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THE ANALYSIS OF TWO-PROFILE ENVIRONMENT GROUND CLUTTER STATISTICS MEASURED USING FORWARD SCATTER RADAR WITH VHF AND UHF BANDS

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Abstract

In this paper, a FSR two-profile environment ground clutter-measured signal with very high frequency (VHF) and ultra high frequency (UFH) at a border of dense forest and free space area are presented. Statistical distribution method is used to model the clutter signal, namely Weibull, Gamma, Log-Logistic and Log-Normal distribution. Two goodness-of-fit (GOF) tests are used to calculate the error between the amplitude of the clutter data and the statistical model, which are the root mean square error (RMSE) and chi-square (CS). At the end of this analysis, Weibull model was found to be the best fit for 64 MHz clutter signal while Gamma model is best fitted at 151 MHz carrier frequency. Another model known as Log-Logistic model fits well to a clutter signal measured with 434 MHz carrier frequency.

Keywords: FSR, VHF, UHF, Weibull, Gamma, Log-Logistic, Log-Normal, GOF, RMSE, CS

Abstrak

Di dalam kertas ini, ukuran isyarat gangguan FSR dua-profil persekitaran tanah dengan frekuensi sangat tinggi (VHF) dan frekuensi ultra tinggi (UHF) di sempadan sebuah hutan dan kawasan lapang dibentangkan. Kaedah statistik cerapan digunakan untuk model isyarat gangguan tersebut, iaitu cerapan Weibull, Gamma, Log-Logistic dan Log-Normal. Dua ujian kebaikan lekap (GOF) digunakan untuk mengira ralat antara amplitud data gangguan dan model statistik, iaitu ralat purata punca kuasa (RMSE) dan chi-square (CS). Di akhir analisis ini, model Weibull didapati lekap dengan baik untuk isyarat gangguan 64 MHz sementara model Gamma lekap dengan baik untuk isyarat gangguan 151 MHz frekuensi bawaan. Model lain yang dikenali sebagai Log-Logistic melekap dengan baik untuk data gangguan yang diukur dengan 434 MHz frekuensi bawaan.

Kata kunci: FSR, VHF, UHF; Weibull, Gamma, Log-Logistic, Log-Normal, GOF, RMSE, CS

1.0 INTRODUCTION

Forward scatter radar (FSR) with very high frequency (VHF) bands is used in target detection [1]. The application of ground FSR is normally for situational awareness [2] such as intruder's detection. The sensors are placed on the ground to detect the target that crosses the coverage area. The potential locations to place the sensor could be in the forest, seaside, free space area and border between two-profile environments.

FSR do not have an exact range resolution for the clutter to be picked up from the large surface area illuminated by the sensor, [3] which is due to the movement of vegetation or small animals. The clutter presence does not only cause errors in target detection but also bring a false alarm to the radar system [4][5]. Therefore, it is necessary to develop an approximate representation of the clutter signal for the radar users, to distinguish between target signal and clutter signal in order to improve the radar system's performance. For this case, the trees swaying due to the wind coming from the free space area causes clutter signal to the radar system.

Measured clutter signal can be described probabilistically due to the fact that it is based on an uncertainty of the environment. There are numbers of distribution models that have been used to model the clutter signal in the literature. In [6], a foliage clutter followed Log-Logistic model, measured the clutter signal using ultra-wideband (UWB) radar in a dense forest. A ground clutter was measured using air surveillance radar (ASR) was found to be fitted with Log-Normal model as shown in [7]. Weibull distribution was used to model the clutter signal measured using FSR in a dense woodland with VHF/UHF carrier frequency as reported in [8]. And in [9], the ground clutter signal was measured using FSR with UHF band where the sensor was located in a dense forest and it was found that Log-Logistic model is the best-fitted model.

Based on the previous researches, most research was dedicated to measure cluttered signal in a dense forest, due to the swaying trees in the forest. However, the wind speed in the forest that contributes towards the clutter strength is not that strong as compared to an open area or at the border of a free space area and a forest. As for open area, the clutter is not that high as compared to the border since there are no swaying trees that causes unwanted signal to the sensor. Therefore, the motivation for this analysis is to model the clutter signal measured at the border of a dense forest and a free space area using FSR with operating frequency of 64 MHz, 151 MHz (VHF band) and 434 MHz (UHF band), where it is normally being used in target detection and recognition, in a way it can improve the target detection to the radar system.

