Neighborhood Localization Method for Locating Construction Resources Based on RFID and BIM

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ABSTRACT

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Mohammad Mostafa Soltani

Construction sites are changing every day, which brings some difficulties for different contractors to do their tasks properly. One of the key points for all entities who work on the same site is the location of resources including materials, tools, and equipment. Therefore, the lack of an integrated localization system leads to increase the time wasted on searching for resources. In this research, a localization method which does not need infrastructure is proposed to overcome this problem. Radio Frequency Identification (RFID) as a localization technology is integrated with Building Information Modeling (BIM) as a method of creating, sharing, exchanging and managing the building information throughout the lifecycle among all stakeholders. In the first stage, a requirements' gathering and conceptual design are performed to add new entities, data types, and properties to the BIM, and relationships between RFID tags and building assets are identified. Secondly, it is proposed to distribute fixed tags with known positions as *reference tags* for the RFID localization approach. Then, a clustering method chooses the appropriate *reference tags* to provide them to an Artificial Neural Network (ANN) for further computations. Additionally, Virtual Reference Tags (VRTs) are added to the system to increase the resolution of localization while limiting the cost of the system deployment. Finally, different case studies and simulations are implemented and tested to explore the technical feasibility of the proposed approach.

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Last but not least, I would like to thank my parents: Mitra Yazdabad and Khosro Soltani, for giving hope to me when I was facing problems and supporting me spiritually throughout my life.

DEDICATION

I would dedicate this thesis is to my lovely parents, Mitra Yazdabad and Khosro Soltani, for their endless love, support and encouragement.

Also, this thesis is dedicated to all those who believe in the richness and limitless of learning.

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LIST OF ABBREVIATIONS

Abbreviation	Description
2D	Two Dimensional
3D	Three Dimensional
AIS-FNN	Artificial Immune System-based Fuzzy Neural Network
ANN	Artificial Neural Network
AoA	Angle of Arrival
AP	Access Point
API	Application Programming Interface
BIM	Building Information Modeling
BP	Backpropagation
BrIM	Bridge Information Modeling
CAD	Computer-Aided Design
CMTL	Cluster-based Moveable Tag Localization
DANN	Discriminant-Adaptive Neural Network
dBm	decibels milliwatt
DOM	Document Object Model
DR	Dead Reckoning
EPC	Electronic Product Code
FAF	Floor Attenuation Factor
FM	Facility Management
FNN	Fuzzy Neural Network
GA	Genetic-Algorithm
GPS	Global Positioning System
GSM	Global System for Mobile communications
GUID	Globally Unique Identifier
HVAC	Heating, Ventilation and Air Conditioning
IAI	International Alliance of Interoperability
IDM	Infrastructure Data Modeling
IFC	Industrial Foundation Classes
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IR	Infrared
ISO	International Organization for Standardization
IT	Information Technology
KL	Kernel-based Learning
k-NN	*k* Nearest-Neighbor
LBS	Location-Based Services
LIDAR	LIght Detection And Ranging

MHz	Megahertz
MIM	Municipal Information Modeling
ML	Maximum Likehood
MLP	Multilayer Perceptron
NBIMS	National Building Information Modeling Standard
PoA	Phase of Arrival
PPE	Personal Protective Equipment
QIM	Quality Inspection and Management
RBFNN	Radial Basis Function Neural Network
RF	Radio Frequency
RFID	Radio Frequency Identification
RIM	Road Information Modeling
ROCRSSI	Ring Overlapping Circle RSSI
RSI	RSSI Spatial Interpolation
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RTLS	Real-Time Location System
RToF	Roundtrip Time of Flight
SDAI	Standard Data Access Interface
SMP	Smallest M-vertex Polygon
STEP	STandard for the Exchange of Product model data
SVM	Support Vector Machine
TDoA	Time Difference of Arrival
ToA	Time of Arrival
UKF	Unscented Kalman Filtering
UWB	Ultra Wide Band
VRT	Virtual Reference Tag
WAF	Wall Attenuation Factor
WKNN	Compared Weighted k-Nearest Neighbor
WLAN	Wireless Local Area Network
XML	Extensible Markup Language

CHAPTER 1 **INTRODUCTION**

1.1 General background

The need for coordination in construction industry is a critical key point to bring multi-disciplines and different contractors and agents in a project together in such highly fragmented environment. The great amount of information and the needs for coordination and decision-making should encourage this sector to use new technologies in order to manage and organize the information sharing and exchanging. Having a smooth procedure for exchanging the different information within the construction phase helps all project entities to save their time and money. Furthermore, working in a site which is changing every days and it can be new and unknown for different contractors brings some difficulties for them to do their tasks properly. For instance, searching for the required resources such as equipment, tools, and materials in a large construction site can consume a long time for the people on the site to find and use the right resources. For instance, a worker can use an electronic screwdriver; after he finishes his job he may leave the tool somewhere near his working area. After some time another workers needs the same tool but he cannot find it. Therefore, he/she has to search all possible places to find that tool which means wasting some time. This small example shows the importance of managing the location for people working in a construction site.

One of the popular technologies which have been used for organizing the information in the construction sector is Radio Frequency Identification (RFID) technology. By using this technology, the data for automatic identification of persons and objects are transmitted by radio waves without physical contact or line of sight between the transmitter and the receiver. The following areas have a great potential for applying RFID in the construction industry: (1) supply chain management and logistics; (2) material, equipment, and tools tracking; (3) project progress management; (4) localization; (5) quality control; (6) lifecycle management; and (7) safety.

Another outstanding tool for managing and exchanging building and project information during the lifecycle of the building is Building Information Modeling (BIM) which can provide a wide range of information. This digital model starts to gather the necessary information from the early design stage, is shared between different contractors and participant agents in the project, and is transferred to the owner for the operation and maintenance phases.

1.2 Research objectives and contribution

This research aims to achieve the following objectives: (1) to investigate the extensibility of BIM for adding RFID components as standard elements of Industrial Foundation Classes (IFC); (2) to investigate a method for the localization of moveable objects equipped with RFID tags using a hand-held reader; (3) to demonstrate the feasibility of proposed methods through the simulation environment and real world case studies.

1.3 Thesis organization

This research will be organized as follows:

Chapter 2 Literature Review: In this chapter different localization and RTLS technologies will be investigated. A summary of current indoor location-based systems will be presented. Then, RFID as key technology in this research, its application in construction industry, and RFID-based localization solutions will be studied.

Chapter 3 BIM Extension for incorporating RFID: This chapter will cover the proposed procedure for adding definitions of the RFID components (i.e. tag, reader and antennas) to the IFC and the respective relationships with the existing definitions of IFC. Furthermore, a case study is developed to validate the feasibility of the proposed idea.

Chapter 4 RFID-based localization system using VRT and ANN: The main proposed method of this research will be explained in this chapter. It will be shown how a user can find the location of moveable resources with the help of a mobile RFID reader. The approach has the benefit of multi-criteria clustering to choose best reference tags' candidate for localization, uses VRTs instead of adding more reference tags which will be costly, and finds the location of the target by applying ANN. The chapter shows the results of our simulation and real world case studies.

Chapter 5 Summary, Conclusions, and Future Work: In this chapter, a summary of this research will be presented and its contributions will be highlighted. Moreover, the limitations of the current work will be investigated and finally the recommendations for the future research will be suggested.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This Chapter will review the literature conducted on RFID, RTLS, BIM, and complimentary mathematical techniques. The mentioned technologies are the foundations of the ideas which will be later discussed in the following chapters. The elements, features, and limits related to RFID technology are clarified. The literature focusing on different localization methods and RTLS technologies is reviewed. The potential and weakness of these methods are critically discussed. BIM technology is explained in this chapter as a digital representation of information of a building, mainly about data storage, data exchange, and IFC. Finally, some mathematical approaches are reviewed to support our proposed method in the next chapters, including clustering, VRT, and ANN.

2.2 Localization and RTLS technologies

2.2.1 Importance of location data

The localization problem has received considerable attention in the area of pervasive computing as many applications need to know where objects are located. Location information is central to personalized applications in areas such as transportation, manufacturing, logistics, and healthcare, and it is the basis for the delivery of personalized and Location-Based Services (LBS) (Papapostolou and Chaouchi, 2011; Li and Becerik-Gerber, 2011). Furthermore, the precise objects location information can be used for several applications (Zhou and Shi, 2009) such as finding missing items in a storehouse (Hariharan, 2006), locating equipment in construction areas (Song, 2006), mobile users localization inside the building (Ji et al., 2006), collision prevention between vehicles (Tong and Zekavat, 2007), and rescuing persons in underground mines (Zhang and Yuan, 2006). Monitoring of personnel movements, material locations, and construction equipment effectively can make the management of projects more productive (Khoo, 2010; Ibn-Homaid, 2002; Fan et al., 2008; Yagi et al., 2005; Grau et al., 2009).

Location information is especially valuable as it has the potential to improve the utilization and maintenance of facilities by: (1) Helping unfamiliar users of a building by providing them with information to navigate around and find their destinations; (2) Facility Management (FM) personnel can be provided with the locations of building components or equipment they need to maintain or repair; (3) Locations of tools and on-site FM personnel and the length of time they spend at each location can be analyzed to monitor the work procedures and improve productivity; and (4) Changes in building occupancy can be detected in real time through location sensing, and energy conservation measures, such as adjustment of lighting and air conditioning, can be automated (Li and Becerik-Gerber, 2011).

2.2.2 Localization levels

The term of localization is defined by Papapostolou and Chaouchi (2011) as the procedure of estimating the current position of a user or an object within a specific region, indoor or outdoor. The determined position can be represented in various ways (e.g., coordinate, region, cell, hierarchical) based on the desired application or the positioning system specifications.

Razavi and Haas (2011) discussed two methods of localization: *fine-grained* localization using detailed information and *coarse-grained* localization using minimal information. Minimal techniques are easier to perform, need fewer resources and have lower equipment costs; however their accuracy is lower than detailed information techniques. Fine-grained node localization using measurement techniques can be classified into broad types based on Time of Flight Techniques, Received Signal Strength (RSS) techniques, Lateration and Angulation Techniques, Distance-Estimation using Time Difference of Arrival (TDoA), Pattern Matching (radar), and Radio Frequency (RF) Sequence Decoding Techniques (Razavi and Haas, 2011). Coarse-grained node localization uses range-free or connectivity-based localization algorithms with no needs for any measurement techniques. In this class, some anchor sensors have stored information about their own location. Therefore, the locations of other sensors can be calculated based on connectivity information, such as which sensor is within the broadcasting range of which other sensors. The researches built on this method (Bulusu et al., 2000; Simic and Sastry, 2002; Song et al., 2006) to determine the closest known locations to the object instead of measuring the distance between an object and reference points. Tracking physical phenomena that have limited range (e.g., physical contact with a magnetic scanner or communication connectivity to Access Points (APs) in a wireless cellular network) helps to determine the presence of an object within a specific range (Razavi and Haas, 2011).

2.2.3 Context-aware information delivery

Manual processes decision-making tasks in the field can be improved by involving location-aware computing (Khoury and Kamat, 2009a). The context-aware information delivery (Aziz et al., 2005) is able to create a user-centered mobile dynamic indoor and outdoor work environment. It has the potential to deliver proper information to on-site mobile users in order to help them take more informed decisions (Schilit et al., 1994). Examples of the broad range of applications, that form the basis of context awareness in construction and FM, include the improvement of project safety, schedule, cost (Caldas et al., 2006) and decision-making (Li and Becerik-Gerber, 2011). Contextual project information can be automatically retrieved and visualized by continuously and accurately tracking mobile users' three-dimensional spatial context (i.e. position and orientation) (Khoury and Kamat, 2009b). Navigation information, studied by Rueppel and Stuebbe's (2008), is an example of information deliverable to mobile users (Li and Becerik-Gerber, 2011).

Li and Becerik-Gerber (2011) identified the need to investigate the application of an information delivery mechanism to the following areas: (1) execution and management of construction activities, e.g. assembly guidance documents, are delivered to the onsite crew; (2) safety and security, e.g. real time monitoring the locations of onsite workers to prevent collisions, or to give a warning when assets are removed without authorization; (3) FM personnel, e.g. an onsite worker is located and his/her context analyzed, so that information such as maintenance history, work orders, or inspection records, is delivered to him/her to facilitate the maintenance work; and (4) emergency reaction, e.g. rescuers are guided to the shortest route inside a building.

2.2.4 Localization technologies

Basically, localization systems rely on ultrasound, magnetic, infrared, vision, and RF technology (Pradhan et al., 2009a; Hightower and Borriello, 2001). Ultrasound-based systems include a transmitter to emit ultrasound pulse and a receiver to collect the emitted pulses to estimate the distance between the receiver and the transmitter (Pradhan et al., 2009a; Want et al., 1992). Although ultrasound-based systems have high accuracy, they need a large number of sensors which are costly compared to RF systems (Pradhan et al., 2009a; Hightower and Borriello, 2001).

Magnetic-based approaches are based on the measurement of the motion with the help of accelerometers, gyroscopes, and magnetometer. The rate of the motion (i.e., acceleration) comes from an accelerometer and the type and direction of the motion are provided by gyroscopes (Fraden, 2011). Additionally, a magnetometer helps the system to find the direction of motion with respect to the earth's magnetic field. Performing Dead Reckoning (DR) technique (Gelb, 1974) with a known rate, type and direction of motion leads to estimating the location of an object based on Inertial Measurement Unit (IMU). In recent years, Pradhan et al. (2009b) and Jimenez Ruiz et al. (2012) proposed combinatorial methods using RFID to improve the accuracy of IMU-based localization methods.

Similar to ultrasound, infrared-based systems include a transmitter and a receiver but they utilize electromagnetic radiation of wavelength greater than visible light instead of sound wave to determine the distance (Pradhan et al., 2009a). Furthermore, image-based localization technologies are relying on the basis of edge detection, feature recognition, and landmark detection using visual tags or image matching (Sim and Dudek, 2003).

The need for the line of sight and the poor performance are two main limitations of these systems. The systems that use radio frequency in different ways to localize the position of a target are called RF-based solutions. Global Positioning System (GPS), RFID, Wireless Local Area Network (WLAN), Bluetooth, and ZigBee are some of the popular RF-based technologies used for localization. Due to their flexibility of deployment, communication range and possibility to work without any line of sight (except GPS), there is a strong trend to use this method for localization.

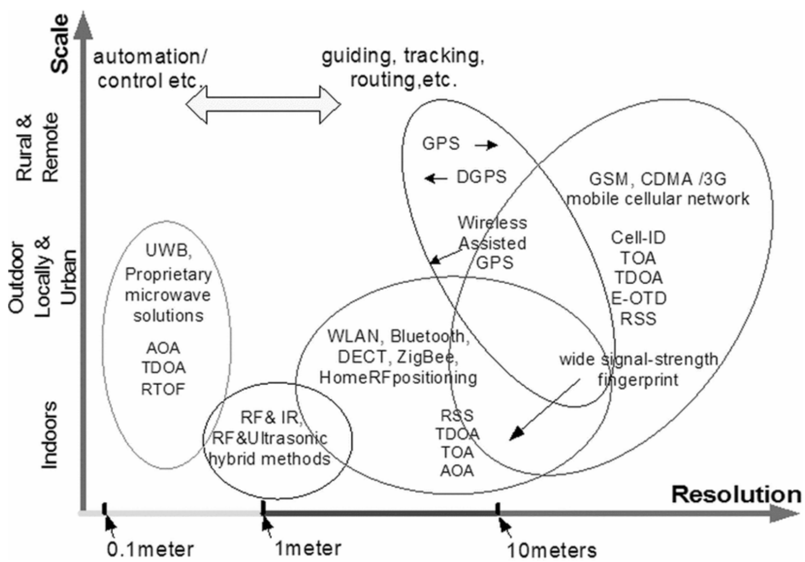


Figure 2-1 Outline of current wireless-based positioning systems (Liu et al., 2007b)

Unlike outdoor environment, GPS cannot meet the need for indoor positioning due to limitation of receiving signals from satellites. Different methods have been proposed for indoor localization. The following systems are addressed by Li and Becerik-Gerber (2011) and Liu et al. (2007b). Additionally, Figure 2-1 depicts a general overview of indoor positioning systems (Liu et al., 2007b; Vossiek et al., 2003). Additionally, Taneja et al. (2010a) evaluated the capability of RFID, WLAN, and IMU as indoor localization technologies in their research for facility management field activities.

