

KADİR HAS UNIVERSITY  
SCHOOL OF GRADUATE STUDIES  
PROGRAM OF MANAGEMENT INFORMATION SYSTEM

**RSSI-BASED HYBRID ALGORITHM FOR REAL-TIME  
PEDESTRIAN TRACKING IN INDOOR ENVIRONMENTS  
BY USING RFID TECHNOLOGY**

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MASTER'S of MANAGEMENT INFORMATION SYSTEM THESIS

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PEDESTRIAN TRACKING IN INDOOR ENVIRONMENTS BY USING  
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EBUBEKİR DEMİR

MASTER'S THESIS

Submitted to the School of Graduate Studies of  
Kadir Has University in partial fulfillment of the requirements for the degree of  
Master of Science in the Program of Management Information Systems

İSTANBUL, JUNE, 2019

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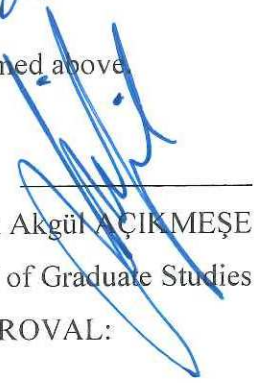
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# RSSI-BASED HYBRID ALGORITHM FOR REAL-TIME PEDESTRIAN TRACKING IN INDOOR ENVIRONMENTS BY USING RFID TECHNOLOGY

## ABSTRACT

The usage and importance of Location Based Services for indoor environments are increasing recently. The knowledge of the exact and real-time location is required by many of these services. Since Global Positioning System (GPS) is not designed for indoor environment, new positioning systems based on new technologies and methods are needed for these type of environments. In this thesis, RFID-based real-time indoor positioning systems and algorithm are developed. Received Signal Strength (RSS) based positioning techniques, are studied in detail. A hybrid algorithm is developed which depends on the mainly fingerprinting. The advantages of each method are emphasized. An original and unique hybrid algorithm is developed in this study in order to overcome available algorithm's' drawbacks. The algorithm and methodology is tested in two different indoor environments. As a result, the accuracy of this original and unique methodology and algorithm is **2,5 m**.

**Keywords:** RFID technology, indoor positioning, Received Signal Strength, fingerprinting, WKNN

# RFID TEKNOLOJİSİ KULLANARAK KAPALI ALANLARDA GERÇEK ZAMANLI RSSI TABANLI HİBRİD YAYA TAKİBİ ALGORİTMASI

## ÖZET

Kapalı ortamlarda lokasyon bazlı hizmetlerin kullanımı ve önemi her geçen gün artmaktadır. Bu servisler için tam ve gerçek zamanlı konum bilgisi gerekmektedir. Ulusal Konumlandırma Sistemi (GPS) kapalı ortamlar için tasarlanmadığından bu tip ortamlar için yeni teknolojiler ve yeni methodlar kullanan yeni konumlandırma sistemlerine ihtiyaç duyulmaktadır. Bu tez çalışmasında, RFID tabanlı gerçek zamanlı iç mekan konumlandırma sistemleri ve algoritmaları geliştirilmiştir. Alınan Sinyal Gücü (RSS) tabanlı konumlandırma teknikleri, detaylı olarak incelenmiştir. Başlıca sinyal haritasına dayanan bir hibrid algoritma geliştirilmiştir. Her yöntemin avantajları vurgulanmıştır. Mevcut algoritmaların yetersizliklerine çözüm olacak orijinal ve özgün bir hibrit algoritma geliştirilmiştir. Geliştirilen algoritma ve yöntem 2 farklı kapalı alanda test edilmiştir. Bu orijinal ve özgün metodoloji ve algoritmanın doğruluğu **2,5** m'dir.

**Anahtar Sözcükler:** RFID teknolojisi, kapalı alan konumlandırma sistemi, Alınan Sinyal Gücü, parmak izi yöntemi, WKNN

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To My Family

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## LIST OF SYMBOLS/ABBREVIATIONS

GPS	Global Positioning System
RFID	Radio Frequency Identification
Wi-Fi	Wireless Local Area Network implementation based on series of 802.11 standards
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
GSM	Global System for Mobile
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema, or Global Navigation Satellite System
IRNSS	The Indian Regional Navigational Satellite System
ToA	Time of Arrival
TDoA	Time Difference of Arrival
AoA	Angle of Arrival
UWB	Ultra Wide Band
ISM	Industrial, Scientific, and Medical Frequency Band
IEEE	Institute of Electrical and Electronics Engineers
kNN	k-Nearest Neighbour Algorithm
WkNN	Weighed k-Nearest Neighbour Algorithm
LoS	Line of Sight
NLoS	Non-Line of Sight
RF	Radio Frequency
WLAN	Wireless Local Area Network
AP	Access Point
GUI	Graphical User Interface
GIS	Geographical Information System
RS232	Recommended Standard 232, a standard for serial communication
RS485	Recommended Standard 485, a standard for serial communication
TCP/IP	Transmission Control Protocol/Internet Protocol
PDF	Probability Density Function

CDF

Cumulative Distribution Function

ISO

International Organization for Standardization



# 1. INTRODUCTION

## 1.1 Motivation of the Thesis

The interest in indoor positioning has been increased in the last few decades. Global Positioning Systems (GPS) technology is insufficient for indoor localization. Not only the human activities inside buildings but also underground mines and facilities demand indoor positioning that cannot be accomplished by the current Global Positioning Systems (GPS) infrastructure. Because of the non-line of sight circumstances and less propagation of GPS signals over building walls and other blocked materials, GPS has significant concern for indoor localization. Consequently, new research attempts are focused to find GPS alternatives that can handle a better indoor positioning coverage for mobile and pervasive location-based services associated with huge buildings and underground facilities. Indoor positioning enables an extensive range of applications and services, such as employee tracking, vehicle tracking, asset tracking, etc.

Miscellaneous systems such as RFID-based, systems, Wi-Fi based systems, cellular-based systems, infrared-based systems have been researched in the literature to improve indoor positioning. RFID-based system is one of the alternative investigation topic so as to complement GPS in indoor environments. More specifically, using active RFID systems is promising due to their extended reading range i.e. up to 100 meter. In this thesis, Radio frequency identification (RFID)-based indoor positioning is investigated. Specifically, RFID received signal strength (RSS) indoor models are improved and fingerprinting based localization algorithms and techniques are proposed.

Another important motivation to study indoor positioning is that recent development about the Internet of Things (IoT). Because of new development in technology and internet, the smart-things concept (e.g. smart home, smart office, smart sensors) is now the part of daily life.

For that reason, not only scientific world but also business world has started to develop new application, software, system and algorithms are to provide various type of smart services for citizens and customers. Indoor positioning in big malls, airports, hospitals can create critical services to increase the quality of life. Therefore, accurate system and algorithms can help and create new services.

Last but not least, the technical difficulty of RFID and RSS-based signal requires state-of-art techniques, algorithms and filters to localize the object in indoor environments accurately. These problems create important opportunities for scientists in order to study on indoor positioning. Therefore, these opportunities has created chance to find state-of-art algorithms and techniques to overcome before-mentioned problems.

## **1.2 Aim and Objective of the Thesis**

The main objective of this thesis is to provide a framework and a unique algorithm for indoor positioning. RFID-based system is the alternative investigation technology so as to complement GPS in indoor environments. There are various technologies that can be applied in indoor environment like bluetooth, wi-fi, infrared etc. Each has even advantages and disadvantages with respect to various metrics. RFID is one of these technologies which has so many applications for different fields. More specifically, using active RFID systems is promising due to their extended reading range i.e. up to 100 meter and several other advantages. In this thesis, Radio frequency identification (RFID)-based indoor positioning is investigated. Specifically, RFID received signal strength (RSS) indoor models are improved and fingerprinting based localization algorithms and techniques are developed and proposed. First of all, the technology and its components are studied in sufficient detail in this study. Their advantages and disadvantages are compared, explained and clarified. The technology and its components are selected with respect to case environment which is mentioned in the following sections. Then, the architecture is designed with respect to selected technology and its components. Not only the technology and but also the architecture should be practically implemented in real-case environment. Therefore, the architecture and technology requirements are examined and designed

in detail. Finally, state-of-art algorithm is developed to localize the object in indoor environment accurately. The performance of the system and the accuracy of the algorithm should be satisfactory with respect to previous studies.

### **1.3 Main Contribution**

This study provides several contributions towards the indoor positioning community. The most significant originality of the study is behind the proposed framework and algorithm. The application of this framework and algorithm is applicable and suitable for any indoor environment which is explained in experimental section. Indoor localization technology for indoor navigation is not obvious and it is a difficult task to improve the reliability and accuracy of the systems. Design of indoor positioning systems has particular challenges such as dynamic nature and complex structure of indoor environments. The technology has already been examined for several years in research projects and many solutions have been proposed in literature. Up until this day, the need for high accuracy indoor localization is still big and booming. The main areas of study is to help users navigate inside large, open and complex indoor environments (e.g. airport, train station, shopping mall) or administrators to track employee, asset, vehicle inside administrative area (e.g. factory, underground mine, goods storage area). In addition to the framework and the algorithm, there are several other reasons why this study is unique and valuable. First, the proposed framework is unique and applicable for various type of indoor environment. Second, the algorithm is unique and reliable for indoor positioning for RFID technology with respect to RSS value. Third, the performance of the developed system is satisfactory comparatively. Finally, the accuracy of the positioning is satisfactory due to application of three scientifically acceptable algorithm.

### **1.4 Organization of the Thesis**

The thesis includes six chapters that cover the corresponding subjects in an organized manner. A brief description of each chapter is as follows:

- Introduction is chapter one and defines the motivation, aim and scope. In addition, it explains the problem statement and main contribution of this study.
- Background is chapter two and explains the Positioning Systems, Approach and Technologies. Also, it defines the several critical metrics to analyze the success of an localization systems.
- Literature Review is chapter three and emphasizes the importance of the indoor localization. It explains the overview of localization technologies, techniques, algorithms, systems for indoor environment.
- The Proposed System Architecture is chapter four and this is the most technical chapter to define and explains the framework and the methodology.
- Experimental Result is chapter five and explains the implementation of framework and the usage of three implemented algorithm with their results.
- Conclusion and Further Recommendations is the final chapter that summarizes this study with discussion, further research and conclusion.

## **2. BACKGROUND**

### **2.1 Positioning Systems**

Positioning is the process of tracking and identifying of people, equipment, and objects. There are several potential positioning systems. Each of which has its advantages and shortcomings. A list of positioning systems that utilize existing infrastructure is highlighted below:

#### **2.1.1 Global Positioning System (GPS)**

GPS is an outdoor positioning system that was fully functionally installed in 1994. It is widely used positioning system in outdoor environments. GPS consists of 24 satellites surrounding Earth. The devices with GPS module integrated receive signal from at least 4 satellites to determine the location itself. Time of Arrival (ToA) and Time Difference of Arrival (TDoA) methodologies are used to determine distance from the satellites. Distance information together with the coordinates of the satellites are sufficient to uniquely determine the location of the receiver. Constant distance from a satellite creates a sphere at space centered at the satellite. Three spheres intersect at a single point which gives for two dimension of the position estimation of the receiver device. Fourth satellite is needed for three dimension of the position estimation of the receiver device. Time synchronization is critical for ToA and TDoA based algorithm and positioning. So, ground stations administrates the satellites by controlling and monitor speeds and synchronizing the clocks. Line of Sight is required for GPS system since ToA and TDoA are employed. Besides, weather conditions that causes delay of signals affects the accuracy of GPS system. Since GPS is administrated by US Government, other outdoor positioning systems with similar architecture was proposed by other governments like GLONASS, Galileo, Compass and IRNSS. The accuracy of the GNSS system is up to 10-20 m

Technology	Approx. Accuracy	Coverage	Cost
Infrared	57 cm -2.3m	Room	Low
Ultrasonic	1 cm- 2 m	Building	High
Audible Sound	Meters	Room	Low
Wi-fi	1.5 m	Building	Low
Bluetooth	30 cm-meters	Building	Low
Zigbee	25 cm	Building	High
RFID	1-5 m	Room	Low
Ultrawideband	15 cm	Building	High
Cellular-based	100-150m	Building	Low
Dead reckoning	10-65 m	Building Independence	Low
Radar	2-3m	Room	Moderate
Raspberry Pi	Not available	Building	Low
LoRa	2 m	Car	Low

**Figure 2.1** Comparison of IPS (Aktas and Cavour 2018)

Technology	Advantage	Disadvantage
Infrared	Low cost	Sunlight interference
Ultrasonic	Good precision	Cost, interference
Audible Sound	Low cost	
	No additional infrastructure	Low precision
Wi-fi	Good precision	Vulnerable to access point changes
	Low cost	
Bluetooth	Good precision	Requires signal mapping
	Low cost	
Zigbee	Provide reuse infrastructure	Low precision
		Require special equipment
RFID	Very low-cost passive side	Very low precision
Ultrawideband	High precision	High cost
	High accuracy	
Cellular based	No interference with devices	Low reliability due to signal propagation
Dead reckoning	No additional hardware	Calculates appx. position
Raspberry Pi	Availability	Requires hardware and software
	Low cost	
LoRa	Long battery	Uncertainty in measurements
	Low power wide	

**Figure 2.2** Advantages and Disadvantages of IPS (Aktas and Cavour 2018)

but the accuracy is assisted by ground station and decreases up to cm level.

### **2.1.2 GSM**

GSM network is the abbreviation of Global System for Mobile communications network which refers to networks consists of base stations and mobile switching centers that covers geographical areas to enable mobile devices communicate in between or other voice or data networks. Each base station forms a cell together with its coverage area. That's why it is cellular network is called interchangeable with GSM network. Each base station is identified with its Cell-ID that the location information can be extracted. Since Cell-ID is shared with the mobile devices in the cell. Mobile switching center forwards the user to the closest base station. The position of the caller is estimated as the position of the base station which is basically the center of the cell. A typical implementation of proximity technique is implemented. The accuracy of the system varies from 2 km to 20 km which is very poor performance.

### **2.1.3 UWB**

Ultra-Wideband (UWB) is an RF technology that indoor positioning can be implemented with centimetre level accuracy with low power consumption. The high accuracy behind the UWB depends on the ToA information provided by the UWB. This technology is emerging and expected to be embedded in smart phones in near future.

### **2.1.4 Wi-Fi**

Wi-Fi is widely used WLAN technology that enables wireless devices network access. 802:11 b,g,n,ac are The Institute of Electrical and Electronics Engineers (IEEE) standards that Wi-Fi is based on. 2.4 GHz and 5 GHz frequency bands are used at Wi-Fi with varying data rates from 10 Mbps to 1 Gbps. Received Signal Strength (RSS) methods can be implemented for indoor localization with Wi-Fi infrastructure. Wi-Fi coverage is maximum 50 meter for each Access Point (AP) that is enough for indoor localization. Besides, the cost of the system can

be evaluated as cheap.

### **2.1.5 Bluetooth**

Bluetooth is wireless technology operates on ISM (Industrial, Scientific, and Medical) 2.4 GHz frequency band. Bluetooth functions up to 15 meter coverage at a 1 Mbps bandwidth. Received Signal Strength (RSS) based localization can be implemented Bluetooth technology by using uniquely identified Bluetooth tags.

### **2.1.6 RFID**

Radio Frequency Identification (RFID) tags have two types, namely passive and active. Passive RFID tags have range limitations that require a tag reader be placed on close proximity in order to read it. The coverage area of the system with passive RFID tags is limited. Active RFID tags have wider range as compared to passive tags. Active RFID reader range can be extended to 100 meter for some products. Similar to Bluetooth and Wi-Fi, Active RFID technology can be used for the operation of positioning system.

## **2.2 Active RFID Positioning System Components**

The positioning system architecture consists of the following units:

**RFID tags.** Each tracked object is attached with a unique active RFID tag in order to identify and track the object. Active RFID tags responses to the requests of readers with their unique identifier.

**RFID readers.** RFID readers are the main infrastructure of the system so that RFID readers measure the RSSI value for each tag within its coverage area and sends to the server through communication interface. RFID readers should be located throughout the detection area such that RFID readers cover the whole area.

**Data Terminal.** Data Terminals are used as part of the system when incompatibility occurs in between the interfaces of readers and server. Data Terminal converts serial communication data to IP packet and IP packets to serial communication data.

**Server.** Server collects all the information gathered from data terminals. Location estimation of the tags is done on the server by using collected information received from the readers.

**Network and Communication Channel.** Communication interface between server and RFID readers may be wired or wireless, i.e. Wi-Fi, Ethernet, RS232 etc.