2.0 MEASUREMENT SETUP

The clutter signals were measured at Forest Research Institute Malaysia (FRIM) where it is located at Kepong, Selangor. The location was chosen due to its wide range area and no target nor human presence during the measurements. The scene of interest for the clutter measurement is at the border of a dense forest and a free space area as shown in Figure 1. The wind from the free space area sways the vegetations (leaves, branches, bushes) and caused an unwanted Doppler signature (clutter) to the baseline of the sensor where the receiver received the transmitted signal directly from the transmitter. The clutter strength can be categorized based on the speed of the winds occurred during the measurements: low (<10 km/h), medium (11-20 km/h) and strong (>21 km/h).

The sensor used to measure the clutter signal is a prototype of FSR micro-sensor network with an omni-directional antenna. There are three frequencies used for this analysis, which are 64 MHz, 151 MHz and 434 MHz. The radiated power for 64 MHz and 151 MHz were about 20 dBm while for 434 MHz was about 10 dBm. The supply range for each module is different: 4.5 V to 15 V for TX1M-64-5 transmitter and RX1M-64-5 receiver modules, 3.1 V to 15 V for LMT1-151-5 transmitter and LMR1-151-5 receiver modules, and 4.5 V to 16 V for TX2M-433-5 transmitter and RX2M-433-5 receiver modules. For this analysis, 12 V power supply is used for both transmitter and receiver modules. Figure 2 shows the measurement setup where the transmitter and receiver are positioned on the ground with a separation distance of 50 meters (a normal distance for FSR testing) [2]. The Doppler signatures captured by the receiver are then saved. Thirty data sets were collected for this analysis where the duration time for each data set was set for 20 minutes. However, only three data sets are used for each frequency in this analysis for results display purposes, representing the clutter strength respectively.

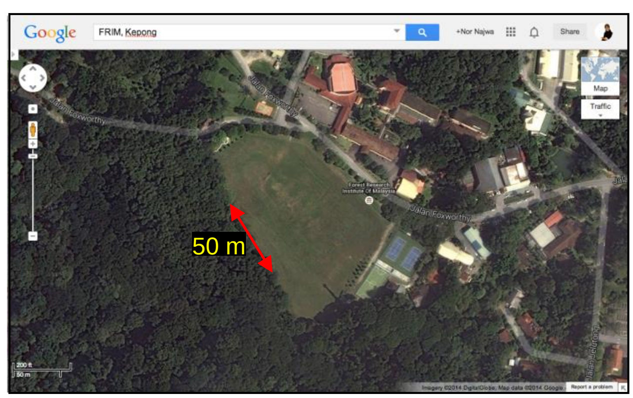


Figure 1 Scene of interest

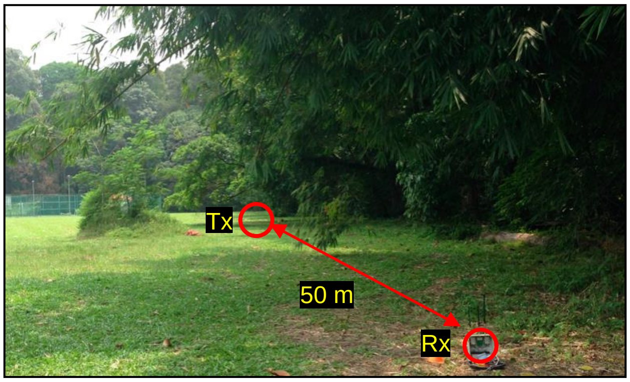


Figure 2 Measurement setup

3.0 MEASURED CLUTTER SIGNALS

The measured clutter signals for 64 MHz, 151 MHz and 434 MHz are shown in Figure 3, 4 and 5 respectively. As the clutter strength (wind speed) increases, the amplitude of the signal also increases as shown in (a) low, (b) medium, and (c) strong clutter. For every level of clutter strength, 434 MHz records the highest amplitude clutter signal followed by 151 MHz and 64 MHz. This is because the clutter amplitude depends on the carrier frequency, the fact that amplitude of a clutter signal increases proportionally to the carrier frequency as stated in [10]. As the amplitude of the clutter signal becomes higher, it will then mask the signal and caused misdetection in radar system. Therefore, a model to represents the clutter signal is needed in order to differentiate between the target signal and the clutter signal.

