Paper

Detection of Aircraft Embedded in Ground Clutter by Means of Non-Doppler Radar

Shuji Sayama* Member
Matsuo Sekine* Member

The Moving Target Indicator (MTI) is usually utilized in order to detect the moving targets embedded in ground clutter. Coherent Doppler radar is used for the typical MTI. As an alternative, we investigate an area MTI using a non-Doppler radar. The area MTI is defined as scan-to-scan cancellation, that is, the observed area is subtracted from scan to scan. This time, we observed an aircraft embedded in ground clutter at Niigata airport by using an X-band non-Doppler radar. It is shown that the amplitude statistics after scan-to-scan cancellation obey a Weibull distribution. To suppress such ground clutter, we apply a noble Constant False Alarm Rate (CFAR) method. An improvement value of target-to-clutter ratio 18.95dB was obtained.

Keywords: area MTI, ground clutter, X-band non-Doppler radar, Weibull distribution, CFAR

1. Introduction

In radar signal processing [(1)], an important problem is the suppression of the various clutter reflected from the ground, sea, sea ice and rain clouds, and the detection of targets, such as aircraft or ships immersed in such clutter. In order to improve detectability in the presence of such clutter, various anticlutter techniques have been utilized. For example, an MTI (Moving Target Indicator) is used against ground clutter [(2)], and the LOG/CFAR (Logarithmic/Constant False Alarm Rate) system is used against Rayleigh-distributed sea and weather clutter having a large dynamic range [(3)]. However, recently, non-Rayleigh distributed clutter has been observed with relatively high-resolution radars. For example, ground [(4)~(7)], sea [(8)~(10)], sea ice [(11)] and weather clutter [(12)] amplitude statistics obey a Weibull distribution, which incorporates the Rayleigh distribution as a special case. Thus, recently, there has been a continuing great interest in various Weibull-distributed clutter. If various clutter obey a Weibull distribution, perfect suppression of the clutter cannot be attained by using the conventional cell-averaging LOG/CFAR system, since the output clutter level is dependent on the variance and hence depends on the shape parameter of the Weibull distribution. To suppress such Weibull-distributed clutter, a new method has been considered [(13)~(16)]. In this paper, an adaptive new Weibull CFAR detector is investigated and applied to the real Weibull-distributed ground clutter after an area MTI.

* Department of Communications Engineering, National Defense Academy
1–10–20, Hashirimizu, Yokosuka 239–8686

2. Observations of Ground Clutter and Targets

Ground clutter was measured at Niigata airport. The area covered from 0.0° to 27.6° (range sweep numbers 0–329) in the azimuth direction and from 2.2km to 4.6km long in the radial direction. The radar characteristics are shown in Table 1.

A data sampling system is illustrated in Fig. 1. The A/D converter digitizes the video-signal in 8 bits. The data are transferred to the following 64kByte×4 DRAM Memory Block. Blocks of "azimuth control unit" and "control block" in this diagram are for angular controlling and for specifying a radial distance of the area of interest by "trigger" from the radar. "Memory management block" is for generating memory address and writing the A/D converted data into internal memory in succession. Sampled data are transferred to a floppy disk through a multi bus and a 16-bit personal computer. Figures 2 and 3 show the amplitude against the azimuth and radial directions with and without an aircraft, respectively. Figure 4 illustrates an area MTI by subtraction from map of Fig. 2 to map of Fig. 3. It is easily seen that an aircraft is detected. In the following, we will investigate the suppression of residue after an

Table 1. Radar parameters

radar	X-band radar
transmitted power (peak)	53 kW
frequency	9,380 MHz
anntenna beamwidth	
holizontal	0.6°
vertical	20.0°
pulsewidth	0.25 μs
pulse-repetition frequency	1 kHz
antenna scan rate	18 rpm
intermediate frequency	60 MHz