- *GPS-Based*: Considering the use of high-sensitivity GPS which is suitable for weak-signal conditions (Schon and Bielenberg, 2008) and Assisted GPS (A-GPS) with ability to send assisting information, such as satellite orbit information, to the receiver (van Diggelen, 2002), the weakness of GPS for indoor environment could be improved. This system is used by SnapTrack (Moeglein and Krasner, 1998), Amtel (Atmel, 2013), U-blox (Thiel et al., 2007), Locata (Barnes et al., 2003).
- *Inertial Navigation Systems (INS):* Jiménez Ruiz et al. (2012) coupled Foot-Mounted IMU and RFID to achieve more accurate pedestrian indoor navigation.
- *Infrared-based solutions,* Want et al. (1992) used a portable Infrared-based transmitter called Active Badge and fixed infrared sensors to provide zone-level localization. PILAS is another similar methods based on infrared sensors (Lee et al., 2006a).
- *Vision-based solutions:* Microsoft research vision group utilized multiple stereo cameras inside a room to determine the location of a person. The method which is called EasyLiving, provides the location and identity of people using the registered depth and images coming from the cameras (Krumm et al., 2000). Another research done by Kunkel et al. (2009) demonstrates using a monochrome Infrared (IR) camera in collaboration with RFID technology to find the exact location of the target. In addition to the Two Dimensional (2D) image, the Three Dimensional (3D) imaging

technology such as laser scanning and Flash LIDAR (LIght Detection And Ranging) enables determining the location of target object (Taneja et al., 2010b).

- *Ultrasound:* The Cricket (Priyantha et al., 2000) and the Active Bat (Harter et al., 2002) location systems are based on ultrasound sensors. By comparing the time of arrival of ultrasonic signals, they could estimate the distance between the signal transmitter and the receiver. Another research, named AMTRACK, used ultrasound sensors combined with RF sensors to improve its performance (Skibniewski and Jang, 2007).
- *RF-based techniques:* There are many technologies based on radio frequency, such as Bluetooth, Cellular, Ultra Wide Band (UWB), ZigBee, WLAN, and RFID, which are further discussed in detail in Section 2.2.5.

2.2.5 RF-based localization

In this section, localization techniques based on radio frequency are specifically reviewed. The well-known approaches, built on the basis of Bluetooth, Global System for Mobile communications-band (GSM-band), UWB, ZigBee, WLAN, and RFID (regarding the potential and advantages of RFID technology for this research, its related literatures are reviewed separately in the next section) are explained in the following.

- *Cellular-Based:* This method refers to indoor positioning systems using global system of mobile/code division multiple access (such as GSM) mobile cellular network to find the position of the mobile user. Although this approach has a low accuracy in densely covered areas the accuracy can go higher (Liu et al., 2007b). Recently, Oussar et al. (2011) introduced their method based on cellular telephony RSSI fingerprints.

- *UWB-based solutions*: The radios with the absolute bandwidths of more than 500 MHz (Megahertz), named as UWB, are based on sending ultra-short pulses (typically less than 1 ns) for communication between tags and receivers. Unlike conventional RF tags, UWB tags consume less power and provide higher accuracy but using this technology needs large amount of infrastructure (Gezici, et al., 2005; Liu et al., 2007b; Becker et al., 2008; Cho et al., 2010). UbiSense (Ubisense, 2013) and Zebra (Gresham, et al., 2004) are two examples of RTLS based on UWB.
- *Bluetooth (IEEE 802.15):* This technology has a lower bit rate (1 Mbps) and shorter range (approximately 10-15m) compared to WLAN (Liu et al., 2007b). *9Solution* (9Solutions, 2013) and *ZONITH* (ZONITH, 2013) are providing indoor locating systems based on Bluetooth standard (Cruz et al., 2011).
- *ZigBee (802.15.4):* ZigBee as a low-power is another technology with mesh grid networking ability which provides a wider range because its nodes can communicate with each other in addition to communication with the reader/receiver sensors. Currently, awarepoint (Awarepoint, 2013), Cubic (CUBIC, 2013), Tag Sense (TagSense, 2013), ZigBEACON (Huang and Chan, 2011), and n-Core Polaris (n-core, 2013) are providing indoor location system based on ZigBee.
- *WLAN-based*: High deployment of WLAN infrastructures inside the buildings makes this technology one of the popular candidates for the indoor localization systems (Mazuelas et al., 2009). In this area, RADAR used an Empirical method and Wall Attenuation Factor (WAF) model for its localization engine (Bahl and Padmanabhan,

2000) and Floor Attenuation Factor (FAF) was investigated by Barsocchi et al. (2009). Another research done by Nobles et al. (2011) investigated the effect of the presence of walls on signal propagation depending on the construction material of the wall. ARIADNE is a localization system proposed by Ji et al. (2006) and Ji and Chen (2010). Mengual et al. (2010) followed a similar way as previous research but they applied ANN for their clustering phase. Interlink Networks (Interlink Networks, 2002) provided a single path-loss model and Lau and Chung (2007) provided a two phases' path-loss model for localization proposes. Following researches (Kontkanen et al., 2004; Castro et al., 2001; Ladd et al., 2005; Roos et al., 2002; Schwaighofer et al., 2003; Youssef et al., 2002; Youssef et al., 2003; Zhao et al., 2011; Mengual et al., 2010; Chang et al., n.d.) used the benefit of probabilistic location estimation, data filtering methods, clustering techniques, and Support Vector Machine (SVM) method based on WLAN. Finally, Vahidnia et al. (2013) used signal-space partitioning seems to reduce the average error.

- *RFID-Based*: As this technology is selected in our proposed method, it will be discussed in Section 2.3 in detail.

2.2.6 Localization methods

The following literatures proposed different categorizations of existing localization methods (Pradhan et al., 2009a, Liu et al., 2007b; Torres-Solis et al., 2010, Fuchs et al., 2011; Razavi et al., 2012; Cisco, 2006; Chan and Baciu, (n.d.); Ni et al., 2011; Mao and Fidan, 2009). Due to the harsh and noisy environment of construction sites, RF-based methods are considered the most reliable approach in this area. Therefore, the main focus in this research is on these methods.

Reviewing different survey studies in this area shows that there is a discordance in the definition of terms by different researches. To overcome this problem the author tried to expand the following sections by merging different opinions to make a clear and harmonized view of RF-based method categorization.

Generally, all RF-based localization approaches can be considered as Geometric-based or Similarity-based (relative localization named by Biaz et al., 2005). The first one uses the geometric features like distance or angle (converting from Received Signal Strength Indicator (RSSI) value) to estimate the position of the target, which is more suitable for obstacle-free environment. The second group finds the location of the target based on the degree of signal similarity of target to each known reference point (Sanpechuda and Kovavisaruch, 2008). Figure 2-2 illustrates an overview of subsequent categories of the RF-based methods. The detail of each category will be discussed in detail in the following sections.

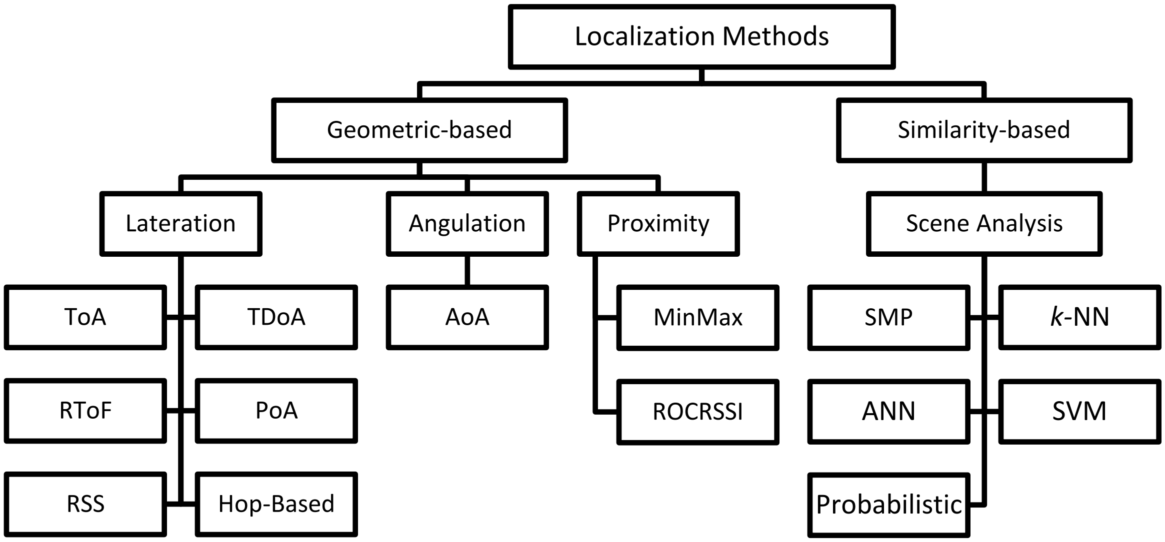


Figure 2-2 RF-based Localization methods

2.2.6.1 Lateration

The Lateration method estimates the position of a target point by measuring the distances of the target to at least three points with known positions. The distance between the target and reference points can be calculated using the following techniques:

Time of Arrival (ToA): The distance between the sender and the receiver can be calculated with respect to the signal travel time between the sender and receiver and the signal propagation speed in the air. This method requires the synchronization of the sender and receiver and is considered as a basic requirement for getting precise distance estimation (Ciurana et al., 2007).

Roundtrip Time of Flight (RToF): This method is based on the measurement of the time-of-flight of the signal from the sender to the receiver. GPS is one of popular technologies using this method (Liu et al., 2007b).

Time Difference of Arrival (TDoA): The idea behind TDoA is to calculate the relative position of the target transmitter by determining the difference in time at which the signals arrive to multiple measuring sensors based on the difference in the signal's propagation delay (Liu et al., 2007b; Vossiek et al., 2003). One of the constrains of this technique is that it is more useful for short distances where there is a line of sight between the receiver and the sender (Fuchs et al., 2011).

Phase of Arrival (PoA): This method is also called Interferometry of Received Signal Phase. It deploys the emission of sine waves with multiple frequencies and the superposition of the different signals is collected at the receiving unit by means of an array of multiple antennas. Using the measured phase shifts and the known wavelengths, the distance between the sender and the receiver can be estimated (Patwari and Hero, 2006).

Received Signal Strength (RSS): It is also known as "Signal attenuation method" in which the strength of a radio signal decreases with increasing travelled distance. Consequently, the distance travelled from the sender can be calculated by measuring the received signal strength (Reichenbach and Timmermann, 2006). The advantage of using this technique is the simplicity of deployment. The weakness of this method is that obstacles or reflections can cause signal attenuation that makes the estimations extremely imprecise. Luo et al. (2011) explained three algorithms which are Trilateration, MinMax, and Maximum Likelihood. More details can be found in the researches of Langendoen and Reijers (2003) and Sugano et al. (2006).

Hop-based: To estimate the distance, this technique is based on the number of hops on the communication path from a sender to a receiver considering an equidistant distribution of the stations between the sender and the receiver deduced from the hop count (Niculescu and Nath, 2003).

2.2.6.2 Angulation

In the **Angle of Arrival (AoA)** based localization approaches, the incidence angles of the received transmitter signal with respect to the known positions of the receiver sensors are calculated. The transmitter can be localized based on these angles by applying a triangulation method (Azzouzi et al., 2011).

2.2.6.3 Scene Analysis

Scene Analysis, also called fingerprinting in some literature (e.g., Li and Becerik-Gerber, 2011; Pradhan et al., 2009a), refers to the algorithms using collected properties of the signal (such as signal power) in the environment and searching for the observed signals (scenes) in a predefined data set that maps them to locations. Using this method can be under two approaches, offline-based or online-based. There are two main stages in each method; first, a training set of signal strength values and their respective location coordinates (i.e., fingerprints) are collected throughout a facility which can be named offline-learning. The trained reference map can be put in operation by two scenarios for localization: (1) a mobile target receives and collects a set of signal strengths from base stations/transmitters scattered in a facility (Bahl and Padmanabhan, 2000); (2) Fixed stations/transceivers collect a set of signal strength from the mobile target (Hightower and Borriello, 2001). The location of the target is estimated by comparing the real-time received signal strength from the target and the recorded signal strength in the training data set (Pradhan et al., 2009a). For instant, the RSS of a WLAN is measured and recorded at known locations a signal map. An unknown location sensor measures its current signal strength pattern and compares it to the previously surveyed signal map to locate itself. The most similar pattern in the signal map is then assumed as the position of the sensor (Elnahrawy et al., 2004). In the online based method, there is no offline-learning, and the system has to collect RSSI coming from all reference nodes with known locations (as a signal map) and estimate the target's location after each data collection point.aaaa

Liu et al. (2007a), Liu et al. (2007b), and Zhou and Shi (2009) explained following algorithms using Pattern Matching techniques for fingerprinting-based positioning:

***k*-Nearest Neighbor (*k*-NN):** The main concept behind the Nearest-Neighbor is that closer the two points, the more similarity of RSSI values of the two points. This closeness can be based on geometric distance or signal similarity. Figure 2-3 illustrates a schematic view of *k* Nearest-Neighbor which *k* in this example is four.

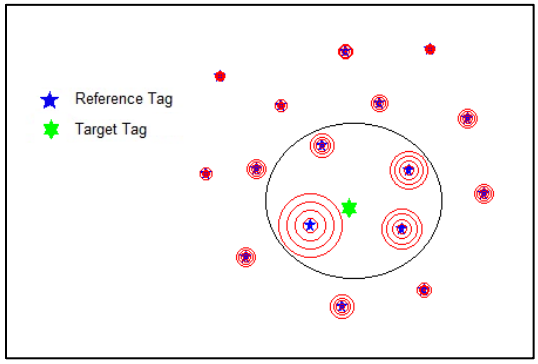


Figure 2-3 Basic of *k*-NN Method

This method uses weighted averaging in order to estimate coordinates of the target tag (*x*, *y*) using the Equation 2-1. W_i is calculated by Equation 2-2 where E_i is the Euclidean distance in signal strengths (Ni et al., 2003).

$$(x, y) = \sum_{i=1}^{k} w_i (x_i, y_i) \qquad \textbf{Equation 2-1}$$

$$w_i = (1/E_i^2)/\left(\sum_{j=1}^{k}(1/E_j^2)\right) \qquad \textbf{Equation 2-2}$$

Since the weights' function is dependent to distance and characteristics of sensors node's receivers, Blumenthal et al. (2007) compared the impact of different power (*g*) of Euclidean distance in Zigbee-based localization networks (Equation 2-3). Furthermore, ZigBEACON system proposed by Huang and Chan (2011) used the basic of *k*-NN algorithm for its indoor location system.

$$w_i = \frac{1}{E_i^g} \qquad \textbf{Equation 2-3}$$

Kernel-based Learning (KL): Similar to *k*-NN method, according to KL's basis, the smaller the distance between the two RSSI is, the smaller physical distance they have from each other (Sanpechuda and Kovavisaruch, 2008). Using KL can be based on classification (Li et al., 2002; Nguyen et al., 2005; Brunato and Battiti, 2005; Zhou and Shi , 2009) or regression category (Pan et al., 2005; Pan and Yang, 2007; Brunato and Battiti, 2005; Ferris et al., 2006; Ferris et al., 2007, Zhou and Shi , 2009).

