SIGN AREA CONVERSION OF RADAR IMAGES

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Abstract

An important trend in contemporary radio-location is the development of methods and facilities for radar image recognition using the received radar images as a base. The authors suggest one possible approach to correlation method of recognition, invariant towards the target aspect angle.

1. INTRODUCTION

In reality, the received image is the sum of the signal and the noise. To find the spectrum for the received signal Fast Fourier Transformation is applied. Each target is a function of two variables: bearing and range, which within the control sector boundaries have different values depending upon the target cross-section; and outside the sector - the value is zero. The reflected radar signal from a complex target presents the vector sum between the reflected signals coming from each element that make the target construction.

It is possible to filter the recorded radar images in order to clear away the noises. Generally, to suppress the impulsive noises median filter application is preferred. Filtering is done in the following manner: a rectangular window with dimension 3x3 moves along the image, and the central pixel value is defined in relation to the surrounding ones. As a result, there is a decrease in value for the surrounding pixels, thus giving an image close to the original. A window with such dimensions gives the opportunity for easy calculations of the logic functions, which check the central point quality. Filters performing this function are called range-invariant filters.

The radar expansion range could be presented as an area limited by the intersection between the radar impulsive volume with the horizontal plane where the radar target is situated. For identification purposes concerning radar images, it is not necessary to input the whole image but only the part carrying the observed target. The image analysis must correspond to the basic methods for processing two-dimensional signals.

The experimental research is carried out using images received from coastal, non-coherent navigational track-while-scan Radar. Analogue-to-digital sampling frequency is 8.1 MHz, with 6-digit analogue-to-digital converter and the received signal is digitized in 64 levels. The images are presented as matrices with dimension 32x32 bytes (points). Each byte presents the discrete value taken from the reflected radar signal at the corespondent point of the surveyed sector. The last byte in the range-rows carries the information about the distance between the Radar and the target.

For the most applications, with target distance larger than 0.5 NM, the target sector could be presented as a rectangular with faces d and Br as follows (see Figure 1):

$$d=\tau.c \tag{1}$$

$$B_r = 2d_0 \tan\left(\frac{\theta_s}{2}\right), \tag{2}$$

where τ is duration of the pulse, c=3.10^8 m/s - the speed of radio-wave propagation, θ_s is bearing and d_0 is the distance to the sector. The input sector size by distance is calculated using the formula:

$$d[m] = 0{,}5N\frac{c}{f_{smp}}, \tag{3}$$

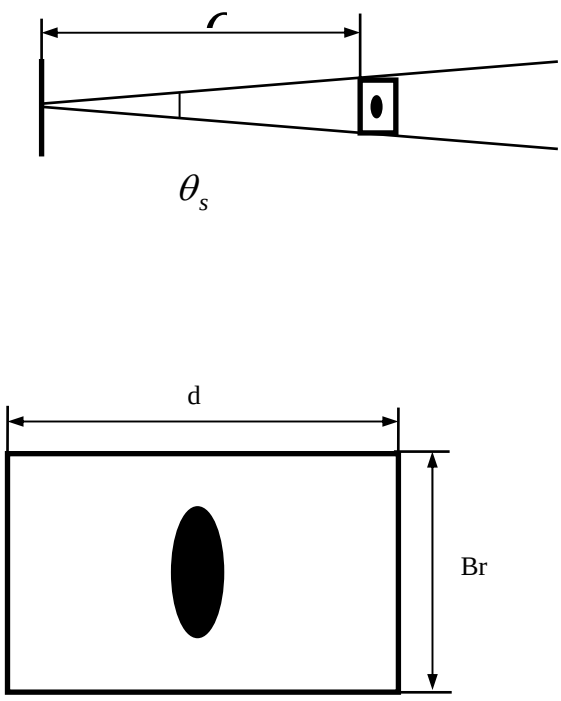


Figure 1. Target sector

where N is the number of input discrete values, f_{smp} is the sampling frequency.

The distance to the targets is 2NM. The dimension of the images concerning the distance is 0.30 NM or 555.6 m. The angular dimension of the image is 6.2° or 401.2 m.

The figures below show targets: across the horizontal is the bearing and the vertical is the range.

