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Research and Development of an Advanced RFID Security System Based on Locating Multiple Tags

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**Research and Development of an Advanced RFID Security System
Based on Locating Multiple Tags**

By

LAKHBIR SINGH

A Thesis

Submitted to the Faculty of Graduate Studies through the

Department of Electrical and Computer Engineering in Partial Fulfillment

of the Requirements for the Degree of Master of Applied Science at

The University of Windsor

Windsor, Ontario, Canada

2016

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April 29, 2016

AUTHOR'S DECLARATION OF ORIGINALITY

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ABSTRACT

Radio Frequency Identification (RFID) has gained a lot of attention lately with the introduction of RFID tags or inlays for a variety of applications. Most common is location tracking which can further be used for detecting the movements of tags from their original positions. In order to develop a system for finding the change in tag positions, a correct combination of RFID tags and reader is vital. Also, better understanding of challenges facing the RF signal can be productive. Environmental factors, antenna radiation pattern and orientation are some key issues, which can undermine this approach. In this thesis, to address some of the challenges a security algorithm for indoor RFID systems is proposed for detecting the change in the tag positions by finding the change in inter-tag distance. Also, several measures have been used to overcome the random nature of the RF signal. Experiments and evaluation of the above-mentioned methods in real time prove the robustness of the techniques considered for providing security.

DEDICATION

*To my loving family:
Father: Surinder Singh
Mother: Jaspreet Kaur
Sister: Manpreet Kaur*

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LIST OF ABBREVIATIONS

ARAT	Active Reader Active Tag
ARPT	Active Reader Passive Tag
CRC	Cyclic Redundancy Check
dBi	Decibels Relative to Isotropic Antenna
dBm	Decibel-milliwatt
EM	Electromagnetic
EPC	Electronic Product Code
FT.	Feet
GEN-2	Generation-2
GPS	Global Positioning System
HF	High Frequency
IC	Integrated Circuit
ID	Identification
IQR	Interquartile Range
LF	Low Frequency
NFC	Near Field Communications
PC	Protocol Control Word
PCB	Printed Circuit Board
PIFA	Planar Inverted-F Antenna
PRAT	Passive Reader Active Tag
RCPI	Received Channel Power Indicator
RF	Radio Frequency
RFID	Radio Frequency Identification
RSS	Receive Signal Strength

RSSI	Receive Signal Strength Indicator
TDS	Tag Data Standard
TID	Tag Identification
UHF	Ultra High Frequency

Chapter 1 INTRODUCTION

In today's world, technology is growing rapidly and becoming necessary in our day-to-day lives. Our dependence on technology in every aspect of our lives has made our life easier and less complicated; Radio Frequency Identification (RFID) is one of the available technologies, which plays a significant role in helping to achieve this.

RFID is the use of radio waves to uniquely identify an object, item or person. This RFID technology gives birth to RFID tags or inlays, which represent a thin wire and a chip circuit, used to read and capture information from an EM source, typically a reader. This combination of RFID tag and reader is the simplest RFID system. The RFID system has been widely adopted as an attractive technology due to its low cost and its high technical capabilities. It has often been used in applications such as asset tracking, industrial automation, supply chain, automatic payments, and homecare and healthcare systems.

One of the most attractive applications of RFID is location tracking. A lot of research has been done in this area and different solutions have been proposed over the years using approaches like RSS- (Received signal strength) based technique, Time-based technique, and Phase-based technique. These techniques can also be used for finding inter-tag distance in case where more than one tag being used. Likewise, different combinations of RFID tags and readers have been used to achieve tag location estimation and inter-tag distance with different types of RFID tags (explained in section 2.2.1 in detail).

The idea for this research came from authentication of paintings in case a real painting is replaced with a fake one. To check any forgery, a security system needed to be free from any hassle and complications. Therefore, the

need for using an RFID tag originated from the need to provide security. Placing tags at different positions on the painting and storing each tag's Electronic Product Code (EPC), as explained in section 2.2.3 in detail, in a database cannot solve all security problems because a forger can use the same tags and place them at the same positions on a fake painting. The fake painting is then identified as a real one because the EPC of the tags attached to the painting is same with the EPC of the tags in database. While placing the tags acquired from original painting on to a fake one, a forger can easily alter the tags positions. Therefore, an interactive security system was needed such that we can detect the positions of the tags attached to the painting and any movement in their positions can be detected, thereby predicting the painting's authenticity. The RFID system with two tags and a reader gives us a possibility of achieving the goal of this research.

This research includes the RFID system, which is comprised of two Ultra-High frequency (UHF) passive RFID tags with UHF passive Hand held RFID reader. The RSS-based technique is preferred over phase- and time-based technique because it is not possible for a handheld device to have a constant phase due to its continuous movement. Moreover, EM waves travel at the speed of light and hence it is difficult to detect accurate time taken by wave from sender to receiver. The RSS technique used in this research is not limited to tags location estimation from the reader and finding the inter-tag distance, but also contributes towards detecting change in the positions of the tags, and ultimately change in inter-tag distance, which forms the basis for our security system. Significant research has been conducted to find the locations or positions of tags and absolutely none of them focuses on detecting the change in the movement of the tags from their

original positions or change in inter-tag distance if considering two tags in an RFID system, as in this case.

The reason for using two tags is simply because it is very easy for a forger to replace one tag and placed on to a fake painting precisely. Moreover, it is not very easy to detect change in the position of a single tag. Movement in the positions of the tags used in the RFID system from their original positions will change their inter-tag distance. Therefore, by using two tags, and finding the change in their inter-tag distance can fulfill the requirement of achieving the research objective. UHF passive RFID tags are used due to their low cost, larger life span, and faster data transfer than other available tags in the market.

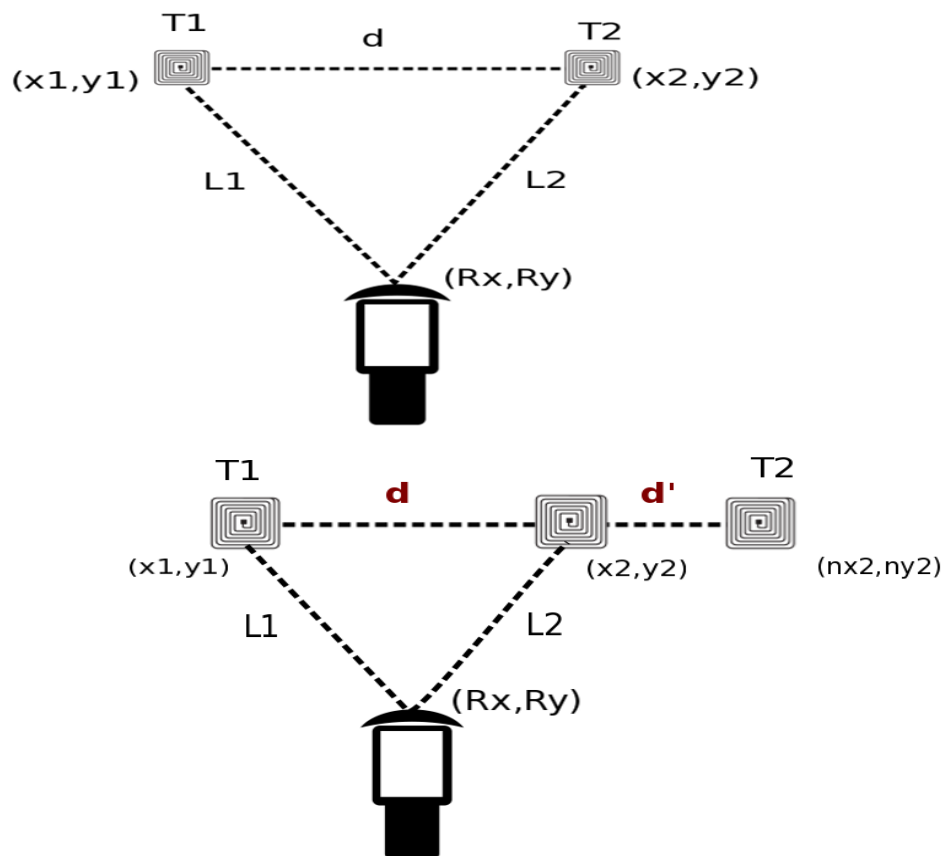


Figure 1.1: RFID system used in research

Figure 1.1 shows an RFID system taken into consideration in which two UHF passive RFID tags are placed at some position (x_1, y_1) and (x_2, y_2) in two-dimensional space with a UHF passive RFID reader at (R_x, R_y) . d is the distance from center of tag T_1 to center of tag T_2 ; L_1 is the distance between reader and tag T_1 ; L_2 is the distance between reader and tag T_2 . If any change occurs in the positions of tags T_2 from (x_2, y_2) to (nx_2, ny_2) and similarly with tag T_1 , distance d between tags will change. This system is not limited to painting authentication but can also be used in applications such as locating multiple moving tags in multi-storing building, used for autistic patient in a hospital for access control, used for providing security to items in museums and auction stores, can also be used in industrial automation for controlling equipment maneuvers, and other applications where any sort of security or control is required.

1.1 Thesis Objective

The main purpose of this research is:

- To develop an advanced RFID security system by detecting the change in the positions of tags from their original positions.

Any change occurs to the positions of the tags will change the inter-tag distance which ultimately changes the detectable parameters and therefore giving us a measure of predicting the movement in tags positions.

1.1.1 Research Goals

- Develop a smart device windows application (using c# programming language) for handheld RFID reader to record signal level from tags involved in RFID system.

- Perform signal level-distance conversion for finding the distances between reader and tags.
- Finding the coordinates of vertices formed by reader and tags in an RFID system by means of nonlinear least-squares optimization, solving the system of nonlinear equations (using Matlab).
- Applying signal-processing measures for improving the location accuracy by designing adaptive Kalman filter (using Matlab).
- Determine the change in distance between the tags from their original positions by finding the change in relative error of inter-tag distance.

1.2 Thesis Outline

This section briefly explains the topic included in this thesis. In chapter 1, thesis introduction, thesis objective, and research goals are given. In chapter 2, background information is presented on RFID technology, RFID system, RFID tag and reader with their types, antenna and its basics, system specifications used in this research as well as a review of relevant work in literature. Chapter 3 outlines in detail the different methods used to achieve the goals and ultimately the objective. This includes a detailed description of the design process and final outcomes. Chapter 4 includes the experimental results. In chapter 5, the thesis concludes with a summary and discussion of possible future work in this area with references and appendix to follow after.

Chapter 2 BACKGROUND AND RELATED THEORY

There has been much research done in the area of RFID for locating tags and its use for security. This chapter focuses on giving an overview of RFID Technology. It then goes on to explain RFID Tags, RFID Reader, Antenna Basics and its popular types and the specification that is used in this Research. The Tag and Reader specification for RFID system are also outlined in detail.

2.1 Radio Frequency Identification (RFID) Technology

In order to explain RFID, we need to understand radio waves. Radio waves are produced when free electrons oscillate in a wire. Electric current is produced in the wire with flow of electrons, which builds electromagnetic field around it. This field sends a wave outward whenever current is changing in the wire. If this methodology proceeds again and again for a period of time, an arrangement of waves is propagated at a discrete frequency, which is nothing but radio waves. Figure 2.1 shows the magnetic field around a wire with constant electric current.

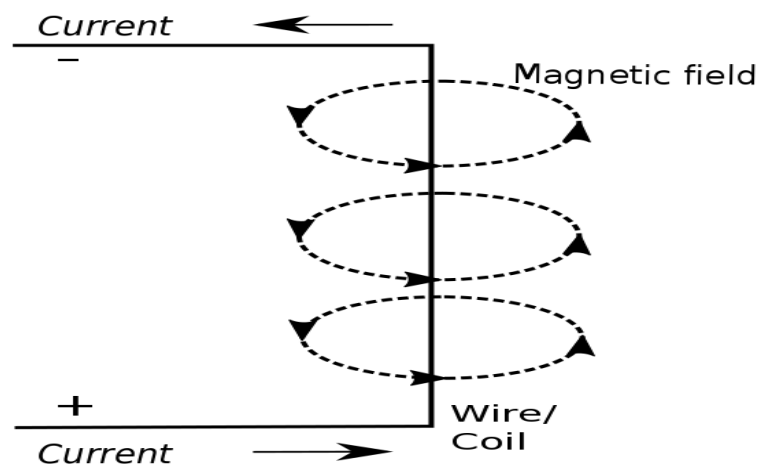


Figure 2.1: Magnetic field around a Wire/Coil

RFID means Radio Frequency identification and is a technique used for the purposes of automatic identifying, tracking, and validating the status, authenticating tags using radio waves.

RFID technology existed for decades and its attaches can be followed down to World War II. For quite a while, RFID might have been utilized to planning radar to track planes, which might have been utilized by numerous nations in that duration of the time [1]. Developments over RF interchanges proceeded through 1950s. In 1960s, scholars and researchers from everywhere throughout the globe published papers viewing RF signal utilization to remote article ID number. In year 1973, first U.S. patent for an active RFID with rewriteable memory was believed to be gain by Mario W. Cardullo [1]. Charles Walton gained a patent for passive transponder in the same quite a while [1]. In mid-1980s, RFID tags been produced by different associations for business purposes. A percentage of organizations afterward opted to low and high radio frequency transponders for quicker information exchange and amazing read and write range [1].

IBM particular architects created and protected an ultra-high frequency (UHF) RFID framework in early 1990s. However, IBM sold their patent with Intermec, a bar code service provider [1]. UHF system advertised more drawn out read range typically 20 feet under beneficial conditions and speedier information exchange [1]. A breakthrough happened in RFID Technology in 1999 when two Massachusetts Institute of Technology professors, David Brock and Sanjay Sarma [1] produced an inexpensive UHF RFID tag. Since 2003, RFID technology attained new statures for introduction of two air interface conventions: Class 1 and Class 0, Electronic Product code (EPC) numbering plan and a network architecture for looking up information connected ahead a RFID tag on the web [1]. With the

introduction of second-generation standard of EPC in 2004 [1], use of EPC became very common and many organizations started utilizing EPC approach for their business purposes. Today, the main applications of RFID are Security access control (automated tolling), Traffic analysis/management, and Retail, Logistics and supply chain management, Antiques monitoring, Vehicle monitoring, and E-commerce.

2.2 RFID System

RFID system is a combination of RFID tags (Transponders) and reader or interrogator. The reader sends out the RF signal carrying commands to the tags and RFID tags responds with its stored data to be authorized, detected or counted. RFID tag and reader are discussed in detail later in this section. A general description of RFID system is given in the Figure 2.2.

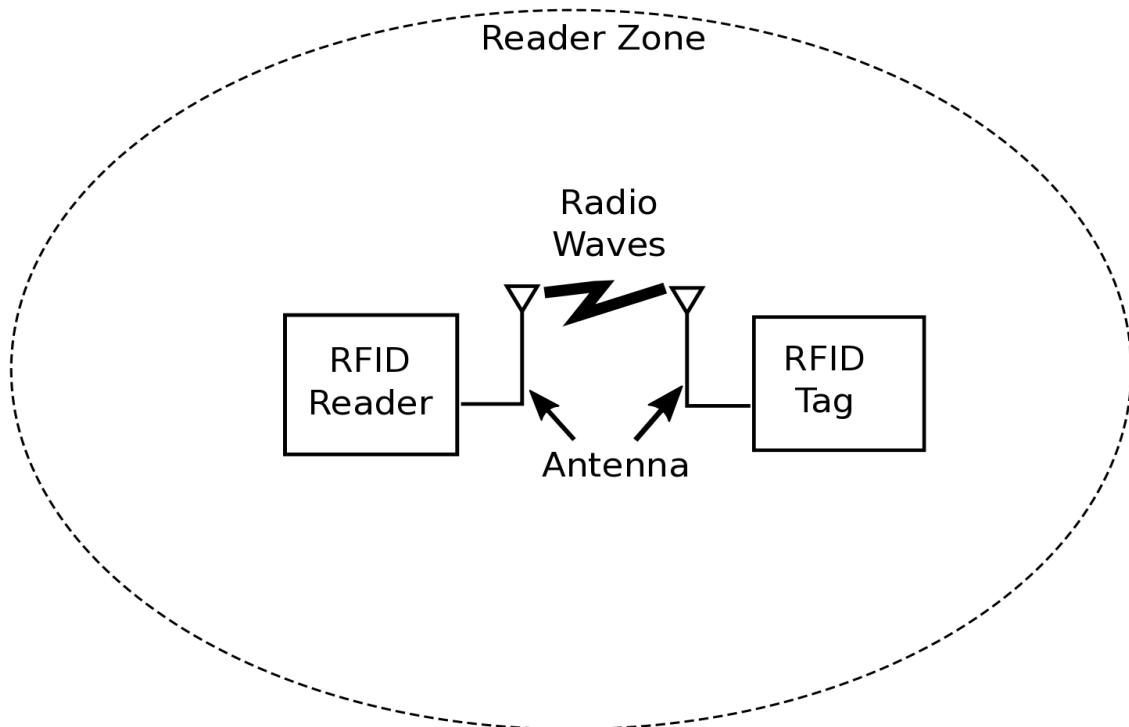


Figure 2.2: General diagram of RFID System

There can be different combinations of RFID system based on the category of tag and reader, most common are given [2] below:

- 1) An active reader passive tag (ARPT): It is a system in which reader RF signal retrieves data from tag.
- 2) An active reader active tag (ARAT): It is a system in which tag continuously sends RF signal to reader.
- 3) A passive reader active tag (PRAT): It is a system in which tag emits radio waves with data to reader, which is then used for further processing.

The ARPT framework used for this research utilizes two passive UHF RFID tags, which communicate with an active RFID reader.

2.2.1 RFID Tag

RFID Tags are tags, labels or inlays, which work on the principle of using radio waves to read and capture information. A typical RFID tag consists of transceiver antenna and integrated chip circuit as shown in Figure 2.3.

Transceiver antenna acts as a transducer between EM field and electric energy [2] and is responsible for bidirectional interfacing. It extracts energy and data from input signal and feed them to the chip circuit.

Integrated chip circuit composed of two sections, Analog and Digital section. In Analog section, Power generator uses the extracted energy and data. Energy used for producing power and data for digital circuitry. Demodulator is used for analog to digital conversion along with clock recovery. In most cases incoming data already has clock recovery attached, for having a synchronous communications otherwise power generator (in case of RFID tag) add one to data and check for same clock when commands return with output. In Digital section, control logic processed the data

received with commands and retrieves the information from the memory. Modulator performs digital to analog conversion with clock recovery after data processing.

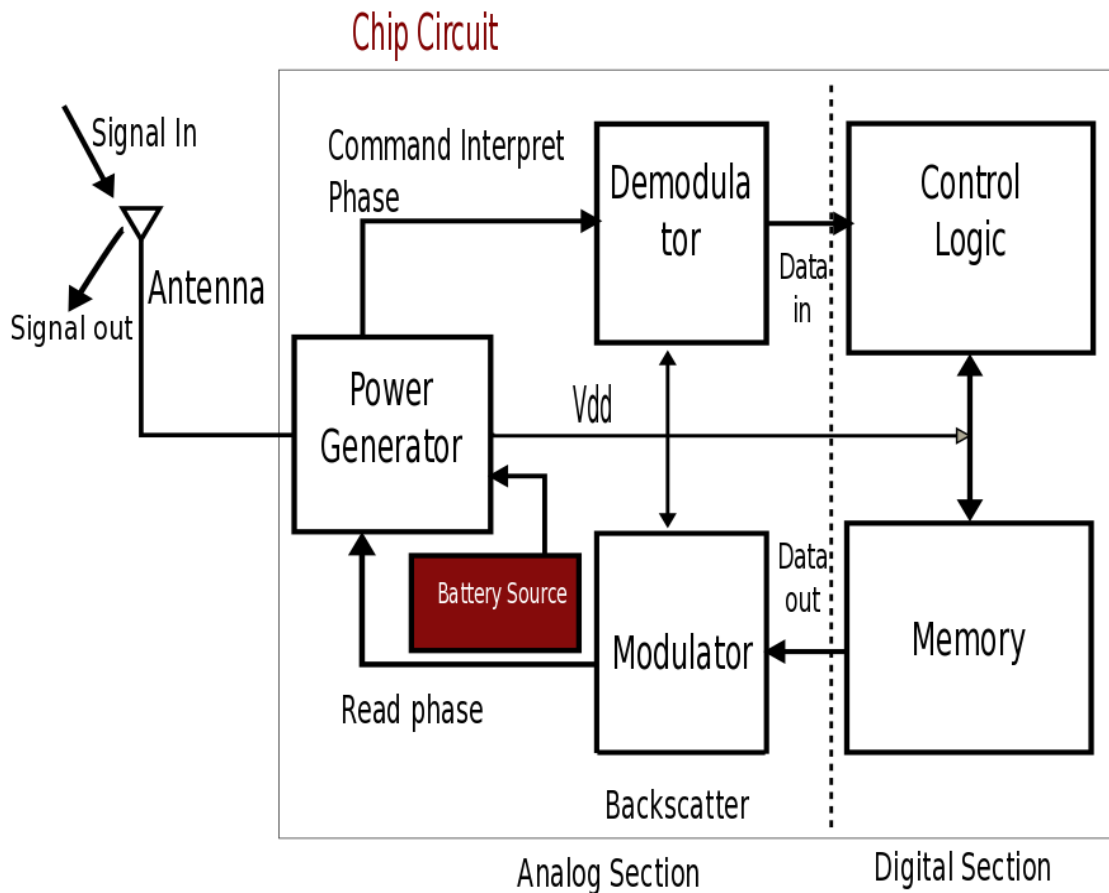


Figure 2.3: Block diagram of RFID Tag

Backscatter modulation occurs for passive and semi passive tags (Discussed in next section) and is defined as Power to be reflected back and scattered in the same direction from where it originated. It usually occurs with variations in tag's load impedance, which causes intended mismatch between antenna and load. Upon receiving and checking data and clock from

modulator, power generator feeds the antenna for transmitting. Return scattered signal is detected and decoded by reader.

2.2.2 Types of RFID Tags

Based on battery source and backscattering, we can categorize RFID tag into three types: Active, Semi passive, and Passive tags [3], which are outlined below one by one.

- 1) Active tag: Tags with its own power source (typically a battery) for tag circuitry and do not possess backscattering modulation, called as Active tags. These tags have capability of initiating communications because they are continuously sending signal, which can then be detected by a reader. Modulator serves the purpose for active transmitter. There are some advantages for active tags like longest range (typically up to 100 feet or more); maximum data transfer with some disadvantages like lifetime of 2 years (approx.), high cost etc.
- 2) Semi passive tag: Tags with a power source (Battery) for tag circuitry and possess battery-assisted backscatter, called Semi Passive tags. These tags do not have active transmitter and hence rely on backscattering for transmitting signal. They have battery lifetime of more than 5 years and read/write range as far as 100 feet (Typical). They are less expensive than active tags and hence preferred more today over active tags.
- 3) Passive tag: Tags, which do not have a battery, instead drive power from the radio waves sent by reader (Source) and possess backscattering for transmitting signal, called as passive tags. These tags do not have on-tag transmitter. They have range for less than 10 meters and lifetime of 20 years or more. Because of their low cost,

these tags have been used in all sectors and preferred over active and semi passive tags.

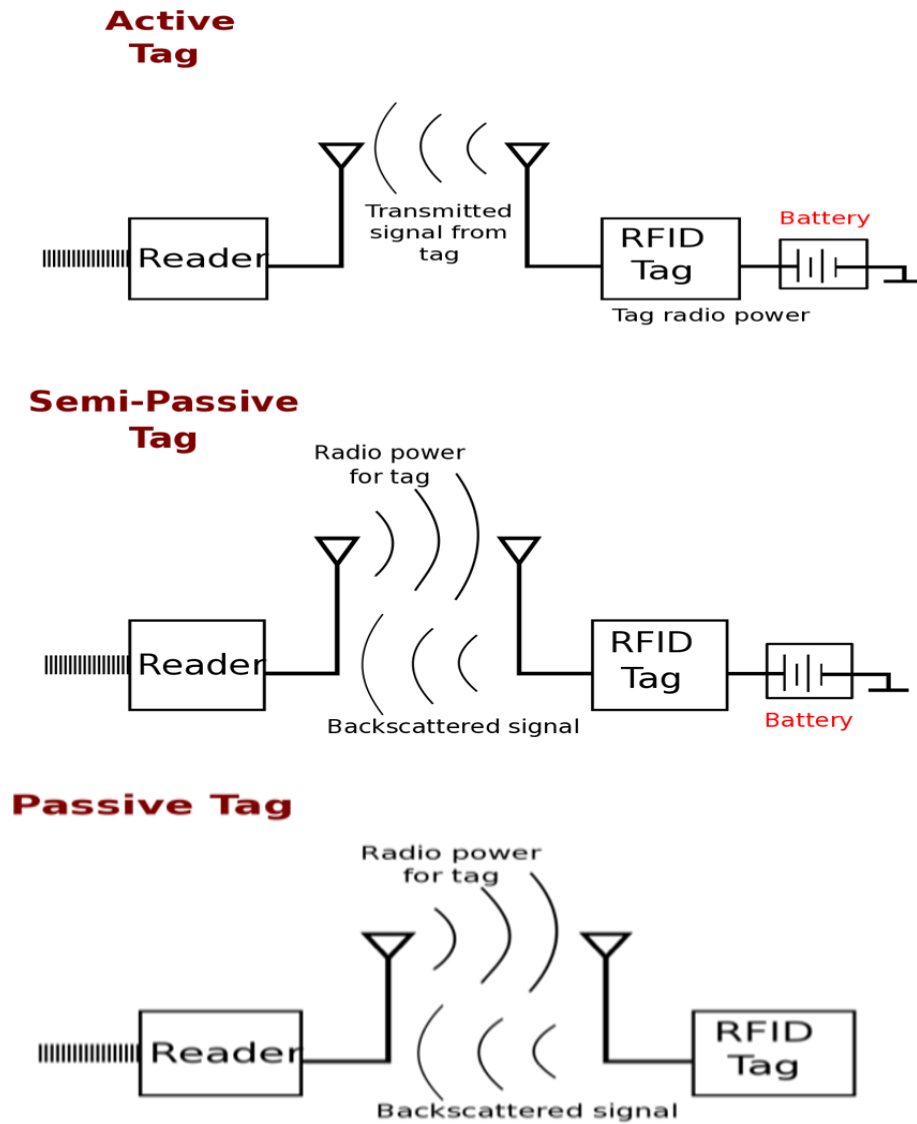


Figure 2.4: Block diagrams for Active, Semi passive, and Passive tag [3]

RFID tags can also be categorized based on frequency of electromagnetic waves used by tag and reader antenna. There are several different

frequencies an RFID system might utilize. Generally, the most common [4] are

- Low frequency (LF), which is 125 – 134 kHz.
- High frequency (HF), which is 13.56 MHz.
- Ultra-high frequency (UHF), which is 433, and 860-960 MHz.

