Detection of moving targets in SAR

A N Leukhin¹, A A Voronin¹ and V I Bezrody¹

¹Mari State University, Lenin Sq. 1, Yoshkar-Ola, Russia, 424000

e-mail: leukhinan@list.ru, v.andrei@protonmail.com, vova.bezrody@gmail.com

Abstract. Radar with ground moving target indication (GMTI) is intended to isolate the signals of moving targets from the whole mass of signals reflected by different objects. In this work, we investigate two approaches to form GMTI images: displaced phase center antenna algorithm (DPCA) and along-track interferometry algorithm (ATI) by using the mathematical model of SAR.

1. Introduction

The moving target indication (MTI) in radars was realized at the end of the Second World War on the basis of acoustic delay lines and became widely used in the postwar period. However, a direct indication made it possible to distinguish only very bright objects, such as airplanes and ships. Later, the systems began to use phase detectors, which significantly reduced the effect of noise. In the 70’s and 80’s, systems were spread that, by filtering in several speed channels, were able to determine the speed of movement. Modern moving target indication systems are divided into various types such as airborne MTI (AMTI), ground MTI (GMTI) or combined stationary and moving target indication (SMTI).

In parallel to the development of MTI, in the 50 years of the 20th century, the technology of synthetic aperture radar (SAR) was invented. Visualization using radars with synthetic aperture is a technique that allows to significantly increase the resolving power of a radar in the direction transverse with respect to the direction of flight and to obtain a detailed image of the radar map of the terrain above which the flight of the aircraft.

Imaging features in radars with a synthesized aperture with the transition to a two-dimensional plane allow using different approaches for the implementation of GMTI. In this paper, we compare two algorithms: displaced phase center antenna (DPCA) and along-track interferometry (ATI) utilizing methods of mathematical modeling.

2. The implementation details of the mathematical model

In the process of modeling a radar image, the problem of constructing electrodynamic and statistical models of the scene.

In our work, we use a combined approach to get a scattered field. Small metal objects (like cars) on the scene are processed by a combination of approximate methods: Physical Optics (PO) and Physical Theory of Diffraction (PTD). These methods are described in works [1, 2, 3, 4, 5, 6]. The most interesting papers [4, 5, 6] describe the calculations of scattered fields, give complete formulas and taking into account polarization effects.
From the other side, approximate methods mentioned above are not fit for dielectric materials and large-scale objects. So, all underlying surface processed with a statistical approach. We have prepared 11 types of materials with respect to polarisation and slipping angle, data was collected from works [7, 8, 9].

A very important stage is the verification of the model obtained. In this case, we used test-objects with previously known analytical expressions to calculate the RCS. Figure 1 shows RCS of various objects. All test diagrams are obtained at a frequency of 10 GHz, size and diameter of each object are equals to 30 cm.

The size of the grid element is also important when simulating the methods described, as well as using Finite Element Method (FEM) [10] or Finite-difference time-domain method (FDTD) methods. In this case, the entire grid is broken into triangles, the maximum edge length of not more than 1 cm. In other words

\[ l_{\text{max}}^{\text{ed}} < \lambda/3, \]  

(1)

where \( l_{\text{max}}^{\text{ed}} \) — maximum edge length; \( \lambda \) — wavelength.

Blue line at figure 1 corresponds to RCS equivalent in case that only triangles can scatter the incident wave. Similar results can be obtained if use analytic formulas from [11].

Red line — equivalent in case that only edges according to PTD can scatter the incident wave. This part is very important at incidence angle close to 90\(^\circ\) The main contribution in edge RCS comes from the sharp edges in the geometry of objects, for example, contribution edges in figure 1(d) to several orders of magnitude lower than that of the surface triangles.

As an example of a complex-shaped object, the RCS of the Tomahawk rocket is presented. Proceeding from the assumption that the entire rocket is made of metal and irradiation occurs at a frequency of 10 GHz with a pure sinusoidal wave.

To model the reflection of the signal from the surface, we used a model of a polygonal surface, representing a surface in the form of a set of elementary elements finite sizes. In this case, the facet size should be less than the resolving power of radar.

Thus, the total scattered field on the stage is calculated as follows, as represented in equation 2.

\[ \vec{E}_{\text{scatt}} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \vec{E}_4, \]  

(2)

where \( \vec{E}_1 \) — the vector of the field strength corresponding to the field scattered on the smooth parts of the scene, \( \vec{E}_1 \) — the field strength vector corresponding to scattering on sharp edges, \( \vec{E}_3 \) — field strength vector arising at multiple reflections, \( \vec{E}_4 \) — the field intensity vector is scattered from the underlying surface.

3. Displaced phase center antenna algorithm

Displaced phase center antenna or (DPCA) implements the usual way to achieve SAR GMTI data as it implements in radar MTI. Two antennas mounted along flight direction, both of them are used to create independent complex radar images. The key operation in DPCA is subtraction one complex image from another as shown in figure 3. The idea is that the same patch ground is on the same pixel on the two images, and the response difference is effectively compensated between the two channels in amplitude and phase.

The system should delay the first image by the amount of time corresponding to the distance between pulses; in that ratio flight speed \( v \) is used.

Figure 4 shows point distribution in DPCA GMTI image. It looks similar to 2D Gaussian distribution with mean equals to zero. In this case, the threshold processing is given by a certain circle in the complex plane with the center at (0, 0).
Figure 1. Test objects for the model: (a) disc, (b) plane, (c) cylinder, (d) sphere.

