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Experimental evaluation of the Constant False Alarm Rate (CFAR) algorithms used in maritime FM-CW radars

Ryszard Wawruch

Gdynia Maritime University, Department of Navigation, Faculty of Navigation
81-345 Gdynia, al. Jana Pawła II/3, e-mail: wawruch@am.gdynia.pl

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Abstract
Paper presents basic information on the Constant False Alarm Rate (CFAR) algorithms and assessment of their practical efficiency in maritime FM-CW radar. Experimental research comprised qualitative assessment of the different CFAR algorithms done by the comparison of radar video signals presented by installed in the Gdynia Maritime University FM-CW radar type CRM-203 utilised these algorithms and pulse radars with digital (Raytheon Pathfinder MK2 and NSC 34) and analogue (Racal Decca AC 1690) display units.

Introduction

In order to detect objects by radar it is necessary to separate in radar signal coming back to the scanner, target returns received from the objects against so called background created by unwanted echoes: atmospheric and inner (receiver) noises, clutters and interferences. In maritime navigation objects means coastline and sea surface objects like ships, aids to navigation and different fix and drifting objects creating obstruction to navigation (ice, etc.). Clutters are created by returns generated by sea (surface clutters) and clouds and precipitation (volume clutters). Separation is done by power threshold above which any return is considered to probably originate from object. If the threshold is low, more targets will be detected but radar video signal will contain returns from coastline and sea surface objects together with unwanted noises, clutters and interferences. It means that radar sensitivity will be high but the probability of proper object detection against unwanted echoes relatively low. If the threshold is high, effect will be contrary to the above mentioned – radar sensitivity will be low but the probability of proper detection relatively high.

Described threshold may be introduced manually by radar operator or in semi or fully automatic manner by the equipment using adaptive algorithm realizing Constant False Alarm Rate (CFAR) detection. In all cases it is done by control of the gain and anti-clutter sea functions. The role of the CFAR algorithm is to determine the power threshold above which any return will be considered to originate from a objected with required probability level. If the background against which objects are to be detected does not change in space and time, a fixed threshold level may be chosen to provide required probability of false detection (false alarm). Probability of false alarm is a function of the signal-to-unwanted echoes (noise, clutter and interference) ratio of the target returns and depends on the probability density function of the unwanted echoes assumed for this condition to be Gaussian (Additive White Gaussian Noise – AWGN). However, in the event of maritime radar, unwanted echoes, mainly sea clutter, are time correlated and change both spatially and temporary. It means, they may not be assumed as AWGN and changing threshold has to be used. The threshold level shall adequately raise and lower to maintain a constant probability of false alarm.

More detailed information on principles of automatic radar detection may be found in [1, 2].

Principle of CFAR detection

In the CFAR algorithm so called cell under test (CUT) has to be selected. It may be the distant cell containing strongest return or return with amplitude higher than the defined level. In the simplest CFAR algorithm, the threshold level is defined by radar operator. In algorithm working in automatic manner the threshold level is calculated by estimating the level of unwanted returns (noise, clutter, interference) around the CUT. This is done by selecting a block of cells around the CUT and calculating their average power level. To avoid impact of the CUT itself on this estimation, cells directly adjacent to the CUT are treated as guard cells and ignored. A target is declared present in the CUT if its amplitude is both higher than amplitude of returns in all directly adjacent cells and higher than average power level. This algorithm is known as cell-averaging CFAR (CA-CFAR). In other CFAR schemes calculation of the average power value is performed separately for cells to the left and right of the CUT and criterion of the greatest-of or least-of these two power levels is used to define the local power threshold. These are greatest-of CFAR (GO-CFAR) and least-of CFAR (LO-CFAR) algorithms. More sophisticated CFAR algorithms select adaptively the threshold level taking into account clutter statistical distribution, e.g. K-distribution for sea clutter. To this family of CFAR schemes belong the ordered statistic (OS-CFAR) and clutter map (CMAP-CFAR) algorithms.

