CLUTTER DISTRIBUTION ANALYSIS OF A TROPICAL FOLIAGE CLUTTER FOR DIFFERENT ENVIRONMENTS BASED ON FSR MICRO-SENSOR NETWORK

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***Abstract* ---Comparison of four different environment on measuring the wind clutter using forward scatter radar (FSR) operates in ultra-high and very high frequency (UHF and VHF) bands is analyzed in this paper. Since there are four different types of environment involved comparison between those four environments concentrating on different types of clutter level ranging from low, medium, strong and very strong on each locations were studied. The pattern of wind clutter level measurement characteristics as an objective in this research is investigated and executed using distribution models at different operating frequencies as well as comparing the data distributions of four different locations to identify the best distribution model. Sample of data in form of Real Strength Signal Indicator (RSSI) signals measured is evaluated using five distributions model. This comparison justified that Border suits the best location as the strongest clutter area amidst Seaside and Free space, while Forest is determined as the lowest clutter area as the accurate distribution of clutter model. The five distributions parameters are evaluated using maximum likelihood estimation (MLE) approach followed by Goodness of Fit (GOF) method by using Root Mean Square Error (RMSE) test to prove the best distributions among the five which are Log-Normal, Log-Logistic, Gamma, Weibull and Nakagami. Gamma, Weibull and Nakagami. Gamma distribution model is discovered as the best distribution model in this research for foliage clutter for all cases of frequency bands and four environments.**

***Keywords*--- FSR, wind clutter, UHF/VHF, MLE, GOF, RMSE, radar.**

I. INTRODUCTION

Radar system which navigates through radio waves can be used to determine the velocity, movement and angle of a target. Radar configuration is divided into two types which are monostatic and bistatic radar. Monostatic radar is where the transmitter and receiver are collocated while bistatic having a considerable distance between the transmitter and receiver to expected target distance. FSR is one type of bistatic which captures signal passing through from the radar transmitter to receiver where the bistatic angle is approaching 180 degree.

Forward Scatter Radar (FSR) is one form of bistatic radar that place antennas for transmission and reception at different locations with considerable distances [1]. This type of radar operates according to Babinet's principle [2] that could detects the moving target, [3, 4] within the distance which resulting signal that much improved in forward direction. Several advantages of FSR [5, 6] lead to highly interest from researchers applied in many applications [7] such as target detection, parameter estimation, Automatic Target Classification (ATC) [8] and cellular systems [9]. FSR can detect and classify target at relatively low frequencies and used widely for ground detection. Hence it can easily being affected by the clutter.

Clutter is echoes or unwanted signal that returned from targets which usually masking real target signals thus complicates the target detection from natural environment, hence degrades the radar performance in detecting the target and worse it could give false alarm. Clutter echoes reflected from ground, trees, weather disturbances, buildings, and flocks of birds may seriously hinder the detection of targets particularly when airborne transponders fail or transmit a weak signal [10]. Clutter can be classified into three categories; a) ground clutter which is reflected from terrain, trees and buildings, b) weather clutter such **as** rain, snow, and storms, areas of dense air and others, c) seasonal clutter generated by migrating flocks of birds.

Numerous researches studied regarding the types of different clutter is found using the forward scatter radar. Paper [11] explore on rain clutter with Continuous Wave (C.W.) radar systems measurements on transmission and reception separately. Echoes received at all ranges of rain simultaneously proved that the highest contribution is near the part of radiated field that is most intense and short raindrops range, but the gap is this research is not focused on FSR system. Study of sea clutter in [12] recorded at 7.5 and 24 GHz using forward scatter radar over a range of microwave frequencies, different locations and at different sea states proved that the clutter spectrum and distribution within limited experiment conditions, range is independent on the carrier frequency, sea state and baseline distance. As sea clutter intensity depends on wind speed, there is slightly difficult in taken the measurements compared to surface clutter such as ground as it non-fluctuating, which opposite of rain or snow clutter. Therefore clutter measurement for ground target detection is studied more aside from other types of clutter.