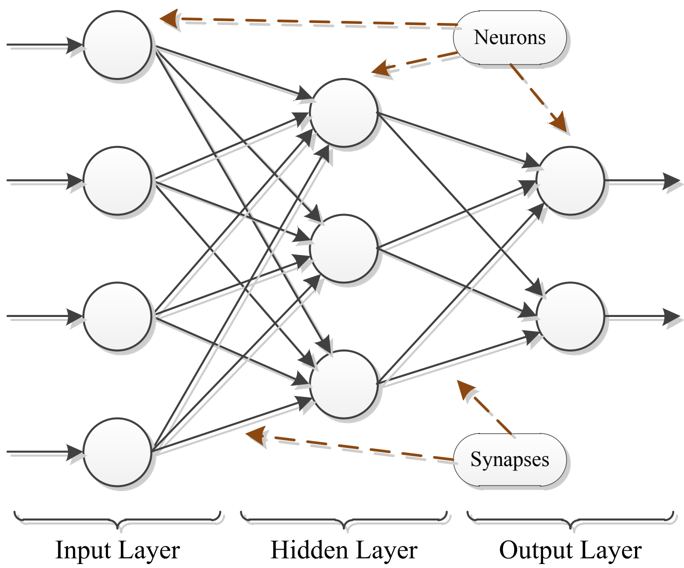
Probabilistic method: The main concept is based on the conditional probability of being the target node in location L_i where there are n possible candidates $L_1, L_2, L_3 \ldots L_n$ and S is a series of RSSI from reference nodes. The chosen candidate meets the following condition (Liu et al., 2007b):

L_i has more chance if $P(L_i \mid s) > P(L_j \mid s)$ and $i \neq j$

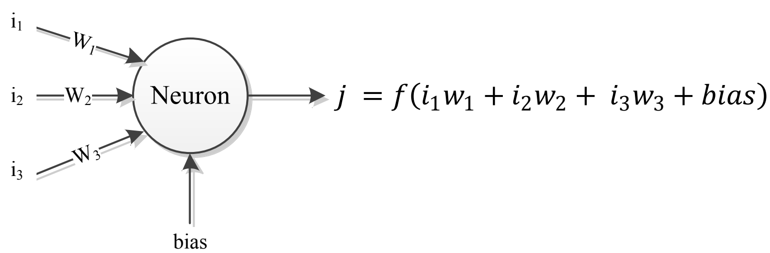
Artificial Neural Network: ANN can be considered as an extremely simplified model of the brain. From mathematical point of view, it is a function estimator which transfers inputs into outputs with the minimum error. Basically, ANN consists of many neurons that co-operate to perform the appropriate function and it is mostly applicable for classification (i.e. pattern matching, feature extraction) and prediction based on existing data. Since this method is going to be used in CHAPTER 4 as a part of proposed method, it is explained more in detail compared to the other approach under the scene analysis category. As an advantage of ANN, a neural network can be trained to perform a particular function by adjusting the values of the connections (weights) between elements. On the other hand, network model can automatically learn the features of inputs and create appropriate outputs that users don't need to know the hidden processes between them. As Figure 2-4(a) illustrates, an ANN contains three main layer, inputs, hidden, and outputs. Each layer involves numbers of neurons connected to the preceding/succeeding layers through some weights (synapses). Figure 2-4 (b) shows that the output of a neuron is a function of the weighted sum of the inputs plus a bias. The function of the entire neural network is equal to the computation of the outputs of all the neurons. To produce the output, an activation function is applied to the weighted sum of the inputs of a neuron. Identity function, binary step function, sigmoid function, and bipolar sigmoid function are the examples of commonly used activation functions (Fausett, 1994). There are three possibilities for training the ANN which can be used regarding the provided data in a problem:

1- Supervised learning (i.e. learning by evaluating the estimated outputs with existing outputs)
2- Unsupervised learning (i.e. learning with no help)
3- Reinforcement learning (i.e. learning with limited feedback)

Unlike probabilistic method, ANN is using to find the nonlinear mapping between RSSI and coordinates of the nodes. After training the network model for the reference nodes with known position, the model is used to estimate the location of target node by knowing its RSSI (Hwang et al., 2011).



(a) A sample mathematical model for a neuron



(b) A sample multilayer ANN with one hidden layer

Figure 2-4 Overview of ANN (adapted from Russell and Norvig, 2003)

Regarding the literature focusing ANN-based localization systems, one hidden layer is optimum value but for choosing the number of hidden neurons, there is no theory to guide it (Marsland, 2011). Martínez Sala et al. (2010a) empirically used 4 neurons in the hidden layer but Battiti et al. 2002 tested 4, 8, and 16 neurons and they achieved the best results by using 16 neurons. Wu et al. (2009) defined this number by using Equation 2-4 and Equation 2-5.

$$N_{hidden} = \frac{N_{input} + N_{output}}{2}$$ **Equation 2-4**

$$N_{hidden} = \sqrt{N_{input} \times N_{output}}$$ **Equation 2-5**

In some literature, Neural Networks were used to map the RSSI values coming from reference nodes to their known coordinates (*x* and *y*). As a result, a trained network can predict the location of an unknown node based on its RSSI value (Mehmood et al., 2010; Mehmood and Tripathi, 2013; Hwang et al., 2011). Wu et al. (2007) took the benefit of Neural Networks to find the distance between target nodes and the APs for their localization algorithm. However, the research of Battiti et al. (2002) showed the results coming from ANN and *k*-NN method were very similar at that period of time. Another research done by Tapia et al. (2011) focused on the mitigation of the ground reflection effect and calibration of the final position using ANN. By the time, Soleimanifar et al. (2011) proposed a real-time error correction approach by using Radial Basis function Neural Network (RBFNN). Finally, Fang and Lin (2008) Compared Weighted *k*-Nearest Neighbor (WKNN), Maximum Likehood (ML), and Multilayer Perceptron (MLP) with their proposed Discriminant-Adaptive Neural Network (DANN) and showed how DANN can improve greatly the accuracy compared to other traditional approaches.

Smallest M-Vertex Polygon (SMP): Close to the idea behind *k-NN*, online RSS values are used to search for candidate locations in signal space based on signal distance between the measured fingerprint and fingerprint entries in the database (Liu et al., 2007b; Prasithsangaree et al., 2002; Pandya et al., 2003; Gwon et al., 2004). MultiLoc took the advantages of SMP in their research (Prasithsangaree et al., 2002). The generalized weighted *Lp* distance between a measured RSS vector $[x_1, x_2 \ldots x_N]$ and a database entry $[x_1', x_2' \ldots x_N']$ is given by Equation 2-6:

$$L_p = \frac{1}{N}\left(\sum_{i=1}^{N}\frac{1}{w_i}|x_i - x'_i|^p\right)^{1/p}$$ **Equation 2-6**

One of the main weaknesses of fingerprinting methods is that they are sensitive to uncontrollable and frequent environmental changes that make the trained signal map unreliable during the localization phase (Papapostolou and Chaouchi, 2011). Additionally, preparing signal map for an environment requires high initial efforts (Fuchs et al., 2011). *Examples:* RADAR (Bahl and Padmanabhan, 2000), HORUS (Youssef and Agrawala, 2008), COMPASS (King et al., 2006) and WIFE (Papapostolou and Chaouchi, 2009) follow this approach.

2.2.6.4 **Proximity**

The idea behind this method is to find the location of an object by determining a set of spatially distributed reference points signal coverage areas of which overlap in an adequate way. Accordingly, the object can estimate its location as the intersection of all its neighbors' coverage areas. Basically, the main key in these approaches are based on the detection of reference points with well-known location. The two main factor effects on the precision of this technique are the number and distribution of the reference points and their signal range (Cabero et al., 2007). Other factors which can result in decrement of the accuracy are attenuation and reflection of the signal (Fuchs et al., 2011)**.** The two popular algorithms under this category are Ring Overlapping Circle RSSI (ROCRSSI) and MinMax (Luo et al., 2011; Liu et al., 2004; Liu et al., 2007a; Langendoen and Reijers, 2003).

Hightower and Borriello (2001) compared some systems taking advantage of proximity method are Active Badges (Want et al., 1992; Kampel, 2001; Orr and Abowd, 2000; Doherty and El Ghaoui, 2001). Torrent and Caldas (2007) assessed the validity of proximity algorithm (MinMax) for the localization of materials on large industrial projects

2.3 RFID-based localization systems

2.3.1 Fundamentals of Radio Frequency Identification (RFID)

Nowadays, there is a need for the automated identification of objects and the collection and storage of their data in different areas. The technology that is used for automatic identification is called Auto-ID. The goal of most Auto-ID systems is performance improvement, minimizing errors in data entry and saving time. Various systems for Auto-ID, such as bar codes, smart cards, fingerprint and RFID technology have been used. Figure 2-5 shows an overview of the classification of techniques for automatic identification and data collection (Kern, 2006).

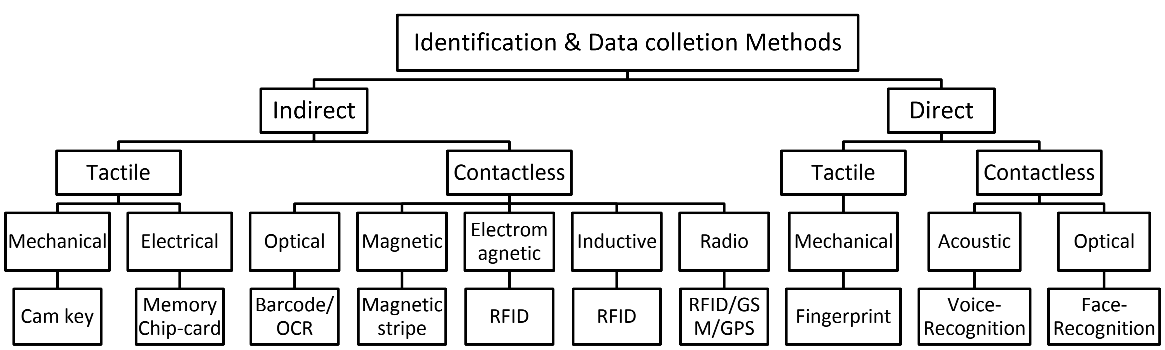


Figure 2-5 Different Identification and Data Collection Methods (Identifikation, 2010)

RFID is a technology in which the data for automatic identification of persons and objects are transmitted by radio waves without physical contact and line of sight between the transmitter and the receiver. In this method, the serial number of a person or an object is stored into a small chip connected to an antenna called RFID-Tag. The RFID technology has three major components as shown in Figure 2-6: The *RFID transponder* or *Tag*, the *Reader* (readers and writers) and the *Information Technology (IT) system* (RFID-blocker, 2010).

The task of the transponders is storing the data and providing readability on demand. There are three main types of transponders: (1) Passive transponders: This model has no internal power supply and receives its required energy from an electromagnetic field generated by the reader antennas, (2) Active transponders: The transponder has its own power supply and can send its information in any set intervals to a receiver, (3) Semi-Active-Passive transponders: The RFID transponder receives the energy required for transmitting and receiving information from an electromagnetic field generated by the reader antennas. Additionally, there is a battery in the tag that is used for the activation of an additional sensor and also for transmitting the data from the sensor to the memory of the tag (Kelm et al., 2009).

Regarding various aspects of RFID, there are some standards related to the *Air Interface Communications protocol* (talking method between tags and readers), *Data content* (formatting data for storage), *Device Communication* (the way of data communication from reader to computer), *conformance* (ways to evaluate that products meet the standard) and *Applications* (how standards are used in shipping labels, for example where do I place labels) (Scansource, 2013).

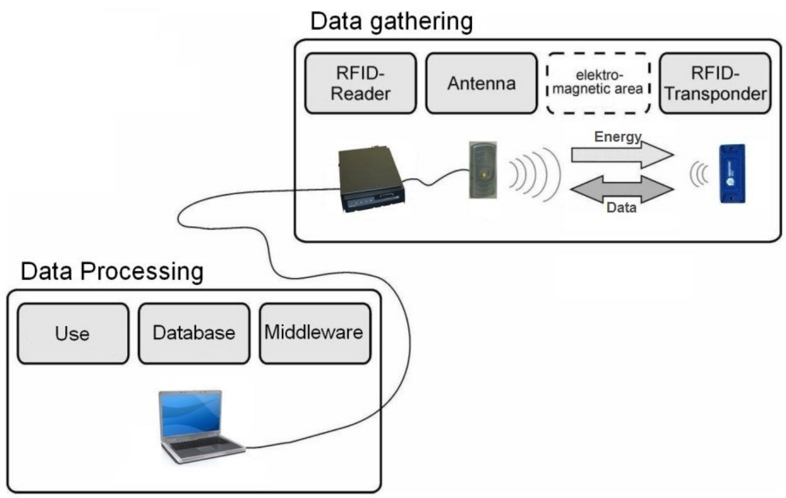


Figure 2-6 RFID transmission system (adapted from Kelm et al., 2009)

The International Organization for Standardization (ISO) and the Electronic Product Code (EPC) Global have been both considered as leaders in the standardization of RFID technology. ISO has provided the 18000 standard and the EPC Global Center has introduced the EPC standard (Violino, 2005).

2.3.2 Application of RFID technology in construction industry

During the last two decades, different industries tried to take the advantage of RFID technology to improve their productivity. Meanwhile, the researchers aware of the benefits of RFID started to propose different application of RFID in construction environment. Jaselskis et al. (1995) in one of the earliest researches in this area discussed the potential applications of RFID technology for concrete processing and handling, cost coding for labor and equipment, and materials controlling. In another research Jaselskis and El-Misalami (2003) provided the general potential application of RFID for metrial management, maintenance, and field operations like personnel management, fleet management, and job status.

Few years later, a European research introduced a wider range of positions for using RFID on construction sites. The potential topics were Quality control, Operation control, Access control, Facilities Management/Maintenance, Tracking resources, Safety/security control, Asset management, Inventory Management Control, Supply Chain Management/Logistics, Planning Logistics as Just-in-time, On-site Inspections, and De-construction and disposals of building materials (National Agency for Enterprise and Construction, 2006).

Torrent and Caldas (2007) focused on automated materials identification and localization model to assess the deviations from materials' actual position to their estimated locations. Moreover, Wang (2008) demonstrated the effectiveness of an RFID-based Quality Inspection and Management (RFID-QIM) for concrete specimen inspection and management. Similar to the previous research, Reisbacka et al. (2008) proposed embedding RFID-tags in the concrete elements enabling them to be identified wirelessly and associated with information in a data system for managing the quality assurance process.

Motamedi and Hammad (2009a) proposed adding structured information to tags attached to the building's components by using RFID technology that to make data related data to the components available during their whole lifecycle from manufacturing stage to disposal phase. Going to the detail, they assumed that a selection of building components such as Heating, Ventilation and Air Conditioning (HVAC) control units, boilers, etc. are equipped by long range RFID tags with enough data storage capacity to carry the data derived from BIM database (Motamedi and Hammad, 2009a, 2009b, 2009c).

In an innovative approach, Soltani (2010) used RFID not only for improving the construction site safety but also for managing the data related to any work-related accident. He assumed that each worker uses his or her Personal Protective Equipment (PPE) equipped by RFID tags, and wearing PPE is checked on the entrance gate of the site by RFID readers. Regarding to the Figure 2-7, in case of any accident, the site supervisor can gather some of required data for filling the report by using data stored on RFID tags attached to different objects or persons.

