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RADAR IMAGE PROCESSING FOR APPLICATIONS IN TARGET RECOGNITION

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Abstract. *This paper describes some algorithms for radar imaging and radar image processing with practical applications in target recognition. A radar-computer interface to digitize and to input signals from incoherent marine surveillance radar into computer as well as specialized signal processing to reduce the amount of information that will be recorded into the computer for further processing is described. Some experimental results that present digitized signals as images, improve their quality and extract more information about the target of observation are demonstrated. The availability of more information about the targets allows to predict their manoeuvring features and hence to improve the targets tracking. Experiments illustrate the ability of radar target recognition to improve tracking and as such to increase the safety of navigation at sea.*

Key words: *Radar – Computer Interface, Radar Signal Processing, Radar Target Recognition and Tracking*

1. INTRODUCTION

RADAR is an acronym of Radio Detection And Ranging. The idea to use radio signals for detection of an object came from Germany, where in 1904 Christian Hulsmeyer obtained a patent for a radio wave device capable of detecting ships [1, 11, 16]. For this purpose Radar system transmits electromagnetic pulse train which propagates through the space. When a radio wave meets an object in the propagation path, some of the energy reflects from this object. Objects of observation, such as ships, bouys, and other aids to navigation are called targets. Any other object such as reflections from the sea surface, rain and other forms of precipitation, clouds and sandstorms, that can potentially be mistaken with target are called clutter. One of the main problems of radar signal processing is how to suppress the clutter for better detection of targets, either by operator or automatically.

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There are a number of different ways to present radar signals on the screen [11]:

The most basic display type is called an A-scan (amplitude vs. time scan). The vertical axis is the strength of the received signal (sweep) and the horizontal axis is the time, i.e. range, as shown in Fig. 1. The A-scan display does not provide information about the direction to the target.

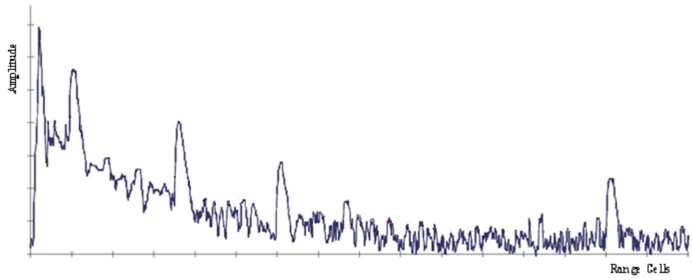

Fig. 1 A-scan display provides information only about the strength of the received signal and does not provide information about the direction to the target

B-scan display is obtained by converting A-scan information into brightness or color and then is displayed on the screen sweep by sweep.

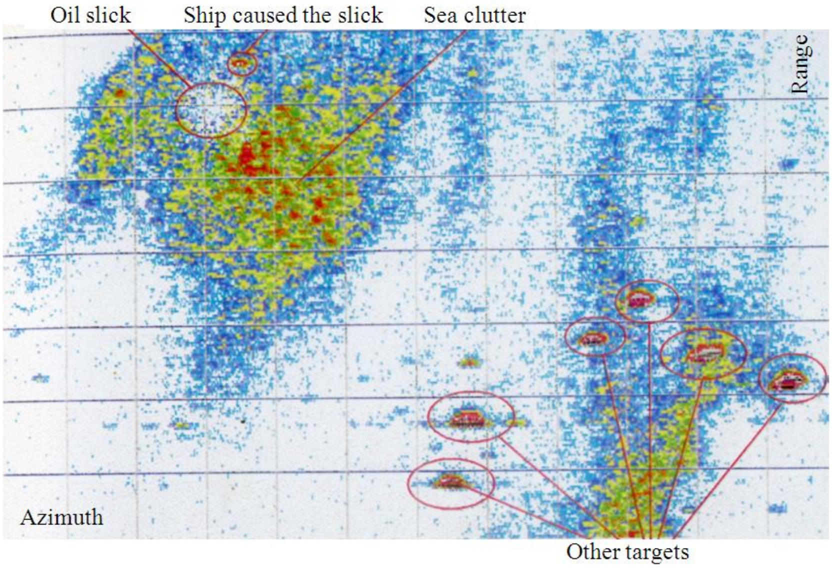

Fig. 2 B-scan display obtained by converting A-scan information into color and then displayed on the screen sweep by sweep