## **2.3 Positioning Approach**

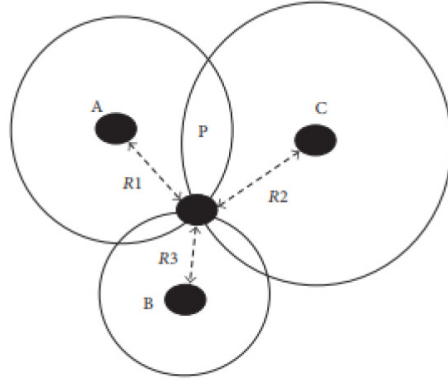
Positioning approach differs in the way in which the data is processed. In Centralized method, localization is centrally calculated. On the contrary, localization is distributed on mobile devices at decentralized method. System design and system topology vary according to positioning approach. System components, component arrangement and distribution together with intended component task depend on the positioning approach. In active RFID Positioning system centralized approach is implemented since RFID tags has limited processing capability.

## **2.4 Wireless Positioning Algorithms**

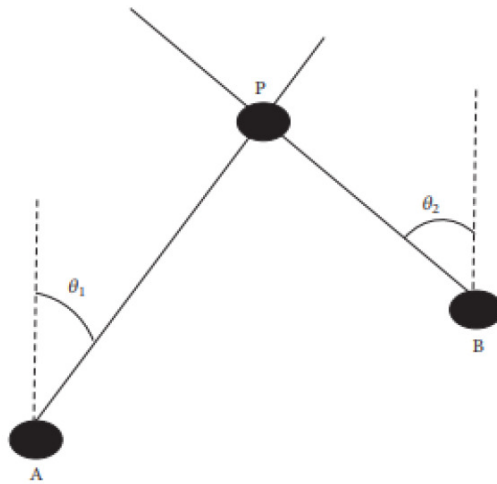
Trilateration, Cell of Origin (CoO), and fingerprinting are three main indoor positioning algorithms. Each algorithm is explained in the following subsections in more detail.

### **2.4.1 Trilateration**

Euclidean Geometry is used to find the position of the target in this method. Measurement of distances with the help of circles, spheres or triangles are used for determining of positions. Distance measurements from known reference points are the basis of the locating a target mobile object. Time of Arrival (ToA) method is a technology that enables distance measurement



**Figure 2.3** Trilateration Based Positioning



**Figure 2.4** Angle of Arrival Based Positioning

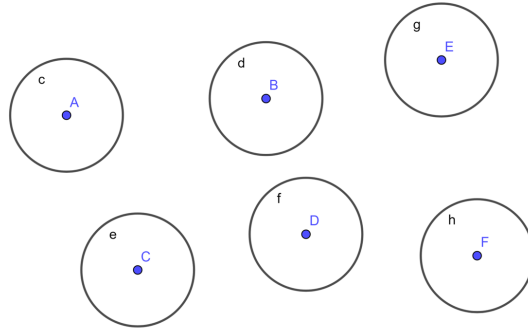
of two points since signal propagation time is directly proportional to the distance travelled by the RF signal. The velocity of signal and the travel time through two points (reference point and blind point) are required to determine the distance. ToA method uses time stamps to carry the departure and arrival time information. ToA method needs time synchronization since travel time is extracted from the absolute time source. Time Difference of Arrival (TDoA) eliminates synchronization requirement. TDoA uses the differences in time of travel for distance measurement, instead of absolute time source. Both in ToA and TDoA methods measuring the travel time precision should be in nanoseconds level as RF signal propagates with the velocity of light. Also, Line-of-Sight (LoS) conditions should be met in trilateration methods. RSSI is another method to measure the distance of two points. Distance from the signal source can be extracted by using path loss model. As the distances from three reference points are known, position estimation can be done by intersecting the spheres (or the circles in 2D) centered at the reference points with radii of distances measured by one of ToA, TDoA or RSSI as shown in 2.3. Angle of Arrival (AoA) method calculates the arrival angle at the receiver that requires more complicated hardware than ToA and TDoA. Two reference point is needed in order to estimate the position of the target with AoA method as shown in 2.4.

$$distance = speed \times time \quad (2.1)$$

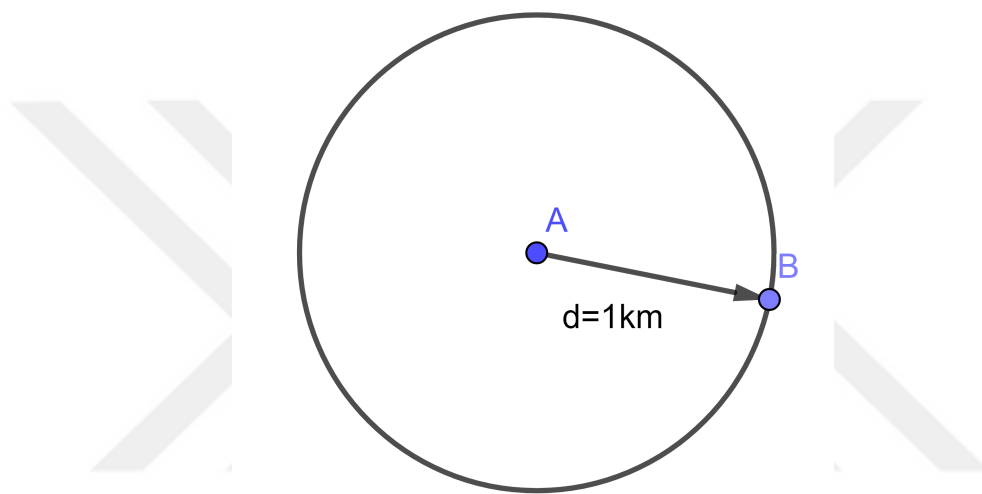
In ToA or TDoA methods basic speed equation is used to determine the distance for trilateration. Light or sound waves are mostly in these methods. Since speed of light or speed of sound at used medium is known and constant. Distance travelled by the light waves or sound waves can be easily extracted by using the above formula.

#### **2.4.2 Cell of Origin (CoO)**

The basic localization method is proximity. This method is the first positioning algorithm originated from E911. When a signal is received from a reference point related with a target, location of the target is estimated as the position of the reference point. The simplicity of the algorithm reduces computational complexity of positioning. However, low resolution and dense reference point requirements are the drawbacks of this method. GSM network is an implementation of proximity positioning technique. The resolution of this method depends on



**Figure 2.5** Cell of Origin Example Coverage Area



**Figure 2.6** Cell of Origin Accuracy Example

the distance of the object and the nearest base station. Figure 2.5 shows an example coverage area of CoO method. The location of the target is estimated as the center of the cell if it is in that circle. CoO method has drawbacks if these circles have intersection areas or if target is not in any of the cells. Figure 2.6 shows an example accuracy. In this example accuracy of the system is 1 km.

### 2.4.3 Fingerprinting

The algorithm in which locations in detection area are correlated with a unique signal parameter to that location is called fingerprinting. Received signal strength (RSS) per location is the

commonly used finger printing parameter as well as other location dependent signal parameters can be used. Fingerprinting method is executed in two phases:

**Offline phase.** Grid points are determined over the detection area. The RSS values received from readers in the area are collected at grid points during the offline phase. RSS model is created for the indoor environment. Collected fingerprint information is stored in a database called signal map. Signal map is main input for estimating the user location in online phase. This is one of the disadvantage of the fingerprinting method since the signal map should be collocated for every case study and for the new environment. Collecting signal for each environment is costly with respect to money and time.

**Online phase.** Real time RSS measurements of the mobile target are compared with the signal map for the detection area by using a positioning algorithm. The disturbance in RSS measurements is handled by fingerprinting method since signal map is also created by the RSS measurements affected from disturbance in the same way. Multipath and fading effects are taken into consideration by fingerprinting method intentionally.

## **2.5 Fingerprinting Localization Algorithms**

During the online phase determining the position needs localization algorithms as mentioned in the fingerprinting chapter. Deterministic algorithms and probabilistic algorithms are the two types of positioning algorithms used in fingerprinting localization method. Widely used examples of each type are described in detail below.

### **2.5.1 K-Nearest Neighbour Algorithm**

kNN (k-nearest neighbour) is the commonly used deterministic location algorithm used in fingerprinting method. Basic goal of kNN is to find the closest grid points in the signal map to the target point by comparing the fingerprint data and actual RSS received. This algorithm defines

the *RSSI distance* between the target and grid point as:

$$R_{(i,t)} = \sqrt{\sum_{n=1}^N (RSSI_{in} - RSSI_{tn})^2} \quad (2.2)$$

where  $RSSI_{in}$  denotes the RSSI value of  $i$ th reference point from the  $n$ th reader,  $RSSI_{tn}$  denotes the RSSI value of target point from the  $n$ th reader and  $N$  is the number of reader RSSI signal received (Ni et al. 2003). Both target and grid have received RSSI values from  $N$  readers. *RSSI distance* is calculated between the target and all reference points. Smaller *RSSI distance* means target and reference points are closer to each other. kNN algorithm uses average of the  $k$  closest grid point for estimating the location of target.

$$(x, y)_t = \frac{1}{k} \sum_{i=1}^k (x_i, y_i) \quad (2.3)$$

where  $(x, y)_t$  denotes the estimated position of target,  $x_i, y_i$  denotes the actual position of the  $i$ th closest with respect to *RSSI distance* reference point and  $k$  denotes the how many nearest neighbours will be taken into account and is set before algorithm works.

Weighted kNN algorithm uses weighted average of the  $k$  closest reference points.

$$(x, y)_t = \frac{1}{\sum_{i=1}^k \frac{1}{R_{(i,t)}^2}} \times \sum_{i=1}^k \frac{1}{R_{(i,t)}^2} (x_i, y_i) \quad (2.4)$$

where  $(x, y)_t$  denotes the estimated position of target,  $x_i, y_i$  denotes the actual position of the  $i$ th closest with respect to *RSSI distance* reference point,  $k$  denotes the how many nearest neighbours will be taken into account and is set before algorithm works,  $R_{(i,t)}$  denotes the *RSSI distance* as defined above. Since WkNN weighting the reference points, WkNN algorithm gives more accurate results. Selecting  $k$  and weighing the points are significant in terms of the accuracy of the system.

### 2.5.2 Maximum Likelihood Algorithm

Maximum likelihood is the probabilistic algorithm to estimate the target position. Joint probability distribution of RSS from each reader at each grid point is needed. In offline phase, Probability Density Functions (PDF) of each grid point for the each reader is determined. To make the calculations simpler, PDFs of the each reader at particular grid point is assumed to

be independent. Although it is not clear that PDFs are disjoint. So, joint PDF becomes the multiplication of the each PDF. In online phase, received RSS signals of target point are included in the resulting PDF function. Position is estimated as the grid point which maximizes the resulting PDF. The details of this algorithm are described in (Karimi 2016).

## 2.6 RSS Propagation Models

RSS propagation modelling is the location method that does not need fingerprinting. Offline phase of fingerprinting and signal map creation operation is replaced with distance formula related with RSSI value of RF signal. Expensive fingerprinting calibration phase is not required with propagation models. Path loss model calculates the signal propagation in free space with the formula:

$$P_r = P_0 - 10n \log_{10} \frac{d_r}{d_0} \quad (2.5)$$

$P_0$  is the power at a reference point  $d_0$ ,  $d_r$  is the distance and  $n$  is the path loss exponent. It is known that  $n = 2$  in free space. However,  $n$  may vary from 4 to 6 in indoor environment conditions. Formula indicates that power density of the signal decays logarithmic as signal travels through the free space. Knowing the parameters in the formula, distance can be extracted from RSS value. So, trilateration method is used to estimate the position of the device. Indoor environments have dense multipath and NLoS conditions that deviates RSS patterns from the path loss model. RSS deviation leads to high distance errors which causes poor position estimation. That's why path loss model is not applied in indoor environments.

## 2.7 System Performance Metrics

There are various type of technology, framework, algorithm and filters for positioning in indoor environments. However, there should be criteria to compare and measure the performance of each positioning system. (Aktas and Cavur 2018) defined several metrics to measure the performance of positioning system : accuracy, availability, coverage area, cost and privacy. To do so, there should be several metrics to measure the developed framework and algorithms. Accuracy is the most significant performance metric. However, accuracy itself is not enough

to show the performance of the positioning system. There are some other critical performance criteria evaluating the positioning system and comparing them. Some performance metrics are listed below:

**Accuracy.** Location error determines the accuracy of a locating system. Accuracy is defined as the mean distance error between the actual and estimated position.

**Precision.** Consistency and coherence of the system define the precision. At each attempt to estimate the distance for the same target system should give the same or similar results. This can be evaluate by using the standard deviation of the error function. Higher system performance indicates smaller mean value of standard deviation.

**Complexity.** Complexity can be evaluated in two categories, software and hardware. Software complexity refers to the software to estimate the location. The localization algorithm used differs the computational time elapsed and the power used. Computational complexity of the algorithm affects the software performance which may be crucial for the battery powered and low processing capability devices. Hardware complexity refers to the hardware used which is out of the scope of this thesis.

**Robustness.** Small changes of the system or changes in physical conditions may affect the system functions. Highly robust systems should be up and running at almost every conditions.

**Cost.** Not only the financial costs but also the time, space and energy cost should be evaluated for the requirement of an indoor positioning system. Space needed for installation, time needed for installation and maintenance ,and energy that the system consumed should be taken into account as performance metric.

**Scalability.** The capacity of designed system, for indoor positioning systems mostly referred to detection area, can be changed easily at a scalable system without affecting the other performance metrics. As the capacity increases the cost and the complexity of the system should

increase at most proportional to the coverage area. And, Accuracy, precision ,and robustness of the system should remain in the same order.

## **2.8 RFID Positioning Systems Design Challenges**

RSS can be used for distance calculation and there are several scientific researches about RSS-based indoor positioning using RFID technology(Çavur 2018). However, many challenges occur while reading RSSI measurements of the RFID devices since RFID is not designed mainly for the positioning purposes. The challenges are listed below: RSSI variations: Environmental noise is added to the RSSI value that causes RSSI value deviations. NLoS cases and the variations of nature of the environment are the main causes of the noise at indoor environments. NLoS conditions are analyzed in detail at (Liu et al. 2013). At NLoS conditions, RF signal travels through different paths by reflecting and refracting which arises multipath problem. Multipath problem hides the actual RSS value that distance will be extracted. Besides, moving objects, mostly people at around, causes environmental variations. Interference: Frequency band of RFID technology is unlicensed. So, same frequency band may be used by any other device which causes interference. Besides, human body itself , composed of Latency: To track an object location determination should take place in real time. So, scanning the signals, network latencies, hardware-dependent latencies, computational complexity based latencies etc. suffer real time processing.

### 3. LITERATURE REVIEW

Literature review and related studies that enlightens the aspects of locating systems based on RSS and mainly RFID are outlined in this chapter. Also, existing RSS based systems and recent advances in indoor locating systems are discussed.

RFID technology has been being used in many areas locating and identifying systems. Most of the passive RFID-based technology positioning system are using proximity method. Since, passive RFID systems has poor coverage area. Still, many researches are focused on general purpose positioning systems based on passive RFID technology such as (Bechteler and Yenigun 2003), (Y. Zhang, Amin, and Kaushik 2007),(Chawla, Robins, and L. Zhang 2010),and (Savochkin 2014), . Besides, passive RFID locating systems on particular context such as robotic industry (Tralie and Fellow n.d.) and (Hahnel et al. 2004), medical industry (Tsai et al. 2006), and library (Choi, Oh, and Song 2006) are the principal applications of the passive RFID technology which is easy to implement and cheap.

Semi-active RFID is the middle stage between passive and active system. It has a medium range with respect to rest of the system. The tag in this system has battery inside but powered by RFID receiver. (Çavur 2018) and (Athalye et al. 2013) have used semi-active RFID tags for indoor localization.

Active RFID is one step further than passive. Since, it has long range and battery powered tags. Active RFID based positioning systems are mostly based on RSSI. Besides, there are some researches focused on phase difference for positioning based on RFID technology (Hekimian-Williams et al. 2010). RSS Based positioning systems have significant challenges as described in the previous section. So, each RSS based research has its own advantages and drawbacks.

Researchers are mostly studied on Wi-Fi systems focusing on RSS based positioning. Since, Wi-Fi is the widely used and easy to implement technology worldwide. These researches may be applied to other RSS based positioning system technologies such as RFID, Bluetooth etc. Since, external influences of the RSS are common in all technologies.

Because the measured RSS value probably has high noise and can easily be effected from environmental changes, kalman filter or extended kalman filter is applied to improve the system performance (Guvenc 2003). (ibid.). (Chadaporn, Baber, and Bakhtyar 2014) shows a simple example of extended kalman filter. Another filtering method is particle filtering. (Gustafsson et al. 2002), (Gustafsson 2010) and (Wang et al. 2007) describe how to implement particle filter for the positioning and tracking applications. In addition to these known filters, there are several other studies concentrating on the unique filters to find the neighbouring or direction of the moving objects in indoor environment which emphasize the importance of the filters in indoor positioning(Çavur and Demir 2017).