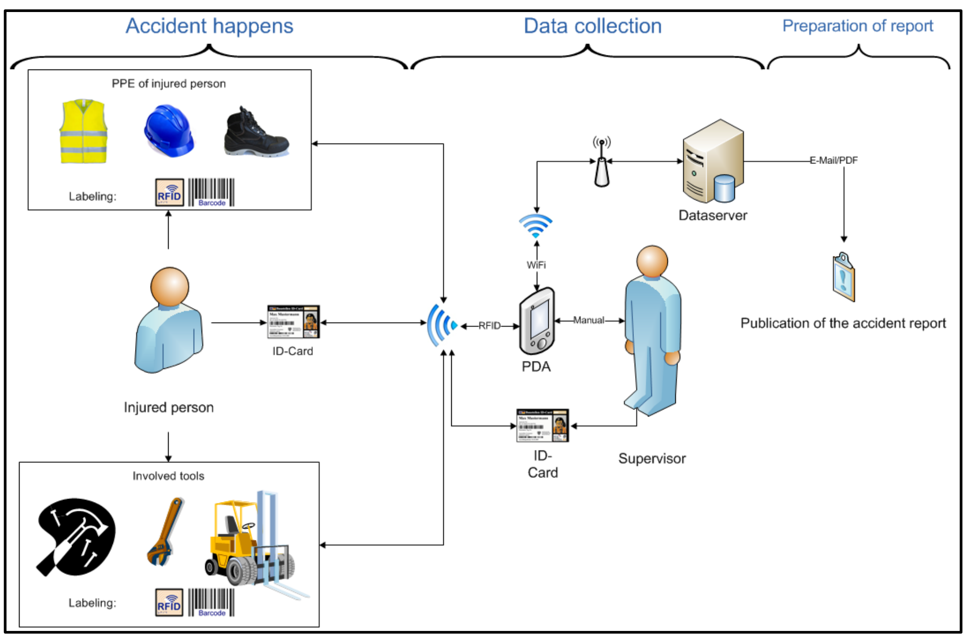


Figure 2-7 Semi-automated accident report system using RFID (Soltani, 2010)

Localization of users carrying on RFID mobile reader or RFID equipped objects is among the most attractive topics in using RFID on construction sites. Taneja et al.

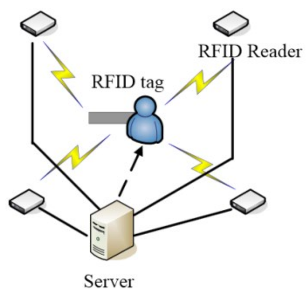
(2010b), Razavi et al. (2012), Montaser and Moselhi (2012a), Motamedi et al. (2012), and Xiong et al. (2013) proposed different approach for utilizing RFID-based localization system on construction. Since the main contribution of this research is to propose a hybrid indoor localization system, reviewing researches related to this topic has the main priority. Therefore, the Section 2.3.3 is allocated specifically to RFID-based localization solutions.

Though there are many researches about utilizing RFID in construction industry, it is not possible to discuss each and every research. Therefore, the author provided a table of information related to different researches using RFID in the construction. The presented information is taken from the research of Erabuild (2006), Helmus et al. (2009), El Ghazali et al. (2012), Guven et al. (2013), and the personal reviewing of the author. The table categorized all the researches in construction into seven groups: supply chain management and logistics, object tracking, project progress management, localization, quality control, lifecycle management, and safety. RFID-based localization algorithms

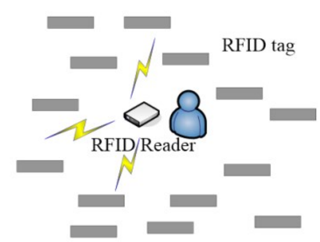
Notwithstanding promising accuracy and ability to fast tracking of RFID, there still is a great potential to remedy the challenges like the interference problem among its components or between its signals and the environment materials for its localization purpose (Papapostolou and Chaouchi, 2011; Joshi and Kim, 2008). More in details, the significant reduction in read range and the data transfer rate by presence of metals or liquid cannot be neglected (Li and Becerik-Gerber, 2011). As a result, there is an essential potential to be invested for solving the RFID interference problem before the utilizing of RFID-based location systems (Papapostolou and Chaouchi, 2011).

RFID localization targets

RFID-based localization can be categorized into two groups: in the first group, *Reader* considers as target but second group considers *Tag* as its target (Sanpechuda and Kovavisaruch, 2008). In the first scenario, RFID tags play the role of reference point for estimating the position of user equipped by the *reader*. However, second scenario aims to find the location of RFID tag attached to the target object with help of deployed either readers or reference tags (Papapostolou and Chaouchi, 2011).



(a) Tag localization



(b) Reader localization

Figure 2-8 RFID-based target localization (Sanpechuda and Kovavisaruch, 2008)

Reader localization:

Determining the location of a mobile robot carrying RFID reader is one the popular contexts in reader localization area. Hahnel et al. (2004) presented a probabilistic measurement model for localization of a mobile robot. Due to technological limitation at that time they forced to use the laser range scanner to prepare RFID map based on the deployed tags in that environment. Lim and Zhang (2006) and Zhang et al. (2009a) developed an approach named *mobile reader dispersed tag*. They formulate the reader localization problem as a pattern matching problem and examined two algorithms (i.e.

Intersection over Union and *Tag-to-Location Mapping Count*) under their proposed method. Ahmad and Mohan (2009) proposed localization process finding Euclidean distance estimated using a propagation model for the relation between RSSI and geometric distance. Using passive reference tags on the floor in grid form can make it possible for the reader to collect the data of those reference tags inside its read range. The next step is to estimate the reader location by calculating the centroid weighted averaging method and Hough transform of the readable reference tags position (Lee and Lee, 2006). To have better accuracy, it needs to increase the density of the reference tags which is costly. To overcome this issue, Han et al. (2007) suggested placing the reference tags in triangular pattern instead of square pattern which can decrease the error to about 18%.

Using a machine learning technique, Yamano et al. (2004) proposed a SVM method. On the first stage which is training phase, the reader acquires the RSS from every tag in various locations. Subsequently, RSS for each location is taught to SVM. Additionally, to reduce the error, ineffective tags for the SVM are removed (Sanpechuda and Kovavisaruch, 2008). Based on random sampling algorithm, Xu and Gang (2006) proposed a Bayesian approach to figure out the position of a moving object knowing the posterior movement probability and the locations of detected tags. The reader position is estimated by maximizing posterior probability based on detected tags' location in the reading range (Sanpechuda and Kovavisaruch, 2008). Eventually, Wang et al. (2007a) research aimed to find the position of a reader by employing the simplex optimization method. Another research done by Soonjun et al. (2009) compared three different methods for position estimation based on fingerprinting approach which are *Maximum*

Number of Intersect Tags, *Maximum and 2nd Maximum Numbers of Intersect Tags*, and *Center of Gravity of Detected-Tags' Locations* (Jingwangsa et al., 2010).

Tag localization:

Hightower and Borriello (2001) applied trilateration on the estimated distance between a target tag and at least three readers (Presented as *SpotON* project). Changing different power levels at the readers in collaboration with reference tags with known location as landmarks was the base of Ni et al. (2004) research under the name of *LANDMARC*. To acquire RSSI for all reference nodes and target node, readers vary their read range, and based on collected data, the *k*-Nearest reference tags are chosen. Then, the position of the target is calculated by using the weight averaging for *k* selected reference tags coordinates. A regional localization system developed by Zhen et al. (2008) used SVM to localize the occupants for lighting control. They deployed many readers in the building to observe the signal strength of the target tag and analyzed the received signal for the localization problem.

For 3D positioning, Wang et al. (2007a) proposed two methods of localization of tags and reader by deploying of tags and/or readers with different power levels, on the floor and the ceiling of an indoor space and using the simplex optimization algorithm for estimating the location of multiple tags (Papapostolou and Chaouchi, 2011). In the research by Stelzer et al. (2004), named *LPM*, TDoA and ToA measurements related to the reference tags and the target tag are used to estimate the location of the target tag.

Bekkali et al. (2007) purposed an analytical method to find the location of the unknown tag by using the multilateration with the help of reference nodes and a probabilistic RFID map-based technique with Kalman Filtering. In this area, Nick et al. (2011) proposed a localization method using Unscented Kalman Filtering (UKF) and reference tags to estimate the location of unknown target tag.

RFInD was a localization system based on a single RFID reader proposed by Saxena et al. (2007). They showed how to localize an object by its proximity to another object. Hekimian-Williams et al. (2010) proposed exploiting phase difference between two receiving antennas for localization to achieve millimeter accuracy. While they focused on precise phase difference measurement and not on the localization algorithm, Than et al. (2012), and Wille et al. (2011) went more to the details of localization issues and stated achieving accuracy of 2 millimeters, although this technique is very sensitive to the situation of the test environment and any changes have great effect on the results.

In a research done by NEC lablatories (Saxena et al., 2007), a target tag can be localized by using only one RFID reader and changing the antenna gain. The main tasks in their work are namely *Proximity Detection* and *Tag Association* (kind of clustering technique is applied). Joho et al. (2009) used probabilistic approach to approximate the location of target tag or mobile agent equipped by RFID reader. Recently, Wang and Cheng (2011) integrated RFID with vision technique to enhance the accuracy of RFID-based tag localization systems.

2.3.3 RFID localization Solutions

2.3.3.1 Lateration-based RFID localization

Based on the explanation of lateration in Section 2.2.6.1, the key point for this method is the distance measurements between reference positions. To obtain the distance, theoretical or empirical model are proposed to relate the received signal strength, ToA, or TDoA to numerical distance between the reader and tag. The following, major lateration-based projects are reviewed based on the research of Li and Becerik-Gerber (2011): (1) Hightower et al. (2000) proposed attaching the tags to mobile nodes as target for localization and deployed three or more readers in the environment to detect the target tag. An empirical function is used to estimate the distance of the target to each reader based on received signal strength data; (2) Yu et al. (2009) used the triangulation method in a clean environment with few partition walls and sponges laid out on the walls to absorb magnetic wave reflection. This clean area dramatically improves accuracy. To map the signal strength and distance, they applied and analyzed offline instead of utilizing an empirical function; (3) Another approach is to apply multilateration method to minimize the sum of error distance between the target tag and all readers based on a signal propagation model to convert the RSSI to distance (Zhou and Shi, 2011).

2.3.3.2 Neighborhood-based RFID localization

Referring to Section 2.2.6.4, the localization approaches using closest neighboring points (with known locations) to the target tag are named Neighborhood method, and the measurement for the nearness of a set of fixed points around the target plays the main role in these approaches. The measured nearness, along with the corresponding known locations, is used to estimate the location of a target. Compared to lateration methods, neighborhood methods have better adaptability in complex and dynamic environment (Li and Becerik-Gerber, 2011).

In addition, Pradhan et al. (2009a), Taneja et al. (2010a), and Li and Becerik-Gerber (2011) used *k*-NN approach separately in their method for their proposed localization systems. However, LANDMARC (Ni et al., 2004) has been one of the favorable methods in this area since 2003, and during the last decade different researches have been done to improve its accuracy and reliability. Two types of tags are utilized in this method, tracking tags attached to the targets and reference tags deployed in the sensing area at known locations. Active RFID tags are preferred to passive tags due to their wide read range and better signal stability.

The readers measure and store RSSI values coming from both target tag and reference tags. The nearness degrees are calculated based on cumulative signal difference between target tags and each reference tag. By using the *k*-NN algorithm the target's location is computed regarding the neighbors' locations and nearness to the target.

Ni et al. (2004) performed a case study to validate their proposed method within an area of 4m × 10m and provided an accuracy of within 1 m with 50% probability and within 2 m with 90% probability. The result of the sensitivity analysis showed that the optimal number of *k* neighbors is four. Furthermore, deploying more readers or reference tags has a positive effect on the accuracy results. According to the researchers, the low accuracy in the signal strength report, high latency or time delay, and variation in tags' behavior are counted as the limitations of the method (Li and Becerik-Gerber, 2011).

2.3.3.3 **LANDMARC enhancements**

Several research teams have been trying to improve LANMARC approach as the basis for the localization. A comprehensive review was done by Li and Becerik-Gerber (2011) and they compared the proposed enhancements in their research. The following is an updated review on LANDMARC improvements' methods with the addition of some new researches in this area.

(1) Improvement of the localization accuracy:

The VIRE method introduced by Zhao et al. (2007) to achieve higher accuracy used imaginary reference tags called *virtual tags* which are virtually distributed between real reference tags to increase the density of the reference tag grids without imposing more cost. A linear interpolation is applied on the RSSI of real reference tags for generating RSSI of the virtual tags. The conditions of their field test with four readers and 16 reference tags are: (1) a semi-closed area without existing of concrete walls and furniture; (2) a spacious closed area with few numbers of metallic objects; and (3) a typical university office with many desks and chairs. An average estimation error of less than 1.5m for locations at the boundary of the sensing area was presented. Additionally, a 0.29m error for other locations with reduction of error ranging from 17% to 73% over LANDMARC was provided in their research.

Zhang et al. (2009b) introduced an algorithm named RFIDiffFreeLoc to improve the accuracy by eliminating the impact of the diversity of reference tags resulting from different tag types or used-time of built-in batteries. They analyzed the impact of noise by performing simulation tests and compared their proposed algorithm with LANDMARC algorithm. Although the result of the tests using four readers at the corners of a noise-free area and a grid of reference tags showed error distance reduction from 0.45 to 0.1m with 50% probability, the reported improvement in the simulated environment with noise, or in practical experiments was less significant.

Adding a signal strength preprocessing phase to improve the accuracy of current techniques was proposed by Hsu et al. (2009). They reduced the received signal fluctuation by using a moving average filter and smoothed the RSSI values for each tag and used the latest RSSI values for calculating a dynamic average. The dynamic average helps the system to minimize the impact of the environmental changes in the sensing area because of significant variance of a single RSSI value. They indicated a 0.1m reduction on the largest error of estimated locations of all targets in the field test over LANDMARC.

(2) Algorithm improvement

A Bayesian-based algorithm was proposed by Yihua et al. (2008) to achieve more accurate location of the target. They took the advantages of LANDMARC to limit the error into a certain scope and applied Bayesian-based localization algorithm that can reach high accuracy level compared to weighted-averaging. However, they stated that the accuracy could be drastically decreased by the increase of measurement error results. Their simulation results showed an error decrement from 1 m to 0.5m.

As a limitation, LANDMARC cannot suggest second possible locations of the target tag in case its first was wrong. To overcome "blind search" situation, de Amorim Silva and da S Gonçalves (2009) proposed LANDMARC+ solution to suggest a possible location of the target tag. By assuming the availability of the same number of readers in each room, the mean Euclidean distance of all tags in each room can be calculated. The room with the smallest distance is chosen as the secondary possible room. Furthermore, Khaan and Antiwal (2009) extended LANDMARC+ to estimate 3D locations of the target tag.

Xiao et al. (2010) and Tang et al. (2011) developed an environmental-adaptive approach to update the signal propagation model in a closed-loop feedback correction manner. They used LANDMARC to predict the region of the target tag.

Yinggang et al. (2011) proposed using pseudo-absolute positioning algorithm in combination of LANDMARC method. To eliminate lots of unnecessary calculations, they selected *k*-Nearest reference tags by LANDMARC and applied their proposed algorithm to estimate the location of the target tag. However, they selected a group of four tags from only 6 reference tags to apply their algorithm in the test.

(3) Error value calibration

A calibration solution was introduced by Jin et al. (2006) on the estimated coordinates of the target node. This approach collects the reference tags that are detected at the same time as the target tag and selects *k* nearest neighbor candidate' reference tags and estimates their location based on RSSI values by applying triangulation method. Then the average error is obtained from the difference between estimated coordinates and actual positions of *k*-Neighbors. Finally, the calculated error is added to the estimated coordinates of the target tag by LANDMARC solution to provide a more accurate location of the target. Unfortunately, the authors did not elaborate on the used triangulation mechanism in their research.

From another point of view, Jiang et al. (2009) suggested to calculate the location of each of the *k*-Nearest reference tags separately and compared them with their actual location. In the last stage, the averaged-error of all selected reference tags is added to the estimated location of target tag from the LANDMARC method.