However, B-scan is preferable for some specific applications. In Fig. 2 is shown how B-scan radar imaging can be used for detection and recording of oil slicks [24]. The image illustrates an oil slick of leakage of approximately 400 liters of hydrocarbons (heavy fuel and used motor oil in ratio 1:3) mixed with 55% of water. The leakage has been accomplished on the distance to the coastal radar of about 1.3 nautical miles (nmi), and was detected on 1.2 nmi, 30 minutes later. The record was carried out with relatively bad weather conditions: wind S, SE 3 ÷ 3.4 m/s, sea 1 – 2, with small wind waves without crest. It is also possible to detect the ship that caused the leakage and some other ships in the vicinity.

And P-display or Plan Position Indicator, PPI is obtained by displaying the converted A-scan information in the same relative direction as the antenna orientation. As a result, a picture of the surrounding situation is displayed on the radar screen where the range is the distance from the center of the screen. PPI is the most natural display and therefore most widely used.

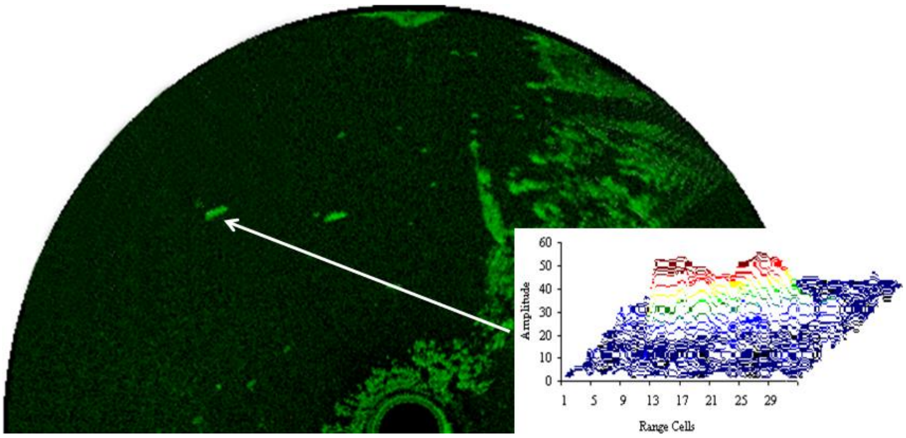

Fig. 3 Target of observation presented as a point on PPI and as a body (in 3D format as azimuth versus range scan)

As the vessel traffic in the world's bodies of water increases, so does the need to insure safe navigation. Safe navigation, in turn, is only possible if enough information on navigational conditions is available. Today's navigational radars provide this information in two stages: first, detection of the navigational objects, and second, definition of the moving parameters. Adding object identification as an intermediate stage could improve the quality of information available for navigation. Object identification in the field of sea navigation means viewing the target not merely as a point but, rather, as a body with inherent maneuvering abilities. The availability of this information would allow navigators to predict a target capacity to maneuver during a trial or under real conditions. This could be used to improve tracking algorithms as well. Fig. 3 represents a part of P-scan over the Black sea coast near Varna and a target of observation, presented in 3D format as azimuth vs. range scan.