Using reference tags is alternative method in RSS based positioning systems. (Huang, Janaswamy, and Ganz 2006) and (Ni et al. 2003) are typical examples of reference tag usage while locating RFID tags. As target and reference tag RSSI values are influenced in the same way, using reference tags is a logical way of handling RSS variations. However, using reference tags is an expensive method with poor scalability. Maintenance of the reference tags are also hard to overcome. Since, batteries of the reference tags may have been over at any time which directly affect the result of the positioning algorithm of the system.

Dead reckoning is an auxiliary method to help estimating the location that estimates the position given that initial position, direction, speed and time passed. This method is not directly applicable for position estimation. But it is used as an assistant tool for estimating location if any other better positioning method is not available for a short time since dead reckoning results have cumulative errors. Mobile device navigation applications uses dead reckoning if GPS is not available. Pedestrian Dead Reckoning is the specific usage of dead reckoning which takes the human steps into account. Human steps can be counted by an inertial sensors like accelerometer, gyroscope etc. which is already available in smart phones. The basics of the

pedestrian dead reckoning is introduced in (Beaugard and Haas 2006). (Jimenez et al. 2009) compares and contrasts the Pedestrian Dead Reckoning algorithms in literature.

Fingerprinting is a method of location determination that uses a fingerprint database of signal or any data related to the position previously collected and compiled. RSS-based positioning systems are suitable for fingerprinting by using the RSSI values. After fingerprint has been established, several algorithms are used to estimate the location. kNN is the widely used deterministic approach used in researches. Many examples and improvements on kNN algorithm has been published (Xie et al. 2016), (Umair, Ramana, and Dongkai 2014).

Trilateration is another algorithm widely used in indoor positioning. (Fu and Retscher 2009), (Lee et al. 2014), and (Savochkin 2014) are typical examples of usage of trilateration technique.

Smart phones are commonly used worldwide. There are various type of smart sensors in smart phones for different purposes. This initiates a new approach to positioning, namely crowd sourcing, which uses many sensors in order to estimate the location. (Alt et al. 2010), (Rai et al. 2012), and (Zhou et al. 2017) are used crowd sourcing as indoor positioning algorithm.

## **4. PROPOSED SYSTEM, ALGORITHM AND ARCHITECTURE**

This chapter provides an overview of the implemented algorithm for the proposed indoor active RFID fingerprint positioning system. A global overview of the proposed system architecture is shown in 4.1 and 4.2.

### **4.1 Proposed System Architecture**

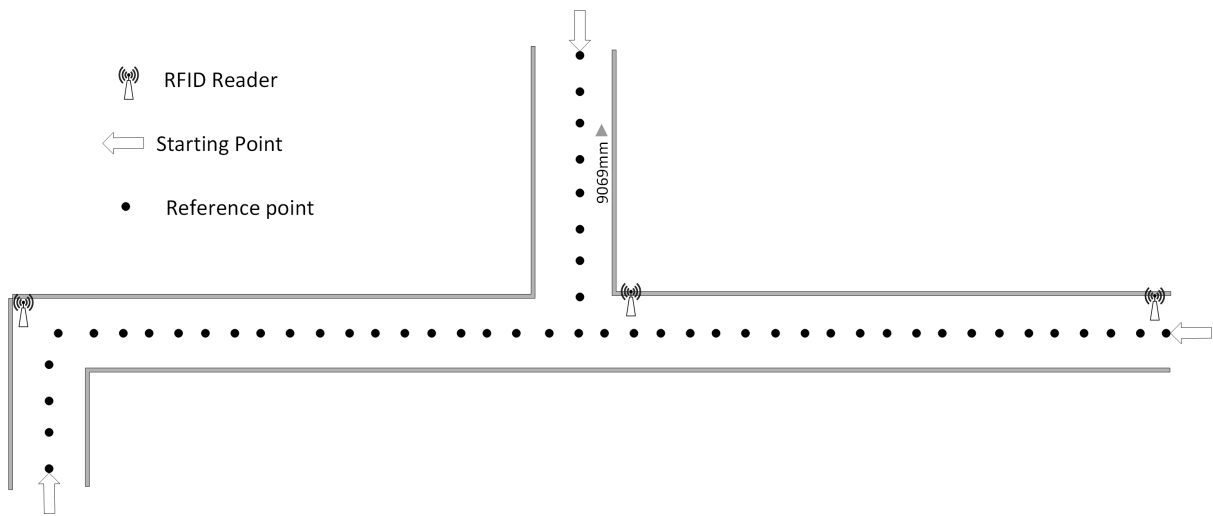
Two different test environment are created in Yıldız Technical University Technopolis. These two case environments are set up and signal map is obtained manually. The Server component of the system is written in Java Programming Language (Gosling and McGilton 1995) together with the PostgreSQL database (Momjian 2001). Server matches the target fingerprint values with database of fingerprints collected at offline phase. Java is an object oriented programming language with Graphical User Interface (GUI) support. Java makes it easy to integrate the results with GIS (Geographical Information System). RFID readers have RS485 interface. Since the RS485 provides a long range communication between readers, it is really suitable for this kind of architecture. Also, an Ethernet to RS485 interface converter is used to communicate with RFID readers as the data terminal. Although RFID products have commercial standards, product specifications may change a little bit according to the vendor.

System components are listed above:

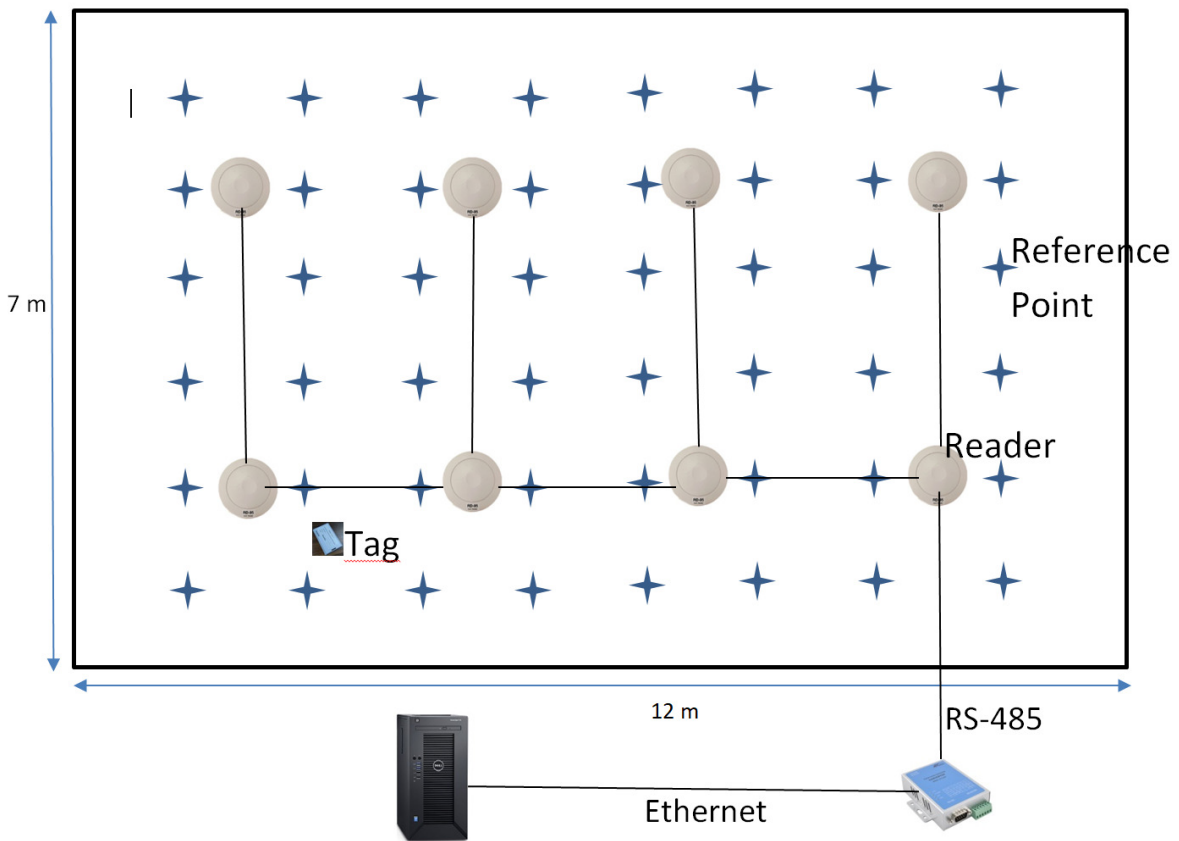
RFID Reader: It operates at 2.4 GHz with RS485 communication interface. Vendor: Tzone (<http://en.tzonedigital.cn>) Brand: TZ-RD-05

Active RFID tag: It operates at 2.4 GHz and compatible with RFID reader. Vendor: Tzone (<http://en.tzonedigital.cn>)

RS485/Ethernet Converter: It converts RS485 signals to Ethernet-TCP/IP packets and vice versa. Vendor: USR-IOT Brand: USR-TCP232-304



**Figure 4.1** Proposed System Architecture Test Environment #1



**Figure 4.2** Proposed System Architecture Test Environment #2



**Figure 4.3** The Reader Used in Experiments

Server Software: Java Programming Language

Server Hardware: Intel Xeon W3520 @2.66 Ghz CPU and 4 GB RAM

Server Database: PostgreSQL version 10

#### **4.2 RFID Reader Communication Protocol**

Since RFID readers have proprietary protocol. We have to implement the protocol on the server side. RFID readers have byte array based protocol sending and receiving data formats are as follows:

Sending data format:

0xAA + Reader ID (3 bytes) + 0x03 in hexadecimal format

Receiving data format:

0x40 + length (1byte) + TZ-RD05 ID (3 byte) + RSSI (1byte) + Tag state (1 byte) + Tag ID (4 bytes) + check code (1 byte) + 0x03 in hexadecimal format

When servers sends the request in proper format to the particular Reader, the reader sends a beacon to the surrounding area and waits for the tags in the coverage area to respond. When



**Figure 4.4** The Tag Used in Experiments



**Figure 4.5** The RS485-Ethernet Converter Used in Experiments

---

**Algorithm 1** Main Execution Algorithm of the System for Scanning the Readers

---

```
1: procedure SCANREADERS
2:   while true do                                     ▷ run this method till the stop button pressed
3:     for each tag Reader in ReaderList do
4:       send scan signal to the Reader
5:       wait for P seconds                             ▷ P is the scan period defined in the system
6:     end for
7:     if stopButtonPressed then
8:       break
9:     end if
10:  end while
11: end procedure
```

---

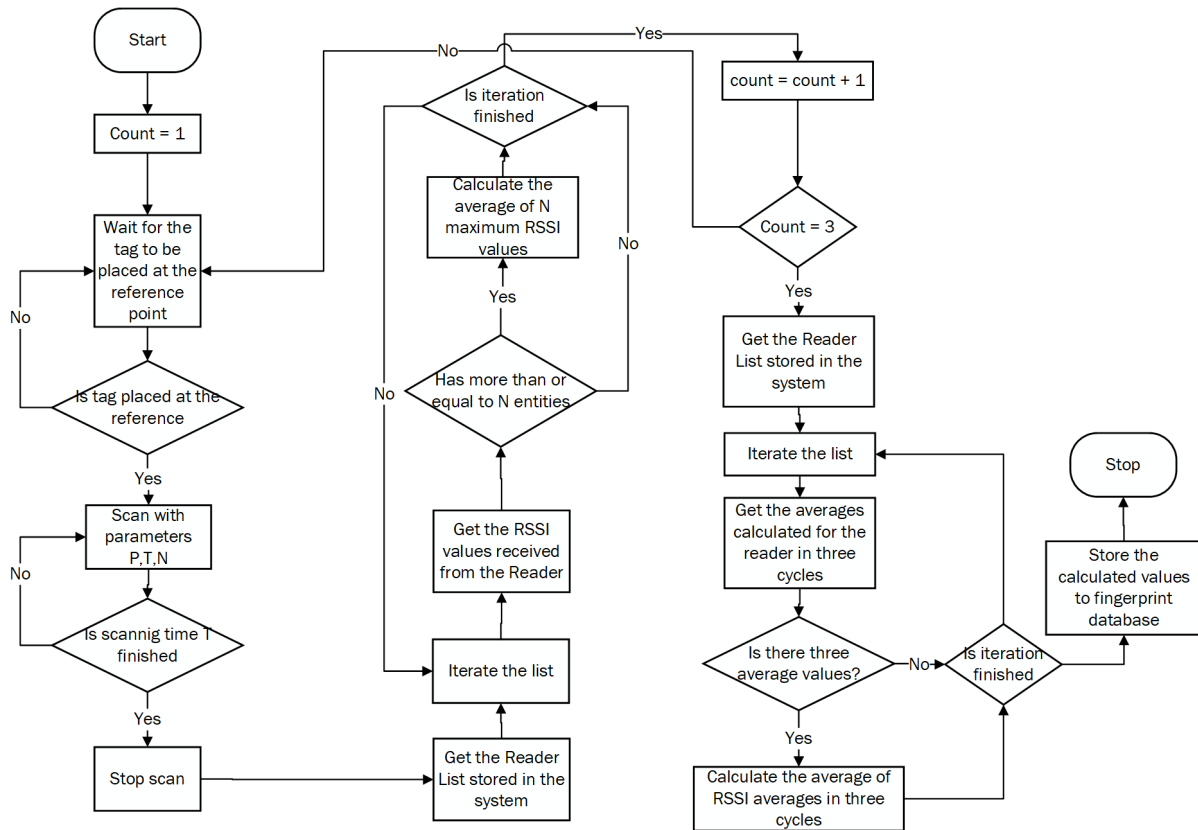
**Figure 4.6** Main Execution Algorithm of the System for Scanning the Readers

response is received from the tags, reader sends response to server in proper format. This mode of operation is called passive mode that server controls the operation and reader always expects the server to scan the tags. The readers should operate in passive mode in order to prevent the readers to scan at the same time which causes electromagnetic interference. The further details of the RFID protocol is describe in appendix.

### 4.3 Hybrid Algorithm

#### 4.3.1 Offline Phase

Signal is collected in offline phase with two people. One person stands at the particular grid point with a RFID tag. The other person controls the server and starts the scan as his colleague is ready at the particular grid point with RFID tag. At every grid point all the readers are scanned during the scan time with a particular scan time and particular sample rate. All the fingerprint data is retrieved from the readers for the reference point. According to (Xue et al. 2017) a number ( $N$ ) of selected maximum RSS observations should be taken into account while

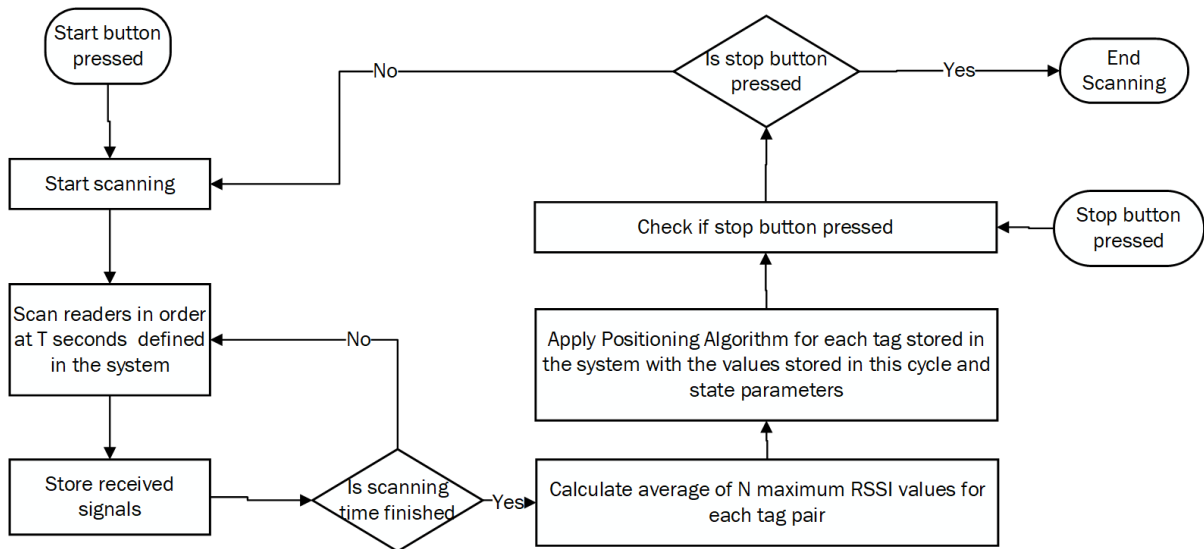


**Figure 4.7** Flow Chart of Offline Phase (Fingerprinting)

taking the average of RSS values taken from particular reader for particular tag at the reference point. So, the received RSS values sorted and top (N) values are used to take the average and the poor values are simply discarded from the fingerprint. If the amount of RSS values retrieved is less than N, all the RSS values are discarded for that reader and reference point. The resulting fingerprint database consist of average RSS value measured during offline phase, location of reference point and reader ID for each reference point and each reader. Obviously, if no signal is received from particular reader from the reference point or the amount of RSS values received are not more than or equal to N, resulting fingerprint database have no entity for that.

