DETECTION OF RADAR TARGET EMBEDDED IN SEA CLUTTER USING A MILLIMETER WAVE RADAR

Shuji SAYAMA, and Matsuo SEKINE
National Defense Academy
1-10-20, Hashirimizu, Yokosuka, 239-8686 Japan
sayama@cc.nda.ac.jp

1. Introduction

In radar signal processing, an important problem is the suppression of the various clutter reflected from the ground, sea and rain clouds, and the detection of targets, such as aircraft or ships embedded in such clutter. In order to improve target detectability in the presence of such clutter, various anticlutter techniques have been utilized[1]. For example, a logarithmic constant false alarm rate (LOG/CFAR) system is used against Rayleigh-distributed sea clutter having a large dynamic range[2].

The LOG/CFAR system makes use of the fact that the amplitudes of sea clutter obey a Rayleigh distribution. The system reduces the clutter output to about the receiver noise level by means of a logarithmic amplifier and a CFAR circuit. However, when the clutter are not distributed according to a Rayleigh distribution, the output clutter level is not kept constant and discrimination of the target from clutter is no longer easy.

It has been long believed that sea clutter amplitudes obey a Rayleigh distribution. However, recently, because of rapid advances in radar technology, non-Rayleigh sea clutter has been observed with relatively high resolution radars. For example, the sea clutter amplitudes obey the log-normal[3], Weibell[4], log-Weibull[5], and K-distributions[6] for various grazing angles, frequencies, pulsewidths and sea states.

Recently, sea-clutter data has been first measured by the present authors using a millimater wave radar with a frequency of 34.86GHz at low grazing angles between 1.3° and 14.0°. It was discovered that the sea clutter amplitudes obey the log-Weibull distributions in terms of the temporal and small scale fluctuations with which a CFAR is concerned. To determine the sea clutter amplitude, we have used the Akaike Information Criterion (AIC), which is superior to the least squares method to fit the distribution to the data. A new method of log-Weibull CFAR is formulated and applied to the suppression of sea clutter and detection of target.

2. Observations of Sea Clutter

Sea clutter was observed using a millimeter wave radar with a frequency of 34.86 GHz, horizontal beamwidth 0.25°, vertical beamwidth 5.0°, horizontal polarization, antenna scan rate 20rpm, pulsewidth 30nsec, pulse repetition frequency 4kHz and a transmitted peak power of 30kW.

Radar echoes were observed from sea in a range interval of 0.2 to 2.12km, over an azimuth interval of 69.63° to 77.31°. The observed area of sea clutter formed waves of a sea state 6. The height of waves were 4 to 6m. This is illustrated in Fig. 1.

Data was recorded digitally on a floppy disk as video signals after passing through an IF amplifier and a phase detector. The amplitude value was recorded on the floppy disk as an 8 bit signal, and hence the minimum and maximum integer values wave 0 and 255, respectively.

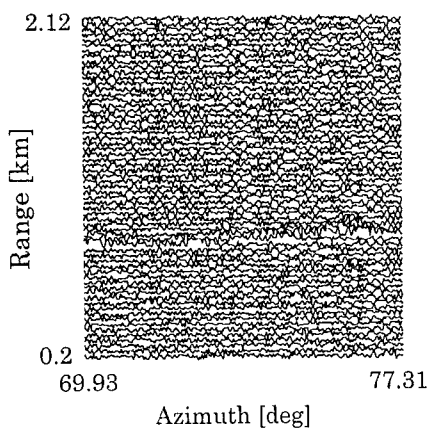

Fig. 1 Observed data

3. Amplitude Distribution of Sea Clutter

Here we investigate the amplitude data of the temporal and small scale range fluctuations with which a CFAR is concerned, we picked out a sample area of 9 range sweep numbers corresponding to the beamwidth of 0.25°. By using this data, we were able to determine the parameters of the log-normal, log-Weibull and K-distributions.

