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A study of SPRT algorithm and New-Guard for radiation detection

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STUDIES ON SPRT ALGORITHM AND NEW-GUARD FOR RADIATION DETECTION

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ABSTRACT

A Study of SPRT Algorithm and New-GUARD for Radiation Detection

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A novel and efficient radiation detection algorithm combined with a measuring unit will produce an ideal detector to battle field radiation measurement problems. Studies of Sequential Probability Ratio Test (SPRT) for radiation detection are essential towards developing efficient and accurate radiation detection algorithms. In this study, the performance of the classical Single-Threshold-Test (STT) and the SPRT First-In-First-Out (FIFO) algorithms is considered. Next, improvements made by the Last-In-First-Elected-Last-Out (LIFELO) algorithm are analyzed. Further, enhancements to the LIFELO algorithm, using the Dynamic Background Updating and Maximum Likelihood Estimator (MLE), are performed.

The thesis also provides detailed requirements for an innovative hand-held radiation detection system and underlines additional features available on a New Generation User Adaptable Radiation Detector (New-GUARD) to help the field survey processes. Currently available technologies are studied to rationalize the need for the New-GUARD prototype. The New-GUARD is compared to similar products that are already available

in the market to show its completeness as a radiation detector incorporated with Global Positioning System (GPS), wireless communication, and a self-correcting system. Primary performance evaluations of the algorithms are executed using Mathematica and further analysis is carried out with Matlab and C.

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CHAPTER 1

INTRODUCTION

An increase in security threats around the world have created a greater emphasis for radiation detection studies. Currently, many departments and national laboratories have dedicated a great deal of time and effort to develop new detection instruments that help quick detection of radiation sources and at the same time decrease human exposure to radiation [1]. A novel and efficient detection algorithm fused together with a measuring unit will produce an ideal detector to battle field radiation measurement problems.

To achieve this objective, it is important to understand the principle of radiation detection. Radioactive material decay occurs via three means: alpha particle, beta particle, and gamma photon emission [2]. Similarly, the three types of nuclear radiation emitted from radioactive atoms are alpha, beta and gamma particles. Radiation measurement is essential when defining the strength of the particles, thus different measurement terms are used according to the field of usage such as radiation emitted by a radioactive source, radiation dose absorbed by a person, biological risk, or health effects [3]. In the United States, conventional radiation units are still preferred and are as follows, Roentgen (R) measures energy produced by gamma radiation, Radiation Absorbed Dose (rad) measures the amount of radiation energy transferred to some mass of material, and Roentgen Equivalent Man (rem) measures biological risk of exposure to radiation [4]. Most scientists in the international community favor the International Unit of System (SI) for radiation measurement, in which gray (Gy) is used in place of rad and sievert (Sv) in place of rem [4].

Radiation is only observable in processes that occur on a scale that is either too brief or too small to be observed directly [5]. Radiation detection is a process that measures the intensity of radiation at a specific location and point of time and uses a detector to perform the measurements. Radiation detectors were originally developed for atomic, nuclear, and elementary particle physics. But now the detector is essential in many diverse areas of science, engineering, and everyday life. These detectors fall into several categories: both fixed position and portable area detection monitors, air monitors, which are continuous and grab samplers, contamination monitors for personnel and area monitoring, and the most commonly used detectors, gas-filled and scintillation detectors [1]. The radiation detectors have undergone progress in science not just by interplay of theory and experiment, but also serving as breakthrough in instrumentation.

The basic idea of radiation detection is to determine the strength of the sample being measured, compute the resultant alarm level, and verify whether the sample is safe or unsafe. A field survey detection process is as follows. First, the technician measures a known group of background samples or area to determine a relative reference level. Then the technician proceeds to the area of survey and starts taking measurements. Every sample measured will produce an alarm. Alarm levels are set according to the intensity of the sample strength. For a background sample, the alarm level will remain zero. The technician keeps moving until a sample with the presence of the source is located. Unless there are a few more of these source samples, the technician does not change course. Finally, at the end of the survey, the technician will compile the readings and the resultant alarms for further analysis. During the survey process the technician is at high risk of exposure towards radiation. Developments are carried out to reduce the occupational hazards of a field surveyor.

1.1 Related Work

Over the past decades, the primary concern in the radiation field has been the safety of the field surveyor. These technicians are exposed to a significant amount of risks when taking the radiation measurements. Considerable research has been conducted to understand the hazards of radiation exposure to human health [6]. Occupational exposure to radiation is governed by the concept of maximum permissible dose (MPD) with the understanding that all exposures should be kept as low as reasonably achievable (ALARA) and in accordance with the International Commission on Radiological Protection (ICRP) and the U.S. National Council on Radiation Protection and Measurements (NCRP) [7]. Since the mere existence of hazards is not a legitimate barrier to progress in any field, the alternative of minimizing the dangers associated with hazardous work had to be accepted and developed [8]. This has involved many aspects concerning development of safe working environment criteria, establishment and maintenance of such conditions, technological enhancements to reduce human exposure, and medical improvements.

Studies have been performed on factors that help improve protection against radiation risk [9-11]. Such factors are time, distance and shielding. In general, an ideal condition for radiation detection and measurements includes less amount of time near a radiation source, farther distance from the source and an increase in shielding against such radiation. Shielding is a popular method to reduce human exposure to radiation, and it is easy to implement. Research and development have been carried out extensively in this area to enable usage of shielding to reduce radiation exposure in working environment [12-15]. Using shielding to avoid radiation will suit those workers who have a physical layer of material between him / her and the source. In contrast, for applications or work related to direct presence at the location of radiation, reduction of exposure time and maintaining a safe distance from the source is a better solution.

Unlike shielding, improvements to other factors requires more than implementation of physical changes. The development based on time and distance involves enhancement of the algorithm, working principle, or computational methods [16-17]. Much focus has been given to obtaining a proper tradeoff between exposure time and accuracy of the radiation measurement. Sequential algorithms are well accepted to strike a good balance for the tradeoff. These algorithms are widely used in many different fields such as: networks [18-19], communications [20], power [21], radiation [22], biometrics [23], and many others. In radiation studies, the dynamic nature of the sequential algorithm gives flexibility to the sample size, decision making, and alarm level. Radiation detection is closely coupled with probability; since the exact nature of radiation is impossible to know, the closet probable scenario is accepted. The Sequential Probability Ratio Test (SPRT) mathematical technique was originally developed by A.Wald in 1947 for process control testing in manufacturing [24]. Radiation detection methods using the SPRT improve detection of the moving source, enhance detection sensitivity, and minimize false triggering [25]. The key objective here is to develop a reliable and fast estimation algorithm for local relative radiation levels.

Deployment of hand-held radiation detectors has been comprehensively studied [26]. Features to help and protect a field surveyor when taking measurements are developed in many national research laboratories [27]. These features are necessary to give the technician more control and flexibility over the measuring unit. Having additional information combined with the technician's experience and knowledge gives him / her a safer tool to perform radiation detection. The study of the necessity to introduce new features for a new generation radiation detector is essential.

1.2 Thesis Outline

In this thesis, the statistical improvements to radiation detection algorithm are analyzed. The first part of the thesis deals with the operation and shortcomings of the First-In-First-Out (FIFO) algorithm used for radiation detection improvements. This is followed by a discussion of possible improvements to the FIFO algorithm. The latter part emphasizes the changes made to the FIFO algorithm and the development of a new algorithm called Last-In-First-Elected-Last-Out (LIFELO) algorithm. Comparisons between both the algorithms are performed to justify the necessity to switch to the LIFELO algorithm. Finally, further improvements to the novel LIFELO algorithm, to give better results and more flexibility, are shown. The simulation results are also presented to reiterate the theoretical findings of the improvements between both algorithms.

The following chapter stresses the advantages of a hand-held radiation detection system and underlines additional features available on a New Generation User Adaptable Radiation Detector (New-GUARD) to help the field survey processes. Currently available and developmental stage technologies are studied to rationalize the need for New-GUARD prototype. The New-GUARD is compared to similar products that are already available in the market to show its completeness as a radiation detector incorporated with Global Positioning System (GPS), wireless communication, and self correcting system.

The thesis is organized into six chapters. Chapter 1 gives the introduction. Chapter 2 introduces the background and the related research. Chapter 3 presents the study of algorithms. Chapter 4 describes a new generation radiation detector. Chapter 5 comprises of results and analysis. Chapter 6 summarizes the conclusion and the future work.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Radiation Background

2.1.1 Radiation Source and Detector

It is found that a few naturally occurring substances consist of atoms which are unstable that is, they undergo spontaneous transformation into more stable product atoms [28]. Such substances are said to be radioactive, and the transformation process is known as radioactive decay. Radioactive decay is usually accompanied by the emission of radiation in the form of charged particle and gamma rays. Outstanding experimental work of Rutherford and Soddy, Pierre and Marie Curie and others established the fact that some types of nuclei are not completely stable [29]. These unstable nuclei emit radiations of three main types, called alpha, beta and gamma radiation. Alpha radiation (α) consists of helium nuclei which themselves consist of two protons and two neutrons. Beta radiation (β) consists of high-speed electrons which originate in the nucleus. Gamma radiation (γ) belongs to a class known as electromagnetic radiation. This type of radiation is often described as consisting of photons which are in some ways analogous to alpha or beta particles [28, 30-31].

The device used to detect, track, and identify high energy particles such as nuclear decay and cosmic radiation is known as a particle detector or better known as a radiation detector. The fact that the human body is unable to sense ionizing radiation is probably responsible for much of the general apprehension about this type of hazard. Reliance must be placed on detection devices which are based on the physical or chemical effects of radiation. These effects include ionization in gases, ionization and excitation in certain solids, changes in chemical systems, and the activation of neutrons. Most of the detectors invented and used so far could be classified into two categories, either gaseous ionization detectors or solid state detectors. Detectors such as ionization chamber, proportional counter, and Geiger-Muller counter fall under the first category. Conductive detectors, Scintillation detectors, and Thermoluminescence detectors belong to the latter category [28, 31-32].

2.1.2 Radiation Hazards

The external radiation hazard arises from sources of radiation outside the body. When the radioactive materials get inside the body it gives rise to an internal radiation hazard, which requires a different method of control [28]. The hazards maybe due to beta, X, gamma or neutron radiation, all of which can penetrate to the sensitive organs of the body. The external hazard is controlled by applying the three principles: time, distance and shielding. The dose accumulated by person walking in an area having particular dose rate is directly proportional to the amount of time they spend in the area. The dose can thus be controlled by limiting the time spent in the area:

$$Dose = doserate \times time \tag{2.1}$$

Next, consider a point source of radiation which is emitting uniformly in all directions. The flux at distance r from a point source is inversely proportional to the square of the distance r. Since the radiation dose rate is directly related to flux, it follows that the dose rate also obeys the inverse square law. The inverse square law may be written:

$$D \propto 1/r^2 \text{ or } D = k/r^2 \tag{2.2}$$

where k is a constant for a particular source. Finally, the third method of controlling the external radiation hazard is by means of shielding. Generally, this is the preferred method because it results in intrinsically safe working conditions while reliance on distance or time of exposure may involve continuous administrative control over workers. The amount of shielding required depends on the type of radiation, the activity of the source and on the dose rate which is acceptable outside the shielding material. The most effective rules consistently employs by radiation workers to minimize exposure when using ionizing radiations are: minimize the time close to radiation sources, maximize the distance away from them and make full use of the shielding [30].

2.1.3 Radiation Measurement

Many results of count rates of the ionization currents made in applications are only provisional when it could be sufficient to simply count rate or ionization current and leave it at that. For a result to be meaningful to others it should include five components as follows:

i. The mean of the series of measurements made for the application of interest

ii. The date and time of day to which the mean refers, called reference time, T_r.

iii. An uncertainty statement-result is invariably subject to uncertainties that must be estimated and stated.

iv. The confidence limit stating the level of confidence of the experiment that the estimated uncertainty will not be exceeded.

v. A statement about the radionuclidic purity of the radioactive material

Results of physical measurements are likely to be subject to errors, e.g failure to correct for the background. They are also subject to uncertainties, e.g. uncertainty about nuclear data obtained from the literature and uncertainties in necessary corrections. Results of measurements of radioactivity and many other properties are subject to two types of uncertainties known as random and systematic uncertainties. While errors could be avoided at least in principle and this will be here assumed, uncertainties cannot be avoided [30, 33]. Systematic uncertainties, e.g. in half life, have to be estimated as best one can, doing guided by conventions and the uncertainty estimates of the experimenters who measured the half life. In contrast, uncertainties in randomly occurring variables can be expected to follow statistical distributions when they can be estimated or verified using statistical theories. It is occurring nuclear decay rates which gave rise to them [30, 33-34].

2.2 Statistical Background

2.2.1 Counting Statistics

The value of counting statistics falls into two general categories. The first is to serve as a check on the normal functioning of a piece of nuclear counting equipment [35]. When this check is performed, the measurements are recorded under environment where the experimental parameters are unvarying. Due to statistical fluctuations, these readings will differ with some degree of internal variation. We need statistical modeling to confidently predict and quantify the occurred variations. The general idea is to maintain the model as close as possible to the fluctuations to avoid any inaccuracy in the model. The second application is generally more valuable and deals with the situation in which we have only one measurement [35]. We can then use the counting statistics to predict its inherent statistical uncertainty and thus estimate an accuracy that should be associated with the single measurement.

2.2.2 Distribution

The Poisson distribution has wide application in many diverse fields, such as decay of nuclei, person killed by lighting, number of telephone calls received in a switchboard, emission of photons excited by nuclei, and appearance of cosmic rays [31]. The Poison distribution is a discrete probability distribution that expresses the probability of a number of events occurring in a fixed period of time, given these events occur with a given known average, and are independent of the time since last event [36]. This distribution was discovered by Simeon-Dennis Poisson and published in 1838 [37]. The formula of Poisson probability mass function is:

$$P(x,\lambda) = \frac{e^{-\lambda}\lambda^{x}}{x!} \qquad \text{for } x = 0,1,2,... \tag{2.3}$$

where λ is the constant rate that the event occurs. The predicted variance of the distribution can be evaluated as [35]:

$$\sigma^2 = \sum_{x=0}^{n} (x-\bar{x})^2 P(x) = \lambda \tag{2.4}$$

giving $\sigma^2 = \bar{x}$.

The predicted standard deviation is just the square root of the predicted variance:

$$\sigma = \sqrt{\bar{x}} \tag{2.5}$$

The Poisson distribution fits a distribution when the following are satisfied [38]:

- The number of changes occurring in non overlapping intervals are independent.

- The probability of exactly one change in a sufficiently short interval of length (h) is approximately λh
- The probability of two or more changes in a sufficiently short interval is essentially zero.

In most cases, the results of radiation measurements are expressed as the number of counts recorded in a scalar. These counts indicate that particles have interacted with a detector and produced a pulse that has been recorded. In turn, the particles have been produced either by the decay of a radioisotope or as a result of a nuclear reaction. In either case, the emission of the particle is statistical in nature and follows Poisson distribution. However, if the average of the number of counts involved is about more than 20, the Poisson approaches the Normal Distribution. For this reason, the individual results of such radiation measurements are treated as members of a normal distribution [31]. The normal distribution is a pattern for a set of data which follows a bell shaped curve. This distribution is also referred to as the Gaussian distribution, named after the great mathematician Carl Friedrich Gauss [36]. This distribution has certain properties; the curve is concentrated in the center and decreases either side. This indicates that the data has less tendency of producing extreme values. The curve is symmetric, underlining the fact that the probability of deviations from the mean is comparable in either direction. Specifically for any normal distribution, two quantities have to be specified: the population mean (μ), where the peak of the density occurs, and the standard deviation (σ), which indicates the spread of the bell curve. Different values of μ and σ yield different normal density curves. The probability density function (pdf) and the cumulative distribution function (cdf) of normal distribution are as follows:

$$f(x;\mu,\sigma)=\frac{1}{\sigma\sqrt{2\pi}}e^{\frac{-(\bar{x}-\mu)^2}{2\sigma^2}} \tag{2.6}$$

$$F(x;\mu,\sigma)=\frac{1}{2}(1+erf\frac{\bar{x}-\mu}{\sigma\sqrt{2}}) \tag{2.7}$$

where the standard normal cdf is just the general cdf evaluated with $\mu=0$ and $\sigma=1$.

2.2.3 Test of Statistical Hypothesis

A statistical test provides a mechanism for making a quantitative decision about a process or processes [39]. The purpose of the test to determine whether there is enough evidence to reject a conjecture or hypothesis about the process. There are two type of statistical hypothesis for any given situation. First is the null hypothesis, symbolized by H_0, is a statistical hypothesis that states that there is no difference between a parameter and a specific value, or that there is no difference between two parameters. The null hypothesis includes an equal sign in its definition of parameter of interest (e.g. H_0: p=0.05). The alternative hypothesis symbolized by H_1, is a statistical hypothesis that states the existence of a difference between a parameter and a specific value, or states that there is a difference between two parameters. This hypothesis includes either a less than sign, a not equal sign, or a greater than sign in its definition of parameter of interest (e.g. H_1: $p<0.05$). There are two types of errors associated with both of the above hypothesis. A type I error occurs when the null hypothesis is rejected given that it is true. A type II error on the other hand occurs when null hypothesis is accepted given that it is false.

Type I error: Rejecting H_0 and accepting H_1 when H_0 is true.

Type II error: Accepting H_0 and rejecting H_1 when H_1 is true.

The test procedure is constructed so that the risk of rejecting the null hypothesis is small. This risk (α) is referred to as the significance level of the test. It is also referred as the maximum probability of committing a type I error. The risk of failing to reject the null hypothesis when it is in fact false is not chosen by the user but is determined by the magnitude of real discrepancy. The risk (β) is usually referred to as the error of the second kind. Large discrepancies between reality and the null hypothesis are easier to detect and lead to small error of the second kind. Also the risk β increases as α decreases.

2.2.4 Sample Size

Determining sample size is a very important issue because samples that are too large may waste time, resource and money, while samples that are too small may lead to inaccurate results. In many cases, minimum sample size for estimation of a process parameter can be easily determined, such as the population mean (μ). The sample mean ($\bar{x}$) calculated from the sample data collected is typically different from the population mean (μ) [40]. Difference between the sample and population means can be interpreted as an error (E). The margin of error (E) is the maximum difference between the observed sample mean and the true value of population mean. The error can be calculated as below [41-42]:

$$E = z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}} \tag{2.8}$$

where σ is the population standard deviation, n is the sample size, $z_{\alpha/2}$ is known as critical value, the positive z that is at the vertical boundary for the area of $\alpha/2$ in the right tail of the standard normal distribution. The sample size necessary for accurate results to a specific confidence and margin error is as follows [14-15]:

$$n = \left[\frac{z_{\alpha/2}\sigma}{E} \right]^2 \quad (2.9)$$

2.2.5 Sequential Probability Ratio Test (SPRT)

Wald's SPRT method has the advantage of handling sequential sampling data [32]. Let $f(x,\theta)$ be the distribution of a random variable x. H_0 represents the hypothesis that $\theta = \theta_0$, and H_1 the hypothesis that $\theta = \theta_1$. Therefore, the distribution of x is given by:

$f(x,\theta_0)$ when H_0 is true

$f(x,\theta_1)$ when H_1 is true

Successive observations on x is denoted by $x_1, x_2, ..., x_m$. For any positive integral value m the probability that a sample $x_1, x_2, ..., x_m$ is obtained is given by:

$$P_{1m} = f(x_1,\theta_1)...f(x_m,\theta_1) \text{ when } H_1 \text{ is true} \quad (2.10)$$

$$P_{0m} = f(x_1,\theta_0)...f(x_m,\theta_0) \text{ when } H_0 \text{ is true} \quad (2.11)$$

The SPRT for testing H_0 against H_1 is defined by the following steps:

1. Two positive constants are chosen A and B (B<A).
2. At each stage of the experiment (at the *m*th trial for any integral value *m*), the probability ratio P_{1m}/P_{0m} is computed.
3. If

$$B < \frac{P_{1m}}{P_{0m}} < A \quad (2.12)$$

then the experiment is continued by taking an additional observation.

4. If

$$\frac{P_{1m}}{P_{0m}} \geq A \tag{2.13}$$

then the process is terminated with rejection of H_0 (acceptance of H_1).

5. If

$$\frac{P_{1m}}{P_{0m}} \leq B \tag{2.14}$$

then the process is terminated with the acceptance of H_0

The constants A and B are to be determined so that the test will have the prescribed strength (α, β). A and B satisfies the inequalities:

$$A \leq \frac{1-\beta}{\alpha} \tag{2.15}$$

$$B \geq \frac{\beta}{1-\alpha} \tag{2.16}$$

For practical computation purposes, the logarithmic ratio of P_{1m}/P_{0m} is used. The reason for this is that the logarithmic represents the sum of the m terms, i.e.:

$$\log\frac{P_{1m}}{P_{0m}} = \log\frac{f(x_1,\theta_1)}{f(x_1,\theta_0)} + \ldots + \log\frac{f(x_m,\theta_1)}{f(x_m,\theta_0)} \tag{2.17}$$

2.3 Algorithm Background

Many algorithms are developed for various applications related to radiation detection. A comprehensive survey of the available algorithms has been performed to obtain substantial understanding of the working principle. Brief descriptions of these algorithms are explained below. The Pacific Northwest National Laboratory (PNNL) has developed computer models for radiation portal monitors (RPM) for screening vehicles and cargo [44]. These models are used to determine the optimal size, configuration, and placement of detectors. Furthermore, it can be used to determine the best alarm algorithm for detecting item of interest while minimizing nuisance alarm. Most of the modeling are done with Monte Carlo code (MCNP) [45] to describe the transport of gamma and neutron alarm. In addition to this algorithm, the PNNL has developed another algorithm for radiation transport modeling. The Monte Carlo [45] methods are typically the tool for simulating gamma-ray spectrometers operating in homeland security settings but the deterministic codes offer potential advantages in computational efficiency for many complex radiation detection problems. Therefore the PNNL collaborated with Sandia National Laboratory (SNL) to develop a Radiation Detection Scenario Analysis Toolbox (RADSAT) using deterministic methods for field calculations and coupling Monte Carlo for detector response [46]. Another algorithm, which helps with radiation detection is the SoftWare for Optimization of Radiation Detectors (SWORD), which is an integrated, end-to-end simulation tool for system architects and detector development teams [47]. SWORD combines realistic radiation environment and nuisance source emission configurations. Additionally, the algorithm support multiple engines, thus both GEANT4 [48] and MCNPX [49] can be used for simulation of instrument resolution, fine geometry detail, and trigger and alarm properties [47]. A simple algorithm to filter statistically varying data has been implemented. The algorithm makes sparing use of microprocessor resources and is usable with integer math, which enhances its usage with single-chip microprocessor units [50]. As a result, very long time constants can be applied without the necessity of waiting for several time constants to pass until the display becomes easy to interpret. Acquiring techniques from different fields to enhance radiation detection are becoming a viable solution. Following this, adaptation of digital algorithms from electrical-engineering field to resolve limitations pertaining to noise and similarity of scintillation characteristics have been performed [51].

Most of the algorithm discussed above does not suit the improvements proposed in this thesis. These improvements involve dynamic sample size for reduction of measurement time. The Sequential Probability Ratio Test (SPRT) provides a better platform for the development of an algorithm, which emphasizes on sample sizes and measurement time limitations. SPRT has been proven successful in many applications [52-55] and is a well known optimal hypothesis testing technique that minimizes the expected sample size for a given error probability [56]. One such application, is a novel approach to automatic classification of quadrature amplitude modulated (QAM) signals algorithm utilizing SPRT. The QAM signals algorithm is formulated by classifying the problem as variable-sample-size test problem [57]. The conclusion of the algorithm research shows that SPRT has several advantages over the classical fixed sample size test. Likewise, in Binary Hypothesis Testing, SPRT requires a minimal sample size to make a decision on whether a signal is normal or faulty. In the context of signal validation, this means that with the same accuracy SPRT can provide the earliest warning for progressive signal faults [58]. In Random Sample Consensus (RANSAC) field, the speed of the RANSAC depends on the probabilities of the two types of errors committed in the pre-test, which are rejection of an uncontaminated model and the acceptance of a contaminated model [59]. The results exhibits that models based on SPRT yields better performance compared to classical models. Moreover, studies have been performed to conclude that SPRT is a statistically valid method to analyze limit standards [60].

