Synthetic Land Clutter and Noise Generation for an Air Defence Radar Training Simulator

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Abstract:

Simulation of land clutter and noise is the key aspect of radar simulation. In real time, radar video represents different target characteristics like surface targets, air targets, clutter and noise. Land clutter is complex part in understanding its characteristics due to uneven surface scattering effects and wave characteristics. In this paper we discuss the different techniques to model the land clutter based on log-normal, Weibull and K-distributions and then simulate the land clutter with these models. In generating the models of log-normal, Weibull and K-distribution, this paper discusses various algorithms like Box-Muller and non linear functions implementation in FPGA like Log, SQRT and sine functions. PowerPC and FPGA based hardware is used in implementation of these functions. Complex algorithms like generating the sequences with Weibull and K-distributions are implemented in the FPGA. PowerPC is used in creating the geometric representation of clutter objects. The mixture data from the FPGA and PowerPC models the synthetic land clutter video in simulation.

Keywords: Simulation, Scenario ,Weibull, log-normal

I. INTRODUCTION

Radar training ensures preparedness of the personnel for radar operations and interpretation of radar data and scenarios which they will experience in real time. Training mode of any radar enables the trainees in handling the tasks and challenges of real world radar data. Radar Simulator is a solution to have training on different radar scenarios. Radar Training Simulator will have functionality to create/simulate various target maneuvering scenarios with the radar characteristics such as Pulse length, Pulse repetition interval, Radar antenna rotation etc. Training simulator of any radar makes the personnel get acquainted with real time situations and get to know about the control procedures for the radar and take proper actions.

The Air Defence Radar plays an important role in Surveillance and Fire control system applications.

The training simulator shall have the following modules:

1. Radar Scenario Generator (RSG)
2. Radar Video Generator (RVG)

The air surveillance radar has a training simulator using a Radar Video Generator (RVG). The training scenario is fed to RVG from Radar Scenario Generator (RSG) and the evaluation of the trainee can also be carried out offline. Trainee can choose the exercises which are stored in the memory of RVG and get trained.

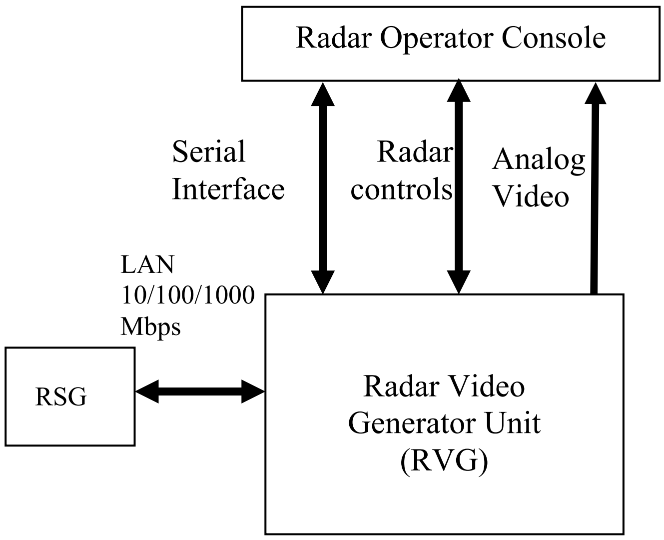


Figure 1: Radar Simulator System

The training simulator for air surveillance radar has been developed with present state of the art indigenously developed hardware and software platform. The entire simulator shall be initiated, controlled and monitored by an Instructor

The training simulator developed can be interfaced with the existing Air Defence Radar. The new hardware design gives the necessary interface which is compatible with radar. The selection on the PPI console will be same however the simulation can be either on-line or off-line decided by the Instructor.

II. CLUTTER MODELS

Clutter Modeling depends on various radar parameters and environmental conditions. Clutter modeling is based on the uncertainty of the environment and it is described probabilistically.

Radar modeling typically includes a system signal model which includes a state and an associated variance. Many distributions provide estimates of the clutter model, and the correct model is one that captures a majority of the data. For example, Rayleigh, Log-normal or Weibull distribution are used to capture radar clutter. For various terrain types like sea or land different models have been developed. Statistics of clutter can also be described by hybrid models distributions like Ricean, Rice-squared, gamma-distribution, log-normal-Rayleigh and log-Weibull if there is a mixture of sea and land profiles.