Despite Automatic Radar Plotting Aids (ARPA) ability to provide large amounts of information, there still exist situations when this information is inadequate and might cause collisions. The majority of recent research indicates that navigation related accidents are caused as a result of inadequate navigational information, most frequently when ships draw near to each other while manoeuvring. If there is a possibility to determine type of a target, then the prediction of its behavior according to the international regulations for preventing collisions at sea could be much more reliable [9, 22, 23]. Recent research in the field of plotting systems has attempted to consolidate recognition and tracking. Therefore Automatic Target Recogniton (ATR) is an important development in the field of radar observation which has received a great deal of attention from navigation experts in recent years.

Most of radar systems used in sea navigation today are incoherent, narrow band, surveillance radar with narrowly pointed antennas and horizontal polarization. It is not always possible to identify the target by detecting its major scattering centers using this technology [12]. That is why the use of ATR in the field of sea navigation is only possible under certain conditions - no clutter, constant aspect of observation of target, etc. Therefore ATR requires additional processing of radar images to provide the required conditions.

This paper is organized as follows. In Section 2, a Radar-Computer interface to digitize radar signals is described as well as specialized signal processing to reduce the amount of information that will be recorded into the computer for further processing. A number of Radar imaging and image processing algorithms are included in Section 3. In the next Section 4, some experimental results are described to illustrate the ability of Automatic Target Recognition, ATR to improve tracking and as such to increase the safety of navigation at sea. And the concluding remarks are given in the last Section.

2. RADAR – COMPUTER INTERFACE

In order to input radar signal for further processing into computer system a special device has been developed [24]. Four signals from radar are used by this device – video signal from the output of the detector, trigger pulse train, heading pulse and antenna orientation pulses. The video signal is applied to video amplifier that forms the dynamic range of the signal and then is digitized by a 6-bit flash ADC. The digitized video runs consecutively to two external blocks of memory and while the current radar sweep is being written into one of memory blocks, the preceding one is being read by the computer from another memory block. This approach allows input the high speed digitized video with delay of only one trigger pulse period. A programmable timer is added to allow input of only a part of radar picture into the computer, selected between two azimuths and two ranges. Thus only the sea area or image of a given target could be selected. The azimuth resolution depends on antenna position pulse rate and normally is between 1024 and 3600 pulses per revolution (ppr). In our case it was 1800 ppr which means azimuth resolution of 0.2º. Once the radar image is in the computer it can easily be retransmitted over telecommunication network using TCP/IP.

The solution, described above, is usually called "PC-Radar". Another approach is also possible. In it functions of PC are performed by a programmable controller with TCP/IP communications abilities [4]. The high-tech electronics allow that in one micro chip be put most of the blocks from the above diagram: Clock Generator, Memory Blocks, Heading pulse and Antenna Position Interface, as well as TCP/IP Framework.

Radar-Computer interface based on TCP/IP is acceptable also onboard by using vessel's network. There are many situations where radar information is necessary not only on the bridge.

In both cases – either coastal or onboard application, one of the most essential problems remains the amount of radar information. When using 6 bits digital conversion every sample equals one byte, i. e. the whole radar image consists of 1800 rows by 256 samples (bytes) each, or approximately of 2 Mbytes per approximately 3 seconds of revolution period. To decrease the amount of information the number of signal levels could be reduced, for example to sixteen (4 bits per sample) or even to four (2 bits samples). This requires an appropriate preliminary processing of radar signal, as CFAR threshold for instance [1, 3, 5, 11]. CFAR (Constant False Alarm Rate) is a statistical term used in the theory of threshold detection. CFAR is a threshold technology that provides an approximately constant rate of false target detections when the noise and clutter levels into the detector are variable.