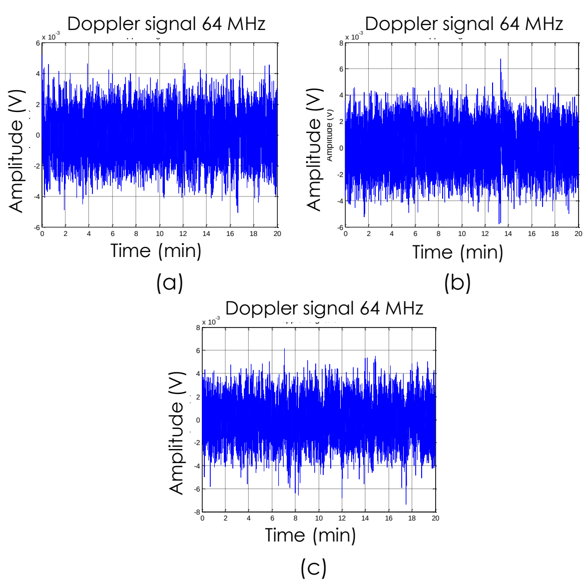


Figure 3 Doppler signal for 64 MHz with clutter strength (a) low, (b) medium, and (c) strong

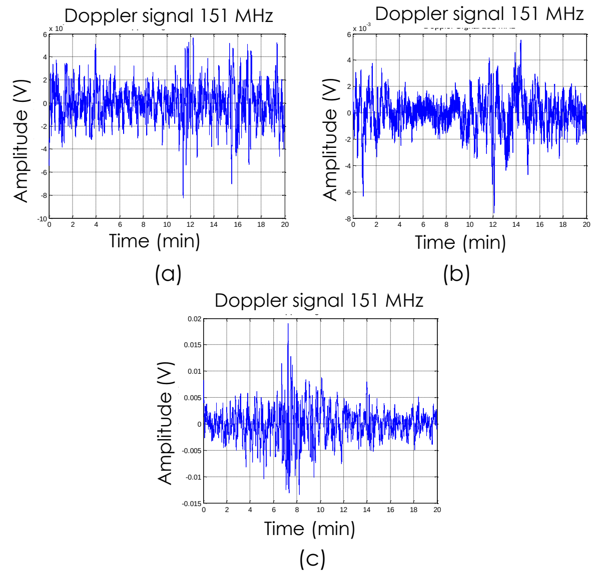


Figure 4 Doppler signal for 151 MHz with clutter strength (a) low, (b) medium, and (c) strong

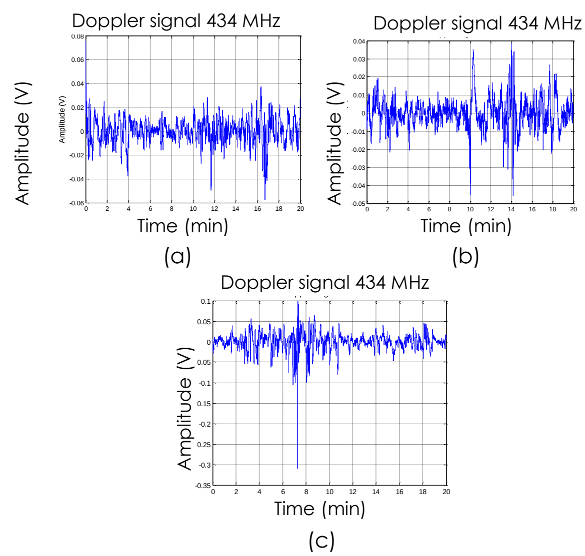


Figure 5 Doppler signal for 434 MHz with clutter strength (a) low, (b) medium, and (c) strong

4.0 PROBABILITY DISTRIBUTION FUNCTION (PDF)

This section shows the comparison between the clutter data with the distribution model in terms of the probability distribution function (PDF). The measured clutter signal is represented in a histogram form to show the probability of the clutter amplitude before the amplitude histogram is tested against the distribution models. Although there are several distribution models available in the literature, four distribution models is used in this analysis namely (a) Weibull, (b) Gamma, (c) Log-Logistic, and (d) Log-Normal, which attracted more interest among researchers.

