CHAPTER 1

# Introduction

## Preface

This chapter introduces the topic of the thesis. The state-of-the-art likelihood ratio test (LRT) based detectors in the presence of non-Gaussian clutter are discussed critically followed by the discussions on the underlying motivation for carrying out this thesis work. The objective of the work is described and the contributions made in this thesis work are highlighted prior to presenting a brief outline of the thesis work.

## 1.1 Introduction

The LRT based detection in the presence of a correlated non-Gaussian clutter encountered in high range resolution and/or low-grazing angle land and sea environments, has gained a special interest in recent years. The generalized likelihood ratio test (GLRT) based detectors which are popularly used for optimum detection in Gaussian clutter environments are also promising to perform effectively in non-Gaussian clutter scenarios. However, the correct formulation of the LRT detectors need 1) a faithful representation and the mathematical tractability of the non-Gaussian clutter, and 2) application of the detection theory incorporating the clutter model to determine the structure of the detector. Therefore, a clutter model which is very accurately applicable to the actual non-Gaussian clutter encountered in practice would be helpful in arriving at an accurate detection method. Presently many researchers prefer to model the non-Gaussian clutter in compound-Gaussian form which can be realized as product of two independent random processes called 'texture' and 'speckle' [1]. However, it is very difficult to formulate an effective LRT detector for the existing compound-Gaussian clutter model unless the slow varying texture component is considered as completely correlated during a coherent processing interval (CPI).

It is found while analyzing the measured practical clutter data (McMaster IPIX radar database) and also from the results given in [2], that the texture part may not be permitted to assume so, particularly in scanning radar applications. That means the challenge of accurately modelling the clutter and obtaining an accurate LRT detector for such clutter scenarios is still open. To overcome the above mentioned problems we propose an accurate K-distributed clutter model applicable to both the land and sea environments. The clutter model is used for proposing a GLRT detector which yields an effective detection performance and promises to retain the desired constant false alarm rate (CFAR) while detecting fluctuating targets.

## 1.2 State-of-the-Art LRT Detectors in Compound-Gaussian Clutter

Formulation of an LRT detector in non-Gaussian clutter comprises of two individual but entirely interconnected assignments to deal with. One is to model a non-Gaussian clutter in such a way that it supports the physical phenomenon of clutter generation, fits well to the real clutter and useful for an effective detection of target. The other is to use a clutter model in a suitable manner while forming the LRT statistic and simplifying the mathematical complexities for arriving at practically implementable detection structure.

The LRT detection methods commonly use a multidimensional compound distribution form of non-Gaussian clutter. For that, a clutter pulse return is assumed as a complex Gaussian random variable and its multidimensional form as spherical invariant random variable which helps in achieving a multidimensional compound-Gaussian probability density function (*pdf*) [3]−[7]. This compound-Gaussian model allows to consider the *pdf* of clutter as Gaussian but its variance, i.e., mean power of clutter is to be assumed as random. The *pdf* of this random variable (clutter mean power) must be defined carefully before applying the compound-Gaussian model to a practical clutter environment [8]−[10]. The Weibull and K-distributions which are consistent with such compound distribution, are popularly used in the state-of-the-art LRT detectors [11]−[14].

However, it is not straightforward to formulate an LRT detector in a practically realizable form unless the random mean power of a compound-Gaussian clutter is assumed as fixed during a CPI. This assumption allows us to formulate an LRT detector in matched filter (MF) form [11], [13], [15] and is also useful for estimating the non-Gaussian clutter covariance matrix [16]−[18]. Furthermore, an asymptotically optimum target detection is possible where the number of pulses used in a CPI is sufficiently high or infinity for an ideal case [14], [11], [19]. However, a severe difficulty comes up when the clutter mean power which is called as 'texture' of compound-Gaussian clutter, varies even within a CPI. In the existing literature, it is preferred by the current researchers to estimate the varying texture by properly modelling it and use an estimator for the same [20]−[22]. Therefore, the problems in the formulation of LRT detection in the presence of a clutter with varying texture may conveniently be addressed by coming up with a useful clutter model, a suitable estimator for the same and using an efficient technique for simplifying the mathematical complexities to arrive at a useful detection structure. However, the challenge of arriving at an accurate and practically implementable detection structure for such clutter scenarios is still to be addressed.

