Advances in Radar Signal Processing Techniques

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Weibull-distributed clutter are reviewed. Most of the clutter received by L, S, X and Ku band radars obeys a Weibull distribution when reflectors are terrain, sea, sea-ice and rain clouds. Clutter suppression techniques for Weibull clutter are also reviewed. Especially, Weibull CFAR is emphasized.

Keywords: radar clutter, Weibull distribution, CFAR

1. Introduction

Radar clutter is defined as the unwanted reflected waves from irrelevant targets. Often such clutter prevents the detection of targets, such as aircrafts, ships etc. This is illustrated in Fig. 1.

How to suppress clutter and to detect target signals from the clutter is one of the most important problems in modern radar technology. To this end, the statistical properties of the clutter echo have been examined for various radar parameters, such as resolution, wavelength, polarization, grazing angles etc (1) (2). The most important property may be the amplitude distribution of clutter. This has been described using a Rayleigh distribution. The Rayleigh distribution is given by

\[ p_R(x) = \frac{2x}{\sigma^2} \exp\left(-\frac{x^2}{\sigma^2}\right) \quad (x \geq 0, \ \sigma > 0) \]  

where \( x \) is the clutter amplitude and \( \sigma^2 \) is the mean square of \( x \). If the clutter obeys a Rayleigh distribution, the LOG/CFAR technique is applicable to clutter (3). The LOG/CFAR receiver consists of a log-amplifier, a subtractor and a anti-log amplifier. After passing a log-amplifier the variance of Rayleigh clutter is manifested as a mean value while the variance of the converted signals is kept constant. When the mean value is eliminated by a subtractor and the signals are passed through an anti-log amplifier, the resulting variance is determined solely by the circuit constants. Thus, we can arrive at a threshold level to find a target under a constant false alarm rate.

However, recent investigations of radar clutter characteristics have shown that the clutter echo can be approximated by a Weibull distribution (5). The Weibull distribution can be expressed by

\[ p_W(x) = \frac{\eta}{\sigma} \left(\frac{x}{\sigma}\right)^{\eta-1} \exp\left[-\left(\frac{x}{\sigma}\right)^\eta\right] \quad (x \geq 0, \ \sigma > 0, \ \eta > 0) \]  

where \( \sigma \) and \( \eta \) are the scale and the shape parameters, respectively. For \( \eta = 2 \) we find the Rayleigh distribution of Eq. (1).

In the following, we shall provide a summary of the measured data of ground clutter, sea clutter, sea-ice clutter and weather clutter, which can be modeled with the Weibull distribution. After describing the observed Weibull clutter, we shall discuss the methods of suppression of Weibull clutter.

2. Ground Clutter

Weibull-distributed ground clutter was reported for various radar resolutions, wavebands and land types. For example, ground clutter from the Rocky mountains obeys a Weibull distributions with the shape parameter of 0.512 for S-band, a 2.0µs pulsewidth, and a 1.5° beamwidth. From low rolling wooded hills and grassland, a Weibull distribution with the shape parameter of 0.626 was observed from L-band radar having a pulsewidth of 3.0µs, a beamwidth 1.7°, and a depression angle of about 0.5° (4). Data taken at X-band, pulsewidth 0.17µs, and beamwidth 1.4° also obeys a
Weibull distribution with the shape parameter of 0.506 to 0.531 for forest at a depression angle of 0.7°, and 0.606 to 2.0 for cultivated land at depression angles of 1.25°, 2.5°, and 5.0° (5). Ground clutter data of cultivated land was measured by the present authors (6) (7), using a high-powered low-resolution L-band air-route surveillance radar (ARSR) at very low grazing angles between 0.21° and 0.32°. It was discovered that the ground clutter amplitudes obey the Weibull distribution with the shape parameters of 1.507 to 2.0. Recently, Schleher (8) (9) proposed the Weibull clutter model to describe sea clutter, for example, Goldstein proposed the log-t detection, which requires a logarithmic detector of the mean, or covariance detection, which requires an exponential detector of the mean. The shape parameters of 0.3 to 0.5. Weibull-distributed ground clutter is summarized in Table 1. It is seen that the increasing shape parameter with increasing depression angle indicates that the distribution is approaching a Rayleigh distribution.