The type of target signal usually is hardly differentiating using forward scatter radar from the surrounding signals as it affected by Doppler signature cause by change of phase that occurs from the interference of target signal and direct leakage signal navigated from transmitter to receiver [13]. The study in [14] indicated that the speed of wind affected the clutter improvement in forward scatter radar in United Kingdom (UK). As measured in operating frequency of 64, 135, 173 and 434 MHz with distances varies within 50m to 200m, the experiment carried out proved that Doppler signal amplitude increases as frequencies and distances increases, as well with escalation of wind speed strength. Therefore, based on those limitations on tropical country climates, investigation at UHF and VHF bands using forward scatter radar micro-sensor networks is explored in tropical country. Extraction of Doppler signal for modelling are represents in histograms form verified that Gamma fit best [15] compared to Log-Normal, Log-Logistic, Weibull and Nakagami. The smallest Root Mean Square Error (RMSE) is Gamma.

In this paper, the foliage clutter which may affect the FSR performance is investigated varies from open space to dense environment which involved Forest, Seaside, Border and Free Space by using Mathcad and MATLAB software for simulation of sample data significantly to investigate the different types of location's best distribution model. The experiment was carried in different locations in order to observe the clutter pattern and its characteristics. This vegetation may sways the surrounding in forms of trees, branches and etch thus contributed clutter effect to radar system placed on the ground to capture the signal. Within the transmitter and receiver that separately located on different baseline length on the ground, clutter could greatly affected the target signal thus it is required to differentiate the clutter signal from the target signal.

The significant of this research is to predict the performance of FSR in certain environment affected by the clutter's existence and besides, to estimate any alarm detected of clutter presence in various kind of different nature in measurement of radar system. Due to that, the relevancy on using FSR as a tool to determine the clutter presence in different environments lead to analysis carried out to observe its pattern of distributions to be modelled. This could improve the radar system's performance in detecting real target signal that being separated from clutter by applying a clutter model developed from the analysis. Hence, the characteristics of clutter need to be observed to attain its pattern hence develop a clutter model of the signal measured.

The approach used in modelling the foliage clutter is probability distribution function (PDF). Parameters of five different statistical distributions consists of Log-Normal, Log-Logistic, Weibull, Gamma and Nakagami will be calculated and represented in forms of histogram. As the experiment is carried out at four different locations, the gap of this research is to investigate the comparison of distributions between those different locations that will be carried out to observe its best pattern that will be used for clutter modelling.

This paper is proceed with Section II of the project methodology, follow with Section III with clutter spectral analysis regarding the characterization of the measured clutter data collection carried out on the four test sites. Section IV will discuss five statistical PDF distributions model. The GOF is explain in this section through RMSE test to prove the minimum error of the accurate distribution. Conclusion for this research is conclude in Section IV.

II. Methodology

The flow chart of this research in Figure 1 started with the literature reviews related to the project mostly focused on forward scatter radar and clutter model types that measured using forward scatter radar.

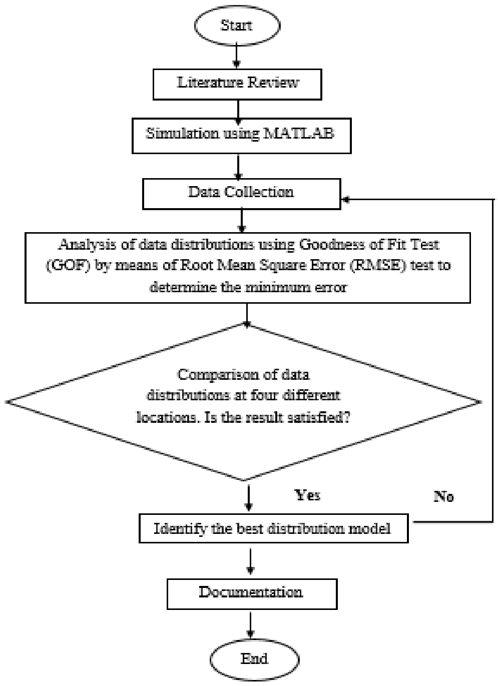


Figure 1: Flowchart of overall project

Considering the previous study, experiments have been conducted in four different test sites; measured up to 40 samples data in form of RSSI signals varies accordingly to the four sites. As referred to previous study [15], the experiments taken place at four different environments which are Seaside, Border, Forest and Free Space. Description on the environments is explained as follows; Forest is a dense planted forest as in controlled environments which means almost no target's presence. Seaside is the location nearby the beach with less existence of variable height of trees along the location. Mostly, high trees grown up in that location. Border take place between the Seaside and Forest environment with less dense of woods and nearby the sea, while for Free Space the experimental setup is done in outdoor area in this case empty parking space.

