Sea Clutter Modelling and Target Detection

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ABSTRACT
This paper mainly concentrates on the detection of target by modeling sea clutter. This is achieved by detecting the targets from the synthesized samples of the compressed noisy echo signal by fixing the threshold using improved correlation technique. These detected targets may include clutter also. To detect and isolate the sea clutters, two steps are followed. 1) The sea clutter radar cross section (RCS) is calculated for the modeled sea clutter reflectivity (σ^0) using NRL model at low grazing angles. This RCS calculation was made for different scenarios and is stored as a database. 2) This database is compared with the estimated RCS of the detected targets from synthesized received signal to detect the actual targets. MATLAB is used for coding and simulation.

Keywords
Clutter; NRL model; RCS; improved correlation technique.

1. INTRODUCTION
Radar radiates the electromagnetic energy from an antenna to propagate in space. The energy intercepted by the target is re-radiated in all directions. Some of the echo energy is returned to and received by the antenna. After amplification by a receiver and with the aid of proper signal processing a decision is made at the output of the receiver as to whether or not a target echo signal is present. At the time of reception, apart from the target information radar also detects some unwanted returns/echoes from other objects. These unwanted returns are termed as ***clutter***. Such echoes are typically returned from ground, sea, rain, animals/insects, chaff and atmospheric turbulences, and can cause serious performance issues with radar systems. So, clutter modeling has to be done to detect the target effectively.

Radars are generally placed in isolated areas like seas, oceans, remote areas etc. So, when the radar is placed near the sea, sea clutter is encountered. Sea clutter on the other side is modeled based on the reflectivity which is dependent on sea state and polarization. As the wind speed changes due to atmospheric disturbances, the sea state also changes which makes the sea clutter reflectivity difficult to evaluate.

Since in early days of radar, hundreds of measurement campaigns have been conducted with numerous papers published and summarized in several books, together this paper gives a brief on how sea clutter is modeled and target is detected. It is, however, still an area in which better and more accurate models are being actively sought. Some existing sea clutter models are given in reference [5].

Reflectivity, defined as σ^0, is the most fundamental characteristic of Sea clutter which is used in evaluating radar performance. The Sea clutter reflectivity also includes the propagation affects from the sea surface. So the reflectivity is generally termed as apparent reflectivity. Sea clutter reflectivity depends on many factors such as sea state, wind velocity, grazing angle, polarization, and radar frequency. In 1991 edition of Nathanson's book [5], he proposed a detailed description on sea clutter reflectivities collecting information from various sources and the results were also tabulated. This book represents the complete database of sea clutter reflectivity available so far. Horst et al and R.N.Trebits et al [10] proposed Georgia Technical Institute (GTI) model and the detailed description is given in [5]. This model has found widespread acceptance in the radar community. As pointed out by Nathanson in the book, his tabulated measured sea clutter data does not agree too well with the GTI model, in case of low grazing angles. NRL model given in [3] was developed to address the inaccuracies of the GTI Model and it provides much better agreement with the experimental data in Nathanson's Tables. When compared to the GTI Model, this model is very efficient at low grazing angles. Hence in this paper NRL model is used to calculate the sea clutter reflectivities. The main idea of this paper is to find the reflectivities of sea clutter and detect the target by fixing a threshold.

There exist many methods to fix the threshold and to detect the target from the echoed signal. Here improved track correlation technique [4] is used to detect the target from the synthesized samples of the compressed noisy echo signal. This technique is used to fix the threshold to compare the likelihood ratio in track to track association. This gives better performance due to the accountability of the estimation error (standard deviation-σ) as well as probability of false alarm (P_{fa}).

The complete paper can be viewed in three sections. Section 2 briefs the existing methods for modeling sea clutter and practical way of calculating the RCS of the target. In section 3, Sea clutter reflectivity (σ^0) modeling using NRL model at low grazing angles is explained. Section 4 briefs the theory behind target detection and clutter isolation. Simulated results and analysis are given in section 5. Finally, conclusion is given in section 6.

2. SEA CLUTTER MODELS
Some existing methods for sea clutter modeling are given below

2.1 Models
2.1.1 GTI (Georgia Technical Institute) model
This is one of the first such empirical model developed at the Georgia Technical Institute around 1978, has received widespread acceptance and was also described in Nathanson's book. Other sea clutter reflectivity models have been proposed but none of them provide much improvement over the GTI model.

