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STATISTICAL ANALYSIS FOR TERENGGANU FORWARD SCATTER RADAR SEASIDE CLUTTER

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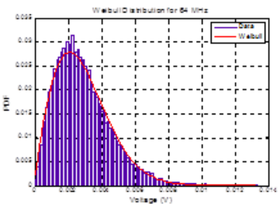
Graphical abstract



Abstract

The statistical analysis for Terengganu, Malaysia seaside clutter is presented in this paper. The measured clutter data were collected using a prototype of forward scatter radar (FSR) micro-sensor network with very high frequency (VHF) and ultra-high frequency (UHF) bands. Four categories of clutter strength were recorded during the measurements, which are low, medium, strong and very strong clutter. The classes were divided according to the wind speed occurred during the measurements period. The analysis is to determine the best-fit distribution model for the measured clutter data. Four types of distribution models are used in this analysis, which are Weibull, Gamma, Log-Logistic and Log-Normal distribution. One of the goodness of fit (GOF) tests called root mean square error (RMSE) is used to prove which distribution is a better fit to the probability distribution of the measured clutter data. The obtained results show that for 64 MHz with all clutter level strength, Weibull distribution provides better fit and records the lowest RMSE. Weibull distribution also fits best to the clutter data for low clutter of 151 MHz. However, for the rest of clutter level strength for 151 MHz, Gamma distribution is the best-fitted model with lowest RMSE values. Log-Logistic distribution proves to be the best fitted model to all clutter level strength of clutter data for 434 MHz with smallest RMSE values.

Keywords: Forward scatter radar; very high frequency; ultra-high frequency; Weibull; Gamma; Log-Logistic; Log-Normal; goodness of fit; root mean square error.

1.0 INTRODUCTION

Forward scatter radar (FSR) micro-sensor network is a special type of bistatic radar that has been used in many applications such as ground target detection [1], target classification [2], in cellular system [3], targets speed estimation [4] and radar cross-section estimation for ground targets [5]. The sensor is equipped with an omnidirectional antenna where a number of sensor pairs can creates one coverage area; the transmitter and receiver is separated with some distance and the transmitted signal is received by the neighboring sensor. The configuration is very useful especially for situational awareness purposes where the target that entering the area will cause a Doppler effect to the transmitted signals. However, since the sensors are positioned on the ground, the Doppler effect not only generated from the desired target but it also happened when there is a movement of any object from surrounding. Those unwanted effect that may interfere with normal radar operations is known as clutter [6].

With the presence of clutter in the radar operation, it will mask the useful target signal and complicates the target detection. This factor contributes to false alarm in signal detection [7][8]. In the case of FSR micro-sensor network for ground applications, vegetations may be grow near or surrounding the sensors. Therefore, the movement of swaying vegetations should be considered as a number of volume distributed scatterers to the radar system.

External signals caused by the vegetations can be described probabilistically in order to predict the performance of radar system. One of the methods is by using probability distribution function (PDF) to model the pattern of the signals [7]. The model can be used as a reference signal to differentiate between the target signals with the clutter signals. Previous studies have proven that the method is applicable to model the clutter signal for various types of clutter source. It is authentically can improve the prediction of radar performance [8-10], can be used to generate a synthetic forest clutter scene [11] and used in developing effective threshold signal detection [12].

Log-Logistic distribution was applied to model foliage clutter using ultra wide band (UWB) radar with operating frequency between 100 MHz and 3 GHz in [13]. Rayleigh, Log-Normal, Weibull and K-distribution are used to model sea clutter by the authors in [14] for Ku-band radar. Besides that, Log-Normal, Weibull and K-distribution are also have been used to model the airborne radar clutter with X-band frequency as claimed in [15]. In [16], Weibull, Log-Weibull and K-distribution are used to model clutter captured by air-route surveillance radar (ARSR) with L-band frequency.

Previous study has been done not for FSR micro-sensor network and the frequency used to operate the radar is high frequency. Furthermore, the measured clutter signals for this analysis were done in tropical seasons country where the weather conditions that caused major effects to the clutter strength are different from the temperate climate seasons country. Due to the different types of radar and operating frequency used from the previous study, the purpose of this analysis is to model a clutter data using the existing distribution models for measured clutter signal using FSR micro-sensor network with VHF and UHF bands for tropical country.