### 4.3.2 Online Phase

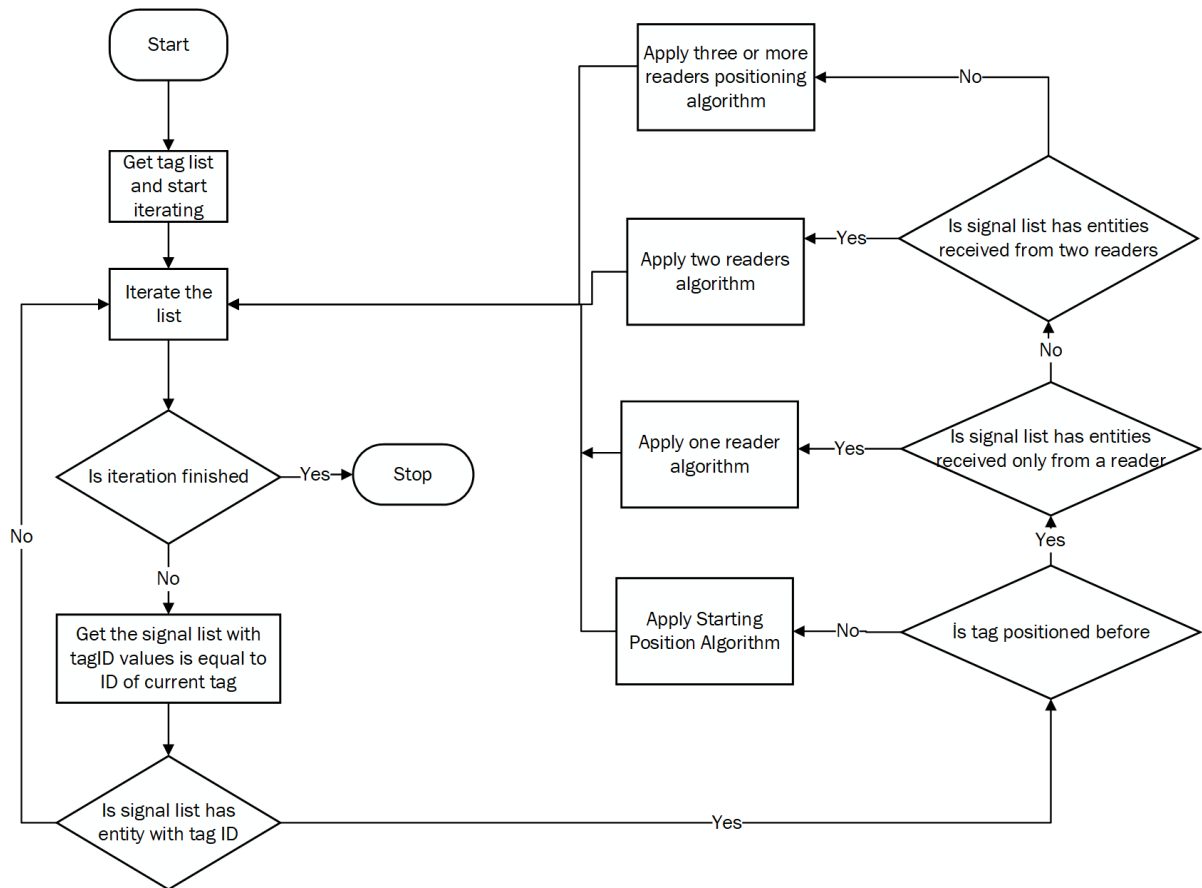
While fingerprint database is completed in offline phase, then the online phase is started. Estimating location is the main goal of the online phase. Online phase is started with the same scan



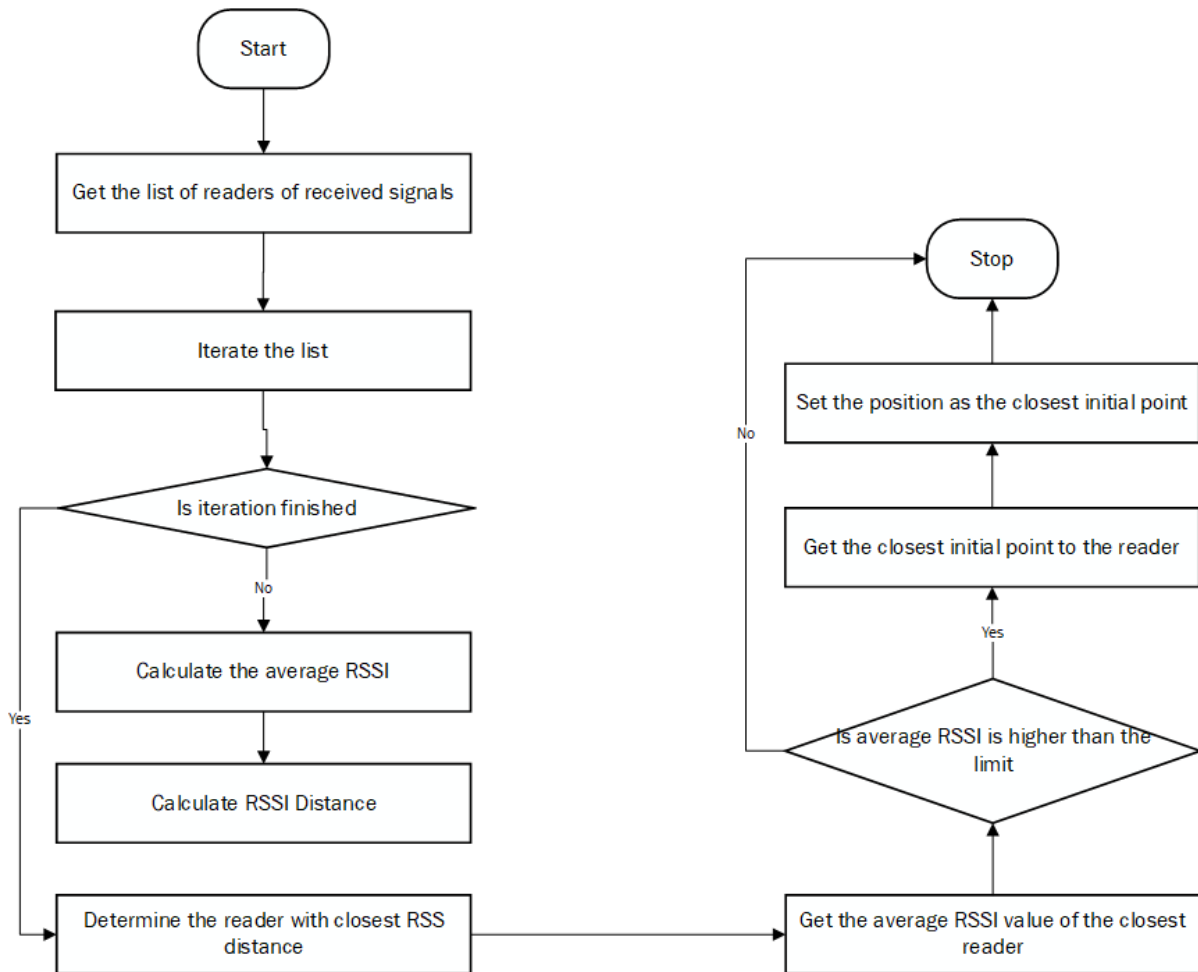
**Figure 4.8** Main Flow Chart of the System in Online Phase

time and sample rate as the offline phase. The tag is located at a place in the coverage area and waited for the system to estimate the location. The fingerprint of the target tag is extracted with completely the same method used for reference points. Since reference and target fingerprint are available, proposed matching algorithm can be applied now. The proposed algorithm is implemented based on RSS distance (Ni et al. 2003), (Xie et al. 2016) and dropped signals in the fingerprint by using java programming language. Although, edges of the reader coverage area are not clear. Still, it is possible to divide the test area in terms of coverage criteria.

**Starting Point Algorithm.** The system has starting points. If a Pedestrian with a tag is detected in the system for the first time, the system tries to estimate the position of the pedestrian in one of the starting points with previously set default speed and inwards direction. Since walking speed does not change too much with respect to pedestrian, Initial speed of the pedestrian is taken as 1.37 m/s. It is assumed that the pedestrian is 19-39 years age male with normal speed (Himann et al. 1988). 4.11, 4.12, and 4.13 shows how initial parameters are set and initial positioning estimation has done. After initial estimation has done, the speed, direction and position of the tag are known. The next estimations are done according to the amount of readers that signal is received



**Figure 4.9** Flow Chart of Decision of Which Positioning Algorithm Will Be Used



**Figure 4.10** Flow Chart of the Starting Point Algorithm

---

**Algorithm 2** Decision Algorithm if a tag already has been positioned

---

```

1: procedure ISFIRSTPOSITIONING(tag)
2:   for each tag positionedTag in PositionedTagsList do
3:     if tag == positionedTag then
4:       return false
5:     end if
6:   end for
7:   return true
8: end procedure
  
```

---

**Figure 4.11** Decision Algorithm if a tag already has been positioned

---

**Algorithm 3** Algorithm to Set the Initial State Parameters

---

```
1: procedure STARTPOSITIONING(tag)
2:   for each tag positionedTag in PositionedTagsList do
3:     if IsFirstPositioning(tag) then
4:       position = getInitialPosition(tag)
5:       direction = inwards
6:       speed = 1.37 m/s
7:     else
8:       StartPositioningAlgorithm(tag)
9:     end if
10:  end for
11: end procedure
```

---

**Figure 4.12** Algorithm to Set the Initial State Parameters

**One Reader Algorithm.** 4.14 indicates the flow chart for one reader algorithm. The uniqueness of this one reader algorithm is that the current algorithms for indoor positioning is accounting and using the RSS received by the reader, however, in this algorithm, the irrelevant points are discarded and used for position estimation. The system has only one RSSI value received from one reader or more RSSI values from the same reader. An RSSI value gives an estimated distance from the reader. In 3-D, the points with equal distance to a fixed point constitute a sphere. In 2-D, points with equal distance to a fixed point constitute a circle. Besides, coverage area is a corridor that may be assumed as a line or curve. So, the intersection points of the circle and the line (or curve) passing through the center of the corridor (possibly two points) are the possible estimations. We have used *RSS Distance* to find the estimated point from *RSSI*. Since there is only one reader, the equation 2.2 is modified as:

$$R_{(i,t)} = |RSSI_i - RSSI_t| \quad (4.1)$$

where  $R_{(i,t)}$  is the RSSI distance of  $i$ th reference point,  $RSSI_i$  denotes the average RSSI value of  $i$ th reference point from the particular reader,  $RSSI_t$  is the average of the measured RSSI values. If there is no RSSI value stored for the particular reader in fingerprint database, RSS

---

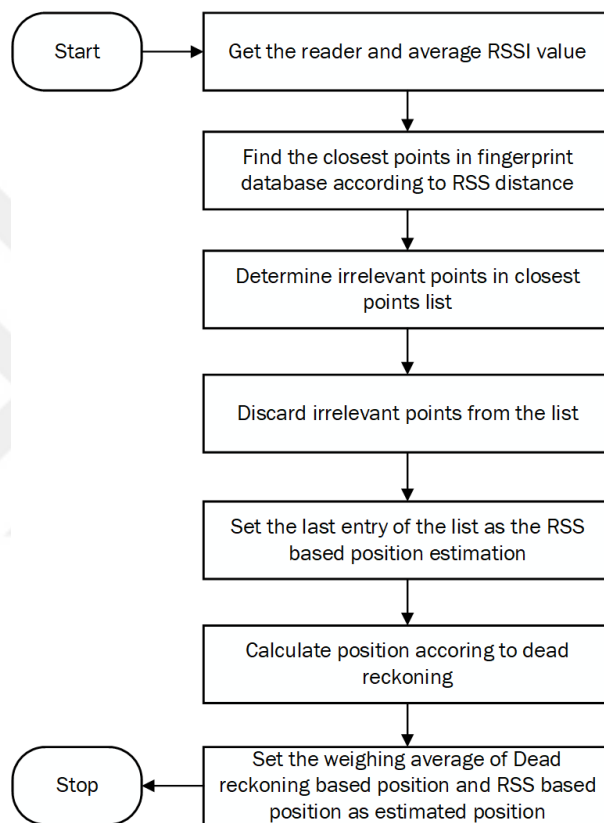
**Algorithm 4** Algorithm to Set the Initial Position

---

```
1: procedure GETINITIALPOSITION(tag)
2:   distance = MAX;
3:   Reader = null;
4:   RSSIval = null;
5:   for each RSSI RSSI in ReceivedRSSISignalList do
6:     if distance is less than getDistanceFromRSSI(RSSI.Reader, RSSI) then
7:       distance = RSSIDistance
8:       Reader = RSSI.Reader
9:       RSSIval = RSSI
10:    end if
11:  end for
12:  if RSSIval is greater than LIMIT then
13:    position = getClosestInitialPoint(Reader) ▷ Closest initial point to the reader
14:    return position
15:  end if
16: end procedure
```

---

**Figure 4.13** Algorithm to Set the Initial Position



**Figure 4.14** Flow Chart of One Reader Algorithm

---

**Algorithm 5** Positioning Algorithm by Using RSSI from One Reader

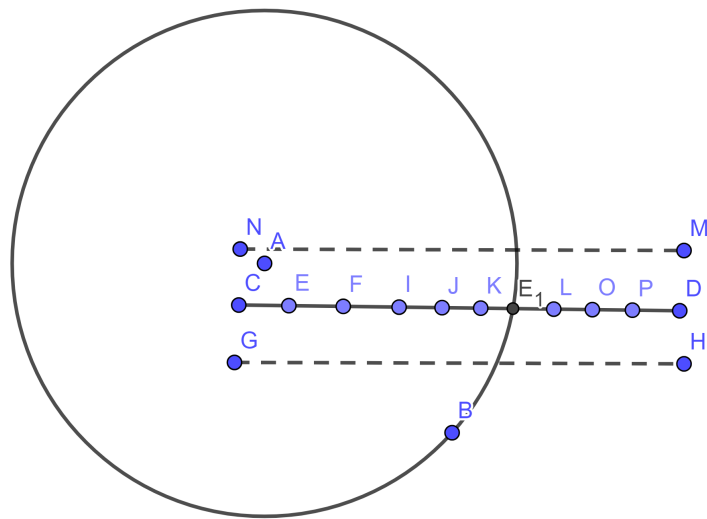
---

```
1: procedure RSSBASEDPOSITIONESTIMATION( $RSSI_m, Reader$ )
2:    $List$  = new empty list
3:    $intersectioncount$  =  $getIntersectionCount(RSSI, Reader)$ 
4:   for each RSSI  $RSSI_i$  in  $FingerPrint(Reader)$  do
5:      $distance$  =  $|RSSI_i - RSS_m|$ 
6:     add  $distance$  to  $List$ 
7:   end for
8:    $IntersectionPoints$  = points of top  $intersectioncount$  element of  $List$  sorted ascending
9:   for each  $point$  in  $IntersectionPoints$  do
10:    if  $point$  is in range of another reader then
11:      remove  $point$  from  $IntersectionPoints$ 
12:    end if
13:  end for
14:  return top  $intersectioncount$  element of  $IntersectionPoints$ 
15: end procedure
```