The radar equation for the received power P_r

$$P_r = \frac{P_t\, G\, A_e\, \sigma}{(4\pi)^2\, R^4} \qquad \text{------------- (1)}$$

P_t = Transmitted power
G = Antenna Gain
A_e = Antenna Effective aperture
R = Range
σ = Radar Cross section of the targets

Clutter characteristics mainly depend on illumination surface of the targets or surface reflectivity which can be noted as effective radar cross section (σ). The reflected power from the land clutter with cross section σ_l is the sum of different scattered power from land. Each reflected power is assumed to be statistically independent distribution in nature. From the central limit theorem, the resulted sum at the receiver tends to be Gaussian distribution. For a non coherent detector the resulted signal follows Rayleigh distribution. This applies when the radar resolution is low. But in case of high resolution radar the distribution tail increases on right side due to complex characteristics of land surface. Thus the distribution of land clutter is not always follows Rayleigh and should be represented by other form. From many practical experiments it is shown that the reflected energy at non coherent detection follows either log-normal or Weibull distribution even some times K-Distribution [1]. For the current generation radars with good resolution, the reflected power fits either log normal or Weibull distribution. In this paper we model the land clutter by log normal or Weibull distribution after the square law detector.

The following equation represents the distribution models for log-normal

$$f(x;\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln x-\mu}{\sigma}\right)^2} \qquad \text{---- (2)}$$

Where $x>0$ and parameters μ and σ are positive real numbers.

The Weibull distribution is given by

$$f(x;\eta,\sigma) = \frac{\eta}{\sigma}\left(\frac{x}{\sigma}\right)^{\eta-1} e^{-\left(\frac{x}{\sigma}\right)^{\eta}} \qquad \text{------ (3)}$$

Where the variable x and the parameters η and σ all are positive real numbers.

III. Implementation

This section discusses the implementation of generating the synthetic land clutter based on log-normal or Weibull distribution. These two distributions are generated in real time hardware using various methods like Box-Muller and non linear functions. Box-Muller method is used in generating random samples with normal distribution [2]. The following equation is used in generating Gaussian random variable z with given mean μ and variance σ.

$$z \;=\; \mu + \sigma\sqrt{-2\log(s)}\cos(2\pi t) \qquad \text{---- (4)}$$

Where s is the uniform random variable.

Once the Gaussian samples are generated, it is most straightforward way to generate a log-normal random number from a Gaussian distribution with mean μ and standard deviation σ and construct random variable

$$r=e^{u} \qquad \text{--------- (5)}$$

Where u is the Gaussian random variable [3].

In case of Weibull's distribution, ξ, a random number uniformly distributed from zero to one is used with the following equation to generate Weibull random number in x.

$$x = \sigma(-\ln\xi)^{\frac{1}{\eta}} \qquad \text{------- (6)}$$

Where σ is the scale and η is shape parameters.

From equations (4), (5) and (6) it is observed that, the necessity of implementation of non linear functions and uniform random number generator in real time hardware. Cordic and BKM algorithms are used in realization of cos, logarithm, square root and exponent functions [4] & [5]. LFSR (Linear feedback shift register) is used in generation pseudo random numbers which is similar to uniform random variable. These methods are implemented in real time hardware based on PowerPC and FPGA. The architecture is shown in fig 3. This hardware has interface to Radar data processing unit and capable to generate simulated radar signals with controls after the square law detector.

