Joint CFAR Detection and Parameter Estimation of Different Marine Targets using Forward Scatter Radar

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Abstract: In this paper we research one joint structure of the CFAR detector and a parameter estimation of the moving different marine targets at the background of a sea clutter using Bistatic Forward Scatter Radar (FSR) system. In our investigates we use the two pulse MTI CFAR processor with K/M-L batch processor and parameter estimator for a marine target with unknown size are investigated on the base of real data records. The aim of the paper is to make statistical estimation of various target parameters [6-9]. These specific parameters necessary for Data Mining Classification have been obtained in the time and the frequency domains for different marine targets.The data itself have been gathered by the team of the Birmingham University using in-house developed FSR.

1. Introduction

The Forward Scatter Radar (FSR) system is a special case of bistatic radar. In such a Bistatic FSR the receive and transmit antennas are fixed and directed at each other, so the target detection takes place when the baseline is crossed. In the sea-based FSR systems, the signal processing for detection of moving marine targets must meet very specific requirements. In these systems, the concept of a point target is not applicable directly ; moreover, majority of parameters like: the moving targets visibility time, the signal amplitude as well as many other parameters are unknown due to their dependence on various factors: target velocity and dimensions, angle of crossing of a radio fence and distance to the receiver [1-5].

Automatic CFAR detection and parameter estimation of moving marine targets in clutter environment using Bistatic Forward Scattering Radar (FSR) is studied in this paper. CFAR processor works effectively only in uncorrelated environment, i.e. when the noise power is sum of thermal noise and residue power after cancellation [18]. Then for removing the correlated sea clutter a 2 pulse Moving Target Indicator (MTI) technique is to be used, as described in [17]. MTI is a method of rejection the marine radar clutter or reduce correlation. Thus the structure of studied target detector includes: MTI rejector of sea clutter, CA CFAR detector, and binary K/M - L nonparametric detector of the package of binary signals with unknown length. The adaptive CFAR processor detects the signal in clutter with unknown power and counts them using the decision rule “K out of M”, for estimating the beginning and L for estimating finish of plots of target.

Our investigations are based on the real records of marine targets radar signals that have been obtained by the team of the University of Birmingham (UK) using Forward Scatter Radar in

2010 year. Studies of the University of Birmingham, show and reaffirm previous such that the amplitude of maritime target signal is rather Rayleigh distributed and the amplitudes of the sea returns are Weibull distributed. The records are made in the form of signal lines presenting boats, yachts, and sea surface with different roughness power.

Our hypothesis is to use simultaneous specific CFAR detector and estimators for the case of FSR moving marine targets both in the time and frequency domains [6-9].The CFAR processor firstly detect single pulses and then count them using a binary nonparametric procedure for detection of pulse packages of unknown length, with the decision rule "M/N–L", in order to estimate their unknown length. After estimation of the pulse package length in the time domain using the CFAR processor, we use the same approach for estimation of the target characteristics in the frequency domain. In that way we obtain several important parameters of moving marine FS targets – the energy of the targets and their velocity. The obtained target signature can be used for estimation of various target parameters in the time and frequency domains. The CFAR processing is a very important procedure and very often used especially in real systems, because it results in producing of precise target images separated from the existing interference. It is performed by removing clutter from the receive signals using the adaptive CFAR threshold. Next the extracted target signatures that are free of clutter can be used to estimate different target parameters for their classifications – the target length and velocity; the reflected energy and power spectrum. The main aim of the paper is to test the statistical change of each parameter like length, average power and energy depending on the signal-to-noise ratio using standard mathematical operation in "Matlab". This could be useful for Data Mining Classification. The paper includes the following sections: Introduction, Maritime Target CFAR Detector and Estimator for bistatic FSR, Numerical Results, Conclusion, and Reference.