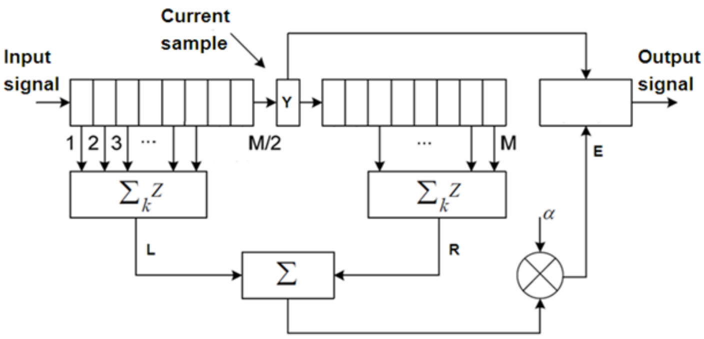

Fig. 4 Block diagram of a CFAR detector

A number of different algorithms is used to calculate the current threshold value depending on the current sea condition [7]:

$$E = E_0 + \frac{L = R}{2}, \tag{1}$$

$$E = \begin{cases} E_0 + \dfrac{L+R}{2}, d \geq D \\ E_0 + \max(L, R), d < D \end{cases}, \tag{2}$$

$$E = \begin{cases} E_0 + \min(L, R), d \geq D \\ E_0 + \dfrac{L+R}{2}, d < D \end{cases}, \tag{3}$$

$$E = \begin{cases} E_0 + \min(L, R), d \geq D \\ E_0 + \max(L, R), d < D \end{cases}, \tag{4}$$

where E_0 is the initial offset,
L – average value for the left window,
R – average value for the right window,
d – current threshold position,
D – initial distance.

Block diagram of a CFAR Detector is shown in Fig. 4 [7]. The time diagrams shown in Fig. 5 illustrate the result of CFAR operation. It is obvious that the CFAR Detector sets the threshold value to provide near optimum clutter suppression by following the average level of radar signal and thus reducing the clutter to a level, close to the level of noise. However, this is very similar to the principal of the adaptive gain.

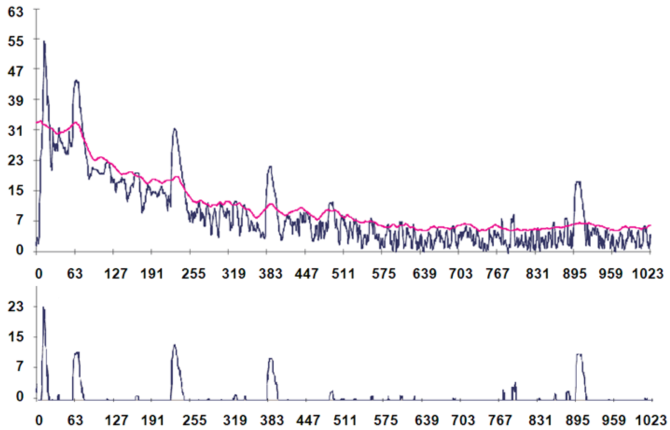

Fig. 5 Time diagram of a radar signal and the adaptive threshold calculated by CFAR detector

3. Radar Image Processing

One of the most common filters for image processing is implemented by using so called "Moving (sliding) window" [2]. Some common types of moving window used here for radar image processing are:

Neighborhood-averaging filters – these filters replace the value of current pixel by a weighted-average of the pixels covered by the window; the weights are non-negative with the highest weight on the current pixel. If all the weights are equal then this is a mean, or linear filter.

Median filters – these filters replace the value of current pixel value by the median of its neighbors, i.e. such value that half of the values in the window are above, and half are below. This usually takes time to implement due to the need for sorting of the values. However, this method successfully removes the noise while preserving edges of the image.

The size of the window depends on the purpose, the number of minimum samples the kernel function needs and the object resolution of the image. For example, assume the image has a small object with the size of N X N pixel area. If the windows size is also N X N, in a smoothing operation using a mean function this object will get smoothed. But if the window size is 2N X 2N then the object of observation may even disappear. So it depends on the purpose whether to remove the object or not.

It is possible however to use variations of the above mentioned filters with different number of pixels, iteration filtration procedure or differential procedure where image and noise are filtered separately, etc.

Some results are shown in Fig. 6 and 7.