Therefore it is safe to conclude that SPRT is a viable technique for constraint optimization problems.

The concern is to determine how applicable SPRT is in radiation field. Research have shown that the properties of SPRT make it favorable for many radiation detection problems, in which alarm decision must be made [61]. For example, the SPRT has been shown to improve monitoring of vehicles [62-63], personnel and packages [64-65]. SPRT properties have been exploited for detection of "off-normal" operation in nuclear reactor surveillance [66-67]. Therefore from the understanding obtain, this thesis performs a statistical studies on SPRT for field survey process and further optimizing the algorithm to reduce false alarm and spatial gap.

CHAPTER 3

SPRT IMPROVEMENT FOR RADIATION DETECTION

This chapter presents the study of algorithms used to analyze the improvements made for developing an accurate and efficient structure for radiation detection. Radiation decay is a random process. Consequently, any measurement based on observing the radiation emitted in nuclear decay is subject to some degree of statistical fluctuation [68]. The detection algorithms form the framework required to process the sample counts and make an accurate interpretation of these measurements. The inherent fluctuations coupled with algorithm imperfections represent an unavoidable source of imprecision or error. The statistical analysis highlights the inconsistency of the measured results compared to the actual results.

The organization of this chapter is as follows: Section 3.1 describes the single threshold test (STT), Section 3.2 studies the SPRT First-In-First-Out (FIFO) algorithm, Section 3.3 presents the SPRT Last-In-First-Elected-Last-Out (LIFELO) algorithm, Section 3.4 views the dynamic background updating, and Section 3.5 explains the Maximum Likelihood Estimator (MLE).

3.1 Single Threshold Test (STT)

A laboratory experiment radiation data were used to compute the results for all the algorithms. The data consists of both gamma and neutron counts per sample. Parameters used to deduce the results are the alarm level and the sample size. A discrepancy in this result translates to a false alarm and spatial gap.

For a decision made using a single sample or STT, the computation is performed using the radiation count of a single sample. First, the mean of the background samples are computed using:

$$\mu_0 = \bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} \tag{3.1}$$

where x_i are individual background samples and N is the total background sample count. Next the standard deviation of the background is given by:

$$\sigma_0 = \sqrt{\mu_0} \tag{3.2}$$

Following this, a threshold level needs to be determined to decide whether the sample contains only the background or the background plus source. An incoming sample is compared to the threshold level given by Equation 3.3 and accordingly producing the output alarm level.

$$T_h = \mu_0 + n\sigma_0 \tag{3.3}$$

In Equation 3.3, n is the alarm increment or the number of standard deviations. When the measurement is below the threshold value the alarm is set to zero. Likewise, when the measurement equals or exceeds the threshold value, the alarm computation is carried out based on the following equation:

$$Al = \left\lceil \log_b(Max[1, \frac{\mu_1 - \mu_0}{\rho\sigma_0}]) \right\rceil \qquad (3.4)$$

where μ_1 represents the source plus background mean, b is the base value, and ρ is the scaling factor. The computed alarm will be 0 or greater depending on the strength of the sample being measured.

When taking measurements in survey areas, the general concern is the condition of a region rather than a single sample. STT gives memoryless computation without taking any samples previously detected into calculation. This could result in misinterpretation of the measurement, due to noise, if the scaling factor is too small. A spike in the reading could arise because of a single radiation source in the background region flagging the region as unsafe.

3.2 First-In-First-Out (FIFO) Algorithm

The First-In-First-Out (FIFO) algorithm generates an alarm level by computing from the oldest data point to the youngest data point available to determine the output of a sample. As the name indicates, at every iteration, samples which were first collected goes through the computation cycle first and give out the resultant reading.

3.2.1 Sequential Probability Ratio Test (SPRT) Basics

The Sequential Probability Ratio Test (SPRT) gives a statistical confidence level to determine results of the measured sample. Observations are collected at a time using Geiger counter unit similar to a radiological survey situation [69]. These observations are Gamma Count (GC) or Neutron Count (NC).

The Null Hypothesis (H_0) is used to represent the possibility that the sample was from low radiation background region, and the Alternative Hypothesis (H_1) is used to represent possibility that the sample was from a higher radiation source plus background region. Test strengths α and β denote false positive (type I) and false negative (type II) errors respectively.

$$\alpha = P(H_1 \mid H_0) \tag{3.5}$$

$$\beta = P(H_0 \mid H_1) \tag{3.6}$$

False positive means that H_1 is accepted while H_0 is true; likewise, false negative means that H_0 is accepted while H_1 is true. Parameters are set to specify the minimum or maximum number of measurements required to make a decision about the sample being source or background. The probably density functions (PDF) correspondent to H_0 and H_1 are $f_0(x)$ and $f_1(x)$ respectively, and all sample measurements are independent of each other. The notations $\{x_1, x_2, ..., x_n\}$ are the measurements of the same spot or sample that has been made so far. The Logarithmic Likelihood Ratio (LLR) is constructed by

$$\Lambda_n = LLR(x_1, x_2, ..., x_n) = log\frac{\prod_{i=1}^{n} f_1(x_i)}{\prod_{i=1}^{n} f_0(x_i)} = \sum_{i=1}^{n} \log\frac{f_1(x_i)}{f_0(x_i)} \tag{3.7}$$

SPRT uses a set of rules to make a decision and for each observation the rules are as follows:

- Accept H_0 and claim that the sample was from a low radiation background
- Accept H_1 and claim that the sample was from a higher radiation source plus background

- Request one more measurement x_i be made over the same sample

To decide which rules are chosen, a set of decision conditions are compared.

1. If $\Lambda_n > B$ accept H_1
2. If $\Lambda_n < A$ accept H_0
3. If $A \le \Lambda_n \le B$ request additional sample

Where A and B are two constants such:

$$A = \log \frac{\beta}{1-\alpha} \tag{3.8}$$

$$B = \log \frac{1-\beta}{\alpha} \tag{3.9}$$

3.2.2 Algorithm

FIFO algorithm generates a conclusion about the sample either being the source or background based on the first several data points of each sample. The data $\{x_1, x_2, \ldots, x_{11}\}$ are the data points of the measured sample and $\{t_{11}, t_{10}, \ldots, t_1\}$ are the respective time the samples were collected. FIFO starts from x_1 to compute for the LLR of the sample measured. Parameters are set to specify the minimum or maximum number of measurements required to make a decision about the location. This is called sample size. The minimum / maximum number of required measurements is denoted by $i\min / i\max$. Parameters $i\min$ and $i\max$ for the source must be smaller than those of the background to keep the exposure time to a minimum.

The process to compute the LLR of a sample is an iteration of numerical analysis. First, the mean and standard deviation is computed for the first data point. Next, take in one more data point into the process until the minimum number of required data points is processed. Following this, LLR computation is generated and compared with the constant values A and B. If the current result is less than the background threshold (A), a decision that the sample is from a background region can be made. Similarly, if the current result is greater than the source threshold (B), a decision that the sample is in a source area can be made. The dilemma occurs when dealing with results in between background and source thresholds. In this situation, more data points are needed to make a decision. If the maximum data points are exhausted and the current result is still in between background and source thresholds, an approximate decision is made based on the following formulas:

- If $\Lambda_{i\max} \leq \frac{A+B}{2}$ accept H_0
- If $\Lambda_{i\max} > \frac{A+B}{2}$ accept H_1

Another important parameter is the overlapping factor $(ilap)$, which treats the sampling sequence as a continuous sequence. Figure 1 describes how the $ilap$ parameter functions. In Figure 1, if $ilap$ is negative, the distance between the beginning of one sample and the next is the absolute value of $ilap$. On the other hand, if ilap is positive, the distance between the beginning of one sample and the next is $n - ilap$, where n is data points of each sample. With this argument, sample data are used efficiently and different samples have same pace from data points.

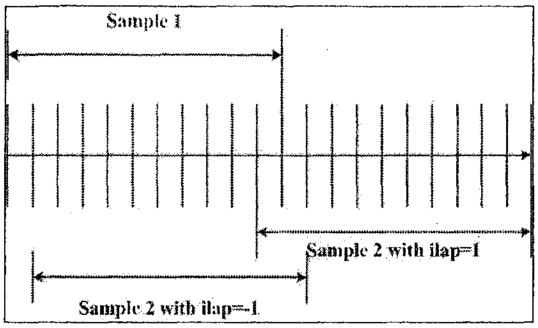


Figure 3.1. Description of ilap

For radiation detection, two distributions are commonly used, normal distribution $N(\mu,\sigma^2)$ and Poisson distribution $p(\mu)=N(\mu,\mu)$. Based on different choices for the distribution functions for H_0 and H_1, there are four potential hypothesis combinations or treatments. These four cases are briefly described below:

Case 1: H_0 using normal distribution and H_1 using normal distribution (NN) ($\mu_1 > \mu_0$)

- Likely combination for low background and low source such as Neutron counts for nuclear waste search.

Case 2: H_0 using normal distribution and H_1 using Poisson distribution (NP) ($\mu_1 > \mu_0$)

- Likely combination for low background and high source such as Neutron counts for Special Nuclear Material (SNM) search.

Case 3: H_0 using Poisson distribution and H_1 using normal distribution (PN) ($\mu_1 > \mu_0$)

- Unlikely combination and kept for comparison purpose.

Case 4: H_0 using Poisson distribution and H_1 using Poisson distribution (PP) ($\mu_1 > \mu_0$)

- Likely combination for high background and very high source such as Gamma counts.

The final step of the algorithm is alarm computation. The outcome of the SPRT process is either accepting H_0 or H_1. If H_0 is accepted the resultant alarm is zero. Else, if H_1 is accepted, then the alarm level must be calculated to indicate the source strength. Linear Departing Coefficient (LDC) is defined as

$$LDC = \left\lceil \frac{\mu_1 - \mu_0}{\rho\mu_0} \right\rceil \tag{3.10}$$

where $\rho(0 < \rho \leq 1)$ is a proportional constant. When $\rho = 1$, the LDC indicates the number of standard deviations away the source is from the mean of the background radiation. The LDC alarm level is very large compared to the desired alarm level. Therefore, the Log Departing Coefficient (LGC) is preferred.

$$LGC = \left\lceil \log_b(Max[1, \frac{\mu_1 - \mu_0}{\rho\sigma_0}]) \right\rceil \tag{3.11}$$

The FIFO algorithm is designed to allow different settings for the user to evaluate the samples. Gamma Count (GC) or Neutron Count (NC) will provide the input data for the algorithm. The user can choose to measure GC, NC, or both GC and NC simultaneously. Another setting that is specified by users is the scaling factor. This consists of two variables ρ and base value b. The base value could be either 2 or exponential value (e). The data point taken to compute the resultant alarm starts from the oldest sample and moves towards the youngest sample. Therefore, the sample being analyzed may not be used in the computation of the alarm. This types of occurrences could result in errors between the radiation sample measured and the resultant alarm.

3.2.3 Experimental Data

The data for the simulation was collected using a handheld radiation detector in an in-door laboratory at Nellis Remote Sensing Laboratory, Las Vegas. The raw data contains many information such as: sample Id (ID), Gamma gross count (GC), Neutron gross count (NC), Gamma alarm (GA), ratio alarm (RA), Neutron alarm (NA), time elapse since sample exposed in seconds (ELAPS), time for individual measure in seconds (SUM60S), and distance from the sample source in feet (DIST). The data points for the simulation are taken to analyze the behavior of the FIFO algorithm. Samples are taken from regions that exhibit constant background and source, transition from background to source, and vice versa.

3.3 Last-In-First-Elected-Last-Out (LIFELO) Algorithm

The Last-In-First-Elected-First-Out (LIFELO) algorithm takes the current sample point to start the SPRT calculation process. Instead of taking a new sample point to help compute the SPRT, the algorithm will take the previous sample points collected in the negative x-direction.

3.3.1 Algorithm

The changes implemented to the algorithm to perform the SPRT in the negative x-direction are as follows. Create a stack of size 11, the maximum number of samples needed to conclude the alarm level of a sample. Push data points of the sample to a stack, and then pop each data point to compute. The reason for stacking is instead of working from the oldest data point to the youngest, stacking will move from the calculated current data point to the oldest available in the stack. The rest of the calculation process is the same as the previous algorithm. Once a decision for the current sample has been made, the stack is emptied and the data points are entered for a new sample. The last change is that instead of taking the data from the original whole *dataIn* vector, data is only taken from the stack. This eliminates the usage of the ilap parameter.

3.3.2 Improvement Measurement

From the previous understanding, the FIFO algorithm has some degree of error when measurement is taken in certain regions. To evaluate the performance of both the algorithms, couple of criteria has been considered. Two major points of consideration when analyzing the data are false alarm and spatial gap. False alarm occurs when there is an inconsistency between the gamma count and the resultant alarm output level. Spatial gap is the distance or number of samples between the sample being computed and the resultant output. For example, when computing for the 39^{th} sample point, a resultant alarm is produced at the 34^{th} sample, translating to a spatial gap of five samples.

3.4 Dynamic Background Updating

Dynamic background updating is used to help increase the reference background level automatically. Initially, a fixed (static) background value (μ_0) was used to compute the resultant alarm level. The background value taken for computation was measured using a sequence of background samples at a particular location before the start of the survey. Initial background calculation is performed using

$$\mu_k = (\frac{k-1}{k})\mu_{k-1} + \frac{SPC}{k} \tag{3.12}$$

where k is the background sample count, SPC is the strength of the sample being measured and μ_{k-1} is the previous background mean. When a technician performs background computation, Equation 3.12 is looped for the entire period as set by the technician. A normal background calculation could be from 30 seconds up to 5 minutes. This background reading will be set as the new μ_0 value and the technician starts the survey process.

To increase the flexibility of the algorithm, dynamic background updating is utilized. The purpose of the improvement is to allow the technician to have an automatic update of the background according to the region surveyed. Automatic background updating will occur when three conditions are satisfied. The conditions are

i. The LLR computation results in $A \leq \Lambda_n \leq B$

ii. The maximum available samples to come out with a decision have been exhausted.

iii. $\Lambda_n < (\frac{A+B}{2})$ and alarm=0

When these scenario arises, the initial background value will be updated using Equation 3.12 and the background mean will be set to the updated background mean $(\mu_0 = \mu_k)$. The remaining of the measurements will be carried out as normal. There has to be a threshold value to ensure that the updated background value does not reach a source. The threshold can be set as

$$\mu_{THD} < \rho\mu_0 \tag{3.13}$$

where ρ is the scaling factor, which is normally set to 6. Now, Equation 3.13 becomes an additional condition for automatic background updating. If this condition is not met, the algorithm will continue to use the previous background mean μ_{k-1} for the remaining computations.

3.5 Maximum Likelihood Estimator (MLE)

Poisson distribution has only one parameter and is estimated as

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{3.14}$$

and the mean and standard deviation are the same. Assume that we have a sequence of an independent observations from a normal distribution $N(\mu,\mu)$ where $\mu(>0)$ is an unknown parameter. Such a model will make good sense to approximate a Poisson distribution $p(\mu)$, especially when $\mu(>0)$ is moderately large [69]. The $N(\mu,\mu)$ distribution obviously belongs to one-parameter exponential family. Having recorded the observations, $X_1, X_2 ..., X_n$, the statistics

$$T_n = \frac{1}{n}\sum_{i=1}^{n} X_i^2 \tag{3.15}$$

is both complicated and (minimal) sufficient for $\mu, n \geq 1$. The maximum likelihood estimator (MLE) for μ turns out to be

$$\mu_{MLE} = \sqrt{T_n + \frac{1}{4}} - \frac{1}{2} \tag{3.16}$$

CHAPTER 4

IDEAL NEW AGE RADIATION DETECTOR

Radiation detection is classified as a hazardous task. The technicians taking the radiation measurement are exposed to the radiation for a long duration of time. Reduction of human intervention while detecting radiation is highly desirable. This is the main drive towards developing a new generation hand held detector which will eventually reduce the need for human to take measurements. The concept is strikingly simple: to use a detector to obtain radiation data, log the information, process, and send it out to a remote location. The information logged and sent out includes radiation data, location information, alarm, and comments. The idea is to implement all features onto a single device with self-correcting capabilities.

There are many such developments taking place at the moment. This chapter will shed some light into these developments, highlighting important features and underlying the major differences to the device proposed. The organization of this chapter is as follows. Chapter 4.1 looks at available devices and technologies and understands each working principle. Chapter 4.2 analyzes the devices and describes ideal detector. Chapter 4.3 talks about proposed development and feasibility.

4.1 Technologies

4.1.1 Proposed Technologies

These technologies are currently in the research and development stage. Prototypes are built to test the capability of the devices. Some of the inventions are still in the incubator stage and will soon be released for consumer use.

A portable radiation detector unit and a portable GPS unit were combined to measure the gamma radiation and subsequently used to map the area of radiation [70, 71]. The research shows that since the device is portable it can be used to access terrains which are accessible only by foot. In the paper, development of an easily useable and portable tool, which performed radiation and positional data logging for post processing, was studied. Mapping of a contaminated area took place in the office after the post processing of the data. The parts for developing this tool were readily available from off the shelf devices. The primary purpose of this development was to prototype a tool which is low cost and easily used. NaI portable gamma detector (Exploranium GR-130) [72] was used for radiation detection. Bluetooth enabled pocket PC (PPC) (iPAQ 2210) [73] is connected to the detector via RS-232 (Brainboxes BL-521) [74] communication device. The GPS unit (Navman BT 4400) [75] is used for position data logging. Microsoft Embedded Visual Basic software performs the data logging process. Data are outputted serially via the RS-232 from the detector to the PPC [70, 71]. The information from the PPC is transferred to the post processing computer using the Bluetooth and the range is up to several tens of meters. The PPC receives position data from the GPS with a transmission range of about 10 meters. Since the unit is hand-held, the GPS is mounted on the head for better reception. The technician carries the detector, GPS, and the PPC around the area being measured. The detector data and position data is transmitted to the PPC periodically. Post processing involves transforming the data logged into a map with regular grid and contour lines [71]. The paper [70, 71] proposes this device because it is low cost, portable and enables large area mapping. The device also has the capability of accessing rough terrains by foot. It is a light weight device and since all the transmission are wireless it is useful when progressing through rough terrain. The device will be a good fit to be used in post-accidents sites.

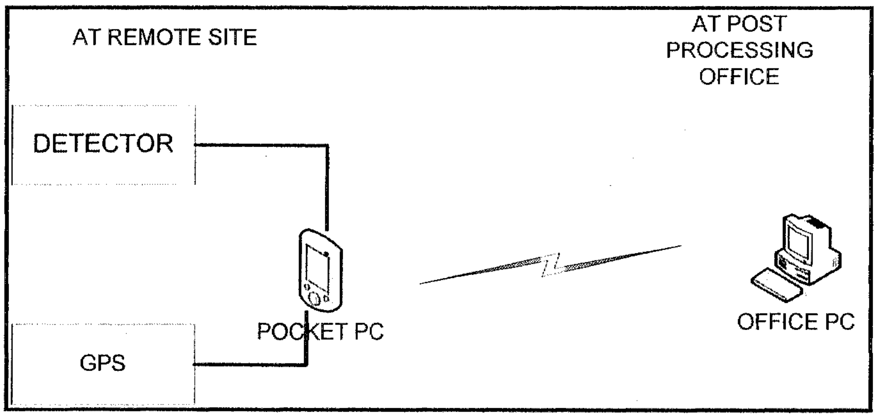


Figure 4.1. Prototype Block Diagram

Surface contamination surveys are carried out by soil sampling using hand-held radiation detectors. This method proves to be costly, time consuming and results in long delays [76]. The research suggests that using accelerated analysis as a solution for the problem does not justify the cost increase. The researchers proposed a method which takes into consideration the real time detector and position data for deducing the resultant output. The prototype uses a large area plastic scintillation (LAPS) as the detector. A HHD 440A mobile unit [77] is used to mediate the LAPS, data display, and laptop. The Motorola GPS gives the positioning information to the mobile unit. Data logging is carried out by the laptop for both the detector count rate and GPS positional data. An additional fixed-base Motorola GPS is used as time-reference correction factor for post processing to increase positional accuracy. The detection process begins by transporting the LAPS and the GPS equipment over the survey area. Recording of the measured count rate and positional information is taken simultaneously while traversing over the survey area. The final step of the process is to combine all the information from the detector and the GPS and make a graphical representation of the surveyed area. The paper [76] proposed this new configuration because this detector can be used rapidly to survey large areas. Site-specific graphical representations of these surveys are used to guide remediation soil sampling.

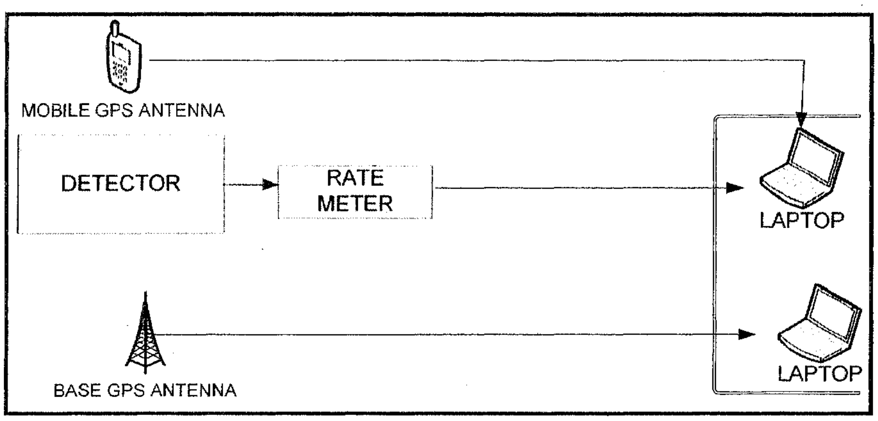


Figure 4.2. Configuration of LAPS / GPS Equipment for Field Use

MFG Inc. in 2001 developed a Global Positioning System (GPS)-based gamma scanning technique for use during site surveys at large area in-situ-leach uranium mine developed in Kazakhstan [78]. According to the researchers, since 2001 the system has improved, and high speed scanning allows 100% coverage of a site in a short period and also providing color-coded output defining gamma exposure rates over the entire site. The system developed for gamma scan uses off the shelf components to build a mobile scanning unit. Ludlum 2350-1[79] radiation detection data logger is used as a radiation display, storage, and has a bidirectional communication (RS-232) with a PC. Ludlum 44-10 [80] 2x2 inch NaI gamma detector on the other hand is used as the gamma scintillator and is connected to data logger. Garmin iQue 3600 [81] is a PDA with an integrated GPS system, which allows data from data logger to be transferred into itself and at the same time logs the positional information. A MFG code is used to process the data in the PDA to enable easy viewing [78]. The GPS data is captured internally in the PDA and the RS-232 transfers data from the data logger to the PDA. The system can be deployed as a backpack configuration or can be changed to cover large areas by using multiple detectors carried on a truck. To enable this change the iQue 3600 is substituted with individual WAAS-enabled GPS [82], and having additional equipments such as USB hub and portable computer. The latter configuration improves the data collection speed [9]. The researchers [78] believe current configuration allows very rapid data collection, development of useful correlations between soil concentrations and gamma exposure rates, and display of very large sets in a flexible and easily reviewed format. The system is currently in use at several U.S. remedial action sites.