2. Maritime Target CFAR Detector and Estimator for bistatic FSR

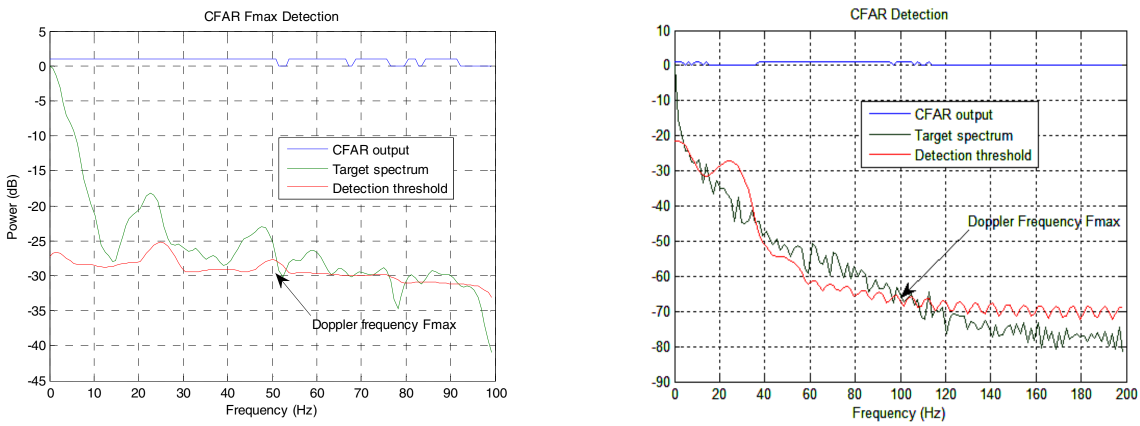
In our investigation, for sub-optimally detection of the FSR marine target with unknown speed and length in conditions of sea correlate clutter with unknown power, we use the adaptive approach for forming MTI CA CFAR statistic rule [13, 15]. This structure consists of: one channel Moving Target Indicator, Square Low Detector, Cell Average Constant False Alarm Detector, a Binary K/M and L nonparametric detectors for a beginning or a finish a plot of target, and estimator of the parameters of target, like length and energy.

The structure of MTI CA CFAR K/M-L processor with parameter target estimator includes: rejector of sea clutter, which uses one or two pulse canceller; standard CA CFAR detectors, and estimator of parameters of target. This estimator uses the product of binary K/M and L nonparametric detectors for a beginning or a finish a plot of target. The adaptive CFAR processor detects single pulses in clutter with unknown power and counts them using the decision rule "K out of M - L", for estimating of the beginning and finish of plots of target. It indicates a beginning of plot or finish of target, when the criterion K/M and L are bigger of the thresholds.

The estimation of the specific parameters from different marine FS targets necessary for Data Mining Classification, are calculated at the output of the original structure of a MTI CA CFAR K/M-L processor in time domain. The calculation of the number of detected package pulses at the output of the K/M-L detector, is performed with a standard mathematical operator in Matlab. This procedure counts the number of pulses that exceed the adaptive threshold and in such a way estimates the signal duration in time. The standard statistical average procedure in Matlab is used to calculate roughly the average estimate of the target power and energy. For this reason we use only the amplitude after rejection residues of clutter, i.e. the difference between all the amplitudes of the signal package and the average CFAR detection threshold. For investigating the robustness of the MTI CA CFAR K/M-L detector, we use estimation on others parameters in the time domain. These are estimates at the output of the K/M-L detector including correlation coefficient and signal-to-clutter ratio. The parameter SNR is calculated as a ratio between the two standard deviations of the detected package pulses after the CA CFAR filtering and the clutter from the tested window, with standard functions in Matlab.