3. Sea and Sea-ice Clutter

Sea clutter is somewhat different from ground clutter. In general, the backscatter coefficient of sea waves is smaller than that of ground terrain. It is also greater for vertical polarization than horizontal polarization and is a maximum value for upwind, minimum value for downwind and intermediate value for crosswind.

It has been long believed that sea clutter amplitude statistics obey a Rayleigh distribution of eq. (1). However, recently, because of rapid advances in radar technology, non-Rayleigh sea clutter has been observed with relatively high resolution radars. For example, Schleher proposed the Weibull clutter model to describe sea clutter data measured at the Applied Physics Laboratory (APL) of the Johns Hopkins University using a Ku-band airborne radar of horizontal polarization, pulsewidth a 1μs and grazing angles between 1° and 30° (10). The shape parameters were η = 1.6 at a grazing angle of 1°, η = 1.65 at 5° and η = 1.78 at 30°. The main result of Schleher is that the increasing shape parameter with increasing grazing angle indicates that the distribution is approaching a Rayleigh distribution.

Recently, sea-clutter data has been measured by the present authors using a fixed antenna of an X-band radar (11). It was discovered that the shape parameters of the Weibull distribution were η = 0.925 at a grazing angle of 3.9°, η = 1.63 at 7.5° and η = 2.06 at 61.4°. Our result is compatible with the result of Schleher. Weibull distributed sea clutter is summarized in Table 2.

Sea-ice clutter was measured by us using an X-band radar which is located at the city of Mombetsu in northern Japan (12). The pulselength of the radar was 0.08 and 0.3μs. It was shown that the amplitude of sea ice obeys a Weibull distribution with the shape parameters of 0.440 to 2.079. The values of the shape parameter for 0.3μs are higher than those of 0.08μs.

4. Weather Clutter

Weibull-distributed weather clutter was also observed using an L-band ARSR in a range interval of 42 to 47.6 nautical miles and 60 to 65.6 nautical miles. It was concluded that Weibull-distributed weather clutter from rain clouds also obey a Weibull distribution with the shape parameter of 1.2 to 2.0 (10).

5. Suppression of Weibull Clutter

As already mentioned, various clutter obey a Weibull distribution. To suppress such clutter, a new method should be considered. To maintain a CFAR in Weibull clutter, for example, Goldstein proposed the log-t detector, which requires a logarithmic detector of the mean and standard deviation of the logarithm of the input clutter sample (14). Hansen has proposed a Weibull CFAR detector that takes into account the nonlinear transformation from the Weibull to the exponential probability density function (15). Recently, based on the use of an additional parallel adaptive detector with a lower threshold, Cole and Chan have considered a doubly adaptive CFAR technique (16). In addition, Clarke and Peters have proposed a similar CFAR detector using a low-level register operating in Weibull clutter (17). An adaptive CFAR system has also been considered by the

Table 1. Weibull-distributed ground clutter.