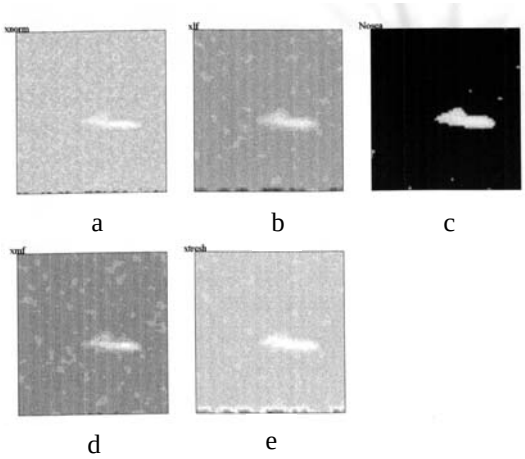


Figure 2. Target images

2. FILTERED SPECTRUM APPLICATION WHEN RECOGNIZING TARGETS

The method used to obtain the amplitude spectrum of the target is applied on several levels:

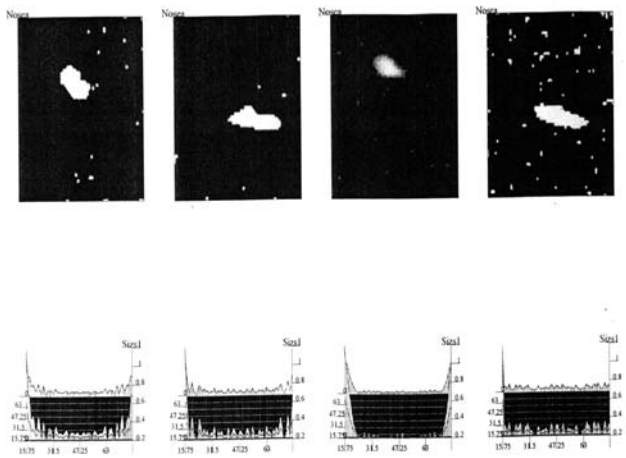
1.Linear filtering (see Figure 2,b) is applied to the real image (Figure 2,a) received from the Radar. Generally, to remove the pulse interference in reality median filtering is applied. In our case too, the level of interference coming from the sea surface, using the same filtration, is the lowest possible. Nevertheless the target form is not preserved (see Figure 2,d). The results indicate that for this type of images (where the most important task is to preserve the target form) the median filtering is not efficient. The linear filter performance characteristic is better with regard to blurred outline. A “threshold” filtration (see Figure 2,e) has been applied also to the linear filtered image. The threshold algorithm is based on the Statistic theory and

defines whether the pixel is damaged from pulse noise or not. For concrete images the threshold filtration does not give satisfying results.

2.When the image is filtered, the “sea” is removed (see Figure 2,c). For the image, only the level of the received sea surface signal is taken into account. Its value is accepted as threshold where the whole image is carried through; thus, the information obtained refers to the target only.

3.The two-dimensional Fast Fourier Transformation algorithm calculates the target’s amplitude spectrum (see Figure 3).

4.Processing with window function, is performed using the convolution between the window spectrum and the target spectrum. The energy spectrum for all real signals is highly uneven - it is characterized with high levels of low frequencies and insignificantly low levels of high frequencies. Worthwhile, in this case, is the real width of the spectrum where the basic signal energy is concentrated. That is the reason for the application of the window function.



Target1 Target2 Target 3 Target 4

Figure 3. Amplitude spectrum for the four targets

2.1. How to apply the obtained amplitude spectrum for image recognition?

The frequencies composing the reflected-signals spectrum weakly depend on the target’s dimensions. For real targets, the received signal is not possible to be taken as stationary, and for this reason the spectrum density is not possible to be used as stable and informative indication for target recognition without processing. The spectrum distribution analysis proves high dependency on the target’s bearing. As conformation

to this argument, the amplitude spectrums of a merchant-ship were calculated using different aspects.

Initially, the following indications were applied as informative signs[4]:

- maximum target spectrum value- Ekstr;

$$W_E = \sum_{i,j=0}^{N-1} S_{i,j}{}^2; \tag{4}$$

- spectrum energy

- general spectrum change

- average spectrum significance

$$V = \sum_{i,j=0}^{N-1} (S_{i+1,j} - S_{i,j}); \tag{5}$$

$$M = \sum_{i,j=0}^{N-1} \frac{S_{i,j}}{Summa} .i.j, \tag{6}$$

where Summa is the sum of all spectrum components ;

- standard deviation- Dev;

- the peak number of spectrum components- Rp.