## 1.3 Motivation

From the above discussion and also from the available literature, it is found that most of the existing LRT detection schemes are formulated using a compound-Gaussian clutter model which is not accurate in the strict sense. Therefore, the detection performance is expected to significantly fall short of the optimum detection schemes, particularly in scanning radar applications.

We know that a target signal can be expressed by using Swerling's target model where the pulse return from target can be assumed as a complex circular Gaussian random variable with zero mean and the variance of the Gaussian *pdf* can be considered as unknown at the detector while formulating the LRT detectors. For detecting such a target signal in the presence of a non-Gaussian clutter using LRT detectors, the compound-Gaussian forms are popularly used in modelling the non-Gaussian clutter, say '$c$' of which the envelop can be represented as $|c|$ and the distribution of $|c|$ can be described using a K-*pdf* [23] as

$$p(|c|) = \frac{2.b}{\Gamma(\nu)} \left(\frac{b.\,|c|}{2}\right)^{\nu} K_{\nu-1}(b.\,|c|), \qquad \nu > -1 \tag{1.1}$$

where $0 \leq |c| \leq \infty$, $\nu$ and $b$ respectively are the shape and scale parameters, $\Gamma(\cdot)$ is the standard Gamma function and $K_{\nu-1}(\cdot)$ is the modified Bessel function of second kind.

However, it is found from the available literature that the formulation of a log-likelihood ratio test (LLRT) detector in compound-Gaussian clutter needs to evaluate non-linear functions which make the formulation very complicated and it is difficult to arrive at an efficiently implementable detection structure. Hence, a sub-optimum approach is used in [11] to find an LLRT detector for such clutter scenarios. On the other hand, it is much more easier to obtain a GLRT detector for optimum detection [12] when the estimates of the unknowns are available. However, for effective detection performance, the GLRT detector needs to use very accurate estimators for the unknown parameters of K-*pdf* which can be given by Therefore, it is required to analyze the detection performance of both the LLRT and GLRT detectors and analyze and compare their performance. It is also required to study the performance of the detectors in compound-Gaussian clutter with varying texture which is encountered commonly in practice.

Since the compound-Gaussian model of K-distributed clutter given in [1] is not attractive in designing an estimator for varying texture, a suitable clutter model is to be found out. A useful clutter model for sea clutter is proposed in [20] and used it in [21] for varying texture estimation by using subspace methods. However, in [20] the texture part was modeled as a sum of sinusoids which were intuitively introduced due to the quasi-periodic nature of the sea surface. Hence, it cannot be applied for land clutter because the texture fluctuation of land clutter caused by the antenna scanning motion is mostly due to a change in the nature of the illuminated area which does not obey any periodicity. Therefore, it is needed to propose a clutter model which should be applicable to both the land and sea clutter.

After achieving a suitable model of clutter with partially correlated texture, it is needed to propose a detector and the performance of the detector to be analyzed to find its effectiveness in various clutter scenarios. An important feature of a detector is its CFAR characteristics which depend not only on the texture *pdf* but also on the accuracy of the clutter covariance matrix estimation. Hence, it is to be ensured that the proposed detector maintains its CFAR behavior very accurately.

## 1.4 Objectives of the Thesis Work

Motivated by the shortcomings of the existing clutter models used in designing the sub-optimum and optimum detectors in K-distributed clutter of which the distribution of envelop is given by (1.1), the present thesis aims at proposing a clutter model for an accurate estimation of clutter mean power and also, arrive at the optimum GLRT detector. Details of the same are as explained below.

