concepts in NSGA-II: a fast non-dominated sorting of the population of solutions and a crowding distance calculation. But dealt with some difficult problem such as ZDT4 problem, the method cannot obtain the true Pareto front. The relative filter operation is added before combining population, and can keep the diversity of the population in the evolutionary. We can use the geometry distance d_{ij} between the two individuals i and j to evaluate the relative degree.

$$d_{ij} = \sqrt{\sum_{p=1}^{P} (x_p^{(i)} - x_p^{(j)})^2}$$

Where P is the number of variables in the optimized problem.

If $d_{ij} > \sigma$, the two individuals i and j will continue the procedure, otherwise only one individuals being chosen randomly will continue the procedure, another individuals will generation randomly where the parameter σ is pre-specified according to the number and scope of variables. The next steps are the same with Deb's NSGA-II in the reference and Fig1.

Some genetic operations are binary tournament selection, simulated binary crossover (SBX) and polynomial mutation used in the paper. Integral code N_p (6bit) the excited phases of element in the antenna array in the pattern synthesis, true phases $\phi = 360/2^6 \times N_p$.

Optimized Problems and theirs Results

a. ZDT4 problem[4]

It is has 21^9different local Pareto-optimal fronts in the search space and collateral noise, of which only one corresponds to global Pareto-optimal front. So it is one of most difficult test MOEA problems. The better result is obtained using the improve NSGA-II than Deb's paper from Fig.2

Minimize $f_1(x) = x_1$

Minimize $f_2(x) = g(x)[1 - \sqrt{x_1 / g(x)}]$

$$g(x) = 1 + 10(n-1) + \sum_{i=2}^{n}[x_i^2 - 10\cos(4\pi x_i)]$$

Where n=10 and x_1=[0,1],x_i =[-5,5], i=2,…,n.

b. Antenna pattern optimization problem[2]

Minimize

$$F_1(a_m, \varphi_m) = \frac{\sum_{m=\cdots} G_r^2(\frac{2R}{c} + m/PRF)\sigma(\frac{2R}{c} + m/PRF)/(R + m/PRF \cdot c/2)\sin\theta(\frac{2R}{c} + m/PRF)}{G_r^2(\frac{2R}{c})\sigma(\frac{2R}{c})/R\sin\theta(\frac{2R}{c})}$$

Maximize $F_2(a_m, \varphi_m) = \max_{\theta}(G(a_m, \varphi_m, \theta))$

$$G(a, \varphi, \Theta) = \sum_{m=0}^{M-1} a_m \exp(j\varphi_m)\exp(jmkd\cos(\Theta))$$

Subject to:

$$g_1(a_i, \varphi_i) = \min(\min_{\theta \in C1} G(a, \varphi, \theta) - A_1, 0)$$

$$g_2(a_i, \varphi_i) = \min(-\max_{\theta \in C2} G(a, \varphi, \theta) + A_2, 0)$$

Where m=1,…,M ,a_m and φ_m are the antenna element excited amplitudes and phases respectively, k is the wave number ,d is the spacing between contiguous elements, θ is antenna beam direction.

$$\Theta = \arccos(\frac{(R_e + H)^2 + R_n^2 - R_e^2}{2(R_e + H)R_n}$$

Using the equation can change the sample position into the antenna beam direction.Where R_e is the earth radius, H=600km is the height of satellite from the earth surface, and work wavelength λ=0.25m, M=20 radiating elements, uniformly spaced at a 0.75 wavelength is chosen.

The results of three examples are obtained in the Fig4 and Table 1,2.many groups exciting phases can be gotten after simulation once, here the highest directivity group is chosen. When PRF equal to1845, the antenna beam is widened and cover the imaging swath, though ASR is increased little. The ASR of two other cases have been improved more, and the directivity are decrease very small.