Three omnidirectional antennas for different frequencies band of 64, 151 and 434 MHz along with different sensor for each frequency, is placed in FSR prototype. The prototype is equipped with antennas and different sensor for transmitter and receiver for the signal's reception. Target signal will be captured by the sensor that positioned somewhere in those different kind of nature. For Forest-dense environment, the FSR prototype is placed under small height of trees for both transmitter and receiver within distance of 50 meters to enable the signal's reception for the three frequencies band. Compared to Border and Seaside, prototype of FSR is positioned under high trees with randomly distance from each other in less dense surroundings, in 50 meters baseline distance between the transmitter and receiver. Data samples that measured in those four locations taken up at 20 minutes for a set of complete data for 64, 151 and 434 MHz, to observe the wind clutter pattern during the measurement period. A complete set of data measured in 20 minutes allow changes of any pattern of non-stationary clutter to be detected by the prototype instead of short period of measurement.

Consequently, by using MATLAB software, simulation is carried out to perform the analysis on different sets of data measured using forward scatter radar micro-networks ranging from low, medium, strong and very strong wind strength condition. Among the four different locations, the samples of data are taken and processed using MATLAB and characterized according to their standard deviation value of each data sorted according to the four types of wind strength. The operating frequency are 64MHz, 151MHz and 434MHz as in UHF and VHF bands.

Analysis of data distributions, extracted through the RSSI into form of Doppler signal will be tested using GOF through RMSE test to determine the minimum error amidst the five distributions model. The five types of distributions model consists of Log- Normal, Gamma, Log logistic, Weibull and Nakagami distributions.

GOF method is applied to evaluate the sample data that fits several distributions model through numerical measures, as this technique concentrated on particular feature of data and compressed it into a single information or data. Through GOF [16], the parameters of distributions is calculated in observing the statistics of parametric models in this research, as five types of distributions is taken into consideration.

From the statistical data obtained from the distributions graphically, RMSE test is chosen as the suitable method in examine the best distribution model between the five forms. RMSE statistics is acknowledged as standard error for data fit and regression. Thence, estimation of random sample data by means of STD is more accurate for this research in absolute fit of measurement by RMSE, predicting the response more specifically. Lower value of RMSE indicate better fit for data distribution of different models [16].

The comparison of distributions between the four different locations will be investigated to determine the best model and location according to the tests performed. Afterward the accurate distribution model is determined, all the data and analysis will be documented in full report.

III. CLUTTER SPECTRAL ANALYSIS

The measured data taken at three different frequencies band 64 MHz, 151 MHz and 434 MHz varies at different strength of wind. Those data are categorized in groups of wind strength in accordance with their standard deviation– low, medium, strong and very strong clutter groups.

1) *Standard Deviation (STD) Error*

The square root of variance is denote as standard deviation (STD) error which determined how the values around the mean is spread out. STD is assign by equation:

$$\sigma = \sqrt{\frac{1}{N}\sum_{I=1}^{N}(x_i - \bar{\mu})^2} \tag{1}$$

Eq. 1 define population to calculate the error of STD for each distribution parameters in this analysis.

2) *Clutter Data Collections*

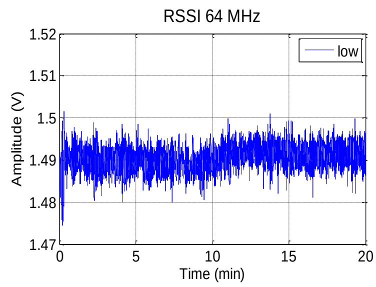
Based on previous research [15], the classification is based on wind speed level, from low, medium, strong and very strong. This method is quite imprecise to notice the difference between the four locations, due to speed of wind is taken before measurement of data started. Therefore, in this research, more accurate method by using standard deviation is preferred to organize the different strength of wind clutter.

Figure 2-5 displays the RSSI signals for the UHF and VHF frequencies measured at different four test sites with their most accurate wind strength level among all the data taken. Based on standard deviation calculation, those four different wind strength level are divided into groups of low, medium, strong and very strong.