The efficiency of the CFAR algorithm defines radar detection capability and sensitivity. The knowledge of its efficiency and limitations, particularly in bad weather condition is important for radar user mainly in case of new radar technologies like Frequency Modulated Continuous Wave (FM-CW) radar introduced nowadays on seagoing vessels and in Vessel Traffic Services (VTS). At present manufacturers and ship and VTS personnel do not have sufficient experience in utilizing this new technology at sea. There are not available any information which CFAR algorithm is most suitable for radars installed in VTS and on ships sailing in different sea areas and in different weather condition in the accessible bibliography and radar manufacturer instructions. Usually manufacturers inform users simply e.g.: that their radars have: automatic detection (Norcontrol), so called “clean sweep” function (Atlas Elektronik), four types of algorithms define as near, near buoy, rough sea, harbour (Furuno), two types of algorithms define as harbour and open sea (Sperry Marine) only and do not present how these functions are realised and how shall be used.

The scarcity of information about automatic detection function realized in maritime radars especially practical usefulness of the particular types of applied CFAR algorithms and recommendation on the principle of their utilisation was the reason of conducting experimental research in the Gdynia Maritime University using FM-CW radar type CRM-203 constructed by BUMAR Elektronika S.A. This radar, as a prototype has different CFAR algorithms available to the user and due to that is convenient for research purposes.

Description of the research

Experimental research has been conducted since winter 2011. It comprises qualitative assessment of the different CFAR algorithms done by the comparison of the radar video signals presented by FM-CW radar type CRM-203 and pulse radars with display units: digital (Raytheon Pathfinder MK2 and NSC 34) and analogue (Racal Decca AC 1690). All these radars are installed in the university building on shore nearby the south entrance to the port in Gdynia The distances between radar scanners positions on the roof of university building are not bigger than a few meters and the field of view of particular radars may be considered as the same (Fig. 1). Basic parameters of the FM-CW radar are presented in table 1.

Table 1. Basic parameters of the FM-CW radar type CRM-203

Parameter	Value
Output power	1 mW, 10 mW, 100 mW, 2 W
Carrier frequency	9.3–9.5 GHz
Frequency deviation switched according to the required scale range	54 MHz at 6 NM, 27 MHz at 12 NM, 13.5 MHz at 24 NM
Range scales	0.25–48 NM
Modulation	Direct Digital Synthesizer (DDS) based linear FM-CW
Sweep repetition period	1 ms
IF bandwidth	4 MHz
Frequency curve slope of IF amplifier	6 dB/oct; 12 dB/oct; 18 dB/oct
Beam width (horizontal/vertical)	0.70°/22°
Polarisation	Horizontal
Analog-to-digital converter	14 bits
FFT signal processing	8192-points FFT
Sampling frequency	8 MHz
Display resolution	1280 × 1024 pixels
Range and bearing accuracies	1% of selected range or 50 m (whichever is greater), 0.7°

More detailed information about FM-CW and pulse radars utilised in the research may be found in [3, 4, 5, 6].

Fig. 1. The field of view of radar antennas

Following parameters of the CFAR algorithm may be chosen in the FM-CW radar type CRM-203:

1. Type of algorithm:
   - FIX (detection without CFAR, voltage threshold given manually by operator);
   - CAGO (normalized ambient average left, greatest of);
   - CASO (normalized ambient average right, smallest (lower) of);
   - CA (duplex normalized ambient average);
   - OS (ordered statistic);
   - CMAP (clutter map).
2. Length of the cell used in CFAR algorithm: 4, 8, 16, 32, 64 and 128.
3. Level of the voltage threshold between 0 and 255 with increment of 1.
4. Attenuation level between 0 and 255 with increment of 1.