Conclusions

Optimum design of antenna pattern for spaceborne SAR performance using improved NSGA-II after validating the ZDT4 problem is presented in the paper. After comparing between the optimized results and uniform weight results in the three cases of antenna beam direction, the valid conclusions of using improved NSGA-II in SAR antenna pattern synthesis can be drawn. The experimented microstrip antenna arrays are being manufactured.

References

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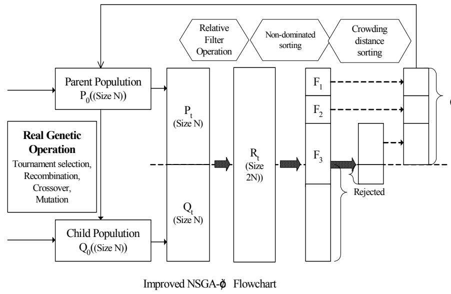


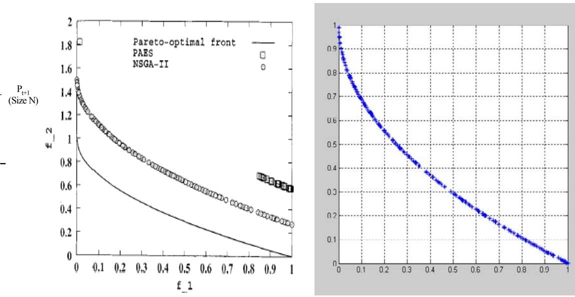
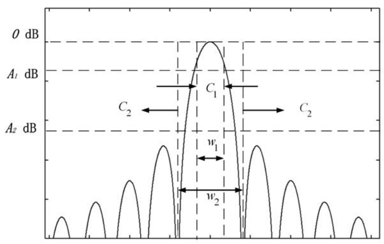


Fig.1 float chart of improved NSGA-II Fig.2 ZDT4 results: Deb's Improve NSGA-II's



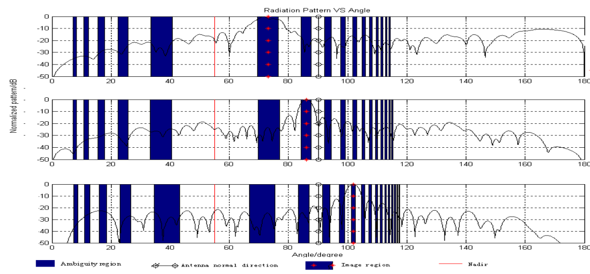


Fig3.Constraints are illustrated Fig4.Synthesized antenna pattern

Table 1 simulation parameter of spaceborne SAR

	PRF (Hz)	Beam direction(°)	Swath width (km)	Directivity (dB)	3dB width (°)	Side lobe level (dB)	ASR (dB)
Optimized weight	1845	18	90	22.04	7.83	-10.60	-40.33
Uniform weight				25.79	3.50	-13.05	-45.62
Optimized weight	1855	31	55	25.51	3.50	-13.20	-38.04
Uniform weight				26.00	3.50	-13.20	-33.32
Optimized weight	1850	47	40	25.83	3.45	-12.7	-22.98
Uniform weight				25.91	3.50	-13.10	-20.48

Table 2 20 element excited phases of the antenna array of the receiver and transmitter

Element number	1	2	3	4	5	6	7	8	9	10
	21	22	23	24	25	26	27	28	29	30
Example1	52	48	42	45	44	38	28	35	35	28
	50	44	50	43	55	42	41	20	16	14
Example2	33	16	30	19	32	24	25	22	23	24
	32	40	44	42	42	41	44	41	41	43
Example3	51	54	50	52	51	51	51	51	49	47
	34	36	37	35	36	36	34	33	36	32

Element number	11	12	13	14	15	16	17	18	19	20
	31	32	33	34	35	36	37	38	39	40
Example1	29	31	33	31	35	37	43	44	44	46
	18	18	17	19	15	17	18	17	20	19
Example2	26	25	24	27	28	27	25	25	23	23
	44	46	39	42	44	39	41	36	41	43
Example3	53	52	51	49	49	49	49	51	48	48
	36	35	34	34	34	34	31	34	35	33