Research on the Sea Spike Suppression Based on Range Domain Characteristics of Relatively High Resolution Radar

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Abstract. With the improvement of radar resolution, especially when the radar works in low erasing angle, the masking effect becomes more and more obvious, and a large number of sea spike arise. This paper mainly uses the relatively high resolution sea radar data, analyses the amplitude and frequency characteristics of the target and the sea peak. Finally, according to the differences of their range domain characteristics, we propose a range domain suppression method of sea spike. Experimental data analysis proves the validity and feasibility of the algorithm.

1. Introduction
Sea clutter and sea spikes have seriously affected the detection performance of marine radars on sea targets. How to suppress the influence of sea spikes has always been a problem in the radar world. Especially with the improvement of radar range resolution, especially when the radar is working at low ground angle, the shadowing effect becomes more and more obvious. The statistical characteristics of sea clutter amplitude echoes no longer obey Rayleigh distribution, and sea spikes appear in large numbers. The sea spike effect is a manifestation of the non-stationarity of sea clutter. For radar echoes, sea spikes often appear as sporadic motions or static "targets" randomly distributed at different distances and angles, with strong echoes and Undulation characteristics [1].

Because the background of sea clutter is complex, and is affected by many factors radar system, wind direction, wave height, etc., subject to different temporal and spatial correlations, it is difficult to have an accurate and complete description method [1]. Sea spikes are essentially broken waves generated by ocean wave collisions, and are not completely equivalent to sea clutter; the randomness and unpredictability of sea spikes are even stronger than sea clutter. In recent years, there has been a lot of literature on sea clutter, but there are still very few specialized studies on sea spikes. The reason for this is that the generation of sea spikes is a process in which sea surges change from steady state to unsteady state. It occurs randomly, is greatly affected by factors such as weather and sea conditions, and has greater uncertainty; research is more difficult There are no specific laws to follow.

For the suppression of sea spikes, the more common target detection method based on sea clutter modeling proposed in literature [3], by establishing a certain clutter and signal model, suppress sea clutter and then suppress sea spikes. The algorithm is very complicated, and the processing of the radar detection front-end often makes the signal deviate from the assumed model, thereby affecting the detection result. References [4, 5] proposed a sea target detection method based on block whitening
clutter suppression based on the time-frequency characteristics of sea clutter and target [6]. In this paper, through the analysis of the measured data, the difference between the sea spike and the target in time and frequency is studied. Combined with the actual radar system, a distance dimensional sea spike suppression method is given, and it is based on the size characteristics of the sea spike.

2. Sea spike characteristics
Although there is no strict physical model of sea spikes, breaking waves are the main reason for the formation of sea spikes [7]. The echo signal of the sea spike is very powerful and has a Doppler frequency shift, which is often regarded as a moving target.

The traditional MTI (Moving Target Indication) algorithm can be used to suppress ground clutter and sea clutter in a specific frequency range by filtering. However, small targets with relatively low speeds will also be filtered out at the same time; the sea spikes have a certain speed of movement. When the Doppler frequency shift is large, not near the filter notch, or the Doppler spectrum is wide, MTI cancellation effect is not obvious.

The number of distance units occupied by sea spike is significantly less than the number of distance units occupied by the target. The echo signal passes through the four-pulse cancellation MTI filter with a width of 20 Hz (-10 Hz to 10 Hz) at a zero frequency through the notch. The sea spikes cannot be suppressed by the MTI filter. Perform the same constant false alarm rate (CFAR, Constant False Alarm Rate) processing on the data before and after the MTI cancellation. After MTI cancellation, some slow and small targets are suppressed, but the sea spike at 14458 still exist. The peaks of the sea undulations are obvious and the target amplitude changes relatively smoothly. The Doppler spectrum obtained by the method of IAA for the sea spikes and targets is converted from Doppler frequency to velocity. The target spectrum peak is narrow and the sea spike peak spectrum is wide. Since the sea spike has a certain speed and the Doppler frequency is not zero, the MTI filter is not ideal for eliminating the sea spike. So even with MTI cancellation, after the CFAR detector, the detection result at the sea spike is still "targeted", and the sea spike is not suppressed; on the contrary, some slow targets are suppressed.