One problem encountered in comparing the GTI model with the Nathanson's tables is that it only relates average wave height to wind velocity (for a "fully risen" sea) by the equation

$$v_w = 8.67(h_{av})^{0.4} \quad (1)$$

The GTI model further allows for separate inputs of average wave height and wind velocity, but the quantitative basis for this generalization has not been presented. The significant wave height is defined as the average value of the 1/3 highest peak-to-trough waves. A good fit is provided by the expression

$$h_{1/3} = 1.6h_{av} = 0.049.SS^{2.6} \quad (2)$$

The agreement considered in equation (2) at sea state (SS) 4 and above is reasonably good, but for sea states of 3 and below large discrepancies are noted.

2.1.2 *NRL (Naval Research Laboratory) model*

NRL is a research laboratory for the United States Navy and the United States Marine Corps.

NRL model for sea clutter [3] is developed by Vilhelm Gregers-Hansen and Rashmi Mittal from Naval Research Laboratory to overcome the defects of GTI model. In this model, the reflectivities for various sea states are calculated for different sea states and polarization at low grazing angles.

2.1.3 *Hybrid model*

Hybrid model was introduced in an attempt to account for the effects of the evaporation duct. This model combines elements of the GTI model with new empirical equations. Comparison of Hybrid model with Nathanson tables show some improvement over the GTI model for vertical polarization [3] but the average error is still large.

2.1.4 *TSC (Technology Service Corporation) model*

The Hybrid model is not valid for sea state 0. Finally, a model developed by the Technology Service Corporation (TSC) was included in a commercial radar performance evaluation software package. This is more complete model including all the parameters and is also valid for sea state 0 [13].

In this paper, for modeling sea clutter, Nathanson's tables [3] are considered as reference. The GTI model for sea clutter proposed in 1978 underestimates sea clutter reflectivity at sea states up to 3 compared to experimental data. Radar which is placed near the sea, the grazing angle or look angle will be very low. Since, NRL model matches these Nathanson's tables up to a maximum error of 2db for grazing angles 0.1^{O} to 10^{O}, NRL model is the best fit to model the sea clutter for low grazing angles.

2.2 Radar Cross Section

The size and ability of a target to reflect radar energy can be summarized into a single term, known as the radar cross-section (σ_c), which has units of m²and is expressed in dbm^2. This unit shows that the radar cross section is an area. RCS calculation for different shapes of the targets is explained in reference [11]. It is calculated based on the range, grazing angle and the power received from the target. In this paper RCS is calculated from the basic radar range equation [8]

$$R = \sqrt[4]{\frac{P_s G^2 \lambda^2 \sigma_c}{P_E (4\pi)^3}} \quad (3)$$

Where,

σ_c Is the Radar Cross Section (RCS)

R Is the range

P_s and P_E are transmitted and received powers respectively

G Is the antenna gain and

λ Is the wavelength

If all of the incident radar energy on the target were reflected equally in all directions, then the radar cross section would be equal to the target's cross-sectional area as seen by the transmitter. In practice, some energy is absorbed and the reflected energy is not distributed equally in all directions. Practically, RCS of the received signal is calculated using various methods as given below,

*Finite difference-time domain method (FD-TD):*In this method we solve Differential form of Maxwell's equations for exact fields.

*Method of Moments (MoM) :*Solve integral form of Maxwell's equations for exact currents.

*Geometrical Optics (GO):*Current Contribution Assumed to Vanish Except at Isolated Specular Points.

*Geometrical Theory of Diffraction (GTD):*Geometrical Optics with Added Edge Current Contribution.

*Physical Optics (PO):*Currents Approximated by Tangent Plane Method.

*Physical Theory of Diffraction (PTD):*Physical Optics with Added Edge Current Contribution.

2.3 NRL Sea clutter model

NRL (Naval Research Laboratory) model [3] is the best fit for clutter modeling as it is applicable for all the sea states unlike GTI, HYBRID and TSC models. Using this NRL model the reflectivity of the surface is calculated by mathematical methods using which RCS is calculated and this result is compared with the experimental result to identify the target or clutter. For the known grazing angle (α) and the transmitted signal frequency (*f*), the reflectivity (σ^0)for both horizontal and vertical polarization is calculated as

$$\sigma^0 = c_1 + c_2 \log_{10} \sin\alpha + \frac{(c_3 + c_4\alpha)\log_{10} f}{1 + c_5\alpha + c_6 SS} + c_7(1 + SS)^{\frac{1}{2 + c_8\alpha + c_9 SS}} \quad (4)$$

Here, *SS* represents the different sea state classification based on the wind speed [3] as shown in table 2. Similarly, c_1 - c_9 are the polarization constants whose horizontal and vertical polarization values are given in table 1.