4.1 64 MHz

Figure 6, 7 and 8 show the PDF comparisons between the clutter data of 64 MHz with the distribution models for low, medium and strong clutter respectively. From the figures, it can be clearly seen that Weibull model fits best to the clutter data for all level of clutter strength.

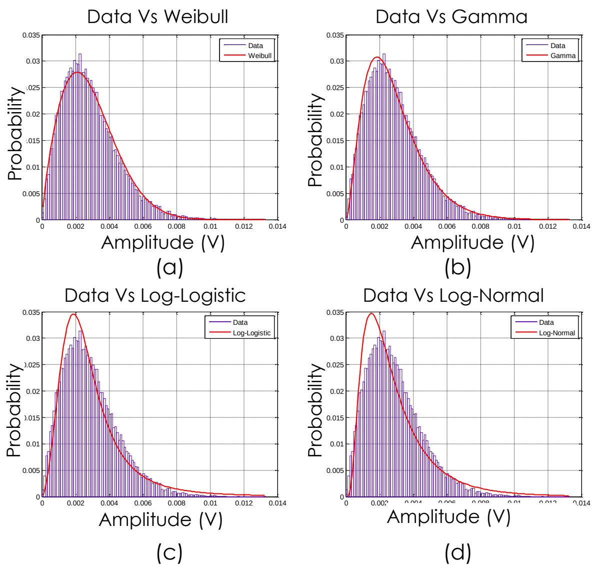


Figure 6 Distribution models for low clutter of 64 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

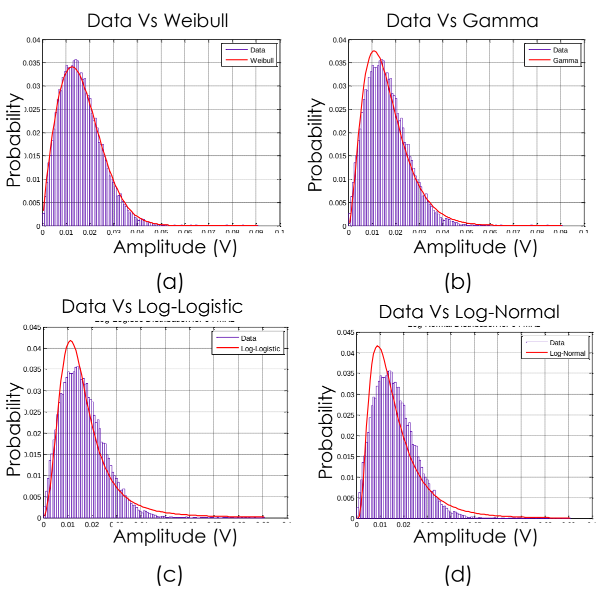


Figure 7 Distribution models for medium clutter of 64 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

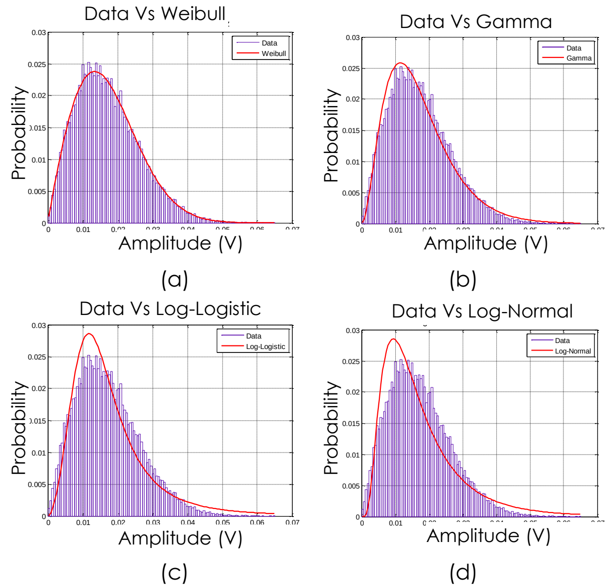


Figure 8 Distribution models for strong clutter of 64 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

4.2 151 MHz

The PDF comparisons for 151 MHz clutter signal with the distribution models for all three clutter strength; low, medium and strong clutter, are shown in Figure 9, 10 and 11 respectively. From the figures (9, 10 and 11), Gamma distribution seems to fits best the clutter data compared to the other three models.