The results are given in table 1. Apparently, they are not stable and they are dependent on the target aspect angle. The results could be applied to determine the target aspect angle, for example:

- the peak number Rp is at its maximum when the aspect towards the target is 90°.

Table 1. Amplitude Spectrum Evaluation

aspects / indication	0°	60°	90°	120°	180°
Ekstr	2.5	2.5	1.8	2.4	2.6
Dev	0.197	0.188	0.159	0.175	0.192
M	13.5	14.0	14.2	14.1	13.6
Rp	1	1	5	1	1

W_E	44	40	28	35	42
V	34	29	19	32	33

Processing based on window function application, as well does not improve the information content and eliminates the peak numbers and the average value of the spectrum range.

In table 2 we have the same indications for four different targets. The results confirm that these indications are not informative enough and even after smoothing they could not be used without further statistic processing. There is no reason to create data with these indications because they are highly dependend on the target aspect angle.

Table 2. Amplitude spectrum evaluation for the four targets

Targets / indi-cations	target 1	target 2	target 3	target 4
Ekstr	1.86	1.9	0.9	3.2
Dev	0.131	0.139	0.077	0.153
M	30.3	30.5	30.1	30.5
Rp	5	11	69	1
W_E	106	105	29	171
V	184	139	52	292

Let's consider linear dependency between the target and the recorded in advance standard image is linear then:

$$E = a + bT, \tag{7}$$

where a and b are coefficients. When their value is defined [3], formula (7) yields:

$$E - m_E = R_{ET} \frac{\sigma_T}{\sigma_E}(T - m_T), \tag{8}$$

where σ_E and σ_T are standard deviation for the sample standard and the target;

R_{ET} - coefficient mutual correlation;

m_E, m_T - mathematical expectation.

Because the left part of the equation and σ_E are of constant value, the result is:

$$R_{ET}\sigma_T \left\{ \begin{vmatrix} t_{11} & t_{12}\dots & t_{1N} \\ t_{21} & t_{22}\dots & t_{2N} \\ \dots\dots & \dots\dots & \dots\dots \\ t_{N1} & t_{N2}\dots & t_{NN} \end{vmatrix} - m_T \right\} = const. \tag{9}$$

Therefore the target in these circumstances is characterized by m_T, σ_T and R_{ET}. As we have determined above, m_T and σ_T are not stable indications, so when identifying, we choose the mutual correlation coefficient as informative indication. This coefficient is calculated using the following formula:

$$R_{ET} = \frac{B_{ET} - m_E . m_T}{\sqrt{\sigma_E^2 . \sigma_T^2}}; \tag{10}$$

where B_{ET} is the mutual correlation moment for the sample standard and the target ;

- σ_E^2, σ_T^2 variance of sample standard and target;

From the central limit theorem it follows, that the data for the sample standard and the target are distributed according to standard law (Formula 10). The determined coefficient for mutual correlation characterizes only linear probabilistic dependency between the two quantities.

The mutual correlation moment is calculated using the formula:

$$B_{ET} = \sum_{i=1}^{N}\sum_{j=1}^{N}(e_i - m_E)(t_j - m_T)p_{ij}, \tag{11}$$

where p_{ij} is the probability for joint occurrence of events E=e_i and T=t_j. The mathematical expectation and the variance are calculated using the standard expressions:

$$m_E = \sum_{i=1}^{2N} e_i p_i, \; m_T = \sum_{j=1}^{2N} t_j p_j, \tag{12}$$

$$\sigma_E^2 = \sum_{i=1}^{2N}(e_i - m_E)^2 p_i, \tag{13}$$

$$\sigma_T^2 = \sum_{j=1}^{2N} (t_j - m_T)^2 p_j \ , \tag{14}$$

where $p_{i(j)}$ is the probability the random quantity E(T) to accept value $e_i(t_j)$.

Table 3. Spectrum mutual correlation coefficient of the target aspects

Aspects / R_{ET}	asp0° asp60°	asp60° asp90°	asp120° asp180°	asp0° asp180°	asp90° asp180°
R_{ET} without filt.	0.983	0.912	0.964	0.928	0.772
R_{ET} with filt.	0.984	0.983	0.944	0.985	0.927

Some calculations have been performed in order to prove the sufficiency of the mutual correlation coefficient; the results are shown in Table 3. It is indicated there that the mutual correlation coefficient has its lowest value when it is between the amplitude spectrum of aspect angle 90° and aspect angle180°.