Hence different types of RFID tags can be named as LF, HF, and UHF Active, Semi passive or Passive RFID tag. Each type of RFID tag has its own advantages and limitations. Depending on the requirement, one can choose an appropriate tags and readers combination. Note that RFID tags and readers must be tuned to the same frequency in order to interact with each other despite frequency hopping is enabled.

2.2.3 Tag Properties

There are different properties or parameters that are associated with RFID tag, which are used by different organizations in a wide spectrum of applications for achieving their respective goals. This section only focuses on properties which have been used in this research or which are of utmost importance such as Electronic product code (EPC), Memory bank, Protocol control word (PC bits), Received signal strength indicator (RSSI) or signal level.

- 1) Electronic product code (EPC): EPC is a globally distinctive code that gives a unique identity to a specific RFID tag, unit loads, locations, different recognizable proof substance playing a part to benefits of the business operations. EPC Tag Data Standard (TDS) specifies the information position of the EPC, and gives encodings for numbering schemes including the identification keys, inside an EPC [5]. Distinct EPCs are used for separate RFID tags; RFID readers capture these

distinct identifiers to identify tags at very high rates and at distances under the reader zone, without having direct line-of-sight communication [5]. These aspects from claiming RFID could make leveraged to support supply chain perceivability and expand stock precision. Basic format for EPC is given below in Figure 2.5.

Header	EPC Manager Number	Object Class	Serial Number
80	0437528	300000	00A103177
8-bits	28-bits	24-bits	36-bits

Figure 2.5: Basic format for Electronic Product Code (EPC) [2]

EPC is divided into four different sections, which are given below as

- **Header:** It associates the length, type, structure, rendition and era of the EPC. It need an 8-bit size and cannot be transformed. Here 80 represent the header (EPC Type) for RFID tag EPC [2].
- **EPC Manager Number:** It is answerable for administering the following partitions as shown in Figure 2.5. It has a 28-bit size and is imprinted during manufacturing, hence irreversible. Here 0437528 represent EPC Manager Number (Manufacturer) for RFID tag EPC.
- **Object Class:** It identifies a class of an object or category of tags to which it belongs. It is also known as Product type and has a 24-bit size [2]. A code given to an object class is also

irreversible after manufacturing of an RFID tag; 300000 represent Object Class (Product type) for RFID tag EPC.

- Serial Number: It identifies of instance, which can be alter or change as per user convenience and has a size of 36-bits [2]. Due to the reversible feature of the code designated to serial number, serial number might be utilized to different security requisitions. 00A103177 represent Serial Number (Unique item) for RFID tag EPC.

Note that 80043752830000000A103177 is EPC of RFID tag.

2) Memory bank: RFID tag memory is divided into four parts: Reserved memory, EPC memory, TID memory, and User memory [6] which are outlined below

- Reserved memory: This memory stores only kill password and the access password (32 bits each) [6]. Kill password deactivate the tag and access password lock/unlock tag's writing capabilities. It holds just two codes and it will be just writable.
- EPC memory: Stores EPC code with 96 bits of writable memory.
- TID memory: Contains the distinct tag ID number, and is imprinted when IC is made. This part cannot be transformed.
- User memory: Stretched out memory, which might store additional data when EPC segment memory is full. There will be no standard method for allocating this writable memory.

3) Protocol control word (PC bits): PC bits are incorporated inside the EPC memory section. Generally, word 1 is allocated to PC bits. Number of bits depends upon word size [7]. EPC data is allocated to word 2 till word N in EPC memory and Cyclic redundancy check

(CRC) is allocated to word 0 and used to check error in the EPC memory [7]. Basic format for PC bits is given below in Figure 2.6.

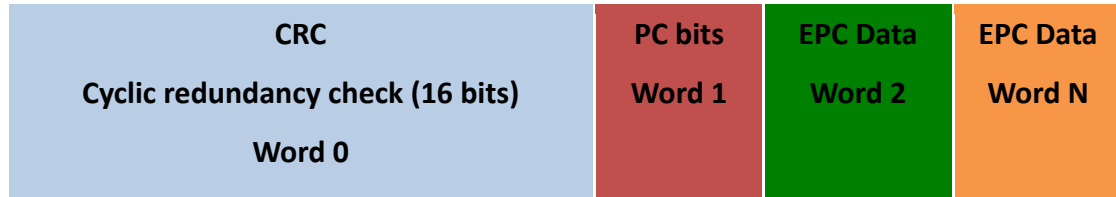


Figure 2.6: Basic format for EPC Memory [7]

- 4) Received signal strength indicator (RSSI): It is the measurement of power present in received radio waves. It is often measured in Decibels-milliwatts (dBm) or in simply watts. RSSI can be expressed as a negative, zero, and positive value. When RSSI is negative then values closer to zero indicate a stronger signal and when it is positive, larger values indicate a stronger signal. Some more modern chipsets utilized RSSI from 0 to 256 alternatively 0 to -127 yet majority of new chipsets utilize 0 to -100. RSSI is reinstated as RCPI (Received channel control Indicator) when working with 802.11 wireless. This property is very important for this research point of view because RSSI is used for signal strength-distance conversion. RSSI can also be called as Signal Strength.

2.2.4 RFID Reader

An RFID reader is a device that provides the connection between the tag data and the application framework product that needs the data. The reader communicates with tags that fall inside its field of operation, performing any number of assignments, for example, basic constant inventory, sifting

(finding tags that satisfy certain criteria), and filtering tags [2], etc. It uses an attached antenna to capture data from tags. Figure 2.7 shows different components involved in RFID reader. Once the information has been received from RFID tag using reader through a connected antenna, it is then sent to middleware (or reader control and application software) [2], which basically connects user application with the information from the reader.

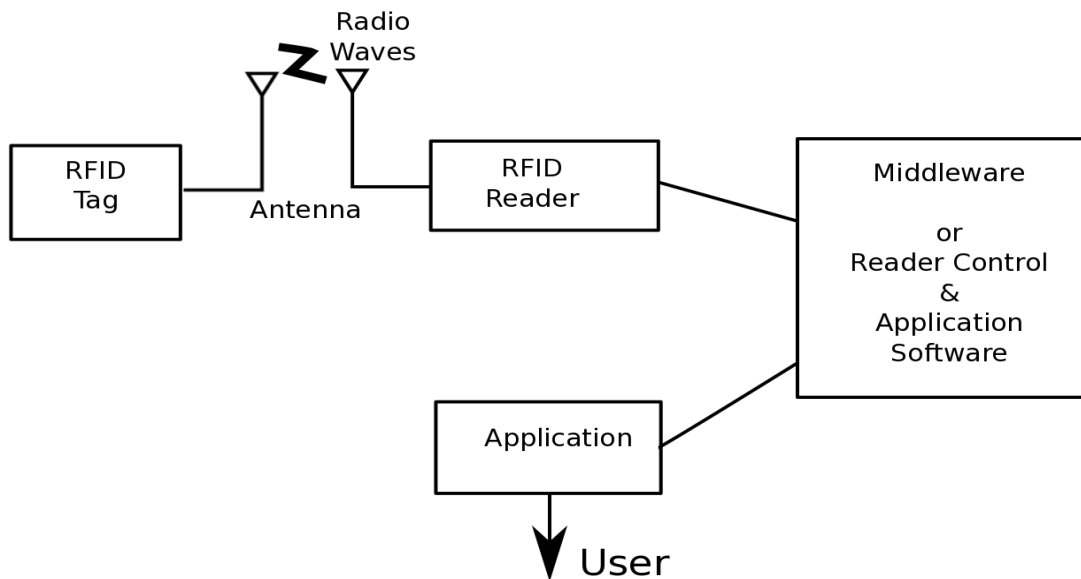


Figure 2.7: General block diagram of RFID reader components

RFID readers can be broadly categorized into two types: Active and Passive readers [8]. Active reader is one, which sends out RF signal to retrieve the information from tag while passive reader is one, which takes the signal from the tags, or any RF source. Readers can also be categorized based on the antenna attachment in a fixed position or coordinated under a movable device for example, a portable, handheld scanner. Readers can also be installed in electronic devices and in vehicles as well. Various active and passive RFID readers are available on the market in the form of a handheld

or fixed reader. Both have their own advantages and limitations. Companies like Zebra, Siemens Motorola etc. manufacture this equipment.

There are various important components in an RFID reader. But the most important one is reader antenna, which is used to transmit and capture signal level. There are two types of antennas, which are generally used in RFID reader - linear and circular-polarized antennas [2]. Linear antennas are responsive to tag alignment, which rely on the tag angle or placement. Antennas that emit linear polarized waves bring long ranges, and large amounts of power that enable their signal to infiltrate through various materials to read tags. On the other hand, antennas that emit circular polarized waves are less responsive to tag alignment, but are capable of delivering as much power as linear antennas and may have difficulty in reading tags. RFID readers and their antennas communicate and work hand in hand with each to identify tags. Electrical current is changed into electromagnetic waves by RFID reader, which are then transmitted into space for capturing by a tag antenna and changed over again to electrical current. An optimal RFID reader selection varies as per the requirement of the application and environment.

Read range which is the separation between the RFID reader and the tags also determines the type of antenna required for the application. Near field or short-range and far field or long-range are two possible ranges in which a reader antenna works [2]. The reader and tag antenna communicating in short-range applications for transferring information, data or energy utilizes the method of magnetic coupling. The read range to these requisitions is less than 30 cm [2]. Also, the vicinity of any dielectrics like plastics, glass etc. cannot make any impact on the identification of the tags in the short-range

applications. On the other hand, the reader and tag antenna communicating in long-range applications for transferring information, data or energy uses the method of electromagnetic coupling. The read range to these requisitions is greater than 30 cm and can be up to several meters [2] and the vicinity of any dielectrics can debilitate the identification of the tags.

2.2.5 Tag and Reader Specifications used for this Research

This section discusses the kind of RFID tags and reader used in this research. RFID system used for this research has two UHF passive RFID tag and a hand held RFID reader. Complete specifications of RFID system components involved are given below.

- 1) RFID tag specification: As two UHF passive RFID tags are used in this research, both of them are of same type. They belong to same Smartrac 273_2 EPC class-1 Gen-2 with Impinj Monza 4 Integrated circuit (IC) and a short dipole antenna of same length (93mm) [9]. They have an operating frequency from 860-960 MHz (902-928 MHz is allowed in North America), -40°c to 85°c of operating temperature, 128 bit to 496 bit of EPC memory, and 32 bit to 512 bit of user memory, and has a very large lifetime (approx. 20 years or more from date of manufacture) [9]. These types of RFID tags are extraordinarily planned for supply chain management, clothing furthermore brand protection, and sports timing which allow ideal execution on non-metallic materials such as cardboard and plastic [9]. Figure 2.8 shows the RFID tag used.



Figure 2.8: Smartrac short dipole 273_2 UHF passive RFID tag [9]

2) RFID reader specification: A Motorola MC3190-Z UHF active RFID hand held reader with operating frequency of 903-930 MHz, read range up to 10 ft. and write to 1.2 ft., and Integrated orientation insensitive antenna is used for capturing information from tags in RFID system [10]. It radiates power of 1 watt, have a 256 MB RAM, and 1 GB Flash [10]. The reason for using hand held reader is nothing but to develop a security system, which can be accessible very easily and can be used frequently and effectively without have to worry about the large and bulkier fixed RFID readers.



Figure 2.9: Motorola MC3190-Z UHF active RFID reader [10]

Just like short dipole UHF passive RFID tag, it also has same applications in supply chain management, industrial automation, and asset tracking. Figure 2.9 shows hand held RFID reader.

2.3 Antenna

An antenna is a device which sends or receives electromagnetic waves. It translates electromagnetic waves acquired from space into electrical current in conductors or vice-versa, depending on whether the antenna acts as receiver or transmitter [11][12].

The pairing of electronics and electromagnetic waves is done by antennas working on both ends either receiver or transmitter. It is a significant component of radio device [12]. In general, there is a relationship between antenna size and the frequency used by the antenna. An antenna size must have the right length for the frequency used but this is not a hard and fast rule for manufacturer [12] while making antennas. In fact, there are contemporary antennas that work with more than one frequency as in case of hopping frequency, which prevents the signal from dropping.

Electromagnetic waves can be radiated and received by an antenna uniformly in all straight and perpendicular directions or likely in a specific direction [12]. It additionally incorporated extra components or surfaces with no electrical unit with the transmitter or receiver, which helps to adjust the electromagnetic waves into a ray or any chosen radiation patterns.

2.3.1 Introduction to Antenna

Antenna adoption for everyday use started way back in 19th century and till around 1890s, world has seen a handful of these devices [11]. These initial

devices were part of the analysis that manifested the very process of conversion of electromagnetic waves [11].

In 1830s, Faraday performed the first experiment, which involved the coupling of electricity and magnetism and hence proved a definitive relationship between them [11]. He smoothly passed a magnet around the coils of a wire connected to a galvanometer and in moving the magnet; he was actually developing a time-varying magnetic field, which must have had a time-varying electric field (from Maxwell-Faraday equation). The electromagnetic waves produced were detected by the galvanometer attached, when coil behave like a loop antenna [11] and therefore proved antenna's functioning.

Antennas played a very important role in the World War II and later on, their utilization revolutionized and changed the life of an average person via radio and television broadcasting [11]. The popularity of antenna was so enormous that in the United States, there was at least one antenna at every house [11]. This booming market of antennas also helps auto industry to compete and eventually grow during the same period [11]. Due to the new advancements in technology in the early 21st century with the introduction of mobile phones has changed the whole idea of antenna numbers and their portability [11]. Research pertaining to antenna growth leads to the development of wireless communication systems, which has become an essential element of our day-to-day life. The new research trend in antenna technology involves extensive research on metamaterials (an artificial material which contains the properties of dielectric and magnetic constants, that might be at the same time negative which ultimately give rise to negative index of refraction) [11]. Some other researches aim at how to

make antennas size shorter for its effective use in individual remote correspondence devices such as mobile phones [11].

New developments in RFID devices suggest that we can have more than one antenna per object [11] and this number will rule antennas utilization in future. As an essential part of communication technologies field, antenna theory is of high importance for electrical and communication engineers.

2.3.2 Types of Antenna

Antenna is an essential part of a communication device which allow for remote communication between a number of separated electric circuits [12]. Antenna gain, aperture, directivity and bandwidth, polarization, effective length and resonance are the properties of antenna, which can be used for categorizing antennas. In this section, we will discuss popular antenna types with their subcategories.

- 1) Wire Antennas: A wire antenna is an elementary radio antenna, comprising of a conducting wire, which is half the length of the maximum wavelength of the antenna [12]. This wire is split in the middle, and a current source (transmitter) separates the two sections as shown in Figure 2.10 for short dipole wire antenna. These types of antennas are fed at the center and any transmission and reception of radio signal is done at the center [12]. Types of wire antennas are: short dipole antenna, dipole antenna, half wave dipoles, broadband dipoles, monopole antenna, folded dipole antenna, loop antenna, and cloverleaf antenna [12].
- 2) Log periodic antennas: These types of antennas are basically used to give better wideband RF reception than dipole antennas which can be achieved with higher gain and directivity [12]. These antennas are also

known as aerial antenna. They categorized into three types of antennas such as bow-tie antennas, log periodic antennas and log periodic array [12][13].

The first type, bow-tie antennas or butterfly cannot be fully classified as log periodic antennas but these antennas lay a good foundation for discussing the initial phase of log periodic antennas [12]. The second type, log periodic antennas are antennas which are developed to achieve a goal of possessing a broader bandwidth [12]. The achievable bandwidth is hypothetically interminable but the real bandwidth attained rely on factors such as how big is antenna structure which is used to measure the lower frequency limit and how accurate the smaller attributes are on the antenna which measures the upper frequency limit [12]. Third, log periodic array are used to work with large frequency band and can be characterized into active and passive regions [12].

- 3) Travelling wave antennas: An antenna in which the current circulations are generated by waves of charges propagated in only one direction in the conductors [12]. These antennas are also known as progressive-wave antenna. These antennas are categorized into three types of antenna such as helical antennas, Yagi-Uda antennas and spiral antennas [12][13].

Helical antenna is an antenna that produces radiation along its own axis [12]. These antennas have a shape of corkscrew and are also classified as axial mode helical antennas. These antennas exhibit some properties about utilizing helix antenna, which would be wider bandwidth and circularly polarized field generation [12] [13].

Secondly, the Yagi-Uda antenna or Yagi antenna has a standout

antenna design among others. Just like helix, these antennas also exhibit some properties about their utilization, which are straightforward construction and have a high gain, which is typically above 10 dB, operating from HF to UHF bands, and typically have littler bandwidth [12][13]. The most common example of Yagi antenna is roof top antenna. And last, spiral antennas are antennas with substantial bandwidth capacity and have association with category of frequency independent antennas [12].

- 4) Aperture antennas: Aperture antennas are antennas that are typically created with the combination of metal walls and dielectric, frequently with ridges [12]. The leaning of radiation fields over the opening of the antenna is a way of measuring fields from these types of antennas [12]. At large distances, the radiated fields originate from the aperture fields, which is in contradiction with Huygens-Fresnel principle, which states that “every point on a given wavefront become the radiating sources from which a spherical wavelet is propagating and the resulting field intensity be found by superposition which generates the next wave front” [12]. Aperture antennas are divided into various categories such as slot antenna, cavity-backed slot antenna, inverted-f antenna, slotted waveguide antenna, horn antenna, vivaldi antenna, and telescopes antenna [12].
- 5) Reflector antennas: Reflector antennas are antennas, which typically operates when an inflated gain (in case of satellite transmission or reception) or a very restricted main ray (in case of secure communication) is required [12]. There is a direct relationship between the gain and the main ray with reflector size, any expansion in reflector size will increase the gain and restrict the main ray [12].

However, large reflectors are difficult to implement due to their substantial size as compared to wavelengths [12].

This antenna categorized into two types: corner reflector, and parabolic reflector. The first one, corner reflector is an antenna that enhances antenna directivity [12]. The second one is parabolic reflector antenna, which is a most common reflector antenna. It is also known as satellite dish antenna [12].

- 6) Microstrip antennas: A microstrip antenna is a small band, extensive antenna created by engraving the antenna component designs in metal outline attached to an insulating dielectric substrate, for instances a printed circuit board (PCB), with a constant metal layer connected to the inverse side of the substrate that layout a ground plane [12]. These antennas are also known as patch antennas. There are various standard shapes for microstrip antenna, which are square, rectangular, circular, and elliptical. Moreover, the feasibility of any continuous shape also exists [12]. Microstrip or patch antennas are getting to be progressively functional on the account that they can be design or fabricated straight into a circuit board [12]. In fact, mobile phone industry is making an extensive use of microstrip antennas due to their smaller shape, lesser expense, and smoothly created capability [12]. Microstrip antennas can be categorized into two types: rectangular microstrip antennas, and planar inverted-f Antennas or PIFA microstrip antennas [12].

2.3.3 Antenna Specification used for RFID System

This section explains the specifications of antenna used for RFID system i.e. for UHF passive RFID tags and a hand held reader. There are two UHF

passive RFID tags used, which belongs to same Smartrac 273_2 EPC class-1 Gen-2 with Impinj Monza 4 Integrated circuit (IC) and a short dipole antenna of same length [9] and a RFID reader which has an integrated orientation insensitive antenna. Both antennas are described below in detail.

- 1) Short Dipole antenna: The short dipole antenna is a modest version of the popular dipole antenna. Short dipole antenna is an antenna, which is made up of two conducting wires connected to each other through a transmitter at the center [14] as shown in Figure 2.10. The meaning of short is smaller size of the antenna relative to wavelength and typically, antenna size is less than one tenth of the wavelength i.e.

$$L < \frac{\lambda}{10}$$

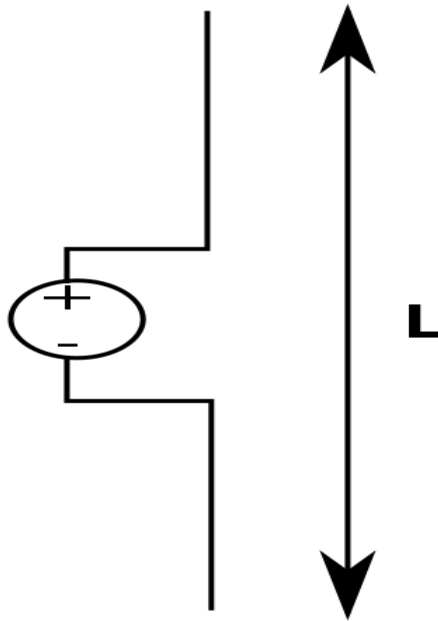


Figure 2.10: Short dipole of length L [14]

The current distribution on the short dipole antenna is given in equation (2.1), when the antenna is aligned in the direction of z-axis and placed its center with its z-coordinates at origin [12]:

$$I(z) = I_0 \left(1 - \frac{2|z|}{L}\right) \quad (2.1)$$

Equation (2.1) shows that the current amplitude on the short dipole is inversely proportional to the length of the dipole which shows longer dipole will have less current. The electric and magnetic fields radiated from the short dipole antenna in the far field [12] are given by:

$$E_\theta = j\eta\beta \frac{I_0 L e^{-j\beta r}}{8\pi r} \sin \theta \quad (2.2)$$

$$H_\phi = \frac{E_\theta}{\eta} \quad (2.3)$$

$$E_r = H_r = E_\phi = H_\theta = 0 \quad (2.4)$$

The exponential term $e^{-j\beta r}$ and $\sin \theta$ in equation (2.2) describes the phase variations and spatial variations of the wave with distance, respectively. The electric field E_θ and magnetic field H_ϕ given in equation (2.2) and (2.4) have finite values and are orthogonal as well as in-phase with each other in case of far field [12]. These fields propagate in the direction opposite from the antenna and are perpendicular to the direction of propagation [12]. These fields act like a plane-wave in far field and their amount decreases by $1/r$ and power reduced [12] by:

$$P(r) \propto \frac{1}{r^2} \quad (2.5)$$

Equations (2.2) and (2.3) demonstrate a relation between the fields and length of the dipole; larger the size, more is the field. There are some other factors for short dipole which needs to be outline in this section which are antenna basics [15] i.e. radiation pattern, antenna gain and polarization.

- Radiation pattern: Radiation pattern is the change in the strength of the radio waves as they propagate away from the antenna [12]. The variation in the radio waves strength can be easily detected in the far field, which depends upon waves angle of arrival [12]. Antennas do not have equal radiation distribution [15]. They have maximum radiation in the direction front of them and the area covering the maximum radiation is called main lobe [12][15]. Similarly, other lobes are side lobes, which have less radiation, and one back lobe, which have more radiation than side lobes but less than main lobe [15]. For better accuracy and reliability, data collection for this research is done in the main lobe. Figure 2.11 shows the radiation pattern for short dipole having an elliptical shape and it resembles a doughnut shape in 3-D. Note that the current is maximum in center and least at the end of the antenna.

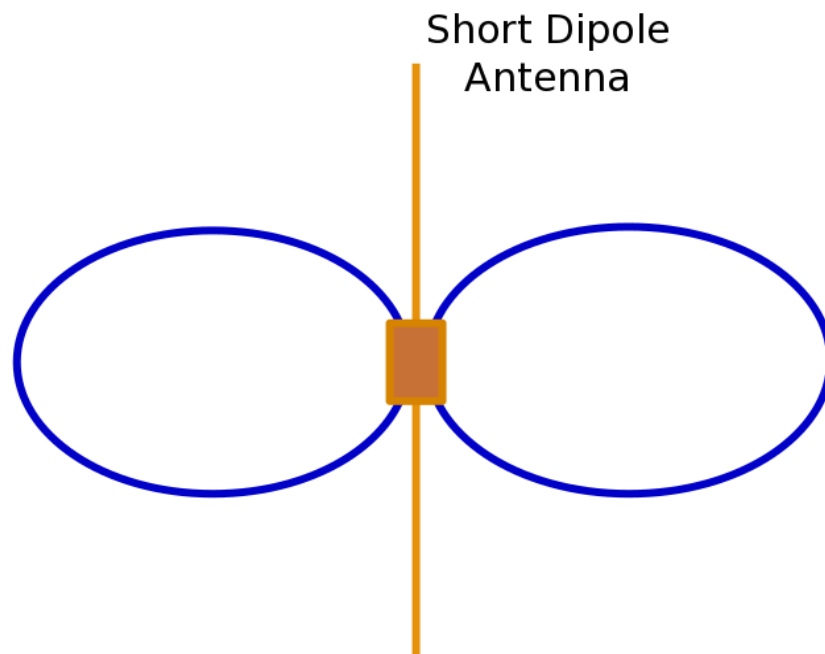


Figure 2.11: Radiation pattern for short dipole antenna [14]

- **Antenna Gain:** Antenna gain is defined as the ratio of amount of power radiated by an isotropic antenna to the amount of power radiated by the antenna [15]. Antenna gain is often used due to its ability of giving precise information about the actual power loss while transmitting and receiving it [15]. Antenna gain can also be expressed as the ratio of total radiated power P_r to the total input power P_{in} supplied to antenna multiplying with the directivity D [15] as given in equation (2.6). Antenna gain for short dipole used in the research is 1 dBi.

$$G = \frac{P_r}{P_{in}} D \quad (2.6)$$

- **Polarization:** RFID tags antennas used in this research support linear polarization. Linear polarization is the propagation of waves totally in one plane [15]. It is further divided into horizontal polarization, which is having wave's electric field parallel to the plane and vertical polarization, which is having wave's electric field perpendicular to the plane [15].

2) **Integrated Orientation Insensitive:** Integrated orientation insensitive antenna is a special kind of antenna for MC3190-z RFID reader used in this research. It has two elements, which can work in horizontal or vertical orientation. They can work with tags that have linear and circular polarization [10]. This distinctive combination optimize the performance of RFID reader with maximizing its read range, write range and coverage area [10]. It gives good results even on most difficult items and environments. This antenna is a patented antenna by Motorola for hand held readers.

Chapter 3 PROPOSED SECURITY ALGORITHM FOR INDOOR RFID SYSTEM

This chapter explains the proposed security algorithm for detecting the change in the positions of UHF passive RFID tags for the indoor RFID system. Each step or method implemented in the algorithm is described below with a separate section in full detail.

