MODELING SYSTEM OF PROCESSING IN RADARS WITH THE SYNTHESIZED APERTURE

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Abstract

Method of synthetic aperture radar modeling is considered in this article. A computer model based on this method was created. A numerical estimation of error of reproduction the radio-contrast image of ground surface from etalon test-images was calculated.

I. INTRODUCTION

Successful solving of a number of important problems, such as ground surface view, small objects detection, operating map-making of extended locations etc. depends on authentic information which can be got via devices installed on a board of an aircraft.

Synthetic aperture radars (SAR), that take a special part among such devices, allow getting radio-contrast high-resolution image of distantly situated objects. Development and producing of such systems is a complex and expensive problem that is why nowadays special methods of mathematical modeling are of a big interest [1, 2].

II. DSEPC FUNCTIONING

A structure of a simulated model can be represented by a set of blocks [Figure 1]:

1 source data and system parameters input;
2 trajectory signal forming;
3 modeling of data processing in SAR;
4 radiolocation image forming (RLI);
5 simulation results estimation.

Source data is aircraft flight parameters, (speed, height, size of map-made surface), SAR parameters (wave length, duration and duty cycle of radiated pulses, shape and directional pattern of antenna, period of synthesizing).

Trajectory signal is formed by means of calculating the trajectory of phase center of antenna (SAR) and chosen method of view [5]. Location (radio-contrast relief) and objects are represented by a number of elementary reflectors, which reflection parameters and coordinates are input according to the problems that are to be solved with simulation. Trajectory signal is processed according to a chosen method of digital signal processing. Processing results go to the special block, which forms RLI frame. In the same block non-coherent accumulation is made. It is applied with the purpose of improvement of characteristics of the received image, i.e. reduction of specl-noise. For numerical estimation of modeling results special methods of statistical processing are used.

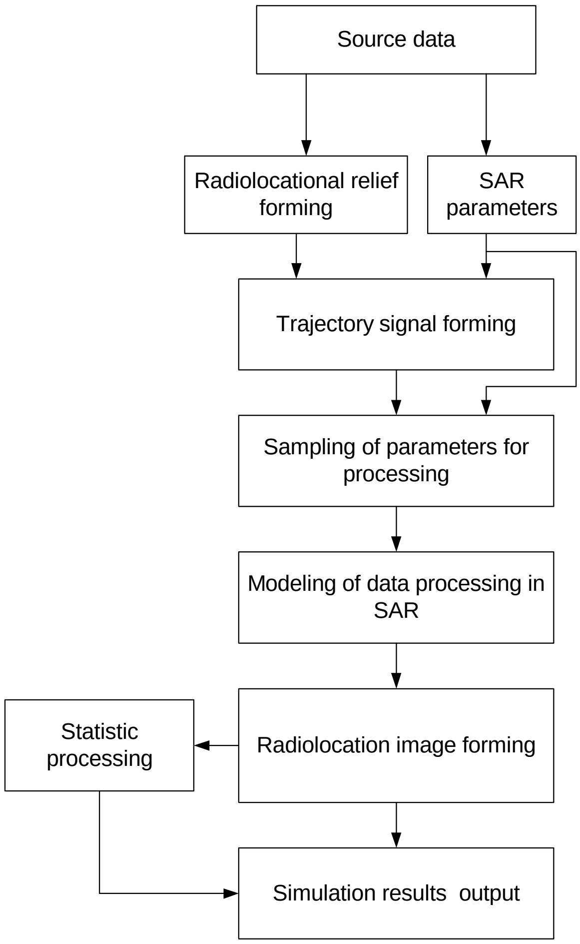


Fig. 1 Structure of SAR model

Basing of this structure, simulating program, which interface is represented on a figure 3, was created.

Input parameters are:

– V – speed of aircraft (m/s);
– H – flight altitude (m);
– resolution element size (m);
– image size (number of resolution elements);
– number of readings for processing.

Etalon test-image, that simulates the reflecting surface, is to be input to the program either. A discrete model of the surface, representing it as a set of elementary quadratic elements, used in a program. Size of these elements depends on resolution of SAR [figure 2].

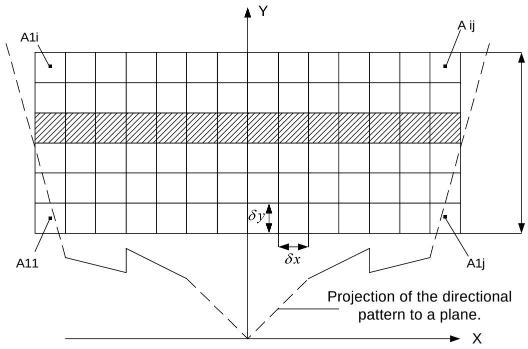


Fig. 2 Arrangement of elementary platforms on a surface

There $\delta y, \delta x$ – resolution across and along the direction line, A_{ij} – value of effective reflecting surface (ERS) of the ij's resoluted element.

Each of them has its unique ERS that defines the element's brightness.