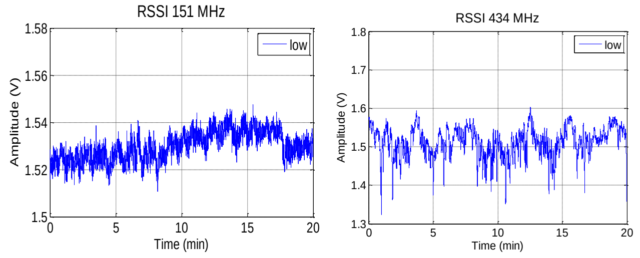
The formula calculated in dividing the clutter wind strength using STD discuss in [14] is;

$$\text{STD} = \left(\frac{\text{high STD value} - \text{low STD value}}{4}\right) + \text{Low STD value} \tag{2}$$

The result of RSSI signals are classified using this formula is shown as in Figure 2 to 5 at four test sides on different frequencies band, at low level of wind strength.

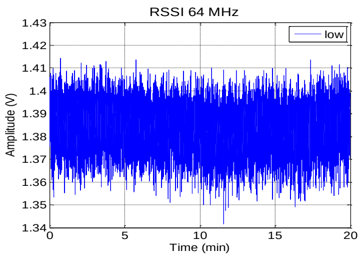


(a)

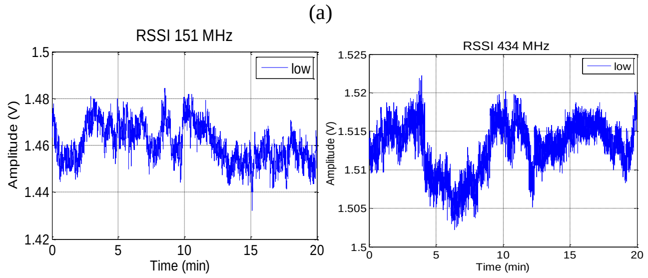


(b) (c)

Figure 2: RSSI signals for (a) 64, (b) 151 and (c) 434 MHz channel frequencies at (a) low, (b) low and (c) low clutter, at Seaside test site.

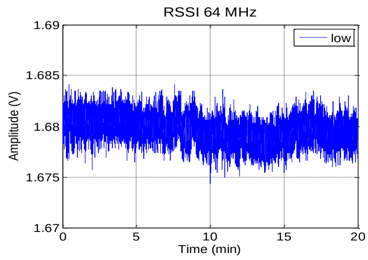


(a)

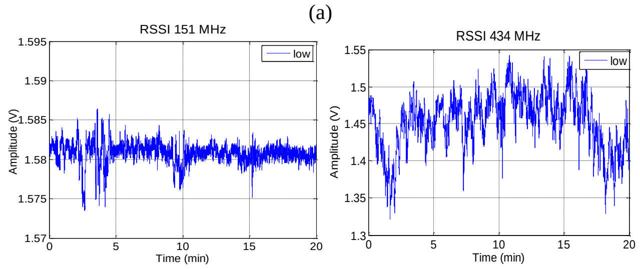


(b) (c)

Figure 3: RSSI signals for (a) 64, (b) 151 and (c) 434 MHz channel frequencies at low clutter, at Forest test site.

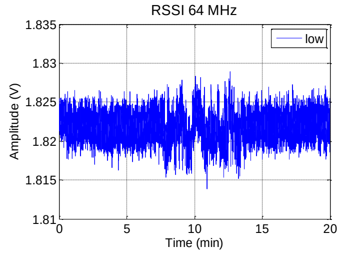


(a)

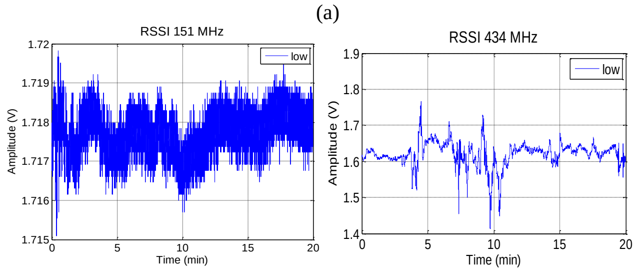


(b) (c)

Figure 4: RSSI signals for (a) 64, (b) 151 and (c) 434 MHz channel frequencies at low clutter, at Free Space test site.