Jiang et al (2009) suggested a different solution compared to Jin et al. (2006) approach. In their approach, the location of each nearest reference tags to the target was calculated using the actual location of other reference tags and the estimated location of the target. This calculation was performed for all nearest reference tags and the error was averaged to be used for correcting the estimated coordinates of the target tag.

(4) Reference tags' improvement

Since the LANDMARC-based solution is structured based on the existence of reference tags, deploying a large number of reference tags has direct effect on the accuracy improvement. Adding more reference tags imposes a heavy computation load, increment of latency, and the more investment in the hardware. The following researches proposed alternative methods of tags' deployment to decrease the density of reference tags with no negative affect on the accuracy (Li and Becerik-Gerber, 2011).

A more flexible localization solution with lower computation load was developed by Sue et al. (2006) under the name of FLEXOR. They proposed to cover the sensing area with boundary reference tags arranged in hexagons and a cell reference tag located at the center of each hexagons. Two localization modes provided are region mode (lower accuracy) and coordinate mode (higher accuracy) for different applications. In the case of the region mode, the system finds the right hexagon based on the RSSI values of the target tag and the *cell tag.* If the goal is to estimate the exact location of the target, then the RSSI values and coordinates of the two closest boundary tags to the target and the cell tag within the hexagon will be used to estimate the coordinates of the target tag (coordinate mode).

However, this method achieved best accuracy with shorter reader power level intervals, large number of readers, and deployment of each of readers on each side of the sensing area. However, the deployment of the reference tags in a hexagons pattern may not be applicable in many real cases.

Close to idea of FLEXOR, Yihua et al. (2009) proposed a triangle pattern for deployment formation of reference tags. The result of their simulations demonstrated that a forth nearest neighbor is the source of error. Therefore, the reference tags were placed in a triangular mesh, and the algorithm has chosen only three nearest neighbors' localization. Li et al. (2009) introduced the "*key reference tag*" approach to reduce the number of reference tags while retaining accuracy. They applied Machine Learning to find and eliminate redundant reference tags.

2.3.3.4 Artificial Neural Network-based RFID localization

Indoor RFID localization systems face usually multipath phenomenon and layout changing. The problem will be more complicated when the systems are based on empirical or theoretical formulas which cannot be adapted to the geographic features of the sensing area. ANN overcomes this limitation by learning the relationship between the signal power and the location of transmitters for each sensing environment (Wu et al., 2009). The following literatures investigate the different applications of ANN for RFID-based indoor location systems.

Wu et al. (2009) applied the Backpropagation (BP) network to find the best location of the target node. They used reference tags as landmark and the RSSI values recorded from each of references are the input for training the network. On the other hand, they allocate one zone to each reference tag presented by a number. During the offline phase, the ANN learns the relation between RSSI values and the zone numbers. After training the model, the network receives RSSI value of the target tag and predicts the zone that the target belongs to.

Martínez Sala et al. (2010a) proposed ANN similar to Wu et al. (2009) research but entered the exact coordinates of the reference tags to the network for training phase instead of using zone's numbers. As result, the ANN could provide the position of the target in the localization phase. In another research, Martínez-Sala et al. (2010b) improved their previous method by adding a clustering phase before training the network. For this phase, they defined each cluster as a set of readers which are associated with a specific area of the sensing environment. Therefore, the network also learns which cluster is more suitable for its corresponding area.

Kehua et al. (2011) suggested using Genetic Algorithm (GA) in addition to BP network to optimize the initial value of ANN weights and thresholds. Lin et al. (2011) defined five ANNs in parallel and used the GA to set the optimized weight values of each neural network based on the performance of each network. Kuo et al. (2012) changed the previous ANN to an Artificial Immune System-based Fuzzy Neural Network (AIS-FNN) because they believed that AIS-FNN has more accurate results and it is much easier to interpret the training results than ANN. Moreover, Huang et al. (2010) developed Fuzzy Neural Network (FNN) architecture to adaptively tune the environmental parameter. In spite of other researches in this area, they used FNN to train the relationship between environmental errors of each reference node with its corresponding coordinates in their network. However, they did not provide any details regarding the results of their localization case study.

Using VRTs in combination with ANN is another method proposed by Ng et al. (2011). Although the concept of adding VRTs between real tags was proposed under the name of VIRE but Ng et al. (2011) used a nonlinear interpolation instead of linear interpolation for preparing the required received signal map. They also suggested applying RBFNN since they believed this network includes simple structure, fast learning and good approximation ability (Ng et al., 2011; Tao and Hongfei, 2007).

Recently, Jiang et al. (2012) proposed an improved LANDMARC algorithm using ANN to achieve better accuracy and precision and also to shield the interference of obstacles by using their method. In this research, a BP neural network contains eight nodes for the input layer, two nodes for the output layer, and 10 nodes in the hidden layer. The input values will be the signal similarity between target and all reference tags. The output node allocated to the target tag coordinates represented. Although the results of their experiment shows an acceptable improvement but it seems they tested in a small sensing area less than 10 m^2. Increasing the scale of the area using only four nearest nodes for training the network can result in large distance error. Therefore it is necessary to add more real or virtual reference tags to overcome the density problem.

2.4 Building Information Modeling (BIM)

The highly fragmented nature of construction industry causes a tremendous amount of coordination to bring multi-disciplines and different contractors and agents in a project together. The complexity of communication between the various stakeholders with the significant effect on the efficiency and performance of the industry is a serious barrier (Isikdag et al., 2008). The high annual lost in this industry due to lack of interoperability and absence of a standard information transfer model between different software applications used in the construction industry showed a major need for developing BIM in order to overcome problems related to interoperability and information integration by providing effective management, sharing and exchange of a building information through its entire lifecycle (Gallaher et al., 2004; Isikdag et al., 2008).

As illustrated in Figure 2-9, the major issues with the documents centric approach versus centralized information centric situation are: (1) significant communication errors and loss of project information; (2) increasing 25-30% of the construction cost by splitting up of processes and lousy communication; and (3) repetition in creation of the same information in different software and entering the same information on average seven times in different systems before a facility is handed over to the owner (Sjogren and Kvarsvik, 2007).

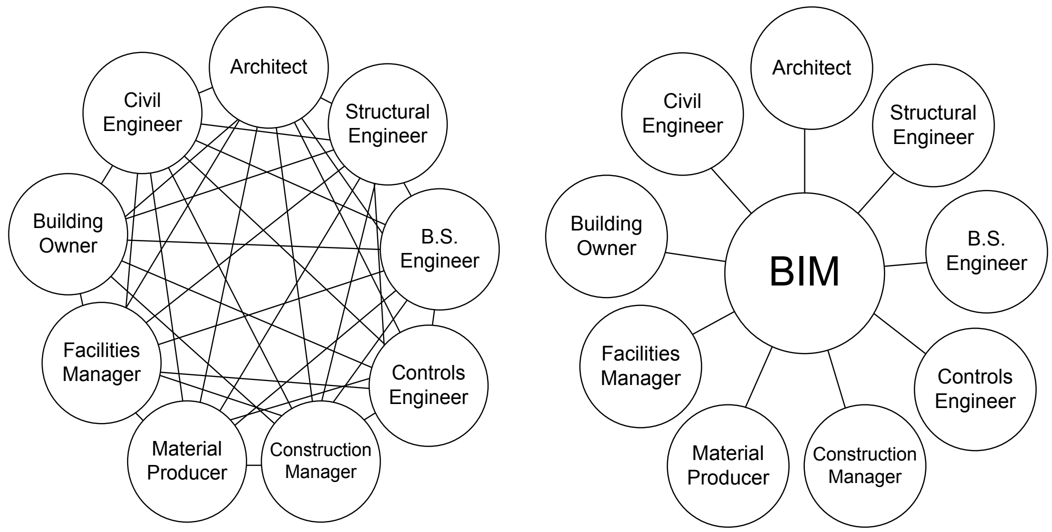


Figure 2-9 Document centric vs. information centric situation (Sjogren and Kvarsvik, 2007)

Since the construction projects are not limited to the construction of building, there are other available data models including Bridge Information Modeling (BrIM), Road Information Modeling (RIM), Municipal Information Modeling (MIM), and Infrastructure Data Modeling (IDM). The central idea behind all aforementioned models is to use the combination of the 3D model and its related database. Therefore, a new definition in each of these models can be extended within the scope of the other models (Hammad et al., 2013).

2.4.1 Definition and scope

Associated General Contractors Guide defines BIM as a data-rich, object-oriented, intelligent and parametric digital representation of facilities. Views and data can be extracted and analyzed based on various users' needs to generate information that can be used to make decisions and improve the process of delivering the facility (AGC, 2005).

National Building Information Modeling Standard (NBIMS) knew BIM as: (1) a product or intelligent digital representation of data about a capital facility, (2) a collaborative process which covers business drivers, automated process capabilities, and open information standards use for information sustainability and fidelity, and (3) as a facility lifecycle management tool of well understood information exchanges, workflows, and procedures which stakeholders use throughout the building lifecycle as a repeatable, verifiable, transparent, and sustainable information based environment (NBIMS, 2007).

Strafaci (2008) stated that BIM is not a product or proprietary software program, but it is an integrated process built on coordinated, reliable information about a project from the design phase through construction and into operation phase. While it has its roots in architecture, the principles of BIM apply to everything that is built, including roads and highways, and civil engineers are experiencing the benefits of BIM in the same way they are enjoyed by architects.

The information storage capability of BIM makes it more than a 3D model. It enables engineers to more easily predict the performance of projects before they are built; respond to design changes faster; optimize designs with analysis, simulation, and visualization; and deliver higher quality construction documentation (Strafaci, 2008). Moreover, it allows the extended teams to exploit useful data from the model to facilitate earlier decision making and more economic project delivery.

2.4.2 BIM data storage, exchange and sharing models

BIM data has the capability to be stored as a digital file or in a database. Additionally, the potency of sharing and exchanging between several applications is another BIM benefit (Isikdag et al., 2008). Going to the detail, ownership and centrality of data differentiate data sharing from data exchange. A one-to-many relationship can be assigned to the data exchange model, which means that the master copy of data is maintained by one software system with ownership authority, the snapshots of data are exported to other users. But in the data sharing model, a many-to-one relationship shows a centralized control of ownership on a master copy of data. The data sharing model simplifies the revision control issue associated with the data exchange model (Isikdag et al., 2007; Vanlande et al., 2008).

Isikdag et al. (2007) and Vanlande et al. (2008) introduced five different methods for storage and exchange of BIMs: (1) Data exchange by using physical mediums (e.g. CD/DVD) or computer networks (e.g. Internet) for transferring physical files; (2) Data sharing through Application Programming Interfaces (APIs) where the BIM physical file can be accessed through proprietary API or a Standard Data Access Interface (SDAI, 2008). For instance, if the physical file is an Extensible Markup Language (XML) file, then the model needs appropriate XML interfaces for data sharing (i.e. APIs supporting Document Object Model (DOM)); (3) Data sharing based on a central database makes accessing the data and using database features such as query processing and business object creation possible for multiple applications and users; (4) Data sharing to access through single unified view, from multiple distributed but synchronized databases; and

(5) Data sharing based on a Web service interface which can provide access either to the BIM stored in central project database, or to an API with the ability to access to a physical BIM file or to the domain specific views of the model.

2.4.3 IFC model

International Alliance of Interoperability (IAI) developed the IFC standard as a standard BIM in supporting and facilitating interoperability across the various phases of the construction lifecycle (Isikdag et al., 2008).

Developing IFC as an object-based, non-proprietary building data model aims to support interoperability across the individual, discipline-specific applications that are used to design, construct, and operate buildings by capturing information about all aspects of a building throughout its lifecycle. Most of the major Computer-Aided Design (CAD) vendors as well as many downstream analysis applications are supporting IFC as a tool to exchange model-based data between model-based applications in the construction industry (buildingSMART, 2013; Khemlani, 2004).

As IFC needed a uniform computer-interpretable representation, STandard for the Exchange of Product model data (STEP) was proposed as the language of its information exchange model. The first attempt for developing STEP happened in 1984, when ISO focused on defining standards for the representation and exchange of product information in general, and continues to be used in various design disciplines, such as mechanical design, product design, and so on.

As an open data exchange format, IFC is publicly accessible to everyone and can be used by commercial applications to exchange data (Khemlani, 2004).

2.4.3.1 **The overall architecture of the IFC model**

Basically, the IFC model covers not only tangible building components (e.g. walls, doors, beams) but also more abstract concepts such as schedules, activities, spaces, organization, construction costs, etc. in the form of entities which comprise name, geometry, materials and relationships. Figure 2-10 illustrates the overall architecture diagram of the IFC4 model is divided into four layers (i.e. resource layer, core layer, interoperability layer and domain layer). Each layer contains several modules that include various entities, types, enumerations, property and quantity sets. The main characteristic of this modular layering system is that an entity at a given level can only be related to, or reference, an entity at the same or lower level, but not an entity at a higher level.

The modular design of IFC is intended to make the model easier to maintain and grow, to allow lower-level entities to be reused in higher-level definitions, and to make a clearer distinction between the different entities so that the model can be more easily implemented in individual discipline-specific applications (Khemlani, 2004).

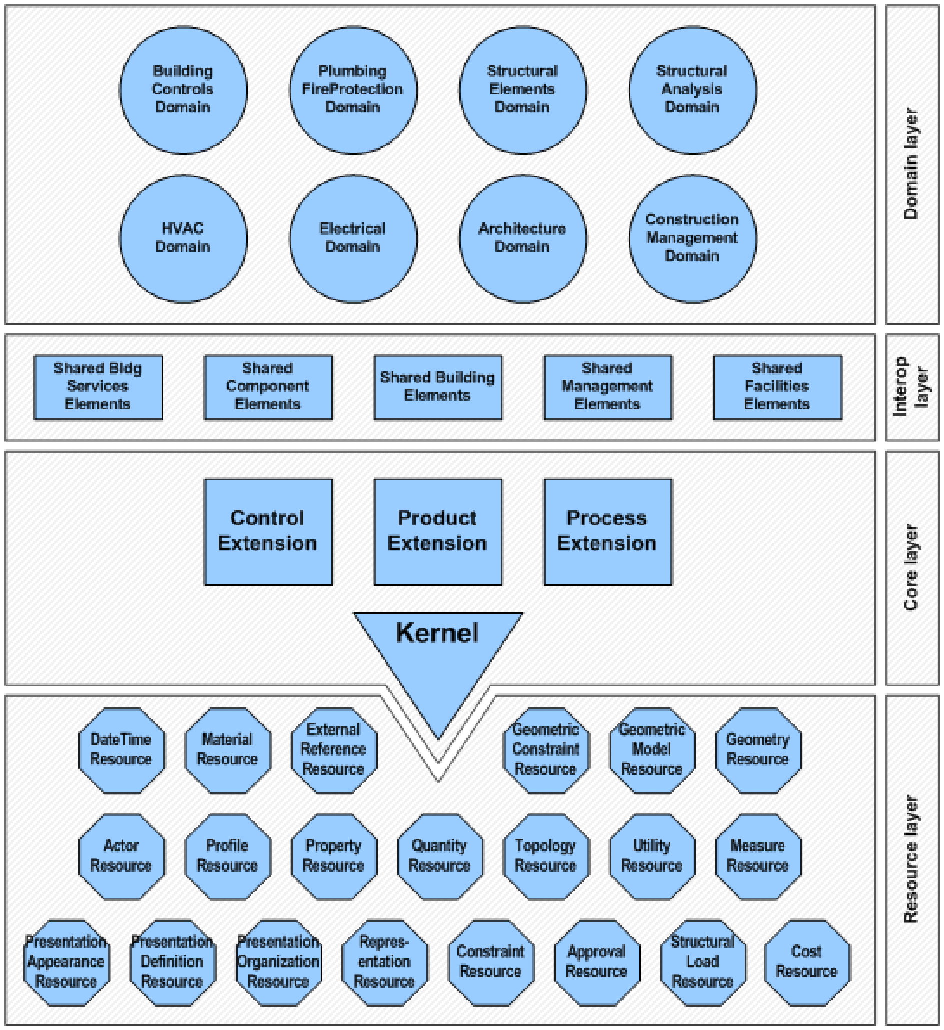


Figure 2-10 Data schema architecture with conceptual layers (BuildingSmart-Tech, 2013)

2.4.3.2 Extending IFC

The IFC standard is an object-oriented approach by corresponding entities to objects together with the inheritance. Applying the inheritance reduces the effort to redefine content as it can be inherited from the super entity. Hence, the description of both the entities and their inheritance relationship is required in the information model to give a full picture of the use of related entities.