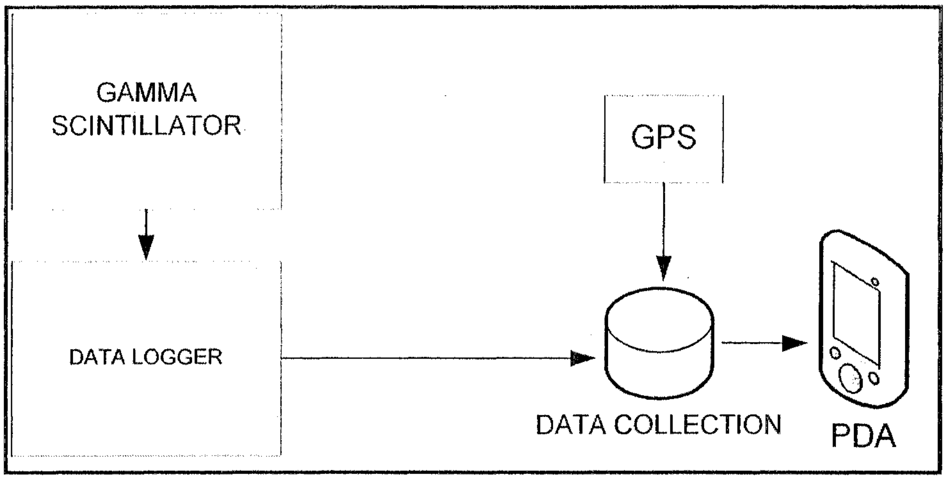


Figure 4.3. System in Backpack Configuration

Lawrance Livermore National Laboratory (LLNL) has developed a prototype that allows detection of radioactive material and mapping the background across a broad area [83]. The researchers emphasize that the prototype is small in size, has high-spectral-resolution detector, long battery life, and operates autonomously. Collaboration with National Nuclear Security Administration allows the prototype to be further enhanced by adding new generation gamma-ray sensors and GPS module built into a cell phone. The unit uses pixilated cadmium zinc telluride (CZT) [84] detectors coupled with an ultra-low-power readout with moderate energy resolution. The GPS system used for this prototype is Trimble Lassen SQ GPS [85], which is integrated into the detector package. The radiation detector is very compact, and therefore, could be placed inside a cell phone. Furthermore, there is two-way text messaging available in the cell phone as well. When a radioactive material is detected, the time and location is tagged. This information is transmitted autonomously via a two-way commercial wireless network to a central server using a socket layer over a transmission protocol / Internet protocol [83]. This is a near-real-time communication and allows for changing detection thresholds, reduces false alarm, and responds to other operational considerations. Display for user interface with dosimetry and consequence management is provided by the cell phone display. The central system monitors the data from the network of devices and provides additional sensitivity by tracking below-threshold alerts, correlating measurements from different detectors passing the same location at different times, and iteratively adjusting system thresholds to account for transient events [83]. The research states that the only maintenance required is charging the battery periodically. This device can be used as radiation alarm, personal dosimeter, search instrument, and analysis tool [83]. According to the developers, this device is ideally suited for military personnel, Transportation Security Administration screeners, U.S. Customs and Border Protection agents, Postal Service personnel, public safety personnel, delivery service workers, and even nuclear search teams.

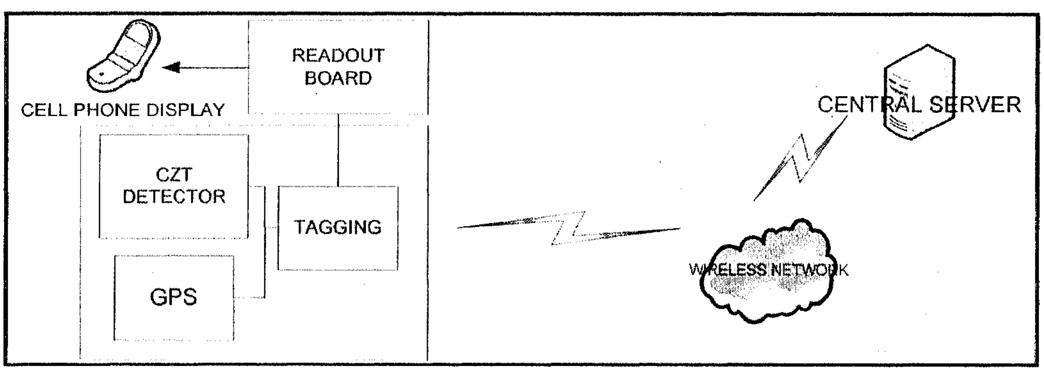


Figure 4.4. Prototype Block Diagram

A network of radiation detection instruments, each having a small solid state radiation sensor module integrated into the cellular phone, provide radiation detection data and analysis directly to users [86]. The paper states that the collected data from the entire network of radiation detection instruments are combined by intelligent correlation / analysis, which maps background radiation and detect, identify, and track radiation anomalies in the region. The instrument comprises of wireless mobile communication device, a detector connected to the mobile communication device, tools for analyzing the data, and display via the same device. The mobile communication device is a cell phone and has the capability of accessing the Internet for data transfer using a web base protocol. The transmission is real-time and is done to the data server of the central monitoring system. The researchers emphasizes that the present invention relates to detection instruments and networks, and more particularly to a cellular telephone-based radiation detection instrument and wide-area detection network comprising a large number of such instruments for monitoring, detecting, and tracking radiation in a given geographic location.

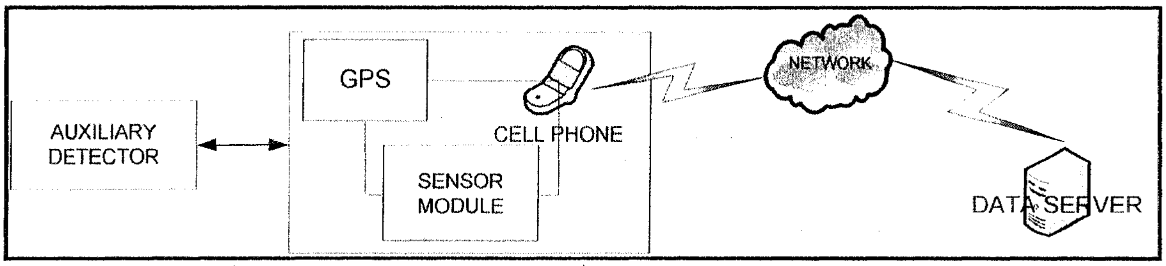


Figure 4.5. Cellular-Based Detector Overview

Lawrance Livermore National Laboratory (LLNL) is working on a PDA that can detect nuclear materials [87]. The device is known as RadNet, and the features include web browsing, PDA, pinpoint location, and detect nuclear materials with cutting edge sensors. The ultimate goal of this project is to create a large network of roaming sensors over a large area. Currently all phones are part of a large network, and the idea is to take it one step further by moving sensors around large area and transmitting information back to a central hub. The information consists of radiation patterns and positions, which enables the authorities to easily detect and track the source. This type of device does not need human monitoring because a microprocessor automatically monitors all the reading and sends an alarm to the central server when the reading is above a threshold level. The researchers believe this prototype could be carried further and built into large assortment vehicles. The technology also can be used to detect chemical and biological agents.

Researches are carried out to introduce a technology where a network of nuclear radiation detectors sense radiation and track possible radiation sources [88]. The paper proposes personal communication devices such as cellular phone, satellite phone, pager, and PDA to have the detector embedded inside them. When radiation levels above a certain threshold are detected, the detector sends signals to the personal communication device to transmit relevant data to the authorities (e.g. central reporting server monitored by FBI). The factors for the assessment include quality of alarm and radiation level. The device proposed is small and non-invasive, thus eliminating arbitrary and uncontrolled action by the user. This device is comprised of wireless personal communication device housing. There is a wireless communication to and from the device allowing transfer of information. The proposed nuclear radiation within the housing is Geiger-Muller tube

[89]. This detector provides a detection signal in response to sensing radiation levels above a predefined threshold [88]. This automatically triggers the transmission of the information to relevant authorities. Each transmitted message contains information such as radiation level, type of event sensed, time of detection, date of detection and unique device identification number. Furthermore, location information sent includes GPS coordinates. The researchers believe what is needed to enhance radiation detection and increase response time is a geographically-distributed network of discreet radiation detectors that can readily be deployed to detect, report, and track the existence of radioactive material.

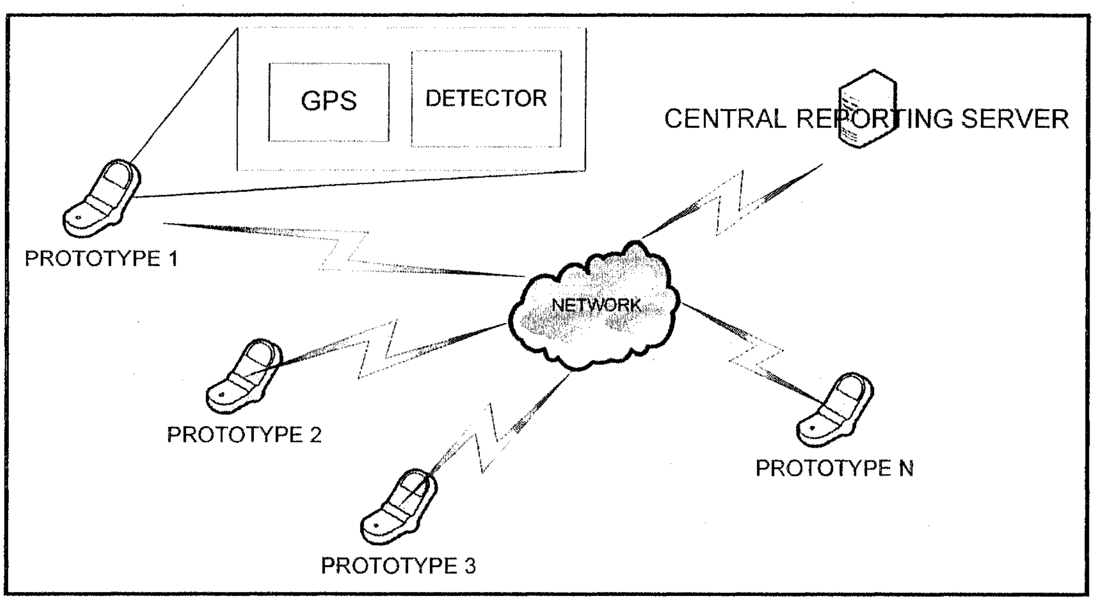


Figure 4.6. Distributed Network of Radiation Detectors

National security forces use custom-developed devices to help detect radiation and wirelessly transmit data for expert analysis [90]. However, the researchers believe the size, weight and complexity often limits their usefulness and surely the field technicians would benefit from smaller, more accurate and more portable radiation detection devices. William Murray from the Los Alamos National Laboratory (LANL) created an innovative solution for a mobile nuclear radiation detector [90]. His innovation is comprised of a radio isotope small enough to attach to a Palm hand-held [91]. The embedded microprocessor in the radiation detector communicates with the Palm hand-held and wirelessly transmits data about a suspected reading for further analysis. When an alarm is triggered, other users can also be alerted by sending the data trough the National Nuclear Triage System [90]. This also enables the official to quickly respond to the danger at hand. The radiological assistance teams for the Department of Energy (DOE) are equipped with the portable radiation detectors [90]. DOE plans to produce more detectors which will be issued to custom officials, law enforcement, and others involved in nuclear emergency situations.

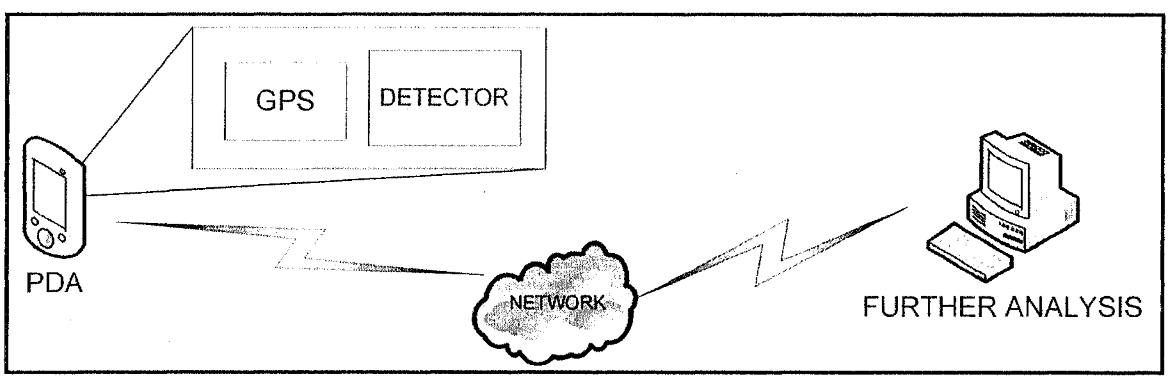


Figure 4.7. LANL Portable Detector

A hand-held system for collecting and storing radiation data and position data is comprised of a hand-held computer with a microprocessor communicating with a storage medium and communication interface [92]. A radiation detector provides data to the hand-held computer and is connected to an interface. The position detector (GPS) sends the position data to the microprocessor. A program code enables the microprocessor to retrieve both position and radiation data individually. Then correlating both the informations and storing them [92]. The process could be performed in any interval set by the user. The intervals could be chosen based on time, position, and distance.

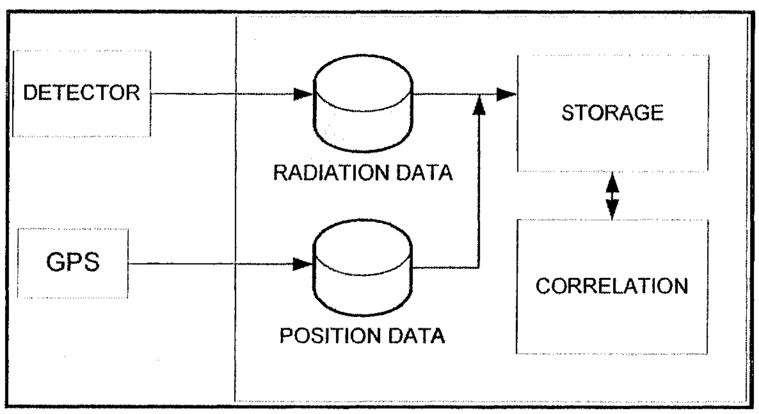


Figure 4.8. Working Principle Layout

4.1.2 Developed Devices

New generation radiation detection devices are already available in the market for usage. There are additional features to the detectors that have not been incorporated yet. These devices allow safer field monitoring for the technicians.

Abacus is a product developed by SE International Inc. [93] to help improve radiation detection. Abacus is a hand-held digital radiation device that enables the user to expedite the detection process. The survey of an area could be completed automatically with the help of a Windows Mobile, Palm Pilot or Windows Computer. For low level alpha, gamma and x-rays, the system has excellent sensitivity. To add to this feature, the internal "guard" detector automatically performs gamma subtraction from the "pancake" detector for an unprecedented beta sensitivity [93]. The software is programmed to allow the user to choose a wide range of applications. The completed survey information is wirelessly transferred via Bluetooth to any desired computer within a distance of 30 ft [95]. Additional features also include a red count light, beeper sound and selectable alarm threshold for quick assessment. From the application point of view, the system allows different screens to be selected for different operations: for example, rate meter screen, total count screen, total dose screen, and data logging screen [94]. The system also allows for common procedures to be performed, such as establishing background count, environmental area monitoring, checking for surface contamination, determining activity, and radiation measurement units. The specifications are highlighted in [93-95], two internal tubes measure radiation and the user can view different type of displays and finally the output is serially connected using Bluetooth.

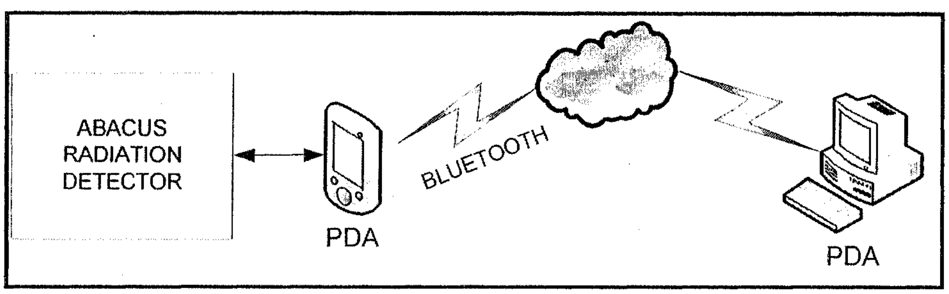


Figure 4.9. Abacus Radiation Detection Configuration

Homeland Security is developing a portable radiation detection and mapping instrument to help emergency personnel to immediately detect and identify the agent and map the boundaries of the event [96]. In case of large-scale event, making quick identification of the agent will save valuable time and help prevent unnecessary casualties. The prototype developed is a hand-held device which measures the intensity of the contamination and simultaneously records geographic information. Navigation software assist emergency personnel to and back from the location of the event. This navigation system relies on the GPS to retrieve the location information. The GPS and radiation data is continuously monitored and sent to the command center via wireless network General Packet Radio Service (GPRS) or (802.11a, b, g) [97]. The processed data can be shown on a map or directly used for real-time events. The reseachers believe that the prototype can be valuable when dealing with a quick response to radioactive, biological, and chemical toxins that would pose long-term danger.

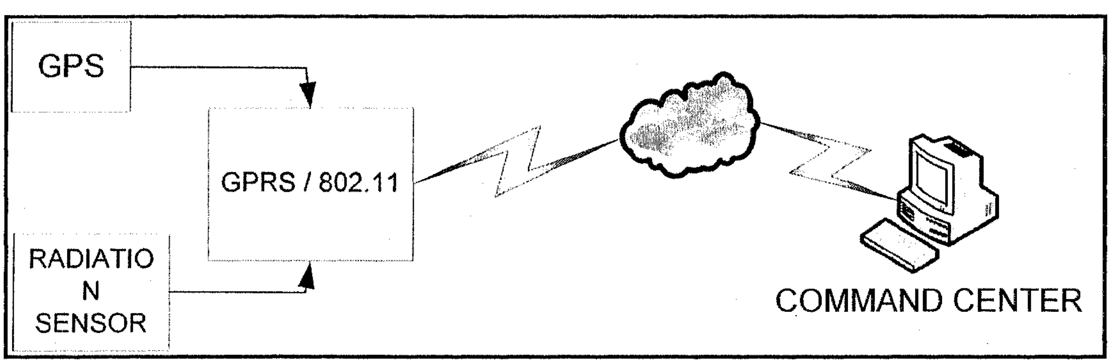


Figure 4.10. Working Principle of Prototype

4.2 In Search of Ideal Radiation Detector

4.2.1 Analysis

An analysis of on going research, development, and the prototype is carried out to further understand the capability of each of the studied devices.

Table 4.1. Technology Comparison part (i)

Technology Developers	Radiation Detector		GPS		Wireless		Processor	
	Single Unit	Multiple Unit	Integrated	Non-Integrated	RS-232 Serial	PSTN / Blue-tooth	PDA / Pocket PC	Laptop
J.Paridaens	✓	×	×	✓	✓	✓	✓	×
US DOD	×	✓	×	✓	✓	×	×	✓
MFG Inc.	×	✓	✓	×	✓	×	✓	×
LLNL	✓	×	✓	×	×	✓	✓	×
Balchunas, Rogers	✓	×	✓	×	×	✓	✓	×
LANL	✓	×	✓	×	×	✓	✓	×
Bosco, Sabados Maddux	✓	×	×	✓	✓	×	×	✓
S.E. Int.	✓	×	×	×	×	✓	✓	×
SKF	✓	×	×	✓	×	✓	×	✓

Table 4.2. Technology Comparison part (ii)

Technology Developers	Device		Graphic		Processing		Self Correcting	
	Single Unit	Multiple Unit	Mapping	Graphs	On-site	Post	Vertical	Horizontal
J.Paridaens	×	✓	✓	×	×	✓	×	×
US DOD	×	✓	✓	×	×	✓	×	×
MFG Inc.	×	✓	×	×	✓	×	×	×
LLNL	✓	×	×	×	×	✓	×	×
Balchunas, Rogers	✓	×	×	×	×	✓	×	×
LANL	✓	×	×	×	×	✓	×	×
Bosco, Sabados Maddux	×	✓	×	×	✓	×	×	×
S.E. Int.	×	✓	×	✓	✓	×	×	×
SKF	×	✓	✓	×	×	✓	×	×

Table 4.3. Overview of Available Technology

Developers	Development Stage	Structure	Field of Application
J.Parideans	R&D, Prototype	Collect radiation and positional data, post-process and map the region	Post accident sites
U.S. DOD	R&D, Prototype	Collect radiation and positional data, post-process and map the region	Survey large area and remedial soil sampling
MFG Inc.	R&D, Prototype	Collect radiation information and positional information, transfer to PDA and instant viewing of result	Survey large area and remedial soil sampling
Lawrance Livermore National Labarotory (LLNL)	R&D, Prototype, U.S. Patent	Geographically distributed network of detectors (cell phone), cover a large area at one time, send information from cell phone to central server and if multiple cell phones show alert, send response team.	Military, Postal Service, public safety personnel, Transportation Security Administration screeners, U.S. Customs and Border Protection agents, delivery service workers, and nuclear search teams
C. Balchunas, D.A. Rogers	U.S. Patent	Geographically distributed network of detectors (cell phone), cover a large area at one time, send information from cell phone to central server and if multiple cell phones show alert, send response team.	Readily be deployed to detect, report and track the existence of radioactive material
Las Alamos National Laboratory (LANL)	R&D, Prototype	Geographically distributed network of detectors (cell phone), cover a large area at one time, send information from cell phone to central server and if multiple cell phones show alert, send response team.	Custom officials, law enforcement, and others involved in nuclear emergency situation
C.D. Bosco, W. Sabados G. Maddux	U.S. Patent	Collection of radiation and positional data, processing and storing for later use	Post accident evaluation and analysis
S.E. International Inc.	Product	Collect radiation reading and transfers to PDA for easier viewing and on-site processing	Technician on survey sites
SKF, Homeland Security	Product	Gives intensity of the contamination and simultaneously recording geographic information, navigates emergency personnel to and from site	quick response to radioactive, biological, and chemical toxins that would pose long-term danger

4.2.2 Ideal Detector

The new direction for radiation detector development is the integration of the detector, global positioning system (GPS) unit, wireless communication, and self-correcting system. In recent years, there have been much research and development of prototypes of such devices. The main focus is to identify the components of an ideal detector for the new generation. Key components for new generation radiation detectors should have the following:

i. Single Unit (Integrated)

Portability is an essential measure towards developing a hand-held detector. A field technician always prefers to carry a single unit which will perform the same functions as multiple devices. For example, a device which has a detector, pocket PC, and GPS as non-integrated parts requires the technician to carry them individually. This may delay the technician when changing any of the settings.

ii. Global Positioning System (GPS)

Tagging the positional data together with the detection data is important for both on-site processing and post-processing. The latitude and the longitude information of a measured area gives the availability to map the radiation strength of the area with relative to the position. This capability provides better visualization for future process since the information can be converted into graphical representation.

iii. Wireless Communication (Bluetooth / Public Switched Telephone Network (PSTN))

The collected data has to be sent in real-time to the central processor for further analysis. This enables other technicians to monitor the detection process remotely.

The collected data has to be sent in real-time to the central processor for further analysis. This enables other technicians to monitor the detection process remotely. Furthermore, when using robots to replace humans for taking reading, it is essential to get a real-time reading of the sample strength.

iv. Pocket PC / PDA

A hand-held central hub that allows monitoring of all the data on-site is necessary to enable easy interface for the technician. A graphical user interface (GUI) available on the PPC or PDA permits easy viewing of the information being measured and collected. These devices allows easy configuration of the settings and user comments.

v. User Interaction / Interrupt

It is important for a field surveyor to have as much control over the detector settings as possible. The surveyor must be able to set many different parameters before, during, and after the detection process to best of his / her knowledge. This reduces the chances of errors as the surveyor has constant watch and control over the measurements.

vi. Self-Correction (Horizontal and Vertical)

To minimize error due to inclination, the detector needs to be coupled with self-correcting devices. When carrying the detector over the survey area, the technician might not point the detector directly to the samples being measured. Due to this tilt, the resultant reading may be higher or lower then the actual reading. A device like accelerometer gives the difference in inclination and allows the PDA to compute out the exact reading.

vii. Compass

A compass enables the technician to locate his / her relative position. Also, the angle reading on the compass helps self-correcting computation process.

viii. On-Site Processing

The radiation detector unit must have the capability to process all the data and immediately show the output in real-time. This is critical for the technician because he / she needs to know the condition of the region, whether it is background or source. This is one of the important steps towards the next generation of detectors, whose main aim is to reduce exposure to hazardous regions.

ix. Graphic Representation

Interpretation of the data as maps or graphs allows easy viewing for the technician.

x. Data Storage

Only important information collected will be sent to the central processor to reduce delay. Other information are stored on the device and taken back to the office after the end of the survey process and then transferred into the central processor. Therefore, it is important to have a sufficient memory on the device to hold all the information.