(a)



(b) (c)

Figure 5: RSSI signals for (a) 64, (b) 151 and (c) 434 MHz channel frequencies at low clutter wind strength, at Border test site.

The clutter increases in amplitude as the frequency escalates from 64 to 434 MHz. Channel frequency 64 MHz represent 1.32V as lowest in Forest and 1.82V as the highest amplitude at Border, while for channel frequency 151 MHz verified the lowest and highest amplitude are 1.48V and 1.72V at Forest and Border. Contrarily, the highest amplitude is 1.79V measured at Border site for 434 MHz while the lowest is 1.523V at Forest. It can be seen there are increment in amplitude as the frequency gets higher.

By looking at the figures above and tabulated data of Table 1, RSSI level for the three frequencies channel at Forest recorded the lowest clutter compare to the other three locations. This is proven referring to Table 1 and 2, as data in Forest recorded only reaches the low wind strength level for 64, 151 and 434 MHz. Otherwise, the strongest clutter was observed in Border for higher frequency 151 and 434 MHz.

In nature of Forest, trees that surround the FSR prototype with sensors implemented inside, afflicted in measurement of clutter signal. The method on placing the prototype under the trees for both transmitter and receiver affected the measurement as well because the wind may swaying only on the upper part causing less detection on clutter signal by the sensor. The surroundings of Forest mostly covered by mixed tropical trees with small height amongst them.

In distinction with Border, the area located in large surrounding by the sides of Forest and Seaside thus allows the swaying of wind more sturdy. Strong magnitude of clutter signal could easily detected by the sensors from swaying of trees as the trees are high enough and the state of sea waves also contribute in strongest clutter. In addition, higher frequency is more sensible to any changes of environment's resolution thus Border suits the best option for strong clutter, as Forest suits low frequency with less resolution detection on clutter signal's changes.

Therefore, the vegetation surrounds the test sites might be less dense to allow the clutter at low frequency affect the signal measured which in Forest, compared to Border as it differ enough producing strong clutter at higher frequencies.

TABLE 1: TABULATED DATA FOR STANDARD DEVIATION VALUE AT (A) SEASIDE (B) FOREST (C) FREE SPACE (D) BORDER

SEASIDE	64MHz	151MHz	434Mhz
Low	0.012437	0.01322	0.02779
Medium	0.014584	0.015522	0.0312
Strong	0.015799	0.017824	0.03461
Very Strong	0.017946	0.020126	0.03802

(a)

BORDER	64MHz	151MHz	434MHz
Low	0.00054025	0.001265	0.008044
Medium	0.0012523	0.001963	0.008827
Strong	0.0019643	0.002312	0.00961
Very Strong	0.002677	0.002661	0.01039

(b)

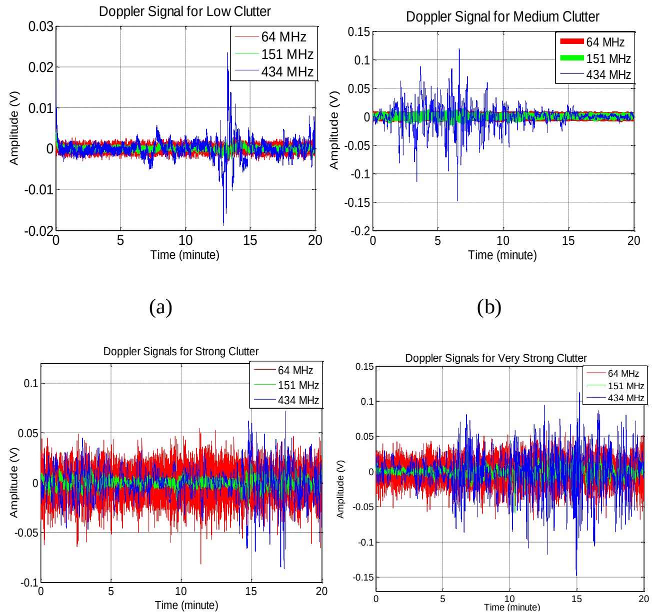
FOREST	64MHZ	151MHz	434MHz
Low	0.01509	0.001845	0.004365
Medium	0.01593	0.002245	0.005558
Strong	0.016776	0.002645	0.006751
Very Strong	0.031866	0.003045	0.007944