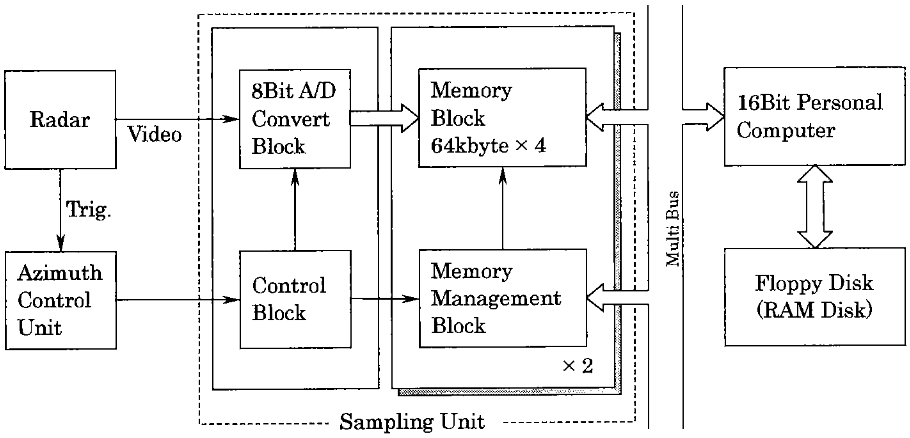

Fig. 1. Data sampling system block diagram

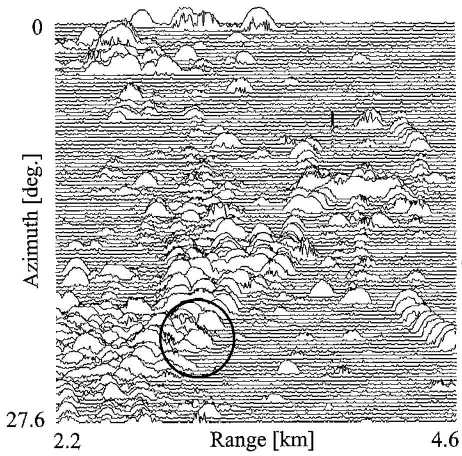

Fig. 2. Amplitude against azimuth and radial directions with an aircraft. Circle means an aircraft

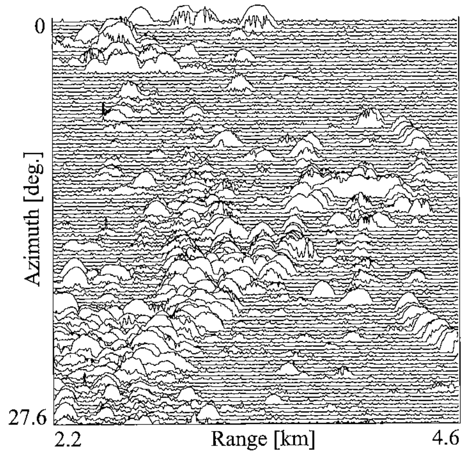

Fig. 3. Amplitude against azimuth and radial directions without an aircraft

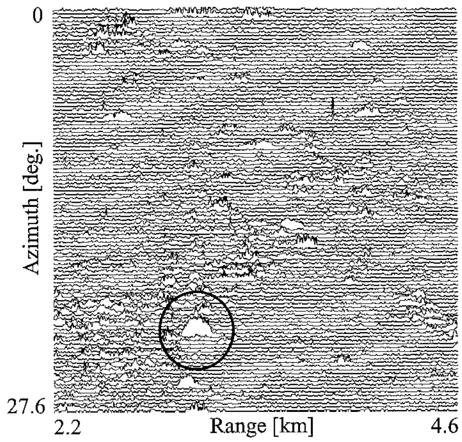

Fig. 4. Processing result after an area MTI. Circle means an aircraft

area MTI.

3. Amplitude Statistics of Residue of Ground Clutter after Area MTI

First, we shall investigate the statistical amplitude properties of the residue of ground clutter after the area MTI. To this end, we consider the Weibull distribution. The probability density function of the Weibull distribution is given by

$$p_c(x) = \begin{cases} \dfrac{c}{b}\left(\dfrac{x}{b}\right)^{c-1} \exp\left[-\left(\dfrac{x}{b}\right)^{c}\right] \\ \qquad (b>0,\ c>0,\ x>0) \\ 0 \quad \text{otherwise} \end{cases} \quad \cdots\cdots\cdots (1)$$

where x is the amplitude of clutter, b is a scale parameter and c is a shape parameter. For $c=1$ and 2, this distribution is identical to an exponential distribution and a Rayleigh distribution, respectively.