3.1 Overview

This section outlines the summary for the proposed security algorithm. This research is based on RSS-based technique [25][26] in which signal level is used to estimate the location of tags and then ultimately used to detect the change in location of tags. Further, any change in positions of tags can be detected by finding change in the relative error in inter-tag distance used in the RFID system. Figure 3.1 describes the general block diagram of the proposed security algorithm. A handheld RFID reader and two UHF passive RFID tags framework is used to achieve localization deployed in geometric composition by using the concept of trilateration in 2-dimensions to obtain unambiguous location. This model suffers from the variations of the signal level and those fluctuations come not only from the RF environment [21][22], but also from the RFID antennas alignment and radiation pattern. In order to minimize the effect of those fluctuations, different signal processing measures such as Interquartile Range, Adaptive Kalman Filter with optimization techniques for nonlinear systems at different stages of the algorithm are used to improve the location estimation. With the improvement in location estimation, accuracy in inter-tag distance is also improved. Different measurements are taken at different distances for separate locations inside a building, relative error for those separate locations

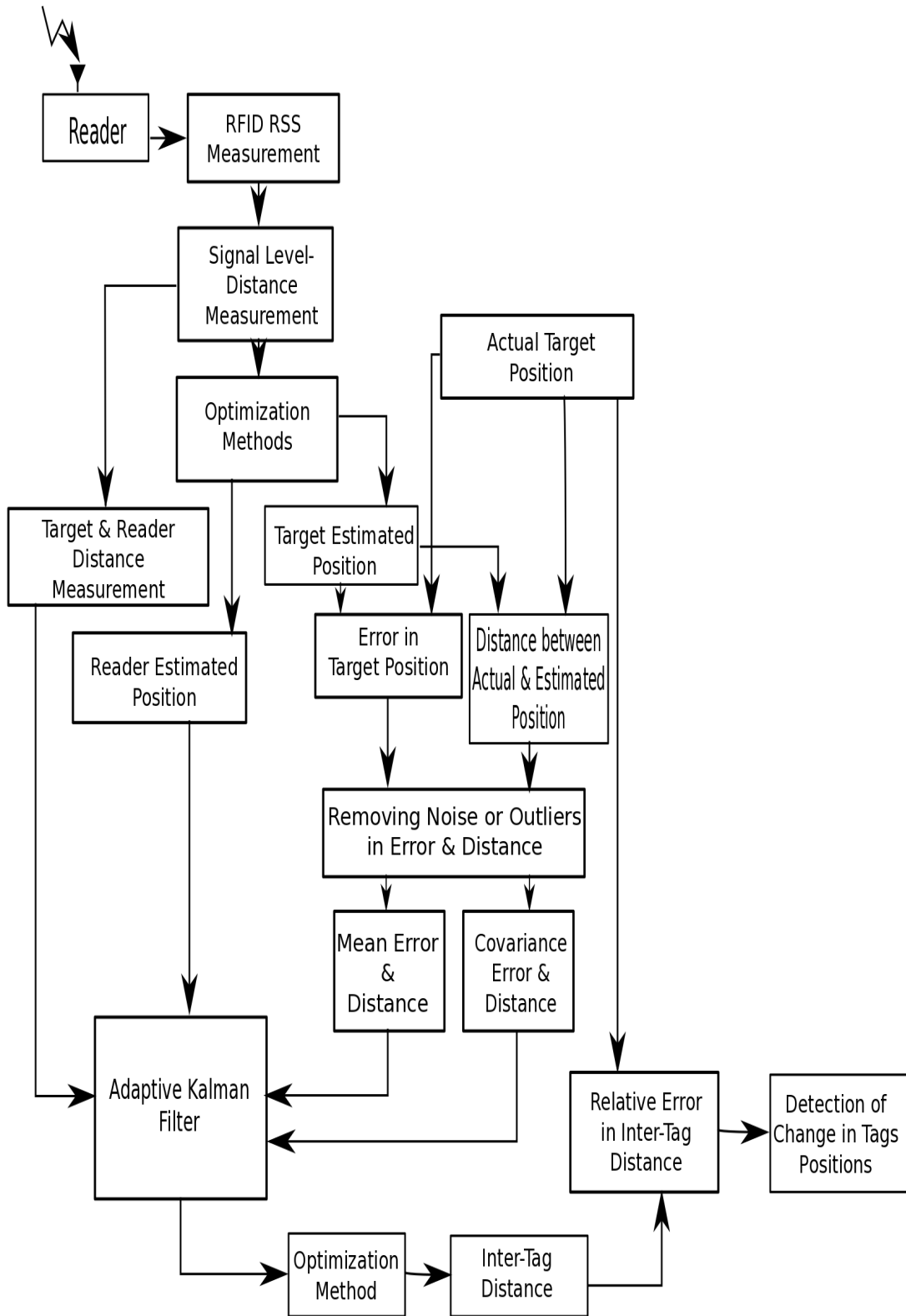


Figure 3.1: Block diagram of the security algorithm for indoor RFID system

at different distances is measured. A tolerance range is then obtained for indoor RFID system for a distance range, which will serve as the basis for this security system. Any change occurring in the positions of tags will make the relative error fall outside the tolerance range. Different methods used in this security algorithm are discussed below in detail.

3.2 Indoor Propagation Model for Far Field Passive RFID System

This section explains how to measure signal level using a c# windows application and then estimate the distance using the measured signal level. First it is necessary to measure signal level or received signal strength indicator (RSSI) from two tags using a handheld RFID reader at different distances for separate locations. Figure 3.2 shows two UHF tags with a RFID reader at different distance values D_1, D_2, \dots and D_n for measuring signal level for separate indoor locations.

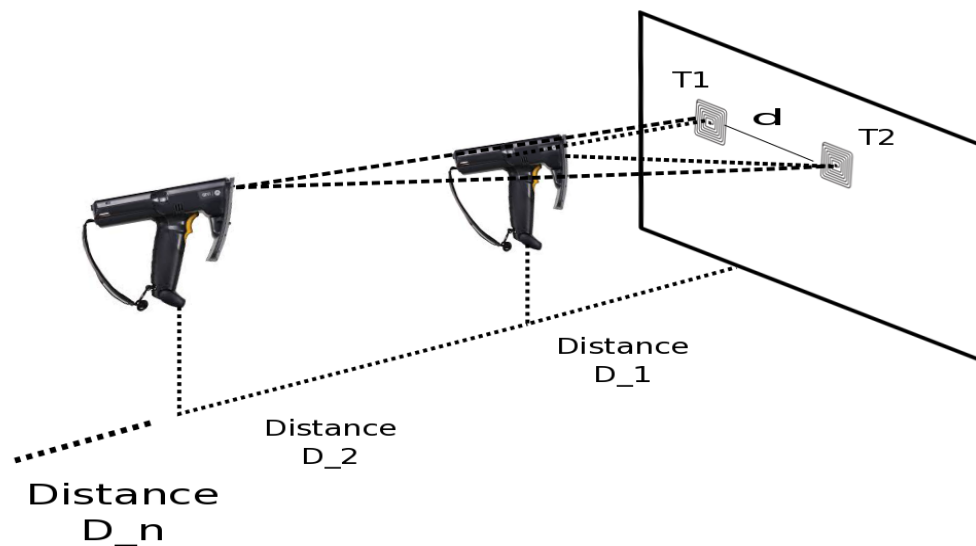


Figure 3.2: Reader-Tag combination for measuring signal level for separate distances

A smart device windows application using c# programming language is designed to measure signal levels from the RFID tags in the reader's coverage area. The code for measuring signal level is comprised of three windows forms in which the first form is the login page; the second form is the form for retrieving the list of items (or paintings) by selecting items by their categories from the database on which a security check is to be performed along with accessing the main database containing other information such as artist name, tag EPC, picture number etc.; the third form is the form for selecting the correct tags associated with the items used for the security check. As the basic idea for this research came from the authentication of paintings using RFID tags, this is the reason behind designing the windows form in this manner. It is possible to assign a picture number to the tags attached with it and store EPC in the database along with some other relevant information like Artist Name. By selecting a picture either by its picture number or artist name, a security check can be performed on the tags associated with selected items. In this way, it is possible to have an RFID system for security check without worry of other tags in the reader coverage area.

In order to perform signal level to distance conversion, an indoor large scale propagation model [16] is used. This model helps in finding tag location for a UHF passive RFID tag, which works on the principle of backscattering. In modulated backscatter scheme, the log-distance path loss in the RFID passive communication can be expressed [16] in the following way:

$$PL(d) = P_{T_{\text{xdbm}}} - P_{R_{\text{xdbm}}} = PL(d_0) + 10 N \log_{10} \frac{d}{d_0} + X_{\sigma} \quad (3.1)$$

where

- $PL(d)$ is the total path loss measured in Decibel (dB).
- $P_{T_{\text{xdbm}}} = 10 \log_{10} \frac{P_{T_x}}{1\text{mW}}$ is the transmitted power in dBm, where P_{T_x} is the transmitted power in watt.
- $P_{R_{\text{xdbm}}} = 10 \log_{10} \frac{P_{R_x}}{1\text{mW}}$ is the received power in dBm, where P_{R_x} is the received power in watt.
- d_0 is an arbitrary reference distance in cm.
- d is the length of the path in cm.
- $PL(d_0) = 10 \log_{10} \frac{P_t}{P_r}$ is the path loss at the reference distance d_0 in Decibel(dB).
- $\frac{P_t}{P_r} = \left(\frac{4\pi d_0}{\lambda}\right)^4 \frac{1}{G_t G_r (g_t \Gamma g_r)}$ is ratio of power transmitted and received by reader transmit and receive antennas.
- G_t, g_t, G_r, g_r are the gains of the reader a tag transmit and receive antennas respectively.
- Γ is reflection coefficient of the tag.
- $(g_t \Gamma g_r) = \frac{4\pi\delta}{\lambda^2}$
- δ is radar cross-section of the RFID tag
- n is path loss exponent and $N=2n$ for RFID passive communication.
- X_σ is zero mean Gaussian random variable with variance σ^2 in dB, is called shadow fading.
- λ is the wavelength in cm.

The results for this whole section can be found in section 4.1.

3.3 Trilateration

Trilateration is the process of relatively calculating the positions of points by taking these points as vertices of the triangle and utilizing the estimation of distances [17]. This process is used to have an unambiguous location of the tags in the RFID system using geometry. Figure 3.3 shows this process with tag T_1 at distance L_1 from the reader and its coordinates at the origin; a circle, representing possible location of the reader relative to this tag, can be drawn with tag T_1 as center and radius L_1 . Similarly, tag T_2 at distance L_2 from the reader placed on the same axis i.e. x-axis in this case; a circle, representing possible location of the reader relative to this tag, can be drawn with tag T_2 as center with coordinates $(d, 0)$ and radius L_2 [31], where d is the distance between center of tag T_1 to the center of tag T_2 .

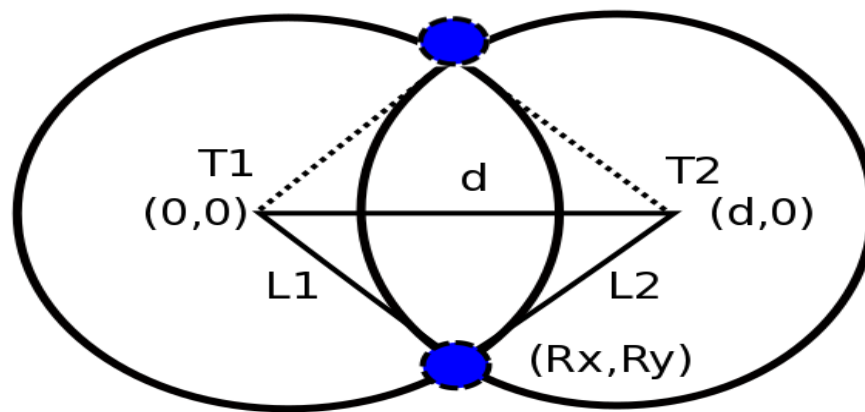


Figure 3.3: Trilateration in two-dimensions

Now, there are two points on the same x-axis with a distance d apart and two circles can be drawn with center and radius. The intersection of two circles represents the reader coordinates as shown in Figure 3.3 as (R_x, R_y) . In this process, there will be two points of intersection; both points are symmetric relative to the line connecting them. Note that tag T_2 is the target.

3.4 Optimization for Nonlinear Systems

Optimization is a methodology, which finds the best of accessible results such that either the maximum or the minimum of the objective function is chosen via an appropriate algorithm. Using the geometry defined by trilateration, two tags can be placed on an object or item on the same axis with a reader at some point in space. First, with the help of distance measurement of tag T_1 from the reader and its coordinates at origin, the reader position (R_x, R_y) can be found by treating it as an optimization problem with equation (3.2) as the objective function. Secondly, with the reader coordinates and the distance measurement of tag T_2 from the reader, the coordinates of target T_2 can also be estimated using optimization. By denoting the coordinates of the i th tag as (x_i, y_i) and length as L_i , the coordinates of the reader (R_x, R_y) can be estimated by solving the optimization problem given in equation (3.2) using nonlinear least-squares algorithm. Once the reader coordinates is estimated, target T_2 coordinates can also be estimated using the same technique with the same function given in equation (3.2) but with different length L_i .

$$F(x, y) = \left| \sqrt{(x_i - R_x)^2 + (y_i - R_y)^2} - L_i \right| \quad (3.2)$$

where

- $F(x, y)$ is the objective function for optimization.
- (x_i, y_i) is the coordinates of i th tag
- (R_x, R_y) is the coordinates of the Reader
- L_i is the length between i th tag and Reader

The same optimization method will be used in the later part of the algorithm once signal-processing measures is applied to find the new coordinates of target, reader, and new distances between tags and the reader. Matlab is used for solving the problem of optimization and the results for this section can be found in section 4.1.

3.5 Interquartile range

Interquartile range (IQR) is basically used to detect an outlier or noisy data. It is a process, which can be used to measure the variability of a data set by partitioning them into quartiles [18]. Analyzed data are separated by their values into four parts referred to as quartiles; entities that partition each part are called the first, second, and third quartiles and are denoted by Q_1 , Q_2 , and Q_3 [18]. They are also defined as 25 percentile, 50 percentile, and 75 percentile, respectively [18]. Figure 3.4 shows a block description of interquartile range. The first quartile denoted by Q_1 is median of values less than overall median; the second quartile denoted by Q_2 is median of the data set; the third quartile denoted by Q_3 is median of values greater than the overall median. Interquartile range can be measured mathematically by subtracting first quartile from the third quartile [18] as shown below:

$$IQR = Q_3 - Q_1 \quad (3.3)$$

An outlier can be removed from a data set by the standard criterion given below for Interquartile range (IQR) [18]:

$$\text{Outlier} = \text{any value below } Q_1 - 1.5 \cdot IQR \text{ and above } Q_3 + 1.5 \cdot IQR \quad (3.4)$$

As the actual distance between the centers of two tags placed on an object considering the concept of trilateration used, the error in the coordinates of the target can be found. It is also possible to measure the distance between the actual and estimated coordinates of the target. Interquartile range (IQR)

criterion is applied to both the parameters defined above to remove a value (Outlier), which increases the variance of the whole dataset, which ultimately increases the disturbance in the dataset. Both, error in target coordinates and the distance between actual and estimates target position will be used as a noise measurement or error in adaptive Kalman filter for producing better estimates of reader coordinates and distance between target and reader.

This method is basically used in this research to reduce the shadowing effect mentioned in section 3.2, as there is no specific value for this parameter. The reason for applying this technique on the error and distance parameters instead on signal level is nothing but to remove the outliers, which can be a direct result of RF fluctuations [21] and statistical error. The results for this section can be found in section 4.1.

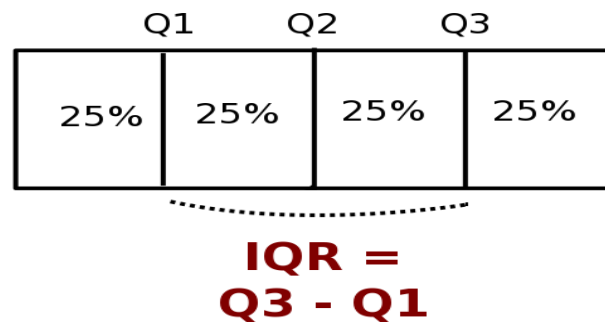


Figure 3.4: Block description of Interquartile Range

3.6 Adaptive Kalman Filter

Adaptive Kalman filter is a recursive algorithm applied to a set of data affected by measurable noise and producing estimations of useful variable with suppressed noise content. [30]. This filter is widely used in signal

processing. Kalman filtering has been utilized effectively for reducing signal noises and it demonstrates considerably high quality results in comparison to other types of filters. It is the one that minimizes the variation in the system [19]. It is used in applications like tracking the trajectory of the moving objects such as planes, ships, satellite etc. Kalman filtering can be utilized to reduce noise from an indoor RF signal for both moving and fixed devices. While applying Kalman filter to fixed location or devices, noise is assumed to be a function of time.

Figure 3.5 shows the general block diagram of an adaptive Kalman filter. Kalman filter can be divided into three models: Process model, Observation model, and new state [16].

- 1) Process model: This model explains the previous or initial state of the estimate and process covariance matrix or error in the estimate. The linear stochastic difference equation for a state of discrete-time controlled process for estimating a new state is [19] given by:

$$X_{kp} = A * x_{k-1} + B * u_k + w_k \quad (3.5)$$

where

- x_{k-1} is the previous state or initial state of the estimate.
- X_{kp} is predicted state of the estimate.
- u_k is the control variable matrix.
- w_k is the predicted state noise matrix.
- A and B is the identity matrixes to avoid dimension mismatch.

As the tags are stationary, the state of the system is not modified with any control variable and the predicted state noise is also zero [16]. Thus the above equation can be written as:

$$X_{kp} = A * x_{k-1} \quad (3.6)$$

Kalman filter is a function of noise; noise statistics is essential for achieving optimal filter output. Process noise in this case is very negligible as compared to measurement noise [16] because a commercial handheld reader is used in this research. Therefore, the process covariance matrix given by equation (3.7) will assumed to be 1 [16]:

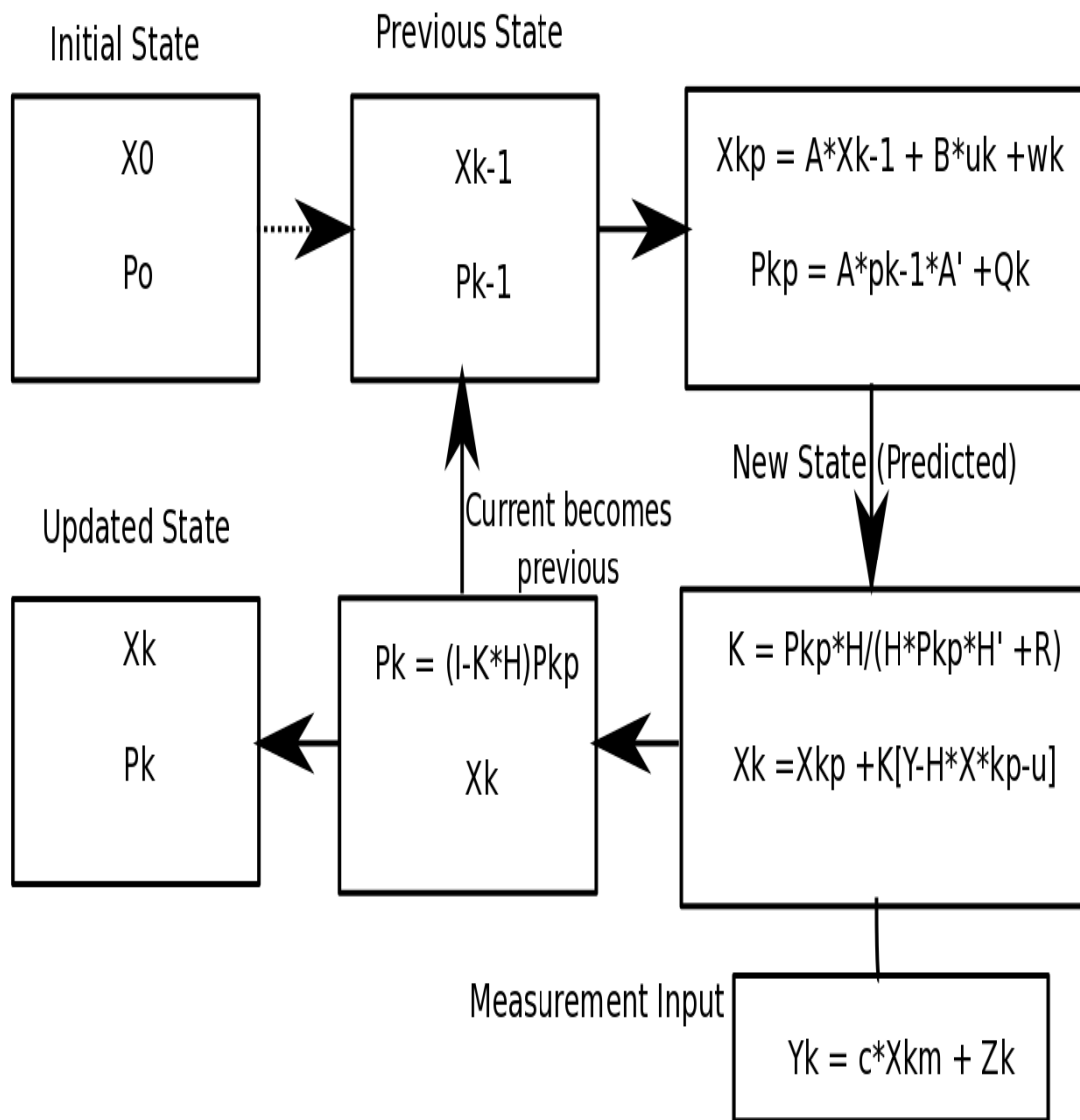


Figure 3.5: Block diagram of Adaptive Kalman Filter [16] [19]

$$P_{kp} = A * P_{k-1} * A' + Q_k \quad (3.7)$$

where

- P_{k-1} is process covariance matrix of previous state or initial state.
- Q_k is process noise covariance matrix.

Therefore

$$P_{kp} = 1 \quad (3.8)$$

2) Observational Model: This model contributes towards finding the Kalman gain, which is used to find the new state of the estimate along with measurement inputs. Kalman gain [19] is defined by the equation (3.9):

$$K = \frac{P_{kp} * H}{(H * P_{kp} * H' + R)} \quad (3.9)$$

where

- P_{kp} is the process covariance matrix.
- R is measurement noise covariance matrix.
- H is identity matrix.

Now, the most important part of Kalman gain is the measurement noise covariance matrix R . It is nothing but the error in target position and the distance between actual and estimated target position as explained in section 4.1. The purpose of using this, as a measurement noise is to reduce the values of the parameter defined above in order to get a new estimate of the reader coordinates and the distance between target and reader. R will remain fixed for all k (where k is the number of samples) because our target is fixed. The measurement input can be given by equation [16] (3.10):

$$y_k = c * x_{km} + Z_k \quad (3.10)$$

where

- x_{km} is new measurement.
- Z_k is uncertainty in the measurement.

3) New or Updated state: This section outlines how a new or an updated state of estimate and process noise for an adaptive Kalman filter can be achieved. New or updated state can be defined mathematically [16] [19] by equation (3.11) and (3.12):

$$X_k = X_{kp} + K[y_k - H * X_{kp} - u] \quad (3.11)$$

$$P_k = (I - K * H)P_{kp} \quad (3.12)$$

where

- X_{kp} is predicted state of the estimate.
- K is Kalman gain.
- y_k is the measurement input.
- u is mean of the error in target coordinates and distance between actual and estimated target coordinates explained in section 4.1.
- P_{kp} is the predicted process noise.
- X_k is the new state of estimate.
- P_k is the new state of process noise or error in estimate.

Now the newly calculated state is used as the starting point for the next step of calculation, and the process continues recursively until all samples are processed. Therefore, an updated state matrix at the end with an improved accuracy is obtained. The first measurement value is used as the initial state of estimation. Due to the use of measurement noise R and the mean u given in equation (3.11), which make our

estimates adapt or change with the error in target coordinates and distance between actual and estimated target coordinates, we defined Kalman filter as adaptive Kalman filter.

Adaptive Kalman filter gives us new estimates for the reader coordinates (R_x, R_y) , new estimate of the distance between target and reader and a new estimate of the distance between new reader coordinates and tag T_1 as shown in Figure 3.6. In order to find new estimate of target coordinates or inter-tag distance, the nonlinear equation (3.13) can be solved by treating it as an optimization problem in the same way as explained in section 3.4.

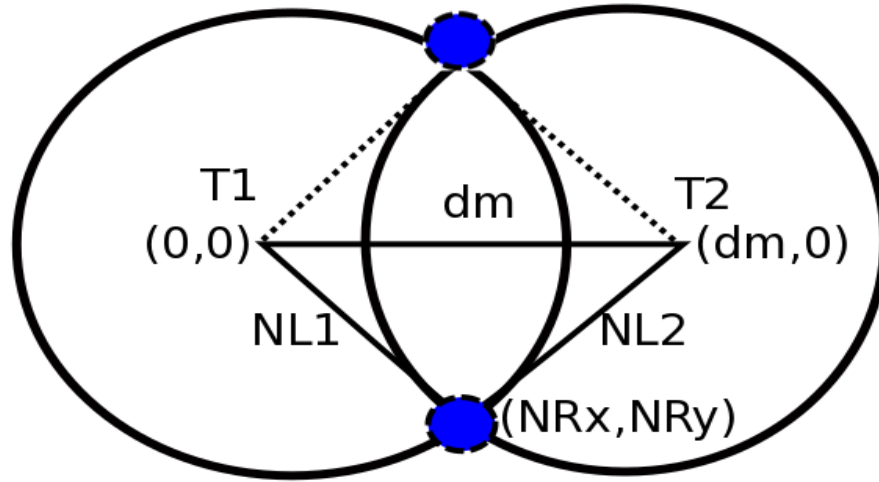


Figure 3.6: Trilateration in 2-dimensional with new coordinates

$$F(d_m) = \frac{NL_1^2 - NL_2^2 + d_m^2}{2d_m} - NR_x \quad (3.13)$$

where

- NL_1 is the new distance estimate between tag T_1 and reader
- NL_2 is the new distance estimate between tag T_2 and reader
- d_m is the new distance estimate between two tags

- NR_x is new x-coordinate estimate of reader.
- NR_y is the new y-coordinate estimate of reader.

The results for this whole section can be found in section 4.2.

3.7 Relative Error

Relative error is defined as the ratio of difference between experimental and actual value and the actual value [20]. It is given in equation (3.14) as:

$$\text{Relative error} = \left| \frac{x_{\text{experimental}} - x_{\text{reference}}}{x_{\text{reference}}} \right| \quad (3.14)$$

where

- $x_{\text{experimental}}$ is the new inter-tag distance estimate.
- $x_{\text{reference}}$ is the actual distance between two tags or inter-tag distance.