The paper is organized with the briefing of the distribution models and RMSE in Section II followed by the description of measured clutter data in Section III. Section IV discusses the results for this analysis and explains the statistical analysis of the clutter data and distribution models. Finally, Section V concludes this paper.

2.0 DISTRIBUTION MODELS AND GOF

The focus for this analysis is mainly on Weibull, Gamma, Log-Logistic and Log-Normal distribution, which attracted more interest even though there are several models available in the literature. In this section, mathematical models used to represent the samples of different clutter signals are discussed. Parameters for each model are determined based on the mathematical equation. The GOF test approach with RMSE method is used in this analysis to identify and prove which model obtained the smallest error between the clutter data and statistical model.

2.1 Distribution Models

2.1.1 Weibull Distribution

There are two parameters in Weibull distribution which are *a* is for the scale parameter while *b* is for the shape parameter. Increasing the value of *a* while holding *b* constant has the effect of stretching out the probability plot as it has the same effect on the abscissa scale while the *b* parameter is equal to the slope of the line in a probability plot.Weibull PDF is given by [17]:

$$f(x \mid a,b) = \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} e^{-\left(\frac{x}{a}\right)^{b}} \tag{1}$$

2.1.2 Gamma Distribution

This model sums of exponentially distributed random variables. The PDF of Gamma distribution is given by [17]:

$$f(x \mid a,b) = \frac{1}{b^{a}\Gamma(a)} x^{a-1} e^{\frac{-x}{b}} \tag{2}$$

where*Γ(a)* is the incomplete Gamma function. It also consists of two parameters which are *a* for the shape parameter and *b* for the scale parameter. Unlike Weibull distribution, the *a* parameter for Gamma distribution represents the slope of the plot while the *b* parameter determines the statistical dispersion of the probability plot. The larger the scale parameter, the more spread out the distribution.

2.1.3 Log-Logistric Distribution

The PDF of Log-Logistic distribution is given by [17]:

$$f(x \mid \mu,\sigma) = \frac{1}{\sigma}\frac{1}{x}\frac{e^{z}}{\left(1+e^{z}\right)^{2}} \; ; \; x > 0 \tag{3}$$

where

$$z = \frac{\log(x) - \mu}{\sigma} \tag{4}$$

The parameter for this distribution is *μ* that indicates its location and *σ* indicates its scale. The location parameter, μ, determines the shift of the distribution as if the value increases, the probability distribution function will shift rigidly to the right, maintaining the shape of the plot. The σ parameter has the same characteristic as a parameter in Weibull distribution and b parameter in Gamma distribution.

2.1.4 Log-Normal Distribution

The parameters for Log-Normal distribution is μ for the location and σ for the scale. The Log-Normal distribution is applicable when the quantity of interest must be positive, since *log(x)* exists only when *x* is positive. The PDF for Log-Normal distribution is shown as below [17]:

$$f(x|\mu,\sigma)=\frac{1}{x\sigma\sqrt{2\pi}}e^{\left\{\frac{-(\ln x-\mu)^2}{2\sigma^2}\right\}}; \quad x>0 \tag{5}$$

The characteristics for Log-Normal distribution parameters are the same as Log-Logistic distribution.

2.2 Root Mean Square Error (RMSE)

The RMSE is the value of the error between the amplitude of measured clutter data and the amplitude of statistical model. It can be obtained by using following equation:

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(c_i-\hat{c}_i\right)^2} \tag{6}$$

Let i be the number of the sample clutter data, c_i is the amplitude value for the clutter data and $\hat{c}_i$ is the amplitude value for the statistical model.

3.0 MEASURED CLUTTER DATA

The clutter data were collected at PantaiSeberangMarang, Terengganu, Malaysia using a prototype of FSR micro-sensor network with VHF and UHF bands. The location was chosen because of the wind factor where the wind coming from the sea is stronger than in town areas and forests. The operating frequencies for the sensor used to collect clutter signals are 64 MHz, 151 MHz and 434 MHz. The type of antenna used for the measurement is omnidirectional antenna where it will collect the clutter signal that surrounds the sensor. The distance between the transmitter and receiver of the sensor is 50 meters and it is located along the seaside of the sea where Rhu trees with around five meters height are the source of the clutter signal. 30 data sets have been collected but only four data sets are displayed in the results part, representing four categories of clutter strength, which are low, medium, strong and very strong clutter. The categories were divided according to the range of the wind speed during the measurements, which are 0-10 km/h, 10-15 km/h, 15-20 km/h and 20-25 km/h respectively.