After analyzing the measured data, we can see that the sea spike mainly has the following characteristics:
1) The distance unit occupied by the sea spike is significantly less than the target (for radar with higher range resolution);
2) The echo of the sea spikes fluctuates rapidly relative to the target on the sea surface, and the fluctuation between the pulses is large;
3) The Doppler spectrum center of the sea spikes is often not zero, and the spectrum components are rich and the spectrum is wide.

This article mainly uses the first feature of sea spikes to discuss the suppression methods of sea spikes.

3. Sea spike suppression method for higher resolution radar
According to the cause of the sea spikes, due to the random generation of broken waves, and the size of the collision is also random according to the intensity of the collision, and the distribution range is relatively scattered; and the sea targets we expect are mainly ships, although different directions and different radar irradiation angles. At this time, the target behaves differently in the size of the radar echo, but there is a rough size range. According to statistics, the size of civilian ships is generally 30m to 100m, and the size of warships is more than 100m, and the distribution is relatively regular. The target echo is wider in width and larger in size than the sea spike. Therefore, this paper uses the difference in size characteristics between the target and the sea spike to distinguish the two, thereby suppressing the sea spike.

After the radar echo is processed by pulse compression and constant false alarm rate (CFAR) detector, the echo is compared with the constant false alarm rate threshold. When the threshold is exceeded, the detection result is "1", indicating that it may be "targeted"; otherwise it is "0", the detection result is "no target". When the radar resolution is high, the size of the "target" can be roughly calculated based on the number of consecutive "1"s.
By setting the threshold for the number of consecutive "1"s at the "target" in the "0" and "1" detection results output by the CFAR detector, the "target" that exceeds the threshold is judged as a "true target", and this CFAR detection is retained result; On the contrary, if it is judged that the "sea spike false alarm" needs to be suppressed, this section of "1" is replaced by "0" output. This algorithm for suppressing sea spikes according to the target size feature is called distance dimensional sea spike suppression.

This article proposes to combine the two methods to suppress sea spikes, the specific steps are as follows.

1) Perform pulse compression processing on radar echo data to improve the signal-to-noise ratio;
2) After the constant false alarm detection (one-time detection), the detection result of "0" or "1" is obtained;
3) Distance dimensional sea spike suppression; specifically, setting a threshold (generally determined according to the expected target size), when the number of consecutive “1” CFAR results exceeds the threshold, it is determined as a “true target” and retained; otherwise, it is determined as "sea spike", suppress all these "1" and change to "0" output;
4) Binary accumulation of the results of distance dimensional sea peak suppression in one wave position;
5) Perform secondary detection on the binary accumulation result, and the secondary detection threshold is taken \[ K_{opt} = 1.5\sqrt{Q} \] (1)

In the above formula, \( Q \) represents the number of pulses of a single wave position per scanning period, and \( K_{opt} \) is the secondary detection threshold with the minimum required signal-to-noise ratio under the same detection probability and false alarm probability according to the Naiman-Pearson criterion.

![Figure 1. Sea spike suppression detection process](image)

According to the above process, whether it is distance dimensional sea spike suppression or binary accumulation detection can be completed within one revolution of the radar scan, the sea spike suppression algorithm is easy to implement in engineering.

4. Measured data processing results

In order to verify the sea spike suppression algorithm in this article, this section will use MATLAB to process the measured data. Figure 2 shows the measured data of a pair of maritime warning radars at a certain wave position. For easy observation, only a small piece of data at a certain wave position and a certain circle is selected here. Although the radar is installed at a certain position on the beach, the first 10,000 distance units belong to land, so the data in this section is intercepted from positions other than 10,000 points, and only 6,000 distance units are intercepted.
After the conventional pulse pressure processing of the measured data, it can be seen that in some distance units, the sea spike phenomenon is serious, and there are relatively dense glitches in the amplitude map (15000 ~ 16000 distance units). Due to the limited effect of the traditional CFAR method on suppressing sea spikes, CFAR detection is performed at this time, and the glitches are detected as "targets" in the detection results obtained. To eliminate glitches and suppress sea spikes, we add distance dimension sea spike suppression and binary accumulation detection after CFAR detection, and the results shown in Figures 3 (b) and 3 (c) can be obtained.