In terms of new variables X and Y defined below, the Weibull distribution Eq. (1) gives a linear relation between X and Y:

$$\left.\begin{aligned} X &= \ln(x) \\ Y &= \ln\left\{-\ln\left(1-\int_0^x p_c(x)\,dx\right)\right\} \end{aligned}\right\} \cdots (2)$$

To determine the shape parameters of Weibull distributed ground clutter in the temporal and small scale range fluctuations with which a constant false alarm rate (CFAR) is concerned, we picked out a sample area of 6 range sweep numbers corresponding to the beamwidth of 0.6°. Four examples for various range sweep numbers are shown in Figs. 5∼8.

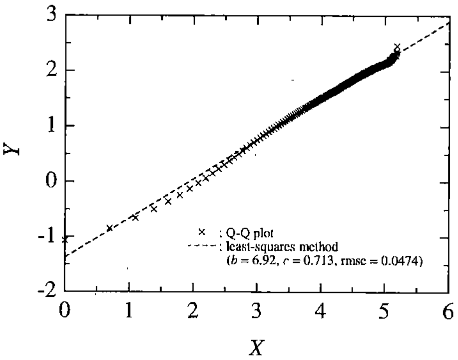

Fig. 5. Determination of parameter b and c in range sweep 0–329

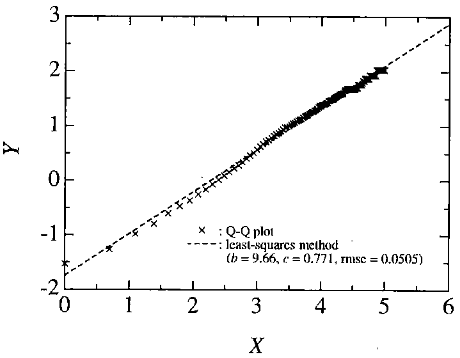

Fig. 6. Determination of parameter b and c in range sweep 204–209

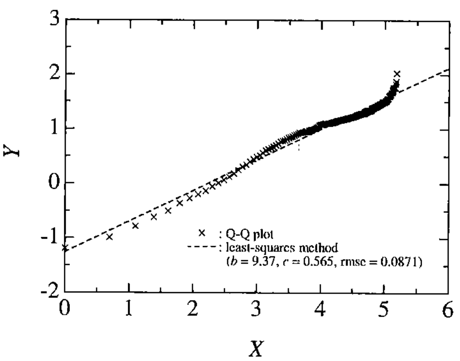

Fig. 7. Determination of parameter b and c in range sweep 254–259

A straight line was fitted to the values of Y and X by the least-squares method. If the data follow a Weibull distribution, they lie on a straight line in this representation, and the slope gives the shape parameter. This method is called Q-Q plot. The root mean square error (rmse) is the deviation of the data points from the straight line drawn by the least-squares method. The values of shape and scale parameters over range sweep numbers 0–329 are summarized in Fig. 9.

There results show that the residue amplitude after the area MTI obey a Weibull distribution with shape parameters of $c = 0.565$ to 0.887. In the following, we shall consider the Weibull/CFAR processor.