3. Numerical Results

The original trial data contains 4 different types of targets that have been recorded. However, since the available data for the analysis is very limited (24 instances), it is decided to organize the actual radar targets into three classes, i.e. the data mining target variable has three distinct values – MISL Boat, Big Boat and Average Boat. The MISL Boat class refers to the trial data recorded for the Birmingham University research team boat, a small rubber boat. The Big Boat class includes the data about various larger boats that have been recorded during the trials, referred to in the original data as a Big boat, Big fishing boat, Big white boat and huge boat. The Average Boat class contains data for the actually recorded Life boat, Police boat, Speed boat, Medium yacht, fast red boat. The number of instances in the three target classes is unevenly distributed. Most of the available data refers to the MISL boat class (18 instances), and it is very limited for the Big Boat class and the Average Boat class (6). There is only one missing value in the target class variable, which is replaced with the mode value – MISL Boat, in cases when the performed algorithms cannot be executed if there are missing values in the target variable.



a) b)

Figure 1 .Signal spectrum after MTI CA CFAR K/M-L detector. a) MISL boat, b) big boat

The spectra of two types of marine targets are shown in Fig.1. This spectral characteristics can be used for estimation of the maximal Doppler frequency.

Our challenge is to test how will change some statistical target parameters in the time domain depending on their signal-to-noise ratio. For these purpose we examine every obtained parameter like the number of samples, time duration (this is the time interval that marine target cross the FS radio barrier) and else the average power and energy. Our hypothesis is that the time duration of the target signal depends on the approximately profile of the object. The next Fig.4 and Fig.5 illustrate our statistical research and the numerical results obtained in the time domain are summarized in the PivotTable.