A tolerance range is formed from the relative error for a distance range at different indoor locations. It is then used as a basis for predicting the change in the positions of the tags by finding the change in the relative error in inter-tag distance that falls outside the tolerance range for a set of distance values.

The results for this section can be found in section 4.3.

Chapter 4 EXPERIMENTAL RESULTS

This chapter outlines the full description of experimental results and findings from this research. In this section, evaluation of the security algorithm for an indoor RFID system performance is given. It contains the results collected followed by their summary and interpretation.

4.1 Indoor Large Scale Propagation Model Results

This section addresses the results related to validation of Indoor Large Scale Propagation Model explained in section 3.2. All measurements were recorded in the manner explained in section 3.2 from two UHF passive RFID tags used in the RFID system. A number of experimental sets were collected with a large number of individual measurements (about 250-550) within each. Each measurement was collected at different separation distance for separate indoor locations to perform signal level-distance conversion.

Different distance is basically the actual distance between the tip of reader antenna and the center of two UHF passive tags. The smart device windows application using *c#* language is designed to capture the signal levels and their respective frequency from tags (full explanation of windows application is given in section 3.2). The reader and tag antenna gains are 1.5dBi [10] and 1dBi respectively, reader antenna power for transmitting is 30dBm or 1 watt, radar cross section is considered to be 1cm^2 , path loss exponent to be 1.8 for the indoor system, and arbitrary reference distance is 10 cm. There is no set value for shadow fading effect, which is caused by environmental factors and will be reduced later in the algorithm by using Interquartile range (IQR) criterion and then by filtering and correction. By putting all these values in equation (3.1) in indoor large-scale propagation model, the distance between reader and tags can be estimated. An estimated

distance vs actual distance graph for two UHF passive tags at four different indoor locations is produced which depicts the estimated or calculated distance value from the indoor large scale propagation formula and the actual distance between reader and tags and given below from Figure 4.1 to 4.8. The reason for taking measurements at four different locations is nothing but to check the behaviour of the RF signal level and how it changes with distances at different locations. The full c# code, which contributes towards measuring signal level, as described in section 3.2 can be found in Appendix A: Signal Level Measurement Code. The code for signal level to distance conversion is written in Matlab and can be found in Appendix B: Signal Level-Distance Conversion Code.

a) Location 1:

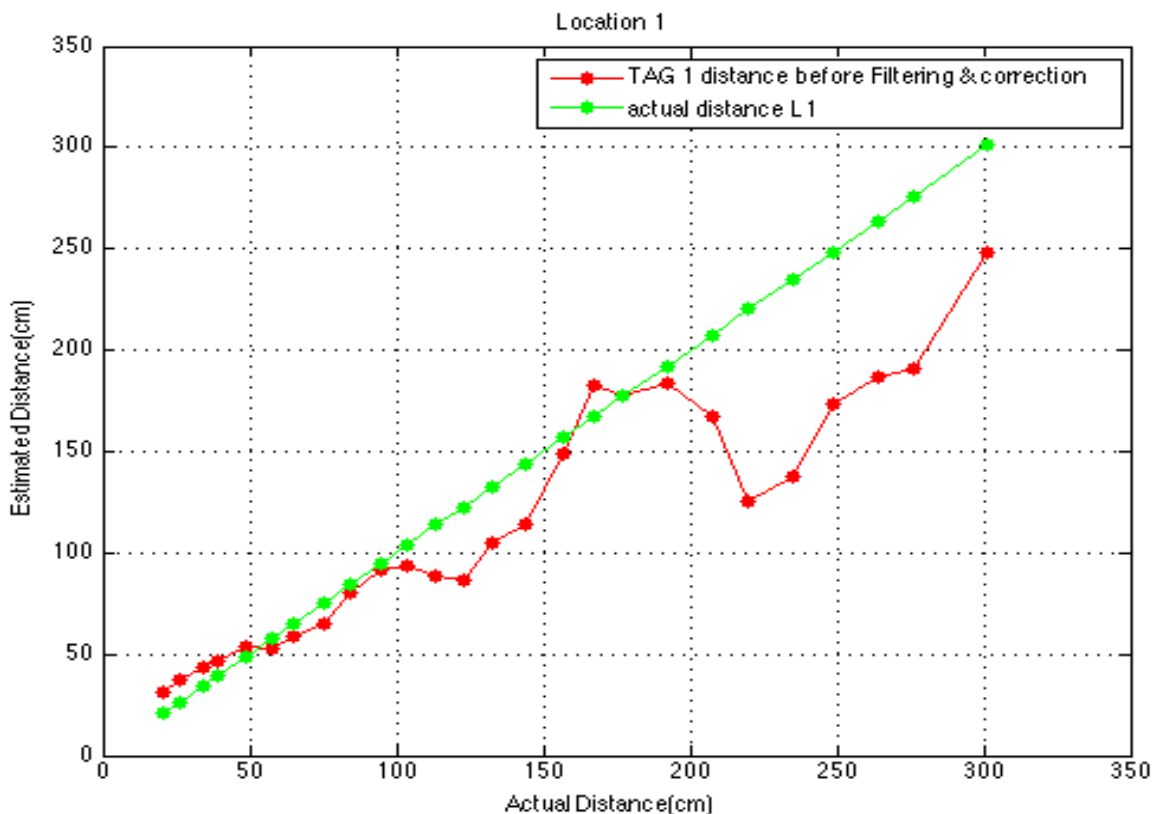


Figure 4.1: Estimated vs Actual distance graph for Tag T_1 at Location 1

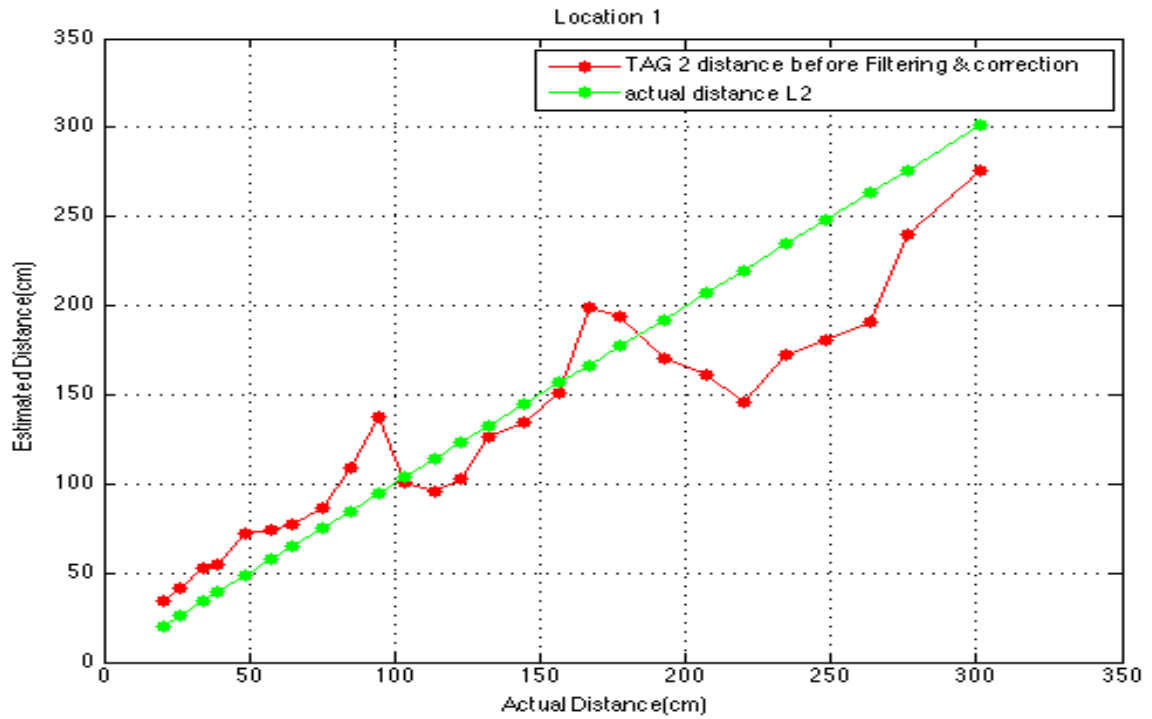


Figure 4.2: Estimated vs Actual distance graph for Tag T_2 at Location 1

b) Location 2:

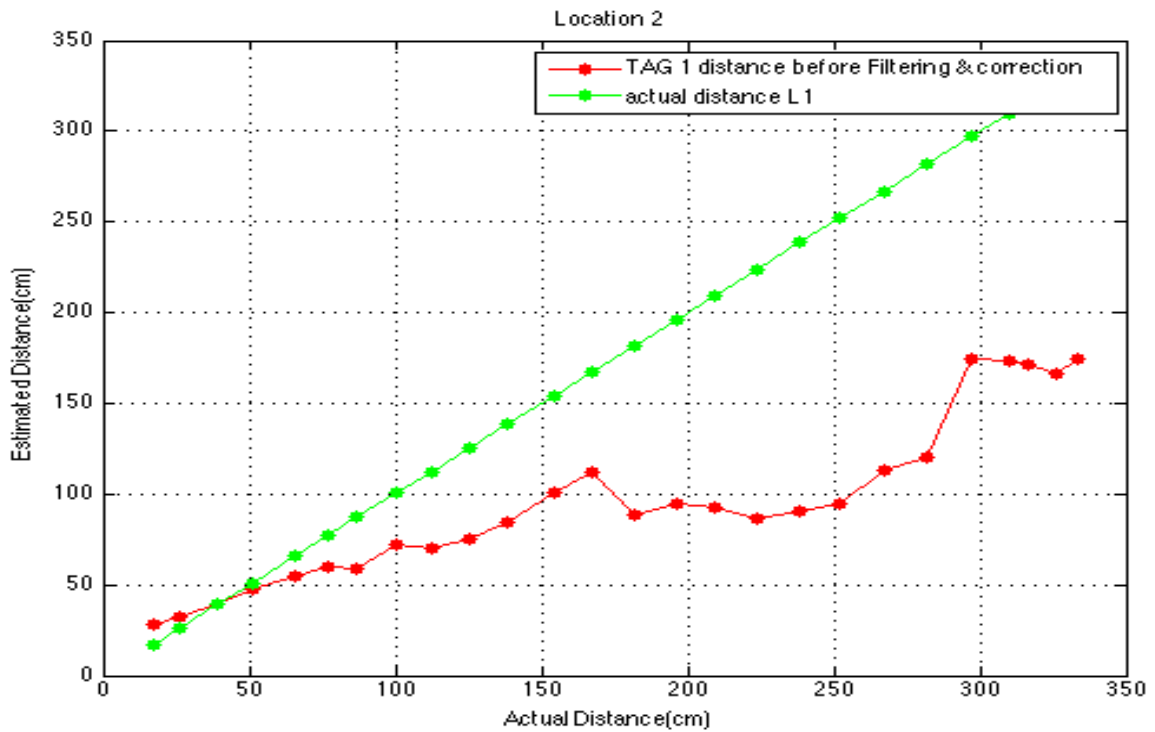


Figure 4.3: Estimated vs Actual distance graph for Tag T_1 at Location 2

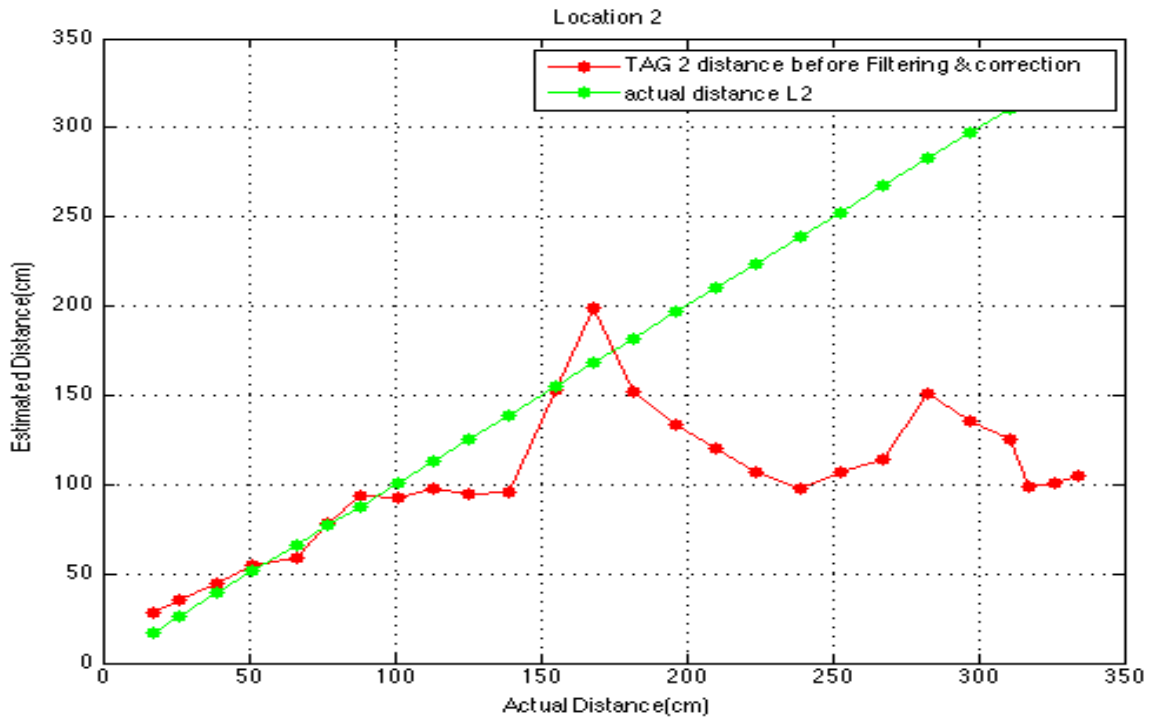


Figure 4.4: Estimated vs Actual distance graph for Tag T_2 at Location 2

c) Location 3:

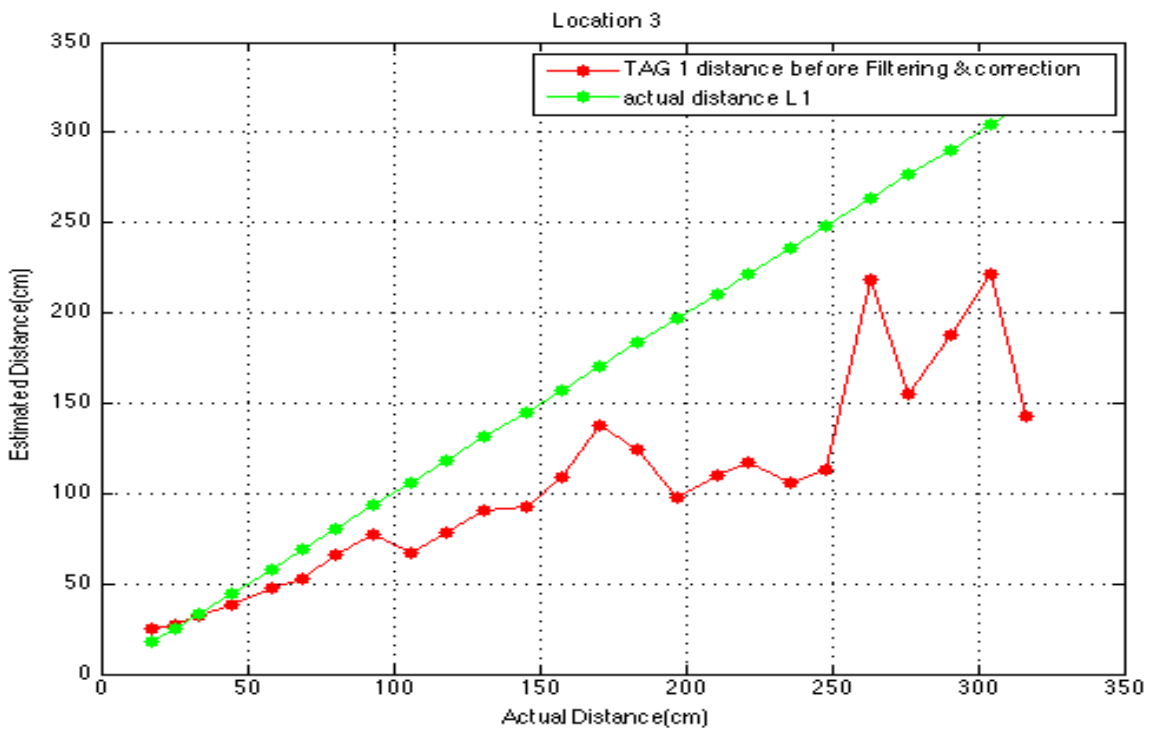


Figure 4.5: Estimated vs Actual distance graph for Tag T_1 at Location 3

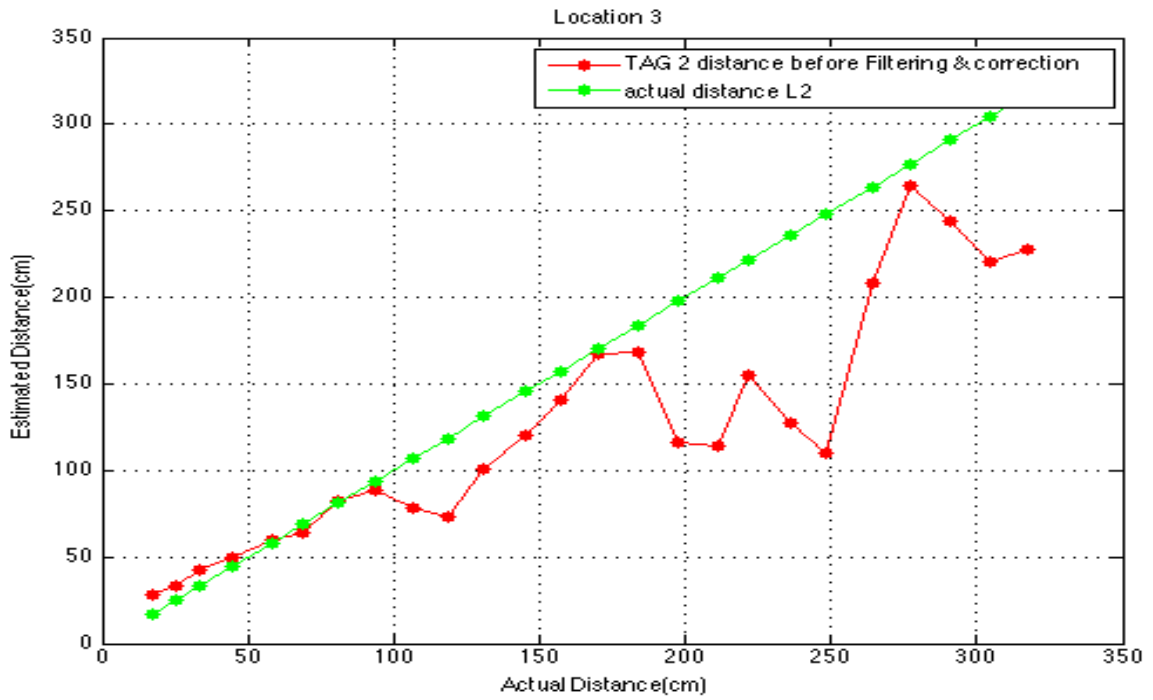


Figure 4.6: Estimated vs Actual distance graph for Tag T_2 at Location 3

d) Location 4:

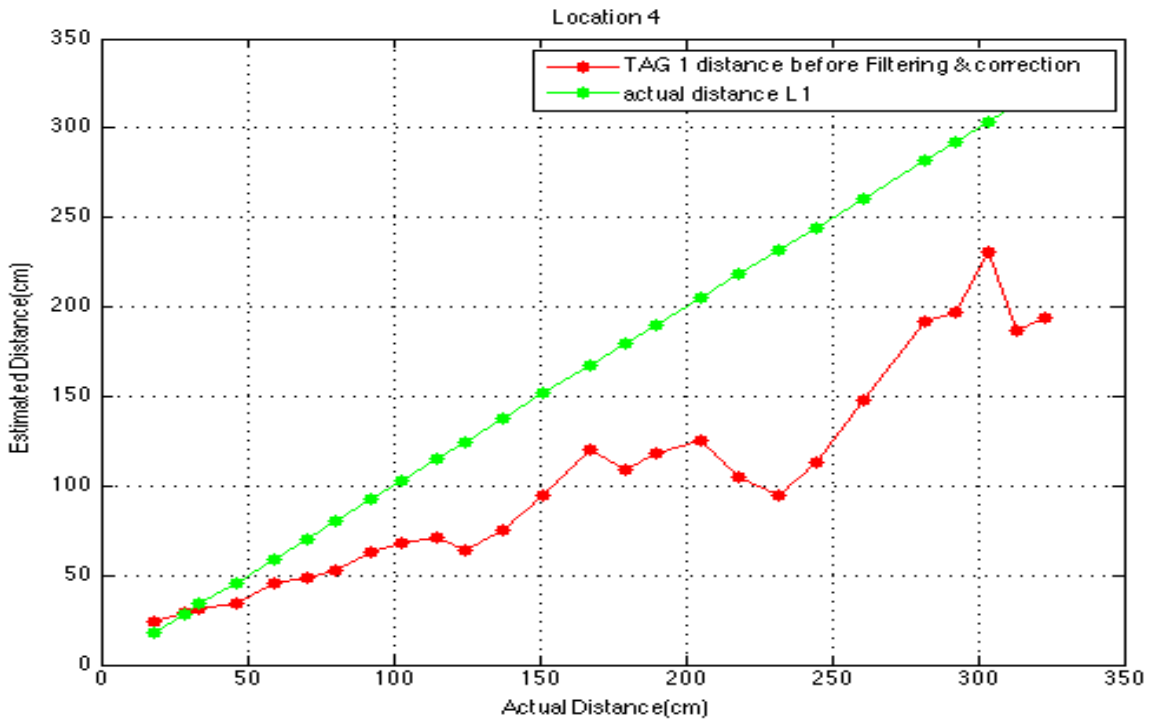


Figure 4.7: Estimated vs Actual distance graph for Tag T_1 at Location 4

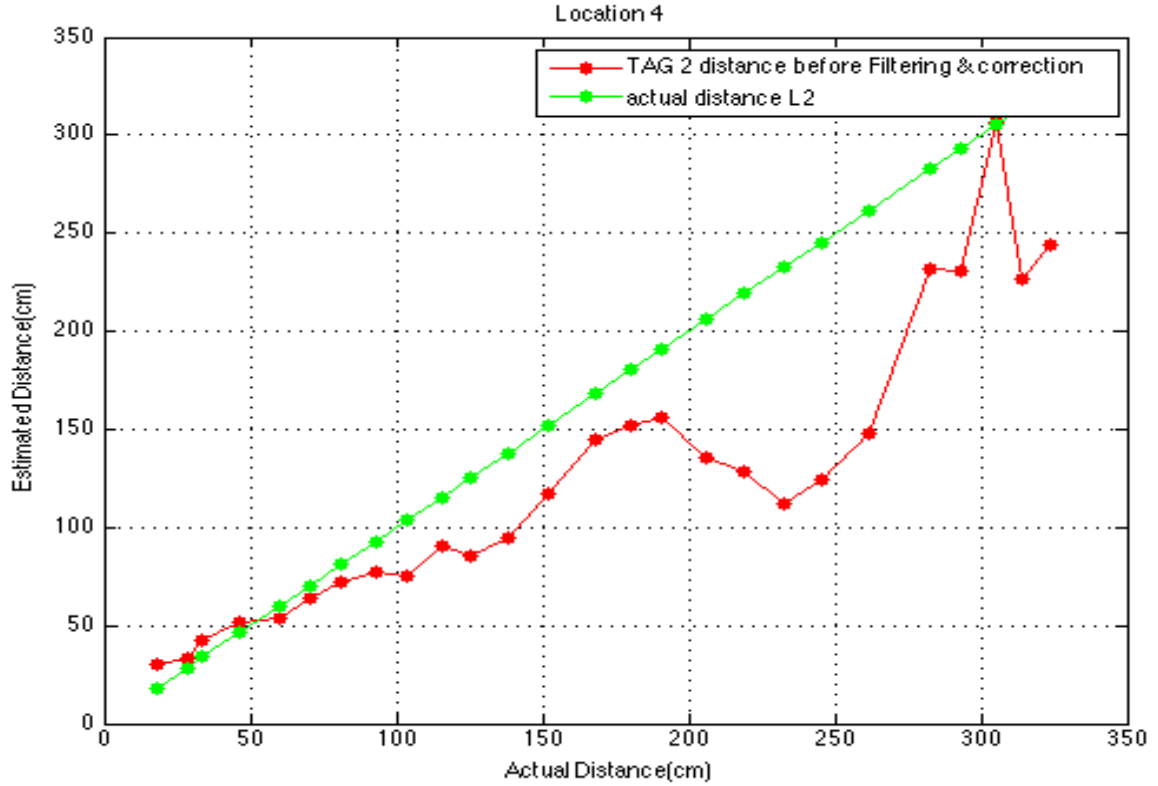


Figure 4.8: Estimated vs Actual distance graph for Tag T_2 at Location 4

Now, trilateration techniques explained in section 3.3 can be applied to the system formed by the reader and tags. Using optimization explained in section 3.4 for non linear equations as given in equation (3.2), the coordinates of reader (R_x, R_y) and the coordinates of the target which is tag T_2 can be found with the help of estimated distance from the reader to tag T_1 and T_2 . This process is repeated at different distances for each location dataset. The code for optimization is written in Matlab and can be found in Appendix C: Optimization for Finding Initial Coordinates Code.

Shadow fading effect given in equation (3.1), can be reduced by using interquartile range (IQR) criterion given in section 3.5. IQR is applied to the error in actual and estimated target coordinates given in equation (4.1) and

the euclidean distance between estimated and actual target coordinates given in equation (4.2).

$$(E_{x2}, E_{y2}) = (d - d'_{x2}, 0 - d'_{y2}) \quad (4.1)$$

$$D = \sqrt{(d - d'_{x2})^2 + (0 - d'_{y2})^2} \quad (4.2)$$

Where

- (d'_{x2}, d'_{y2}) is the estimated coordinates of target T_2 .
- (E_{x2}, E_{y2}) is the error coordinates of target T_2 .
- d is the x-coordinates of target or inter-tag distance.
- D is distance between actual and estimated target coordinates.

Figure 4.9 shows the error target coordinates with the actual target coordinates and reader coordinates. These coordinates values given in the Figure 4.9 are the mean values for location 1 dataset at a distance of 20 cm. Similarly, this process is repeated for all location at every distance.