4.1 Development

4.1.1 Proposed Prototype

The proposed prototype, which will be developed, consists of many features that should be on an ideal radiation detector. A GPS integrated with a PDA will be used as the housing and serves as the backbone of the radiation detector. Positional information will be logged into the PDA, and since the system is integrated, there are no worries about delay in transfer of information from the GPS unit to the PDA. The latitude and longitude of the location is tagged simultaneously with radiation data. This information will be used to map and identify different regions: source and background. We want to embed a radiation detector to the PDA. This will give us a single device that can perform all features desired. A single unit is preferred by the field surveyors because it is easy to handle and the concentration is only on a single device to acquire all the information necessary.

Real-time transfer of the information collected is essential in developing a new generation of radiation detectors. The data needs to be transferred to a central server for further processing. Since the main aim is to keep the unit as small as possible, extensive analysis to the data cannot be performed on the PDA. Therefore, technicians at the backend will process the real-time data and come up with the analysis result faster than the conventional method where the data will be stored on the device while taking measurements and be brought back to the central server at the end of the survey for processing. For the prototype proposed, there are two types of wireless communication. First, is the Bluetooth which is readily available with the PDA. Bluetooth allows many devices to connect to the PDA simultaneously for unidirectional or bidirectional processing. For example, the radiation detector has an option to send the measured sample reading to the PDA via the Bluetooth. Another wireless communication available is using the existing public switched telephone network (PSTN) for cell phones to send information to the central server. For instance, when the field surveyor comes across a dubious reading, he / she can make a comment and send it using the text message service available. This gives an opportunity to the backend technician to analyze the problem and alert the field surveyor immediately if the area is hazardous. This feature is important when the radiation detection unit is transported over the survey area on a robot while controlling the detector remotely.

When a field surveyor is taking a measurement, there are many situations when an error could occur. Since the terrains in the regions are rugged, probability for error increases due to the inclination of the detector. To overcome this problem a self-correcting system has been proposed. The self-correcting system consists of an accelerometer, dipping meter and compass. A compass and dipping meter will give the reference for the angle and azimuth reading and the accelerometer will align the detector back to the origin based on the x, y, and z dimensions. Reading from these devices coupled with the measurement from the detector will be used to compute final reading. The compass is also used to help the surveyor to navigate around the survey area.

An extra memory space for storage is added to the prototype. This allows the PDA to store all the information collected and later transfer to the central server for processing. This is a precautionary method against leaving out any small details when a survey is carried out. Since there has to be a transfer of information from on-site to backend in real-time, there is limitation on the amount of information that can be transferred. Therefore, only important data is transmitted in real-time and others are stored for post survey transfer.

Post-processing of the data is a common practice in radiation detection analysis. The goal is to reduce technician's exposure to high radiation / hazardous area. Thus, it is important for the technician to receive result from on-site processing analysis about the region. Instead of post-processing both the positional and radiation data and finally mapping the area, our prototype will perform an automatic update when the data is received and simultaneously map the region. This enables the technician to observe the trend of the region he / she has transverse and make better judgment to avoid exposure to high radiation area. This prototype also allows the user to interrupt the computational process and make changes to the settings. Since the surveyor has knowledge of the region, it is important to allow the technician to make changes to the settings, such as updating the background reading or retake a sample reading.

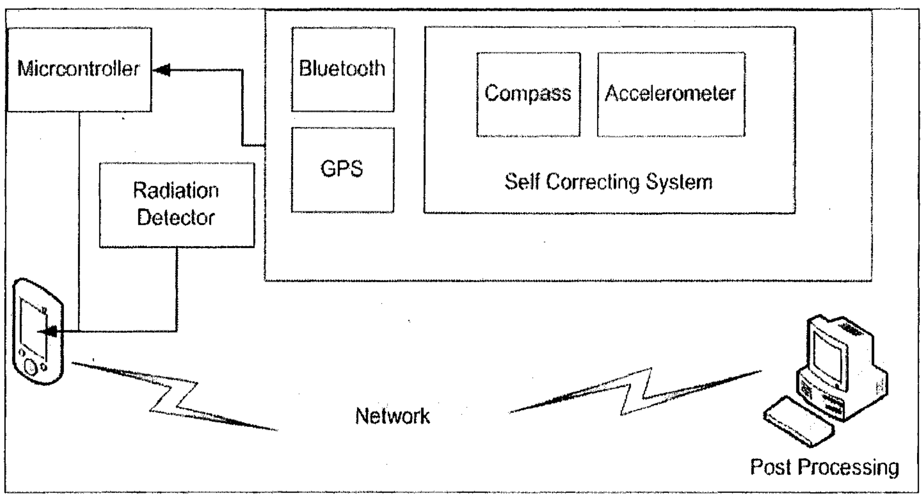


Figure 4.11. Proposed Prototype Block Diagram

The prototype also has graphic user interface (GUI), for easy viewing. Selection options are performed using touch screen making it easier for the technician to operate. The display allows for multiple graphs or maps to be viewed at the same time. User can also run multiple measurements like gamma count and neutron count simultaneously. There is graphic representation of the processed data. Instead of just plain text, the user can view the data in a map mode to see the distribution of radiation pattern across the surveyed area. Another mode allows the user to view the strength of each sample using graph representation. The graphs get updated every time a new sample is detected and computed. The prototype is coupled with multimedia system which allows the technician to capture image of the area and send for further analysis. This can also be performed for video footage. Alarm sounds are set according to user preference.

4.3.2 Feasibility

Development of this prototype has many objectives. The main objective is to reduce human exposure to radiation. Others include eliminating human intervention while taking the reading, ease of usage, and multiple functions in a single device. On route to achieve these objectives, the feasibility of the development, cost and marketing has to taken into consideration for the success of the product development.

The parts required to build this prototype were carefully studied and selected. Most of the components used are commercially available off the shelf (COTS) items. The intriguing part of the development involves developing the communication link between all these devices such as: PDA, GPS, detector, dipping meter, compass, accelerometer, memory card, and Bluetooth. Some of the devices have two connections between them, for instance, the detector and the PDA. These devices are connected via Bluetooth and serial / USB cable. This is to ensure that if one connection fails, the technician can switch to the other. Most of the devices are large in size. The goal is to keep the size of the final product as small as possible (held in a single hand). But combining all devices as they are does not fulfill our aim. Therefore we need to remove certain parts of the devices leaving only the essential parts. There are plans to combine all the power distribution into a single power unit and hardwire between all devices. This allows compaction of the unit and subsequently achieves one of our objectives. A code will be written to communicate all devices with PDA. The language used for the code is Visual Studio (VS).net and the operating system is Windows Mobile. Therefore, the development of the prototype is expected to be smooth and no major problems are foreseen.

The expected cost for the prototype development is justifiable. Since all the parts are from COTS items, these parts should function according to their specifications. There are not any changes or development need to be made to these devices. The only extensive cost will incur when developing the communication module to connect all devices. But even this will become cheap after it is completed and mass production is carried out. Therefore, the cost for the prototype will be justified.

The completed prototype will be widely accepted because of the security and functionality it brings upon its users. Having the device allows a field surveyor to take measurements without worrying about exposure to hazardous area. With the GPS, wireless communication and self-correcting system available, the prototype ensures the occurrence of error is reduced tremendously. The device is also easy to use and handle. Since it is compact, the device can be held on one hand. GUI available on the PDA enables easy visualization of the data collected. The prototype can perform multiple processes at the same time eliminating the need for having separate detectors. The wireless communication allows the device to be controlled remotely. Now a robot can house the detector on itself and allow the technician to maneuver the robot across the survey area collecting sample readings. This is a key feature as it totally keeps humans away from survey area and consequently reduces their exposure to radiation.

CHAPTER 5

PERFORMANCE ANALYSIS

In this section, Mathematica software is used to obtain simulation results for the algorithms. Further analysis of the data was performed using Matlab and C software. The experiments were set up to simulate as close as possible to a real working condition of a radiation detector during a field survey. The parameters were set according to individual algorithms and case basis [1]. Some of these parameters are constants for initial simulations such as:

- Test strengths: α =0.05 & β =0.01
- Threshold value: *aval* = -4.55388, *bval* = -2.98568 & *cval* = -0.784097

The input data for the simulations was obtained from an experiment performed in a laboratory to replicate radiation samples. The raw input data attained consist of information as follows:

- Sample Identification (ID)
- Gamma Count per sample (GC)
- Neutron Count per sample (NC)
- Gamma Alarm (GA)
- Neutron Alarm (NA)

Figure 5.1(a) and 5.2(a) shows the strength of each sample in the order it was collected. The data points taken to analyze the behavior of the algorithms contain many different regions. Figure 5.1(b and 5.2(b) depicts 50 samples that are taken from regions that exhibit all possible scenario that is, constant background and source, transition from background to source, and vice versa, for meticulous analyzing. To extensively support the investigation, other similar regions are used for analysis and deduction towards a concrete conclusion.

For the initial analysis, computational results of both Gamma and Neutron samples are shown. Since the performance of both the Gamma and Neutron samples are expected to be similar, the latter portions of the analysis only considers the Gamma samples.

5.1 Analysis of STT

The input data was collected using a Geiger counter unit [2], replicating a radiological survey situation. The resultant alarm produced by the detector unit is given by Gamma alarm, which is computed using methods similar to STT. Figure 5.3 and 5.4 illustrates the deviation of alarm strength between the Gamma alarm produced by the Geiger unit and the FIFO algorithm. Taking a closer look into the figures, it is observed that alarms produced by STT are highly dependent on the individual sample gamma strength alone. On the other hand, the FIFO algorithm takes into consideration samples measured previously to compute the alarm level. There are large discrepancies between both the alarm readings, especially in the strong source regions. Since the primary concern of the investigation is an entire region rather than a single sample, the FIFO algorithm will be used from this point onwards.

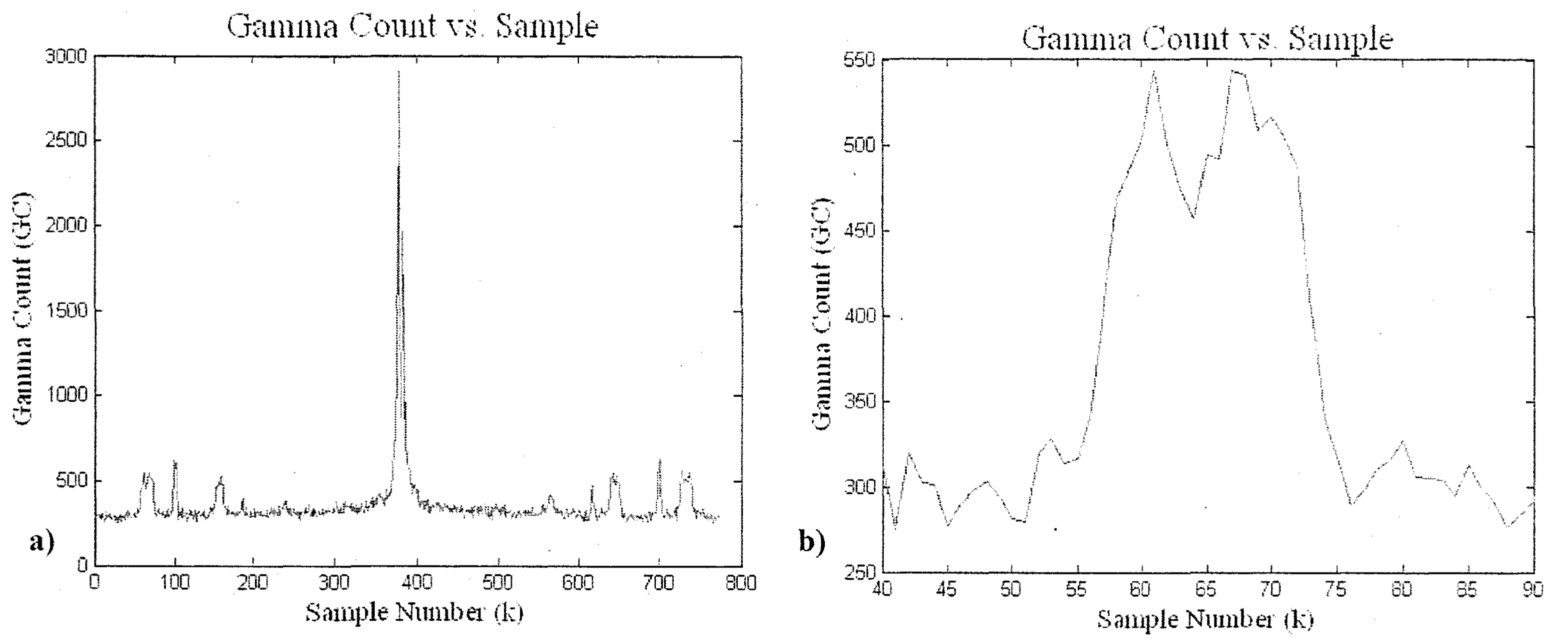


Figure 5.1. Gamma Sample Distribution: (a) Input Data Gamma Count, (b) Sample 40 until 90 Gamma Count

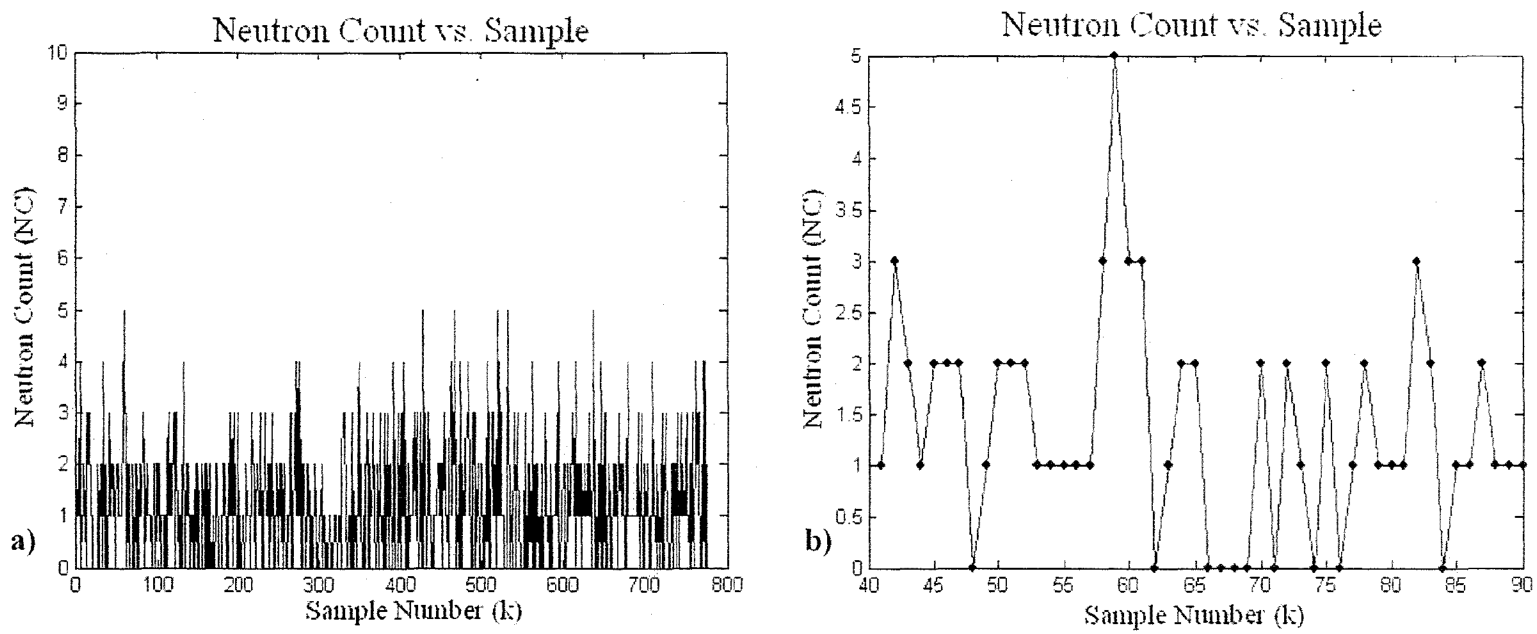
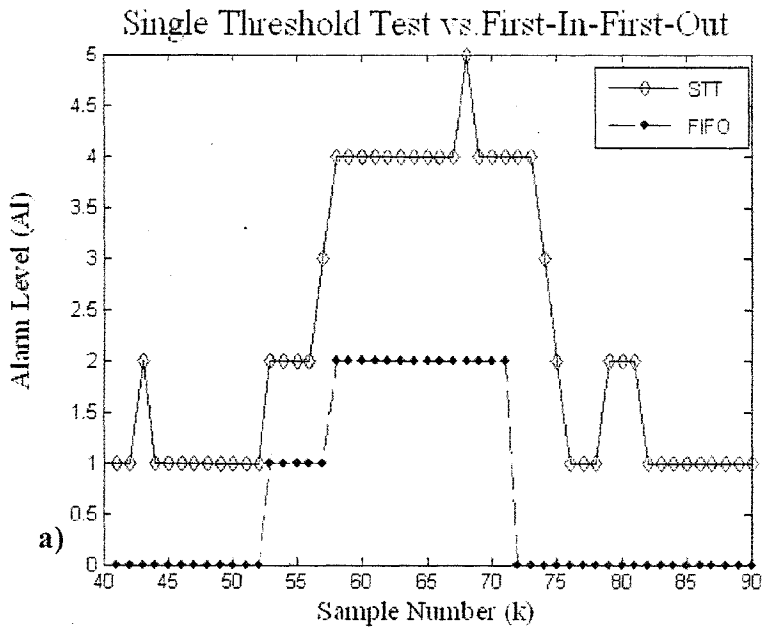


Figure 5.2. Neutron Sample Distribution: (a) Input Data Neutron Count, (b) Sample 40 until 90 Neutron Count



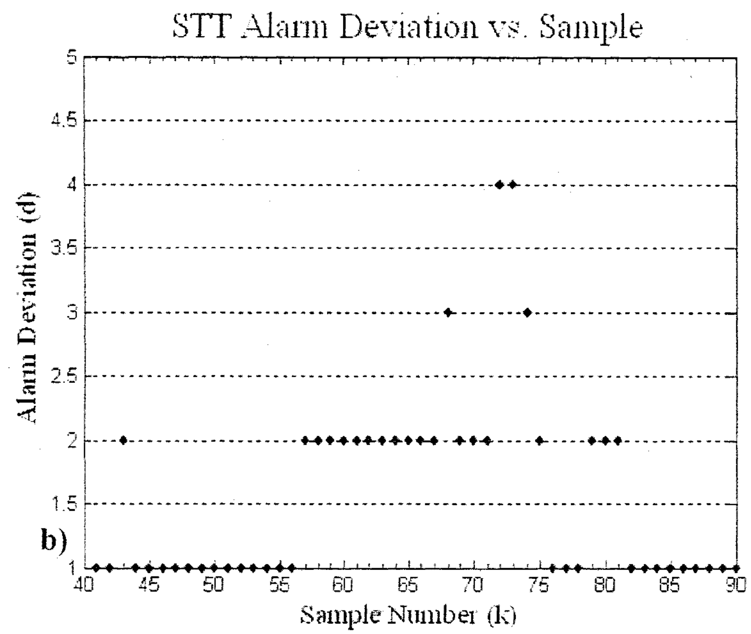


Figure 5.3. Gamma Alarm Deviation: (a) Alarm Level using STT and FIFO, (b) Alarm Deviation between STT and FIFO

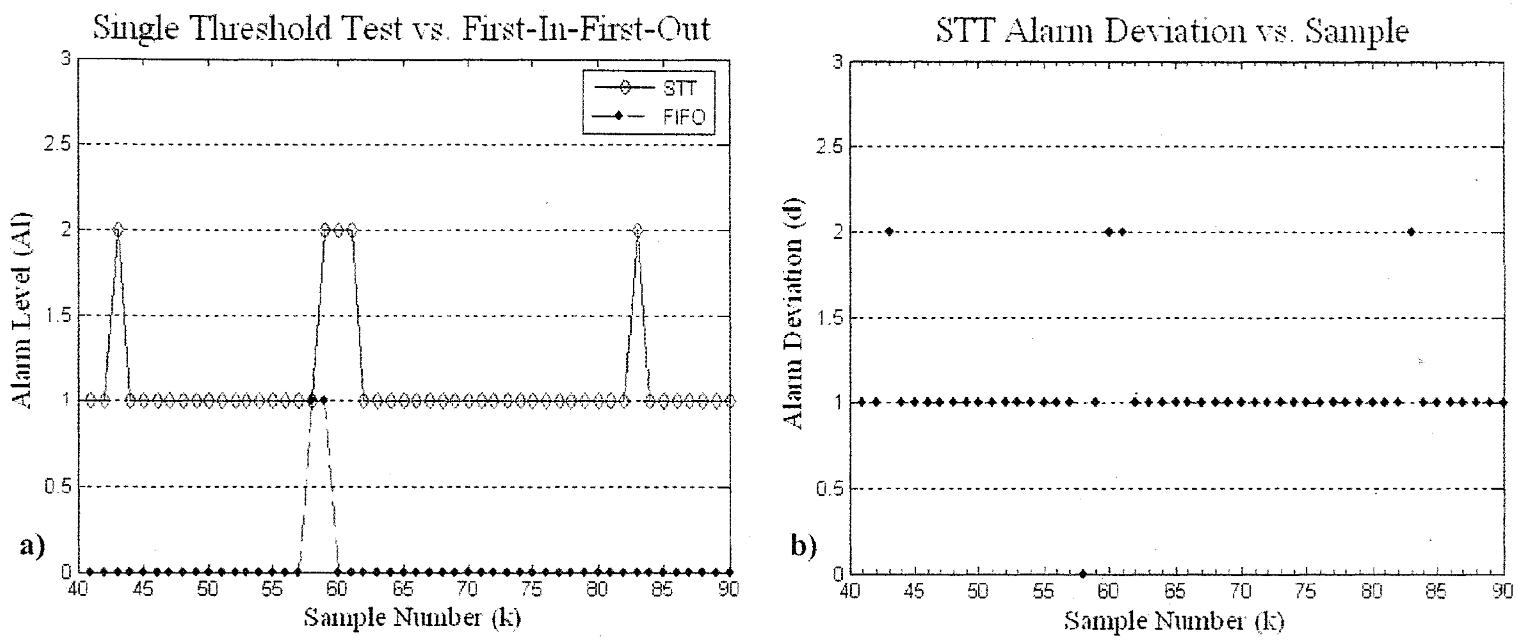


Figure 5.4. Neutron Alarm Deviation: (a) Alarm Level using STT and FIFO, (b) Alarm Deviation between STT and FIFO

5.2 Analysis of FIFO

The FIFO algorithm allows four potential hypothesis combinations and the performances of each of the combinations are shown. The experiment is set up by varying the null and alternative hypothesis between normal distribution and Poisson distribution. The observation from Figure 5.5 indicates that the alarm levels are close to similar for all of the hypothesis combinations. Therefore, this analysis by itself is not sufficient to decide on the optimal hypothesis combination required to minimize errors. Figure 5.7 elaborates further, using specified analysis region that the alarm differences are too small and can be considered negligible. Since all the hypothesis combination performances are equal, the combination which gives the fastest output or resultant alarm is deemed optimal. This translates to sample size and the hypothesis combination with the smallest sample size is considered the most efficient.