The IFC specification is written using the EXPRESS data definition language which has the advantage of being compact and well suited to include data validation rules within the data specification. Additionally an ifcXML specification is provided as an XML schema 1.0, as defined by W3C (buildingSMART, 2013).

There are three mechanisms to extend the IFC standard; (1) new entities or types definitions, (2) using proxy elements, and (3) using the property sets or types (Weise et al., 2008). Zhiliang et al. (2011) noted that defining new entities or types is the best way to extend the IFC standard among the three alternatives since the newly defined entities and types can then be used in the same way as the existing ones. However, it normally takes at least two years to define new entities by IAI (Weise et al., 2008). For the other two alternatives, additional implementation agreements about the definition of the property sets and proxy elements are required, if they are used to share data with other application software. Hence, the other two alternatives are more practical to meet specific local requirements.

2.4.3.3 **Related research**

Froese et al. (1999a, 1999b) analyzed the IFC classes related to project management including project planning and cost estimation. Their implementation and testing confirmed the applicability of overall approach of the model and provided recommendation for potential improvements. Weise et al. (2000) proposed an extension for the structural engineering domain which was not supported in the IFC standard at the time. The same group further suggested an IFC extension for structural analysis (Weise et al., 2003) that contained the conceptual modeling and the envisaged actors and usage scenarios leading to data exchange views. Fu et al. (2006) presented a holistic architecture of nD modeling tools based on the IFC. They have also developed an IFC-viewer as central interface of nD modeling tool. Ma and Lu (2010) discussed an approach for representing information resources by analyzing available IFC entities and relationships. Ma et al. (2013) presented an IFC-based information model for the construction cost estimating for tendering in China. Their research included information requirement model for construction cost estimating for tendering in China, and an IFC extension for representing the model.

Sørensen et al. (2008 and 2010) mentioned that the product and process model ontology IFC supports the RFID by the use of the *IfcClassificationReference* class, a subtype of *IfcExternalReference*. By adding the Globally Unique Identifier (GUID) from the RFID tag to the IFC model as an *ItemReference* it can be associated with any building element in the virtual model. There is also an inverse relationship between an *IfcClassificationReference* and *IfcRelAssociates* which would give the possibility to navigate back from an External reference to an *IfcBuildingElement* (subtype of *IfcObject*) (BuildingSmart-Tech, 2013). They recommended to model RFID tags not only as an ID attribute but as an object or property set in the IFC model with properties such as GUID, current location, planned location, time and date for tag reading, user name, and active/deactivated tag. However, there is no effort to propose an specific extension for RFID systems to the IFC.

2.5 Summary and conclusions

This chapter reviewed the concepts, techniques, main technologies and standards that are used in the current research. The literature review included the information about RTLS technologies and context aware information delivery and RFID based localization techniques. Furthermore, the basics of RFID technology, including components and details about different tag types, operating frequencies and standards, were discussed. Active RFID technology is selected in this research as a localization tool due to its emerging popularity in the construction industry, ease of use, robust radio propagation, and wide read range.

Moreover, ANN is considered for the calculation of the location of the target tag in the proposed method due to its capability to estimate the location more accurately. In addition to ANN, VRT is used to increase the density of the reference tags in the construction site without imposing additional costs for the deployment of more real reference tags. BIM was also covered in this chapter, including data storage/exchange /sharing models and IFC.

CHAPTER 3 BIM EXTENSION FOR INCORPORATING RFID

3.1 The need for including RFID definitions in a BIM

RFID system, as the technology used in this research for the localization of moveable target using moveable RFID reader on construction sites requires an appropriate interaction between data available in BIM and RFID system components. Motamedi and Hammad (2009a) introduced the concept of distributed BIM on RFID tags' memories but this idea has remained conceptual. Therefore, there is a need for further research and standardization efforts in adding definitions of RFID system components (i.e., tags, readers and antennas) to the IFC model as a standard BIM format. In this chapter, a detailed requirements gathering and modeling are performed (Motamedi et al. 2013a). These include the following steps: (1) Identifying RFID technology components (explained in Section 0); (2) Identifying properties for each RFID component type including *Physical properties* and *specifications* such as electrical, radio, enclosure rating and shape; *Operation properties* such as installation date and the write cycle count; and *Data management properties* such the markup language; and (3) Identifying the relationships with other elements (explained in Section 3.2.4).

As explained in Section 2.4, the proposed method can be applied to other types of information modeling (e.g. BrIM, RIM, MIM, and IDM) used in the construction industry. The main reason for choosing BIM instead in this research is because of its popularity, well development, and the existing of more tools to test the proposed method.

As explained in Section 2.3, various research and industrial projects suggested attaching RFID to objects for the localization of the target objects during the construction phase of the project. It is also proposed to include the tags in the design of the objects as an integrated component. Consequently in some cases, the tag can accompany the object throughout the lifecycle to host related information. Assuming that RFID tags and readers will be extensively available in the construction site, they can be considered as components of the facility and localization system. Thus, there will be a need for a standard and formal definition of RFID systems in BIM.

Available RFID tags in the construction site can store data related to resources, elements, components, equipment and even for temporary placement, e.g., reference markers. These data are dynamic and taken from a standard BIM database. Figure 3-1 shows how data chunks from the BIM database are copied into the memories of different RFID tags. For example, the tag can contain the location coordinates of the object it belongs to or a place which is known as a reference marker for the localization system. In order to interrelate the objects' information in a BIM and their associated tags' memory, the relationship between the objects and their associated tags should be identified and modeled. Having these relationship defined in a BIM, the process of selecting data to be stored on tags' memory can be facilitated. For example, in order to copy an object's last position on the tag's memory, the related object to the chosen tag is identified through the existing relationships and its new position are queried within the model without further need for measurement. The selected data is then copied to the tag's memory.

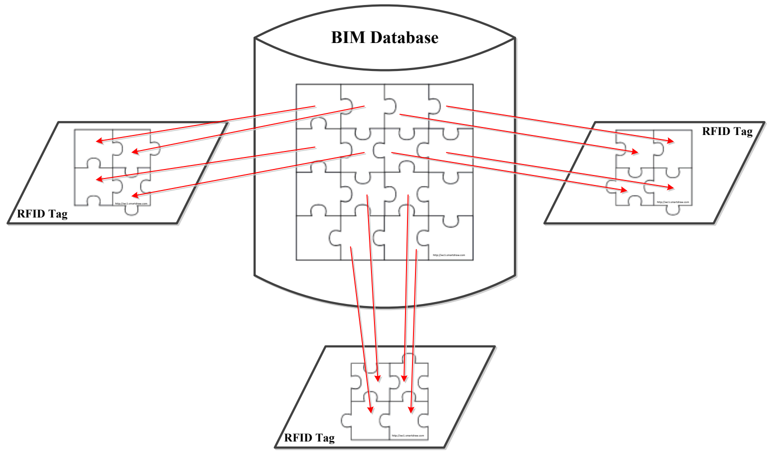


Figure 3-1 Conceptual BIM-Tag Data Relationship (adapted from Motamedi and Hammad, 2009a)

3.2 Proposed extension for IFC

Definitions and data structure of the recently released IFC4 standard are considered as the basis for the proposed extension module. To avoid the unnecessary expansion of the model, it is investigated to add the minimum number of new definitions of objects and relationships on this version of IFC while reusing the available relationships and property sets.

3.2.1 Requirements gathering for RFID system definitions

Various resources are used for the design phase including the RFID manufacturer's data sheets and specifications, scenario/case studies in which RFID technology is utilized for lifecycle management of facilities (e.g., Motamedi and Hammad, 2009; Ergen and Guven, 2009). In order to identify the relationships between RFID components and objects or building components, our proposed framework in which RFID tags are assigned or attached to objects or building components is used.

3.2.2 Sample scenario: updating the location coordinates of an object as a reference point

An RFID *reference tag* is a tag the memory of which contains the coordinates of the object it is attached to (Motamedi et al. 2012). Having the information available on the reference tags will provide users with the ability to estimate the position of the objects with unknown locations and equipped with RFID tags. In order to update these location data on the reference tag, the BIM database is used.

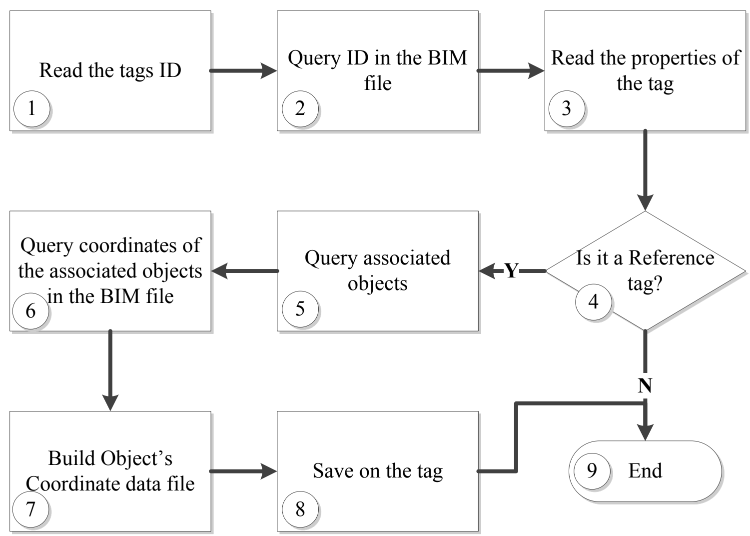


Figure 3-2 Process flowchart to update assets' coordinates on a reference tag (adopted from Motamedi et al. 2013a)

Figure 3-2 shows the process flowchart to update the objects' coordinates on the reference tag's memory: (1) The tag is scanned and the ID is read by the software; (2) the software queries the ID in the BIM database; (3,4) software reads the properties of the scanned tag on the IFC file and verifies if the detected tag is a reference tag; (5) using available relationships in the IFC file, the software identifies the related object; (6) the software reads the location coordinates of the object from the IFC file; (7) it builds the data file containing the queried data; and (8) the data file is merged into the data on the tag.

3.2.3 RFID system elements

RFID hardware can be grouped in three major categories: (1) RFID tag (transponder), (2) RFID reader (Transceiver), and (3) antenna. Each of these entities and their associated attributes should be defined. An antenna is defined in IFC as an enumeration of *IfcCommunicationsApplianceType.* Hence, this definition can be used to model the antenna attached to readers and tags (Motamedi et al., 2013a).

The RFID components are defined under the *IFC Electrical Domain* schema which forms a part of the *Domain Layer* of the IFC model (BuildingSmart-Tech, 2013). A new type (i.e. *RFIDSystemType*) is proposed to be defined in IFC with four enumerations: (1) passive tag, (2) active tag, (3) passive reader, and (4) active reader. Figure 3-3 shows the hierarchy of entities for the new defined object. Other possible types, such as *Semi-Active RFID* that inherits properties of both active and passive tags, can be identified using a combination of properties related to each of the above major types.

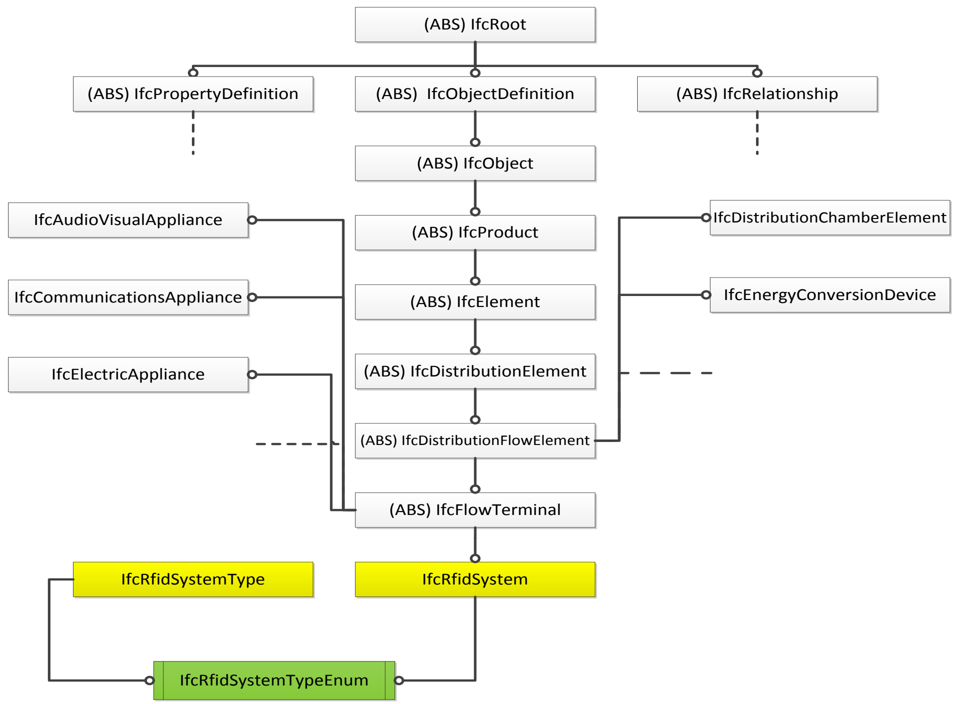


Figure 3-3 IFC hierarchy for RFID system

3.2.3.1 RFID system properties definition

As explained in Section 3.2.1, various resources are used to identify the required property sets of RFID system's components. For example, data sheets provided by RFID tags manufacturers were used to identify the required set of electrical and radio property types to be included. A survey of available RFID systems is conducted to identify various shapes and casing materials for RFID tags. Moreover, properties related to the operation of RFID components during the lifecycle are added such as installation date, current battery level and the incremental write cycle count. These data are used to identify the state of RFID usage at any given time. These data can be used to plan for replacement or maintenance of the tags that are reaching their end of lifecycle. Due to the fact that RFID tags' memory is used to store data, some properties related to the data should be captured. For example, various standard IDentifiers that are assigned, the type of cipher that is used to encrypt the data (Motamedi et al., 2011), and the markup language are required to be defined. It is also suggested to add a local copy of the memory content of the tags in the BIM database. Having a local copy of the last updated content of the memory can be used to check data integrity and synchronization.

The properties of RFID systems are defined according to *property set assignment concept* of the IFC. Available property sets are reused, such as *Pset of Electrical Device Common*, *Condition*, *Environmental Impact Indicators*, *Manufacturer* (Type and Occurrence), *Service Life,* and *Warranty*. IFC standard (BuildingSmart-Tech, 2013) can be referred to the details of the above-mentioned sets.

Table 3-1 Proposed property sets (Motamedi et al., 2013a)

Property set	Description	Example	Active Tag	Passive Tag	Reader
Standard compliance	Communication, memory, ID type, and data type standards	ISO18000	✓	✓	✓
Range	Operating readability range of tag or reader	300 m	✓	✓	✓
Frequency	Communication frequency range for the tag	915 MHz	✓	✓	✓
EPC number	Universal identifier as defined in the EPCglobal tag data standard	urn:epc:id:sgtin:0134 000.213254.343	✓	✓	
TID	32-bit transponder identification number	2E8E0D4C	✓	✓	
Total memory size	Total size of tags memory	32 KB	✓	✓	
Shape type	(1) *Label*, (2) *Ticket*, (3) *Card*, (4) *Glass bead*, (5) *Integrated*, (6) *Wristband*, (7) *Button*	Label	✓	✓	
Battery type	Battery type standard	LR AA	✓		
Battery level	Percentage of available battery	40%	✓		
Reader type	*Mobile, Fixed*	Mobile			✓
Number of antennas	Total number of supported or attached antennas	4	✓	✓	✓
Reader buffer	Number of tags that can be read	400			✓

Separate property sets are defined to include RFID type-specific information. For example, the battery life can be only a property of active tags. Table 3-1 shows some of the recommended property items for all RFID system entities. More details can be found in (Motamedi et al. 2013a). These property items are placed in five property sets (PSet) that are: RFID Common PSet (for properties that are shared between all types), Active tag Pset, Passive Tag Pset, Active reader Pset, and Passive reader Pset (Motamedi et al., 2013a).