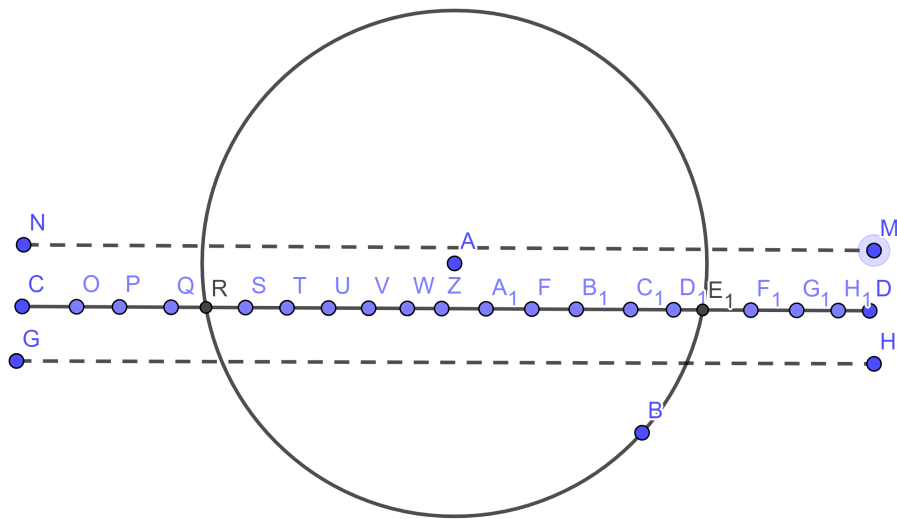
---

**Figure 4.15** Positioning Algorithm by Using RSSI from One Reader

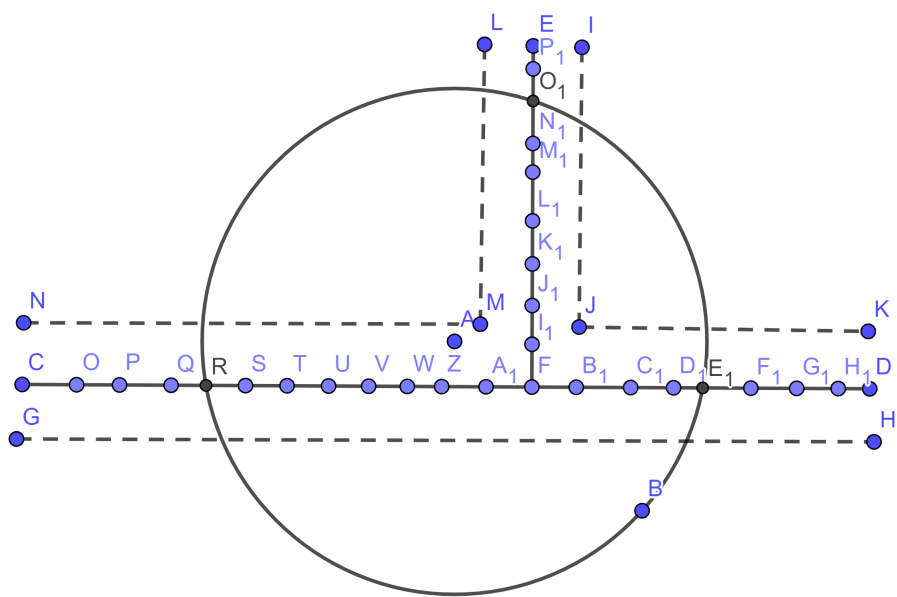
Distance is not calculated and this reference point simply out of consideration. The reference points which have the minimum RSS distance are possible estimated positions based on RSS information. Local minimum points of  $R_{(i,t)} = |RSSI_i - RSSI_t|$  function are taken as possible estimated positions. Local minimum point of discrete function is defined as the point which the function have lower values than the adjacent points. When environmental effects are ignored, minimum RSS distance points constitute a circle centered at the reader. So, local minimum points of the function are found at the intersection points of circle and the reference point list. As shown in Figures 4.17, 4.16 and 4.18 there may be one, two or three possible intersection points between reference point list and the circle. If one of the intersection points are in the range of another reader, then it is discarded from estimations list and remaining intersection point(s) is taken into account. The design of the system should be done properly such that



**Figure 4.16** An Example Illustration of Reference Point List and Circle Intersection at One Point



**Figure 4.17** An Example Illustration of Reference Point List and Circle Intersection at Two Points



**Figure 4.18** An Example Illustration of Reference Point List and Circle Intersection at Three Points

---

**Algorithm 6** Positioning Algorithm by Using Dead Reckoning

---

```
1: procedure GETPOSITIONBYDEADRECKONIG(initialposition,speed,direction,time)
2:   distance = speed  $\times$  time                                 $\triangleright$  estimated distance that target proceeded
3:   position = getPositionReferenceList(initialposition,direction,distance)
4:   return position
5: end procedure
```

---

**Figure 4.19** Positioning Algorithm by Using Dead Reckoning

the count of remaining intersection points should be only 1. Moreover, the speed, direction and the position at  $t$  seconds before are known. The position is estimated with respect to dead reckoning by the following formula:

$$(x, y)_{dr} = (x, y)_{prev} + speed \times time \quad (4.2)$$

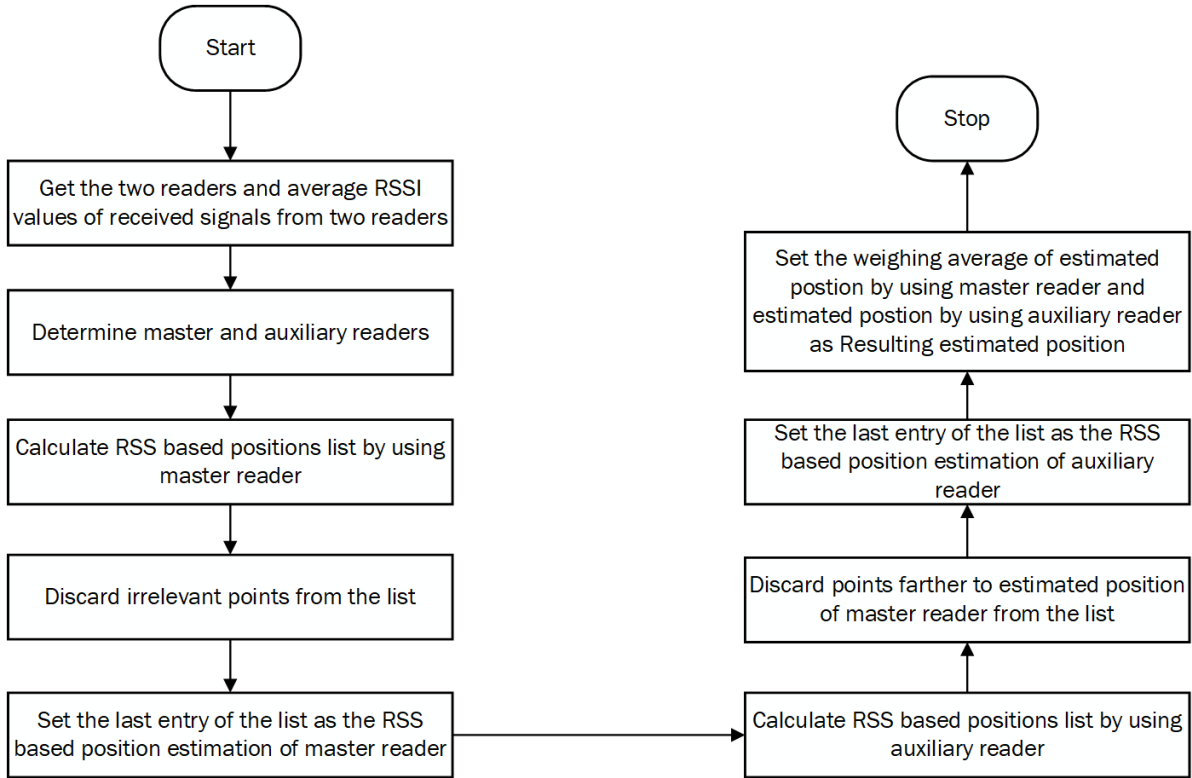
where  $(x, y)_{prev}$  denotes the last estimated position,  $speed$  denotes speed of the pedestrian as calculated before and  $time$  denotes the time difference between the current estimation and previous estimation. This formula is not scalar since target is not moving linearly in proposed system architecture. The distance is applied according to the possible path of the target. The position is estimated by the following formula:

$$(x, y)_{est} = C_{rssi} \times (x, y)_{rssi} + C_{dr} \times (x, y)_{dr} \quad (4.3)$$

$$C_{rssi} + C_{dr} = 1 \quad (4.4)$$

where  $(x, y)_{est}$  denotes the estimated position,  $(x, y)_{rssi}$  denotes the position extracted from RSSI information according to the algorithm 4.15,  $(x, y)_{dr}$  denotes the position calculated by using dead reckoning.  $C_{rssi}$  and  $C_{dr}$  are the weighting coefficients that are tuned by experiments.

**Two Readers Algorithm.** The system has RSSI values received from two readers. As described above, an RSSI value gives an estimated distance from the reader. In 2-D points with equal distance to a fixed point constitutes a circle. Since we have two readers, two circles are



**Figure 4.20** Flow Chart of Two Readers Algorithm

needed to consider. A similar algorithm for one reader can be applied for two reader cases. First, the two RSSI values are compared. The reader with highest value RSSI has chosen as *Master* reader. The remaining reader is called *Auxiliary*. Since it is assumed to be the closest one. Thus, RSSI values from closest reader are more reliable. One reader algorithm is applied to *Master* reader with a change in choosing intersection point. The intersection points which are out of the range of the *Auxiliary* reader are discarded. As described in one reader algorithm, the design of the system should be done properly such that the count of remaining intersection points should be only 1. Next, One reader algorithm is applied to *Auxiliary* reader with a change in choosing intersection point. The intersection point which is close to the selected intersection point of *Master* reader is the selected intersection point of *Auxiliary* reader.

$$(x, y)_{est} = C_{master} \times (x, y)_{master} + C_{aux} \times (x, y)_{aux} \quad (4.5)$$

$$C_{master} + C_{aux} = 1 \quad (4.6)$$

where  $(x, y)_{est}$  denotes the estimated position,  $(x, y)_{master}$  denotes the position extracted from RSSI information of *Master* reader,  $(x, y)_{aux}$  denotes the position extracted from RSSI information of *Auxiliary* reader.  $C_{master}$  and  $C_{aux}$  are the weighting coefficients that are tuned by experiments.

**Three or More Readers Algorithm.** When the system has RSSI values received from three or more readers, an enhanced weighted k-nearest neighbour algorithm is applied. The flow chart of the algorithm is shown in 4.21.

An RSS fingerprint of a point (target or reference) consists of entries with reader ID and the average of (N) number of selected maximum RSS observations. While matching two fingerprints, RSS values related with the same reader IDs should be matched. However, a particular RSS value in a fingerprint may not match with the comparing fingerprint since it does not have an RSS value with the same reader ID. In such cases, simply drop the RSS values from matching fingerprint. The amount of dropped signals from target fingerprint is denoted as  $T(i, t)$  while matching  $i$ th reference point and target  $t$ . Similarly, the amount of dropped signals from reference fingerprint is denoted as  $F(i, t)$  while matching  $i$ th reference point and target  $t$ . These values are taken into account while estimation the location.

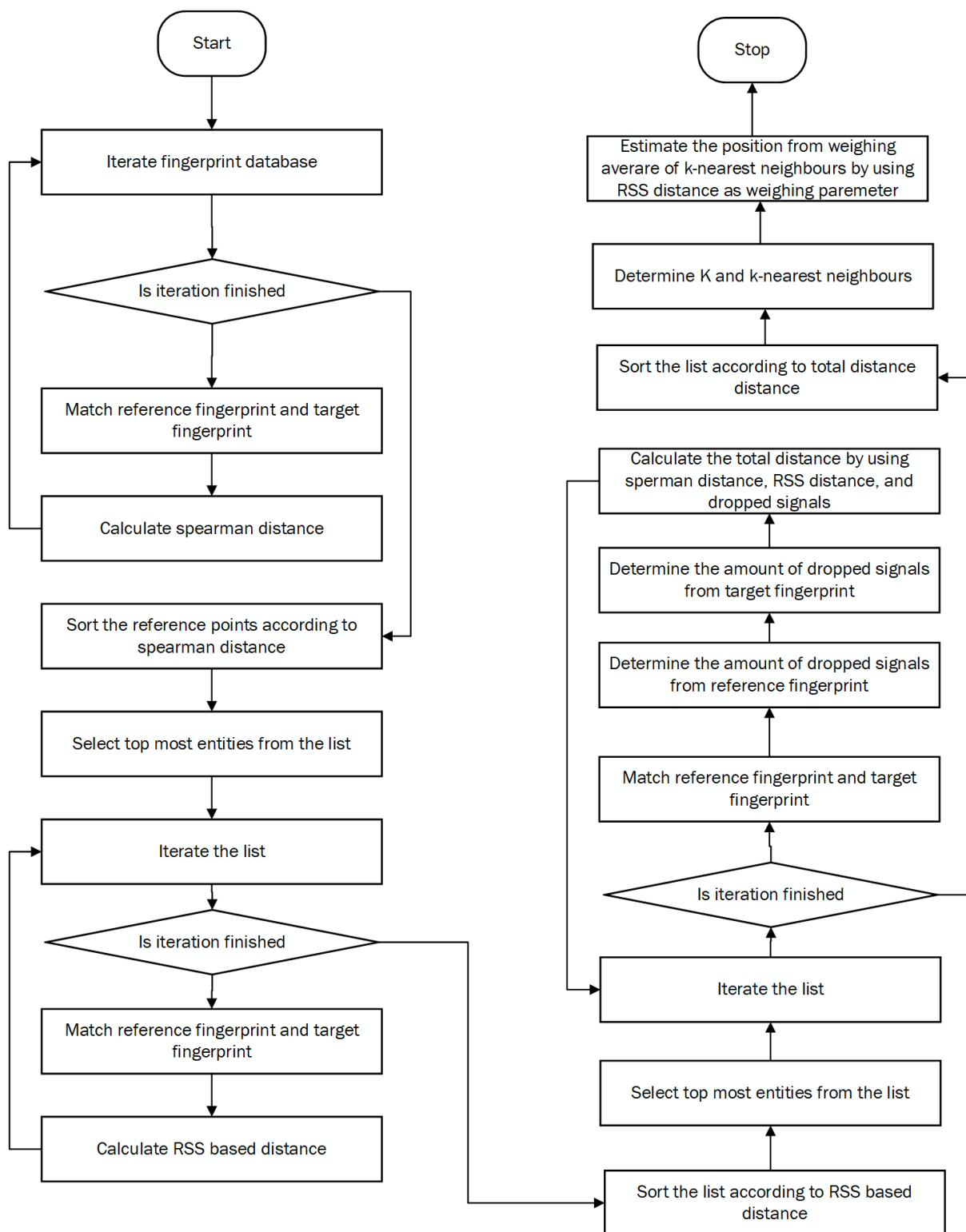
Using *Spearman distance* in fingerprint based localization algorithms is offered at (Xie et al. 2016) and explained in detail. It evaluates the similarity of two point based on rankings of RSS values received from different readers assuming that RSS values decreases monotonically as the distance between reader and tag increases. The *Spearman distance* is defined by the following formulas:

$$S_{(i,t)} = 1 - \frac{6 \times (\sum_{i=1}^N d_i^2 + c)}{n \times (n^2 - 1)} \quad (4.7)$$

$$d_i = order_{ti} - order_{ri} \quad (4.8)$$

$$c = \sum \#ofties \frac{m(m^2 - 1)}{12} \quad (4.9)$$

where  $S_{(i,t)}$  is the *Spearman distance*,  $order_{ti}$  is the order of the RSSI value of the  $i$ th reader in the fingerprint of the target,  $order_{ri}$  is the order of the RSSI value of the  $i$ th reader in the



**Figure 4.21** Flow Chart of Three or More Readers Algorithm

fingerprint of the reference. When two or more RSSI values are the same in a finger print, the order of the tied entries are the average of the orders. So, a correction factor  $c$  should be added to equation.

The *RSSI distance* between target fingerprint and reference fingerprint is defines as follows:

$$R_{(i,t)} = \sqrt{\sum_{n=1}^N (RSSI_{in} - RSSI_{tn})^2} \quad (4.10)$$

where  $R_{(i,t)}$  represents the RSSI distance,  $RSSI_{in}$  denotes the RSSI value of  $i$ th reference point from the  $n$ th reader,  $RSSI_{tn}$  denotes the RSS value of target point from the  $n$ th reader, and  $N$  represents number of entries in the matching fingerprint.

The resulting rank of the  $i$ th reference point with respect to the target is calculated as:

$$M_{(i,t)} = w_s \times S_{(i,t)} + w_f \times F_{(i,t)} + w_t \times T_{(i,t)} + w_r \times R_{(i,t)} \quad (4.11)$$

where  $M_{(i,t)}$  is the resulting ranking value of the  $i$ th reference point with respect to target  $t$ ,  $S_{(i,t)}$  is the spearman rank of the  $i$ th reference point with respect to target  $t$ ,  $F_{i,t}$  is the amount of dropped signals from  $i$ th reference fingerprint with respect to target  $t$ ,  $T_{(i,t)}$  is the amount of dropped signals from  $i$ th target fingerprint with respect to  $i$ th reference fingerprint,  $R_{(i,t)}$  is the RSSI distance of the  $i$ th reference point from target  $t$ .  $w_s, w_f, w_t, w_r$  are the weighing parameter experimentally tuned according to improvements of the results.

