Analysis of possibility to improve the civil marine radar efficiency during navigation in the Arctic waters

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Abstract. The paper presents the civil marine radar (CMR) efficiency in the polar waters in the case of advanced signal processing based on the optimal filtering of the voltage coming to the intermediate frequency amplifier. The structure of the radar subsystem was modified by adding two complementary filter units that allow to transform the filter frequency response into the almost sinc-function curve providing much better detection of weak radar echoes. The studies have shown that the updated radar matched filter makes it possible for CMR to observe objects with relatively small scattering cross section at the considerably longer distances than up-to-date CMR. Also it is explained that this radar signal processing doesn’t require the increasing of CMR cost which can also be considered as advantage of the method.

1. Introduction

Marine navigation in the Arctic is extremely complicated process and at present it’s possible to provide its safety and efficiency only if vessel is equipped by civil marine radar (CMR). This navigational tool makes it possible for seafarers to detect quite small objects, identify them, measure their position and motion parameters in bad weather conditions. Nevertheless CMR performance is considerably restricted in the Arctic waters. As a result CMR often becomes inefficient equipment to detect such dangers of navigation as icebergs and other ice objects. CMR efficiency is also decreased in the polar waters for detection and measurement the position of quite big objects (vessels, coast line e.t.c) if there is a heavy sea and severe meteorological conditions (fog, snow storm, heavy shower and hard frost) [1]. That’s why the improvement of CMR performance in the Arctic is supposed to be the extremely crucial issue to provide the safety of navigation in the polar seas. At present the International Marine Organisation (IMO) as well as international academic community carry out legislation and research to provide mariners with high effective radar technologies that will be useful in every navigational situation [2].

This paper presents new methods of radar signal processing that makes possible for CMR to detect and track the small-size targets at long distances in the severe clutter environment relevant to the Arctic waters.

2. Research methods

CMR efficiency can be analyzed using such parameter as signal-to-noise ratio (SNR) of response from radar targets. This technique enables to estimate CMR performance taking into consideration the influence of radar clutter. In this case it’s possible to assess separately the radar signal, coming from the target and the power of the echoes returning from all other objects located in the aerial beam at the same time. Using SNR it’s easily to analyze CMR detection, accuracy and tracking efficiency in every
possible clutter environment. SNR is energy parameter of radar which gives approximately 90% of contribution into CMR quality characteristics. At the same time CMR performance depends also on the set of nonpower parameters of radar incoming signal such as its polarization, frequency shifts etc. That’s why analyzing the CMR disadvantages in the Arctic region we will focus attention primarily on the SNR value in different navigational situations relevant to the polar waters. In addition we will also take into consideration the signal parameters that are independent on its energy if they exert significant influence on the CMR performance in certain specific situations. Combination of these approaches enables to make the comprehensive analysis of radar applicability to provide safety of navigation in accordance with the IMO requirements. But in this case such analysis can be carried out by relatively simple methods including computer simulation of appropriate radar components and subsystems.

3. Disadvantages of CMR in the Arctic to be overcome
First of all we will consider the expected value of radar response power for the targets which are specific in the polar waters. Ice in the Arctic is presented by several types such as icebergs, pan, sludge ice, fast shore ice etc. In the High North sea areas large icebergs have cross section of approx. 200 m and sticking up out of the water up to 25 m. These objects gives radar echo which average power is comparable to the radar signal coming from small vessels such as small size trawler [1]. Other ice objects generate usually much less power of radio wave reflected towards the radar. At the same time every ice block gives usually unstable radar response [2]. In the Fig.1 the receiving signal coming from ice block with cross section of 30 m is presented. In the Fig.2 the enlarged fragment of this signal is depicted, the fragment corresponds to the minimal amplitude of the pulse echoed from the examined ice block:

Figure 1. Input radar signal, coming from the ice block
Analyzing the SNR of data presented in the Fig.1 and Fig.2 it’s possible to conclude that such object can be detected quite easily only in the 60% of radar observations. In 20% of monitoring results the echoes are so weak that they are impossible to be detected among the interferences. The scattering cross section corresponding to this object varying from 0.2 m² up to 150 m².

In the Arctic seas the radar performance is significantly influenced by cloudiness [3]. The reason for this phenomenon is that in this region the clouds often are located at the so low height (100-200 m) that they get inside the radar’s directivity pattern and form quite strong echo that is perceived by radar receiver. As a result, the clouds in the Arctic are able to obscure the real CMR targets making impossible their detection. It’s good to mention here that using rain anticlutter circuit tuning it’s possible to suppress partly the interferences caused by thin clouds located at the short-range distances [4]. In this case radar gain is continuously increasing up to the maximal value at the end of pulse repetition cycle in combination with the integration of radar receiver signal. In this situation signal coming from thin clouds is relatively weak random process with approximate zero expectation value and integration forms the signal proportional to this expectation. Finally, the special logic circuit integrated inside the CMR receiver compares this value to the threshold and if it is not exceeded such signal is suppressed. But sometimes such conditions are not obtained. For example if low-sized target is observed at the middle-range scale in the area where thick clouds are located the signals coming from the target and from the clouds will be approx. of the same value. In this case rain antilcutter circuit is ineffective and doesn’t provide high contrast between real target and interferences (both signals will be suppressed and as a result there is a high risk to not detect the dangerous target). If rain antilcutter circuit is switched off in this conditions then both the target and interferences are observed in the radar screen but it’s almost impossible for operator to detect the target in such situation [5].