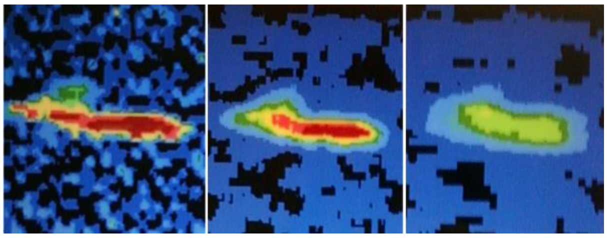

Fig. 6 Raw radar image of a target (13,800t ferry-boat) and filtered images with linear (low-pass) filter using 3×3 and 5×5 pixel windows

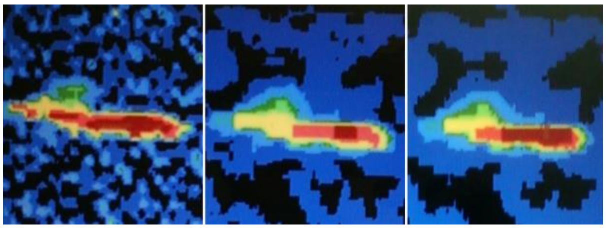

Fig.7 Raw radar image and filtered images with median filter using 3×3 and 5×5 pixel windows

One of the best ways to eliminate noise from radar image is to combine threshold and Median filtration algorithms. Fig. 8 illustrates the result of this approach. The threshold is defined by using samples from the reflections of the sea taken from the raw image (left) and then applied to each sweep of the image filtered with median filter using 3×3 pixel window.

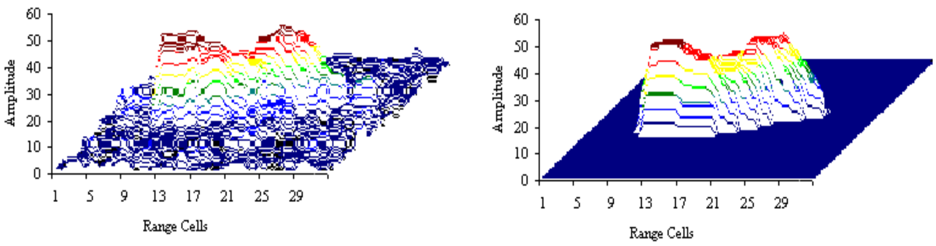

Fig. 8 The 3D raw radar image (left) and the filtered image as a result of a combined algorithm applied (right)

4. Radar Target Recognition

As is well known the signal carrying information about the object of observation during the process of Automatic Target Recognition, (ATR) is usually accompanied by different kind of noises. Therefore the ATR problem has to be considered as a probability-theoretical problem, and the methods and algorithms which are used to solve this problem have to be based on the theory of statistical decisions [12, 23]. According to this theory image identification is reduced to establishing correspondences between the object of observation and some metric space, mostly n-dimensional Euclidean space, **E**n. In this case the object which has to be recognized needs to be presented as a point or vector, belonging to this space. The classification of the object into a given group (class) is defined by distance between points in this space.

The target of observation here is presented by five parameters (n = 5), each calculated by using filtered image of the target, as follows:

$$L_R = 2\sqrt{d^2 - \left[d^2 - \left(\frac{\Delta d_t}{2} \right)^2 \right] \cos^2\left(\frac{\Delta\theta_t}{2} \right)}, \tag{5}$$

where d is the distance to the target,

Δd_t – the size of the image of the target by range;

$\Delta\theta_t$ – the image size by azimuth.

The parameter L_R represents the radar length of the target of observation;

$$V_R = m_{00} = \sum_{i=1}^{M} \sum_{j=1}^{N} i^0 j^0 x_{ij} , \tag{6}$$

where $M = N = 32$ is the size of the image;

x_{ij} – the value of the current pixel.