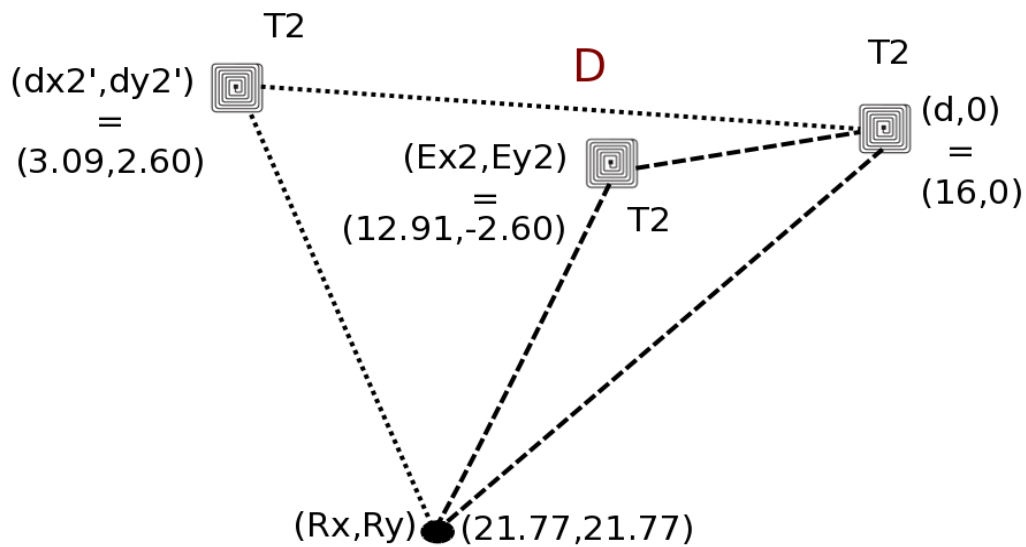


Figure 4.9: Target-reader coordinate diagram

Once the coordinates from equation (4.1) and distance from equation (4.2) can be estimated, IQR criterion is applied on these dataset at every distance for each location. Figure 4.10 to 4.12 show the boxplot for the target error coordinates and the euclidean distance between actual and estimated target coordinates for location 1 dataset at a distance of 20 cm. Similarly, this process is repeated for all location at every distance. The results from this sample dataset states that the error data has no outlier or noise, which can increase the variance in the adaptive Kalman filter. The code for Interquartile range (IQR) is written in Matlab and can be found in Appendix D: Interquartile Range Code.

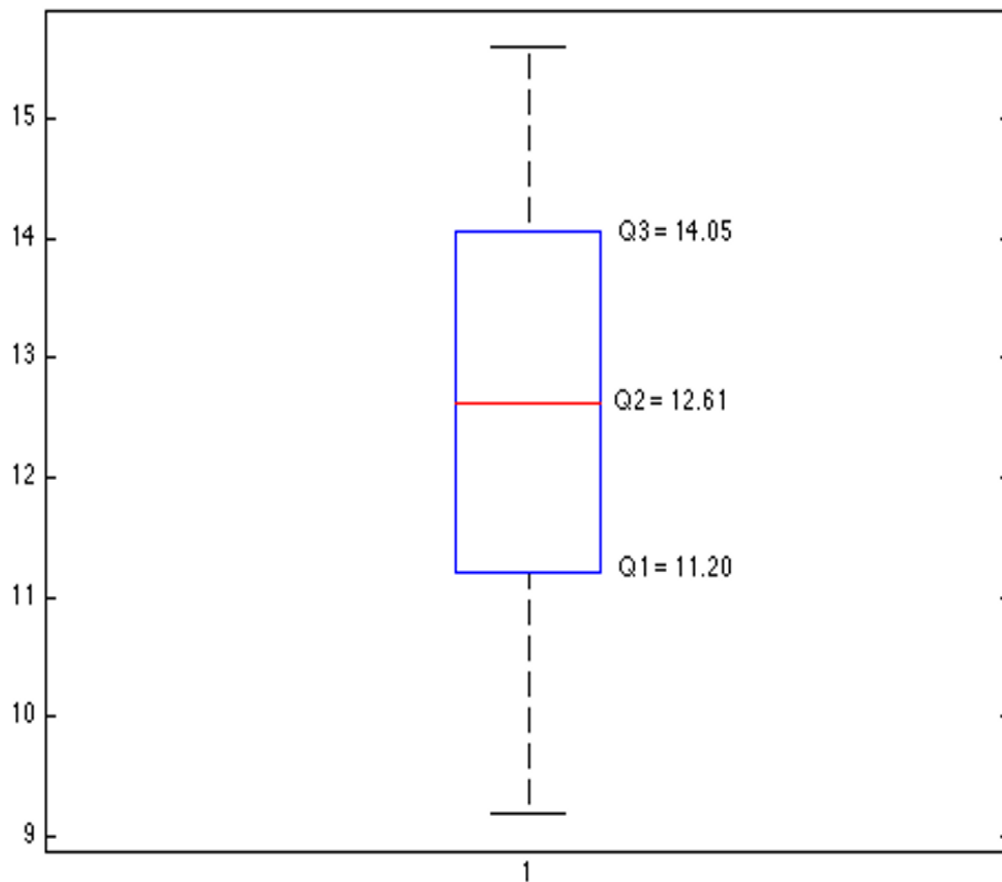


Figure 4.10: Boxplot for E_{x2}

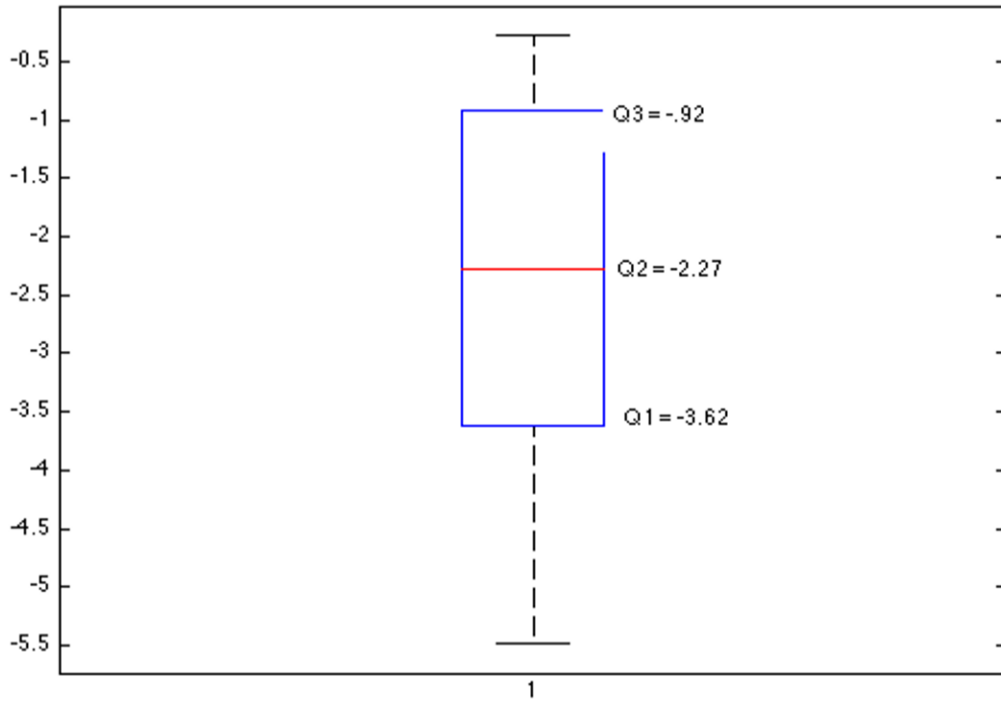


Figure 4.11: Boxplot for E_{y2}

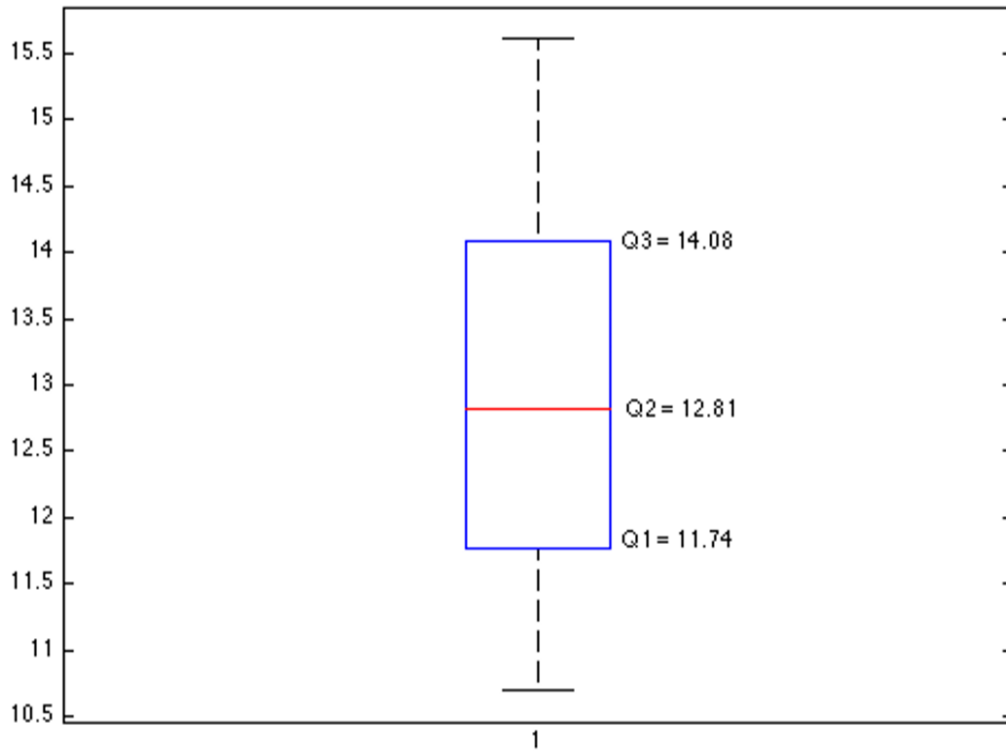


Figure 4.12: Boxplot for distance (D) between actual and estimated target coordinates

4.2 Adaptive Kalman Filter Results

In this section, results processed with adaptive Kalman filter explained in section 3.6 are outlined. The error in target coordinates and the distance between estimated and actual target coordinates explained in section above would serve the purpose of reducing error from the target T_2 coordinates. Adjustment to the distance value between tag and reader can be made with respect to the covariance and the mean of the noise measurement. By considering all aspect and parameters mentioned in section 3.6, new filter estimates of distances between tags and reader are obtained. Given below are the estimated distance vs actual distance graphs from the same four indoors locations after filtering and correction is applied, which were considered for estimating distance in section 4.1. The code for Adaptive Kalman Filter is written in Matlab and can be found in Appendix E: Adaptive Kalman Filter Code.

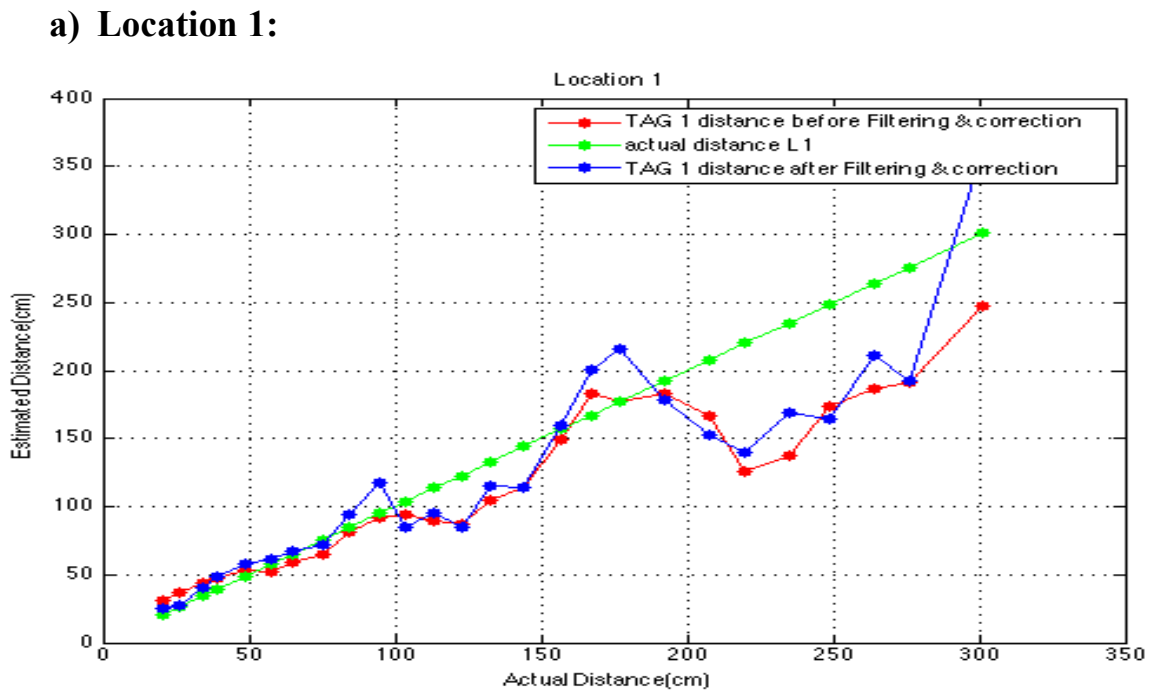


Figure 4.13: Estimated vs Actual distance graph for Tag T_1 at Location 1 after filtering

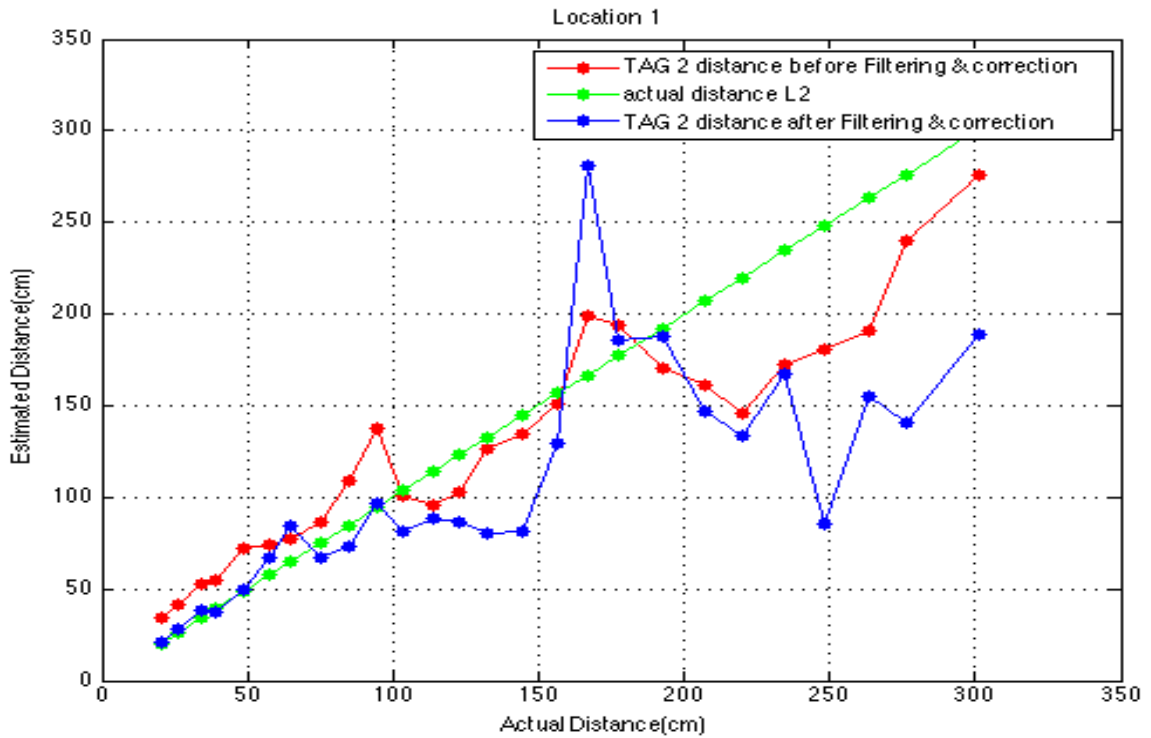


Figure 4.14: Estimated vs Actual distance graph for Tag T_2 at Location 1 after filtering

b) Location 2:

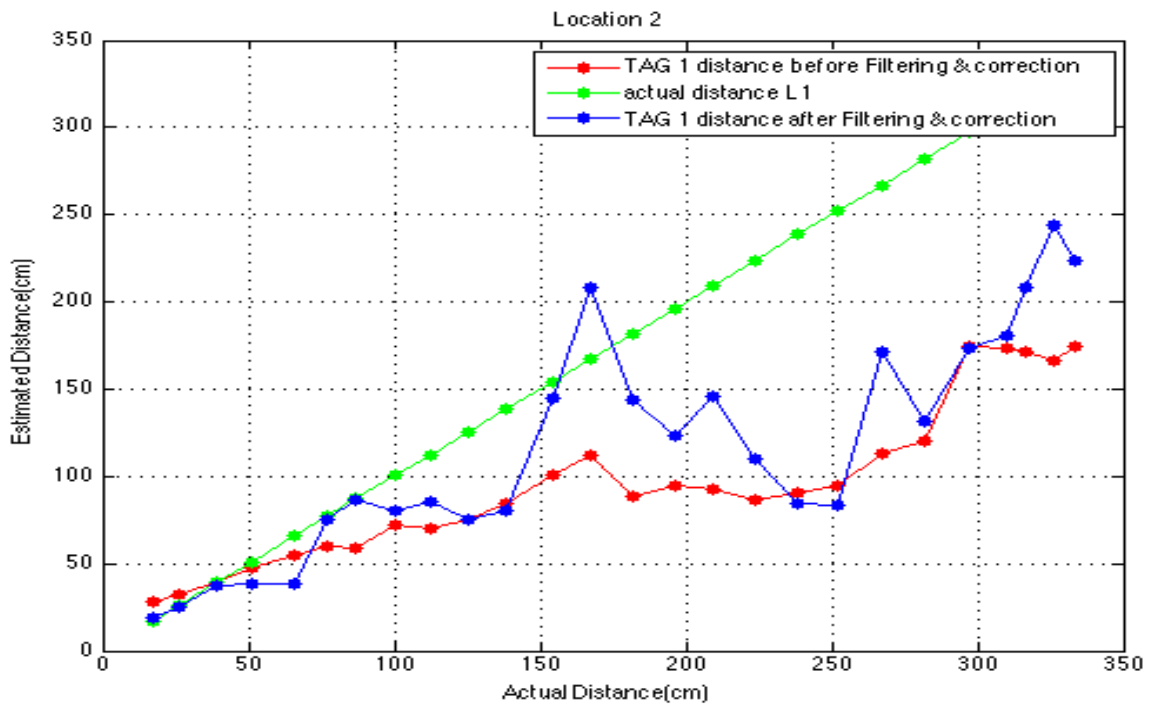


Figure 4.15: Estimated vs Actual distance graph for Tag T_1 at Location 2 after filtering

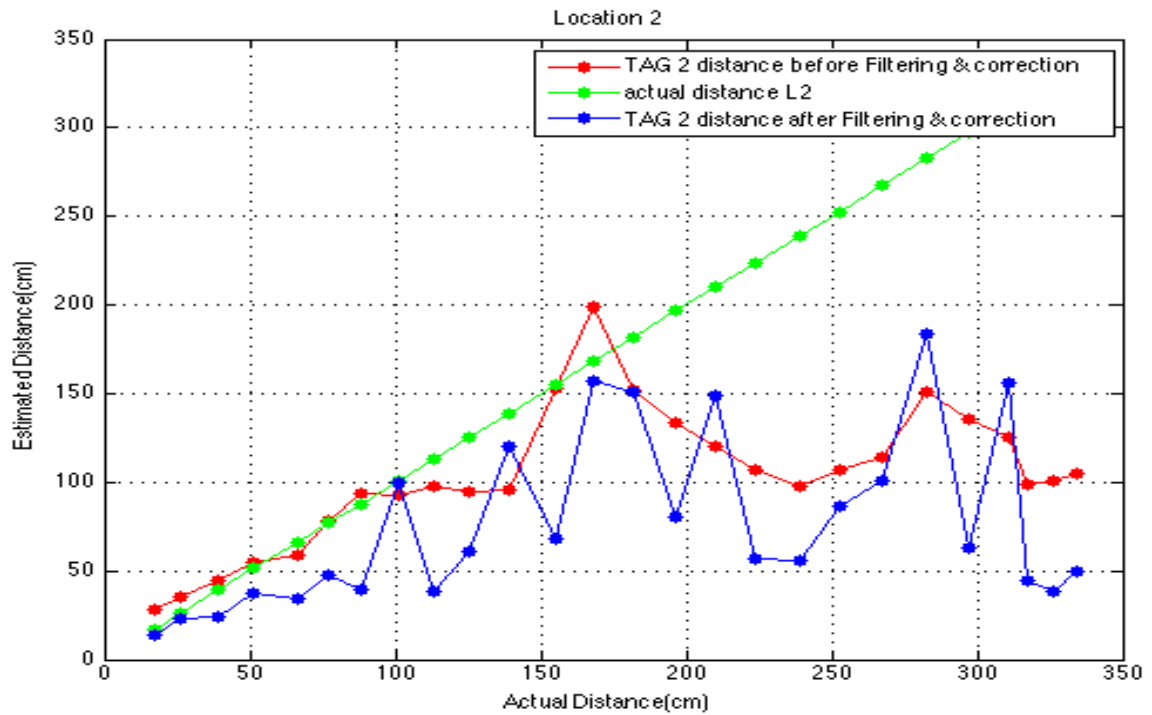


Figure 4.16: Estimated vs Actual distance graph for Tag T_2 at Location 2 after filtering

c) Location 3:

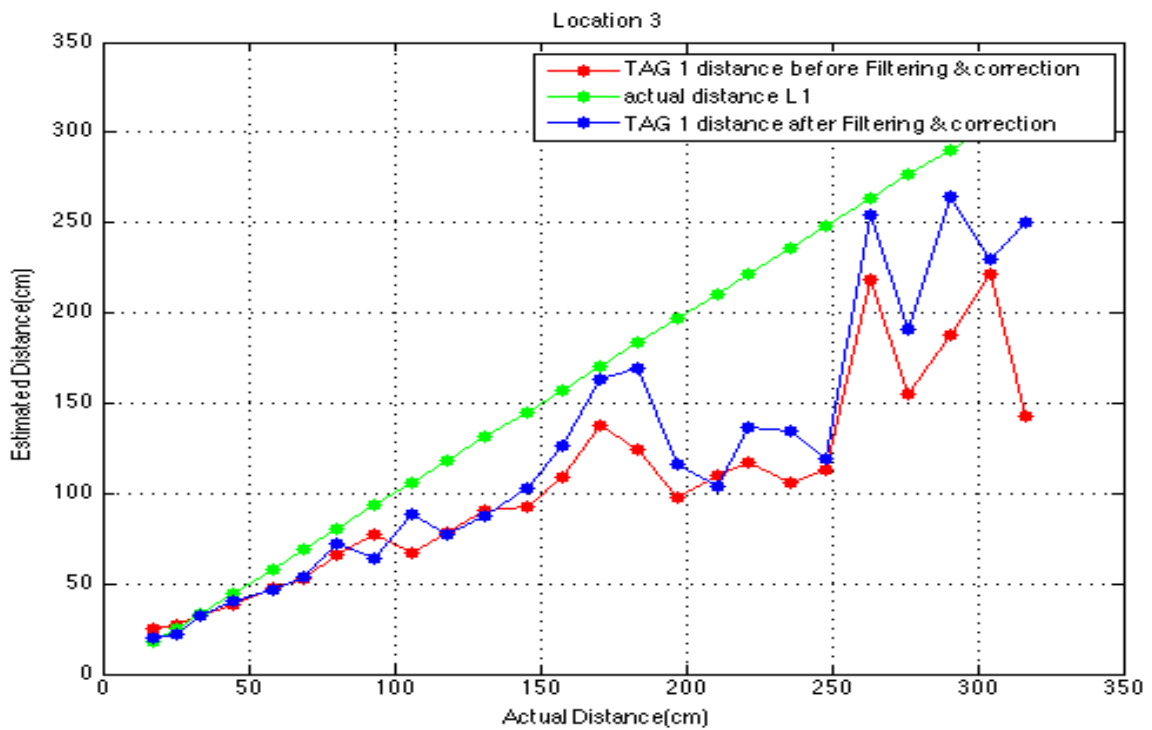


Figure 4.17: Estimated vs Actual distance graph for Tag T_1 at Location 3 after filtering

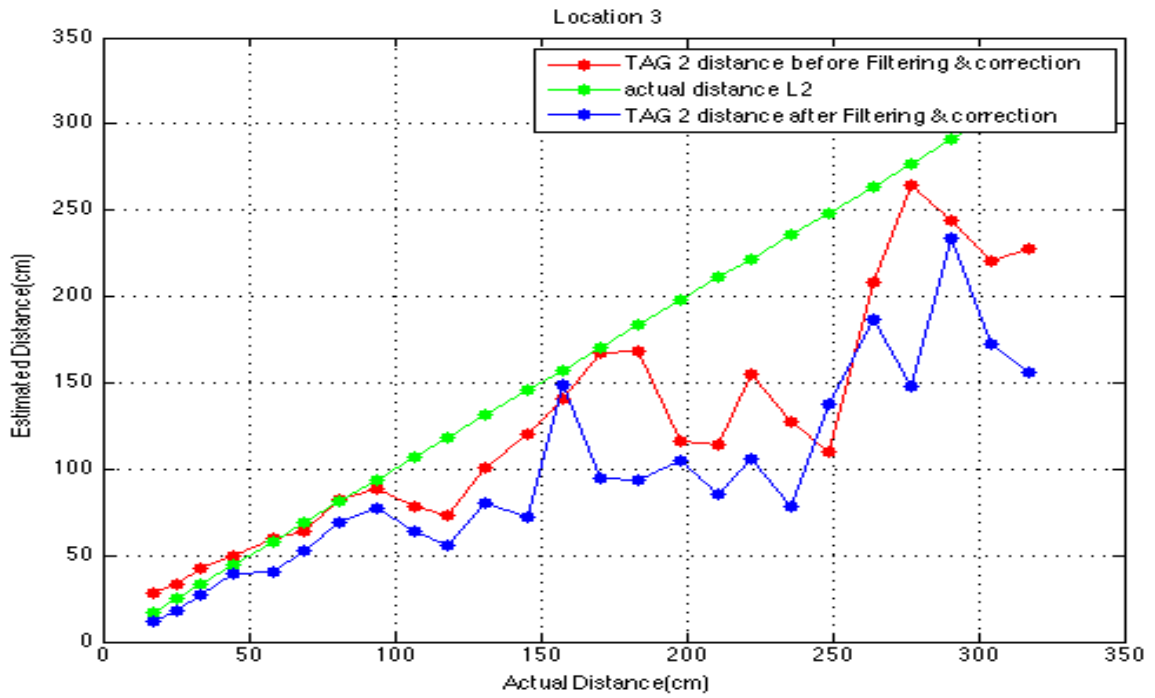


Figure 4.18: Estimated vs Actual distance graph for Tag T_2 at Location 3 after filtering

d) Location 4:

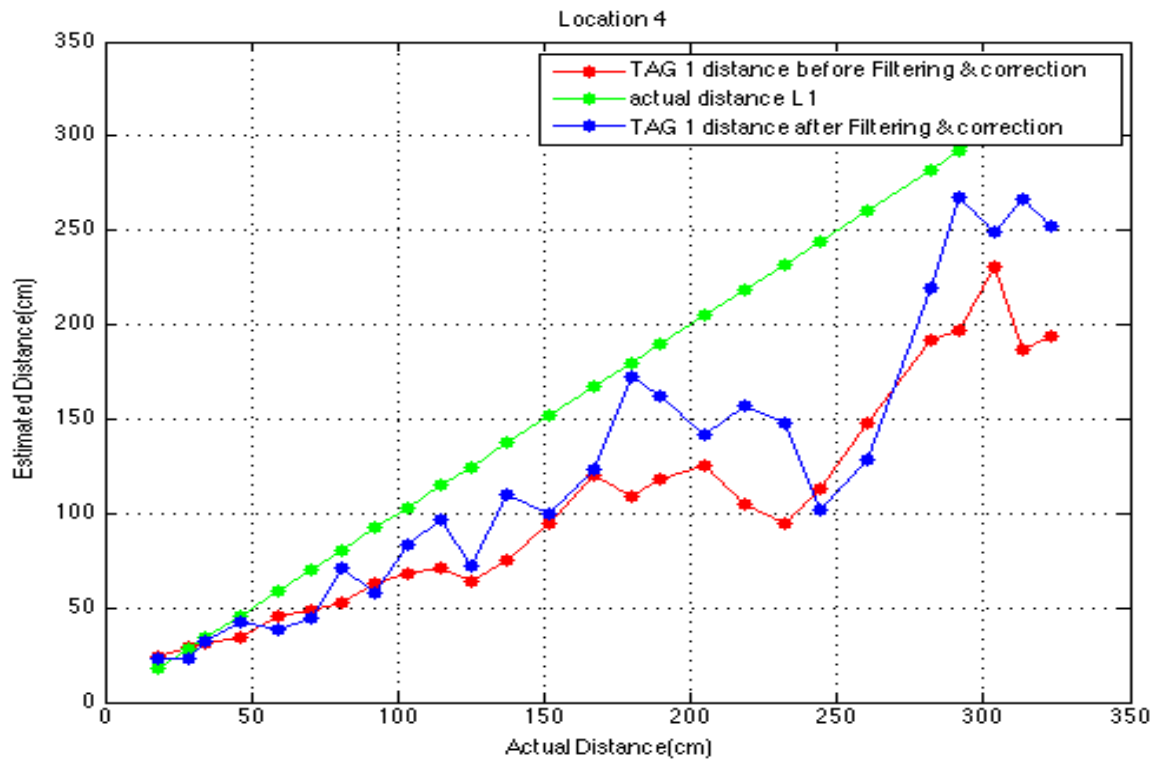


Figure 4.19: Estimated vs Actual distance graph for Tag T_1 at Location 4 after filtering

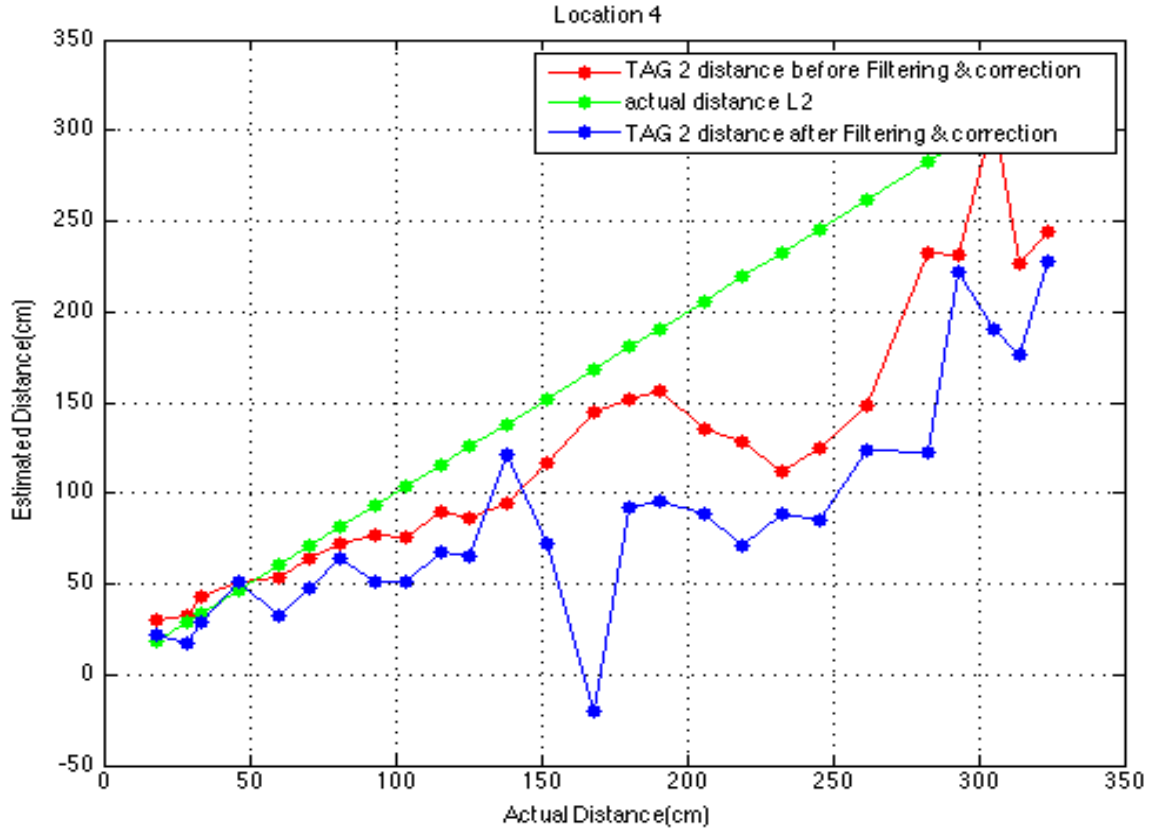


Figure 4.20: Estimated vs Actual distance graph for Tag T_2 at Location 4 after filtering

Note that as the reader move away from the tags, the variation in the estimated value increases, which is evident in all location graphs for both RFID tags used for the RFID system. Again by using optimization explained in section 3.6 for non linear equations as given in equation (3.13), the new estimates for reader coordinates (NR_x, NR_y) and the new target coordinates which is tag T_2 can be estimated with the help of new estimated distance between the reader and tag T_1 and T_2 as shown in Figure 3.6. This process is repeated at every distance for each location. Hence, new inter-tag distances d_m for all location can be estimated. The code for Optimization for Finding Inter-Tag Distance is written in Matlab and can be found in Appendix F: Optimization for Finding Inter-Tag Distance Code.

4.3 Relative Error Results

In this section, the results after taking relative error between experimental and actual value are discussed. The actual distance value between centers of one tag to center of another tag is 16 cm; below are the results for all four-location dataset.

a) Location 1:

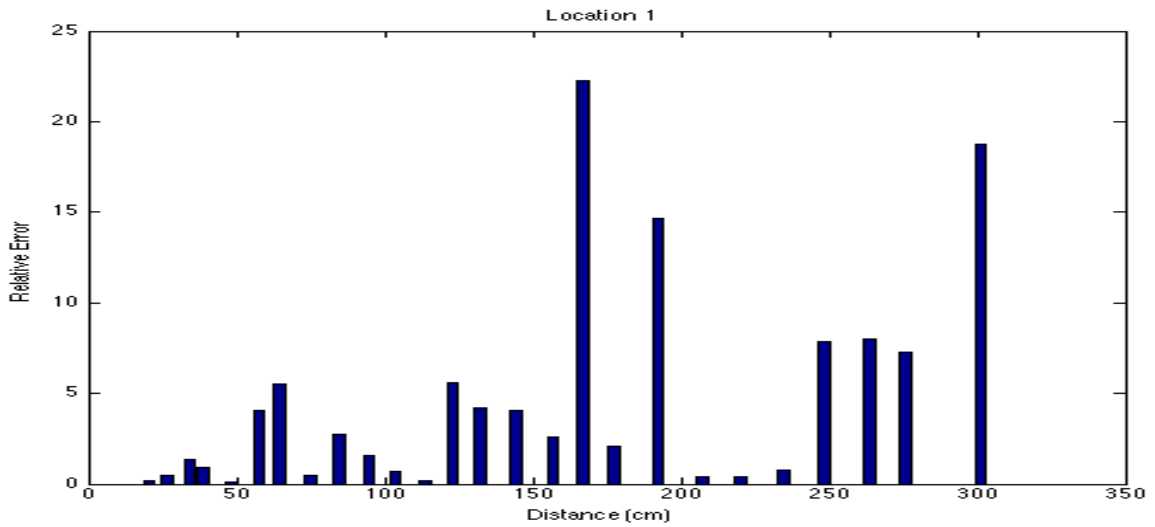


Figure 4.21: Relative Error vs Distance graph for Location 1

b) Location 2:

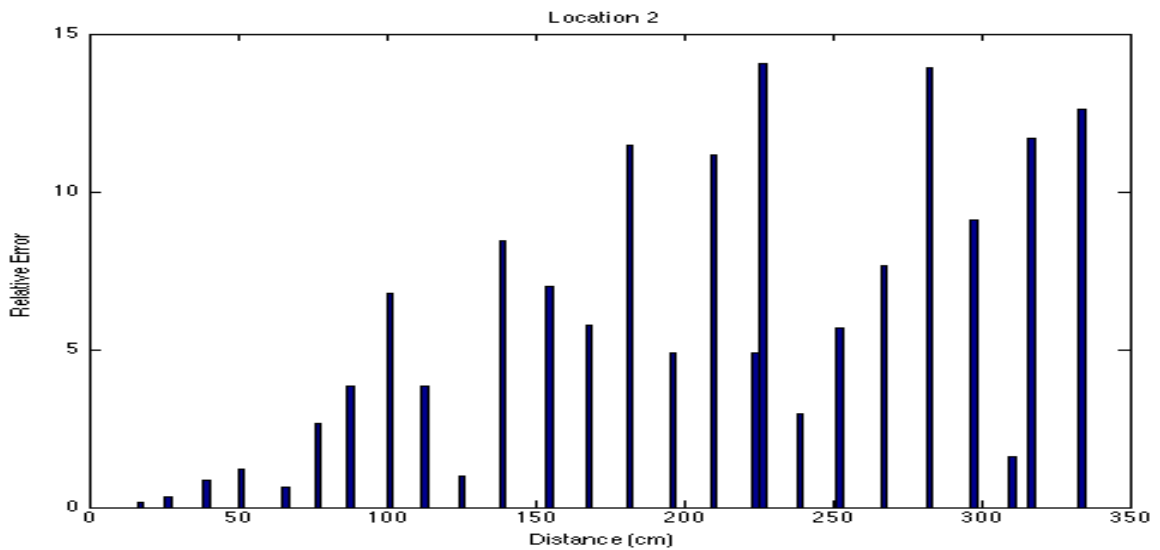


Figure 4.22: Relative Error vs Distance graph for Location 2

c) Location 3:

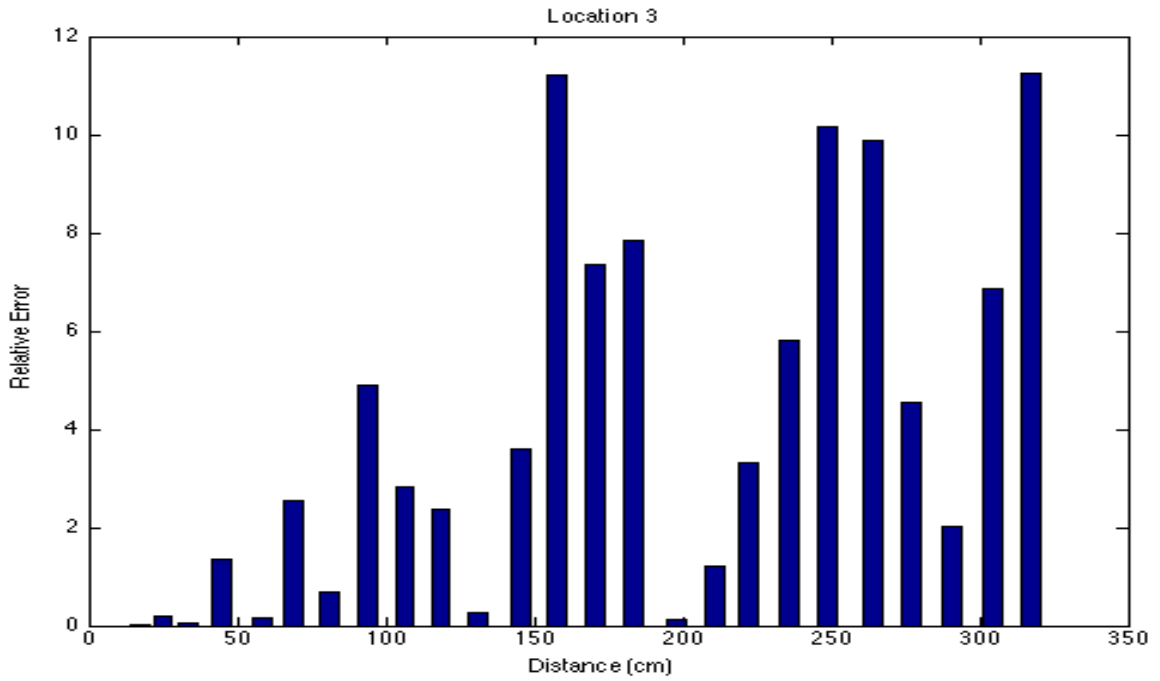


Figure 4.23: Relative Error vs Distance graph for Location 3

d) Location 4:

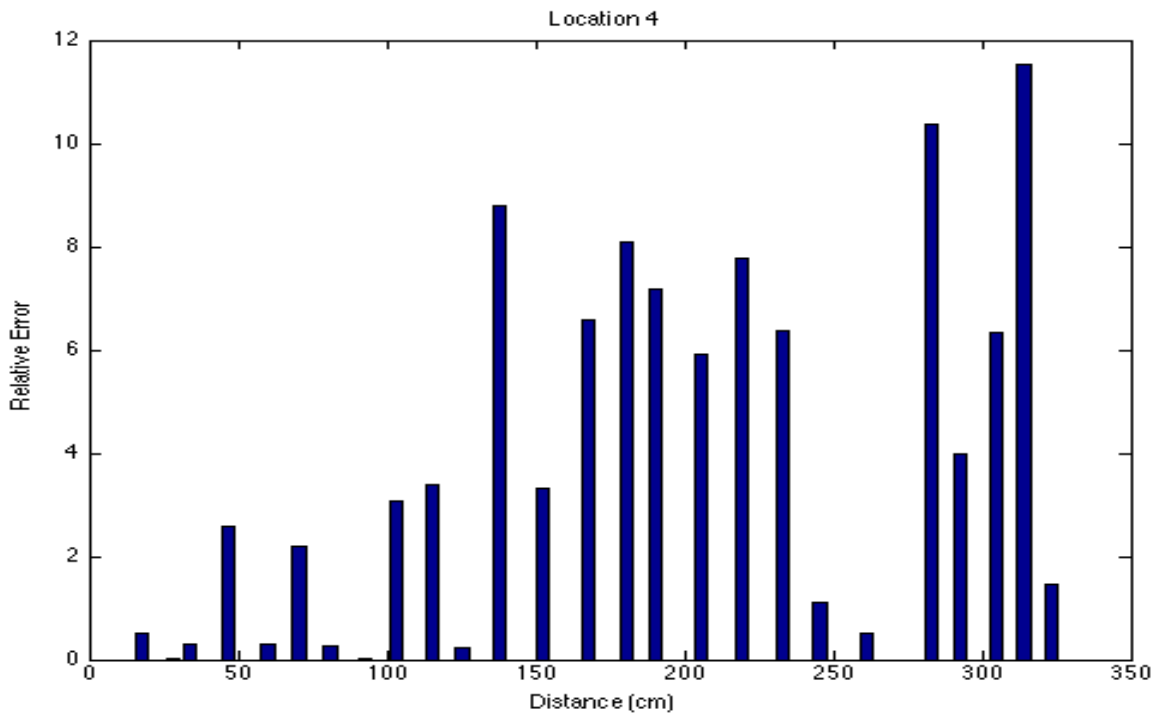


Figure 4.24: Relative Error vs Distance graph for Location 4

Relative error results suggest that from 14-60 cm, the relative error remains within certain limits and varies without an identifiable pattern beyond 60 cm. Therefore, a tolerance range is obtained for this distance range from the results at different locations which is given in the Table 4.1 below:

Distance Range	Tolerance Range for Relative Error
14-20(cm)	0.0325-0.5136
21-30(cm)	0.0165-0.5800
31-40(cm)	0.0576-1.321
40-50(cm)	0.8815-2.5824
50-60(cm)	0.0939-0.6368

Table 4.1: Tolerance range of relative error for a Distance interval

Any change in inter-tag distance will make relative error fall outside the tolerance thus making the movement in tag positions detectable. Below are the results, when inter-tag distance changes from its actual distance, which is 16 cm in this case. A relative error vs distance graph for tag movement is drawn, when inter-tag distance changes. The blue bar represents the unsuccessful detection of tags movement; the red bar represents successful detection of tags movement; the green error bar represents the tolerance range.

1) Change in Length 1mm:

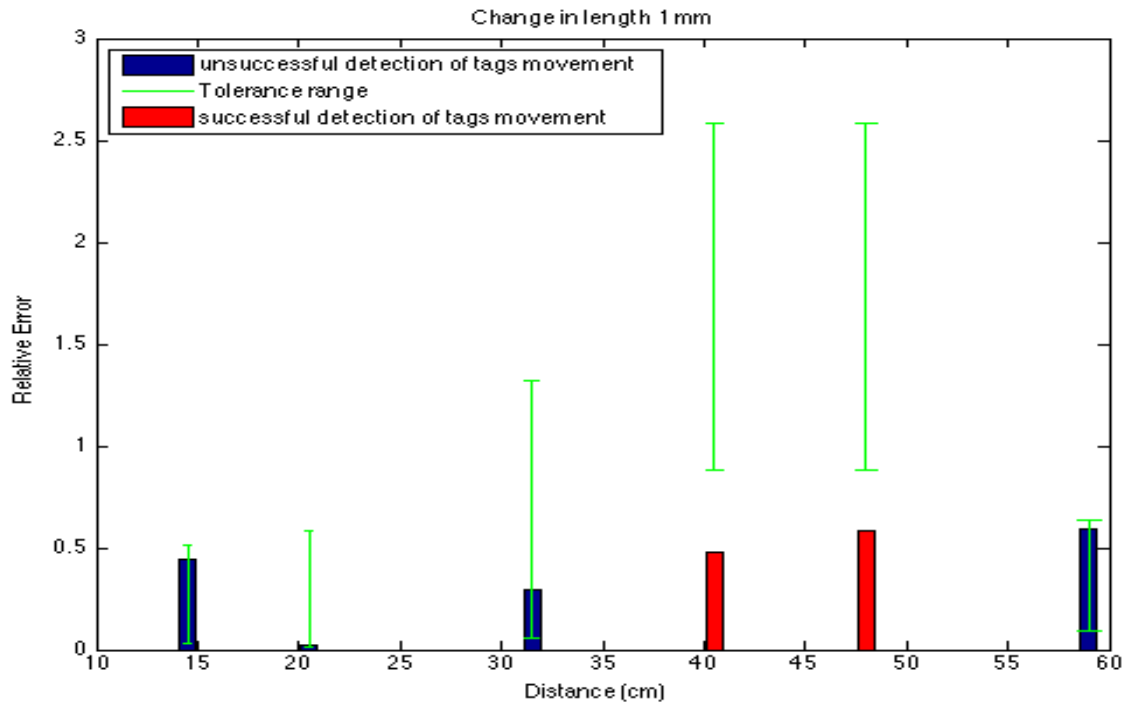


Figure 4.25: Relative Error vs Distance graph for 1mm inter-tag movement

2) Change in Length 3mm:

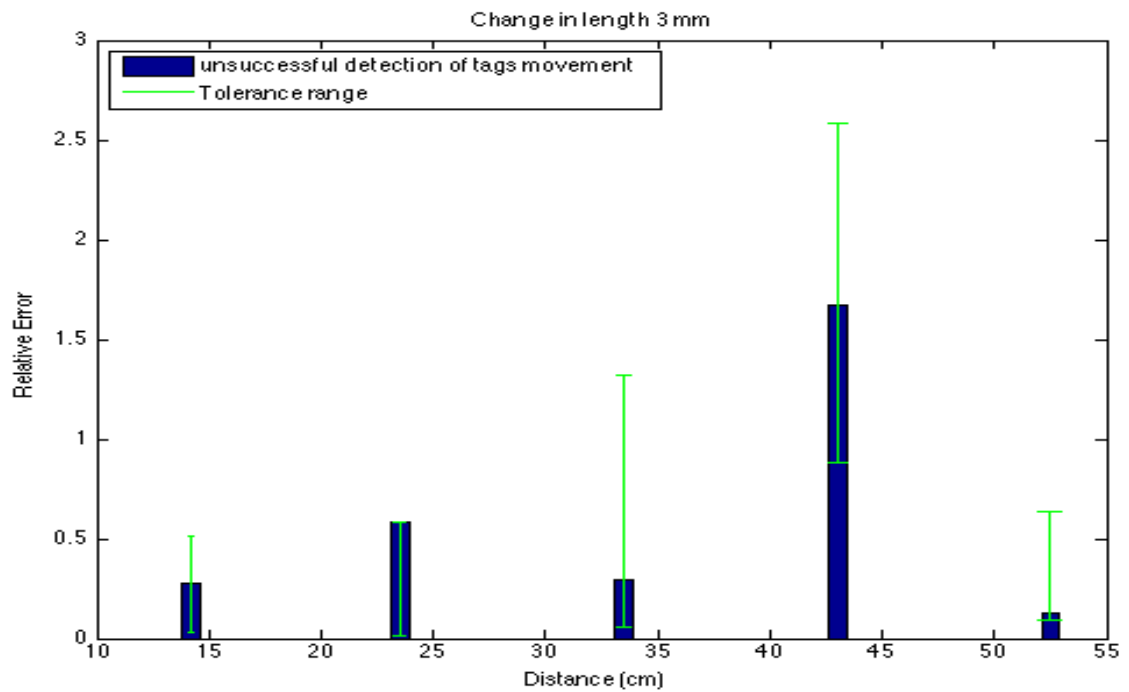


Figure 4.26: Relative Error vs Distance graph for 3mm inter-tag movement

3) Change in Length 5mm:

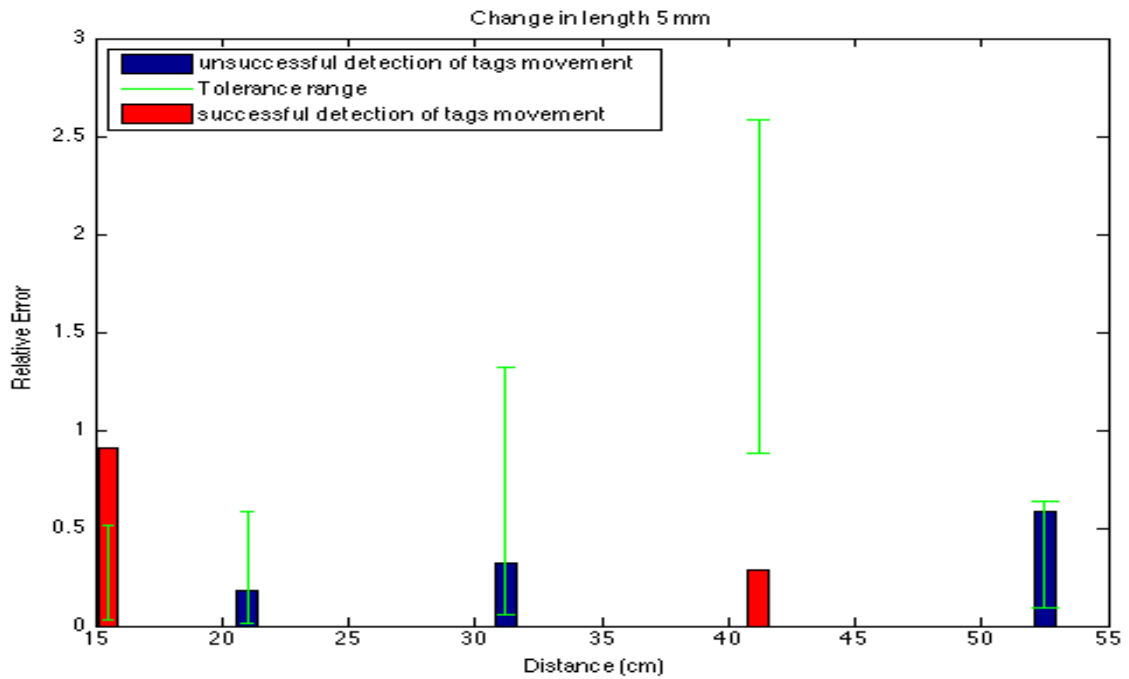


Figure 4.27: Relative Error vs Distance graph for 5mm inter-tag movement

4) Change in Length 7mm:

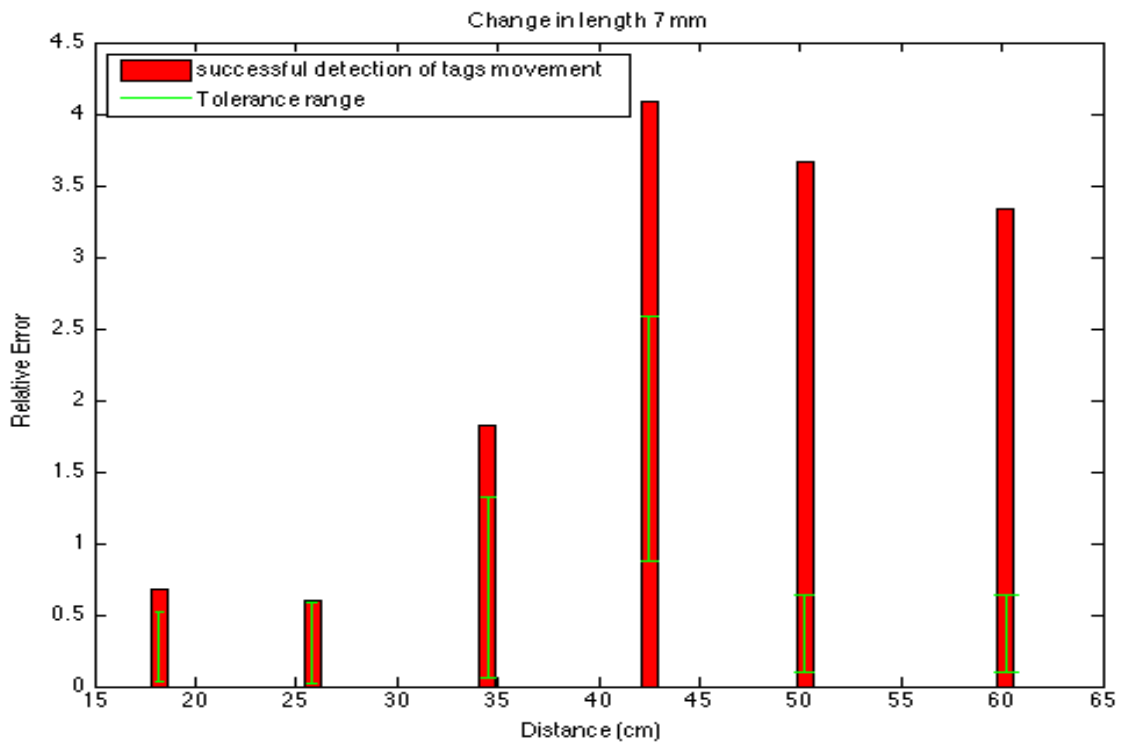


Figure 4.28: Relative Error vs Distance graph for 7mm inter-tag movement

5) Change in Length 9mm:

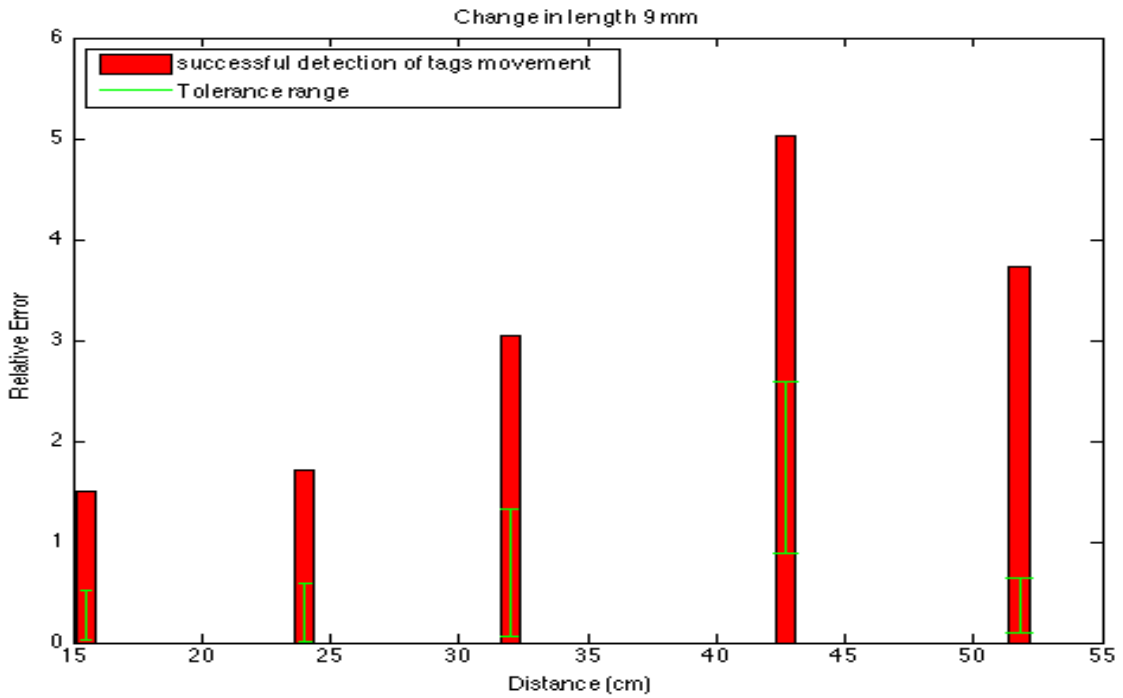


Figure 4.29: Relative Error vs Distance graph for 9mm inter-tag movement

6) Change in Length 11mm:

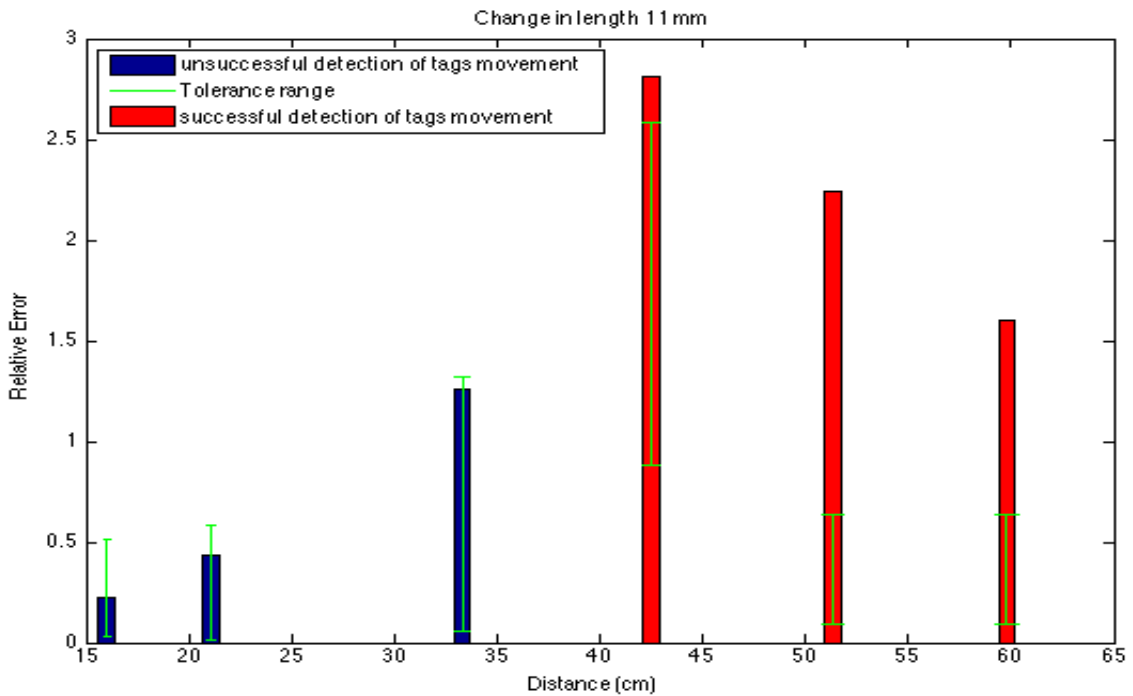


Figure 4.30: Relative Error vs Distance graph for 11mm inter-tag movement

7) Change in Length 1.5 cm:

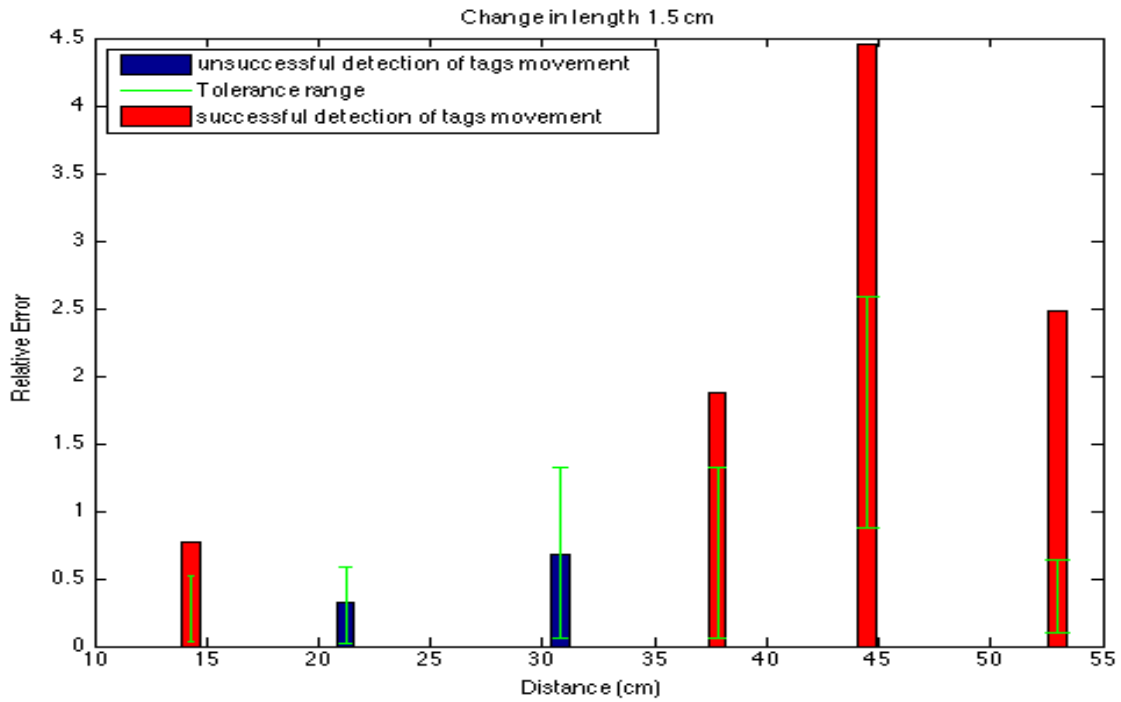


Figure 4.31: Relative Error vs Distance graph for 1.5cm inter-tag movement

8) Change in Length 2cm:

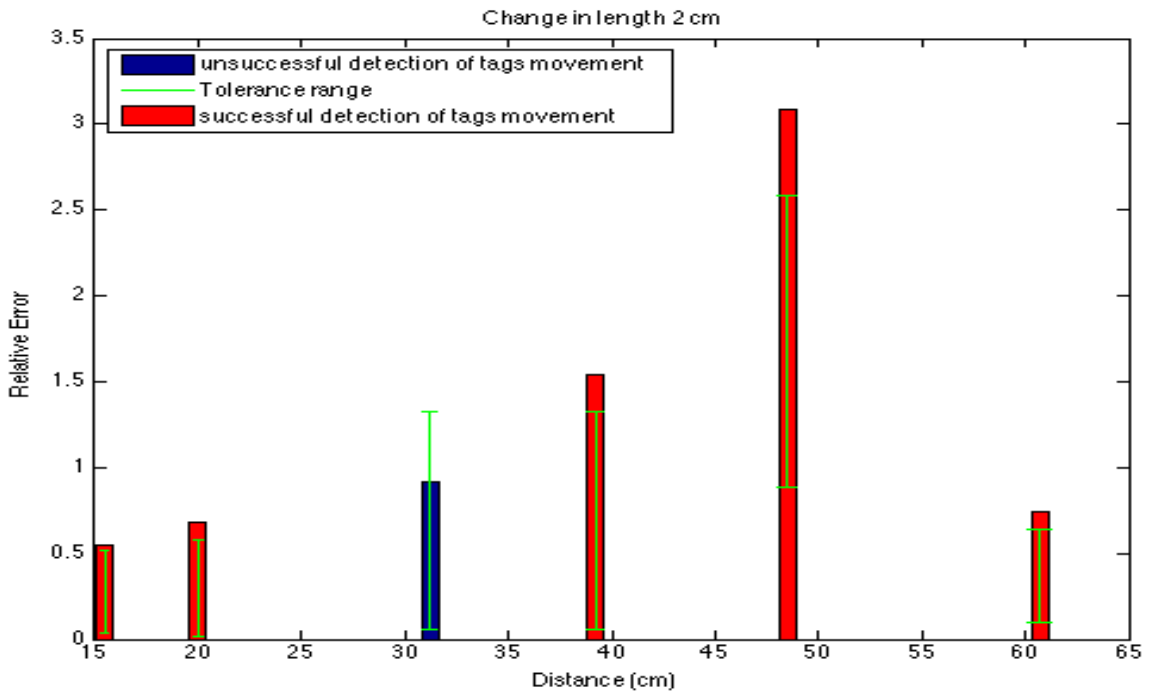


Figure 4.32: Relative Error vs Distance graph for 2cm inter-tag movement

4.4 Results Summary

In this section, results summary is outlined and experimental results state that security algorithm for Indoor RFID system works efficiently with RFID system considered for this research. The main highlights from this research findings are given below:

- Successful detection of tag movement up to 7mm and beyond with exception for 1mm and 5mm.
- Detection pattern starts after 7mm change in inter-tag distance, which is distance range, is from 35cm to 60cm.
- Finding distance between tags and reader up to 1 m with good accuracy.
- Successful use of Large-scale propagation model (far-field) for shorter distance.
- Effective use of Adaptive Kalman Filter for locating tagged items.
- Any change in inter-tag distance up to 6-7mm can be detected while working in 35cm to 60 cm distance range.

Chapter 5 CONCLUSION AND FUTURE WORKS

This chapter outlines conclusion and explains future works for this research.

5.1 Conclusion

In this thesis, the idea for using two UHF passive RFID tag with an active RFID handheld reader works very well for providing a security to indoor RFID systems. A low cost, low complexity and accurate results have been achieved with the RFID system used in this research. Adaptive Kalman filter selection, when two RFID tags are placed in a geometric composition can provide great security.

There are various methods used to achieve the objective but two major approaches stand out the most: First, the use of trilateration for finding the coordinates of the reader and target with the help of optimization. This gives a good way of utilizing the power of geometry to maximum. By considering the fact that the tag T_1 coordinates are fixed and the target tag T_2 has error in coordinates, this problem can be solved. Two fixed tags with some distance apart and a movable reader can utilize this concept to detect change in inter-tag distance to great accuracy. Second, use of relative error solves the problem of saving any signal levels value from any of the two tags into the database. Moreover, real signal levels samples from different indoor locations has been used, which gives me more advantage over storing signal levels in form of clusters or as a unique code for a particular distance value in the database. This makes the system less complex and more users friendly. The relative error technique with a detection range paves the way for locating and providing the security to tag in offline mode with greater accuracy.

The proposed security algorithm is highly dependent on the number of RSSI samples received by RFID reader to conduct the security test for an RFID system, which means it is a little time consuming concept. However, to know the behaviour of RF signal, large numbers of samples are required.

5.1. Future works

For future works, there are lots of things which can be done on the proposed security algorithm for indoor RFID systems. The most important one is to find another filter, which can work with even less number of RSSI samples although adaptive Kalman filter tries to overcome this problem to some extent. Bayesian filter can solve this problem of taking large samples but still not good enough. A customized filter for handling the problem of large RSSI samples would be a great research topic and certainly a great contribution to RFID field and a huge benefit for this security concept.

Some other recommendations for future work related to the security model is: Combination of UHF passive and active tags, Use of only UHF active tag; Use of different types of UHF passive tags such as half-wave dipole antenna UHF passive tag; Use of reader which radiates more power than 1 watt; Use more than two RFID tag, to have a comprehensive approach for making this model more robust and accurate.

This model can also be used with fixed antennas in a large room with optimal use of antenna power, their correct orientation, good understanding of their overlapping reading zone that can provide better results. This model can also be used for providing access control to hospitals with autistic patients, patients with disabilities and retirement buildings. This model can also be used in industrial automation for controlling any equipment maneuvers by detecting change in the positions of another device with a RF

source. More research is required to explore the potential area where this security concept can be used and ultimately proves helpful for mankind.

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APPENDIX A: SIGNAL LEVEL MEASUREMENT CODE

```
// Window form 1: Login Page
using System;
using System.Linq;
using System.Collections;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.IO;
using System.Drawing;
using System.Text;
using System.Threading;
using System.Windows.Forms;
using Symbol.RFID3;
using Microsoft.Win32;
using System.Runtime.InteropServices;
using MySql.Data.MySqlClient;
using System.Security.Cryptography;

namespace RFID_Security_2
{
    public partial class Form1 : Form
    {
        public Form1()
        {
            InitializeComponent();
        }

        private void Form1_Load(object sender, EventArgs e)
        {
            textBox2.PasswordChar = '*';
        }

        private void Login_Click(object sender, EventArgs e)
        {
            try
            {
                if (string.IsNullOrEmpty(this.textBox1.Text) |
                    string.IsNullOrEmpty(this.textBox2.Text))
                {
                    MessageBox.Show("Provide Username and Password");
                }
            }
        }
    }
}
```

```

        MySqlConnection conn = new MySqlConnection("server=192.168.1.142;port =
3306;database=mydatabase;User Id=adminuser;Password=adminuser;");
        conn.Open();
        MySqlCommand cmd = new MySqlCommand("select * from mydatabase.login
where Username = '" +
            textBox1.Text + "' and Password = '" +
            textBox2.Text + "'", conn);
        MySqlDataReader dr = null;
        dr = cmd.ExecuteReader();
        if (dr.Read() && this.textBox1.Text == dr["Username"].ToString()
            && this.textBox2.Text == dr["Password"].ToString())
        {
            MessageBox.Show("Login Successful");
            MainMenuform ps = new MainMenuform();

            ps.Show();
            this.Hide();

        }
        else
            MessageBox.Show("Please Check Username & Password");
    }
    catch(Exception ex)
    {
        MessageBox.Show(ex.Message);
    }
}

private void Cancel_Click(object sender, EventArgs e)
{
    textBox1.Text = string.Empty;
    textBox2.Text = string.Empty;
}

private void menuItem1_Click(object sender, EventArgs e)
{
    System.Windows.Forms.DialogResult Exititem =
        System.Windows.Forms.MessageBox.Show("Do you really want to exit the
application?", "Exit", MessageBoxButtons.OKCancel,
        MessageBoxIcon.Question, MessageBoxDefaultButton.Button1);

    if (Exititem == DialogResult.OK)
        Application.Exit();
}

```

```

    }
}
// Windows form 2:MainMenuform
using System;
using System.Linq;
using System.Collections;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.IO;
using System.Drawing;
using System.Text;
using System.Threading;
using System.Windows.Forms;
using Symbol.RFID3;
using Microsoft.Win32;
using System.Runtime.InteropServices;
using MySql.Data.MySqlClient;

namespace RFID_Security_2
{
    public partial class MainMenuform : Form
    {
        public MainMenuform()
        {
            InitializeComponent();
        }

        private void MainMenuform_Load(object sender, EventArgs e)
        {
            comboBox1.Text = "Select by category";
        }

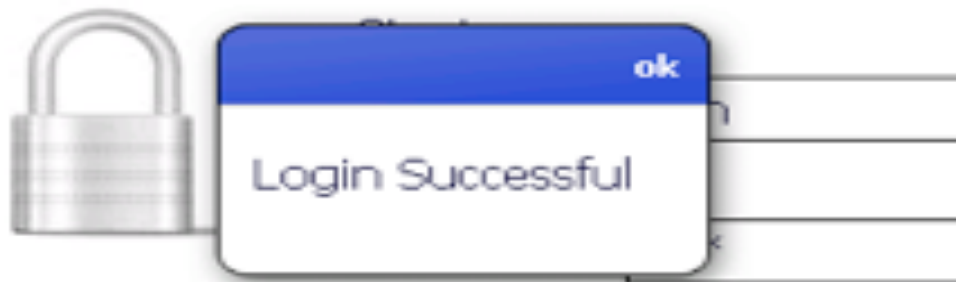
        private void comboBox1_SelectedIndexChanged(object sender, EventArgs e)
        {
            try
            {
                if (comboBox1.Text.ToString() == "Select by Picture")
                {
                    MySqlConnection con = new MySqlConnection("server=192.168.1.142;port = 3306;database=mydatabase;User Id=adminuser;Password=adminuser;");
                    MySqlDataAdapter d_a1 = new MySqlDataAdapter("select distinct Picture from mydatabase.sampledata order by Picture;", con);
                    DataTable d_t1 = new DataTable();
                }
            }
        }
    }
}

```

//Screenshots of Login Page



Welcome Admin



RFID Security

Cancel

Login



```

        d_a1.Fill(d_t1);
        PictureSelection ps = new PictureSelection();
        ps.Storelist.DisplayMember = "Picture";
        ps.Storelist.ValueMember = "Picture";
        ps.Storelist.DataSource = d_t1;
        ps.Show();
        this.Hide();
    }
    else if (comboBox1.Text.ToString() == "Select by Artist Name")
    {
        MySqlConnection con = new MySqlConnection("server=192.168.1.142;port =
3306;database=mydatabase;User Id=adminuser;Password=adminuser;");
        MySqlDataAdapter d_a2 = new MySqlDataAdapter("Select distinct ArtistName
From mydatabase.sampledata order by ArtistName;", con);
        DataTable d_t2 = new DataTable();
        d_a2.Fill(d_t2);
        PictureSelection ps = new PictureSelection();
        ps.Storelist.DisplayMember = "ArtistName";
        ps.Storelist.ValueMember = "ArtistName";
        ps.Storelist.DataSource = d_t2;
        ps.Show();
        this.Hide();
    }
}

catch(Exception ex)
{
    MessageBox.Show(ex.Message);
}

}
private void DBbutton_Click(object sender, EventArgs e)
{
    DatabaseForm bd = new DatabaseForm();
    bd.Show();
    this.Hide();
}

private void menuItem1_Click(object sender, EventArgs e)
{
    Form1 fm = new Form1();
    fm.Show();
}

```

```

        this.Hide();
    }
}
}
// Database button code: Windows form 2
using System;
using System.Linq;
using System.Collections;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.IO;
using System.Drawing;
using System.Text;
using System.Threading;
using System.Windows.Forms;
using Symbol.RFID3;
using Microsoft.Win32;
using System.Runtime.InteropServices;
using MySql.Data.MySqlClient;

namespace RFID_Security_2
{
    public partial class DatabaseForm : Form
    {
        DataTable dt;
        MySqlConnection con_n = new MySqlConnection("server=192.168.1.142;port =
3306;database=mydatabase;User Id=adminuser;Password=adminuser;");

        public DatabaseForm()
        {
            InitializeComponent();
            datbas_data();
        }
        private void menuItem1_Click(object sender, EventArgs e)
        {
            MainMenuform rd = new MainMenuform();
            rd.Show();
            this.Hide();
        }
    }
}

```


//Screenshots of MainMenuform



```

private void datbas_data()
{
    try
    {
        con_n.Open();
        MySqlDataAdapter sda = new MySqlDataAdapter("select * from
mydatabase.sampledata;", con_n);
        dt = new DataTable();
        sda.Fill(dt);
        dataGrid.DataSource = dt;
        con_n.Close();
    }
    catch (Exception ex)
    {
        MessageBox.Show("Can't connect to database" + ex.Message);
    }
}

private void add_Click(object sender, EventArgs e)
{
    con_n.Open();
    MySqlDataAdapter daaa = new MySqlDataAdapter("select * from
mydatabase.sampledata;", con_n);
    daaa.Fill(dt);
    dataGrid.DataSource = dt;
    dt.Rows.Add(dataGrid.CurrentRowIndex);
    daaa.Update(dt);
    con_n.Close();
}

private void Delete_Click(object sender, EventArgs e)
{
    con_n.Open();
    MySqlDataAdapter daa = new MySqlDataAdapter("select * from
mydatabase.sampledata;", con_n);
    daa.Fill(dt);
    dataGrid.DataSource = dt;
    dt.Rows.RemoveAt(dataGrid.CurrentRowIndex);
    daa.Update(dt);
    con_n.Close();
}
}
}
}

```

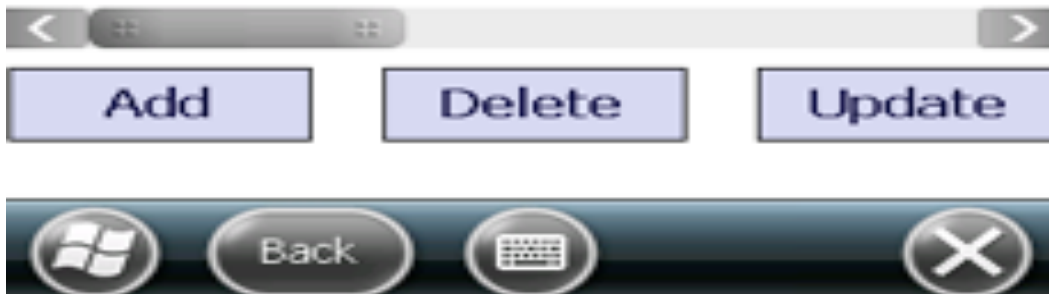
//Screenshots of Database button



A screenshot of a mobile device showing a table with the following data:

ID	Picture	ArtistNar	Owner/C	Ov
1	Picture 1	MF	IDIR	ID
2	Picture 1	MF	IDIR	ID
3	Picture 3	Frances	SS	W

The table is displayed in a mobile application interface with a status bar at the top showing the time 3:39 and various icons.



```

// Windows form 3: PictureSelection (Measuring Signal Level or RSSI with their
//corresponding frequency from tags associated with RFID system in operation)
using System;
using System.Linq;
using System.Collections;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.IO;
using System.Drawing;
using System.Text;
using System.Threading;
using System.Windows.Forms;
using Symbol.RFID3;
using Microsoft.Win32;
using System.Runtime.InteropServices;
using MySql.Data.MySqlClient;
using System.Diagnostics;

namespace RFID_Security_2
{
    public partial class PictureSelection : Form
    {
        public MainMenuform mainmn;
        internal RFIDReader readerAPI;
        internal TagData readTag;
        public ushort[] antID;
        private Symbol.RFID3.TriggerInfo TriggerInfo = null;
        private Symbol.RFID3.PostFilter post_fil = null;
        private Symbol.RFID3.AntennaInfo ant_info = null;
        internal bool pic_load;
        public PictureSelection(MainMenuform _mainmn)
        {
            InitializeComponent();
            mainmn = _mainmn;
            readTag = new Symbol.RFID3.TagData();
        }
        public PictureSelection()
        {
            InitializeComponent();
            readerAPI = new RFIDReader("127.0.0.1",5084,0);
            readerAPI.Connect();
            TagStorageSettings tst = readerAPI.Config.GetTagStorageSettings();
            tst.TagFields = TAG_FIELD.ALL_TAG_FIELDS;
        }
    }
}