(c)

FREE SPACE	64MHz	151MHz	434MHz
Low	0.003004	0.000969	0.011553
Medium	0.009335	0.003025	0.026894
Strong	0.015666	0.005081	0.042235
Very Strong	0.021997	0.007137	0.057576

(d)

Figure 6 demonstrates the example of Doppler signal for 64, 151 and 434 MHZ respectively extracted from RSSI signal using filter and amplifier, at Border test site ranging from low, medium, strong to very strong clutter strength. Doppler signal is crucial component as modelling for the clutter will be tabulated based on this signal data, which next indicate by five distribution models



(a) (b)

(c) (d)

Figure 6: Doppler signals for 64, 151 and 434 MHz channel frequencies at (a) low, (b) medium, (c) strong and (d) very strong clutter

TABLE 2: TABULATED DATA BASED ON STANDARD DEVIATION RANGE FOR SEASIDE, FOREST, FREE SPACE AND BORDER LOCATION AT 64, 151 AND 434 MHZ

Test Sites	Seaside				Forest				Free Space				Border			
Wind Strength	L	M	S	VS	L	M	S	VS	L	M	S	VS	L	M	S	VS
64	20	0	0	2	20	0	0	0	10	3	3	0	23	16	0	1
151	16	0	1	5	19	0	1	0	9	5	2	0	35	0	0	5
434	6	0	3	9	17	1	0	2	7	5	1	1	27	3	2	8

IV. Statistical Clutter Data Analysis

A. *Probability Distribution Function Models*

This sections characterized the parameters for the five distributions model amount to Log-Normal, Log-Logistic, Gamma, Weibull and Nakagami distributions. These are described with a finite set of parameters using a specific equation.

1) Log-Normal Distribution

The equation of Log-Normal distribution is accustomed by [17]:

$$f(x \mid \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\{\frac{-(In\, x-\mu)^2}{2\sigma^2}; x \geq 0 \tag{3}$$

This distribution enact normal distribution logarithm suited only if the interest quality is positive value considering when x is positive, log(x) will only exist.

2) Log-Logistic Distribution

The Log-Logistic distribution is logistically allocated by means and standard deviation using two parameters. Log-Logistic PDF indicated by equation below [17]:

$$f(x \mid \mu, \sigma) = \frac{1}{\sigma}\frac{1}{x}\frac{e^2}{(1+e^z)^2} \quad ; x \geq 0 \tag{4}$$

where;

$$z = \frac{\log(x) - \mu}{\sigma} \tag{5}$$

Parameter μ is assigned for location while σ as scale parameter.

3) Gamma Distribution

Parameters that returned by Gamma PDF are; a equals to shape parameter while b represents scale parameter. The Gamma incomplete function denoted by $\Gamma(a)$ .These parameters represent by equation [17]:

$$f(x \mid a, b) = \frac{1}{b^a\,\Gamma(a)} x^{a-1}\, e^{\frac{-x}{b}} \tag{6}$$

4) Weibull Distribution

The Weibull distributions consists of parameter a as scale, and parameter b as shape, returns positive values. Positive Weibull pdf triggered by values of x if positive, otherwise it returns zero as shows in equation below [17]:

$$f(x \mid a, b) = \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} e^{-\left(\frac{x}{b}\right)^b} \tag{7}$$

5) Nakagami Distribution

The equation of Nakagami distribution given below as [17]:

$$f(x \mid \mu, \omega) = 2\left(\frac{\mu}{\omega}\right)^{\mu} \frac{1}{(\mu)}\, x^{2\mu-1} e^{\frac{-\mu}{\omega}x^2} \tag{8}$$

The Nakagami distribution is distribution that equipped with μ as shape parameter and ω as scale parameter, for $x > 0$; $\omega > 0$. While parameters μ and ω equate Nakagami pdf, x^2 expressed Gamma pdf with parameters μ as shape and ω/μ as scale.