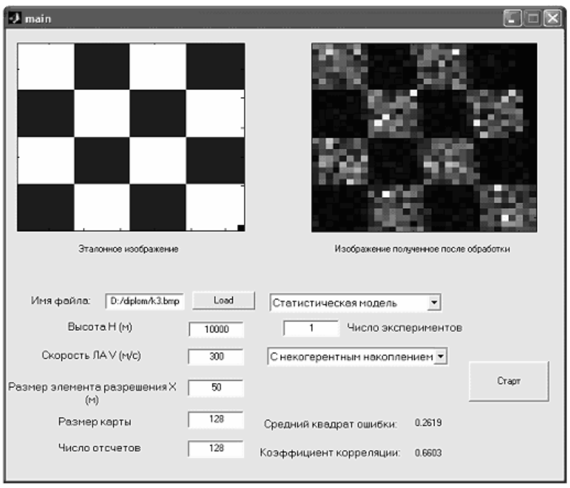


Fig. 3 Program interface

Forming of complex trajectory SAR signal is made by etalon image of map-made part of ground surface. In this program was accepted the phenomenological models of trajectory signal. She leaned on extensive experimental data. The mathematical description process of interaction the electromagnetic waves with real types terrestrial covers is not mentioned while producing this model. [3].

III. MODEL TRAJECTORY SIGNAL

Numerous experimental and theoretical researches show, that in most cases it is possible to build an algorithm of forming the signal reflected by a terrestrial surface within the framework of multidimensional normal model.

If radiated signal is narrow banded it is possible to find it's complex enveloped. Then, reflected from i-th element signal looks is described by the following formula [4]:

$$\dot{U}_i(t) = K_i \dot{F}(t - t_r)\, \dot{\chi}(t - t_r) \exp(-j\Psi_i(t)),$$

where K_i – is a coefficient, representing power of a probing signal and its attenuation while propagating, an effective reflecting surface of an elementary reflector, influence of the antenna directional pattern, $\dot{F}(t)$ – complex envelope of a probing signal, t_r – delay for propagation of a probing signal, $\dot{\chi}(t)$ – sample function of a complex Gauss random process with zero mean, $\Psi_i(t)$ – regular change of a signal phase for i-th elementary reflector.

In this case elementary platforms can be set in the cartesian system of coordinates on plane XOY. So they are unequivocally connected with a number of a platform, ij i.e. $x_{ij} = f(i,k), y_{ij} = f(i,k)$. At the discrete moments of time t_n (at n-th point of flight trajectory) quartered components of reflected signal can be calculated as a sum of quarter components of partial signals reflected from elementary platforms of some area S_n. This area defines a structure of the elementary platforms that reflect signal in this moment of time [5],

$$U_{cn} = \sum_i \sum_j^{(S_n)} K_{nik}(\eta_{nij} \cos\varphi_{nij} - \xi_{nij} \sin\varphi_{nij}),$$
$$U_{sn} = \sum_i \sum_j^{(S_n)} K_{nij}(\eta_{nij} \sin\varphi_{nij} + \xi_{nij} \cos\varphi_{nij}),$$

where η_{nij}, ξ_{nij} – discrete selective values for the moments t_n of normalized gauss random processes, not correlated at various i and j and correlation for various n. K_{nij} 's and φ_{nij} 's can be found from these formulas:

$$K_{nij} = \sqrt{\frac{G_0^2 \lambda^2 P_0}{(4\pi)^3} \sigma_{ij}} \, \frac{G(\alpha_{nij}, \beta_{nij})}{R_{nij}^2},$$

,

$$\varphi_{nij} = \frac{4\pi}{\lambda} R_{nij},$$

wнere λ and P_0 are wave length and average power of radiated signal; G_0 – coefficient of antenna's amplification (for power); σ_{ij} – an effective reflecting surface of an elementary platform with number i, j; $G(\alpha, \beta)$ – normalized directional pattern on power; $\alpha_{nij}, \beta_{nij}, R_{nij}$ – polar coordinates of an elementary platform with number i, j – in n-th point of a trajectory in system of coordinates connected with antenna.

Produced program allows to define the quantity of elementary platforms inside the element of resolution. Program can work both with determined and with statistic of model trajectory signal (model of slowly fluctuating the radiolocation object).

There are several parameters that can be used for estimation of quality of radio contrast images got as a result of processing. One of such parameters is an energy of a mistake (a square root-mean-square errors of reproduction the radio-contrast image) δ_{sr}^2 [6, 7].

$$\delta^2 = \frac{\sum_i \sum_j \left(A(i,j) - B(i,j) \right)^2}{\sum_i \sum_j \left(B(i,j) \right)^2},$$

$$\delta_{sr}^2 = \frac{\sum_q \delta^2}{q}$$

where $A(i,j)$ – values of the radio contrast image array (received image), $B(i,j)$ – the etalon test image,
I – number of a line, j – number of a column, q – quantity of experiments.