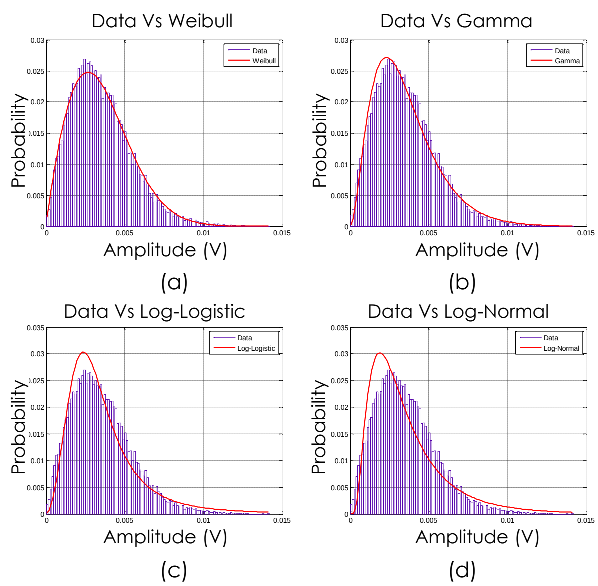


Figure 9 Distribution models for low clutter of 151 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

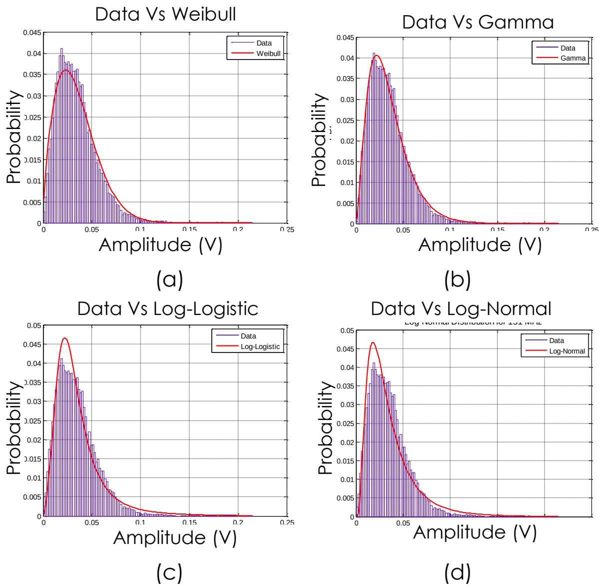


Figure 10 Distribution models for medium clutter of 151 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

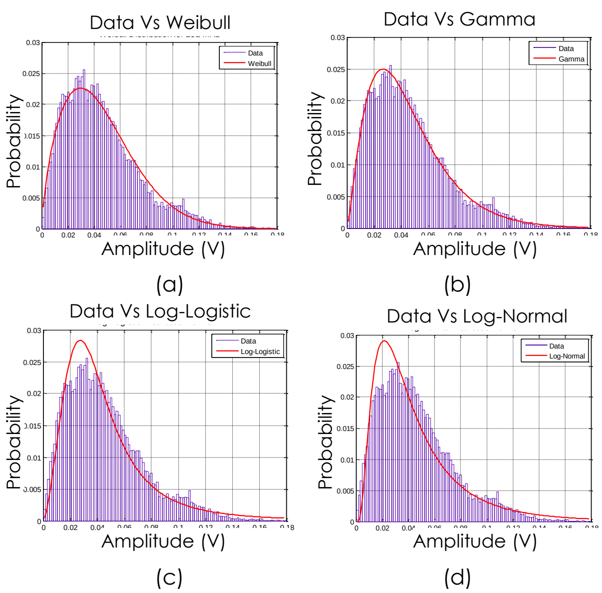


Figure 11 Distribution models for strong clutter of 151 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

4.3 434 MHz

The clutter signals of 434 MHz are compared to the distribution models and are shown in Figure 12, 13 and 14 for low, medium and strong clutter respectively. Clearly from the figures mentioned, among the four models, Log-Logistic distribution fits best the clutter data.