Figure 5.8 illustrates the sample size used to deduce the resultant alarm level calculated using base $(e) = 2.718$ for the LLR and alarm computations. An ideal situation requires SPRT to use 3 to 8 samples to generate a positive alarm $(al \geq 1)$ and more samples to confirm the background $(al = 0)$. These figures illustrate three situations:

- Sample size of alarm=0
- Sample size of alarm=1
- Sample size of alarm$\geq$2

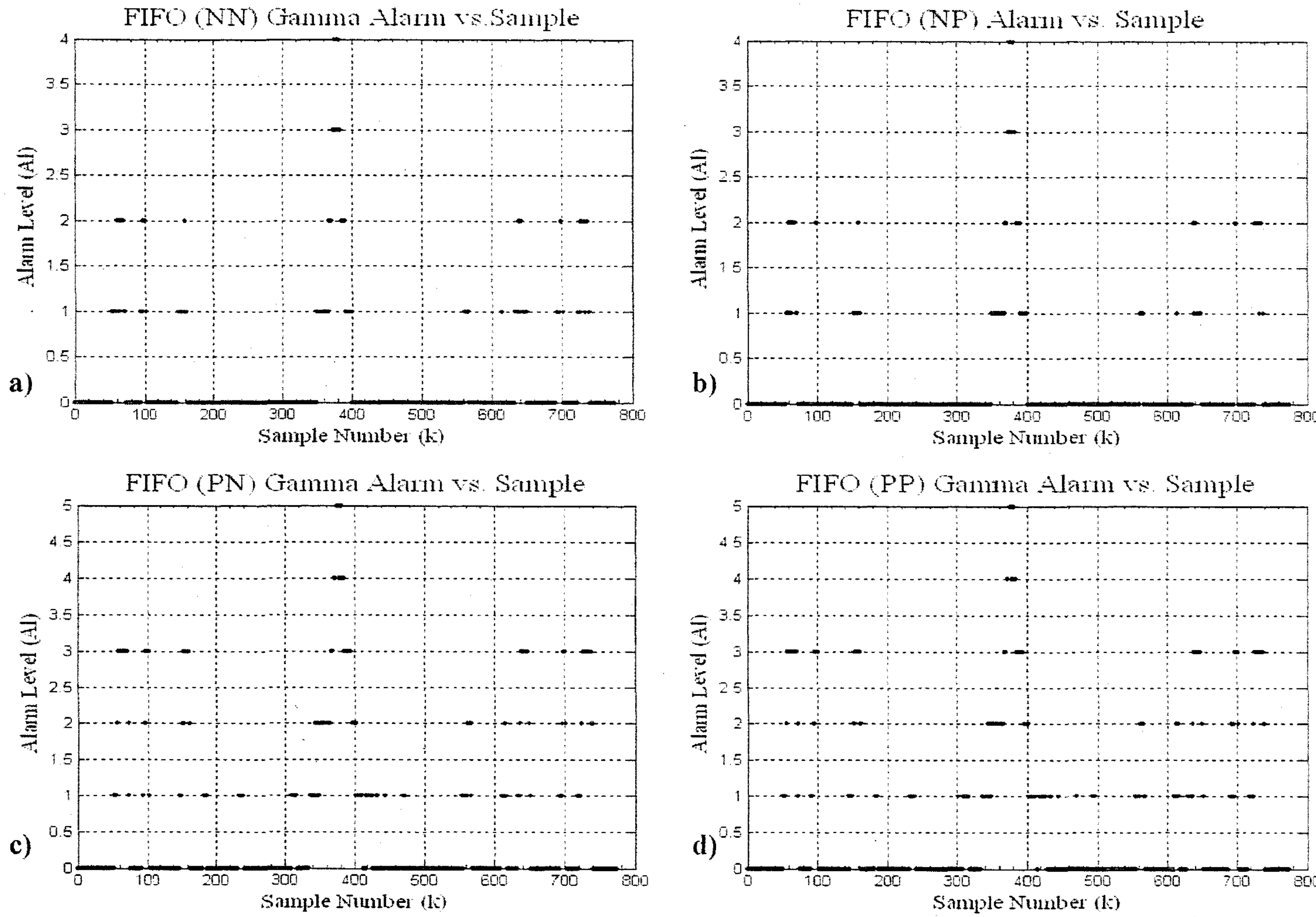


Figure 5.5. FIFO Gamma Alarm: (a) H_0=Normal and H_1=Normal, (b) H_0=Normal and H_1=Poisson, (c) H_0=Poisson and H_1=Normal, (d) H_0=Poisson and H_1=Poisson

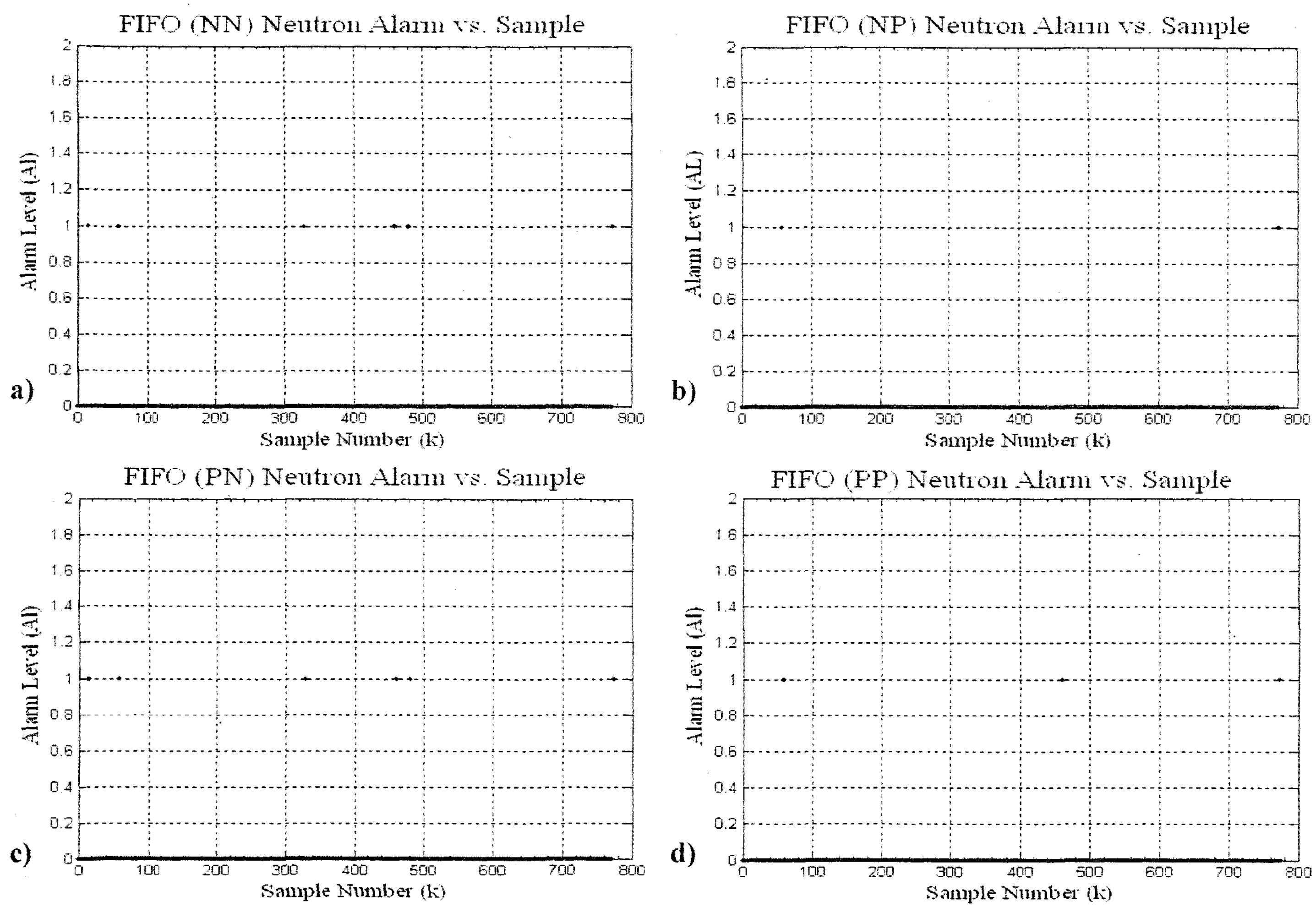


Figure 5.6. FIFO Neutron Alarm: (a) H_0=Normal and H_1=Normal, (b) H_0=Normal and H_1=Poisson, (c) H_0=Poisson and H_1=Normal, (d) H_0=Poisson and H_1=Poisson

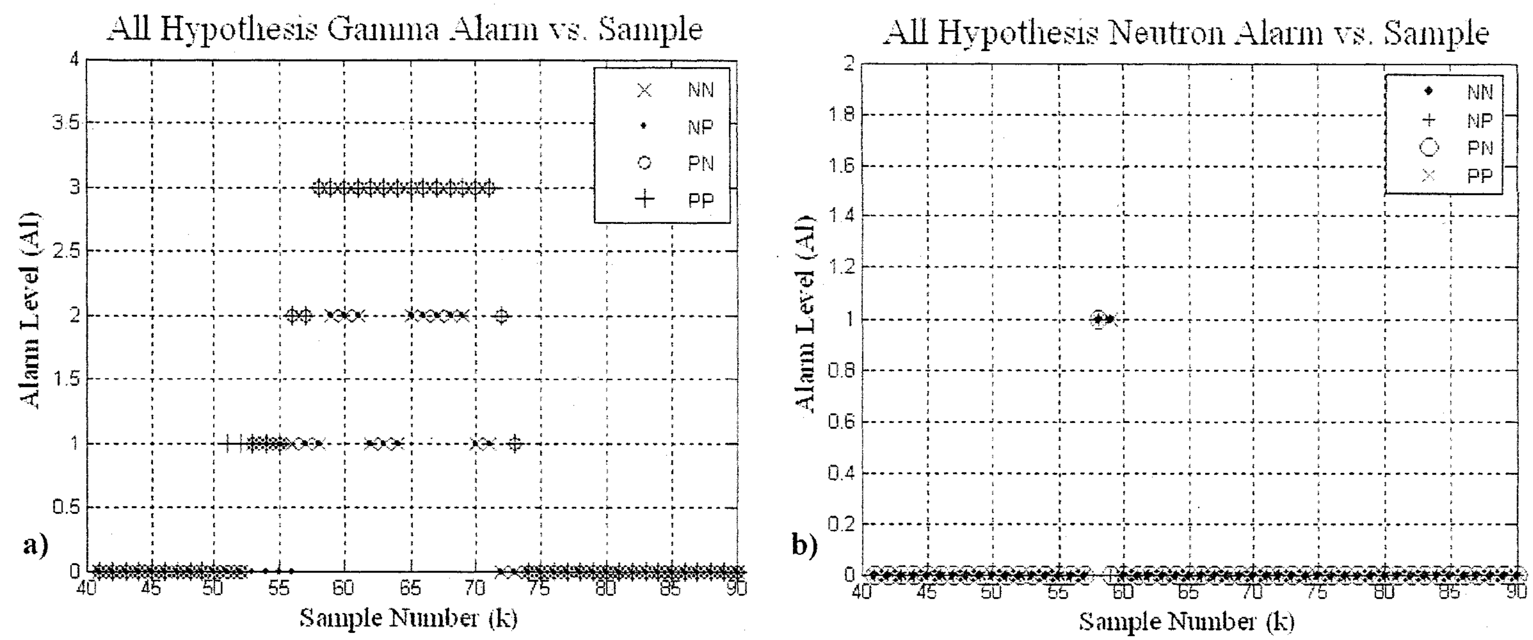


Figure 5.7. Hypothesis Alarm Difference: (a) Gamma Alarm, (b) Neutron Alarm

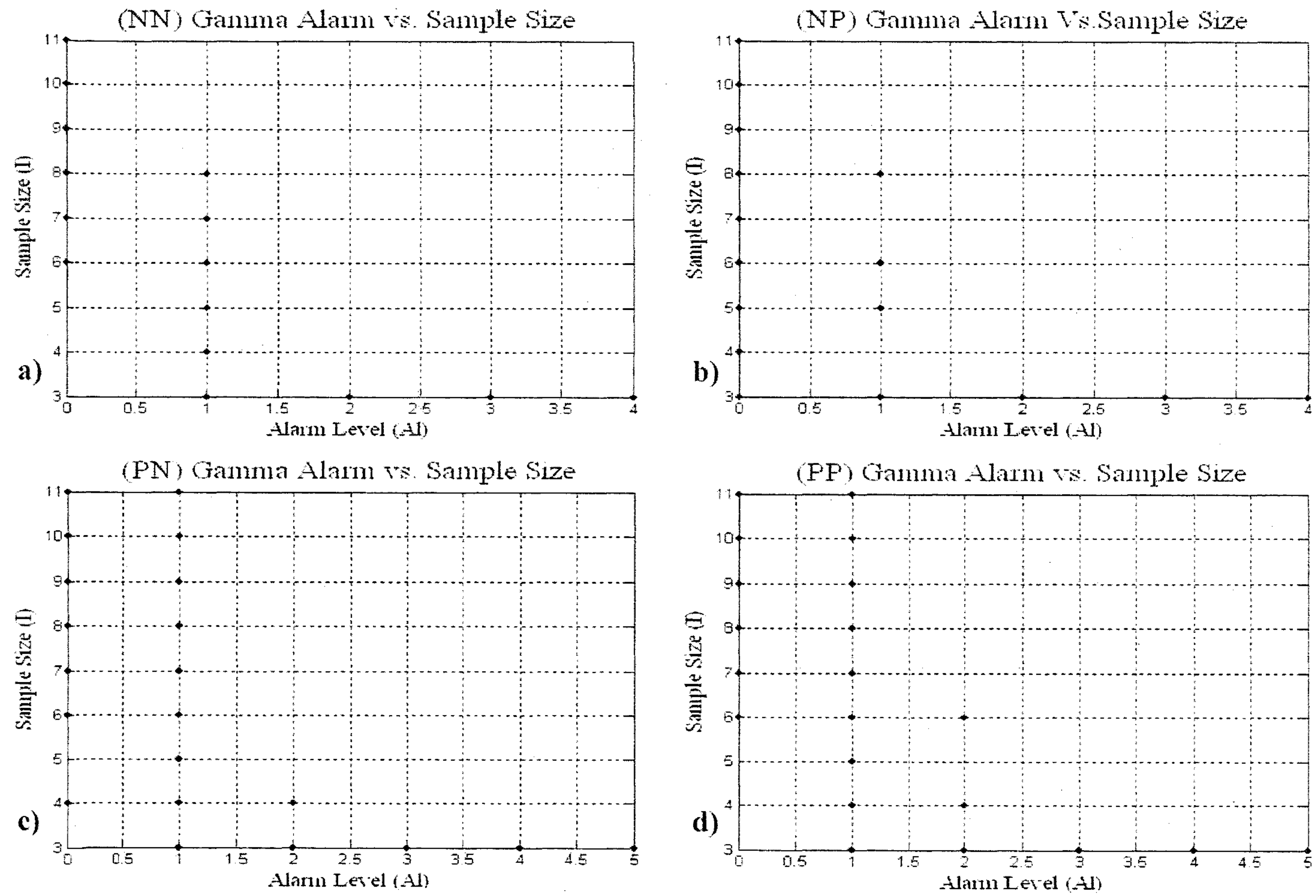


Figure 5.8. FIFO Sample Size for Alarm Generated using Base (e): (a) H_0=Normal and H_1=Normal, (b) H_0=Normal and H_1=Poisson, (c) H_0=Poisson and H_1=Normal, (d) H_0=Poisson and H_1=Poisson

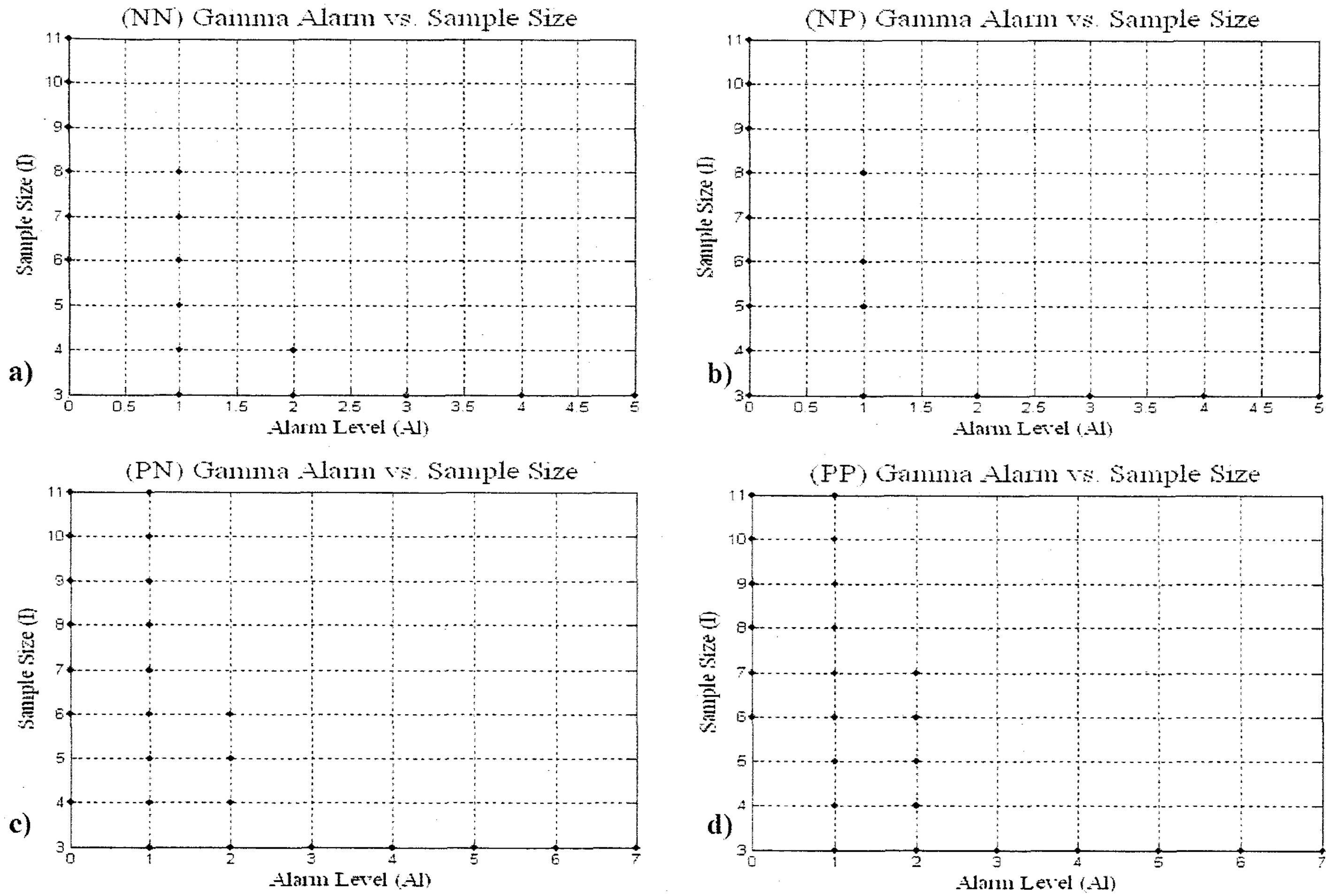


Figure 5.9. FIFO Sample Size for Alarm Generated using Base (2): (a) H_0=Normal and H_1=Normal, (b) H_0=Normal and H_1=Poisson, (c) H_0=Poisson and H_1=Normal, (d) H_0=Poisson and H_1=Poisson

The NP hypothesis plot has the overall smallest sizes for alarm >0 and uses the least amount of samples for alarm =0. Similar simulation is performed by changing the base (e) to base (2). This is to reiterate the results and strengthen the conclusion. Figure 5.9 shows sample size for alarm level computed using base (2). It is observed that the behavior of all hypothesis are similar to base (e). Again the NP hypothesis has the overall smallest size for all the alarms generated. These facts suggest that NP hypothesis combination is a better choice for gamma detection. Therefore, from here onwards all the simulations and results analysis are performed only for NP hypothesis combination.

5.3 Analysis of LIFELO

To analyze the results in detail and show the advantages and disadvantages of the FIFO and LIFELO algorithm, a cluster of sample points are chosen in a manner that there is a change from the background to the source and vise versa. Table 5.1 describes the regions in detail. Two major points of consideration when analyzing the data are false alarm and spatial gap.

Table 5.1. Sample Set A

Region No.	Region Type	Transition	Sample No.
1	Background	No	30-40
2	Background to Source	Yes	41-49
3	Source	No	50-60
4	Source to Background	Yes	61-72
5	Background	No	73-80

In Figure 5.10, both algorithms generate an alarm level (AL) of 0. There are no false alarms in this region since all the samples are background. But the FIFO algorithm generates the alarm five sample points away from the youngest sample. This algorithm exhibits spatial error of five samples. In Figure 5.11, the false alarm level generated by the LIFELO algorithm will be higher than that rendered by the FIFO algorithm. The LIFELO algorithm takes the youngest sample being measured and moves towards the oldest sample. If the youngest sample is a source then the algorithm will require two additional samples to help decide the alarm level and consequently generate alarm of 1 or greater. On the other hand, FIFO algorithm takes the oldest sample available and moves towards the youngest sample. If the youngest sample is source and the oldest sample is background, the computation begins from the background sample to the source. The computation may generate alarm before reaching the youngest sample, therefore giving a false alarm reading for the sample measured. Ideally the spatial error in this region varies. Spatial error should be minimal at the beginning of the transition region and increases as the region approaches source. With the present of weak sources in the region, the spatial error all remains at five samples. In Figure 5.12, FIFO algorithm generates false alarm. The alarm level generated by LIFELO algorithm will be higher in the initial part of this region. This occurs because FIFO algorithm still uses sample from the background and the transition region to deduce the alarm level for the youngest sample. On the other hand, the FIFO algorithm uses only three samples to generate the alarm level and therefore having a spatial gap of eight samples. In Figure 5.13, FIFO algorithm generates false alarm. The reason for this occurrence is similar to Region 2, but now the youngest sample is background and the oldest sample is source. For example, the algorithm begins computation using source samples and moves towards background samples. The resultant alarm may be generated before reaching the youngest sample. Therefore the strength of the FIFO alarm is higher than the LIFELO alarm in this region. The LIFELO algorithm uses background and weak source samples to begin the alarm computation. The spatial error behaves similar to Region 2, being minimal at the beginning and increasing as the region changes to background. But since the region has high source therefore it has spatial error of eight samples. In Figure 5.14 Region 5 is similar to Region 1, having spatial error of five samples.

Different regions among the samples are chosen to show that this analysis holds true. Similarly, five regions with samples behaving the same as the previous analysis are selected to justify the findings.

