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SAR small target detection and recognition.

Submit to - Algorithms for Synthetic Aperture Radar Imagery
(or 31)
Advanced Image Formation techniques
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1996-1997 Engineer (GPS/GLONASS navigation boards) of the design office NAVIS (Moscow), written science work: Differential System for marine in accordance with new Russian standard (taken into manufacturing of DGPS stations by NAVIS). Young scientist of the Kharkov Aviation Institute.

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INTRODUCTION.

Synthetic aperture radar (SAR) provides good resolution of images, but sometimes desired resolution is much more higher. Common methods such as changing signal parameters, using complicated antenna arrays provides higher resolution, but expensive.

In this paper presented method of increasing resolution due to advanced processing technique without changing SAR parameters. Space resolution, which is determines by space ambiguity function of signal (image of SAR is a convolution of real image and space ambiguity function), was considered as a resolution-quality appraisement. Of course, higher resolution provides higher quality of image and allows detecting small targets and recognizing more accurately their parameters.

STANDARD ALGORITHM.

Input signal in antenna $u(t) = e\{\int_\Omega \dot F(\vec r)\dot S_R(t,\vec r)d\vec r\} + n(t)$, where $\dot F(\vec r)$-scattering coefficient for element $\vec r$ of the surface; $\dot S_R(t,\vec r)$- received signal in case $\dot F(\vec r) \equiv 1$ (or reference signal during processing); $n(t)$- additive delta-correlated gaussian noise.

Well-known standard algorithm (due to maximum likelihood method) supposes input signal as a delta-correlated gaussian, so optimal signal processing for surface imaging is founded as a decision of the variational equation

$$\frac{\partial}{\partial a}\ln\ p[u(t)/\hat{\dot F}(\vec r) + a\dot g(\vec r)]\ \Big|_{a=0} = 0\ .$$

Solution of this equation is

$$\dot Y(\vec r) = \int_\Omega \hat{\dot F}(\vec r)\dot\Psi(\vec r,\vec r_1)d\vec r_1\ ,$$

where $\dot Y(\vec r) = \int_0^T u(t)\dot S_R^*(t,\vec r)dt$ - output of the optimal system ($u(t)$-input SAR signal, $\dot S_R^*(t,\vec r)$- conjugated reference signal).

As we see, optimal output is equal to image of the surface $\hat{\dot F}(\vec r)$, smoothed by the Synthetic Aperture Radar Space Ambiguity Function $\dot\Psi(\vec r,\vec r_1)$ -SAR SAF (convolution in space of these two functions). Moreover, it is necessary to smooth this image again because $\hat{\dot F}(\vec r)$ is random phase-amplitude function (by image processing techniques).

PROPOSED ALGORITHM.

As we see, signals from different points in space are correlated by the space SAF SAR, so resolution of image is determined by the width of this function. Of course, space ambiguity function is determined by SAR signal and antenna parameters, so usual ways for small target detection are changing signal and/or antenna parameters.

But if we'll consider input signal as a correlated in time process with a function of correlation $R[t_1,t_2,\vec l(\vec r)] = < u(t_1)u(t_2) >$ (of course, we can do it, because of collecting in time signal from one point- synthesizing aperture), additive noise still delta-correlated, derived solution (maximum likelihood method) in this case will be:

$$\frac{1}{4}\int_D (s^{\,0}[\vec r,\, l\,](\vec r))\left|\dot\Psi_W(\vec r,\vec r_1)\right|d\vec r_1 = \left|Y_B(\vec r)\right| - N_0 E_W(\vec r)\,,$$

(this equation describes optimal system due to proposed algorithm) where: $\dot{\Psi}_W(\vec{r},\vec{r}_1)$ - space ambiguity function of the proposed algorithm $\dot{\Psi}_W(\vec{r},\vec{r}_1)=\int_0^T\int_0^T \dot{S}(t_1,\vec{r}_1)W(t_1,t_2)\dot{S}(t_2,\vec{r})dt_1dt_2$ ($W(t_1,t_2)$ - is a reciprocal correlation function); $\dot{\Psi}^*_W(\vec{r},\vec{r}_1)$ - conjugated complex function $\dot{\Psi}^*_W(\vec{r},\vec{r}_1)=\int_0^T\int_0^T \dot{S}^*(t_1,\vec{r}_1)\dot{W}(t_1,t_2)\dot{S}^*(t_2,\vec{r})dt_1dt_2$; $E_W(\vec{r})=\frac{1}{2}\int_0^T\left|\dot{S}_W(t,\vec{r})\right|dt$ - energy of the new reference signal $\dot{S}_W(t_2,\vec{r})=\int_0^T \dot{S}(t_1,\vec{r})W(t_1,t_2)dt_1$; $\dot{Y}_B(\vec{r})$ - output of the proposed optimal system, $\dot{Y}_B(\vec{r})=\int_0^T\int_0^T u(t_1)W(t_1,t_3)\dot{S}(t_3,\vec{r})dt_3dt_1$; $\dot{Y}^*_B(\vec{r})=\int_0^T\int_0^T u(t_1)W(t_1,t_3)\dot{S}^*(t_3,\vec{r})dt_3dt_1$ - conjugated output.