3.2.4 Relationships with other objects

The RFID tag/reader is either attached to an object/building element or is part of it (as a subcomponent). These relationships are physical attachment or decomposition type. Although each tag/reader is attached to only one element, an element can be physically attached to several RFID tags/readers.

The *decomposition* relationship between an RFID tag and the associated element can be defined using existing IFC relationship definitions. Entities such as *IfcRelDecomposes* and its subtype *IfcRelAggregates* are used to realize this relationship between tags and their associated elements.

In order to describe the physical connectivity between an RFID tag/reader and an object or building component, *IfcRelConnectsElements* together with *IfcConnectionGeometry* are used. *IfcConnectionGeometry* is added to describe the geometric constraints of the physical connection of two objects. The physical connection information is given by specifying exactly where at the relating and related element the connection occurs.

Additionally, IFC provides the eccentricity subtypes, to describe the connection when there is a distance between the tag and the element. IFC provides the following connection geometry/topology types: (1) point/vertex point, (2) curve/edge curve, and (3) surface/face surface (Motamedi et al., 2013a).

Furthermore, one or many elements or spaces can be logically assigned to a tag in order to keep data related to them on its memory. The following are different alternatives for object-to-tag assignments: (1) A single object is assigned to a tag (*object tag*): The tag contains data about one asset. In this scenario, the tag is attached to the asset; (2) A group of objects is assigned to a tag (*group object tag*): More than one object is assigned to the tag (for example, reference tags placed in an specific zone); (3) Several spaces and/or objects are assigned to a tag (*reference tag*): The tag contains data about the space (e.g. coordinates, room number and occupants) and data about selected objects in that space; (4) A space is assigned to a tag (*area tag*): The tag contains data about the space (e.g. floor plan, occupants); and (5) A group of spaces is assigned to a tag (*zone tag*): The tag contains data about a group of spaces (e.g. contains department name). Figure 3-4 conceptually shows the relationship of an RFID tag and associated and attached assets and spaces. All of the above-mentioned logical relationships between tags and elements can be described in IFC using *IfcRelAssignsToProduct* entity (Motamedi et al., 2013a).

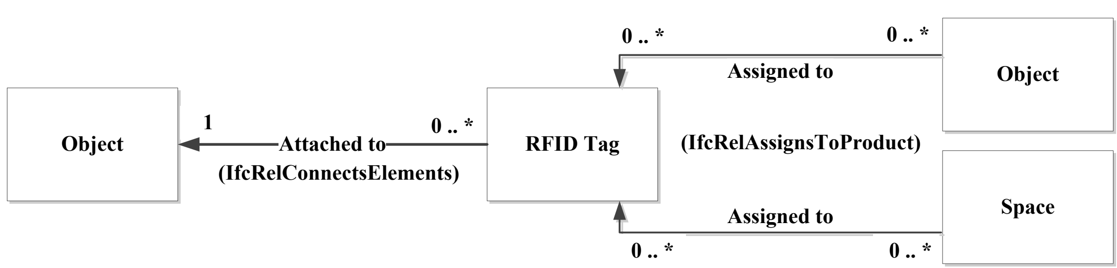


Figure 3-4 RFID tag attachment and assignment relationships (Motamedi et al., 2013a)

3.3 Case study

3.3.1 Modeling RFID tags in BIM application

A sample construction site has been modeled in Autodesk Revit Architecture 2012 (Autodesk, 2012) to show the feasibility of the proposed method. RFID active tags are modeled in Revit environment under the electrical equipment category. The model is then exported to IFC and extra code is added to the EXPRESS file in order to define new properties and relationship for tags and assets based on IFC4 standards. The modified IFC model is then viewed by standard IFC viewer called *Nemetschek IfcViewer* (Nemetschek Allplan GmbH, 2009) to verify the consistency of the model.

In the case study (Figure 3-5), active long range tags are attached to the building structural elements (e.g., columns) since they are permanent objects during the construction phase. The coordinates of the columns are stored in the tags attached to them. Additionally, information of all other related tags to each tag in each zone is added to the memory of that tag.

Figure 3-5 illustrates an overview of the site. Six zones are defined and shown will transparent colors. A selected number of columns are equipped by RFID tags as reference tags for the localization system. Markers shown in orange are used where there is no permanent object for attaching RFID reference tags (e.g. corners and around each storage area).

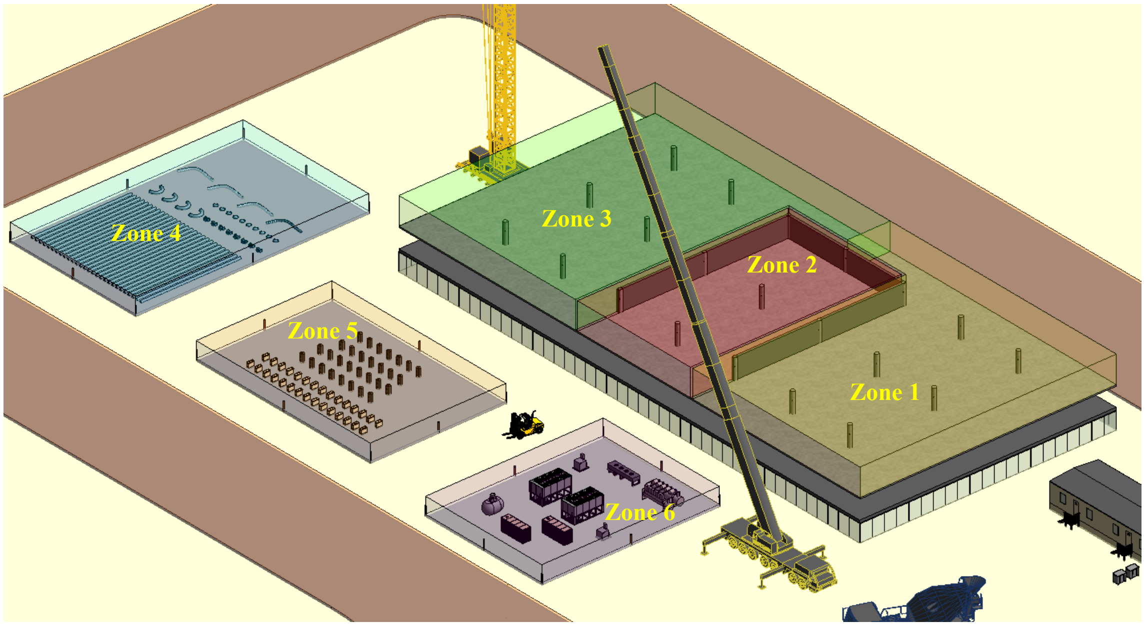


Figure 3-5 Detailed 3D view of a sample construction site

In our case study, active tags are assigned to several RFID tags and one specific zone (reference tag). In order to facilitate the data access, it is attached to columns or markers in side of each defined virtual zone (Figure 3-6 and Figure 3-7).

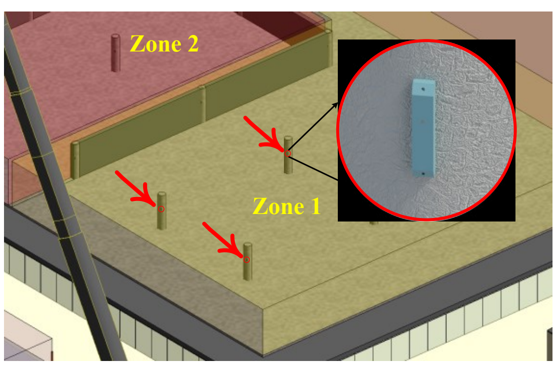


Figure 3-6 Modeled active tag attached to the structural columns

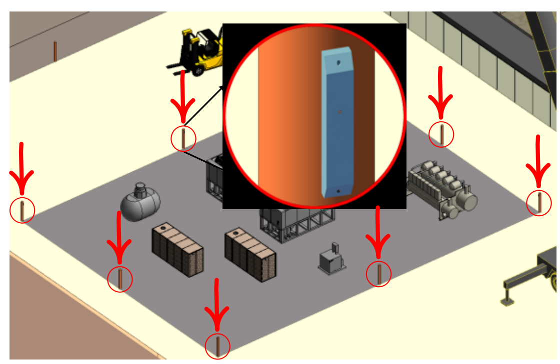


Figure 3-7 Modeled active tag attached to the markers

Three main relationship types are defined for the active *reference tags*: (1) *physical relationship (attachment)*: which is the relationship between the tag and the object it is attached to (i.e. column or marker); (2) *Spatial containment*: the relationship between the tag and the space containing the tag (i.e. zone). Figure 3-6 shows the area of zone one (transparent yellow) which is assigned to the active tags within this area; (3) *Assignment to objects*: it is a logical relationship between specific objects or tags and a specific tag. It is neither physical, nor spatial.

3.3.2 Adding relationships using STEP language

After creating the model objects in the Revit application, various relationships should be defined. The current version of the tool supports only the spatial containment relationship (i.e. *IfcRelContainedInSpatialStructure).* Hence, the model is exported to IFC format and other relationships are manually added using the EXPRESS format (BuildingSmart-Tech, 2013). Figure 3-8 shows the relationship between various elements including the building structural elements (i.e. columns) and their attached RFID tags. The numbers of relationships shown in Figure 3-8 correspond to the noted numbers in the comment column of Table 3-2.

As shown in the Figure 3-8, the *reference tag* (i.e. ActiveTag_RT1) is assigned to three other RFID tags and one zone and it is attached to a column (i.e. Column_1). The figure also identifies the used type of IFC's objectified relationships to be added to the IFC file in order to realize the required relationship for the case study. *Nemetschek IfcViewer* is used to validate the procedure of adding new lines to the IFC file of the model (Nemetschek Allplan GmbH, 2009).

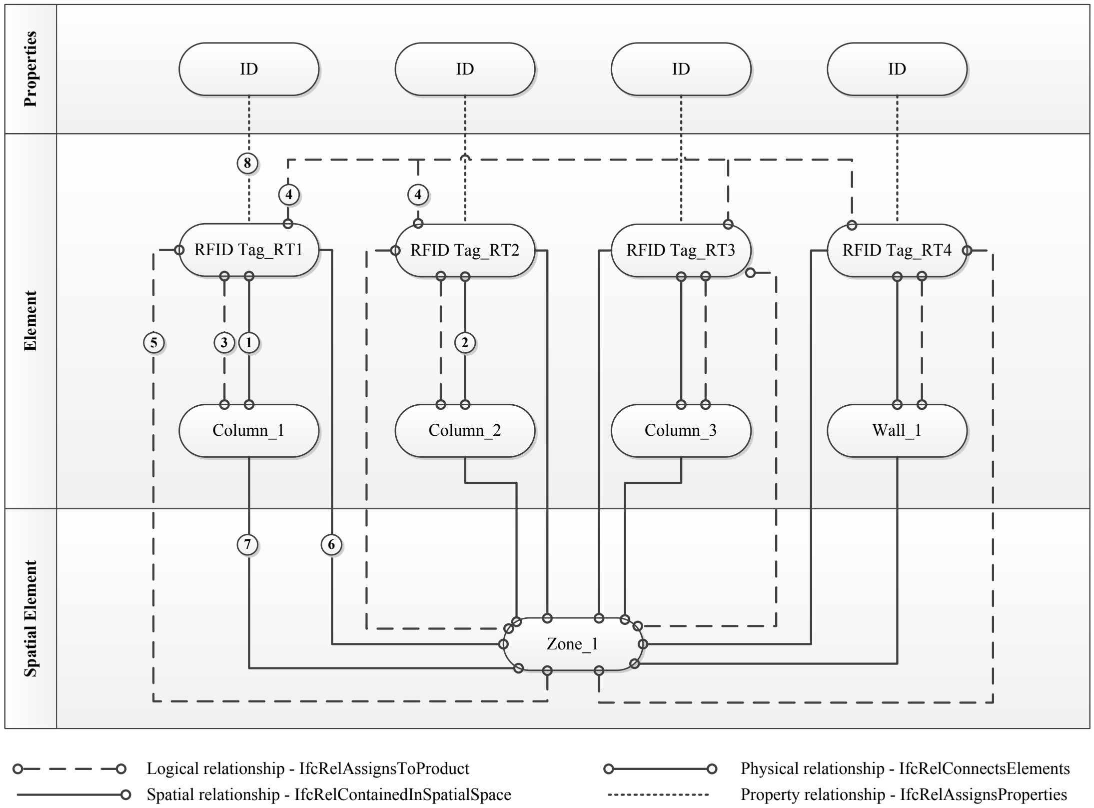


Figure 3-8 Case study entities and relationships

Table 3-2 shows parts of the modified IFC file that describes the following: (1) the *definitions* of some elements (i.e. the active *reference tag* (RT1), column (Column_1), the zone (Zone_1); (2) the *coordinates* of RT1, RT2 and Column_1; (3) various *relationships* including: *physical relationship* between *reference tag* and column, *logical relationships* between *reference tags* and columns, *logical relationships* between *reference tags* and all assigned objects, tags, and spaces, *spatial relationship* between Zone_1 and all the *reference tags* within that zone; and (4) sample *property set definitions* and their values for sample *reference tags* (RT1 and RT2) and column (Column_1).

Furthermore Table 3-2 includes the sample data to realize the scenario to update the coordinates of an object as a reference point. It includes the definitions of the active reference tag (RT1) (#31635), the definitions of Column_1 (#14928) and Zone_1 (#74), the coordinates of the column (#14925), the physical relationship between the RT1 and the Column_1 (#38597), the spatial relationship between Zone_1 and all objects within this zone including RT1, RT2, Column_1, and Column_2 (#38444), and the property set for RT1 (#38607).

The application that is used to update the tags should have a procedure to lookup the needed entries in the IFC database and create a new file to be merged into the memory of scanned RFID tag.