Average coefficient of correlation of images K can be used either for estimation [6, 7].

$$K = \frac{\sum_i \sum_j \left(A(i,j) - A_m \right) \left(B(i,j) - B_m \right)}{\sqrt{\left(\sum_i \sum_j \left(A(i,j) - A_m \right)^2 \right) \left(\sum_i \sum_j \left(B(i,j) - B_m \right)^2 \right)}}$$

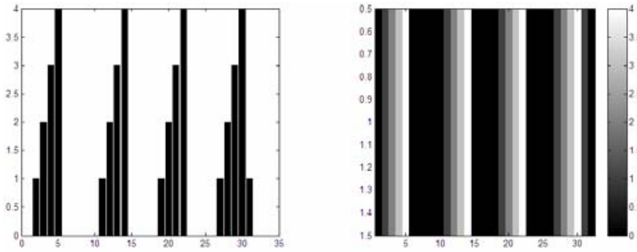
,

wнere $A(i,j)$ – values of massive the radio contrast image (the received image), $B(i,j)$ – the reference image A_m, B_m, – average values of massive A and B, I – number of a line, j-number of a column.

IV. CALCULATION

On a first stage of modeling a process of radio contrast image with size 1x32 elements of resolution reception was simulated. As etalon test images 4 kinds of ERS distribution were chosen (see below). Left figure represents ERS distribution along the line and on the right figure the radio contrast image of a line is represented. Result of modeling are given in tables № 1 and 2

1.



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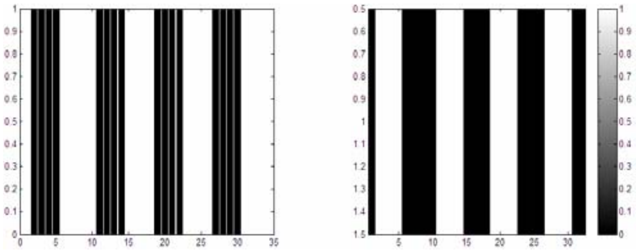

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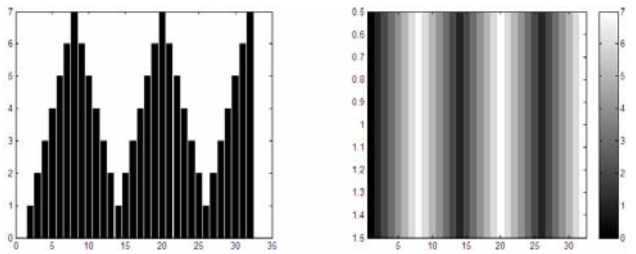

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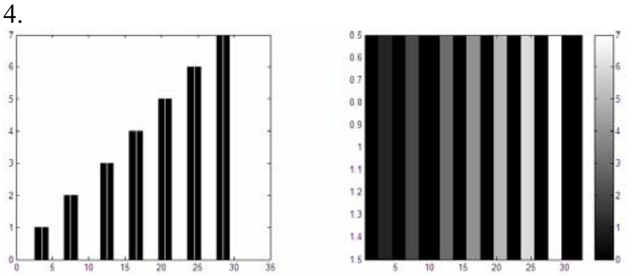

Table №1

Resolution (meters)		A number of the etalon image			
		1	2	3	4
50	δ^2	0.8895	0.9638	0.9365	0.7620
	K	0.6273	0.5623	0.3207	0.7216
25	δ^2	0.9075	0.9386	1.0275	0.8219
	K	0.6047	0.5845	0.4858	0.7487
12.5	δ^2	0.9960	1.0286	1.0220	0.9190
	K	0.5512	0.5109	0.4008	0.7047

Analysis of tables 1 helps to draw the following conclusions. The average square mistake of reproduction the structure of images does not depend much on a type of the etalon test image. It aspires to 1 independently of SAR resolution.

These results completely match the statements of random signals spectral analysis theory [6, 7].

It is known that the estimation of spectral density on each frequency by method of DFT is insolvent. Its relative root-mean-square error aspires to one. That is why the error of specific ERS definition of each resoluting element is mostely equal 100 %.

Table №2

Resolution (meters)		A number of the etalon image			
		1	2	3	4
50	δ^2	0.8548	0.8659	0.9876	0.8397
	K	0.5936	0.5607	0.3972	0.6038
25	δ^2	0.4767	0.4953	0.4876	0.4493
	K	0.7296	0.6954	0.5280	0.7654
12.5	δ^2	0.2630	0.2673	0.2589	0.2555
	K	0.8173	0.7968	0.6509	0.8507

This effect can be partly decreased by means of non coherent accumulation (see table №2). Averaging of a plenty of independent readouts received for each resoluting element, brings sufficient results.

While modeling averaging was carried out only for 4 closely situated elements. By this the relative root-mean-square error was reduced only twice.

On a second stage of modeling a process of radio contrast image with size 32x32 elements of resolution reception was simulated. The laws received at the analysis of errors on line RLI, as a whole are fair and for the image, as the separate staff.

V. CONCLUSION

The offered method of SAR modeling allows to create and investigate mathematical models of any complexity.

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