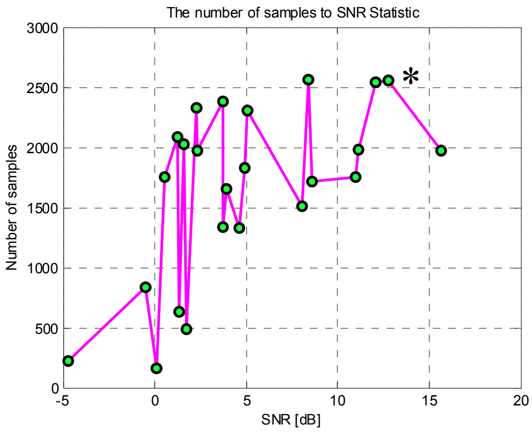


Figure 2: Changing of number of samples to SNR

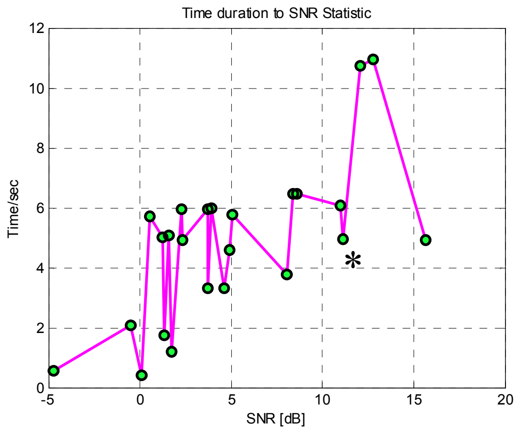


Figure 3: Changing of time interval to SNR

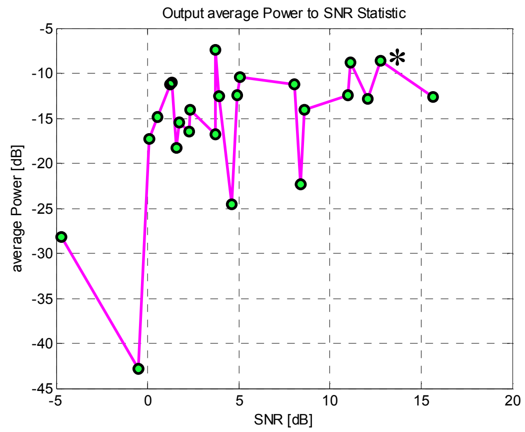


Figure 4: Changing of average Power to SNR

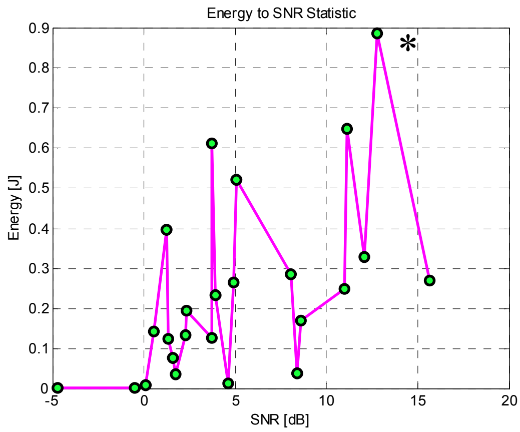


Figure 5. Changing Energy to SNR

The PivotTable describes the estimated parameters. There are six columns. The first one includes the type of different marine targets that we study. The second and third columns include the number of samples and the time duration of signals from every target of the study. How it was mentioned above this could be approximately the profile of the object. The fourth and fifth columns contain the average signal power and the signal energy at the CFAR detector output. The last column contains the signal-to-noise ratio estimated at the same time at the output of the CFAR detector. The way of their mathematical calculation is described above. An important feature is that the values in table are arranged in increasing order according to SNR values. In this way we constructed graphs shown in Fig. 2 ÷ Fig.5.

PivotTable 1

N:	Different type of boats	The number of samples (Length of boat)	Time duration (sec)	Estimated output power $P_{s,avr}$ (dB)	Output Energy E_s (J)	Signal to noise ratio "SNR" (dB) (CFAR output)
1	„MISL" boat	220 samples	0.55s	-28.1411dB	0.0008J	-4.7207dB
2	„MISL" boat	839 samples	2.09s	-42.7876dB	0.0001 J	-0.5034dB
3	Speed motorboat	2028 samples	5.07s	-18.2373dB	0.0761J	1.6085dB
4	„MISL" boat	2333 samples	5.94s	-16.4490dB	0.1321J	2.2635dB
5	„MISL" boat	1334 samples	3.33s	-7.3643dB	0.6119J	3.7074dB

6	„MISL" boat	1713 samples	6.46s	-14.0518dB	0.1685J	8.6061dB
7	Fish boat	1755 samples	6.09s	-12.4689dB	0.2485J	10.9812dB
8	Big boat	1983 samples	4.95s	-8.8276dB	0.6494J	11.1074dB
9	Big fishing boat	2543 samples	10.74s	-12.8779dB	0.3277J	12.0818dB
10	„MISL" boat	1970 samples	4.92s	-12.6399dB	0.2682J	15.6458dB

From Fig 2÷Fig.5 we can make the following conclusions. With increasing the SNR the other values are not increased exponentially. The reason of that is the impact of external factors for detection of targets. These can be the bad meteorological conditions including the strong wind and the wind waves giving rise the high level of see clutter. Each of them reduces the probability of detection of the number of samples and their derivatives like the power and the energy. It is found that the probability of detection depends on the receiver gain, the distance from the receiver to the boat, the sampling frequency, the repetition period, and the wavelength of transmission. In PivotTable and all graphics you can see the very small value of the detected samples (220 samples), and therefore the very short time duration (0.55s) and respectively the very low average power (-28.1411dB) almost two times and half lower compared to other measurements and so the low energy (0.0008J). All this leads naturally to the very low signal-to-noise ratio (-4.7207). The reason of that is the observed higher level of sea clutter The other interesting fact is that the numbers of signal samples from Big boat and the “MISL” boat are almost equal. The reason of that are the above-mentioned test conditions: high level of sea clutter and low SNR and vice-versa low level of sea clutter and high SNR. From the other side you can see from the table and all figures that the boat with the highest SNR value is “MISL” but the other values of its parameters are not the best. This is due to the lower level of sea clutter at the very good test conditions. The best values of parameters has “Big boat” at eight row of the table where they are marked with (*) on the whole graphics.

4. Conclusions

In this paper we obtained the statistical estimates of target parameters in the time domain, which show how the special target parameters necessary for Data Mining Classification are changed depending on the signal-to-noise ratio. These results are investigated on the base of real data records that have been obtained by the team of the Birmingham University using FSR. This approach can be successfully used for target detection in the other radar and GPS-based passive bistatic radar systems.

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