```

```

readerAPI.Config.SetTagStorageSettings(tst);

if (readerAPI.IsConnected == true)
{
    MessageBox.Show("connected");
}
else
    MessageBox.Show("not connected");
}

private void PictureSelection_Load(object sender, EventArgs e)
{
    CISbutton.Enabled = false;
    Storelist.SelectedItem = null;
}

private void Storelist_SelectedIndexChanged(object sender, EventArgs e)
{
    if (Storelist.SelectedItem != null)
        CISbutton.Enabled = true;
}

public Hashtable antennasetting(int p_ow, uint A_gain, int rec_sen)
{
    Hashtable output = new Hashtable();
    if (readerAPI.IsConnected == true)
    {
        Symbol.RFID3.ANTENNA_EVENT_TYPE.ANTENNA_CONNECTED.Equals(true);
        ANTENNA_MODE.ANTENNA_MODE_MONOSTATIC.Equals(true);
        antID = readerAPI.Config.Antennas.AvailableAntennas;

        int[] txValues = readerAPI.ReaderCapabilities.TransmitPowerLevelValues;
        int[] rxvalues = readerAPI.ReaderCapabilities.ReceiveSensitivityValues;
        int an_ID = antID[antID.Length - 1];

        if (an_ID == 1)
        {
            Antennas.Config antConfig = readerAPI.Config.Antennas[antID[antID.Length - 1]].GetConfig();
            Antennas.PhysicalProperties ph =
readerAPI.Config.Antennas[antID[antID.Length - 1]].GetPhysicalProperties();

```

```

uint ag = ph.AntennaGain;
A_gain = ag;
int r_s = rxvalues[0];
rec_sen = r_s;
int index_1 = txValues.Count();
antConfig.TransmitPowerIndex = (ushort)(index_1 - 151);
int powermax = antConfig.TransmitPowerIndex;
p_ow = txValues[index_1 - 151];

if (null == ant_info)
{
    ant_info = new Symbol.RFID3.AntennaInfo(antID);
}
else
{
    ant_info.AntennaID = antID;
}

antConfig.TransmitPowerIndex = (ushort)powermax;
antConfig.ReceiveSensitivityIndex = (ushort)r_s;

if (readerAPI.ReaderCapabilities.IsHoppingEnabled)
{
    FrequencyHopInfo hopInfo =
readerAPI.ReaderCapabilities.FrequencyHopInfo;
    int index = antConfig.TransmitFrequencyIndex;
    antConfig.TransmitFrequencyIndex = (ushort)(index);
}
else
{
    int[] freq = readerAPI.ReaderCapabilities.FixedFreqValues;
    int f_re = 0;
    antConfig.TransmitFrequencyIndex = (ushort)(f_re);
}
pic_load = true;
readerAPI.Config.Antennas[antID[antID.Length - 1]].SetConfig(antConfig);
}

}
else
{
    MessageBox.Show("Connect to a Reader");
}
}

```

```

output["Int"] = p_ow;
output["UInt"] = A_gain;
output["Int_1"] = rec_sen;
return output;

}

private void data_tab( out DataTable d_table)
{
    DataTable dtable = new DataTable();
    dtable.Columns.Add("e_", typeof(string));
    dtable.Columns.Add("r_", typeof(sbyte));
    dtable.Columns.Add("i_", typeof(int));
    dtable.Columns.Add("f_", typeof(int));
    dtable.Columns.Add("F_time", typeof(double));
    dtable.Columns.Add("L_time", typeof(double));
    if(readerAPI.IsConnected == true)
    {
        try
        {
            readerAPI.Actions.PurgeTags();
            Stopwatch timer = new Stopwatch();
            timer.Start();
            while (timer.Elapsed < TimeSpan.FromSeconds(2))
            {
                readerAPI.Actions.Inventory.Perform(post_fil, TriggerInfo, ant_info);
            }
            timer.Stop();
        }
        catch (Exception ex)
        {
            MessageBox.Show(ex.Message+ " for few seconds");
        }
        Symbol.RFID3.TagData[] tagdata = readerAPI.Actions.GetReadTags(10000);
        if (tagdata != null)
        {
            for (int i = 0; i < tagdata.Length; i++)
            {
                Symbol.RFID3.TagData tag = tagdata[i];

                string tagID = tag.TagID;
                sbyte Rssi = tag.PeakRSSI;
                int ch_idx = tag.ChannelIndex;
            }
        }
    }
}

```

```

        double time1 = tag.SeenTime.UTCTime.FirstSeenTimeStamp.Millisecond;
        double tim_1 = tag.SeenTime.UTCTime.LastSeenTimeStamp.Millisecond;
        FrequencyHopInfo hopInfo =
readerAPI.ReaderCapabilities.FrequencyHopInfo;
        int index = 1;
        int[] freqs = hopInfo[index - 1].FrequencyHopValues;
        int frequency = freqs[ch_idx-1];
        DataRow dr = dtable.NewRow();
        dr["e_"] = tagID;
        dr["r_"] = Rssi;
        dr["i_"] = ch_idx;
        dr["f_"] = frequency;
        dr["F_time"] = time1;
        dr["L_time"] = tim_1;
        dtable.Rows.Add(dr);
    }
}

}

d_table = dtable;
int ff = d_table.Columns.Count;
}

private void CISbutton_Click(object sender, EventArgs e)
{
    if (readerAPI.IsConnected == true)
    {

        int Int = new int() { };
        uint Uint = new uint() { };
        int Int_1 = new int() { };
        Hashtable outcome = antennasetting(Int, Uint, Int_1);
        int p = (int)outcome["Int"];
        int rsen = (int)outcome["Int_1"];
        uint gain = (uint)outcome["Uint"];
        DataTable d;
        DataTable table;
        tagid_check(out d);
        data_tab(out table);

        int count = table.Rows.Count;
        int c_t = d.Rows.Count;
        DataTable tab_rs = new DataTable();

```



```

DataTable tab_rs1 = new DataTable();
DataTable tab_rs2 = new DataTable();

for (int i = 0; i < c_t; i++)
    for (int j = 0; j < count; j++)
        {
            {
                string tagepc = (string)d.Rows[i]["TagEPCID"];
                string tagepc_rc = (string)table.Rows[j]["e_"];
                if (tab_rs.Columns.Count == 0 && tagepc == tagepc_rc)
                    {
                        tab_rs.Columns.Add(" " + tagepc + " ", typeof(sbyte));
                        tab_rs1.Columns.Add("Cha_idx" + tagepc + "", typeof(int));
                        tab_rs1.Columns.Add("frequency" + tagepc + "", typeof(int));
                        tab_rs2.Columns.Add("Fstm" + tagepc + "", typeof(double));
                        tab_rs2.Columns.Add("Lstm" + tagepc + "", typeof(double));
                        DataRow drow = tab_rs.NewRow();
                        DataRow d_ow = tab_rs1.NewRow();
                        DataRow d_w = tab_rs2.NewRow();
                        drow[" " + tagepc + " "] = (sbyte)table.Rows[j]["r_"];
                        d_ow["Cha_idx" + tagepc + ""] = (int)table.Rows[j]["i_"];
                        d_ow["frequency" + tagepc + ""] = (int)table.Rows[j]["f_"];
                        d_w["Fstm" + tagepc + ""] = (double)table.Rows[j]["F_time"];
                        d_w["Lstm" + tagepc + ""] = (double)table.Rows[j]["L_time"];
                        tab_rs.Rows.Add(drow);
                        tab_rs1.Rows.Add(d_ow);
                        tab_rs2.Rows.Add(d_w);
                    }
                else if (tab_rs.Columns.Count == 1)
                    {
                        string col_na = tab_rs.Columns[0].ColumnName;
                        if (col_na.Contains(tagepc_rc) && tagepc == tagepc_rc)
                            {
                                DataRow drow1 = tab_rs.NewRow();
                                DataRow d_ow1 = tab_rs1.NewRow();
                                DataRow d_w1 = tab_rs2.NewRow();
                                drow1[" " + tagepc + " "] = (sbyte)table.Rows[j]["r_"];
                                d_ow1["Cha_idx" + tagepc + ""] = (int)table.Rows[j]["i_"];
                                d_ow1["frequency" + tagepc + ""] = (int)table.Rows[j]["f_"];
                                d_w1["Fstm" + tagepc + ""] = (double)table.Rows[j]["F_time"];
                                d_w1["Lstm" + tagepc + ""] = (double)table.Rows[j]["L_time"];
                                tab_rs.Rows.Add(drow1);
                                tab_rs1.Rows.Add(d_ow1);
                                tab_rs2.Rows.Add(d_w1);
                            }
                    }
            }
        }

```

```

}

else if (!col_na.Contains(tagepc_rc) && tagepc == tagepc_rc)
{
    tab_rs.Columns.Add(" " + tagepc + " ", typeof(sbyte));
    tab_rs1.Columns.Add("Cha_idx" + tagepc + "", typeof(int));
    tab_rs1.Columns.Add("frequency" + tagepc + "", typeof(int));
    tab_rs2.Columns.Add("Fstm" + tagepc + "", typeof(double));
    tab_rs2.Columns.Add("Lstm" + tagepc + "", typeof(double));
    DataRow drow2 = tab_rs.NewRow();
    DataRow d_ow2 = tab_rs1.NewRow();
    DataRow d_w2 = tab_rs2.NewRow();
    drow2[" " + tagepc + " "] = (sbyte)table.Rows[j]["r_"];
    d_ow2["Cha_idx" + tagepc + ""] = (int)table.Rows[j]["i_"];
    d_ow2["frequency" + tagepc + ""] = (int)table.Rows[j]["f_"];
    d_w2["Fstm" + tagepc + ""] = (double)table.Rows[j]["F_time"];
    d_w2["Lstm" + tagepc + ""] = (double)table.Rows[j]["L_time"];
    tab_rs.Rows.Add(drow2);
    tab_rs1.Rows.Add(d_ow2);
    tab_rs2.Rows.Add(d_w2);
}
}
else if (tab_rs.Columns.Count > 1)
{
    string r_r = null;
    string[] columnNames = tab_rs.Columns.Cast<DataColumn>().Select(x
=> x.ColumnName).ToArray();
    foreach (string r in columnNames)
    {
        if (r.Contains(tagepc_rc))
        {
            r_r = r;
        }
    }
    if (r_r == null)
        r_r = tagepc_rc;

    if (r_r.Contains(tagepc_rc) && tagepc == tagepc_rc)
    {
        DataRow drow3 = tab_rs.NewRow();
        DataRow d_ow3 = tab_rs1.NewRow();
        DataRow d_w3 = tab_rs2.NewRow();
        drow3[" " + tagepc + " "] = (sbyte)table.Rows[j]["r_"];
        d_ow3["Cha_idx" + tagepc + ""] = (int)table.Rows[j]["i_"];
    }
}

```

```

        d_ow3["frequency" + tagepc + ""] = (int)table.Rows[j]["f_"];
        d_w3["Fstm" + tagepc + ""] = (double)table.Rows[j]["F_time"];
        d_w3["Lstm" + tagepc + ""] = (double)table.Rows[j]["L_time"];
        tab_rs.Rows.Add(drow3);
        tab_rs1.Rows.Add(d_ow3);
        tab_rs2.Rows.Add(d_w3);
    }
    else if (!(r_r.Contains(tagepc_rc)) && tagepc == tagepc_rc)
    {
        tab_rs.Columns.Add(" " + tagepc + " ", typeof(sbyte));
        tab_rs1.Columns.Add("Cha_idx" + tagepc + " ", typeof(int));
        tab_rs1.Columns.Add("frequency" + tagepc + " ", typeof(int));
        tab_rs2.Columns.Add("Fstm" + tagepc + " ", typeof(double));
        tab_rs2.Columns.Add("Lstm" + tagepc + " ", typeof(double));
        DataRow drow4 = tab_rs.NewRow();
        DataRow d_ow4 = tab_rs1.NewRow();
        DataRow d_w4 = tab_rs2.NewRow();
        drow4[" " + tagepc + " "] = (sbyte)table.Rows[j]["r_"];
        d_ow4["Cha_idx" + tagepc + ""] = (int)table.Rows[j]["i_"];
        d_ow4["frequency" + tagepc + ""] = (int)table.Rows[j]["f_"];
        d_w4["Fstm" + tagepc + ""] = (double)table.Rows[j]["F_time"];
        d_w4["Lstm" + tagepc + ""] = (double)table.Rows[j]["L_time"];
        tab_rs.Rows.Add(drow4);
        tab_rs1.Rows.Add(d_ow4);
        tab_rs2.Rows.Add(d_w4);
    }
}
}

if (tab_rs.Columns.Count != d.Rows.Count)
{
    MessageBox.Show("All" + Storelist.Text + "tags are not found");
}

string[] col_mn = tab_rs.Columns.Cast<DataColumn>().Select(x =>
x.ColumnName).ToArray();
StreamWriter sw = null;
sw = new StreamWriter(@"file.txt", true);
for (int i = 0; i < tab_rs.Columns.Count; i++)
{
    sw.Write(tab_rs.Columns[i].ColumnName + "\t");
}

```

```

    }
    sw.WriteLine();
    foreach (DataRow row in tab_rs.Rows)
    {
        foreach (DataColumn col in tab_rs.Columns)
        {
            sw.Write(row[col] + "\t");
        }
        sw.WriteLine();
    }
    sw.Close();
    sw = new StreamWriter(@"file1.txt", true);
    for (int i = 0; i < tab_rs1.Columns.Count; i++)
    {
        sw.Write(tab_rs1.Columns[i].ColumnName + "\t");
    }
    sw.WriteLine();
    foreach (DataRow row in tab_rs1.Rows)
    {
        foreach (DataColumn col in tab_rs1.Columns)
        {
            sw.Write(row[col] + "\t");
        }
        sw.WriteLine();
    }
    sw.Close();
    sw = new StreamWriter(@"file2.txt", true);
    for (int i = 0; i < tab_rs2.Columns.Count; i++)
    {
        sw.Write(tab_rs2.Columns[i].ColumnName + "\t");
    }
    sw.WriteLine();
    foreach (DataRow row in tab_rs2.Rows)
    {
        foreach (DataColumn col in tab_rs2.Columns)
        {
            sw.Write(row[col] + "\t");
        }
        sw.WriteLine();
    }
    sw.Close();
}

```

else

```

        MessageBox.Show("Connect to a reader");
    }

    public void tagid_check( out DataTable va_l)
    {
        DataTable d_1 = new DataTable();
        if (Storelist.DisplayMember == "Picture")
        {
            MySqlConnection con = new MySqlConnection("server=192.168.1.142;port
= 3306;database=mydatabase;User Id=adminuser;Password=adminuser;");
            con.Open();
            MySqlDataAdapter d_a = new MySqlDataAdapter("select TagEPCID from
mydatabase.sampledata Where Picture = '" + Storelist.Text + "'", con);
            d_a.Fill(d_1);
            con.Close();
        }
        else if (Storelist.DisplayMember == "ArtistName")
        {
            MySqlConnection con = new MySqlConnection("server=192.168.1.142;port
= 3306;database=mydatabase;User Id=adminuser;Password=adminuser;");
            con.Open();
            MySqlDataAdapter d_a = new MySqlDataAdapter("select TagEPCID from
mydatabase.sampledata Where ArtistName = '" + Storelist.Text + "'", con);
            d_a.Fill(d_1);
            con.Close();
        }
        va_l = d_1;
    }

    private void BackItem_Click(object sender, EventArgs e)
    {
        MainMenuform mn = new MainMenuform();
        mn.Show();
        this.Hide();
    }

    private void ExitItem_Click(object sender, EventArgs e)
    {
        System.Windows.Forms.DialogResult Exititem =
        System.Windows.Forms.MessageBox.Show("Do you really want to exit the
application?", "Exit", MessageBoxButtons.OKCancel,
        MessageBoxIcon.Question,
        MessageBoxDefaultButton.Button1);
    }

```

```
    if (Exititem == DialogResult.OK)
        Application.Exit();
    }
}
```

//Screenshots of PictureSelection form



Store Items

- Picture 1
- Picture 3

CheckItemSecurity



APPENDIX B: SIGNAL LEVEL-DISTANCE CONVERSION CODE

```
clear
clc
% file_1 & file_2 are signal level and their respective frequencies taken
% from two tags at different distance instances at any location 1 to 4
files_1 = '/Users/PRINCE/Documents/MATLAB/Distance
Function/Data_set/RFID3_90(Loc_4)/Length3_90';
files_2 = '/Users/PRINCE/Documents/MATLAB/Distance
Function/Data_set/RFID3_90(Loc_4)/Frequency3_90';
l_file = fullfile(files_1, '*.mat');
f_file = fullfile(files_2, '*.mat');
Len_file = dir(l_file);
Fre_file = dir(f_file);
for nn = 1:size(Len_file,1)
    name_ = Len_file(nn).name;
    nae_ = Fre_file(nn).name;
    L_Name = fullfile(files_1,name_);
    F_Name = fullfile(files_2,nae_);
    load(L_Name,'unnamed');
    % a sample of Signal level from two tags at one particular distance at
    % any location 1to 4
    x1 = unnamed;
    load(F_Name,'unnamed');
    % a sample of Frequencies from two tags at one particular distance at
    % any location 1to 4
    x2 = unnamed/10.^3;
    m_1 = size(x1,1);
    n_1 = size(x2,1);
    minlength_ = min(size(x1,1),size(x2,1));
    if m_1>n_1
        x1 = x1(1:minlength_,1:2);
    elseif m_1<n_1
        x2 = x2(1:minlength_,1:2);
    end

    for j = 1:size(x2,1)
        for k = 1:size(x2,2)
            x_2(j,k) = (3*10.^8)/(x2(j,k)*10.^6);
        end
    end
end
% a sample of wavelengths from two tags at one particular distance at
% any location 1to 4
```



```

    x_2 = x_2(1:minlength_,1:2);
% Antenna Gain for reader
gt = 1.5;
% Antenna Gain for tag
gr = 1;
% arbitrary reference distance
r_ds = 10;
% Path loss exponent
n = 1.8;
N = 2*n;

%signal level to distance conversion for two tags
for i= 1:size(x1,1)
    dist_06(:,i) = (10.^((30-x1(i,1)- 36.976 + 10*log10(gt) + 10*log10(gr)+
20*log10(x_2(i,1)*100))/36));
    dist_10(:,i) = (10.^((30-x1(i,2)- 36.976 + 10*log10(gt) + 10*log10(gr)+
20*log10(x_2(i,2)*100))/36));
end
dist_06(dist_06 == inf) = [];
dist_10(dist_10 == inf) = [];
dist_06(dist_06 == 0) = [];
dist_10(dist_10 == 0) = [];
m_ = size(dist_06,2);
n_ = size(dist_10,2);
minlength = min(size(dist_06,2),size(dist_10,2));
if m_>n_
    dist_06 = dist_06(1:minlength);
elseif m_<n_
    dist_10 = dist_10(1:minlength);
end
% mean of all the sample distance from two tags at one particular
% distance.
% red dots in the estimated v/s actual distance graph shows these two
% below given values at different distance instance for every location
l1(:,nn) = mean(dist_06,2);
l2(:,nn) = mean(dist_10,2);

```

APPENDIX C: OPTIMIZATION FOR FINDING INITIAL COORDINATES CODE

```

% Optimization for finding the reader & target T2 coordinates
act_dis = 16;
% dist_06 is a set of distance values for tag T1 calculated
% from signal level samples for a particular distance instance
% for any location 1 to 4
for ii = 1:size(dist_06,2)
    x0 = [0,0];
    c = dist_06(:,ii);
    % using fsolve for solving nonlinear equations with
    %levenberg-marquardt algorithm which is a nonlinear least-squares
    %algorithm
    options = optimoptions('fsolve','Algorithm','levenberg-marquardt',...
        'TolFun',1e-6,'MaxFunEvals',1500,'MaxIter',1500,'TolX',1e-6);
    fun = @(x)co_ord(x,c);
    [x(:,ii),fval(:,ii),exitflag(:,ii)] = fsolve(fun,x0,options);
end
% x is reader coordinates(Rx,Ry)
x = abs(x(1:2,1:minlength)));

%Objective function for nonlinear equation as explained in CH 3.1.3 for
%finding the reader coordinates as x with tag t1 at (0,0)& distance L1 as c
function f = co_ord(x,c)
f = abs((sqrt((0-x(1)).^2 + (0-x(2)).^2))-c(1));
end

% dist_10 is a set of distance values for tag T2 calculated
% from signal level samples for a particular distance instance
% for any location 1 to 4
for jj = 1:size(dist_10,2)
    y0 = [0,1];
    g = [x(1,jj),x(2,jj),dist_10(:,jj)];
    % using fsolve for solving nonlinear equations with
    %levenberg-marquardt algorithm which is a nonlinear least-squares
    %algorithm
    options_1 = optimoptions('fsolve','Algorithm','levenberg-marquardt',...
        'TolFun',1e-6,'MaxFunEvals',1500,'MaxIter',1500,'TolX',1e-6);
    fun1 = @(y)co_ord1(y,g);
    [y(:,jj),fval1(:,jj),exitflag1(:,jj)] = fsolve(fun1,y0,options_1);
end

```

```
% y is target T2 coordinates  
y =abs(y(1:2,1:minlength));  
  
%Objective function for nonlinear equation as explained in CH 3.1.3 for  
%finding the Target T2 coordinates as y with reader coordinates as (g1,g2)  
%& distance L2 as g3  
function fn = co_ord1(y,g)  
fn = ((sqrt((g(1)- y(1)).^2 + (g(2)- y(2)).^2))-g(3));  
end
```

APPENDIX D: INTERQUARTILE RANGE CODE

```
% Error in targetcoordinates and Distance between actual & estimated
% Target coordinates
for ii_ = 1:size(y,2)
    M_error(:,ii_) = [act_dis-y(1,ii_); 0-y(2,ii_)];
    errr_2(:,ii_) = sqrt((act_dis- y(1,ii_)).^2 + (0-y(2,ii_)).^2);
end

% Interquartile range (IQR) applying on error M_error & Distance errr_2
b_p = sort(M_error,2);
b_p1 = b_p(1,:);
b_p2 = b_p(2,:);
b_p4 = sort(errr_2,2);
q25_1 = median(b_p1(b_p1 < median(b_p1,2)));
q75_1 = median(b_p1(b_p1 > median(b_p1,2)));
q25_2 = median(b_p2(b_p2 < median(b_p2,2)));
q75_2 = median(b_p2(b_p2 > median(b_p2,2)));
q25_3 = median(b_p4(b_p4 < median(b_p4,2)));
q75_3 = median(b_p4(b_p4 > median(b_p4,2)));
IQR_1 = (q75_1 - q25_1);
IQR_2 = (q75_2 - q25_2);
IQR_3 = (q75_3 - q25_3);

% Output dataset after IQR is applied
err_f = b_p1(b_p1 > (q25_1-(1.5*IQR_1)) & b_p1 < (q75_1+1.5*IQR_1));
err_f2 = b_p2(b_p2 > (q25_2-(1.5*IQR_2)) & b_p2 < (q75_2+1.5*IQR_2));
err_f3 = b_p4(b_p4 > (q25_3-(1.5*IQR_3)) & b_p4 < (q75_3+1.5*IQR_3));
```

APPENDIX E: ADAPTIVE KALMAN FILTER CODE

```
% Adaptive kalman filter with all its parameter
B=0;
w = 0;
u = 0;
q = 0;
% Dataset for filter
x2 = x2(1:minlength,1:2);
x0_ = [x(1,:) x(2,:) dist_10'];
% Mean and Covariance of Error in Target coordinates & Distance between
% actual and estimated coordinates after removing Shadow effect
u1 = [mean(err_f);0];
u2 = [mean(err_f2);0];
u3 = [mean(err_f3);0];
uk = [u1 u2 u3];
R1 = cov(err_f,1);
R2 = cov(err_f2,1);
R3 = cov(err_f3,1);

for iii = 1:3
    % Initial process noise
    p0 =1;
    z = 0;
    x0_1 = [x0_(1,iii);0];
    % Measurement Noise covariance matrix
    if iii == 1
        R = R1;
    elseif iii == 2
        R = R2;
    elseif iii == 3
        R = R3;
    end
    c_c = [1 0;0 1];
    t = 1/(x2(1,2)*10.^6);

    for s = 2:size(x,2)
        A = [1 t;0 1];
        % New predicted estimate
        x_ = A * x0_1 + B*u +w;
        % New predicted process noise
        P = A * p0 * A' + q;
        H = [1 0;0 1];
```

```

% Kalman gain
K_gain = (P * H)/((H*P*H')+R);

x_0 = [x0_(s,iii);0];
% Measurement Input
y_ = (c_c * (x_0)) + z;
% Updated state estimate
x_f = x_ + K_gain*(y_ - (H*x_)-uk(:,iii));
% Updated process noise
P_f = (1 - K_gain * H) * P;
% updated process noise becomes previous
p0 = P_f;
si_R1 = size(p0,1);
di_R1 = p0(si_R1:si_R1-1:end-1);
if all(di_R1(:)==di_R1(1))
    p0(si_R1:si_R1-1:end-1) = 0;
end
x0_1 = (x_f);
t = 1/(x2(s,2)*10.^6);
end
% updated estimate become previous
x0f_1(:,iii) = x_f;
x0f_(:,iii) = x0f_1(1,iii);
end
x_fin(:,nn) = x0f_;
l1_fin(:,nn) = sqrt((0 - x_fin(1,nn)).^2 + (0 - x_fin(2,nn)).^2);
% Kalman Filter estimate for Distances between tag 1 & 2 with reader
d_fin(:,nn) = [l1_fin(:,nn); x_fin(3,nn)];

```

APPENDIX F: OPTIMIZATION FOR FINDING INTER-TAG DISTANCE AFTER FILTERING CODE

```
% Optimization for finding inter-tag distance after filtering
a_d = [d_fin(1,nn),d_fin(2,nn),x_fin(1,nn)];
d_0= 16;
opts = optimoptions(@lsqnonlin,'Algorithm','levenberg-marquardt',...
    'TolFun',1e-6,'MaxFunEvals',2500,'MaxIter',1500,'TolX',1e-6);
fun3 = @(d_)co_ord2(d_,a_d);
% d_ is inter-tag distance after filtering
[d_(:,nn),fval3,exitflag3]= lsqnonlin(fun3,d_0,[],[],opts);

%Objective function for nonlinear equation as explained in CH 3.1.5 for
%finding the Target T2 coordinates as d_1 with reader coordinates x-cood. as
%a_d3 & distance NL1,NL2 as a_d1 & a_d2
function fn_1 = co_ord2(d_,a_d)
fn_1 = (((a_d(1)).^2 - (a_d(2)).^2 + (d_(1)).^2)/(2*d_(1)))-a_d(3);
end
```

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