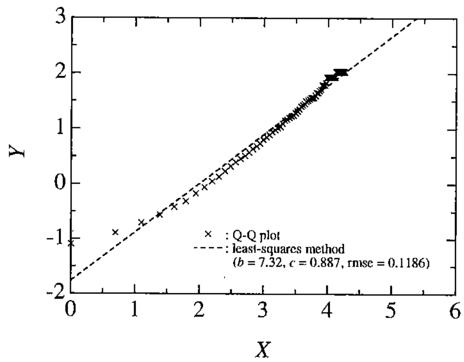

Fig. 8. Determination of parameter b and c in range sweep 312–317

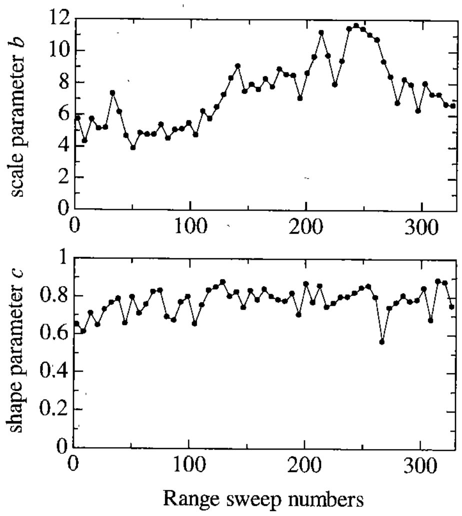

Fig. 9. Shape and scale parameters for different range sweep numbers

4. Suppression of Weibull Distributed Ground Clutter

To maintain a CFAR in Weibull clutter, for example, Goldstein [13] proposed the log-t detector, which requires a logarithmic detector of the mean and standard deviation of the logarithm of the input clutter sample. Hansen [14] has proposed a Weibull CFAR detector that takes into account the nonlinear transformation from the Weibull to the exponential probability density function. In this case, it is necessary to determine two Weibull parameters, the shape and the scale, by using a finite number of data samples passed through a logarithmic amplifier. An adaptive CFAR system has also been considered by the present authors [15][16]. This is based on a threshold level determining from the calculated output variance, and using this threshold level, it is possible to maintain CFAR for various clutter that follow the Weibull distribution.

The above proposed four Weibull CFARs requires the determination of the Weibull parameters before setting the threshold level. On the other hand, our newly proposed Weibull CFAR is based on the threshold level setting from the moment expansion and it is not necessary to determine the Weibull parameters to maintain CFAR. Here we consider maintaining CFAR for different shape parameters of the Weibull distribution.

If the input signal voltage x, distributed according to the Weibull distribution shown in Eq. (1), is passed through an idealized logarithmic amplifier, then the output y is represented by

$$y = k\ln(lx) \quad (k,\ l:\ \text{constant}). \quad \cdots\cdots\cdots\cdots (3)$$

The mean value of y is

$$\langle y\rangle = k\ln(lb) - \frac{k}{c}\gamma \quad \cdots\cdots\cdots\cdots (4)$$

where γ is Euler's constant, which is equal to $\gamma = 0.5772\cdots$. We define v as

$$v = y - \langle y\rangle \quad \cdots\cdots\cdots\cdots (5)$$

and z as

$$z = me^{nv} \quad (m,\ n:\ \text{constant}). \quad \cdots\cdots\cdots\cdots (6)$$

Substituting Eqs. (3), (4) and (5) into Eq. (6), we obtain

$$z = m\frac{x}{b}e^{\frac{\gamma}{c}}. \quad \cdots\cdots\cdots\cdots (7)$$

Here we used the relation $kn = 1$. Thus, after passing through an anti-logarithmic amplifier, the J th moment of the output signal is written as follows:

$$\langle z^J\rangle = m^J \exp\left(\frac{J}{c}\gamma\right)\Gamma\left(\frac{J}{c}+1\right), \quad \cdots\cdots\cdots\cdots (8)$$

where Γ is the gamma function. The false alarm probability p_{fa} is the probability that a clutter signal above the threshold T is misjudged as a target signal and it is given by

$$p_{fa} = \int_T^{\infty} p(z)\,dz = \exp[-(T/me^{\gamma/c})^c] \quad \cdots\cdots (9)$$

We now put the threshold level T as

$$T = \sum_{J=1}^{R} a_J[\langle z^J\rangle]^{1/J}, \quad \cdots\cdots\cdots\cdots (10)$$

where a_J are constants and R is a number of a_J. From Eqs. (8), (9) and (10), we obtain

$$p_{fa} = \exp\left(-\left[\sum_{J=1}^{R} a_J\left\{\Gamma\left(\frac{J}{c}+1\right)\right\}^{1/J}\right]^c\right). \quad \cdots\cdots\cdots\cdots (11)$$

To maintain a CFAR in observed Weibull clutter [4] from the shape parameters $c = 0.5$ to $c = 2$, the false alarm probability p_{fa} in Eq. (11) must be constant for $c = 0.5$ to $c = 2.0$. To obtain such constant values from $c = 0.5$ to $c = 2.0$ for various p_{fa}, we found the constants a_J in Eq. (11) by computer simulation. Thus, by determining the constants a_J, we can obtain the constant false alarm p_{fa}, independently of the shape parameter c.

To maintain CFAR, a computer simulation was made for four constants a_J. A finite number of samples $N = 32$ was considered. An Example of p_{fa} versus c is shown in Fig. 10.