$M_{(i,t)}$  is calculated for all reference points for a target fingerprint  $t$ . Reference points are sorted according to  $M_{(i,t)}$ . Reference points with Smallest  $M_{(i,t)}$  values are assumed to be the nearest neighbours of target  $t$ .  $K$  nearest neighbours are selected to calculate the location. Choosing  $K$  is done as shown below as described in (Thirumuruganathan 2010).

$$K = \sqrt{n} \quad (4.12)$$

we have chosen  $k$  nearest neighbours. Since  $k$  nearest neighbours are selected, WkNN method is used to determine the location of the target.

$$(x, y)_t = \frac{1}{\sum_{i=1}^k \frac{1}{R_{(i,t)}^2}} \times \sum_{i=1}^k \frac{1}{R_{(i,t)}^2} (x_i, y_i) \quad (4.13)$$

where  $(x, y)_t$  denotes the estimated position of target,  $x_i, y_i$  denotes the actual position of the  $i$ th closest with respect to *RSSI distance* reference point,  $k$  denotes the how many nearest

---

**Algorithm 7** Algorithm for Updating State Parameters

---

1: **procedure** UPDATESTATEPARAMETERS

2:      $distance = getDistance(P_n, P_{n-1})$    ▷ distance is not the closest distance, distance is the distance through reference points.

3:      $direction = sign(getDistance(P_n, P_{n-1}))$

4: **end procedure**

---

**Figure 4.22** Algorithm for Updating State Parameters

neighbours will be taken into account and is set before algorithm works,  $R_{(i,t)}$  denotes the *RSSI distance* as defined above.

This algorithm is an improved version of WkNN algorithm. Choosing nearest neighbours are done not only *RSSI distance* but also *Spearman distance*, the amount of dropped signals from target fingerprint and The amount of dropped signals from reference fingerprint. Besides, weighting nearest neighbours method is the same with WkNN method.

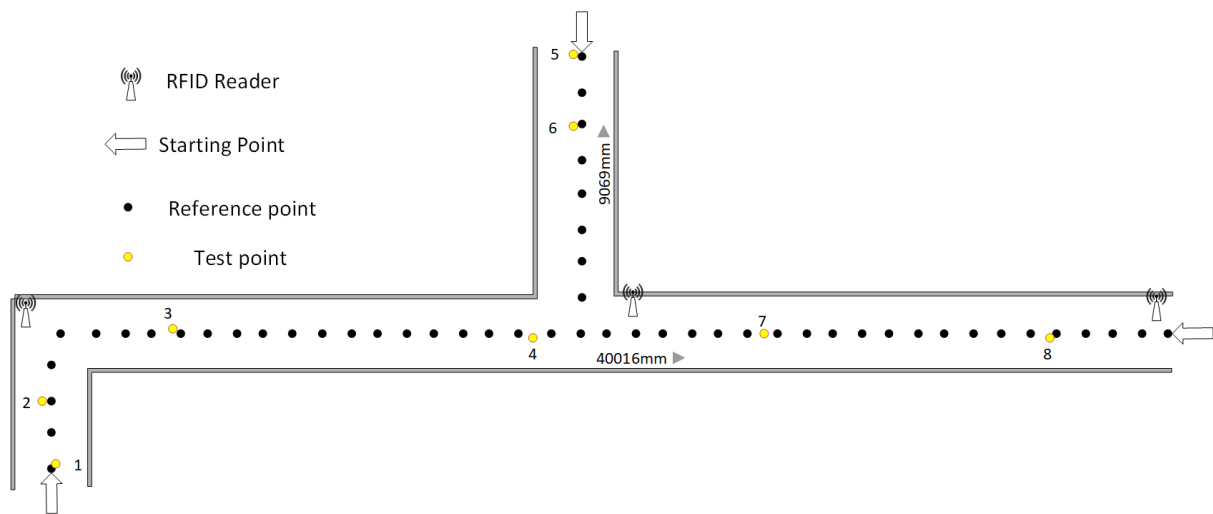
**Updating State Parameters.** Dead reckoning is a part of the proposed solution. So, speed, direction and position of the tag are the state parameters. Each parameter is updated after estimating the position. Position is updated as stated above. Speed is updated by calculating the distance of the current position and previous position divided by the time elapsed. Direction is updated according to the sign of the result.

## 5. EXPERIMENTAL RESULTS

The proposed system with the hybrid algorithm is tested, developed and updated in a real environment. The results, accuracy and the performance of the system is discussed in this chapter. Positioning accuracy of the proposed system is evaluated based on the experimental results. The test environment has been prepared on on the basement floor of the Yıldız Technical University Technopolis building. Also, another test environment has been prepared on the closed parking area to test the 4 or more reader. Figure 4.1 shows the floor plan of experimental site. The system parameter  $X = 2$ ,  $T = 12s$  and  $P = 400ms$  are set during the experiments. 8 test point has been used for testing the accuracy of the system hoping that each two points will have processed in different positioning algorithm. Points are shown in Figure 5.1. The system has a stateful process. Thus, at every experiment it is waited the system to be in steady state that makes up to 5 positioning estimation cycle, especially for the test points around the center reference points. On the other hand, at starting points there is no need to wait a long time. At each test point, the position of free tag is calculated three times at least. The Error distance between the estimated position and the actual test point is determined by using classical Euclidean distance:

$$Error = \sqrt{(x_t - x_e)^2 + (y_t - y_e)^2} \quad (5.1)$$

where  $(x_t, y_t)$  is the test point coordinates and  $(x_e, y_e)$  is the estimated point coordinates of the proposed system. During the experiments coefficients are fine tuned and best results are gained with  $C_{rssi} = 0,8$  and  $C_{dr} = 0,2$  in one reader algorithm,  $C_{master} = 0,7$  and  $C_{aux} = 0,3$  in two readers algorithm and  $w_s = 0,25$ ,  $w_f = 0,15$ ,  $w_t = 0,10$  and  $w_r = 0,50$  in three or more readers algorithm. The system is tested three times for each of the test point. Table 5.1 shows the results of the experiment with errors in meters for the proposed hybrid algorithm. By using the same test points and the same measurement result, also WkNN method has been



**Figure 5.1** 8 Test Point Used in Experiments at Proposed System Architecture #1

Test Point	Test 1 Error	Test 2 Error	Test 3 Error	Average Error
Test Point 1	0.45	0.45	0.45	0.45
Test Point 2	2.21	2.87	3.43	2,83
Test Point 3	2.51	3.08	2.05	2,54
Test Point 4	4.49	2.20	2.71	3,13
Test Point 5	0.75	0.75	0.75	0,75
Test Point 6	3.37	3.05	3.76	3,39
Test Point 7	2.82	2.97	2.16	2,31
Test Point 8	3.57	4.85	5.90	4,77

**Table 5.1** Table of Error Distances in Meters of Experiment of Proposed Hybrid Algorithm

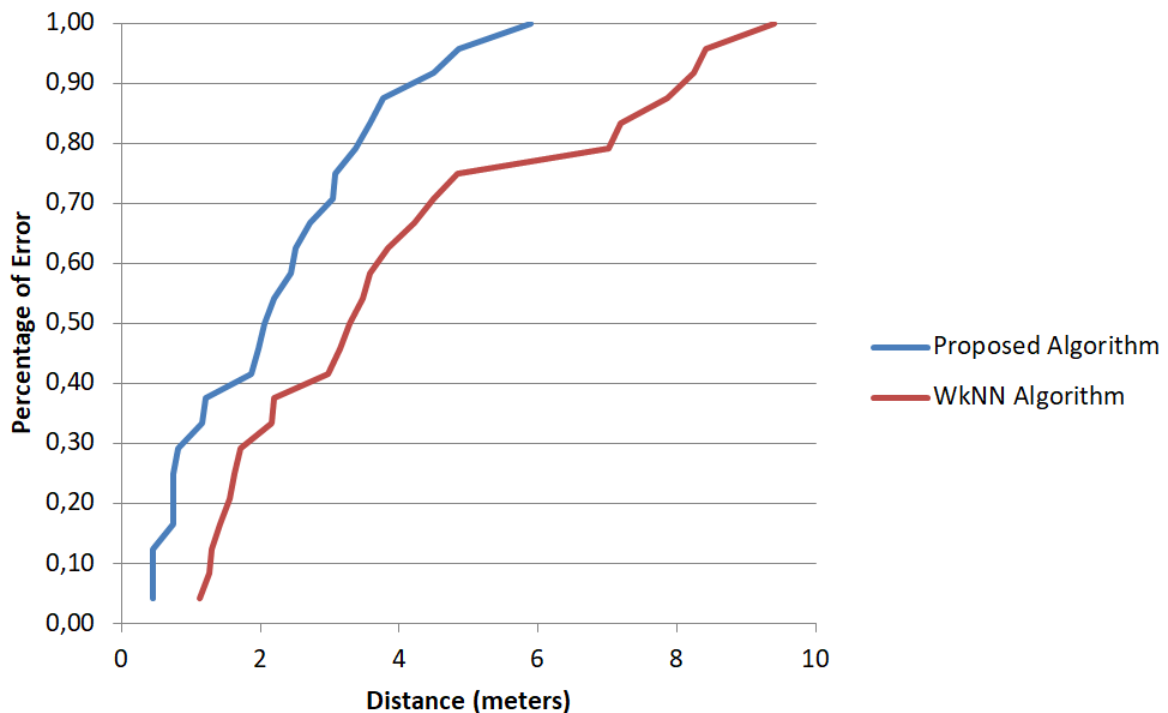
Test Point	Test 1 Error	Test 2 Error	Test 3 Error	Average Error
Test Point 1	1.29	1.13	1.62	1.34
Test Point 2	7.87	9.41	8.25	8,51
Test Point 3	3.83	1.72	2.20	2,58
Test Point 4	4.49	3.47	3.14	3,73
Test Point 5	1.42	1.27	1.55	1,41
Test Point 6	8.41	7.19	7.01	7,53
Test Point 7	3.29	2.97	2.16	2,80
Test Point 8	3.57	4.21	4.84	4,20

**Table 5.2** Table of Error Distances in Meters of Experiment of Weighted kNN Algorithm

used to calculate the position. The Table 5.2 shows the results of the experiment with errors in meters for the WkNN algorithm. The proposed system results in comparable accuracy with approximately 2,5 m average positioning error. In order to show the accuracy of the proposed system, the cumulative distribution function (CDF) of the positioning errors calculated for the 24 measurements of the experiment is used. Figure 5.2 shows the CDF. Y axis of the CDF is the percent of results taken from 24 measurements which is less than or equal to X axis. As seen from the CDF %50 of the results are less than 2.5 m that means average accuracy of the system is 2.5m. However average accuracy of the WkNN algorithm is 3.3 m.

As it can be seen from the results above, proposed hybrid algorithm is compared with WkNN algorithm. Since proposed system has stateful algorithm and proposed architecture has less readers as compared to other system, state information is used to decrease the error and proposed algorithm gives more accurate results than the widely used fingerprinting algorithm, WkNN. At Starting point algorithm, since pedestrian is assumed to be in front of the starting point, proposed algorithm is specialized based on the assumption so that it gives more accurate results than the WkNN algorithm. At one reader algorithm and two readers algorithm, number of readers are not enough to acquire accurate results from the WkNN algorithm. However, proposed algorithm uses state information to get more accurate results. At three or more readers

## Cumulative Distribution Function



**Figure 5.2** Cumulative Distribution Function of Error Measured in Experiments

algorithm, proposed system takes Spearman distance, RSSI distance and the dropped signals are into account. On the other hand, WkNN algorithm uses only RSSI distance into account. That's why, proposed system gives slightly more accurate results.

Proposed system architecture can be defined as one dimensional field since pedestrian is walking on a line (or curve). This brings additional assumptions on the two or three dimensional positioning algorithms. By using additional assumptions and some improvement on WkNN algorithm, designing more accurate positioning systems can be possible. In this proposed system architecture, the assumptions had been implemented successfully. This work shows by using additional assumptions it is possible to get more accurate positioning results with using less readers.

There are similar studies using various type of infrastructure, technology, algorithm with differ-

ent results. For instance, it was used similar coverage area, at least 7 APs and wi-fi technology to get 2.1 m accuracy in one of the study (Shin et al. 2012). In this study, proposed algorithm needs only 3 readers with similar coverage area and has comparable accuracy 2.5 m. In another study, it was used slightly bigger coverage area, total of 14 APs and wi-fi technology to get 2.19 m accuracy (Jekabsons, Kairish, and Zuravlyov 2011). Again, proposed algorithm is cost effective solution as compared to (Shin et al. 2012) and (Jekabsons, Kairish, and Zuravlyov 2011) with similar accuracy guaranteed in our study. Finally, 8 Wi-Fi APs is used by (Gholoobi and Stavrou 2015) at slightly bigger coverage area. The resulting accuracy of the system is 1.9 m. As seen from the above studies, more readers (APs) is needed to get similar accuracy performance with respect to our proposed system, infrastructure and algorithm. In this study, we used less reader density to get comparable accuracy performance by using RFID technology with a unique algorithm and performance-oriented infrastructure.

As seen from the above works, more Readers (APs) is needed to get similar accuracy performance. In this work, we had used less reader density to get comparable accuracy performance.

## 5.1 Tuning Parameters

The parameters used in the system are discussed in this section. The accuracy experiments are calculated based on the conclusions of this section. As it is mentioned before, scanning period (P), scanning time (T) and the amount (N) of maximum number of values while calculating the average of RSSI values are used in the system. The effect of these parameters should be analyzed and tuned in order to get better accuracy performance from the system. In order to tune the parameters better, five measurements are achieved with the same parameters and calculate the variance of results. The variance is calculated as follows:

$$V = \frac{1}{5} \sum_{i=1}^5 (RSSI_i - RSSI_{avg})^2 \quad (5.2)$$

$$RSSI_{avg} = \frac{1}{5} \sum_{i=1}^5 RSSI_i \quad (5.3)$$

where  $RSSI_i$  denotes the average RSSI value measured at  $i$ th measurements. Tests are accomplished at the Proposed System Architecture #2 in Figure 4.1.

Reader	T=1s	T=2s	T=3s	T=5s	T=10s	T=20s	T=30s	T=50s
180181	-	-	-	-	-	-	0	0
180192	-	-	-	-	0	0	0	0
180165	-	-	-	-	-	-	-	-
180177	-	-	-	-	0.04	0	0	0
180173	-	-	-	-	-	-	-	-
180196	-	-	-	-	0.04	0	0.04	0.04
180199	-	-	-	-	0	0.06	0.06	0.06
180180	-	-	-	-	0.16	0.16	0.20	0.16
180170	-	-	-	-	-	-	-	-

**Table 5.3** Table of Standard Deviation with Varying Value of (T) Scanning Time

**Scanning Time (T).** It is clear that as scanning time increases the positioning accuracy increases. However, positioning algorithm is intended to work in real-time. Thus, scanning time should be as less as possible in order the system work in real-time. Besides, the target may change the location during the scanning time which causes mis-localization. The system is tested with the following values: T=1s, T=2s, T=3s, T=5s, T=10s, T=20s, T=30s, T=50s. P=300ms and X=2 is set and remained same in all tests. Results of the experiment is shown in Table 5.3. It is clear that all the reader should be scanned in the system during scanning time. Since we have used 10 readers in proposed system case 2, scanning time should be at least ten times more than the scanning period. So, scanning times less than this value does not give average and deviation parameters.

**Scanning Period (P).** Scanning period is the time in between the sending read requests of two adjacent readers. Scanning time should be long enough to read the tags in the environment without any data loss, and should be as short as possible since real time processing is needed. Lower P values causes electromagnetic interference in the environment and data loss through the serial communication cable. The system is tested with the following values: P=10ms, P=20ms, P=30ms, P=50ms, P=100ms, P=200ms, P=300ms, P=500ms, P=1000ms, P=2000ms. T=20s and X=2 is set and remained same in all tests. Results of the experiment is shown in Table 5.4.