The processing procedure applying window function increases the correlation level between the separate aspects.

To choose the appropriate value of the mutual correlation coefficient in order to be used as a “threshold” in image recognition, the average value of R_{ET} has been calculated for the different aspects of 50 targets (Figure 4).

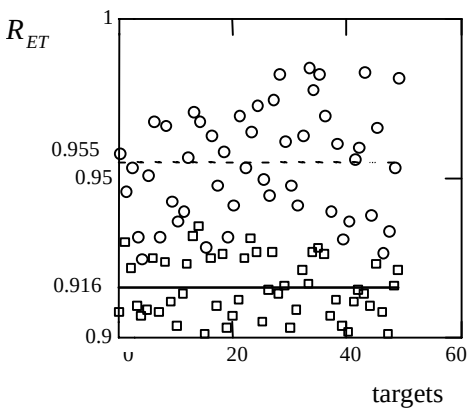


Figure 4.

The average R_{ET} values are presented before processing with window function with squares and after processing - with circles. The mathematical expectation for the results in these two cases is 0.916 and 0.955 respectively.

In the database only one target image is recorded independently of the target aspect angle. Thus the volume of the necessary data is shortened significantly.

If $R_{ET} \geq R_{ETtrh}$ during recognition (where R_{ETtrh} is “threshold” for recognition) the received signal belongs to this target class. Table 4 presents the correlation coefficients among four different targets.

Table 4. Mutual correlation coefficient of image spectrum for different targets

target / R_{ET}	target 1 target 2	target 1 target 3	Target 1 Target 4	Target 2 Target 3	target 2 target 4	target 3 target 4
R_{ET} without filt.	0.786	0.882	0.737	0.844	0.848	0.784
R_{ET} with filt.	0.877	0.878	0.851	0.808	0.891	0.866

To determine R_{ETtrh} some experimental research has been performed. At the bottom part of Figure 5 are presented the results from the obtained mutual correlation coefficients for one target to the other 49 ignoring the aspect. At the top for comparison Figure 4 is duplicated. The mathematical expectation of results is 0,791 and 0,847, before and after processing respectively.

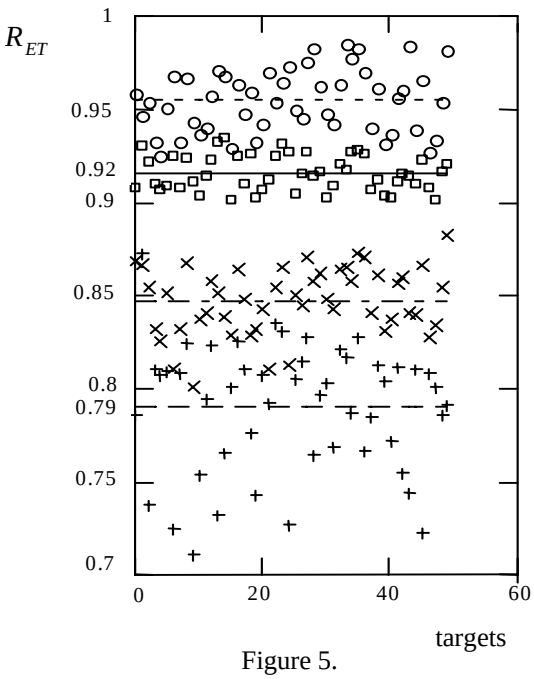


Figure 5.

The selection of R_{ETtrh} is made after determining the practical variance limit of the mutual correlation coefficient, respectively $UL_{R_{ET}}$ - upper limit of variance and $LL_{R_{ET}}$ - lower limit of variance, between which P.100 % of the obtained values [3] are locked with probability γ. They are calculated using the following formulas:

$$UL_{R_{ET}} = m_{R_{ET}} + k.\sigma_{R_{ET}}; \tag{15}$$

$$LL_{R_{ET}} = m_{R_{ET}} - k.\sigma_{R_{ET}}, \tag{16}$$

where $m_{R_{ET}}$ is the mathematical expectation of R_{ET};

$\sigma_{R_{ET}}$ - standard deviation;

k - table determined coefficient.

The standard deviation is calculated as follows:

$$\sigma_{R_{ET}} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n-1}\left[R_{ET_i} - m_{R_{ET}}\right]^2}, \tag{17}$$

where n is the size of the sample.