Table1. Constants for horizontal and vertical polarizations- curtesy[3]

POLARIZATION		
CONSTANT	**HORIZONTAL**	**VERTICAL**
C1	-72.76	-48.56
C2	21.11	26.30
C3	24.78	29.05
C4	4.917	-0.5183
C5	0.6216	1.057
C6	-0.02949	0.04839
C7	26.19	21.37
C8	0.09345	0.07466
C9	0.05031	0.04623

After finding the reflectivity (σ^0) a database is tabulated for the different sea states at different grazing angles. The RCS (σ_c) of the sea clutter at different states is calculated using equation (5) for the known clutter's area (A_c)

$$\sigma_c = \sigma^0 A_c \quad (5)$$

Table 2. Sea states for different wind speeds

Sea State	Wind Speed kt	Wave Height, ft	Duration/fetch
1(smooth)	<7	1	1/20
2(slight)	7-12	1-3	5/50
3(moderate)	12-16	3-5	15/100
4(rough)	16-19	5-8	23/150
5(very rough)	19-23	8-12	25/200
6(high)	23-30	12-20	27/300
7(very high)	30-45	20-40	30/500

3. TARGET AND CLUTTER ISOLATION

3.1 Synthesizing The Noisy Echo Signal

The received signal is the combination of target signal, clutter signal and noise. So while synthesizing the received signal the clutter and noise are added along with the delayed transmitted signal. The noise added is additive white Gaussian noise which is generated using equation (6), based on the required noise figure (*NF*) and the receiver noise bandwidth (*B*)

$$PN = K.T.B.NF \quad (6)$$

Where, K-Boltzmann's Constant and T-Temperature (300 K)

3.2 Target detection

In practical scenarios, when an electromagnetic pulse is transmitted, the signal is expanded to effectively detect the target. So, now at the receiver the expanded pulse has to be compressed. In our case the pulse is transmitted for 200ns which is expanded to 10µs. So, when the received pulse is again compressed to 200ns, we get 50 (10µs/200ns) range cells. Among these 50 some may contain target information, clutter information and noise.

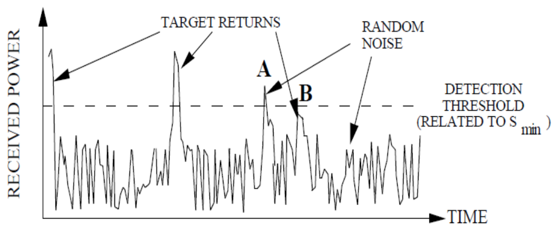

Figure 1. Received power versus time

A is a false alarm: the noise level is greater than the threshold. **B** is a miss: a target is present, but it is not detected.

The threshold level is fixed to detect target returns against a background noise. If the reception is greater than the threshold level, then the target is detected.

To fix the threshold, improved correlation technique is used to detect the targets (along with clutter as target).To find the threshold level (*T*), we use probability of false alarm (P_{fa}) and standard deviation (σ) of the received signal [4].

$$T = \sqrt{-2.\sigma^2.\ln P_{fa}} \quad (7)$$

3.3 Detected Target's RCS Estimation

Time delay (τ) in the target reflected signal is obtained by cross correlating the transmitted and the received signals. Equation (8) gives the radar range (*R*). RCS (σ_c) of the detected targets are found using equation (9) for the known transmitted and received signal power (P_t and P_r) along with the known antenna gain (*G*).

$$R = \frac{C\tau}{2} \quad (8)$$

$$\sigma_c = \frac{P_r}{P_t}.\frac{R^4}{G^2}.\frac{(4\pi)^3}{\lambda^2} \quad (9)$$

4. RESULTS

4.1 Finding reflectivity

The reflectivity values for the sea clutter are calculated from equation (4) and are tabulated in table 3 and 4.