The disadvantage of the method is that, in essence, the energy difference between the two images is used to determine the motion. The phase is not an informative random process. However, the simplicity of arranging threshold processing makes DPCA convenient to use.

Figure 5 represents a group of images that appear in DPCA processing.

Figures 5(a) and 5(b) present fragments of two common SAR images, that taken with small time delay. Along the road from left to right car moves with speed 100 km/h. A human eye can find some difference in the image, but if we use full SAR images it will be hardly possible. Figure 5(c) created by subtraction image 5(b) from 5(a), moving vehicle become the most bright object on the scene. Figure 5(d) represents the result of threshold detection. The object was deconstructed into two bright points, but mostly result is pretty consistent.

4. Along-track interferometry algorithm

The basic idea of along-track interferometry algorithm is similar to DPCA algorithm. Two complex SAR images, taken under identical geometries separated by a short time interval, with the interferometric phase called "The ATI-SAR algorithm". Between phase centers of two antennas located along the track with separation $B_x$ SAR data are collected in an ideal
Figure 2. An example of an object of complex shape.

Figure 3. Image processing scheme using the DPCA algorithm.

unsquinted (zero-Doppler) stripmap mode.

The form of the probability density of this points is described in equation (3).

\[ f_c(\eta, \psi) = \frac{2n^{n+1} \eta^n}{\pi \Gamma(n) (1 - |\rho|^2)} \cdot \exp \left( \frac{2n\eta |\rho| \cos(\psi - \theta)}{1 - |\rho|^2} \right) \cdot K_{n-1} \left( \frac{2n\eta}{1 - |\rho|^2} \right) \]  

(3)

where \( n \) — number of views; \( |\rho| \) — correlation coefficient; \( \Gamma() \) — Gamma function; \( K_n() \) — modified Bessel function \( n \)-th kind; \( \theta \) — element that appears heterogeneous areas such as
urban areas because of multi scattering effects in certain. In our work we assume that $\theta = 0$. 

Equation 3 was derived in [12].

It is the more complicated way to separate points from moving targets from the background by using threshold processing, because of the form of distribution which presented in figure 7.

Interferometry of two images allows seeing differences in phase, which is more reliable with
objects which have fast oscillating radar cross-section. Gray line in figure 6 represents an equipotential line of two-dimensional function presented in equation (3).

Figure 8 represents a group of images that appear in ATI processing. Figures 8(a) and 8(b) is similar to figures 5(a) and 3(b) due to same experiment setup. Figure 8(c) represent result of $|I_1 \cdot I_2^*|$ operation. Similar figure 8(d) represent result of $\arg(I_1 \cdot I_2^*)$ operation. Figure 8(e) represents the result of threshold processing.

The resulting image is not so good as at figure 5(d), there is exist a false target below the main one. We think that is probably the fault of our implementation threshold selection. This is indirectly supported by the fact that a false target has a low amplitude and a large phase change. That does correspond to the clutter points with corrupted phase. That influence could be reduced for example by throwing away points with low magnitude. This issue was not considered in this work.
5. Conclusions
In this paper, we presented complete image results of modeling GMTI processing algorithms for SAR. Algorithms show a pretty similar result. Figures 5(d) and 8(e) represent the results of processing GMTI with DPCA and ATI algorithms. Target on both images has divided into several parts. In figure 8(e) it is possible to see a small false target, but as we think ATI algorithm has a potential in threshold processing due to utilizing not only magnitude plane, but the phase-magnitude plane.

The use of a mathematical model with a lack of experimental data makes it possible to investigate various kinds of algorithms without limiting ourselves to the range of available wavelengths, the types of polarization, and the quality of the antenna system. In the future, it is possible to develop algorithms for multichannel GMTI SAR in that way.

6. References
[1] Ufimtsev PY 2009 Theory of edge diffraction in electromagnetics (California: The Institution of Engineering and Technology)
[2] Gordon W B 1975 IEEE Transactions on Antennas and Propagation 23 590-592
[3] Jeng S K 1998 IEEE Transactions on Antennas and Propagation 46 551-558
[4] Borzov A B, Suchkov V B and Sokolov A V 2004 Journal Of Radio Electronics
[5] Borzov A B, Suchkov V B, Shakhtarin B I and Sidorkina Y A 2014 Journal of Communications Technology and Electronics 59 1356-1368
[6] Suchkov V B 2013 Systems and means of communication, television, and broadcasting
[7] King C and M oore R K 1973 A survey of terrain radar backscatter coefficient measure program Tech. Rep. 2432
[8] Katz I and Spetner L M 1960 Journal of Research of the National Bureau of Standards 64 485
[9] Skolnik M 2008 *Radar Handbook* (New York: McGraw Hill,)

[10] Vorotnikova D G and Golovaskin D L 2017 Difference solutions of the wave equation on GPU with reuse of pairwise sums of the differential template *Computer Optics* 41(1) 134-138 DOI: 10.18287/2412-6179-2017-41-1-134-138

[11] Baskakov A I, Zhutiaeva T S and Lukashenko Y I 2011 *Locating methods of research objects and environments* (Moscow: Academia)

[12] Gao G, Shi G, Yang L and Zhou S 2015 *Remote Sensing* 7 1836-1854

**Acknowledgments**

The work is executed at financial support of the Ministry of Education and Science of the Russian Federation, project No. 2.2226.2017/Project Part and project No. 2.9140.2017/Basic Part.