Reader	P=10ms	P=50ms	P=100s	P=200s	P=300s	P=500ms	P=1000ms	P=2000ms
180181	-	-	-	-	-	-	0	0
180192	-	-	-	-	0	0	0	0
180165	-	-	-	-	-	-	-	-
180177	-	-	-	-	0.04	0	0	0
180173	-	-	-	-	-	-	-	-
180196	-	-	-	-	0.04	0	0.04	0.04
180199	-	-	-	-	0	0.06	0.06	0.06
180180	-	-	-	-	0.16	0.16	0.20	0.16
180170	-	-	-	-	-	-	-	-

**Table 5.4** Table of Standard Deviation with Varying Value of (P) Scanning Period

**The Amount (N) of Maximum values for Calculating Average RSSI.** As we have mentioned before average of RSSI values are used for calculating position. According to (Xue et al. 2017) a number (N) of selected maximum RSS observations should be taken into account while taking the average of RSS values taken from particular reader for particular tag. Optimum N should be determined for our proposed system. The system is tested with the following values: N=1, N=2, N=3, N=4, N=5, N=6, N=8, N=10. T=20s and P=300ms is set and remained same in all tests. Results of the experiment is shown in Table 5.5. As seen from the tables above when T is increased after 20s, P is increased after 300ms and X is increased after 2 variance is not changed significantly. So, T=20s, P=300ms, and N=2 selections are reasonable choices. All the test during accuracy measurements are done with these parameters. Since 3 readers are used in Proposed System Architecture #1, T=6s, P=300ms, and N=2 selections can be used for this system.

Reader	N=1	N=2	N=3	N=4	N=5	N=6	N=8	N=10
180181	0	0	-	-	-	-	-	-
180192	0	0	-	-	-	-	-	-
180165	0.04	0.04	-	-	-	-	-	-
180177	0.04	0.04	-	-	-	-	-	-
180173	-	-	-	-	-	-	-	-
180196	0.04	0.04	-	-	-	-	-	-
180199	0.06	0.06	-	-	-	-	-	-
180180	0.16	0.16	-	-	-	-	-	-
180170	-	-	-	-	-	-	-	-

**Table 5.5** Table of Standard Deviation with Varying Value of (N) The Amount of Maximum Values of RSSI

## 6. CONCLUSION AND FURTHER RECOMMENDATIONS

A summary of implemented system and performance of the proposed indoor positioning algorithm is provided in this chapter. After All, we have provided a conclusion about the study and further recommendations for future improvements.

### 6.1 Conclusion

The cases of indoor positioning systems based on literature study are explored in this thesis. Variations of fingerprinting techniques are used most frequently for the proposed system. Although unsteady RSS signals have drawbacks, this thesis has used fingerprinting method. Multipath effects, obstructions, body effect, fading are the main causes of unsteady RSS signals. However, for indoor environments this method succeeds high accuracy for localization. Because, fingerprinting does not need extra infrastructure. Quick deployment, easiness of applying and cost-effectiveness are advantages of the technology. Positioning algorithm used is the important key element of RFID fingerprint-based indoor localization. By using less readers indoor positioning with reasonable accuracy is achieved with improvements in fingerprinting methods and with the help of auxiliary methods.

Proposed hybrid algorithm is compared with WkNN algorithm. Since proposed system has stateful algorithm and proposed architecture has less readers as compared to other system, state information is used to decrease the error and proposed algorithm gives more accurate results than the widely used fingerprinting algorithm, WkNN. All cases are studied in detail and in each case state information and/or any other assumptions that fully fit the case are used to increase the accuracy.

Proposed system architecture can be defined as one dimensional field since pedestrian is walking on a line (or curve). This brings additional assumptions on the two or three dimensional positioning algorithms. By using additional assumptions and some improvement on WkNN algorithm, designing more accurate positioning systems can be possible. In this proposed system architecture, the assumptions had been implemented successfully. This work shows by using additional assumptions it is possible to get more accurate positioning results with using less readers.

As shown in the experimental results, proposed algorithm has higher accuracy than the widely used WkNN algorithm. Providing more information about the infrastructure of the system installed gave advantage to the proposed algorithm to increase the accuracy. Although, the proposed system is not so scalable. Still, proposed algorithm has many implementation areas.

## **6.2 Further Recommendations**

Recommendations are made in this section to improve the proposed system to have more accurate indoor positioning systems and to make the system better work in real time by increasing the speed of the system.

- The RSS quality of the RFID devices are mainly based on the vendor. To some extend, Accuracy of the system may be increased by using better RFID devices.
- The system parameters are fine tuned with manual experimental work. The system may auto configure the parameters for getting the best accuracy.
- Since RSS based systems are prone to error, Ultra wide band technology may be used for centimeter level accuracy.

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## APPENDIX A: INTERFACE OF THE SOFTWARE

Figure 6.1 Data Terminal Status Menu shows the status of the data terminal. Data terminal can be connected to server or not.

Figure 6.2 Reader Status Menu shows the status of the reader. The communication between the server and the reader may be active or passive.

Figure 6.3 Add layer menu is used to import layer to the software that is stored locally. layer files should be in shp file format.

Figure 6.4 shows the Main menu with GIS interface. Base map, the location of the pedestrian in real time, the location of the readers and the location of the reference points can be seen from the Main Menu.

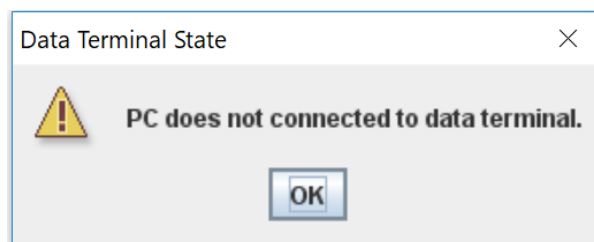
Figure 6.5 Signal Map menu is used to create the fingerprint database. All the fingerprint measurements are done manually and inserted to signal map database one by one.

Figure 6.6 Add Employee and Tag Menu is used to add an employee and tag together to the system. Each employee corresponds to a tag and vice versa.

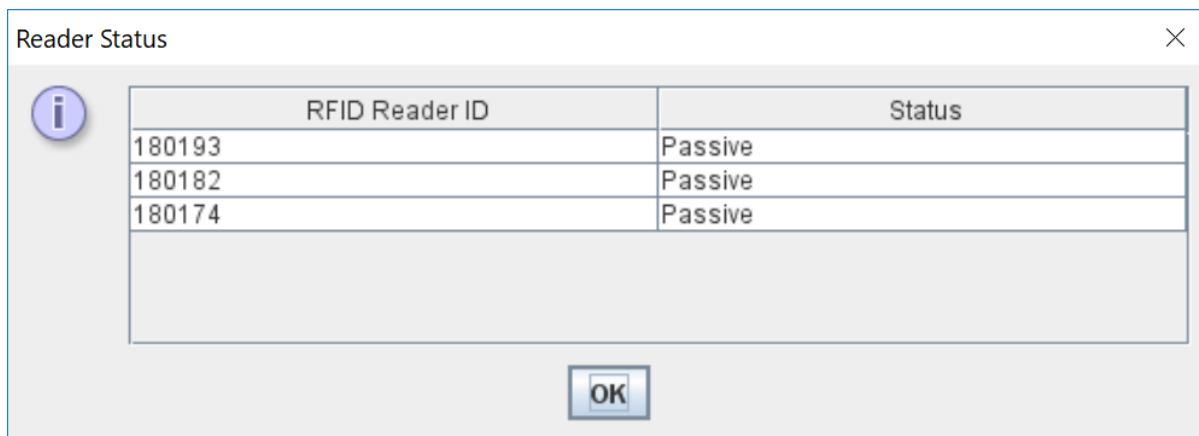
Figure 6.7 Add Machine and Tag Menu is used to add a machine and tag together to the system. Each machine corresponds to a tag and vice versa. Although, this thesis focused on pedestrian tracking. Software is ready to track machines also. Especially machines in underground mines are focused.

Figure 6.8 Daily Report Menu is used to get the daily report of employees stored in the system. entry and exit times of employees can help the employer. This Menu provides capability to the system as employee attendance control system. Date specific reports can be generated from this menu. Besides, software has capability to export this report to excel file.

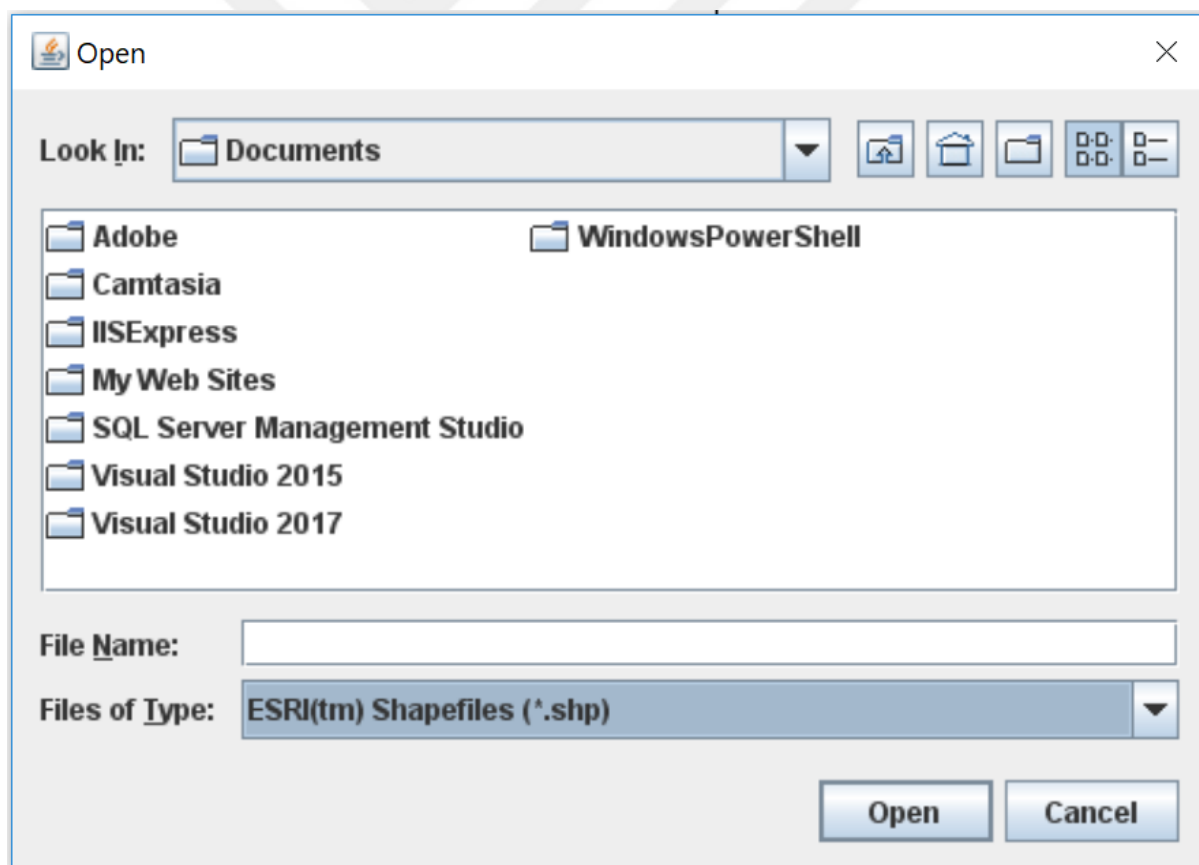
Figure 6.9 Staff Report Menu is used to get the report of particular employees stored in the



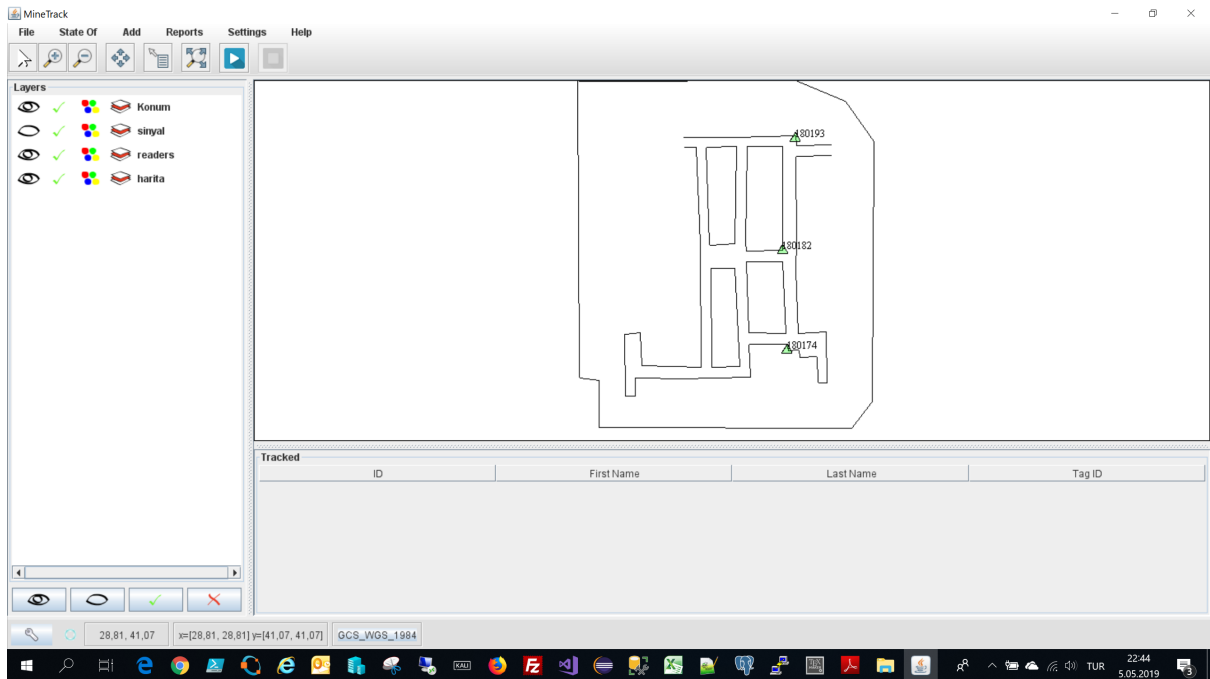
**Figure 6.1** Software Interface: Data Terminal Status Menu



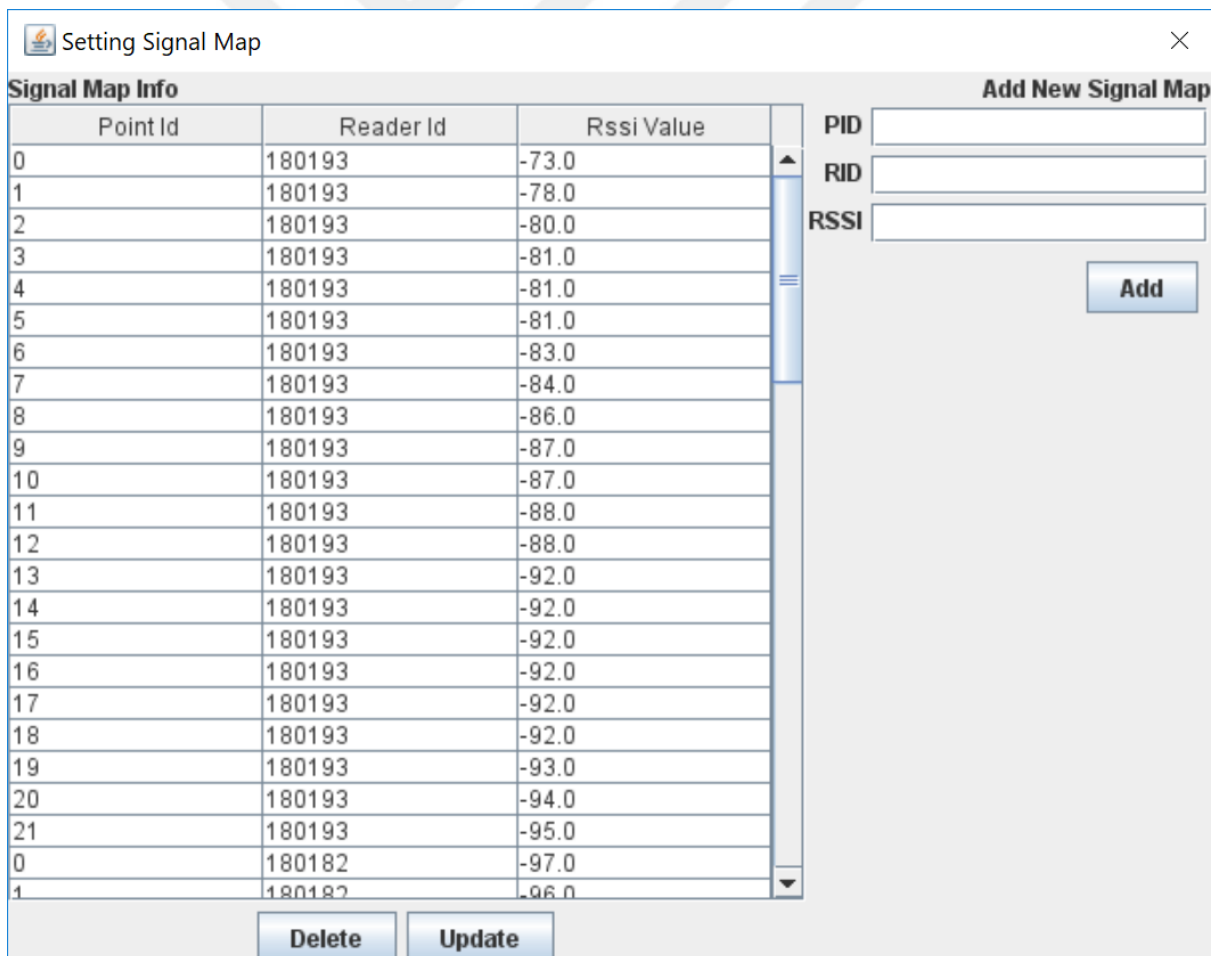
**Figure 6.2** Software Interface: Reader Status Menu