Table 5.2. Sample Set B

Region No.	Region Type	Transition	Sample No.
1	Background	No	335-343
2	Background to Source	Yes	344-360
3	Source	No	361-382
4	Source to Background	Yes	383-394
5	Background	No	395-405

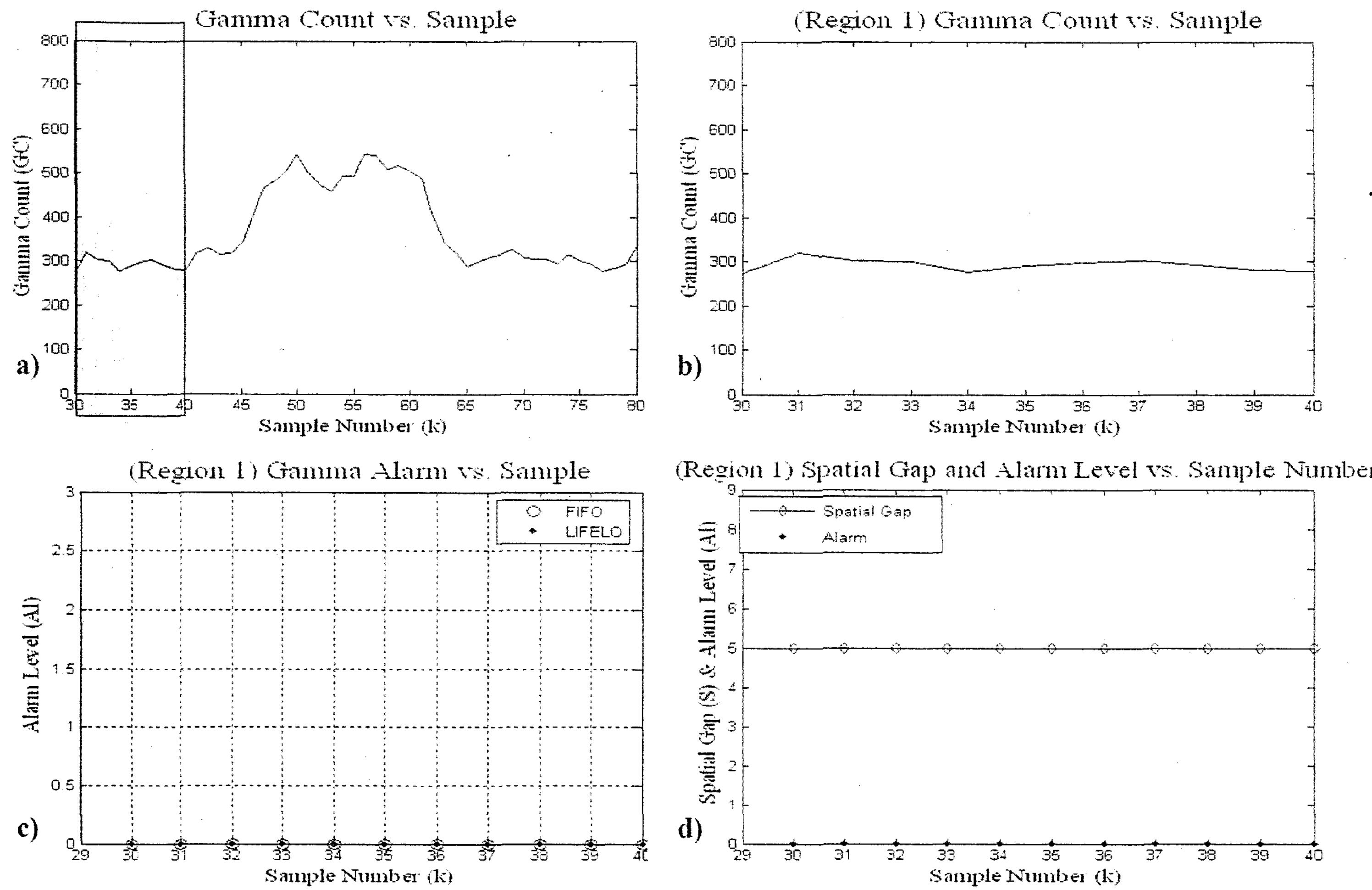


Figure 5.10. Region 1: (a) Region 1 in Entire Cluster (b) Region 1 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

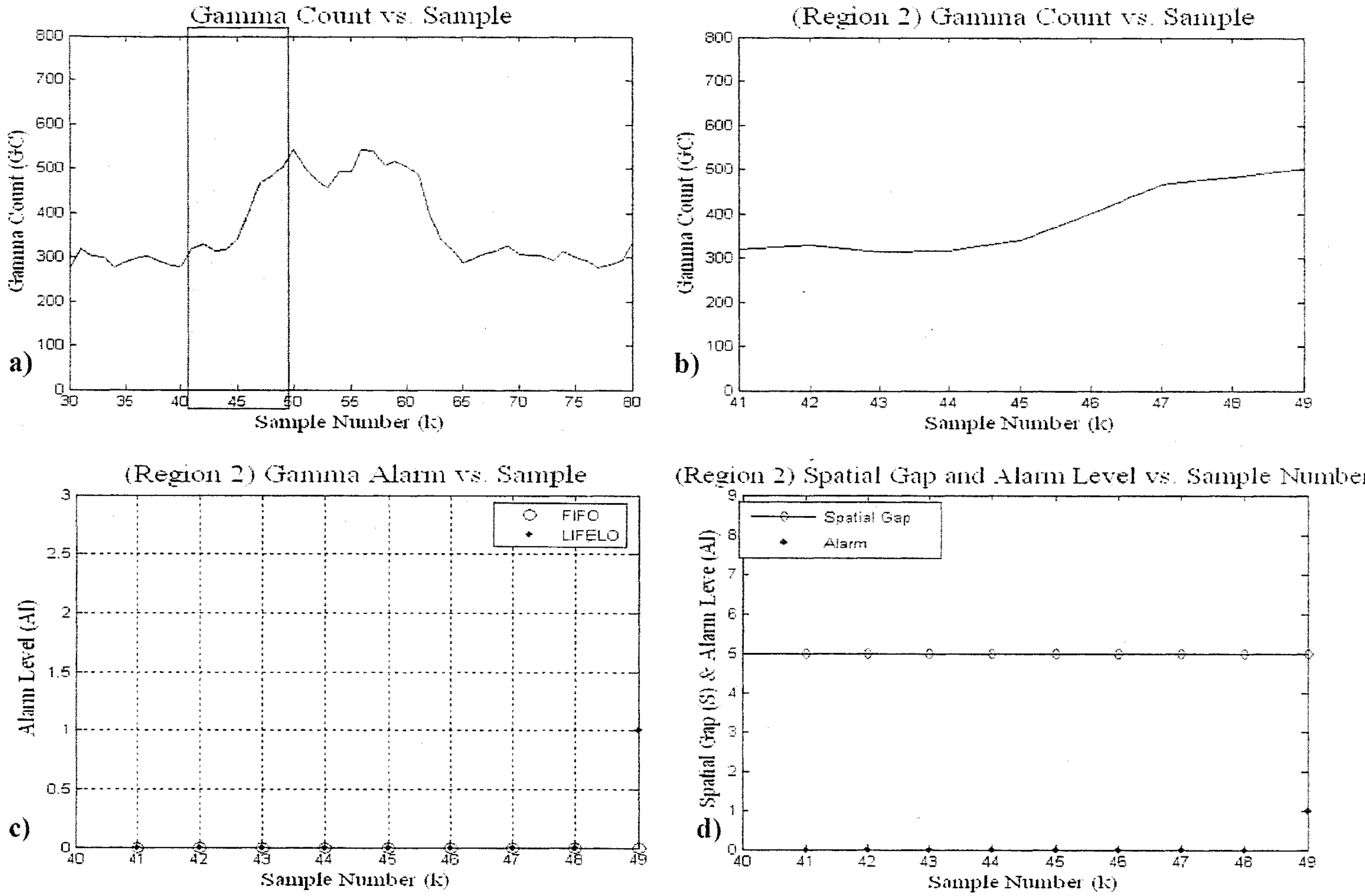


Figure 5.11. Region 2: (a) Region 2 in Entire Cluster (b) Region 2 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

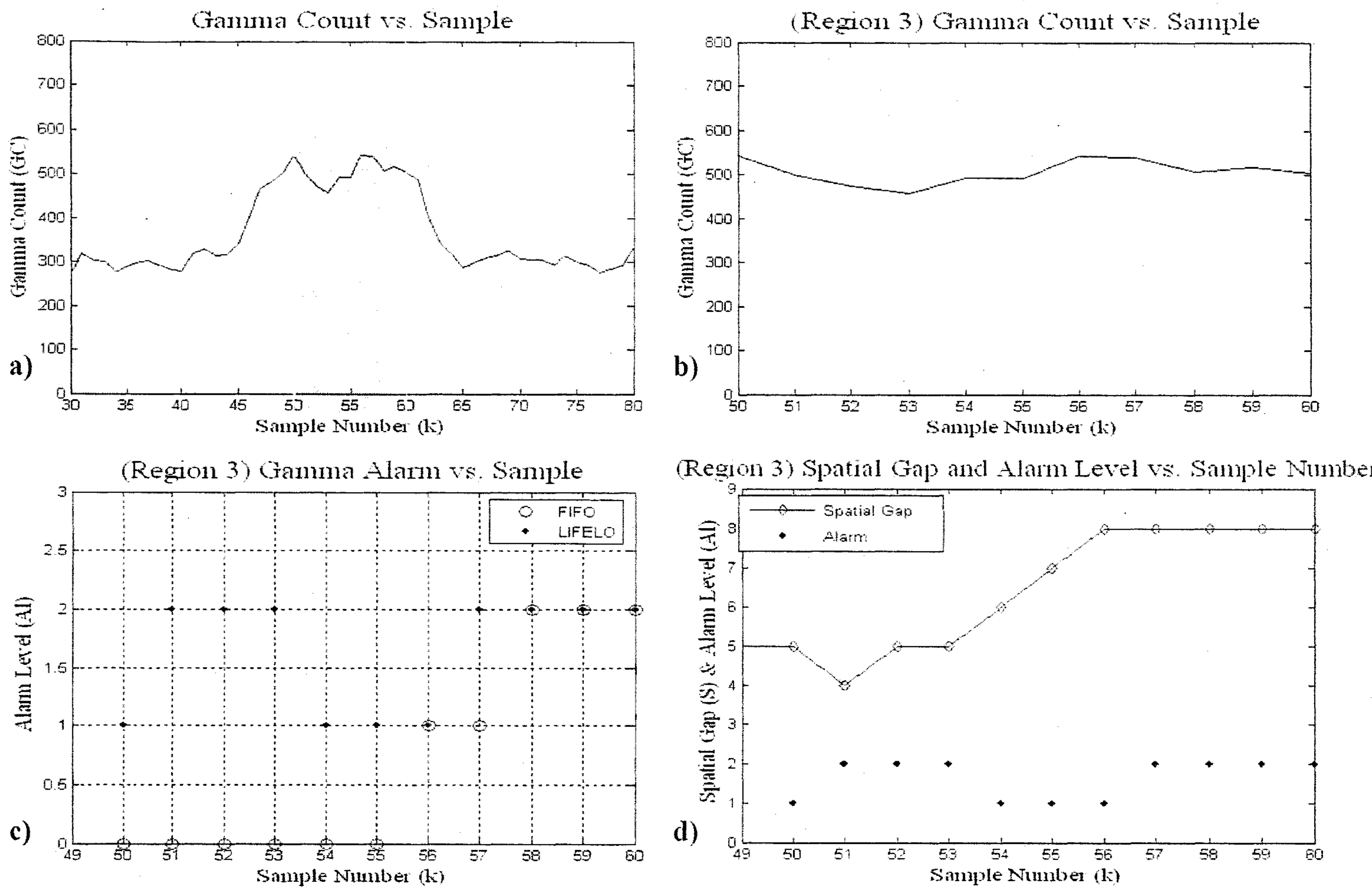


Figure 5.12. Region 3: (a) Region 3 in Entire Cluster (b) Region 3 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

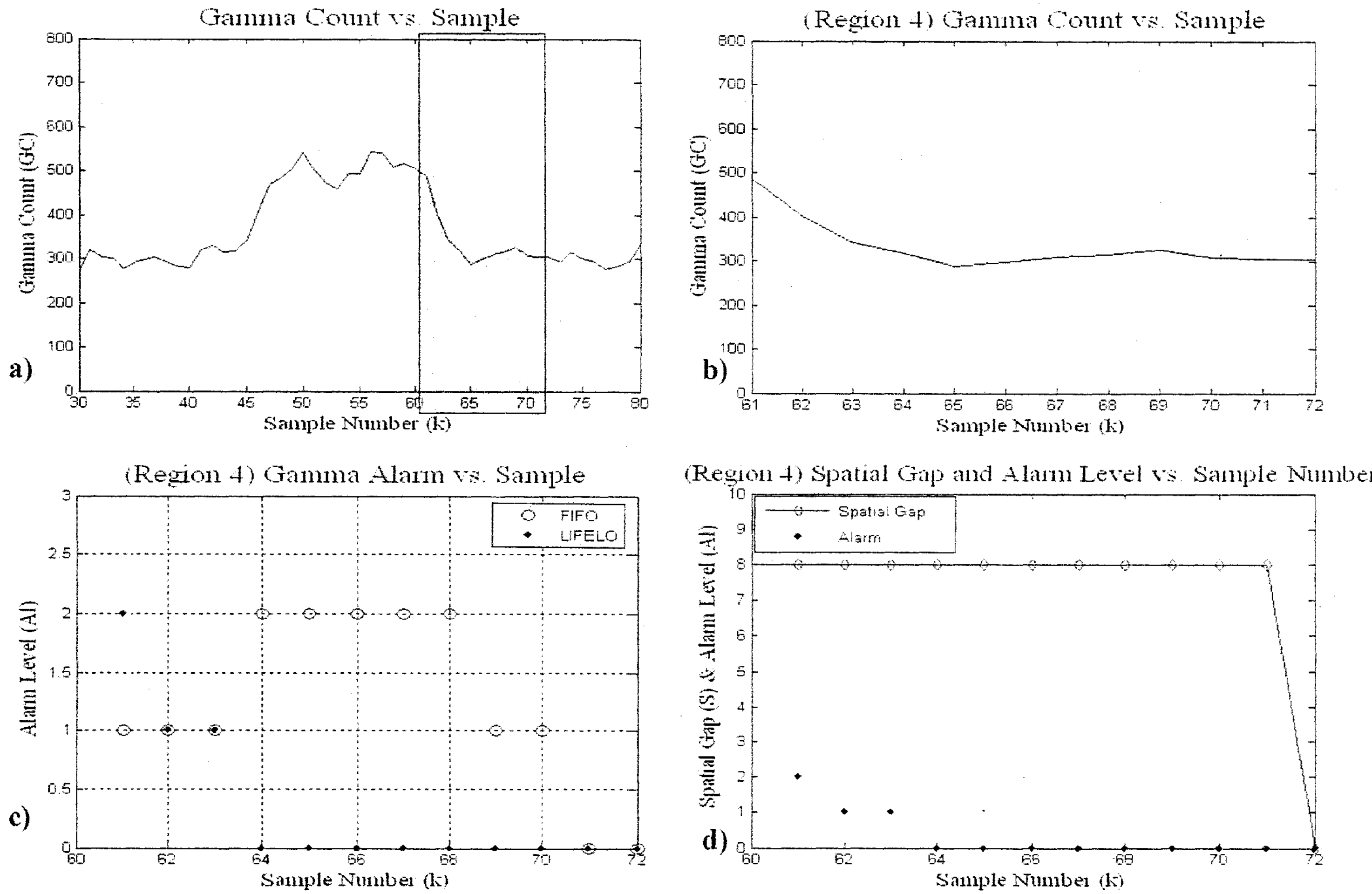


Figure 5.13. Region 4: (a) Region 4 in Entire Cluster (b) Region 4 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

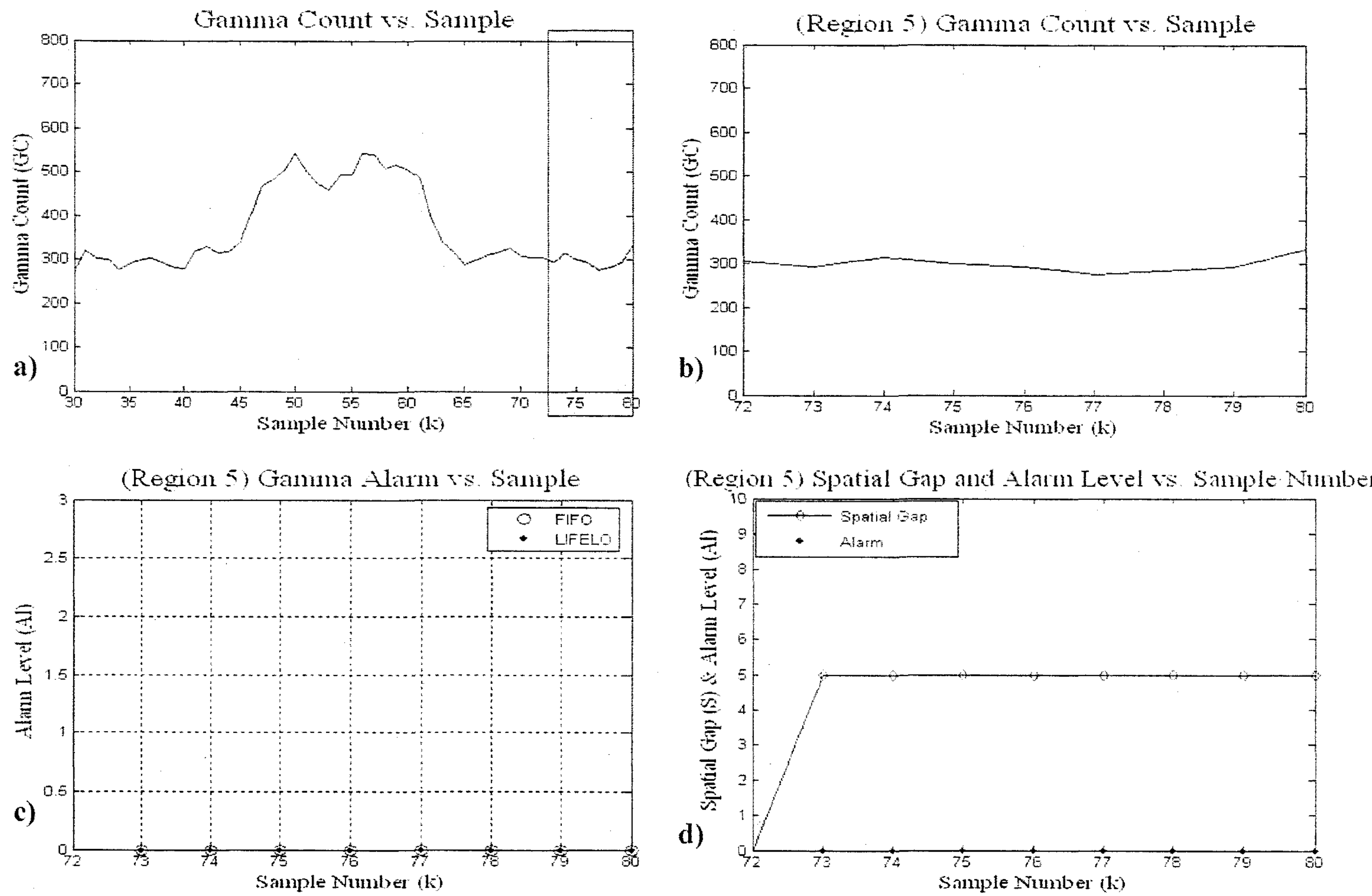


Figure 5.14. Region 5: (a) Region 5 in Entire Cluster (b) Region 5 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

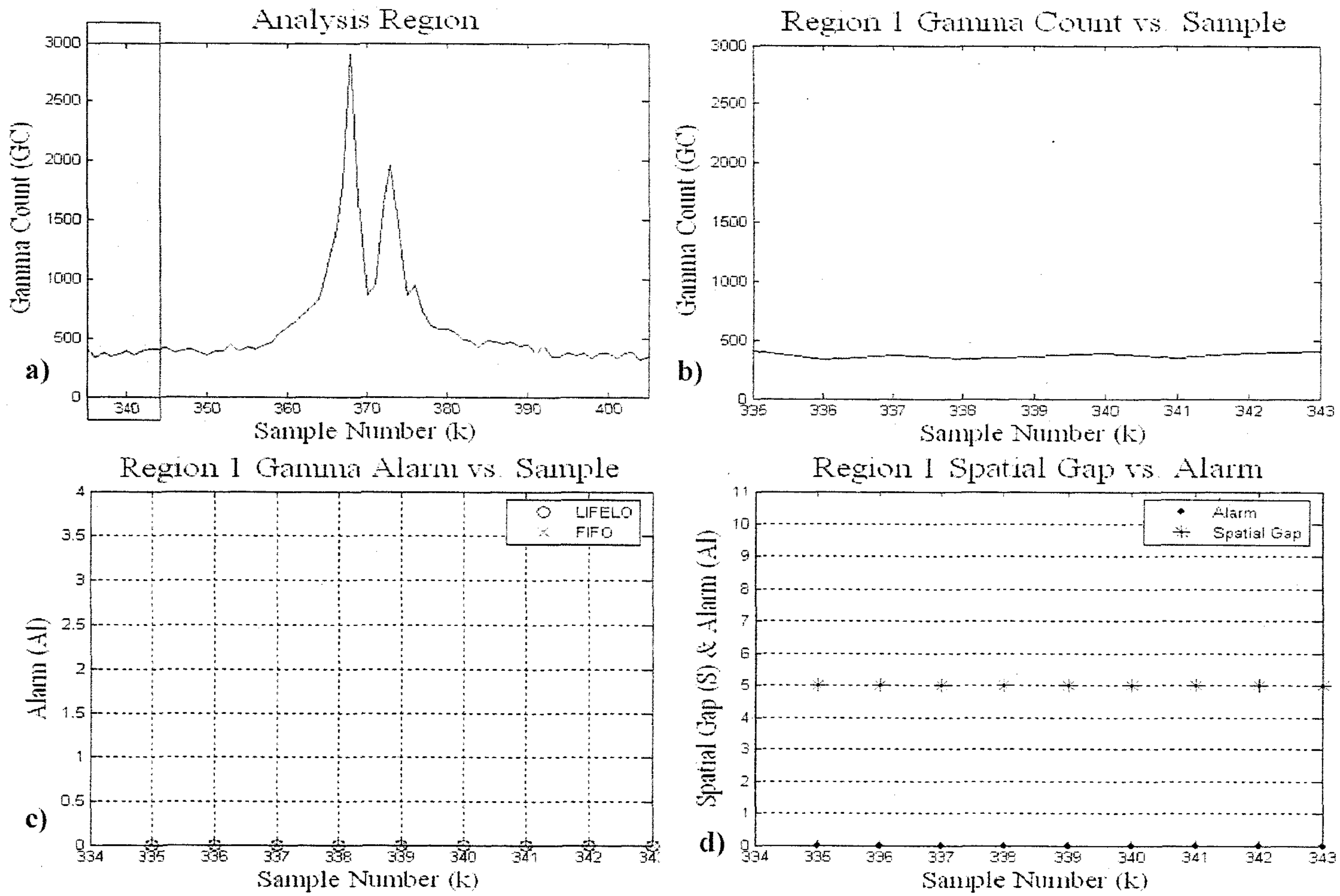


Figure 5.15. Region 1: (a) Region 1 in Entire Cluster (b) Region 1 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

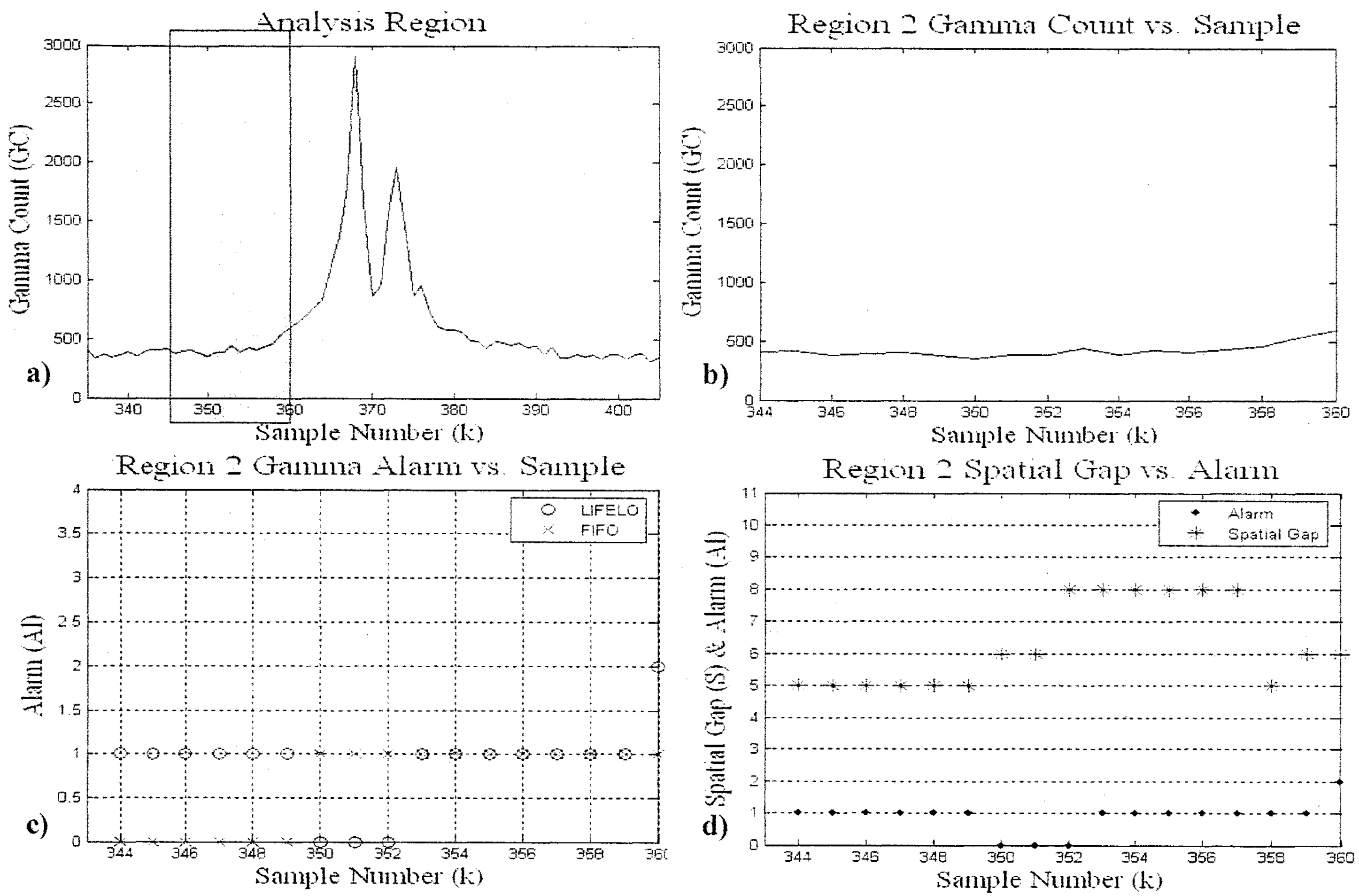


Figure 5.16. Region 2: (a) Region 2 in Entire Cluster (b) Region 2 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