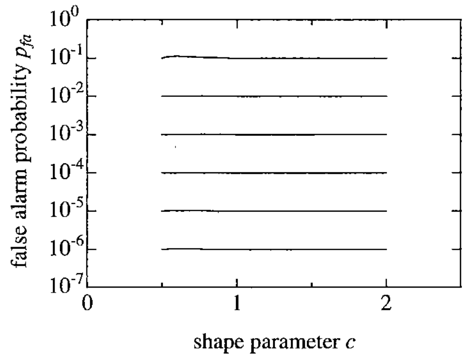

Fig. 10. p_{fa} versus c for four parameters a_1, a_2, a_3 and a_4

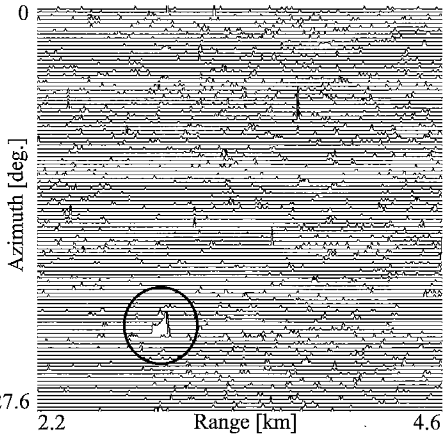

Fig. 11. The result of Weibull CFAR for $p_{fa} = 10^{-1}$. Circle means an aircraft

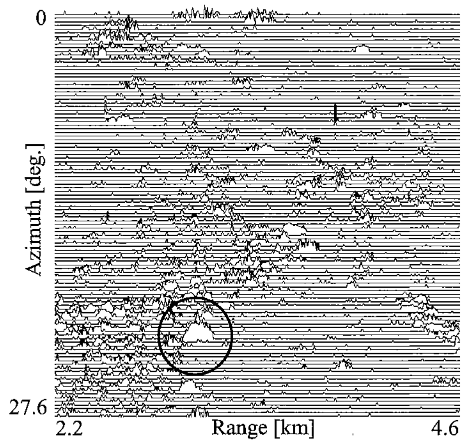

Fig. 12. The result of the conventional detection method for $p_{fa} = 10^{-1}$. Circle means an aircraft

Table 2. Numerical values of four parameters

p_{fa}	a_1	a_2	a_3	a_4
10^{-1}	-19.7798	56.3313	-51.5012	16.2657
10^{-2}	-13.4644	25.8685	-14.9536	3.91194
10^{-3}	3.89492	-30.7555	40.1210	-11.9262
10^{-4}	19.5258	-73.6396	72.6980	-17.2925
10^{-5}	27.3573	-83.9486	63.4808	-5.63650
10^{-6}	23.8588	-50.7647	1.30352	26.8281

If we consider the three parameters a_1, a_2 and a_3, then p_{fa} is not constant for various shape parameters from $c = 0.5$ to $c = 2$. Furthermore, if we consider more five, six parameters than four parameters, we obtain the same result as the four parameters. Thus we considered the four parameters a_1, a_2, a_3 and a_4.

Numerical values of four parameters using Eq. (11) are shown in Table 2. This method was applied to ground clutter data of Fig. 4 using four parameters for $p_{fa} = 10^{-1}$. The result is shown in Fig. 11. In case of Fig. 4, the Target-to-clutter ratio (T/C) was 11.36dB, while T/C in Fig. 11 was 30.21dB. Thus, we obtained 18.95dB improvement. If we consider the conventional detection method by determining the threshold level for $p_{fa} = 10^{-1}$ in Fig. 4. This is shown in Fig. 12. Then we obtain T/C = 20.77dB and 9.41dB improvement. Thus, it was concluded that our method is superior to the conventional detection method.

5. Conclusion

Measurements of ground clutter returns have been reported using a non-Doppler X-band radar. Data have been recorded by an A/D converter. It has been shown that the residual amplitude after the area MTI obeys a Weibull distribution with shape parameters from $c =$ 0.565 to 0.887. By applying the Weibull CFAR after the area MTI, the unsuppressed residual ground clutter was suppressed with the improvement of 18.95dB.