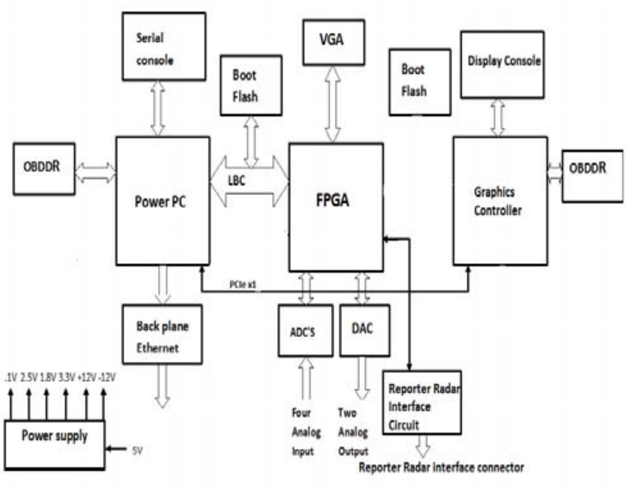


Figure 3: Simulator Hardware Architecture

PowerPC has various interfaces like Onboard DDR2 memory, Boot flash and FPGA on eLBC bus, Two Ethernet Controllers and Graphics controllers on PCI express controller. All analog and control signals to/from radar data processor is interfaced to FPGA. Graphics controllers are interfaced to PowerPC over PCI express link. Graphic controllers also has interface of 512Mb on board DDR2 memory. It has one display console also.

Flow diagram is shown in fig4 to synthesize land clutter based on the methods discussed above equations (4), (5) and (6). These methods are implemented in FPGA and PowerPC based on the processing capability.

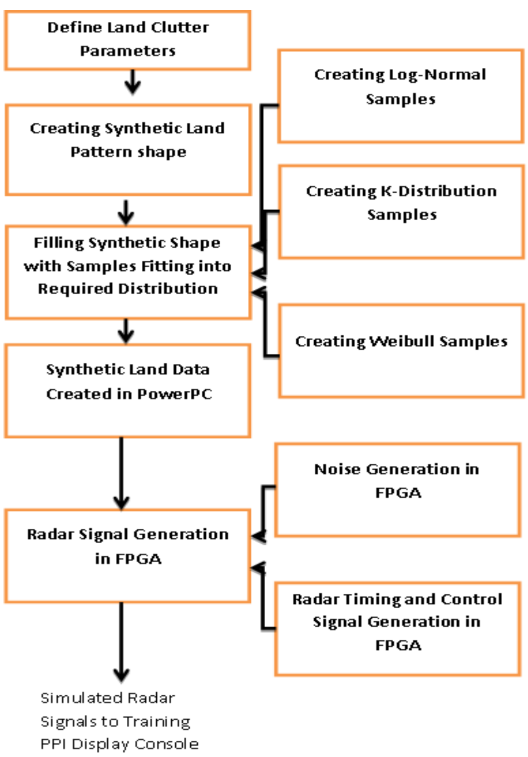


Figure 4: Simulator Algorithm and Signal Flow Chart

The Land clutter models to be implemented in SBC follow the following data flow model where the computations of the distributions are carried out in POWERPC and then sent to the external world as simulated data by FPGA.
To model any land clutter parameters have to be loaded like the radar resolution, grazing angle of the radar and frequency of operation. Then based on the input parameters required distribution profile for creating the land clutter model is selected and the synthetic shape of the land clutter is filled with the selected distribution.
The synthetic land data samples generated in POWERPC are communicated to FPGA with noise generation.
The land profile created is fed to the training simulator in sync with the Radar characteristics like Pulse Length, Pulse Repetition Interval, Radar antenna rotation etc by the FPGA

IV. SIMULATION RESULTS

Synthetic land patterns are created in Matlab are shown in fig 5. These land patterns are generated with parameters like size and location with respect to radar centre. The shapes generated with random in shape looks similar to real time land patterns. Land patterns are filled with grey levels which follow the distributions of Weibull, log-normal or K-distribution. Depending on the characterization radar signal parameters and terrain to be simulated, particular distribution is used in simulation. For low grazing angles radar reflections are more fit into the log-normal distribution or Weibull. Generation of the signals with the different nature distributions is the major challenge in FPGA based hardware.
Here are the simulation results of land clutter models with white guassian noise where the range intensities follow log-normal distributions simulated shown in figures below