B. *Goodness of Fit Test*

Goodness of fit test used involved maximum likelihood estimation through root mean square error (RMSE) to calculate parameters of each distribution. In order to identify the smallest error, RMSE is used to indicate the difference between clutter data and statistical distribution model. The equation for RMSE is stated as in Equation [17]:

1) Root Mean Square error (RMSE)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(c_i - \widehat{c_i})^2} \tag{9}$$

The clutter data number of sample is represents by i, clutter data amplitude value denoted by c_i; while $\widehat{c_i}$ is the statistical model's amplitude value.

The clutter data are represents in five distributions model as shown in Figure 7-9 varies at channel frequencies of 64, 151 and 434 MHz.

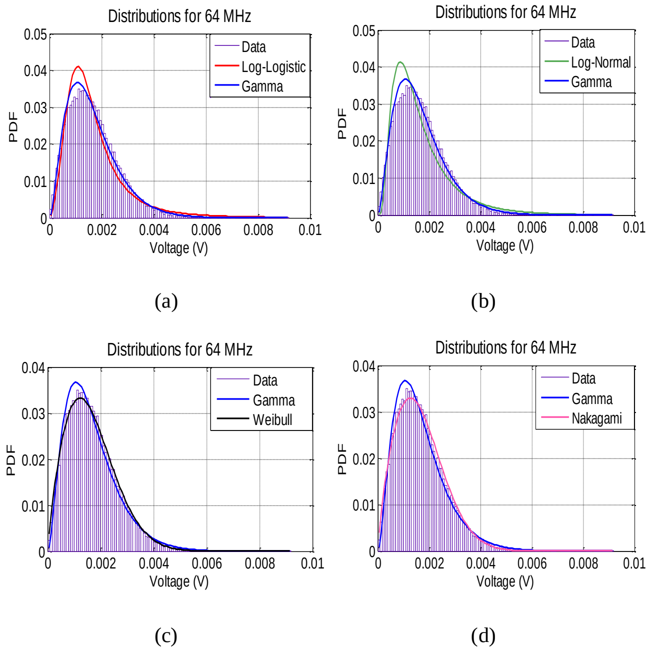


Figure 7: Comparison of distribution models for 64 MHz at (a) Gamma vs Log-Logistic (b) Gamma vs Log Normal (c) Gamma vs Weibull and (d) Gamma vs Nakagami.

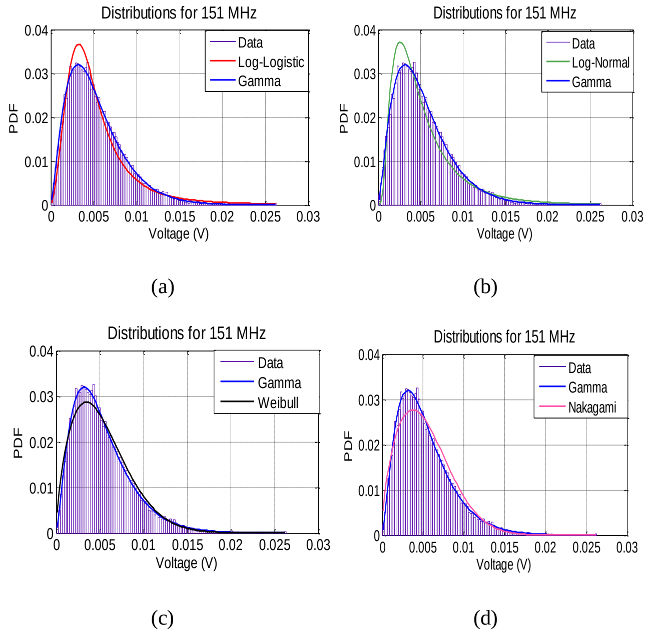


Figure 8: Comparison of distribution models for 151 MHz at (a) Gamma vs Log-Logistic (b) Gamma vs Log Normal (c) Gamma vs Weibull and (d) Gamma vs Nakagami.