In the two figures of Figure 3 (a) and Figure 3 (b), the dots of different colors represent the detection results of different pulses in a circle; for ease of observation, only the original amplitude of the CFAR
threshold distance unit is retained in the figure (Distance units that do not exceed the threshold are not
displayed). Figure 3 (c) is the average value of all the pulses within a circle of the wave position after
the binary accumulation and the secondary detection result in the time domain after the distance Weihai
spike suppression. It can be seen from Figure 3 that through the sea spike suppression process in this
article, it can be clearly seen that short or large sea spikes are suppressed.

When performing simulation processing, combining radar parameters and the sea surface
environment, in order to avoid false alarms of sea clutter, this article selects the unit to choose the
Daheng false alarm (GOCFAR). Corresponding CFAR detectors have one side protection unit number
\( N = 15 \), and one side reference unit number \( M = 32 \). The threshold coefficient \( T_{GO} = 15dB \), iterative
calculation according to formula 2 can be obtained [9], corresponding to the false alarm probability
\( P_{fa} = 3 \times 10^{-3} \).

\[
P_{fa} = 2 \left(1 + \frac{T_{GO}}{M}\right)^{-M} - (2 + \frac{T_{GO}}{M})^{-M} \times \left\{ \sum_{k=0}^{M-1} \left( M-1+k \right) \left( 2 + \frac{T_{GO}}{M} \right)^{-k} \right\}
\]

(2)

Adjust the threshold coefficient, select a piece of measured data with known target position for the
test, and count the false alarm probability and detection probability of only CFAR detection and the
entire sea spike suppression processing, and obtain the ROC curve as shown in FIG. 8. The detection
probability is the probability that the target exists and the final detection result is "targeted", which is
the probability of correct judgment; the false alarm probability is the probability of no target, but the
final detection result is "targeted", which is the probability of wrong decision.

\[
\hat{p}_d = \frac{n_d}{N_m}
\]

(3)

\[
\hat{p}_f = \frac{n_f}{M_m-N_m}
\]

(4)

Where, \( \hat{p}_d \) and \( \hat{p}_f \) are the detection probability and false alarm probability obtained by Monte Carlo
test statistics, \( M_m \) is the total number of distance units participating in the detection, \( N_m \) is
the number of distance units occupied by the target; \( n_d \) represents the number of distance units where the detection
result at the target location is "targeted" and \( n_f \) represents the number of distance units at the non-
target location detection result is "targeted". According to the above formula, the threshold is gradually
adjusted, and the detection and false alarm probability of a wave position of about 30,000 distance units
are statistically obtained to obtain the following ROC curve.

It can be seen from FIG. 8 that the detection process of sea spike suppression proposed in this paper
has a lower false alarm probability and a higher detection probability compared with the traditional
CFAR only detection, and the overall detection performance is greatly improved. It should be added
that after simulation verification, the binary accumulation detection after the distance dimensional sea
peak suppression and the non-coherent accumulation before the CFAR detection have similar
suppression effects on the sea spikes, and the two can be replaced with each other. Multiple tests have
shown that, by selecting the measured data of different directions and different circles, similar results
can be obtained after the above detection process. The effectiveness of the algorithm in this paper to
suppress sea spikes has been verified.

![Figure 4. Comparison of sea spike suppression method and CFAR only detection results](image-url)
5. Conclusion
In this paper, combined with the measured data of marine radar, the time and frequency domain characteristics of the sea spikes are analyzed. The main source of the sea spikes is the fragmented waves on the sea surface. Its instantaneous energy is large, and it has a Doppler frequency shift. Traditional algorithms (such as MTI) are not effective in suppressing sea spikes, and may also affect the detection of slow and small targets. The algorithm based on sea surface modeling is computationally intensive and has low real-time performance. At the same time, the performance of the algorithm is easily affected by radar front-end processing, and its robustness is average.

In this paper, according to the difference between the target and the size of the sea spikes, the detection process for suppressing sea spikes proposed by the higher resolution marine radar is easy to be implemented in real time by the hardware. It has great flexibility when the threshold is set differently. Multiple tests of the measured data It proves that its inhibitory effect on small-sized sea spikes is immediate. However, it is undeniable that with changes in the environment such as wind direction, sea conditions, radar angle of ground sweep, etc., when the size of the sea spikes becomes larger, the suppression effect of the algorithm in this paper deteriorates rapidly. Therefore, target tracking algorithms such as inter-frame correlation or Track Before Detection (TBD) may also be needed to further distinguish and suppress the target and sea spikes based on their motion characteristics.

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