These CFAR parameters may be defined for the following different parameters of the scanner, transceiver and processing algorithms:

1. Scanner rotation speed between 12 and 30 rpm/min with increment of 1 rpm/min.
2. Anti clutter sea – three levels: 6 dB/oct; 12 dB/oct; 18 dB/oct.
3. Receiver gain level before signal digitalisation (automatic/manual) between 0 dB and 63 dB with increment of 1 dB.
4. Carrier frequency – 10 different values in the band 9300–9500 MHz defined by manufacturer.
5. Type of window algorithm: Bartlett, Blackman, Gaussian, Hamming, Hanning, Harris, Kaiser, rectangular, triangle and Von Hann.
6. Differentiation – switched on/off.
7. Pulse clutters correlation – switched on/off.
8. Fix clutters correlation – switched on/off.
9. Clutter chart – switched on/off.
10. Binary integrator with the "M-of-N" rule – switched on/off and utilising any value of integers between 0 and 30 as *m* and *n* parameters.

Tests has been conducted in different weather conditions in all seasons of the year, including dif-

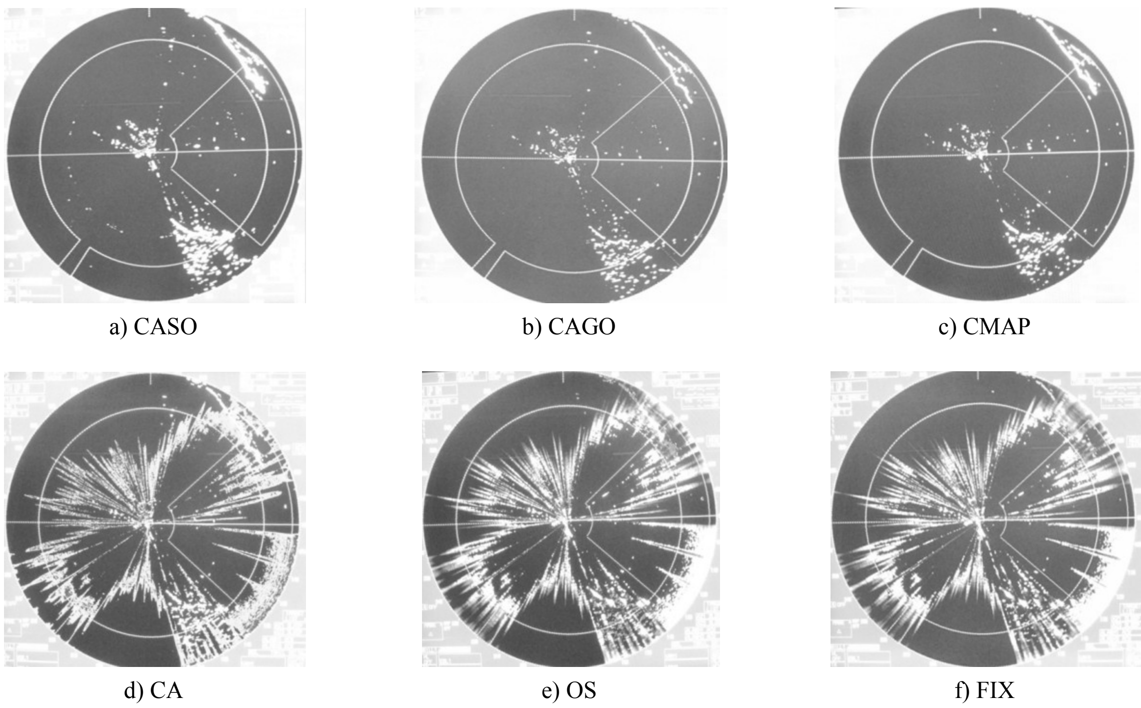
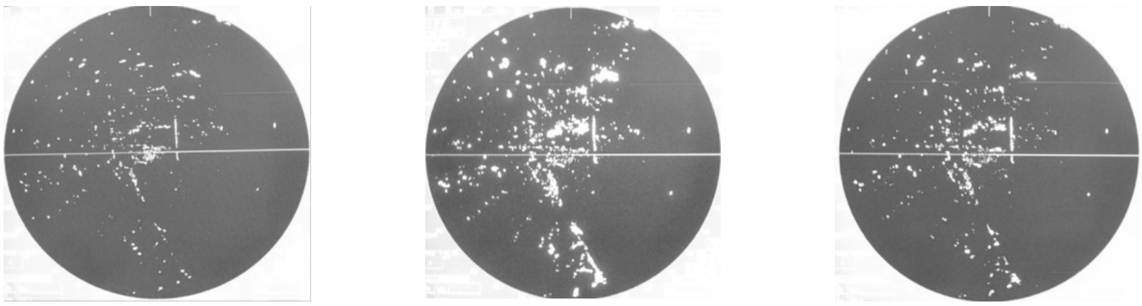