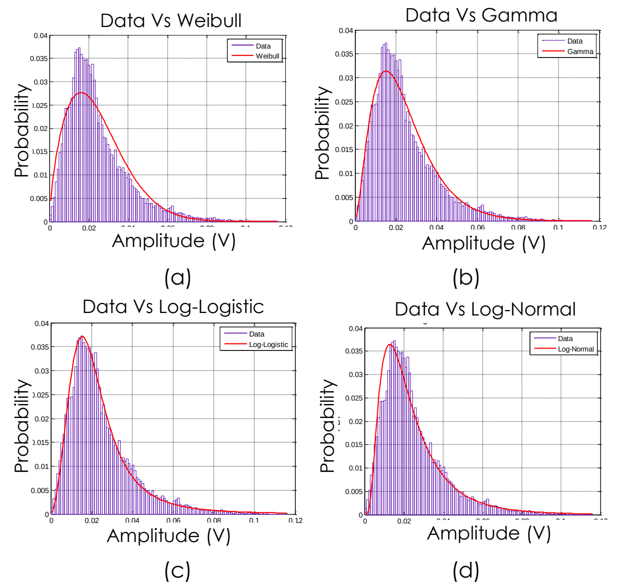


Figure 12 Distribution models for low clutter of 434 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

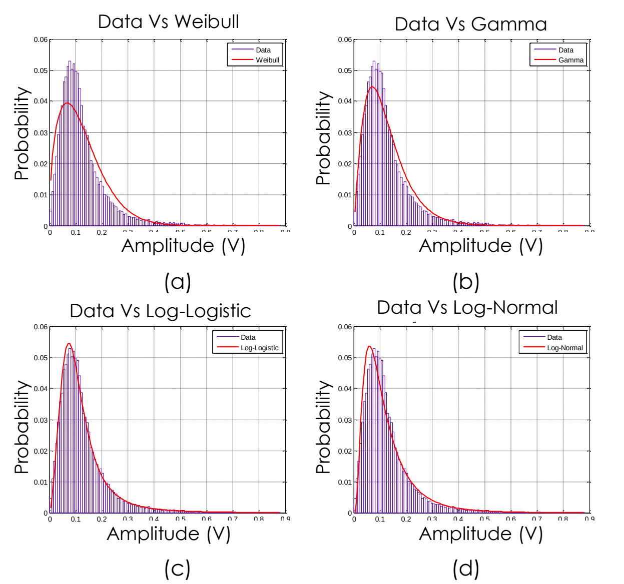
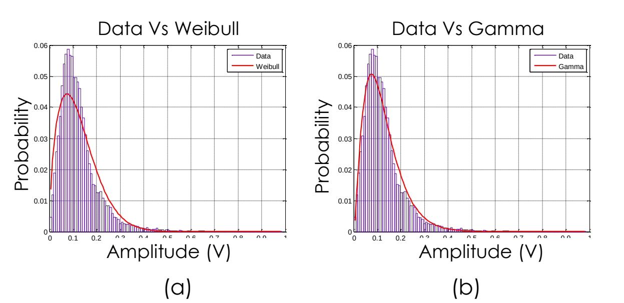
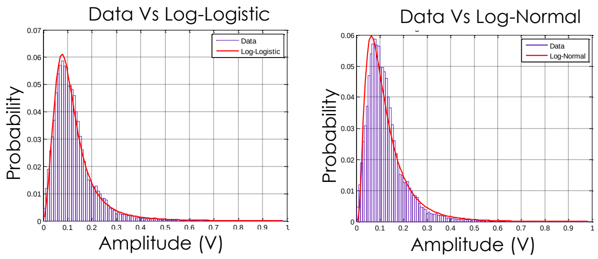


Figure 13 Distribution models for medium clutter of 434 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal





(c) (d)

Figure 14 Distribution models for strong clutter of 434 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

5.0 GOODNESS-OF-FIT (GOF) TESTS

In order to prove that the distribution model fits best to the clutter data based on the plot observation, two goodness-of-fit (GOF) tests are used in this analysis, which are root mean square error (RMSE) and chi-square (CS). The tests are vital in calculating the error between the amplitude of measured clutter data and the amplitude of statistical model. The equations for both tests are shown in Table 1.