The parameter V_R represents the radar volume of the target of observation. It is also the first moment of the image, defined by Hu [13];

The last three parameters are the next three moments of Hu – m_{01}, m_{10}, and m_{11}, calculated as

$$m_{lk} = \sum_{i=1}^{M} \sum_{j=1}^{N} i^k j^l x_{ij} , \tag{7}$$

Bayes' approach to target identification is employed because it insures the lowest level of risk [12]. If it is presumed that the values of parameters have a normal (Gaussian) distribution, then this approach needs to include computing the distance between the measured vector v and the mean vectors v_{mi} , $i=1..k$ of the k different classes. The "chi-square" distance is employed for this purpose:

$$d_{\chi^2}(v, v_{mi}) = \sum_{p=1}^{n} \frac{k\left(v[p] - v_{mi}[p]\right)^2}{\sum_{j=1}^{k} v_{mj}[p]} , \tag{8}$$

According to this metric the object of observation represented by the vector v will be attached to the class "i", if:

$$d_{\chi^2}(v, v_{mi}) < d_{\chi^2}(v, v_{mj}) \text{, for each } i \neq j. \tag{9}$$

In the process of developing experiments the tendency was to choose metric which gives the best result under equal conditions. However, it is possible to apply other metrics.

To test the potential of ATR in marine navigation three targets were chosen. The targets were observed in various aspect angles and their radar images were formed and saved on the computer disk.

To eliminate the dependence on the aspect-angle of observation the images were grouped in four different subclasses. Each group consisted of about 100 images as shown in Table 1. The computer images of targets were used as training samples to calculate the mean vectors for each target and for each aspect angle.

Table 1 Number of images used as training samples for each subclass of targets

Aspect angle of observation	00°	30°	60°	90°
Target 1	31	38	32	32
Target 2	38	42	40	33
Target 3	33	37	33	32
Total number of images	102	117	105	97

Any other aspect angle of observation can be easily transformed to one of the aspect angles shown in the picture due to the symmetry (i. e. aspect angle of 120° to 60°, aspect angle of 330° to 30°, etc.), as shown in Fig. 9.

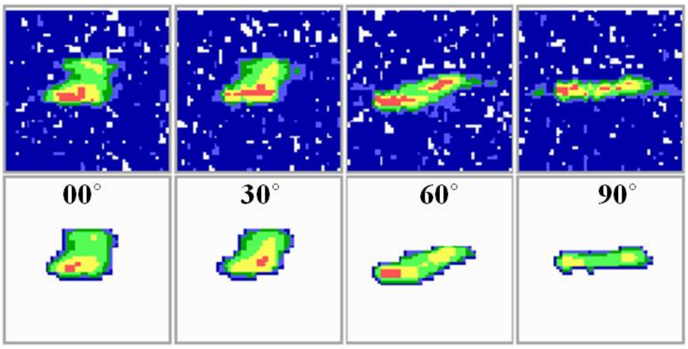

Fig. 9 Each class of targets is described by four different subclasses according to aspect-angle of observation for 0˚, 30˚, 60˚ and 90˚, respectively

A test set of 30 randomly selected images of all targets for each aspect-angle was used to test the ability of this approach in ATR. Results shown in the table were calculated as a divisor of the number of correct (true) classifications by the total number of experiments:

$$P = \frac{N_T}{N}.100 \cdot \qquad (10)$$

The results are shown in Table 2.

Table 2 Test results of ATR in percentage of correct answers

Aspect angle of observation	Correct classifications
00°	90.0%
30°	93.3%
60°	91.5%
90°	70.0%

Neural networks also can be applied successfully in Radar Target Recognition [18, 19, 21].

5. Conclusion

The experimental results indicate that Radar Target Recognition can be successfully implemented for navigation purposes. The findings can be used to estimate the tonnage class, approximate size and potential manoeuvring abilities of the target of observation, and then to be applied for improvement tracking of targets of observation and as such, to increase the safety of navigation at sea.

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