The practical limit of variance is calculated for two samples: the first for the mutual correlation coefficient of one target under different target aspect angle, and the second - for different targets. 95% of the major population elements fall within the intervals (0.9÷1.0) and (0.80÷0.89) with confidence level probability γ = 0.95 (see Figure 6).

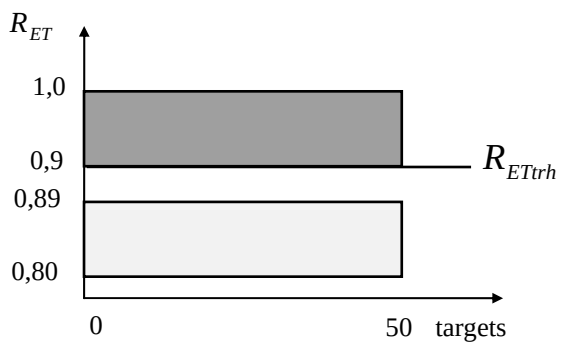


Figure 6.

Using the defined limits for R_{ET}, we choose R_{ETtrh} = 0.9. If then an image of unknown target is received, when the target belongs to the class targets, for which R_{ET} between the sample standard and the unknown image, is higher or equal to 0.9, with probability 0.95, using the above method.

A control check of the statistical hypothesis whether the mutual correlation coefficient R_{ET} is significant, is done using the Student criterion with confidence level probability 0.99. All values obtained meet the condition $|t_{cal}| > t_{st}$, so the mutual correlation coefficient is significant, with level of significance 0.01.

3. SOFTWARE

The software is developed using program module principle that gives the opportunity for open program use.

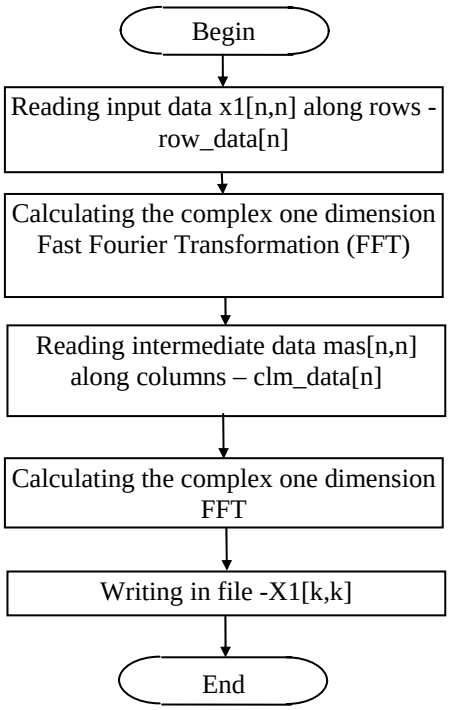


Figure 7. Algorithm for two-dimensional spectrum analysis

The input data are recorded in hexadecimal form in a file. The conversion in decimal numbers is done with a program written in MATLAB 4.0. The target presentation, filtering, sea elimination and the spectrum visualization are done with the help of the program language from MATHCAD 6.0+. Each level of processing is recorded in a file and is possible to be used for other calculations.

Programs with C and Assembly analyze the two-dimensional spectrum for TMS320C50 [2, 6] (see Figure 7). The calculation time of the Discrete Fast Fourier Transformation for data file with size 32x32 is 94μS, and the data exchange through the serial port is done for 0.2μS (5 MHz).

In the Assembly program, the digital data is consecutive - first, the real part of the number then the imaginary part. Every report covers two memory cells. For an easy addressability the real part of the report is located at even address, and the imaginary - at uneven. The shift of every report from the base is done by increase in the counter register with 2. The transformation is recorded over the input data thus destroying it. The sine function is calculated in advance, and it is available in a table that could be read using the basic Assembly program.

For N points - Fast Fourier Transformation, the number of the function values is 5N/4 [5]. The image spectrum of the target is recorded in a file. The window function spectrum is calculated in advance using MATHCAD 6.0+, and it is also filed. Processing with window function is done in the same environment by using convolution between the two data files.

4. CONCLUSIONS

1.An efficient and simple algorithm which gives opportunity to work in real time is obtained by applying correlation method for radar image recognition.

2.The adopted method of spectrum analysis using the Discrete Fast Fourier Transformation proves its efficiency when processing the radar images.

3.The linear filtering and the following sea removal give the best results for the specific application when processing the received “raw” image.

4.The offered stable informative indication for identification is efficient and decreases the necessary database multiple times.

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