Let *i* be the number of the sample clutter data, while *O* is the observed value which is the amplitude value for the statistical model and *E* is the expected value which is the amplitude value for the clutter data.

Table 1 GOF tests

Test	Equation
Root Mean Square Error (RMSE)	$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - E_i)^2}$
Chi-Square (CS)	$\sum_{i=1}\frac{(O_i - E_i)^2}{E_i}$

The calculated errors for clutter signal 64 MHz, 151 MHz and 434 MHz using both tests are tabulated in Table 3. From the table, the RMSE and CS values for Weibull model record the smallest error for 64 MHz clutter signal as compared to the other four models, indicating that it is the best model that fits the clutter signal. The RMSE and CS values for Gamma model shows that it was able to record the smallest error for 151 MHz clutter signal. Log-Logistic model provides the smallest RMSE and CS values for clutter signal of 434 MHz.

6.0 DISTRIBUTION MODEL PARAMETERS

To complete the statistical analysis for the measured clutter signal, the parameters for the distribution model are determined. Each model used in this analysis consists of two parameters as shown in Table 2. The calculated parameters based on its equation are tabulated in Table 3. The obtained parameters for the best-fit model are used to model the clutter signal.

Table 2 Distribution model parameters

Distribution	Equation	Parameters
Weibull	$f(x\|a,b) = \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} e^{-\left(\frac{x}{a}\right)^{b}}$	*a* = scale *b* = shape
Gamma	$f(x\|a,b) = \frac{1}{b^{a}\Gamma(a)} x^{a-1} e^{\frac{-x}{b}}$	*a* = shape *b* = scale
Log-Logistic	$f(x\|\mu,\sigma) = \frac{1}{\sigma}\frac{1}{x}\frac{e^{z}}{(1+e^{z})^{2}}$	*μ* = location *σ* = scale
Log-Normal	$f(x\|\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\left\{\frac{-(\ln x-\mu)^{2}}{2\sigma^{2}}\right\}}$	*μ* = location *σ* = scale

Table 3 Error values and estimated distribution model parameters for 64 MHz, 151 MHz and 434 MHz clutter signal