One more negative effect common for the Arctic Ocean is sub-refraction when the trajectory of radio wave is deflected towards the sky in the case of high temperature contrast between cold atmosphere and relatively warm sea surface [6]. Sub-refraction phenomenon occurs regularly in the polar waters in the spring and in the autumn when large areas of water are already free of ice but the air temperature can be less than 20°C below zero (at least during 1-2 hours). In such situation the majority of distant objects are not emitted by CMR radio waves (deflected radar beam miss the target) or only slight share of reflected pulse energy comes back to the radar position.

To sum up we can conclude that radar observation in the Arctic often is inefficient process because of weak target’s echo relative to the power of radar receiver noise. So to improve the CMR efficiency during navigation in the polar waters it’s necessary to design the advanced methods of radar signal
processing that make possible to increase the power of signals echoed from targets or to suppress the considered above interferences.

4. Advanced methods of radar signal processing

The energy of signal coming to the position of CMR location, which primarily determine radar efficiency depends on many factors including the power of radar transmitter [7]. But increasing the signal energy by increasing the transmitter power doesn’t provide considerable expansion of radar detection range [8]. It’s much more efficient to improve SNR provided by CMR using the advanced matched filter integrated in the radar receiver.

Up-to-date CMR transmit very high frequency pulses of rectangular shape. To get the maximal possible SNR for such pulse before its detection it’s needesary to process it by filter with frequency response which is complex conjugate to the pulse spectrum [9]. It meanes that frequency response curve of the filter must be the same as the amplitude spectrum of radar pulse. This spectrum curve is the absolute value of well known sinc-function and is depicted in the Fig.3:

![Figure 3. Amplitude spectrum of radar pulse (f_0 – pulse carrier frequency, τ_p – pulse length)](image)

The matched filters that are integrated in the modern CMR have the frequency response curve represented in the Fig.4. Such filter is built by the basic possible schematic circuit and its output signal energy is a little bit more than 90% of pulse energy (this part of pulse energy is concentrated inside the 1st lobe of amplitude spectrum). As a result the radar detection range doesn’t exceed 66% of maximal possible one (maximal possible radar detection range is the distance such that it’s theoretically possible to observe a target by the radar in the case if 100% of echoed pulse energy is utilized during its reception). It’s supposed to be acceptable to have 10% loss of pulse energy as a compromise between achievable radar performance parameters and its cost. But the same loss of energy can’t be considered as admissible in the critical conditions of radar observations that are common for the Arctic region [10].
Using special circuit it’s possible to get frequency response curve which approximates pulse amplitude spectrum much better compared to the modern CMR’s filter. To do it the matched filter structure must include three blocks: the 1st one is filter resonant to the frequency of the CMR sounding pulse, the 2nd block is filter tuned in to frequency of the 2nd upper lobe of the spectrum, the 3rd block is filter tuned in to frequency of the 2nd lower lobe of the spectrum. Each of the blocks in this scheme is magnetically connected with other blocks, as a result the equivalent frequency response of this circuit is transformed in the curve which is depicted in the Fig. 5:

In the case when signal is processed by advanced matched filter about 99% of signal energy is utilized in optimal way. Since the radar detection range is proportional to the 1/4 power of signal energy the distance of consistent detection for objects with small scattering cross section in the case of using advanced matched filter can be increased by more than 45%.

It’s also possible to improve CMR efficiency if this navigation tool will be equipped by dedicated target detector (DTD) which function is to identify the target in the case when it was already observed by radar formerly. This circuit consists of memory unit, ARPA interface unit and the computer of target’s maneuvering parameters. DTD identifies how many tracking channels are free of operation at every time moment. If any of the channel is free it will be used by DTD to track the target which is not
selected by navigator for acquisition (for example this object is located far from the own vessel and is supposed to be safe). During this process DTD computer calculates the object’s scattering cross section as a function of aspect angle. This data array is then compared to the data base of targets stored in DTD’s memory. If no similarity is detected the object is recorded in the memory unit as a new target and its maneuvering parameters are continuously being analyzed to calculate their maximal possible values. As a result, during the next observations this target will be reliably detected and identified much faster even in the case when pulses echoed from this object are being received against the background of powerful interferences. Moreover, if navigator uses the radar to assess the risk of collision with target recorded into DTD memory simulating a trial manoeuvre it’s possible to plot in the screen not only the expected trajectory of the target but also a probable deviations from the line if the target will change the course or speed due to unforeseen circumstances. It’s worth to mention that such method of target identification doesn’t depend on the energy of echoed signal and will be useful in every possible clutter environment.

5. Conclusion
The methods of CMR efficiency improvement considered above will provide considerable enhancement of their main performance parameters (target detection probability, detection range of objects with small scattering cross section, accuracy and reliability of target tracking) without any effect on the other characteristics of these tools in every possible conditions of radar observations. That’s why these advanced methods of radar signal processing will be extremely useful during navigation in the Arctic waters when radar performance is essentially restricted by variety of negative factors. At the same time these techniques don’t require the radar power increasing or the considerable complication of radar structure therefore their application almost will not affect the price of these navigational systems.

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