SMALL TARGET DETECTION/RECOGNITION OF TWO ALGORITHMS.

Space ambiguity functions determine resolution in space. Comparison of resolution of two algorithms is shown below. Cross-sections of SAR Space Ambiguity Functions for standard algorithm (solid line) and proposed algorithm (dot line) SAR are shown below (for two coordinates in Cartesian basis). As we can see from pictures, resolution of the proposed algorithm is higher - this allow to detect and recognize small targets.

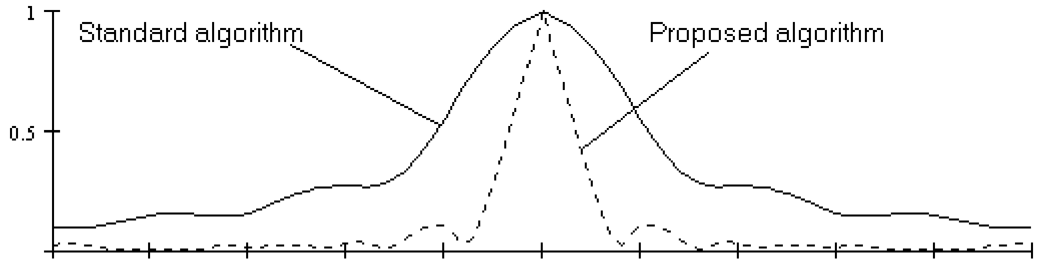

Figure 1. X-axis cross section of the SAR SAF.

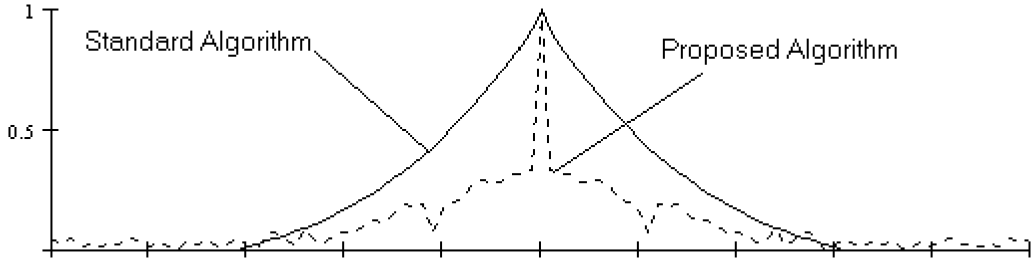

Figure 2. Y-axis cross section of the SAR SAF.

These cross-sections show possibility of small target (or small target parameters) recognition and **figure 3** shows probability of small target detection.

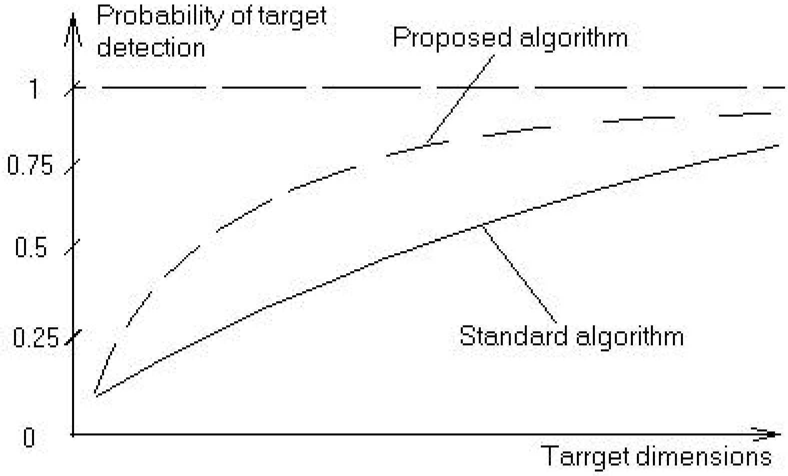

Figure 3. Probability of target detection.

CONCLUSION.

As we can see from results, proposed algorithm offers significant gain in SAR small target detection and recognition. Of course, usage of this algorithm requires additional calculation, but it is less expensive than changing SAR parameters. So, it may be used on conventional working SAR platforms for small target detection and more accurate recognizing.