Frequency (MHz)	Clutter Strength	Distribution Models			
		Weibull	**Gamma**	**Log-Logistic**	**Log-Normal**
64	**Low**	$RMSE_W$ = 0.0007 CS_W = 0.0068 a = 0.0017 b = 1.8467	$RMSE_G$ = 0.0011 CS_G = 0.0132 a = 2.8382 b = 0.0005	$RMSE_{LL}$ = 0.0022 CS_{LL} = 0.0578 μ = -6.6385 σ = 0.3669	$RMSE_{LN}$ = 0.0029 CS_{LN} = 0.1042 μ = -6.6903 σ = 0.6688
	Medium	$RMSE_W$ = 0.0006 CS_W = 0.0047 a = 0.0019 b = 1.8401	$RMSE_G$ = 0.0012 CS_G = 0.0174 a = 2.8280 b = 0.0005	$RMSE_{LL}$ = 0.0025 CS_{LL} = 0.0726 μ = -6.5353 σ = 0.3676	$RMSE_{LN}$ = 0.0032 CS_{LN} = 0.1283 μ = -6.5883 σ = 0.6705
	Strong	$RMSE_W$ = 0.0005 CS_W = 0.0029 a = 0.0021 b = 1.9635	$RMSE_G$ = 0.0014 CS_G = 0.0217 a = 3.0598 b = 0.0006	$RMSE_{LL}$ = 0.0023 CS_{LL} = 0.0579 μ = -6.4112 σ = 0.3520	$RMSE_{LN}$ = 0.0031 CS_{LN} = 0.1121 μ = -6.4684 σ = 0.6497
151	**Low**	$RMSE_W$ = 0.0016 CS_W = 0.0270 a = 0.0021 b = 1.6580	$RMSE_G$ = 0.0012 CS_G = 0.0158 a = 2.4380 b = 0.0007	$RMSE_{LL}$ = 0.0019 CS_{LL} = 0.0456 μ = -6.4637 σ = 0.3955	$RMSE_{LN}$ = 0.0028 CS_{LN} = 0.0993 μ = -6.5111 σ = 0.7183
	Medium	$RMSE_W$ = 0.0018 CS_W = 0.0361 a = 0.0017 b = 1.5571	$RMSE_G$ = 0.0008 CS_G = 0.0089 a = 2.2488 b = 0.0006	$RMSE_{LL}$ = 0.0018 CS_{LL} = 0.0377 μ = -6.6828 σ = 0.4119	$RMSE_{LN}$ = 0.0023 CS_{LN} = 0.0664 μ = -6.7251 σ = 0.7437
	Strong	$RMSE_W$ = 0.0028 CS_W = 0.0919 a = 0.0037 b = 1.5177	$RMSE_G$ = 0.0013 CS_G = 0.0209 a = 2.2592 b = 0.0015	$RMSE_{LL}$ = 0.0014 CS_{LL} = 0.0272 μ = -5.9070 σ = 0.4040	$RMSE_{LN}$ = 0.0019 CS_{LN} = 0.0499 μ = -5.9345 σ = 0.7242
434	**Low**	$RMSE_W$ = 0.0028 CS_W = 0.0932 a = 0.0133 b = 1.5371	$RMSE_G$ = 0.0019 CS_G = 0.0408 a = 2.1659 b = 0.0055	$RMSE_{LL}$ = 0.0014 CS_{LL} = 0.0240 μ = -4.6253 σ = 0.4226	$RMSE_{LN}$ = 0.0038 CS_{LN} = 0.1857 μ = -4.6769 σ = 0.7663
	Medium	$RMSE_W$ = 0.0033 CS_W = 0.1401 a = 0.0103 b = 1.4117	$RMSE_G$ = 0.0020 CS_G = 0.0597 a = 2.0001 b = 0.0047	$RMSE_{LL}$ = 0.0012 CS_{LL} = 0.0140 μ = -4.9215 σ = 0.4296	$RMSE_{LN}$ = 0.0018 CS_{LN} = 0.0424 μ = -4.9437 σ = 0.7681
	Strong	$RMSE_W$ = 0.0047 CS_W = 0.2549 a = 0.0239 b = 1.2974	$RMSE_G$ = 0.0029 CS_G = 0.1036 a = 1.7301 b = 0.0127	$RMSE_{LL}$ = 0.0024 CS_{LL} = 0.0590 μ = -4.1010 σ = 0.4723	$RMSE_{LN}$ = 0.0030 CS_{LN} = 0.1067 μ = -4.1342 σ = 0.8391

7.0 CONCLUSION

This paper shows the analysis of the statistical distribution for ground clutter measured using a prototype of FSR Micro-Sensor Network with 64 MHz, 151 MHz (VHF) and 434 MHz (UHF). The clutter data were collected at the border of a dense forest and a free space area, where the wind from the free space area sways the trees from the forest, causing a Doppler signature to the radar system. The analysis was done with the comparison of a plotted graph between the clutter data with the distribution model curve to determine the best-fit model among the four types of distribution models used in this analysis, which are Weibull, Gamma, Log-Logistic and Log-Normal distribution. The next step was to use two GOF tests to prove the chosen distribution model by providing the smallest error value between the clutter data and the statistical model, namely RMSE and CS. At the end of the analysis, Weibull model was found to be the best-fit model for 64 MHz clutter signal for all clutter level while Gamma model is suitable to be used to represent the 151 MHz clutter signal. The clutter signal with 434 MHz operating frequency is found suitable to be represented using Log-Logistic model for all clutter level.

The chosen model with the parameters is useful in developing the clutter model where it can be used to enhance the radar performance and clutter cancellation for a better target detection.

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