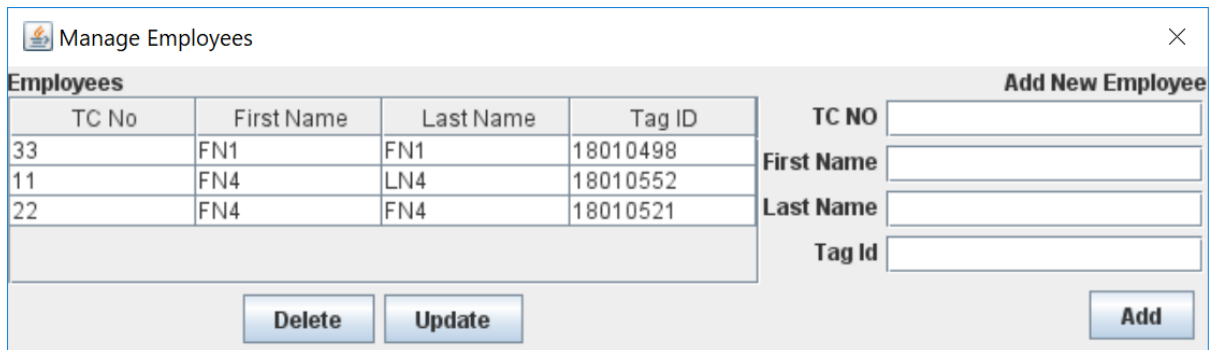
**Figure 6.3** Software Interface: Add Layer Menu



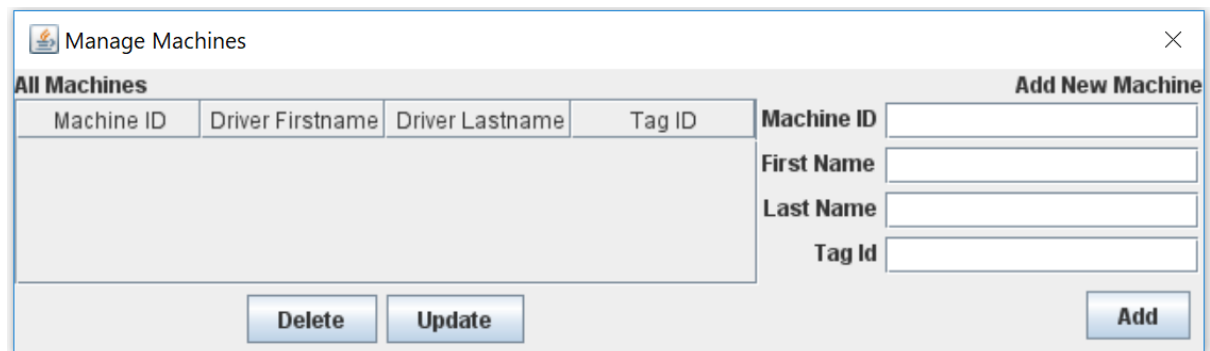
**Figure 6.4** Software Interface: Main Menu



**Figure 6.5** Software Interface: Signal Map Menu



**Figure 6.6** Software Interface: Add Employee and Tag Menu



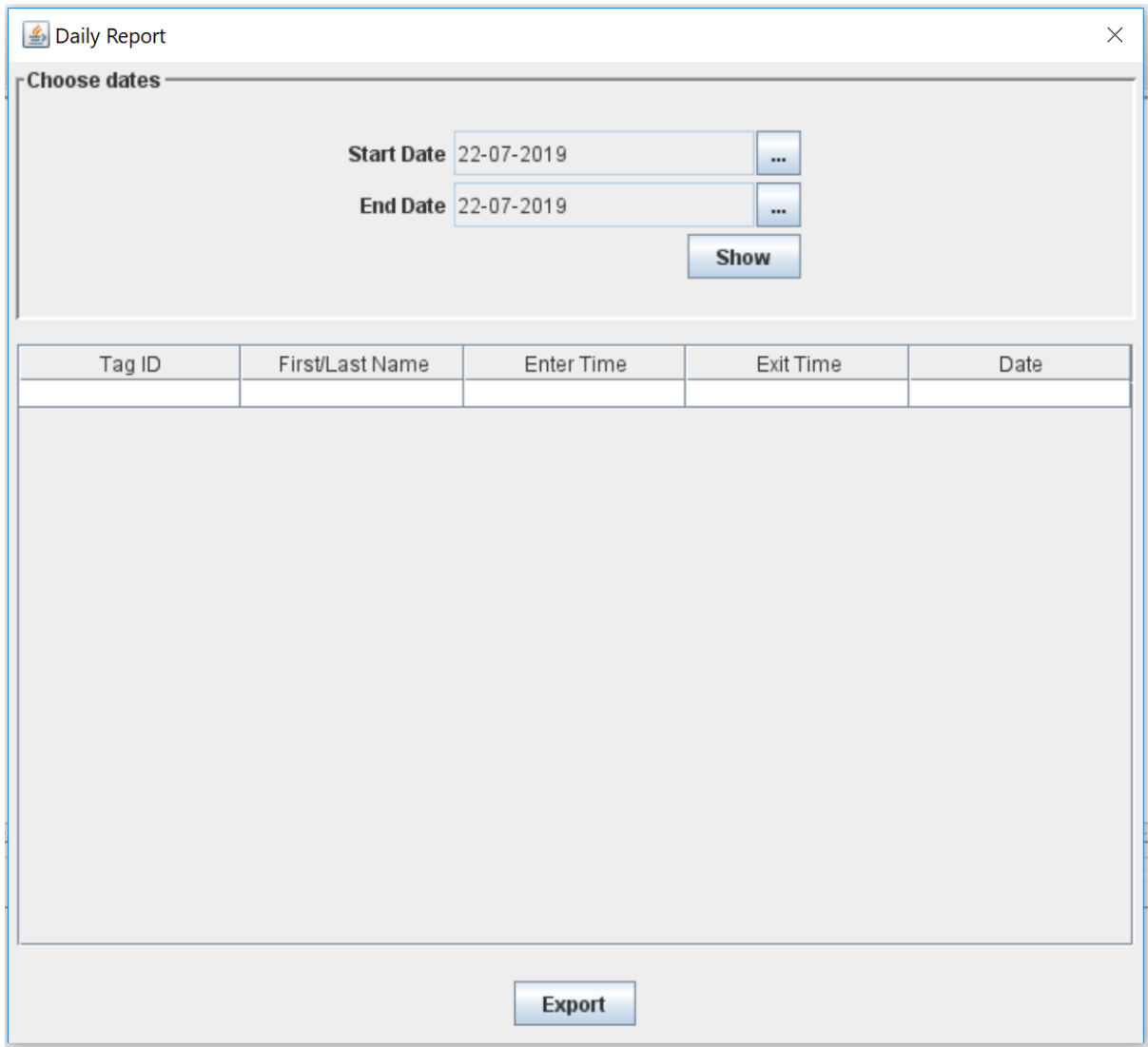
**Figure 6.7** Software Interface: Add Machine and Tag Menu

system. This Menu is an auxiliary menu to the Daily Report Menu. Employee specific reports can be generated from this menu. Besides, this reports can be exported to excel file.

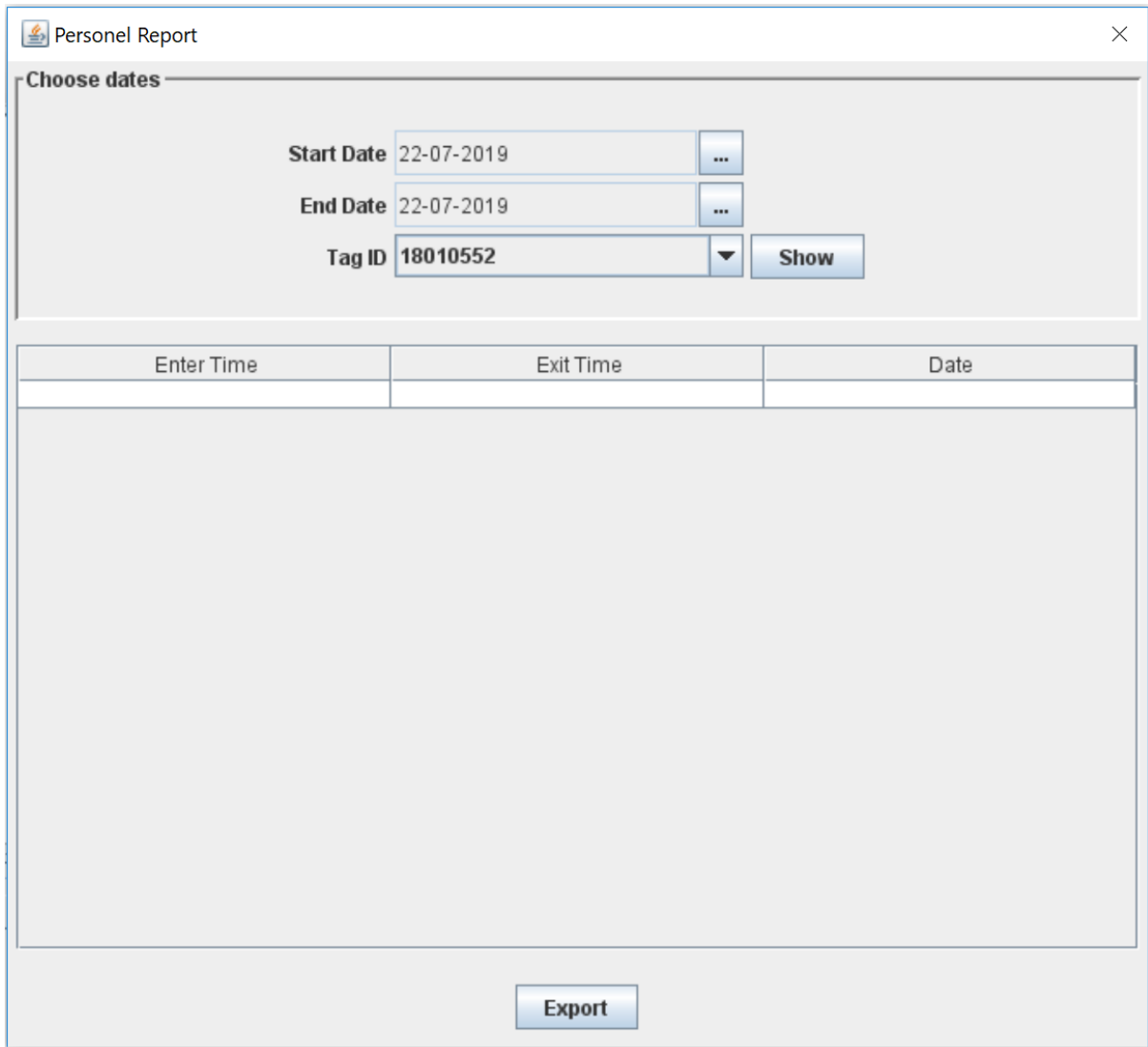
Figure 6.10 Admin Login Menu is used to get access to the administrative level panels such as Signal Map Menu. Username and password is not shared with ordinary users of software. This menu is used while initial installation of the system or system upgrade.

Figure 6.11 Button Bar is used especially for GIS capabilities of the software. Plain cursor button is used to activate the cursor for selecting any object from the map. Zoom in button is used to zoom in the map. Zoom out button is used to zoom out the map. Pan button is used to fit the map to the active screen. info button is used to get detailed information of clicked object on the map such as coordinates, id, tag id, name, surname, type etc. Full Extend button is used to display full extend of all layers. Start button is used to start the positioning algorithm and tries to connect the readers to get information about tags. Stop button is used to stop scanning of readers.

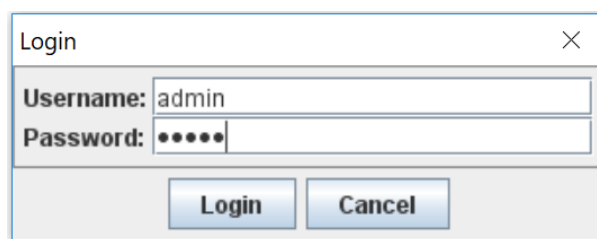
Figure 6.12 Layers Panel shows the layers in the system. Deleting or Modifying the layer can be done by using this panel. Also, enabling or disabling the layer from map is possible from



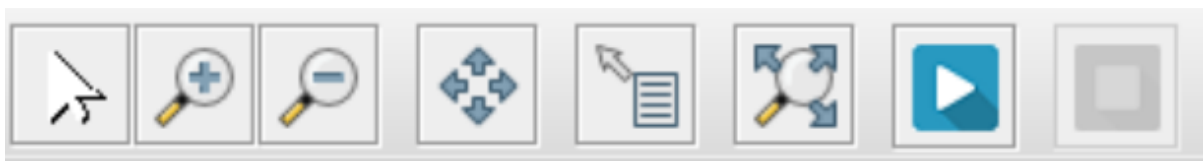
**Figure 6.8** Software Interface: Daily Report Menu



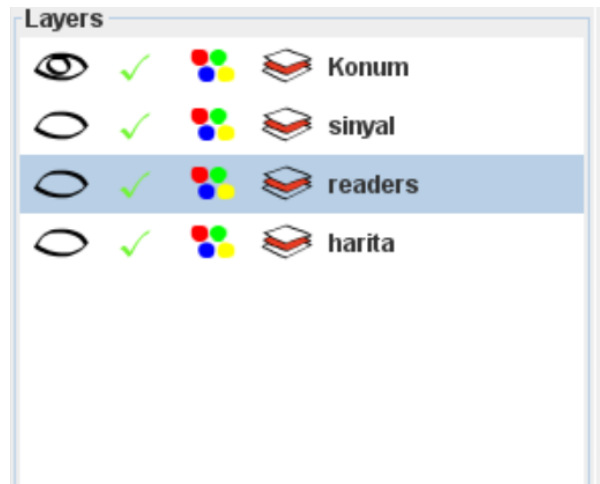
**Figure 6.9** Software Interface: Staff Report Menu



**Figure 6.10** Software Interface: Admin Login menu



**Figure 6.11** Software Interface: Button Bar



**Figure 6.12** Software Interface: Layers Panel

Tracked			
ID	First Name	Last Name	Tag ID

**Figure 6.13** Software Interface: Tracked Employee Panel

this panel.

Figure 6.13 Tracked Employee Panel shows the active employees being tracked by the software. This panel is updated permanently after starting positioning algorithm.

## APPENDIX B: RFID PROTOCOL

ISO (International organization for Standardization) manages the standards of communication between RFID tags and RFID readers. ISO 18000-V4 is the standard that describes the 2.4 Ghz active RFID protocol. However, the protocol between the reader and the server is vendor specific. Thus, RFID readers have proprietary protocol. The RFID readers have byte array based protocol. sending and receiving data formats are as follows:

Received data format:

Begin character(1 byte) + Reader ID (3 bytes) + End Code (1 byte)

Sent data format with Reader ID and Tag ID and RSSI value:

Begin character(1 byte) + length (1 byte) + Reader ID (3 byte) + RSSI (1 byte) + Tag State (1 byte) + Tag ID (4 bytes) + Check Code (1 byte) + End Code (1 byte)

Sent data format with Tag ID only:

Begin character(1 byte) + length (1 byte) + Tag State (1 byte) + Tag ID (4 bytes) + Check Code (1 byte) + End Code (1 byte)

Sent data format with Reader ID and Tag ID:

Begin character(1 byte) + length (1 byte) + Reader ID (3 byte) + Tag State (1 byte) + Tag ID (4 bytes) + Check Code (1 byte) + End Code (1 byte)

Sent data format with Tag ID and RSSI value:

Begin character(1 byte) + length (1 byte) + RSSI (1 byte) + Tag State (1 byte) + Tag ID (4 bytes) + Check Code (1 byte) + End Code (1 byte)

*BeginCharacter* : 0x40

*Length* : Length of Reader ID + Tag State + Tag ID bytes

*ReaderID* : Unique ID of the reader

*RSSI* : RSSI value in -dBm

*TagState* : State of the tag

*TagID* : Unique Tag ID

*CheckCode* : Check Code of the data stream

*EndCode* : 0x03