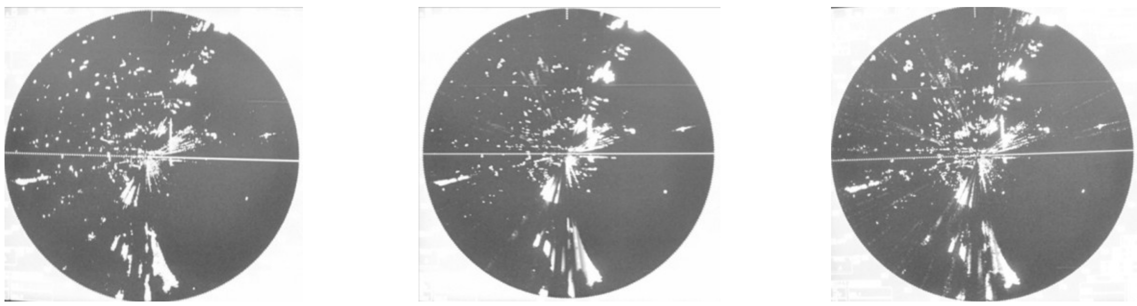
Fig. 2. Radar video signal received on the range of 12 nautical miles for the same weather condition and the same all radar parameters, including detection parameters except type of the CFAR algorithm (length of cell 128, level of voltage threshold 2, attenuation 40)

ferent sea state, ice, snow and rain conditions. There have been checked effects of the utilisation of different types and parameters of CFAR algorithm. The assessment was conducted by the comparison of the radar video signal presented on display monitors of the FM-CW and pulse radars on the following ranges of observation:

1. 22,224 meters (12 nautical miles) enabling presentation of the whole Polish part of the Gulf of Gdańsk.