Table3. Reflectivity for horizontal polarization

GA	SS1	SS2	SS3	SS4	SS5	SS6
0.5	-108.425	-97.959	-89.356	-80.756	-72.249	-66.898
1	-81.34	-76.59	-70.26	-64.49	-60.36	-57.45
5	-78.5956	-72.041	-67.286	-61.406	-56.445	-50.429
10	-64.0241	-59.850	-54.539	-49.144	-45.693	-42.201

GA- **Grazing angle** **SS-Sea State**

Table4. Reflectivities for vertical polarization

GA	SS1	SS2	SS3	SS4	SS5	SS6
0.5	-103.42	-91.526	-84.586	-76.696	-67.896	-61.207
1	-76.33	-70.96	-64.56	-59.24	-55.69	-53.41
5	-62.719	-57.320	-51.130	-48.073	-44.108	-41.209
10	-47.188	-43.772	-39.505	-35.332	-31.224	-27.163

From tables 3 and 4 it is observed that the reflectivity is increasing with increase in sea state and also increase in the grazing angle

The RCS is calculated with respect to grazing angle. RCS given in the below tables is with respect to the grazing angles 0.5 to 10.

Table5. Computed RCS for different clutter reflectivity's of horizontal polarizations

RCS	SS1	SS2	SS3	SS4	SS5	SS6
0.5	-64.5032	-56.324	-49.346	-42.64	-36.546	-31.25
1	-43.3486	-38.4598	-35.132	-29.56	-26.36	-24.39
5	-40.4458	-36.4589	-32.146	-27.89	-24.78	-20.61
10	-30.5438	-26.7836	-21.375	-18.36	-15.44	-12.56

Table6. Computed RCS for different clutter reflectivity's of vertical polarizations

RCS	SS1	SS2	SS3	SS4	SS5	SS6
0.5	-60.222	-54.372	-45.336	-37.543	-32.664	-27.983
1	-38.335	-33.239	-30.452	-25.879	-23.557	-21.765
5	-28.447	-24.312	21.5573	-18.979	-15.668	-14.887
10	-18.446	-14.339	-11.359	-8.9916	-7.5369	-5.9981

Table 5 and 6 shows as the reflectivity increases the radar cross section RCS also increases since RCS is directly proportional to reflectivity equation (5)

4.2 Transmitted signal

A cosine signal is generated with certain time duration.

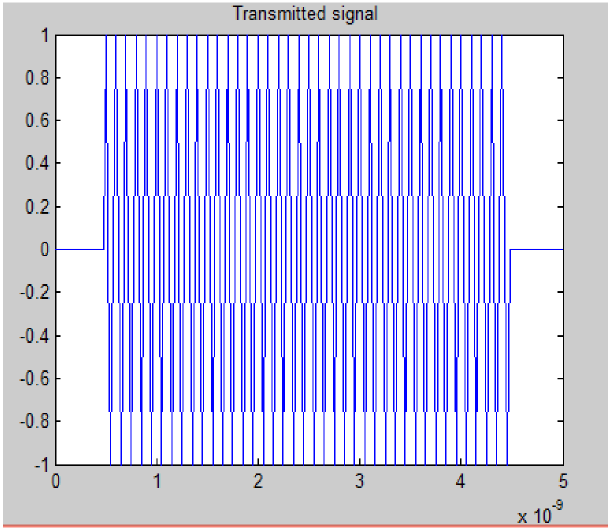

Figure2. Transmitted signal

4.3 Received signal

The received signal is a combination of target signal, clutter signal and noise. The noise added to the signal is the AWGN noise. The power of the received signal is obtained by multiplying transmitted signal amplitude with the transmitted power. The amplitude of the received signal will be equation (10).

$$A = \frac{P_t}{4\pi r^3}\frac{\lambda^2}{R^4}\sigma_c G^2 y \qquad (10)$$

The final received signal is given by

$$P_r = A\cos(\omega_c t + \omega_d(t+\tau)) \qquad (11)$$

The clutter signal is synthesized by multiplying the received signal with different amplitudes. Thus the final signal is a result of the target signal, clutter signal and the noise signal.

4.4 Practical Approach

In practical scenarios, if a cosine signal is planned to transmit for 200ns, it is expanded to 10µs before transmission so as to detect the target effectively. When this 10µs pulse is received back it is again compressed to 200ns to obtain the original pulse width. When this 10µs pulse is compressed to 200ns pulse and sampled at 5MHz sampling rate, we get 50 range bins(10µs/200ns) each of which contains a target information. In these 50 range bins there exits target, clutter and the noise.

First the noise is removed by fixing a threshold and then the remaining clutter and target are differentiaited based on the RCS values. The compressed recceived signal samples are shown in figure(3).