4.0 RESULTS AND ANALYSIS

The results of this analysis are divided into three parts representing the operating frequencies used which are 64 MHz, 151 MHz and 434 MHz, where each frequency consists of four categories of clutter strength; low, medium, strong and very strong clutter. For each category of clutter strength, there are four types of distribution models are shown which are (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

The calculated parameters and RMSE value for all models for 64 MHz, 151 MHz and 434 MHz are tabulated in Table 1, Table 2 and Table 3 respectively.

4.1 64 MHz

Distribution models for low clutter are shown in Figure 1 whereas Figure 2 shows the distribution models for medium clutter. For strong and very strong clutter, the distribution models are shown in Figure 3 and 4 respectively. From the figures mentioned, it can be clearly seen that the Weibull distribution fits the 64 MHz clutter data perfectly in all clutter level. Gamma distribution provides a bit higher PDF amplitude at from the peak value of PDF amplitude of clutter data compared to Weibull distribution. Log-Logistic and Log-Normal distribution provide the same PDF amplitude but the highest compared to Weibull and Gamma distribution. However, Log-Normal distribution seems to be a bit shift to the left from Log-Logistic distribution.

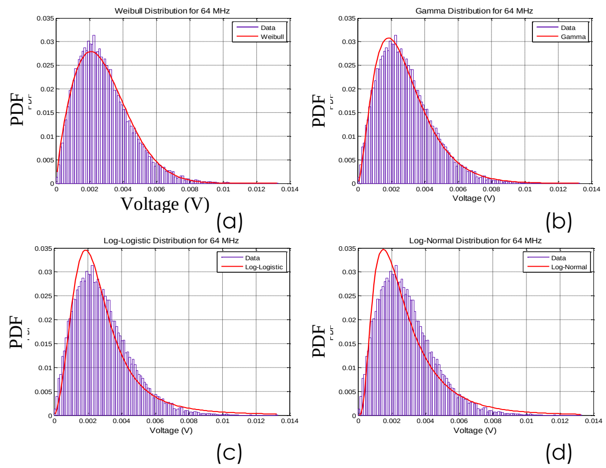


Figure 1 Distribution models for low clutter of 64 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

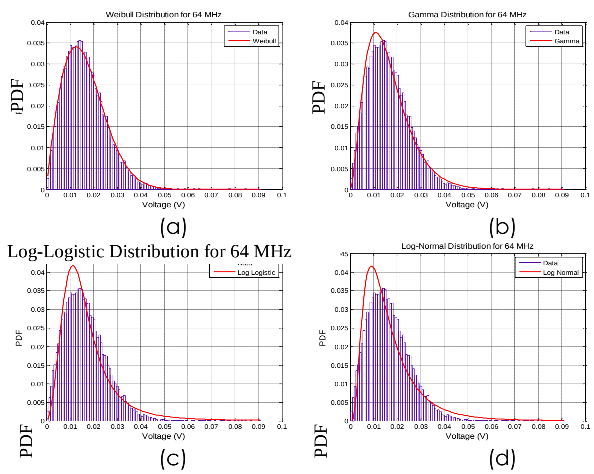


Figure 2 Distribution models for medium clutter of 64 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal

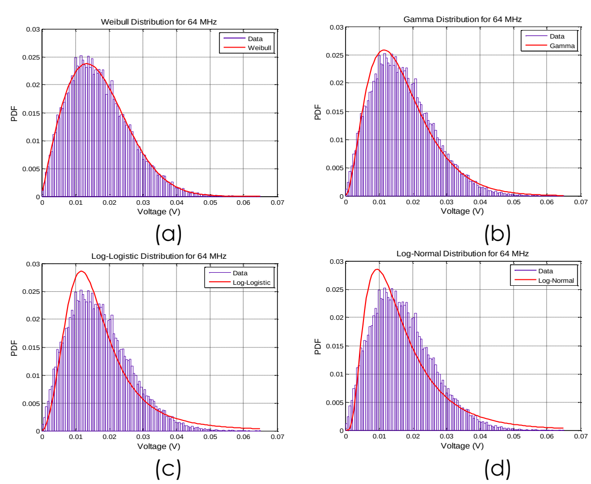


Figure 3 Distribution models for strong clutter of 64 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