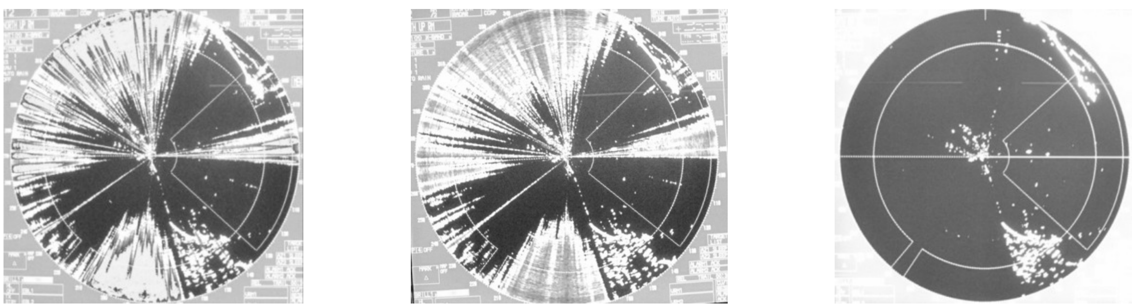


a) CASO b) CAGO c) CMAP



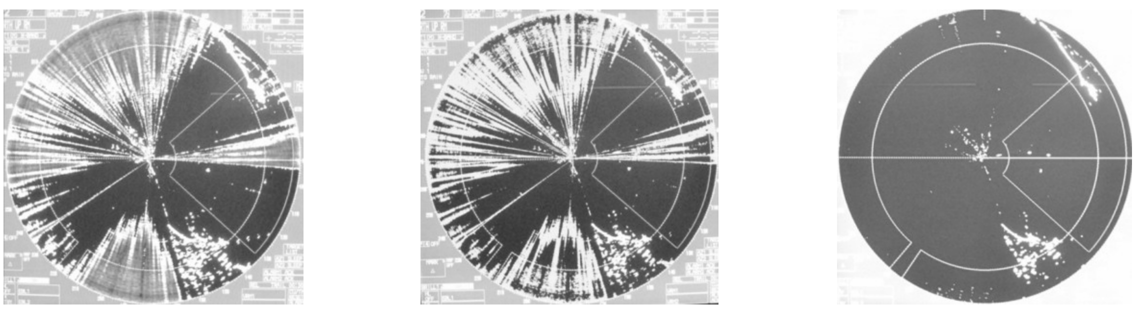
d) CA e) OS f) FIX

Fig. 3. Radar video signal received on the range of 1.5 nautical miles for the same weather condition and the same all radar parameters, including detection parameters except type of the CFAR algorithm (length of cell 128, level of voltage threshold 2, attenuation 40)



a) length of cell: 4 b) length of cell: 64 c) length of cell: 128

Fig. 4. Radar image on the range of observation 12 nautical miles received for CASO CFAR algorithm and different values of the length of cell



a) threshold 0 b) threshold 50 c) threshold 100

Fig. 5. Radar image on the range of observation 12 nautical miles received for CASO CFAR algorithm and different values of the voltage threshold

2. 2778 meters (1.5 nautical miles) to check the utility of the particular types and parameters of the CFAR algorithm on the smaller distances for returns received from object in the Gdynia harbour and town.

Results of the research

Samples of the research results are presented on figures 2–5. Figure 2 shows radar video signal received on the range of 12 nautical miles for the same weather condition and the same all radar parameters, including detection parameters except type of the CFAR algorithm (length of cell 128, level of voltage threshold 2, attenuation 40).

As may be observed on figure 2 two groups of CFAR algorithms give very often completely different effects. Pictures a, b and c (schemas CASO, CAGO and CMAP) present radar image with different sensitivity but without distortion characteristic for images received using schemas CA, OS and FIX (pictures d, e and f). Similar effect of the application of particular CFAR algorithms was received for range of observation equal to 1.5 nautical miles (Fig. 3).

On the ranges of observation 6 nautical miles and bigger the best radar image was received for CFAR CASO algorithm. CAGO schema was more efficient on the smaller ranges. But even for these two CFAR algorithms, application of improper values of other CFAR parameters (length of the cell and voltage threshold and attenuation levels) may result in considerable distortion of presented radar video signal (Figs 4 and 5).

Conclusions

On the basis of the carried out measurements, it was stated that:

1. The best FM-CW radar image and detection possibility were obtained for CASO CFAR algorithm on the ranges equal to 6 nautical miles and bigger and for CAGO algorithm on the smaller ranges of observation.
2. The efficiency of particular CFAR algorithms depends strongly on values of the length of cell and levels of voltage threshold and attenuation selected by the operator.
3. The usage of differentiation, correlation (pulse and fix clutters) and integration functions accessible in the tested radar influences the efficiency of the CRAR algorithm.
4. The efficiency of the CRAR algorithm depends on the transmitter carrier frequency used by radar inside X band.
5. It was not observed influence of the scanner rotation speed (in the range between 12 and 30 rpm) on the efficiency of the CRAR algorithm.
6. During the research was possible to obtain the same detection distances of coastline, floating aids to navigation and ships by tested FM-CW radar type CRM-203 and the modern pulse radars Raytheon NSC34 and Pathfinder MK2.
7. The large number of available reciprocally correlated controls effecting radar detection possibility and quality of radar image impedes work out of the recommendation regarding setting picture on the tested radar.

Experimental researches described in this paper are time-consuming due to the necessity of waiting for particular weather conditions mainly ice and snow conditions in the winter time period. They are continued in order to define some recommendations on the principle of use of particular CFAR algorithms and their results will be presented during the next MTE conference.

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