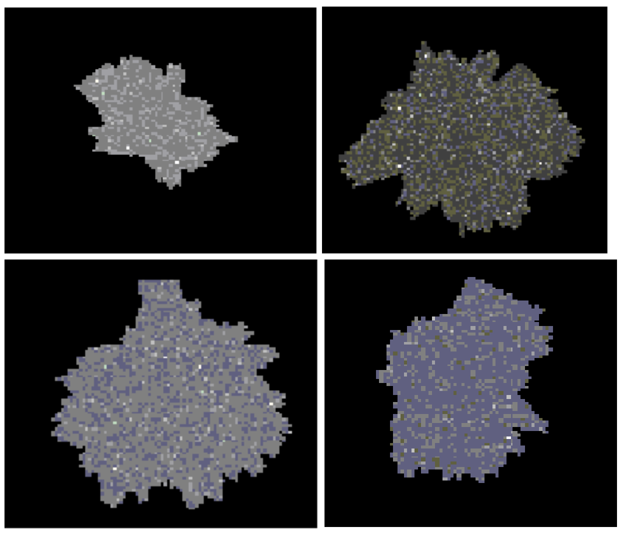
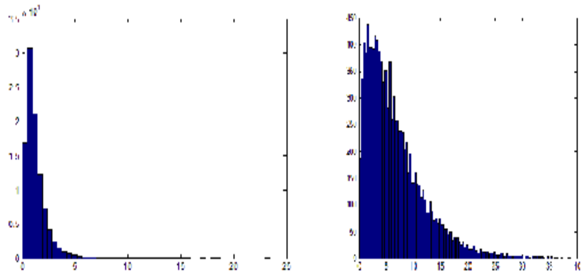
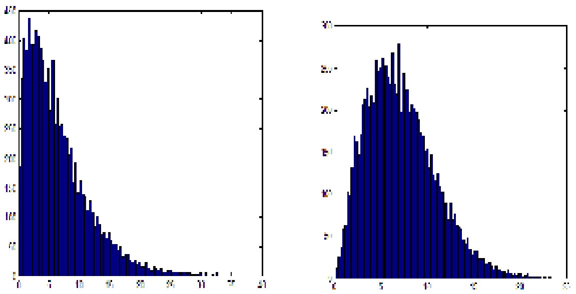


Figure 5: Simulation results of land Clutter Models

The simulation results of Weibull distributions are carried out in Matlab with different scale and shape parameters are shown in fig 6(a) and (b) below



(a). Log-normal Distrubutions



(b) Weibull Distributions

Figure 6: Simulation results of (a) Log-Normal (b) Weibull with Different Scale and shape parameters

V CONCLUSION

The radar clutter types like rain, chaff are volume-distributed and other clutter types like terrain and sea are surface-distributed and returns from the aircraft are pointed targets. The properties of the particles or surface producing echoes effect the statistics of the clutter. Land clutter statistics depends on environment variables and incident power of the radar and grazing angles of the radar. This paper explains the methodology to implement the land clutter as part of training simulation by using the log – normal and Weibull distributions.

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D Ranganath has joined CRL-BEL in 2006. He has more than 9 years of experience in design and development of embedded signal processing hardware for radar applications. He is involved in radar data processing and algorithms for radar raw data compression. He has certification from American Society for Quality (ASQ) as a "Certified Reliability engineer". He is currently involved in design of multi-core and graphics based embedded designs.

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L Ramakrishnan obtained B.Tech (Electronics Engg) from MIT, Anna University & ME (ECE) from Osmania University. Starting his career at HAL, worked in various projects including Air borne Transponders, Airborne radar for modern Indian fighter aircrafts, Air Route Surveillance Radar, Radio Proximity fuses for missile systems etc. His area of professional interest includes Design and Development of front ends for Radar, Wireless & Communications Systems. He is currently serving as Principal Scientist & Group Head at Central Research Laboratory, BEL. He is presently involved in the design and development of embedded computing products & signal processing sub systems for radar applications. His current area of research interest includes development of Ultrawide Band Radars. He has over fifteen reputed publications to his credit. As part of team, he has been bestowed with Raksha Mantri's award under Innovation Category and BEL R&D Excellence Awards for different projects. He is part of the IT Standardisation subcommittee, Defence Standardisation Cell, MoD. He is Member (IEEE) and certified PMP.