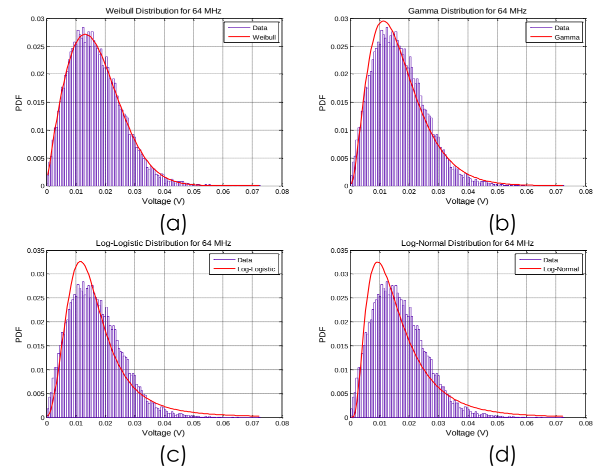


Figure 4 Distribution models for very strong clutter of 64 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

4.2 151 MHz

This part starts with distribution models for low clutter shown in Figure 5 followed by medium clutter in Figure 6. Figure 7 and Figure 8 show the distribution models for strong and very strong clutter respectively. From Figure 5, Weibull distribution seems to be the best-fitted model for low clutter of 151 MHz. Gamma, Log-Logistic and Log-Normal distribution seem to provide higher PDF amplitude from the peak of the clutter data compared to Weibull distribution. However, Figure 6, 7 and 8 show that Gamma distribution fits the clutter data compared to Weibull, Log-Logistic and Log-Normal as the Weibull distribution provides lower PDF amplitude and higher slope from the clutter data while Log-Logistic and Log-Normal provide higher PDF amplitude and lower slope.

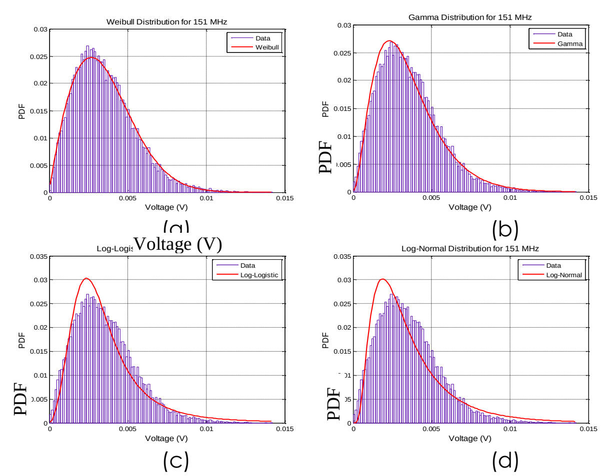


Figure 5 Distribution models for low clutter of 151 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

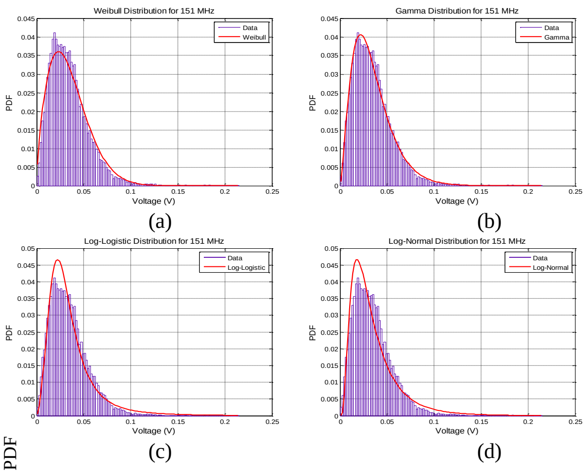


Figure 6 Distribution models for medium clutter of 151 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