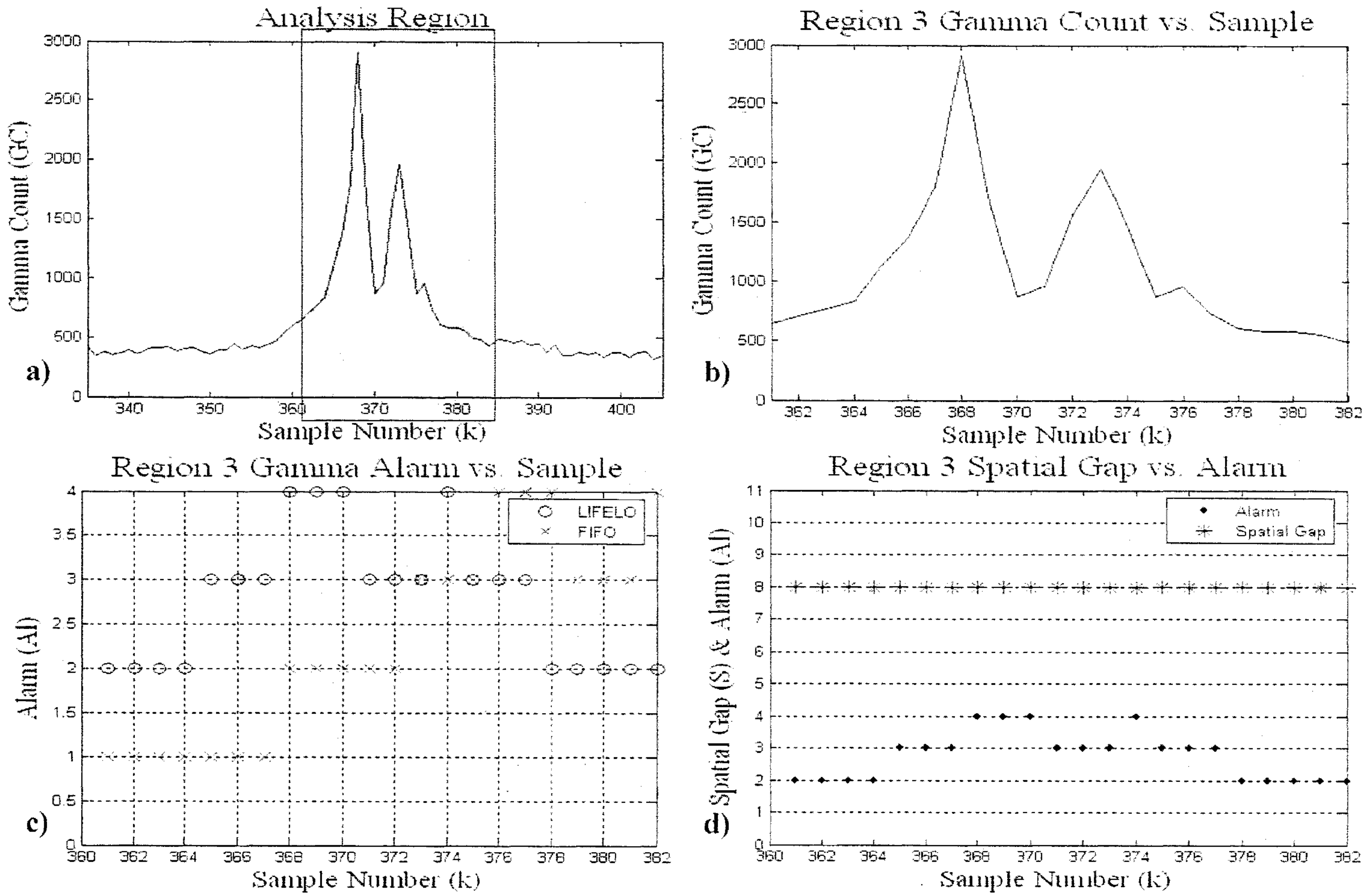


Figure 5.17. Region 3: (a) Region 3 in Entire Cluster (b) Region 3 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

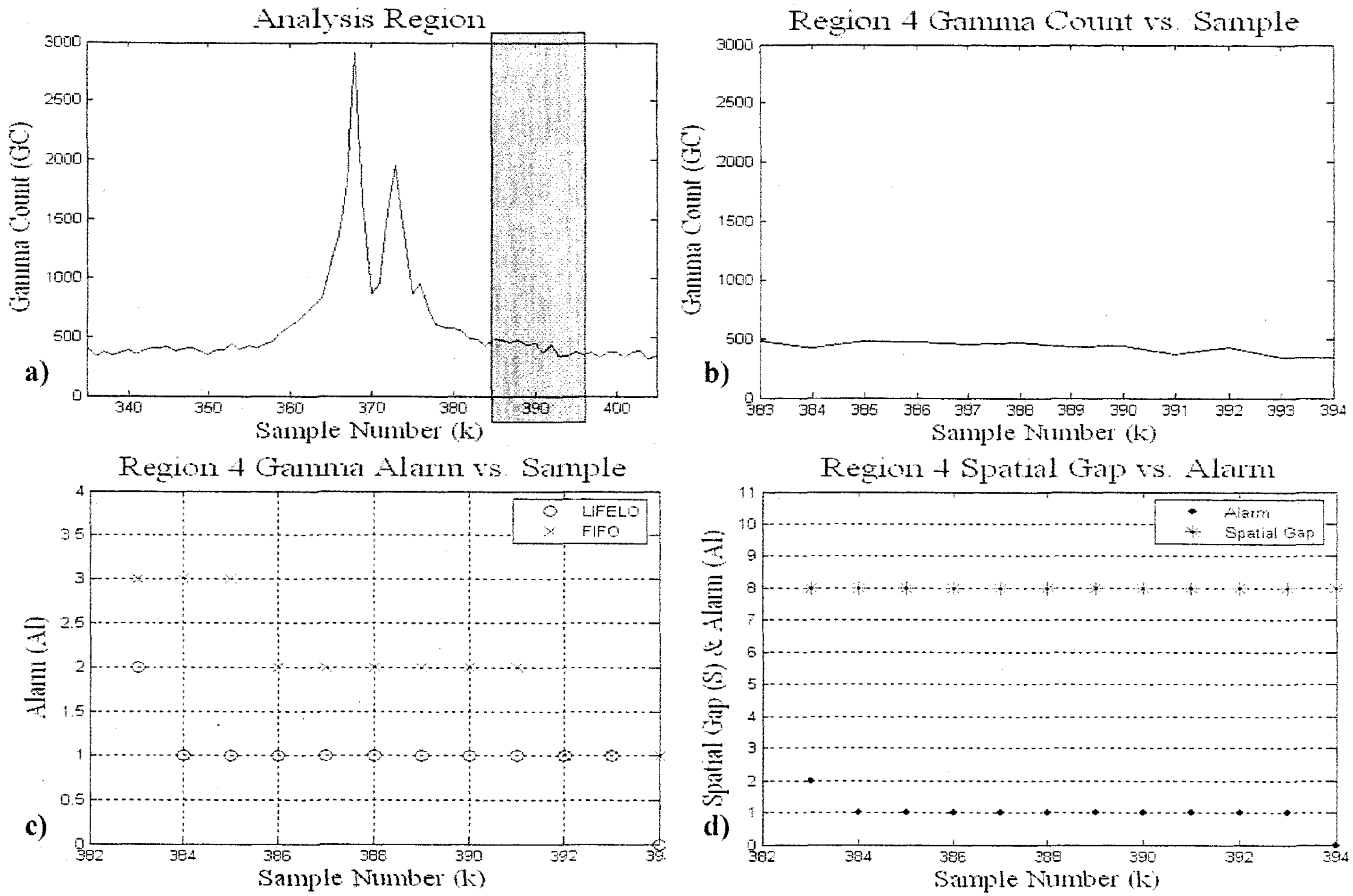


Figure 5.18. Region 4: (a) Region 4 in Entire Cluster (b) Region 4 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

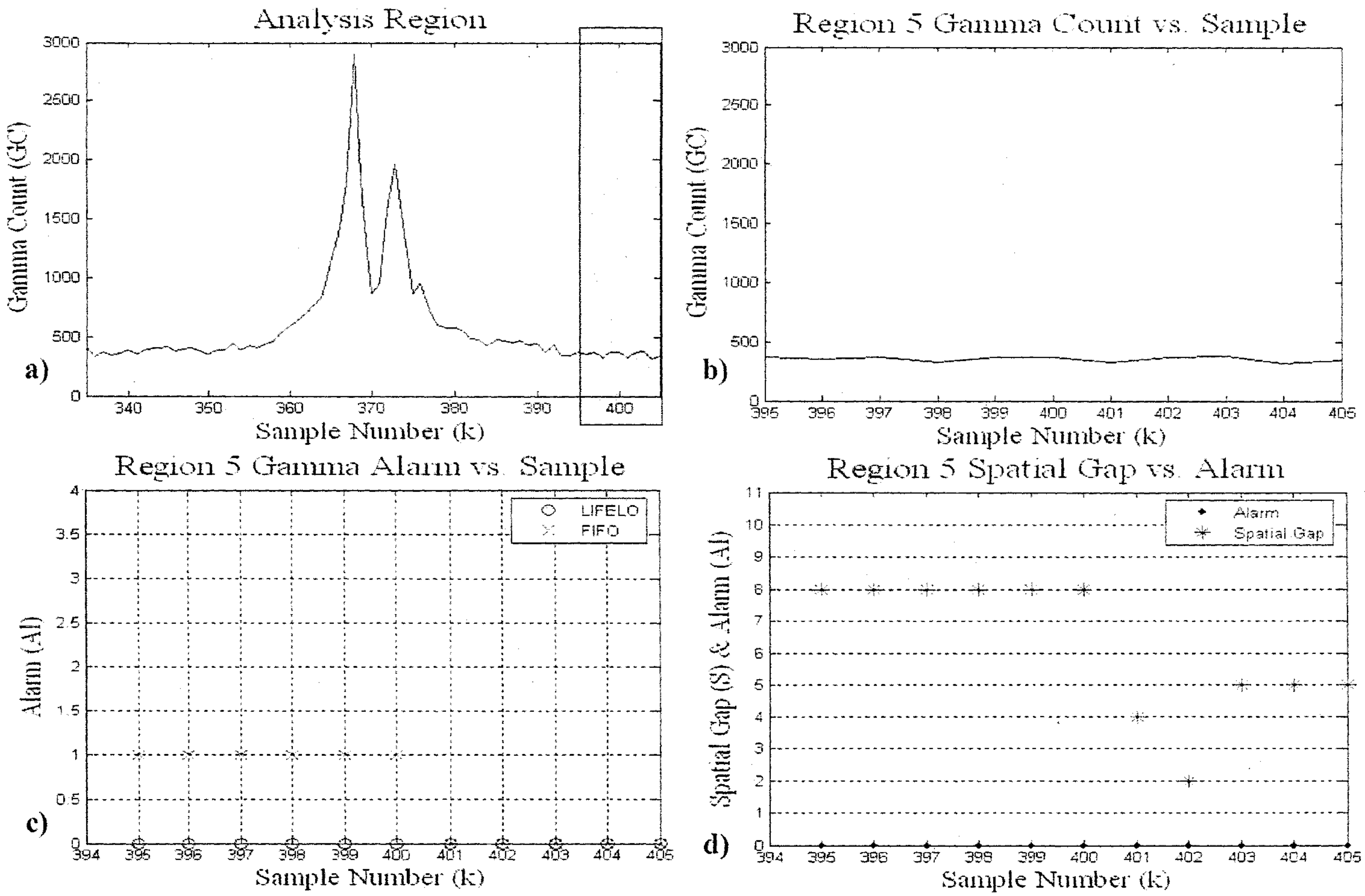


Figure 5.19. Region 5: (a) Region 5 in Entire Cluster (b) Region 5 GC, (c) FIFO and LIFELO GC Alarm, (d) Alarm Level and Spatial Gap

5.4 Analysis of LIFELO with Dynamic Background Updating

To further improve on the LIFELO algorithm, dynamic background updating is performed. This is a process of recalculating the reference background and used from that sample point onwards. The updating process is an autonomous process, which happens when the preset conditions are met. To analyze the results of the dynamic background updating, different parameters were used for the test strengths as shown in Table 5.3. Figure 5.20 exhibits the difference in resultant alarm between algorithm with and with out dynamic background updating. It can be observed that the numbers of alarm deviations are not as high as the number of background updating. This is due to the fact that the updating is done with a very small factor and consequently does not affect the alarm reading unless the sample strength is in the border of source and background. A small updating factor is used to avoid rapid increase in the background value. If this is not taken into consideration, there are high possibilities that a technician taking the reading might be exposed to a source region because the updating has shown the source sample as background. The large step size may raise a condition where an actual source sample will be accepted as background before the technician realizes this error and rectify the error.

Table 5.3. Dynamic Background Updating Parameters

α	β	*Aval*	*Bval*	*Cval*	No. of Updating
0.05	0.01	-4.553887	2.985682	-0.784097	15
0.05	0.05	-2.944439	2.944439	0.00000	10
0.05	0.1	-2.251292	2.890372	0.319540	9
0.01	0.01	-4.595120	-4.595120	0.00000	22
0.005	0.01	-4.600158	5.288267	0.344055	23
0.001	0.01	-4.604170	6.897705	1.146768	39
0.0001	0.01	-4.605070	9.200290	2.297610	73

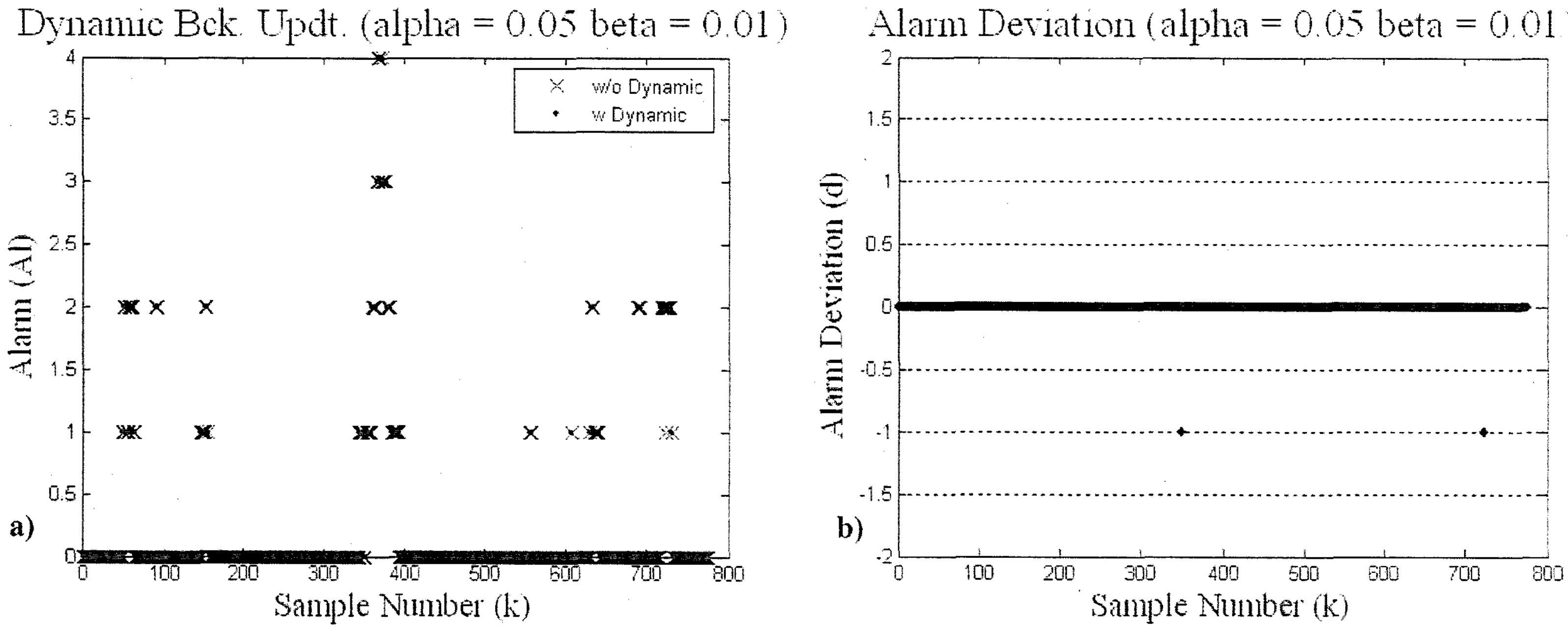


Figure 5.20. Dynamic Background Updating ($\alpha = 0.05$ & $\beta = 0.01$): (a) With and Without Background Updating, (b) Alarm Level Difference between With and Without Background Updating

The background updating generally happen when the samples measured are in background region and there are not much variations between the strength of the samples. Table 5.4 shows the variation of the sample and the points of background updating for $\alpha = 0.05$ and $\beta = 0.01$.

Table 5.4. Samples Used for Dynamic Background Updating with Parameters

$(\alpha = 0.05 \;\&\; \beta = 0.01)$

Sample No.	Old Bck. Mean	Updated Bck. Mean	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}
47	322.547112	322.532625	401	340	316	314	328	320	279	281	293	303	298
143	322.532625	322.533747	400	333	342	308	331	318	344	313	296	291	298
177	322.533747	322.525787	394	369	328	313	310	296	304	292	313	299	291
178	322.525787	322.522659	348	394	369	328	313	310	296	304	292	313	299
179	322.522659	322.520499	299	348	394	369	328	313	310	296	304	292	313
180	322.520499	322.522864	337	299	348	394	369	328	313	310	296	304	292
181	322.522864	322.525359	297	337	299	348	394	369	328	313	310	296	304
182	322.525359	322.526345	299	297	337	299	348	394	369	328	313	310	296
394	322.526345	322.672149	342	349	438	376	442	432	474	451	474	451	474
395	322.672149	322.800883	374	342	349	438	376	442	432	474	451	474	451
396	322.800883	322.913122	354	374	342	349	438	376	442	432	474	451	474
407	322.913122	322.930348	321	304	341	316	380	371	328	373	374	330	375
486	322.930348	322.917446	367	326	341	271	326	337	275	293	350	291	306
554	322.917446	322.927850	390	369	361	345	319	301	332	317	324	353	339
628	322.927850	322.923635	402	367	330	324	313	294	301	304	315	327	342

Observation of Table 5.4 indicates all the sample points where dynamic background updating occurs are relatively close to the reference background mean value. The background mean values increases or decreases depending on the 11 previous samples taken to compute the resultant alarm. Figure 5.21 until 5.26 show results of different test strengths. The different parameters give flexibility to the amount of error that is accepted by the algorithm. α represents the probability of first type of error, which indicates the probability that a sample is source given it is background. Therefore, if the α is decreased the probability of error will decrease too. When the new α parameters are used for updating, the samples which are high background or low source will generate different alarm reading. Hence there will give more difference in alarm reading when the α value is decreasing. Similarly, the same works for the β value. When the parameter is decreased there will be more alarm differences. These are shown in figure 5.21 until 5.26. Since the updating is autonomous, it is important to be performed by an experienced technician. These technicians will have the knowledge to analyze a region when the dynamic background updating resultant alarms mask the actual source sample and represented it as background.