<table>
<thead>
<tr>
<th>Terrain type</th>
<th>Frequency band</th>
<th>Depression angle (deg.)</th>
<th>Resolution (μs×deg.)</th>
<th>Shape parameter η</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocky mountains</td>
<td>S</td>
<td>-</td>
<td>2.0 × 1.5</td>
<td>0.512</td>
</tr>
<tr>
<td>Wooded hills</td>
<td>L</td>
<td>0.5</td>
<td>3.0 × 1.7</td>
<td>0.626</td>
</tr>
<tr>
<td>Forest (March–August)</td>
<td>X</td>
<td>0.7</td>
<td>0.17 × 1.4</td>
<td>0.506</td>
</tr>
<tr>
<td>Forest (November)</td>
<td>X</td>
<td>0.7</td>
<td>0.17 × 1.4</td>
<td>0.531</td>
</tr>
<tr>
<td>Cultivated land (April)</td>
<td>X</td>
<td>1.25</td>
<td>0.17 × 1.4</td>
<td>0.606</td>
</tr>
<tr>
<td>Cultivated land (May)</td>
<td>X</td>
<td>1.25</td>
<td>0.17 × 1.4</td>
<td>0.704</td>
</tr>
<tr>
<td>Cultivated land (April)</td>
<td>X</td>
<td>2.5</td>
<td>0.17 × 1.4</td>
<td>1.143</td>
</tr>
<tr>
<td>Cultivated land (May)</td>
<td>X</td>
<td>2.5</td>
<td>0.17 × 1.4</td>
<td>1.143</td>
</tr>
<tr>
<td>Cultivated land (April)</td>
<td>X</td>
<td>5.0</td>
<td>0.17 × 1.4</td>
<td>1.818</td>
</tr>
<tr>
<td>Cultivated land (May)</td>
<td>X</td>
<td>5.0</td>
<td>0.17 × 1.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Cultivated land (January)</td>
<td>L</td>
<td>0.21–0.32</td>
<td>3.0 × 1.23</td>
<td>1.507–2.0</td>
</tr>
<tr>
<td>Open agricultural terrain</td>
<td>X</td>
<td>&lt; 1</td>
<td>0.1 × 1</td>
<td>0.3–0.5</td>
</tr>
</tbody>
</table>

Table 2. Weibull-distributed sea clutter.

<table>
<thead>
<tr>
<th>Sea state</th>
<th>Frequency band</th>
<th>Grazing angle (deg.)</th>
<th>Resolution (μs×deg.)</th>
<th>Shape parameter η</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Ku</td>
<td>1</td>
<td>0.1 × 5</td>
<td>1.16</td>
</tr>
<tr>
<td>3</td>
<td>Ku</td>
<td>3</td>
<td>0.1 × 5</td>
<td>1.65</td>
</tr>
<tr>
<td>3</td>
<td>Ku</td>
<td>30</td>
<td>0.1 × 5</td>
<td>1.78</td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>3.9</td>
<td>0.25 × 0.6</td>
<td>0.98</td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>7.5</td>
<td>0.25 × 0.6</td>
<td>1.63</td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>61.4</td>
<td>0.25 × 0.6</td>
<td>2.06</td>
</tr>
</tbody>
</table>
A normal unprocessed video is shown in Fig. 2(a). The conventional LOG/CFAR technique was applied to normal sea clutter. As shown in Fig. 2(b), the residue of sea clutter is seen. This means that sea clutter does not obey a Rayleigh distribution. A new Weibull CFAR processor was considered. A distribution converter, which can convert Weibull-distributed signal with arbitrary parameters to Rayleigh-distributed signal, is placed in the previous stage of the conventional LOG/CFAR. The result is shown in Fig. 2(c). Sea clutter was completely suppressed and we can easily detect a ship embedded in sea clutter. Figure 2(c) means that sea clutter obeys a Weibull distribution.

6. Conclusion

For various radar resolutions, wavebands, terrain types and sea states, ground, sea, sea-ice and weather clutter have been reported to obey the Weibull distribution for various depression and grazing angles. It was concluded that the increasing shape parameter with increasing depression and grazing angles indicates that the distribution is approaching a Rayleigh distribution for ground and sea clutter. To suppress such Weibull-distributed clutter, Weibull CFAR techniques are reviewed. A new Weibull CFAR was applied to sea clutter. In conventional LOG/CFAR system, it was difficult to detect a ship. On the other hand, in Weibull CFAR processor, sea clutter was perfectly suppressed and a ship embedded in clutter was clearly seen.

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References


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