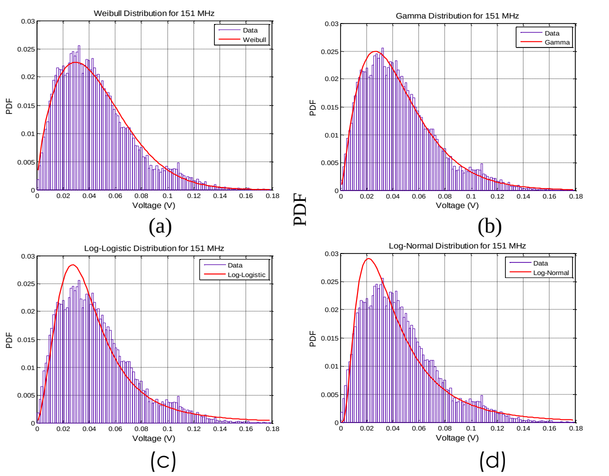


Figure 7 Distribution models for strong clutter of 151 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

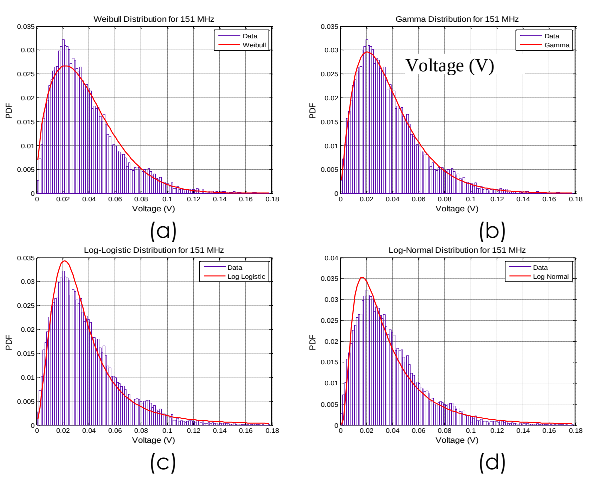


Figure 8 Distribution models for very strong clutter of 151 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

4.3 434 MHz

The distribution models for 434 MHz clutter data with low, medium, strong and very strong clutter levels are shown in Figure 9, 10, 11 and 12 respectively. The Log-Logistic distribution is seemed as the best-fitted model compared to Weibull, Gamma and Log-Normal distribution. Weibull and Gamma distribution provide lower PDF amplitude from the peak amplitude of clutter data and higher slope. The PDF amplitude of Log-Normal distribution is quite the same with Log-Logistic distribution. However, Log-Normal distribution seems to be a bit shifted to the left from the clutter data.

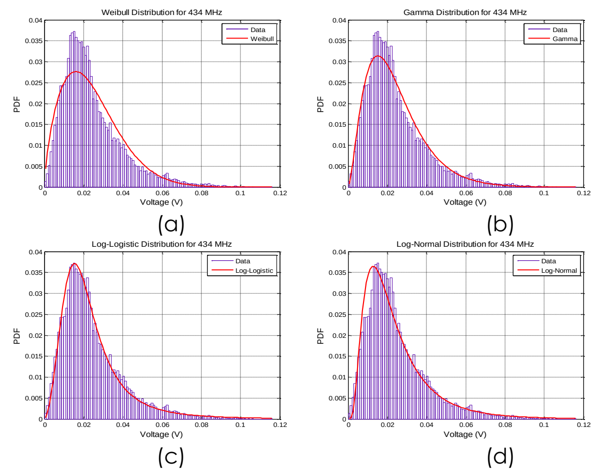


Figure 9 Distribution models for low clutter of 434 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

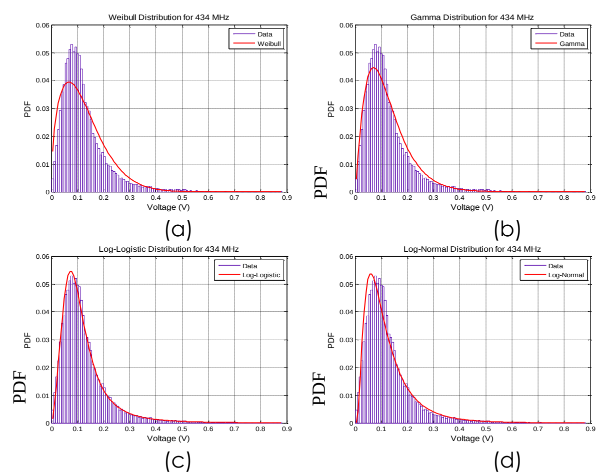


Figure 10 Distribution models for medium clutter of 434 MHz, (a)Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