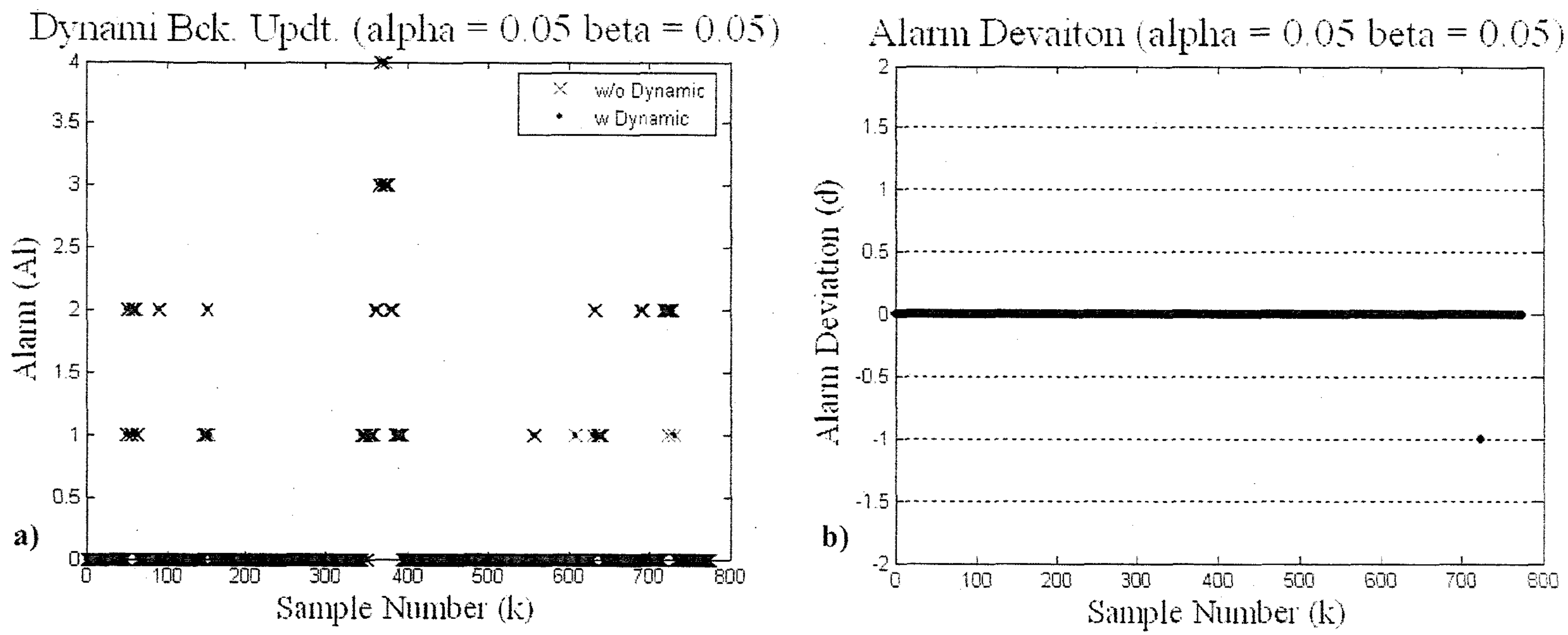


Figure 5.21. Dynamic Background Updating ($\alpha = 0.05$ & $\beta = 0.05$): (a) With and Without Background Updating (b) Alarm Level Difference between With and Without Background Updating

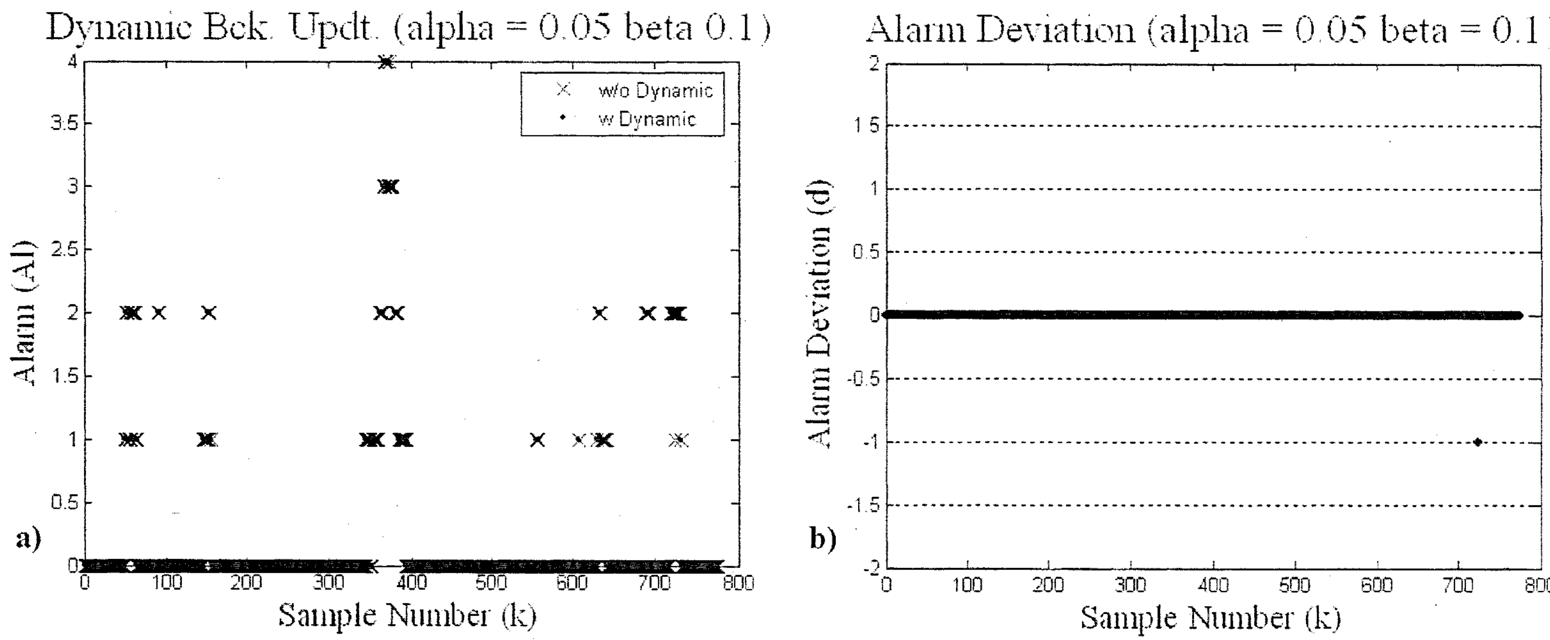


Figure 5.22. Dynamic Background Updating ($\alpha = 0.05$ & $\beta = 0.1$): (a) With and Without Background Updating (b) Alarm Level Difference between With and Without Background Updating

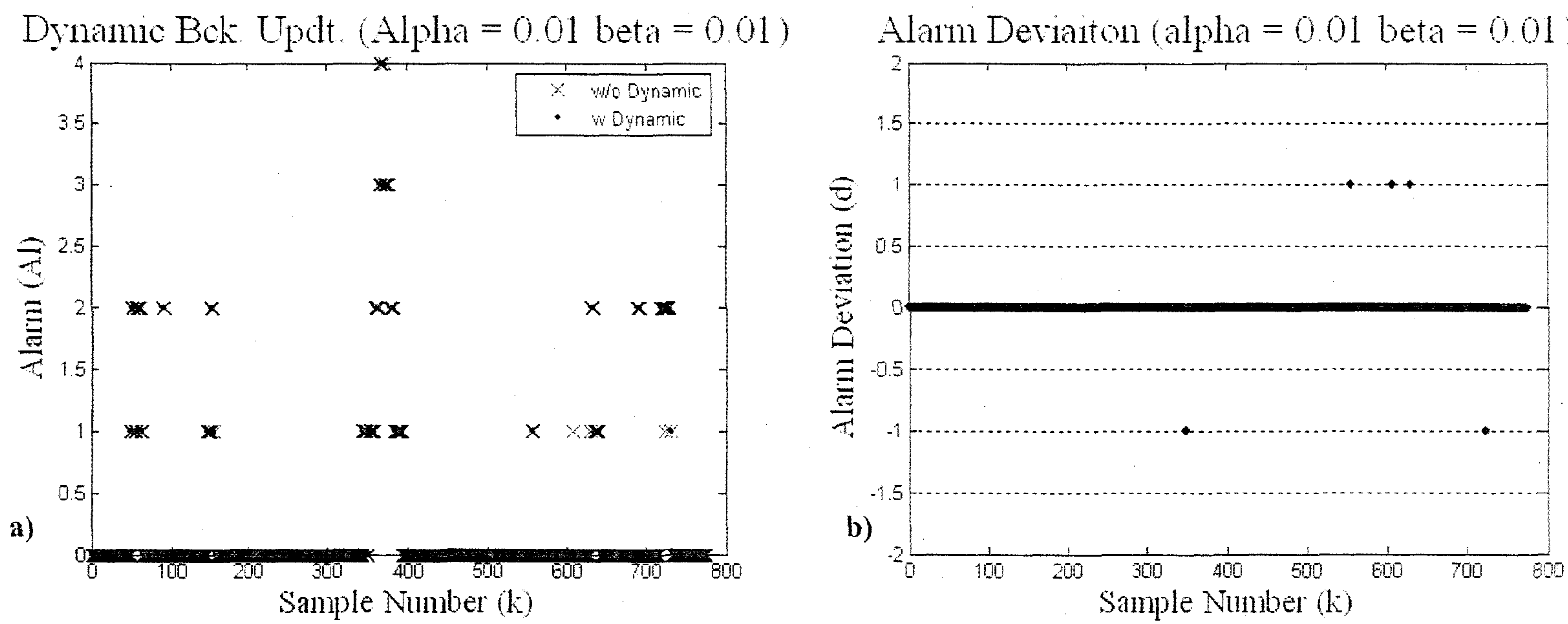


Figure 5.23. Dynamic Background Updating (α = 0.01 & β = 0.01): (a) With and Without Background Updating (b) Alarm Level Difference between With and Without Background Updating

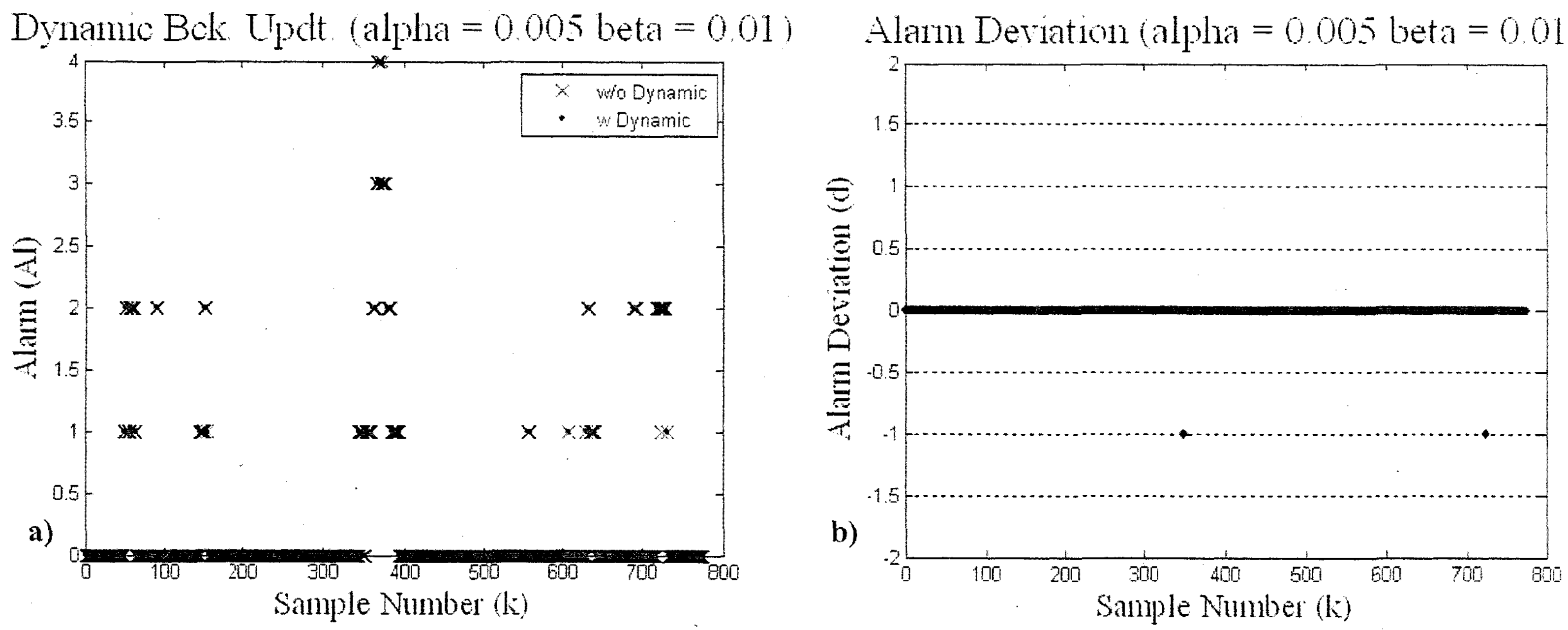


Figure 5.24. Dynamic Background Updating (α = 0.005 & β = 0.01): (a) With and Without Background Updating (b) Alarm Level Difference between With and Without Background Updating

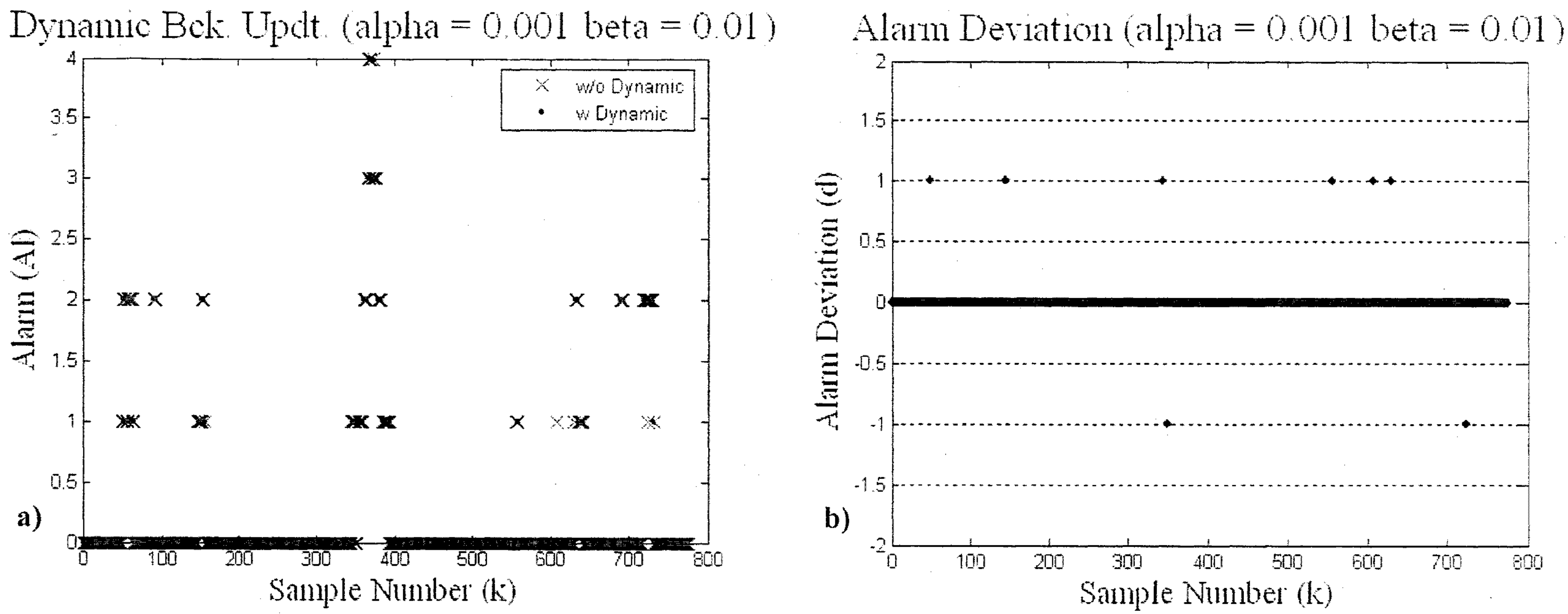


Figure 5.25. Dynamic Background Updating ($\alpha = 0.001$ & $\beta = 0.01$): (a) With and Without Background Updating (b) Alarm Level Difference between With and Without Background Updating

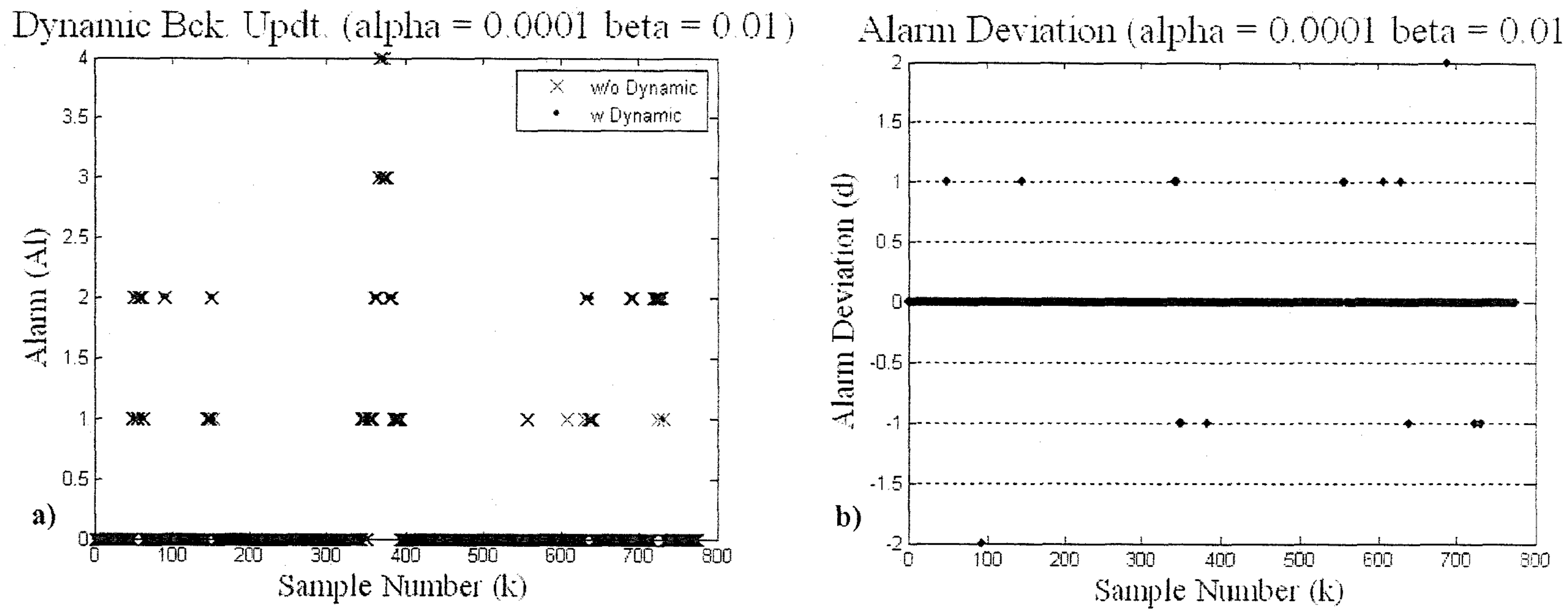


Figure 5.26. Dynamic Background Updating ($\alpha = 0.0001$ & $\beta = 0.01$): (a) With and Without Background Updating (b) Alarm Level Difference between With and Without Background Updating

5.5 Analysis of LIFELO with MLE

Next the simulation parameters have been change to analyze the LIFELO with MLE alarm level. Figure 5.27 illustrates the difference between the LIFELO algorithm with and without MLE computation (without MLE is taken as the reference point). From figure 5.27 (a) and (b), it can be analyzed that an algorithm using MLE computation depicts small changes for the NN and NP distributions. For the NP distribution, the resultant alarm will be nearly similar to the NP distribution without the MLE except for a sample. This is because the distribution uses normal distribution for the background and so MLE does not have much effect. The MLE only affects the Poisson distribution and therefore, in Figure 5.27 (c) and (d) changes can be observed when the PN or PP hypothesis is used. The PN and PP hypothesis gives drastic changes in the resultant alarm because the background is taken as Poisson distribution. Since, in our analysis, the primary concern has been the NP distribution, therefore the MLE does not have much impact. The LIFELO with MLE algorithm performs as an added safety because it gives better alarm reading when there is a transition from source to background or background to source.

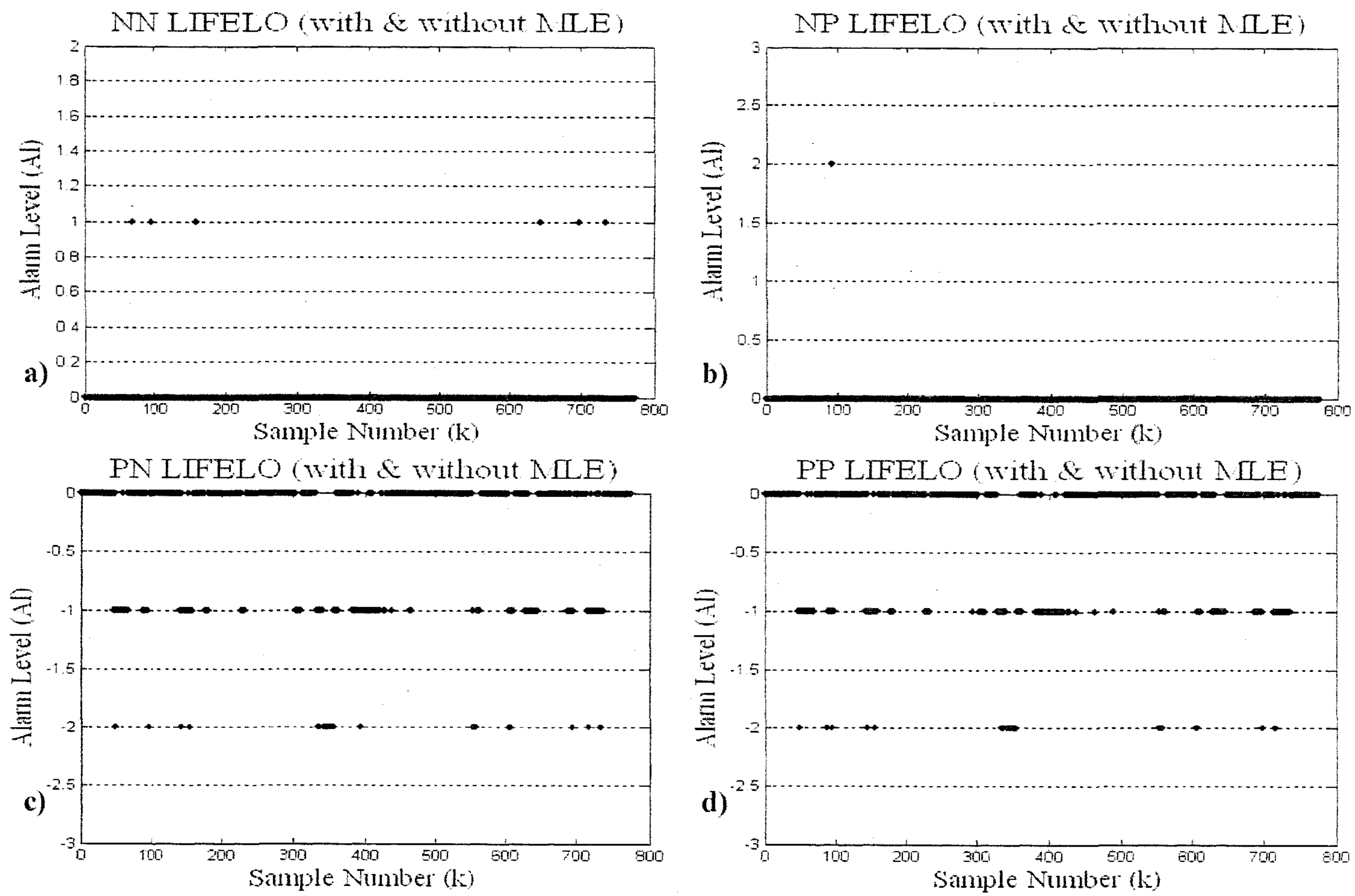


Figure 5.27. Difference in LIFELO with and without MLE: (a) NN Distribution, (b) NP Distribution, (c) PN Distribution, (d) PP Distribution

CHAPTER 6

CONCLUSION

The development of an accurate and efficient algorithm for radiation detection was considered. The initial part of the thesis dealt with justifying the need to convert from the classic STT to algorithms using the SPRT. From the simulation results, it can be concluded that the STT performs well for determining the alarm for a single sample. However, this does not help towards our objective of creating safer methods for radiation detection. The primary concern is the entire region measured, rather than a single sample in the region. To achieve this a memoryless algorithm does not suffice. With the introduction of the FIFO algorithm, sequential analyses of the current and previous samples are performed prior to the alarm computation. This allows for a more confident alarm determination consequently agreeing with maintaining safe detection methods. Comparison between the STT and FIFO indicates that the FIFO outperforms the STT when determining alarm levels for any region. This eliminates errors due to occurrence of source spikes or background drops which might prevent the field surveyor to continue or stop taking measurement in that area.

The performance of the FIFO algorithm was studied and compared with the improved LIFELO algorithm. The spatial error and false alarm have been detected and reduced. The LIFELO algorithm is spatial error-free, while the FIFO algorithm has spatial error depending on the region of the sample. In the source region, the spatial error is high: nearly eight samples; in the background region, the spatial error is five samples. The spatial error is the lowest in the beginning of both the transition regions, from background to source and source to background. The FIFO algorithm generates a false alarm, and the alarm output is shifted to the right (alarm occurring after the LIFELO alarm has occurred). For the FIFO algorithm, false negative readings occur in Region 2 and this scenario is potentially dangerous for technicians taking the readings. Alarm readings in Region 4 are false positive. Comparison between the two algorithms clearly indicates that the LIFELO algorithm outperforms the FIFO algorithm and will be used for future consideration.

Further improvements to the LIFELO algorithm are made. First, the algorithm is allowed to perform dynamic background updating. This enables an automated updating of the background when the technician encounters a stretch of background regions. The dynamic updating gives a better ratio between the background and source alarm levels. Another improvement introduced is the MLE for the Poisson distribution. The resultant alarm levels show that LIFELO with MLE gives more alarms and indicates in detail the difference between weak and strong source samples.

The study on the fusion of radiation detector with GPS, wireless communication, and a self-correcting system was presented in chapter 4. Findings from the studies point out that most of the devices available or under development do not cater to a field survey of radiation detection. Furthermore, these devices are not a single unit and require a central processing to aid with the detection process. Thus the New-Guard comprises of that is required to enable a technicians to take readings while protecting themselves. Additional features that allow easy viewing and manipulation of the data serve as extra advantages.

The next step will be to fuse both technologies and develop a radiation detector with GPS, wireless communication and a self-correcting system incorporated with the detection algorithm. The flexibility of the New-GUARD enables the technician to choose from many different modes such as FIFO or LIFELO, with or without dynamic background updating, with or without MLE, parameter change, graphical representation and others. Embedding all the features into a single unit permits a field surveyor to be fully equipped to perform radiation detection.

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