- Study the existing LRT detectors for the existing clutter models to find the detection characteristics and critically analyze their performance while working in the presence of a clutter with partially correlated texture.
- Study the clutter generating phenomenon and come out with an accurate K-distributed clutter model and validate it through measured practical clutter data for both the land and sea surface backscattering.

- Use the clutter model to propose a robust GLRT detector which may need to propose a suitable estimation technique for varying texture estimation.
- Extend the proposed estimation techniques and use in the proposed detection scheme for maintaining the correct CFAR behavior.

## 1.5 Contributions Made in the Thesis

The overall contributions made in the thesis are summarized below.

1. A comparative study on performance of the existing MF form of LLRT and GLRT detectors available in the literature is made for various clutter scenarios. The performance of the existing MF detector is extensively analyzed to examine its effectiveness in detection of moving targets in clutter with partially correlated texture.

2. Studied the amplitude statistics and correlation properties of K-distributed clutter data measured by a practical radar. The measured data is used to study the effect of antenna scanning motion on clutter correlation properties, its variation with range and also, the change of correlation values for different scattering characteristics of land and sea.

3. Proposed a K-distributed clutter model in compound-Gaussian form aiming to accurately accommodate the effect of antenna scanning motion. The techniques for model parameter estimation and simulation of the proposed model clutter are given. The proposed clutter model is validated through measured practical clutter data of both land and sea.

4. A GLRT based detector using the above clutter model is proposed for an accurate and effective detection performance. In this scheme we have also come out with an estimator for time varying texture of clutter encountered in scanning radar applications. The detection performance of the proposed GLRT detector is mathematically analyzed and experimented with various clutter scenarios.

5. To provide correct CFAR behavior, the above estimator of time varying texture is extended for an accurate estimation of texture as well as clutter covariance matrix which can be used in the above GLRT detector. The accuracy of the estimator is examined by applying it to real clutter data obtained from a scanning radar.

6. The above estimator requires to use a bank of sub-Doppler eigenfilters with an extremely narrow passband. Hence, the estimator may not perform efficiently when the passband of eigenfilters is not sufficiently narrow. To overcome such shortcomings another estimation technique which uses the data of several scans is proposed and it is found from the experimental results that the estimator is attractive for use in CFAR GLRT detection.

## 1.6 Outline of the Thesis

In **Chapter 2**, we present the background literature of the work including fundamentals of the LRT based detection schemes and their CFAR detection in non-Gaussian clutter. A brief discussion on non-Gaussian clutter models and their compound-distribution form which can be applied to land and sea clutter environments is given here. A description on radar arrangement for data collection and the site map involved in backscattering to the real clutter data used in our experiment is also given.

In **Chapter 3**, the performances of the LRT detectors available in the literature are studied mathematically and also through simulation experiments. A comparative study of the detection performances of LLRT and GLRT detectors are carried out. The limitations of the existing MF form of GLRT detector applied for target detection in compound-Gaussian clutter with partially correlated texture are also discussed in detail.

To study the comparative performances of the above LLRT and GLRT detectors we simulate compound-Gaussian clutter and the detection schemes. It is shown by using the experimental results that the GLRT detector performs always better compared to the LLRT detector as expected. Since the GLRT detector is optimum in structure, easier to formulate and also performs better it is opted and its performance characteristics in various practical clutter scenarios are studied. It is found that the GLRT detector is very effective even at reduced speckle correlation values which are encountered very frequently in practice. However, while formulating the above LRT detectors the texture part of the compound-Gaussian clutter was considered as completely correlated which is not valid in practice, particularly in scanning radar applications. Therefore, it is interesting to study the performance of the existing GLRT detector in clutter with partially correlated texture. We mathematically analyzed the performance which is validated through experimental results. The corresponding results are discussed in this chapter from which we observed that the existing GLRT detector performance deteriorates with the reduction of texture correlation. This behavior motivated us to obtain an effective GLRT detector that uses an accurate clutter model as proposed in the next chapter.