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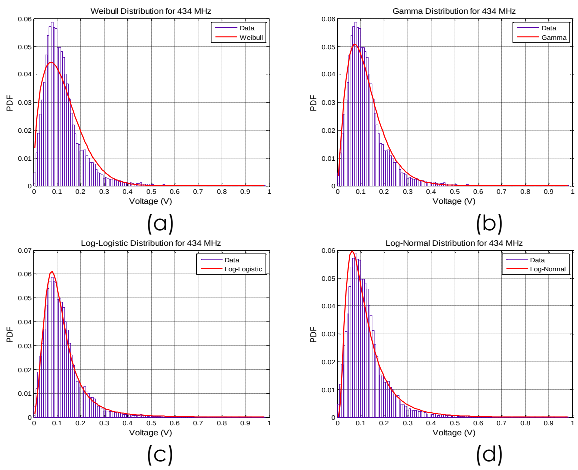

Figure 11 Distribution models for strong clutter of 434 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

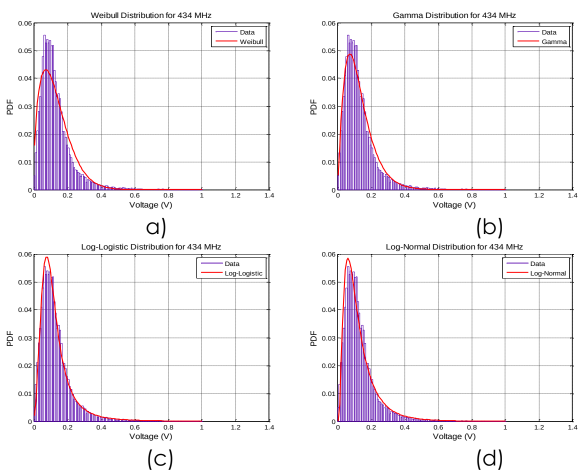

Figure 12 Distribution models for very strong clutter of 434 MHz, (a) Weibull, (b) Gamma, (c) Log-Logistic and (d) Log-Normal.

In Table 1, Weibull distribution obtains the smallest RMSE value for all 64 MHz clutter levels. Weibull distribution also records the smallest error value for low clutter with operating frequency of 151 MHz as shown in Table 2. However, for medium, strong and very strong clutter of 151 MHz, Gamma distribution records the smallest error value. Log-Logistic distribution obtains the smallest RMSE value for all four-clutter levels of 434 MHz as shown in Table 3.

Table 1 Estimated parameters and RMSE Values for 64 MHz.

Clutter Strength	Distribution Models *Weibull*	*Gamma*	*Log-Logistic*	*Log-Nornal*
Low	a = 0.0032	a = 2.8145	μ = -5.9924	μ = -6.0438
	b = 1.8325	b = 0.0010	σ = 0.3677	σ = 0.6719
	RMSE$_W$ = 0.0007	RMSE$_G$ = 0.0009	RMSE$_{LL}$ = 0.0021	RMSE$_{LN}$ = 0.0029
Medium	a = 0.0193	a = 3.0529	μ = -4.1831	μ = -4.2400
	b = 1.9606	b = 0.0056	σ = 0.3527	σ = 0.6506
	RMSE$_W$ = 0.0006	RMSE$_G$ = 0.0015	RMSE$_{LL}$ = 0.0027	RMSE$_{LN}$ = 0.0036
Strong	a = 0.0185	a = 3.0171	μ = -4.2301	μ = -4.2854
	b = 1.9116	b = 0.0054	σ = 0.3535	σ = 0.6503
	RMSE$_W$ = 0.0006	RMSE$_G$ = 0.0014	RMSE$_{LL}$ = 0.0023	RMSE$_{LN}$ = 0.0030
Very Strong	a = 0.0189	a = 3.0897	μ = -4.2026	μ = -4.2594
	b = 1.9707	b = 0.0054	σ = 0.3504	σ = 0.6450
	RMSE$_W$ = 0.0005	RMSE$_G$ = 0.0015	RMSE$_{LL}$ = 0.0025	RMSE$_{LN}$ = 0.0033

Table 2 Estimated parameters and RMSE Values for 151 MHz.