The log-normal distribution is written as follows:

$$P_{LN}(x) = \frac{1}{\sqrt{2\pi}\sigma x}\exp\left[-\frac{(\ln x-\mu)^2}{2\sigma^2}\right] \tag{1}$$

Here x is the amplitude of the return signals, μ is an average of $\ln x$ and σ is the standard deviation of $\ln x$.

The log-Weibull distribution is written as follows:

$$P_{LW}(x) = \frac{c}{bx}\left(\frac{\ln x}{b}\right)^{c-1}\exp\left[-\left(\frac{\ln x}{b}\right)^{c}\right] \tag{2}$$

Here b is a scale parameter and c is a shape parameter.

The K-distribution is written as follows:

$$P_K(x) = \frac{4h^{\nu+1}}{\Gamma(\nu)}x^{\nu}K_{\nu+1}(2hx) \tag{3}$$

Here h is a scale parameter and ν is a shape parameter. $\Gamma(x)$ is a gamma function and $K_\nu(x)$ is the νth modified Bessel function. For $\nu=\infty$, the K-distribution is identical to the Rayleigh distribution.

4. Determination of Sea Clutter Amplitude Using AIC

The design of a CFAR depends on a knowledge of various amplitude distributions of the clutter. To this end, we discuss the Akaike Information Criterion (AIC)[7] which is a rigorous fit to the distribution to the data.

Considering two or more hypothetical probability distribution models, we have a criterion by which the model gives an optimum fit to the data. This is called Akaike Information Criterion which is abbreviated by AIC. The AIC is explained as follows: First we assume that the true probability distribution (p_1, p_2, $\cdots$, p_N) is known. Here p_N is the probability that the Nth event occurs. Next we will consider a sufficiently large number of trials. Then the Nth event will occur approximately $m = Mp_N$ times. As a model, we assume the probability distribution (q_1, q_2, $\cdots$, q_N). By observing the M samples obeying this distribution, the probability W is written as

$$W = \frac{M!}{m_1!\cdots m_N!}q_1^{m_1}\cdots q_N^{m_N} \tag{4}$$

Here W is the probability that we obtain the probability distribution (m_1, m_2, $\cdots$, m_N). By taking a logarithm of both sides of Eq. (4) and dividing by M, we obtain

$$\frac{1}{M}\ln W \rightarrow B(p,\ q) = \sum p_n \ln\left(\frac{q_n}{p_n}\right) \tag{5}$$

where $B(p,\ q)$ is called the Kullback-Leibler entropy[7]. From the above discussion, the probability is that the predicted distribution realized becomes large with larger values of B. In this sense, B is used as a model estimation, i.e. the lager values of B mean a good model.

The Kullback-Leibler entropy is rewritten as

$$B = \sum p_n \ln q_n - \sum p_n \ln p_n \tag{6}$$

The second term on the right-hand side depends only on a true distribution. Therefore, only the first term plays an important role in estimating the model. This term is interpreted as an expected value of $\ln(q_n)$. Therefore, the first term is estimated from the M numbers of the observed values x_1, x_2, $\cdots$, x_M. Then the logarithmic likelihood L is defined as

$$L = \sum \ln\{f(x_N)\}, \quad f(x_k) = q_N \text{ for } x_k = N \tag{7}$$

Here a function $f(x)$ is a probability that the observed values are x, and depends on the model. The larger L is the better model. Now we assume that the probability density function $f(x)$ has parameter θ. Then we can write the probability density function model as $f(x:\theta)$ for a stochastic variable x and parameter θ. If θ have k numbers of parameter, then θ are k-dimensional vectors. In this case, the logarithmic likelihood $L(\theta)$ is defined as

$$L(\theta) = \sum \ln f(x:\theta) \tag{8}$$

Equation (7) is determined from the observed values. However, if $f^*(x)$ is a true probability density function, then the true logarithmic likelihood is written as

$$L^*(\theta) = M\int f^*(x)\ln f(x:\theta)dx \tag{9}$$

Usually, $L^*(\theta)$ cannot be calculated, as long as the true probability density function is not known. However, it is known that $L(\theta_0) - k$ is an unbiased estimation of the logarithmic likelihood $L^*(\theta_0)$. Here θ_0 is the maximum likelihood estimation to obtain the largest $L(\theta)$. Therefore, finally, the AIC for a given model is defined as

$$\begin{aligned} \text{AIC} &= -2[\{\text{maximum logarithmic likelihood}\} - \{\text{number of parameter included in the model}\}] \\ &= -2\{L(\theta_0) - k\} \end{aligned} \tag{10}$$

The model which yields the smallest AIC is regarded as the best one. Next we will apply this AIC to the sea clutter data.