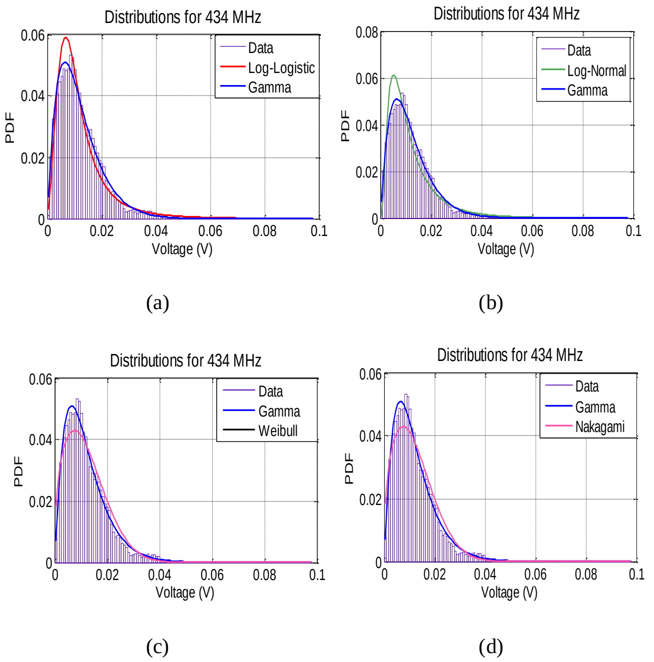


Figure 9: Comparison of distribution models for 434 MHz at (a) Gamma vs Log-Logistic (b) Gamma vs Log Normal (c) Gamma vs Weibull and (d) Gamma vs Nakagami.

The comparison for the three channel frequencies is proceed with Gamma distribution versus other distributions, Log-Normal, Log-Logistic, Weibull and Nakagami. Due to most accurate distribution for 64, 151 and 434 MHz likely is Gamma distribution, the comparison observed is proved by calculation of RMSE to get the most accurate distribution model that suits the best for clutter modelling.

Figure 7-9 respectively, shows that for (a) Log- Logistic versus Gamma provides higher amplitude compared to Gamma distribution while (b) Log-Normal shift a bit to the left of the histogram compared from Gamma distribution. Weibull and Nakagami seems quite suits the distribution likely Gamma. Only for Nakagami, it reaches the slope quite steeper. Weibull results in lower amplitude compared to Gamma, exhibits as the close distribution shape as well as Log-Logistic for the modelling of clutter.

TABLE 3: AVERAGE ESTIMATED ROOT MEAN SQUARE ERROR

Frequency	Distribution Models				
	Log-Normal	Log-Logistic	Gamma	Weibull	Nakagami
64 MHz	0.0017	0.0019	0.0016	0.0024	0.0038
151 MHz	0.0034	0.0022	0.0016	0.0027	0.0031
434 MHz	0.0032	0.0020	0.0015	0.0030	0.0036

Table 3 shows the calculation for average estimated RMSE for the five distributions. Gamma could be observed exhibit the lowest error, compared to others distribution thus proved that it's the suitable model for wind clutter modelling. The lower the value of RMSE, the better the distribution fit as the suitable model. Gamma is most accurate distribution of measuring the response of clutter's presence applied in different environments.

V. CONCLUSION

FSR micro-sensor network used in this experiment that has been conducted in tropical country measured the windy foliage as it is chosen as the main purpose in observing the pattern of clutter signal, focused on the wind pattern clutter strength ranging from low, medium, strong to very strong in order to execute an accurate analysis. The channel frequencies cover up 64, 151 and 434 MHz included in VHF and UHF bands. RSSI clutter signal is extracted as Doppler signal that used in modelling of the clutter. Border is chosen as the strongest area of clutter while Forest as the lowest clutter strength area due to analysis carried out. Forest as a dense environment face difficulty in detecting clutter presence, compared to Border that located in more open area thus allowing more clutter signal to be detected by the FSR prototype.

Histogram of different five types of distribution which are Log-Logistic, Log-Normal, Gamma, Weibull and Nakagami demonstrated the modelling of the clutter signal tested in this experiment. Comparing the five distributions model, Gamma is chosen as the exact model, observed from the histograms. RMSE proved the Gamma distributions model as the most accurate for 64, 151 and 434 MHz frequencies band, as the lowest error recorded. Based on the results obtains, a clutter model can be developed to predict the ground based radar's performance in specific environment condition.

In the future, sample of data should be added up at the experimenter's site to acquire more accurate result. As this research is strictly focus on wind clutter nature of climate, therefore to improve the result, data sample could be taken at different weather climate but in similar environments to observe the difference.

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