Clutter Strength	Distribution Models *Weibull*	*Gamma*	*Log-Logistic*	*Log-Nornal*
Low	a = 0.0040	a = 2.9293	μ = -5.7753	μ = -5.8313
	b = 1.8931	b = 0.0012	σ = 0.3589	σ = 0.6652
	RMSE$_W$ = 0.0007	RMSE$_G$ = 0.0013	RMSE$_{LL}$ = 0.0022	RMSE$_{LN}$ = 0.0031
Medium	a = 0.0511	a = 2.4206	μ = -3.2564	μ = -3.3091
	b = 1.6792	b = 0.0188	σ = 0.4022	σ = 0.7269
	RMSE$_W$ = 0.0017	RMSE$_G$ = 0.0011	RMSE$_{LL}$ = 0.0024	RMSE$_{LN}$ = 0.0031
Strong	a = 0.0390	a = 2.6817	μ = -3.5150	μ = -3.5597
	b = 1.7067	b = 0.0129	σ = 0.3724	σ = 0.6783
	RMSE$_W$ = 0.0011	RMSE$_G$ = 0.0009	RMSE$_{LL}$ = 0.0021	RMSE$_{LN}$ = 0.0026
Very Strong	a = 0.0421	a = 2.2389	μ = -3.4738	μ = -3.5183
	b = 1.5757	b = 0.0168	σ = 0.4172	σ = 0.7482
	RMSE$_W$ = 0.0015	RMSE$_G$ = 0.0007	RMSE$_{LL}$ = 0.0017	RMSE$_{LN}$ = 0.0023

Table 3 Estimated Parameters and RMSE Values for 434 MHz.

Clutter Strength	Distribution Models			
	Weibull	***Gamma***	***Log-Logistic***	***Log-Normal***
Low	α = 0.0273 b = 1.6889 $RMSE_W$ = 0.0030	α = 2.6842 b = 0.0090 $RMSE_G$ = 0.0018	μ = -3.8913 σ = 0.3669 $RMSE_{LL}$ = 0.0013	μ = -3.9168 σ = 0.6637 $RMSE_{LN}$ = 0.0022
Medium	α = 0.1399 b = 1.5811 $RMSE_W$ = 0.0042	α = 2.5164 b = 0.0496 $RMSE_G$ = 0.0026	μ = -2.2639 σ = 0.3720 $RMSE_{LL}$ = 0.0013	μ = -2.2923 σ = 0.6837 $RMSE_{LN}$ = 0.0030
Strong	α = 0.1388 b = 1.5075 $RMSE_W$ = 0.0041	α = 2.3220 b = 0.0536 $RMSE_G$ = 0.0024	μ = -2.2908 σ = 0.3867 $RMSE_{LL}$ = 0.0016	μ = -2.3148 σ = 0.7081 $RMSE_{LN}$ = 0.0033
Very Strong	α = 0.1452 b = 1.5185 $RMSE_W$ = 0.0038	α = 2.3259 b = 0.0559 $RMSE_G$ = 0.0022	μ = -2.2430 σ = 0.3899 $RMSE_{LL}$ = 0.0015	μ = -2.2697 σ = 0.7095 $RMSE_{LN}$ = 0.0029

4.0 CONCLUSION

The statistical analysis of Terengganu seaside clutter is presented in this paper. The measured clutter data used for the analysis were collected using a prototype of FSR micro-sensor network with three omnidirectional antennas operating in frequencies of 64 MHz, 151 MHz and 434 MHz. The purpose of the analysis is to determine the parameters value of the best-fit distribution model based on the measured clutter data. The decision was done by comparing four types of distribution models, which are Weibull, Gamma, Log-Logistic, and Log-Normal. RMSE is used to calculate the error between the clutter data and statistical model in order to prove that the chosen distribution is the best-fit model. The smallest error value indicates the best model. At the end of the analysis, it has been found that for all level of clutter strength with 64 MHz operating frequency, the distribution model that fits the clutter data with lowest RMSE is Weibull distribution. It also fits the clutter data for low clutter of 151 MHz. However, for the rest of clutter levels for 151 MHz, Gamma distribution fits best to the clutter data. Log-Logistic distribution is found to be the best-fitted model for 434 MHz clutter data for every clutter level. From the results obtained, it shows that the best fitted model changes as one changes frequency. It is because that there are differences between each frequency in terms of its amplitude probability. As the frequency higher, the clutter amplitude will increase.

The parameters obtained can be used to develop an accurate clutter model. The model is useful especially to predict the radar performance and to develop a synthetic environment.

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