In **Chapter 4**, we propose a clutter model and validated it through experimental studies using measured data. The measured clutter data analysis, method for clutter model parameter estimation and the technique for simulating the proposed model clutter are discussed in detail in this chapter. A brief discussion on the macroscopic phenomena of clutter generation and the studies on the measured clutter data are given to demonstrate the texture partial correlation and its variation with the antenna scanning rate. We used the McMaster IPIX radar database which provides measured experimental data for both the static and scanning radars.

The validity and applicability of the proposed clutter model is demonstrated by comparing the autocorrelation function (ACF) and *pdf* characteristics of the simulated data obtained from the model and that obtained from measured data. To simulate the proposed model clutter we computed the model parameters from the measured clutter data. The technique of optimum parameter estimation using the maximum likelihood (ML) method and the proposed simulation technique which uses the above model parameters for simulating a clutter with specific characteristics are discussed in detail. From the presented experimental results, an excellent match between the synthetic and measured data of both the land and sea clutter is found. The close agreement between the model and the measurement clearly illustrates the validity, accuracy and applicability of the model. The suitability of the proposed model in LRT detector formulation is also commented in the course of discussions in this chapter.

Then, in **Chapter 5**, we propose a GLRT based detector for detecting fluctuating targets in the presence of clutter which can be modelled as per our proposed model.

The technique for estimating the clutter covariance matrix on-line and the detection performance of the detector are discussed elaborately.

Detailed mathematical derivations are made and the formulations of the GLRT detector which can detect a target in the presence of a clutter with varying texture are given in this **Chapter 5**. The mathematical steps clearly show that the GLRT statistic obtained for the clutter model is useful in formulating and arriving at an attractive MF detection structure. In this detection scheme it is necessary to estimate the speckle covariance matrix of the cell under test (CUT) and the clutter mean power level which is obtained by separating out the textural part from the clutter product process. However, it was challenging to estimate that because the parameters of the texture Gamma *pdf* and its correlation length is unknown at the detector. Hence, a suitable estimation technique which is found to be very effective and attractive in estimating varying texture without the knowledge of texture or speckle correlation values is proposed. To assess the performance of the proposed GLRT detector we mathematically analyzed the detection performance which is also studied through simulation experiments for various clutter scenarios and compared it with that of the existing MF detector. Experimental results are presented to demonstrate the performance superiority of the proposed detector and to show that the performance of the proposed detector is insensitive (robust) to the texture fluctuation.

In **Chapter 6**, we propose two estimation techniques for time varying texture and the experimental results are used to demonstrate the accuracy and applicability of those estimators. A detailed discussions on the performance of the detector and the in-depth study on the CFAR behavior of the detector while using the proposed estimation techniques is also given.

The proposed estimation techniques are categorized in to two types, one estimates the varying texture by using the pulse returns of a particular range cell collected over several scans and the other uses the pulse returns of a single scan only. Both the techniques have their merits and demerits which are elaborately discussed in this chapter. The accuracy and applicability of the estimator which uses the data of a single scan are examined by applying it to the measured clutter data for both land and sea backscattering. The experimental results illustrate that the proposed estimator can reliably be used for practical applications. However, it is necessary that the passband of the eigenfilters used in both the estimation schemes must be extremely narrow which is very difficult to achieve in practice. Otherwise the estimator which uses the data of a single scan must have a limited accuracy in estimation due to the spectral leakage. To avoid such shortcomings we propose an alternative technique which estimates the texture of a particular pulse return by using the data of previous scans. The detailed discussions on this second estimation technique and its applicability in the proposed GLRT detector are given in this chapter. The estimation technique is found to be very attractive for use in practical systems and it is effective, too. The corresponding experimental results are presented to demonstrate that the estimator can reliably be used in the proposed GLRT detector for maintaining the correct CFAR behavior.

**Chapter 7** describes the insights and conclusions that are drawn from the thesis work. Also, the directions for future work are given in this chapter.