(Manuscript received March 18, 2003,
revised June 9, 2003)

References

(1) M. Sekine: Radar Signal Processing Techniques, The Institute of Electronics, Information and Communication Engineers, Tokyo, Japan (1991) (in Japanese)

(2) M.L. Skolnik: Introduction to Radar System, McGraw-Hill, New York (1980)

(3) J. Croney: "Clutter on radar displays," *Wireless Eng.*, Vol.33, pp.83–96 (1956)

(4) M. Sekine and Y. Mao: "Weibull Radar Clutter," IEE Radar, Sonar, Navigation and Avionics Series 3, London (1990)

(5) M. Sekine, S. Ohtani, T. Musha, T. Irabu, E. Kiuchi, T. Hagisawa, and Y. Tomita: "Weibull-distributed ground clutter," *IEEE Trans. Aerosp. & Electron. Syst.*, Vol.AES-17, No.4, pp.596–598 (1981)

(6) M. Sekine, S. Ohtani, T. Musha, T. Irabu, E. Kiuchi, T. Hagisawa, and, Y. Tomita: "MTI processing and Weibull-distributed ground clutter," *IEEE Trans. Aerosp. & Electron. Syst.*, Vol.AES-18, No.4, pp.729–730 (1982)

(7) S. Sayama and M. Sekine: "Weibull, log-Weibull and K-distributed ground clutter modeling analyzed by AIC," *IEEE Trans. Aerosp. & Electron. Syst.*, Vol.AES-37, No.3, pp.1108–1113 (2001)

(8) D.C. Schleher: "Radar detection in Weibull clutter," *IEEE Trans. Aerosp. & Electron. Syst.*, Vol.AES-12, No.6, pp.736–743 (1976)

(9) D.K. Barton: Radar Clutter, Artech House, Dedham, Massachusetts (1975)

(10) M.W. Long: Radar Reflectivity of Land and Sea, Artech House, Dedham, Massachusetts (1983)

(11) H. Ogawa, M. Sekine, T. Musha, M. Aota, and M. Ohi: "Weibull-distributed radar clutter reflected from sea ice," *IEICE Trans. Commun.*, Vol.E70-E, No.2, pp.116-120 (1987)

(12) M. Sekine, T. Musha, Y. Tomita, T. Hagisawa, T. Irabu, and E. Kiuchi: "On Weibull-distributed weather clutter," *IEEE Trans. Aerosp. & Electron. Syst.*, Vol.AES-15, No.6, pp.824–830 (1979)

(13) G.B. Goldstein: "False-alarm regulation in log-normal and Weibull clutter," *IEEE Trans. Aerosp. & Electron. Syst.*, Vol.AES-9, No.1, pp.84–92 (1973)

(14) V.G. Hansen: "Constant false alarm rate processing in search radars," in "Radar—present and future," IEE Conference Publication, Vol.105, pp.325–332 (1973)

(15) M. Sekine, T. Musha, Y. Tomita, and T. Irabu: "Suppression of Weibull-distributed clutters using a cell-averaging LOG/CFAR receiver," *IEEE Trans. Aerosp. & Electron. Syst.*, Vol.AES-14, No.4, pp.823–826 (1978)

(16) M. Sekine, T. Musha, Y. Tomita, T. Hagisawa, T. Irabu, and E. Kiuchi: "Suppression of Weibull-distributed weather clutter," Proc. of the IEEE International Radar Conference, pp.294–298 (1980)

Shuji Sayama (Member) received the B.S. degree from Tokyo Institute of Technology in 1992, and the M.S. and Ph.D. degree in Engineering from the same institute in 1994 and 1997. He is now an Associate Professor at National Defense Academy, Japan. He has been engaged in research on radar signal processing.

Matsuo Sekine (Member) received the Dr.Sci. degree in Elementary Particle Physics from Tokyo Institute of Technology in 1970. Since 1970, he has been engaged in research on quantum electrodynamics, electromagnetic field theory, radar and signal processing, and applications of superconductivity to microwave technology. From 1981-1982 he worked at the Department of Applied Electronics, Lund Institute of Technology, Sweden as a Visiting Professor, and in 1988 was with the Department of Electromagnetic Theory of the Royal Institute of Technology, Stockholm, Sweden. Prof. Sekine is now with the Department of Communications Engineering at National Defense Academy, Japan. He is listed in the 1995 Marquis Who's Who in the World. He is a chair of IEEE Instrumentation and Measurement society, Japan Chapter.