In this simulation,there exist 50 samples in which one of the sample represents one target information,three clutter information and rest of them are the representation of the noise. Let the target amplitude be 0.0035 and the clutteramplitudes are 0.004, 0.0055 and 0.006. The noise added to the signal is random noise which has a peak value of 0.003.

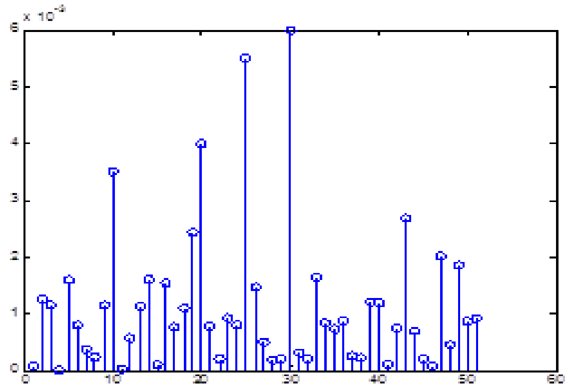

Figure 3. Compressed echo signal

Here, the figure shows the plot of all the 50 different pulses each representing different target information.

The threshold level is fixed to detect target returns against a background noise and interference. Threshold (*T*) is calculated using equation (10). By fixing the probability of false alarm (P_{fa}) as 10^{-4} [4] along with the estimated standard deviation (σ=0.0006) of the received samples shown in figure (3), threshold is estimated as 0.0025. The threshold value thus obtained is greater than the noise level. Thus, the target can be easily detected. The noise peak obtained is 0.003 and the target and clutter values are 0.0035, 0.004, 0.0055, and 0.006. Thus, the threshold is more than noise level and less than the target values. Therefore, the targets are identified as shown in figure (4). It is also observed that even though synthesized received signal has only one target, figure (4) shows 4 target detected. It shows that other three are may be from clutter.

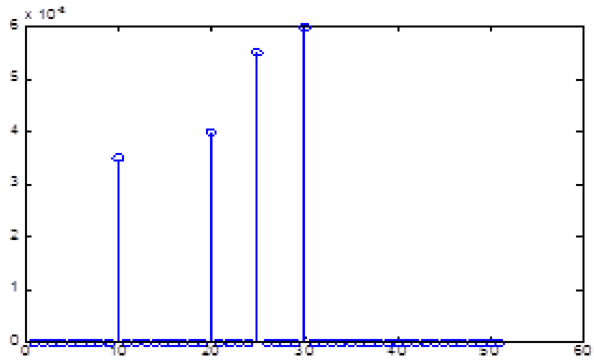

Figure4. Target detection based on improved correlation technique

RCS of the detected targets are found using equation (12) and are compared with the RCS of the sea clutter data base shown in Table 5 and 6. When it matches with the data base then it indicates the clutter returns. Otherwise it will be considered as a target returns. Figure (5) shows the final detected target after removal of the clutter.

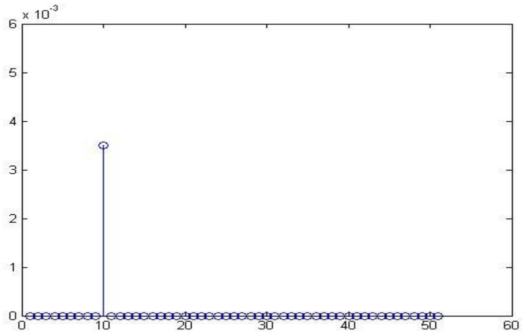

Figure5. Final detected target after removing the clutter

5. CONCLUSION

The sea clutter is modeled using NRL model taking reflectivity as the main parameter. The reflectivity for different sea states and grazing angles is calculated and the dependency of reflectivity is shown. RCS is calculated using obtained reflectivities. The transmitted cosine signal with a rectangular pulse is generated and the received signal is synthesized which is a composite of target signal, clutter signal and the noise signal. The concept of range resolution is used to differentiate target and clutter on calculating the received power and fixing a threshold. This model is more efficient at low grazing angles. Whenever the wind speed is more than about 40kt, peculiarities and uncertainties in the generation of surface roughness begin to emerge more strongly. Therefore, at sea state more than 6, when the grazing angle is high, the reflectivity cannot be found using NRL model. Thus, other models like GTI, Hybrid and TSC models are used to calculate the reflectivity of sea surface.

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