We investigated the log-normal, log-Weibull, and K-distributions using this AIC. We have found that sea clutter obeys a log-Weibull distribution. Two examples for range sweep numbers 200-207 and 240-247 are shown in Figs. 2 and 3.

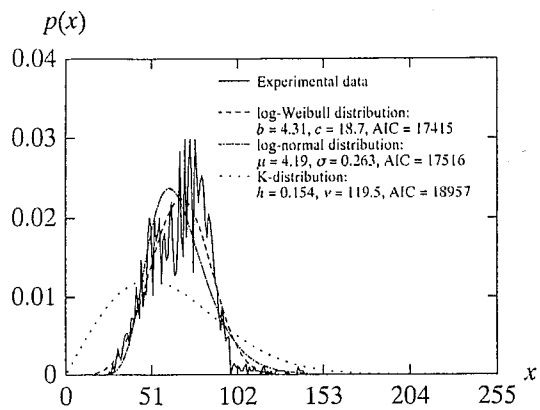

Fig. 2 AIC value of the difference between log-normal and log-Weibull distributions is the smallest.

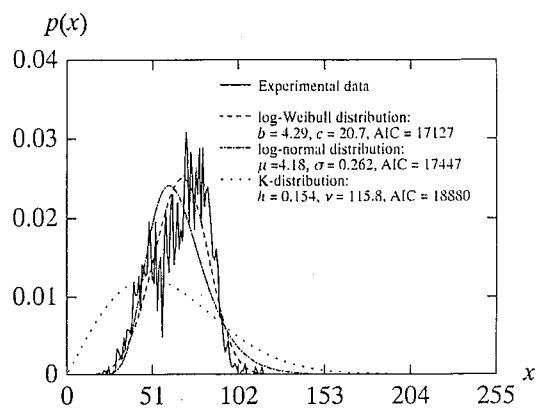

Fig. 3 AIC value of the difference between log-normal and log-Weibull distributions is the largest.

5. Suppression of Sea Clutter and Detection of Target

To maintain a CFAR in log-Weibull distributed sea clutter, we transform $\left(\frac{\ln x}{b}\right)^c \to z^m$ in Eq.(2). Then we obtain

$$p(z) = mz^{m-1}e^{-z^m} \tag{11}$$

where m is a constant. For $m = 2$, we applied our method to the raw data in Fig. 1 and obtained the processing result shown in Fig. 4, after setting a threshold level. The false alarm probability is $P_N = 4.3\times10^{-3}$ and the detection probability is $P_D = 57\%$.

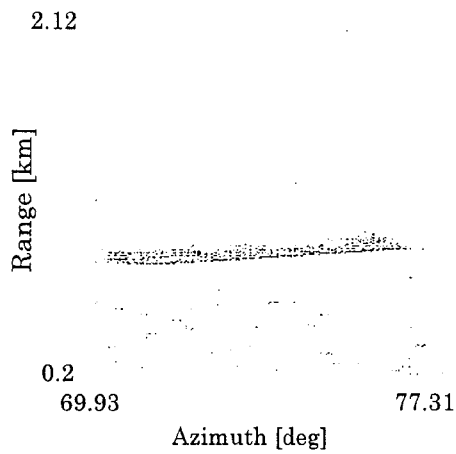

Fig. 4 Result in CFAR processing

6. Conclusions

Measurements of sea clutter have been reported using an X-band radar. It has been shown that sea clutter obeys a log-Weibull distribution. By applying log-Weibull/CFAR, sea clutter has been suppressed and a target has been detected.

References

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