Table 3-2 Part of EXPRESS code for the model

EXPRESS Code	Comment
/* Definitions */	
#14928=IFCCOLUMN('*GUID*',#33,'M_Concrete-Round-Column:300mm:300mm:116507' ,$,'300mm',#4936,#4933,'116507');	Definition of "Column_1"
#14845=IFCCOLUMN('*GUID*',#33,'M_Concrete-Round-Column:300mm:300mm:116483' ,$,'300mm',#4895,#4892,'116483');	Definition of "Column_2"
#31635=IFCBUILDINGELEMENTPROXY('*GUID'*,#33,'RFID Active Tag3:RFID Active Tag:RFID Active Tag:154693',$,'RFID Active Tag',#31634,#31628,'154693',.ELEMENT.);	Definition of "Active Tag_RT1"
#34846=IFCBUILDINGELEMENTPROXY('*GUID*',#33,'RFID Active Tag4:RFID Active Tag:RFID Active Tag:170619',$,'RFID Active Tag',#34845,#34839,'170619',.ELEMENT.);	Definition of "Active Tag_RT2"
#74=IFCSPACE('*GUID*',#33,'1','',$,#61,#73,'Zone',.ELEMENT.,.INTERNAL.,$);	Definition of "Zone_1"
/* Coordinates */	
#34843=IFCCARTESIANPOINT((-5659.35|,2299.71|7,431.87|));	Coordinates of ActiveTag_RT1
#31632=IFCCARTESIANPOINT((-667.21|,1239.61|,1408.45|));	Coordinates of ActiveTag_RT2
#14925=IFCCARTESIANPOINT((-6193.54|,1111.19|,11.15|));	Coordinates of Column_1
/* Physical Relationships */	
#38597=IFCRELCONNECTSELEMENTS('2OgF5E9XmOp0Kb4HQka4kC',#33,$,$,$,#14928,#31635);	Relationship (1): Attachment of ActiveTag_RT1to the Column_1
#38748=IFCRELCONNECTSELEMENTS('2OgF5E9XmOp0Kb4HQka4kC',#33,$,$,$,#14845,#34846);	Relationship (2): Attachment of ActiveTag_RT2to the Column_2
/* Logical Relationships */	
#38598=IFCRELASSIGNSTOPRODUCT('*GUID*',#33,$,$,#14928,$,# 31635)	Relationship (3): Assigning Column_1 to the ActiveTag_RT1
#38599=IFCRELASSIGNSTOPRODUCT(' *GUID* ',#33,$,$,(#14928 ,#34846,#74),$,#31635);	Relationships(4), (5): Assigning ActiveTag_RT2 and Zone_1to the ActiveTag_RT1
/* Spatial Relationships */	
#38444=IFCRELCONTAINEDINSPATIALSTRUCTURE('3ttcsXY_L8NeEnekK02B0i',#33,$,$,(#14928,#14845,#34846,#31635),#74);	Relationships (6), (7): Spatial relationship for objects inside "Zone_1"
/* Property Sets Definitions */	
#38606=IFCPROPERTYSET('*GUID*',#33,'Pset_Condition',$,(#31635,#34846));	Condition property set
#38607=IFCPROPERTYSET('*GUID*',#33,'Pset_RFIDSystemActiveTag',$,(#31635,#34846));	Relationship (8): Active RFID property set relationship
/* Relating Property sets to elements */	
#38608=IFCRELDEFINESBYPROPERTIES('*GUID*',#33,$,$,(#14928),#31635);	Relating “condition property set to Column_1 and RFID property sets to ActiveTag_RT1

3.4 Summary and conclusions

The needs, motivations and benefits of extending BIM to cover standard definitions of RFID systems were investigated in this chapter. One of the main targets for proposing this model was to support the methodology of an RFID-based localization approach which will be introduced in the next chapter

The conclusions of this chapter are as follows: (1) The requirements' gathering was performed in order to identify the related attributes and relationships for RFID system components using the scenario for updating the location coordinates of an object as a reference point was investigated; (2) The properties of RFID systems were defined by reusing the available property sets or by adding separate property sets to include RFID type-specific information; (3) Different relationships including physical attachment, decomposition type, and logical assignment were investigated and standardized to cover all possible relationships between RFID tags and different entities of BIM; and (4) a sample model of a construction site was developed using the existing and newly added definitions and relationships in IFC to validate the applicability of the proposed model. Moreover, to realize the proposed extension of IFC, various IFC-compatible tools were utilized and tested. However, several limitations for extending the definitions and some compatibility issues for browsing an IFC file using different BIM tools were found which need to be further investigated in the future.

CHAPTER 4 RFID-BASED LOCALIZATION USING VIRTUAL REFERENCE TAG AND ARTIFICIAL NEURAL NETWORK

4.1 Introduction

Construction projects have a highly fragmented nature with different entities, contractors, and involved agents. Opposite to the other industries, construction projects aim to provide a unique product at the end of the project. This product is a result of a process which is different from one project to another but is similar in nature. Bringing different contractors together in one job site requires a great amount of coordination to work efficiently. Managing materials, equipment, and tools is a time consuming and needs a great amount of efforts. On one side, they should be protected against the theft and on the other side they should be placed at known places and by reachable by the workers. In the previous chapter, a new model for using RFID within IFC was proposed. This model helps tracking moveable objects to be more efficient, practical, affordable, and reliable. This chapter proposes a new method for tracking prefabricated elements, equipment, and tools to overcome the aforementioned problems.

In this method, some RFID tags are placed on the construction site as reference points for the localization system. The tags can be attached permanently or temporarily to any physical object which is defined in the BIM model. The corresponding object coordinates can be extracted from BIM and stored in the memory of the tag as the location of the tag. In case there is no suitable object in the area on the site to attach the tag to, a marker can play the role of a reference point but its position has to be defined in BIM and then stored in memory of the tag attached to it. This process avoids further measurements for finding the positions of the tags on the construction site since their data can be extracted from the BIM data base. Having the information coming from the BIM on one hand, and using RFID technology on the other hand, prepare the foundation of the proposed localization method using a movable device. In the next section, the proposed concept for indoor/outdoor moveable target localization based on the BIM information is introduced.

4.2 Cluster-based Movable Tag Localization (CMTL)

In the method, it is assumed that reference tags are attached to the building structural elements since they are fixed and permanent. In case those permanent elements for placing the reference tags are not available, marker stands can be placed temporarily to hold the reference tags. Target objects (i.e. prefabricated building elements, electrical components, mechanical components, tools, instruments, and etc.) are equipped with long range, omnidirectional and identical tags. The coordinates of RFID tags that are attached to fixed objects (reference tags) are derived from BIM. Moreover, it is assumed that the target tags are stationary for the period of localization and the user equipped with a handheld reader is moving within the facility to collect RSSI values and locate assets.

CMTL can be categorized under neighborhood-based localization techniques where *fixed* objects are used as *reference points* to help locating *moveable* targets. The similarity of RSSI between target tags and reference tags is used for localization. The RSSI received from reference tags and target tags are logged by a handheld RFID reader at several locations and processed to determine the similarity between signal strength patterns. Tags that show similar signal patterns are considered to be spatially adjacent. This similarity of patterns stems from the fact that the radio signals of the neighboring tags are affected by the same environmental effects. This method does not use RSSI values to estimate the distance between the reader and tags due to the unreliability of this conversion in construction noisy environments (Motamedi et al., 2013b).

4.2.1 Process of movable tags localization

As shown in Figure 4-1, a user equipped with a handheld RFID reader moves in the site and collects the RSSI values from all surrounding tags at different locations (e.g. L_1, L_2, and L_3 in Figure 4-1). Recorded RSSI values are those received from reference tags (R_i) attached to *fixed* objects that have their locations and from a tag attached to a movable object with no location information (T).

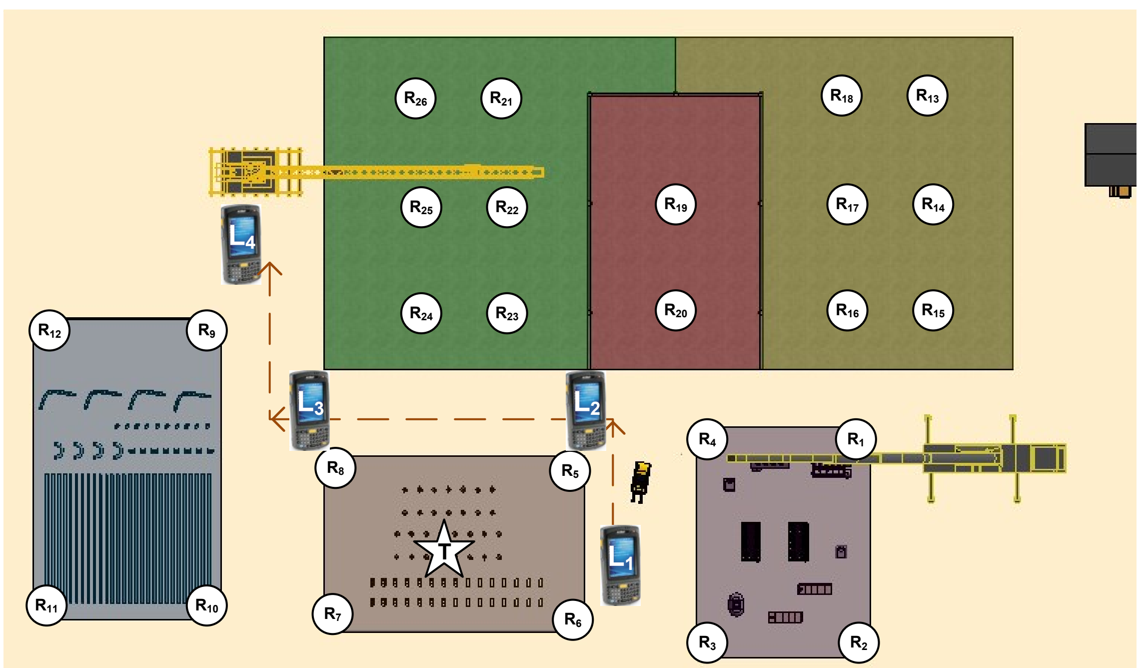


Figure 4-1 Sample scenario of localization process

In this method, the received RSSI values from the target tag are compared to those received from the reference tags at different data collection steps. By using a pattern matching algorithm, the reference tags that exhibit similar signal patterns to those of the target tag are identified. Finally, a group of reference tags is selected and their coordinates are used for localizing the target tag as explained in the following sections (Motamedi et al., 2013b).

Figure 4-2 shows the process flowchart to locate a specific movable object: (1) The user scans the area to detect the tag that is attached to the target object; (2) If the target tag is not in the range of the RFID reader, the user needs to change his/her location to be able to detect the tag; (3) As soon as the target tag is detected by the reader, the user starts logging the RSSI received from surrounding tags. The user remains stationary during the data collection for a short time period of Δt; (4) The logged data are processed by the data processing module which includes: filtering logged RSSI values to eliminate the values that are out of range as the result of sudden noises, errors in recording data, hardware errors, etc.; data averaging and pattern matching to compare the pattern of the RSSI of the target tag with all reference tags using a pattern matching algorithm; and clustering to group reference tags considering the result of pattern matching and their spatial distribution; (5) The location of the target object is estimated based on the result of the pattern matching, clustering and other information such as spatial constraints. The localization module uses Virtual Reference Tags (VRTs) in case of low reference tags' density and applies ANN to estimate the location of the target tag; (6, 7) If the logged data are not adequate for accurately estimating the location, the user is prompted to move to a new location and to continue logging data; and (8) After estimating the location of the target tag, it is shown on the site plan (Motamedi et al., 2013b).

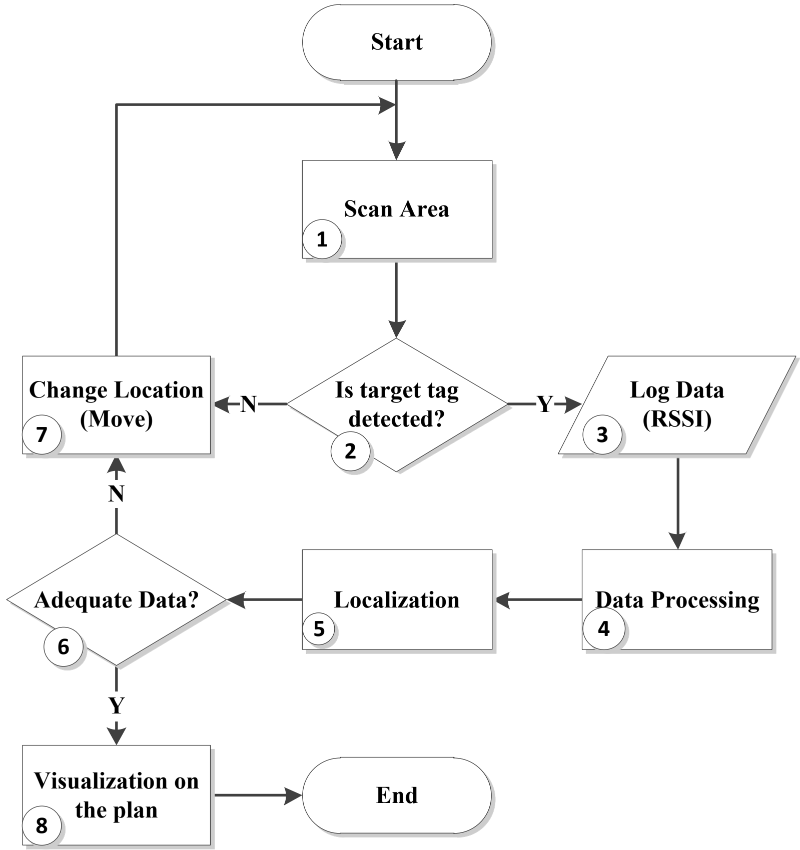


Figure 4-2 Process flowchart of localizing a specific movable target object

The details of filtering, averaging, pattern matching, clustering and ANN-based localization method are given in the following sections.

4.2.2 Filtering and averaging

At each data collection step, several RSSI values from various tags are sensed and logged by the reader. The data collection takes place when the user is stationary for a short duration of Δt. As the tags and the reader are not moving for the period of data collection, the received RSSI value from each tag is expected to be constant. However, variations in the received values result from small changes in distance, ambient noise, multi-path effects and several other changing environment factors. On the other hand, some received values can be outside the expected range and show systematic errors such as recording errors and sudden signal blockage. These values should be filtered out from the logged data and then the average RSSI value for each data collection step should be calculated to be used for the pattern matching. Outliers and multi-path and signal blockage effects are two major sources of errors that should be filtered (Motamedi et al., 2013b).

During the data collection, it is assumed that there are *n reference tags*, *p target tags,* and *m different data collection steps* in the construction site. RSS_s^i denotes the averaged RSSI value for the i^{th} tag (reference or target) at the s^{th} data collection step calculated using Equation 4-1. $RSS_{s,x}^i$ denotes a single logged RSS value recorded from the i^{th} tag at the s^{th} data collection step; where z_s^i is the total number of recorded RSSI values for the i^{th} tag at the s^{th} data collection step after filtering (Motamedi et al., 2013b).

$$RSS_s^i = \left[\sum_{x=1}^{z_s^i} RSS_{s,x}^i \right] / z_s^i \qquad \textbf{Equation 4-1}$$

4.2.3 Pattern matching algorithm

The goal of pattern matching is to determine which reference tags (R_i) show similar signal patterns to the signal pattern received from the target tag (T_j). The least square difference method is employed to calculate the similarity of reference tags to the target tag. $\beta_{R_j}^{T_i}$ is the *distance indicator (pattern dissimilarity)* value between the i^{th} reference tag and the j^{th} target tag after *m* data collection steps (Equation 4-2). The matrix of β (Equation 4-3) is constructed using the calculated values from Equation 4-2 (Motamedi et al., 2013b).

$$\beta_{R_i}^{T_j} = \sqrt{\sum_{s=1}^{m} (RSS_S^{R_i} - RSS_S^{T_i})^2}$$ **Equation 4-2**

$$\beta = \left[\beta_{R_i}^{T_j}\right]_{i=1,..n;\, j=1,..p}$$ **Equation 4-3**

The β values in the j^{th} column of the matrix indicate the distance indicators for each reference tag to the j^{th} target tag. The least β value in each column shows the reference tag that is assumably closer to the associated target tag (Motamedi et al., 2013b).

4.2.4 Identifying the target area by clustering reference tags

In some cases, the reference tags which are not spatially close to the target tag show similar signal patterns to that target tag. This can happen randomly or can be caused by the movement pattern of the user while collecting data and the layout of the site due to the symmetry of the distribution of reference tags with respect to the data collection path. For example if the user walks in a corridor where two rooms are located on two sides, there might be cases that reference tags located in different rooms across the corridor show similar signal patterns due to symmetry. Figure 4-3(a) shows an example layout of several reference tags and a target tag. Figure 4-3(b) shows the similarity of each reference tag represented by a circle where the diameter of the circles is inversely proportional to the β value. LANDMARC method selects the best k reference tags based on the β values sorting and uses weighted averaging to locate the target tag. However, this technique may select reference tags that are far from the target. Therefore, the localization based on LANDMARC method suffers from a large error as shown in Figure 4-3(c) (Motamedi et al., 2013b).

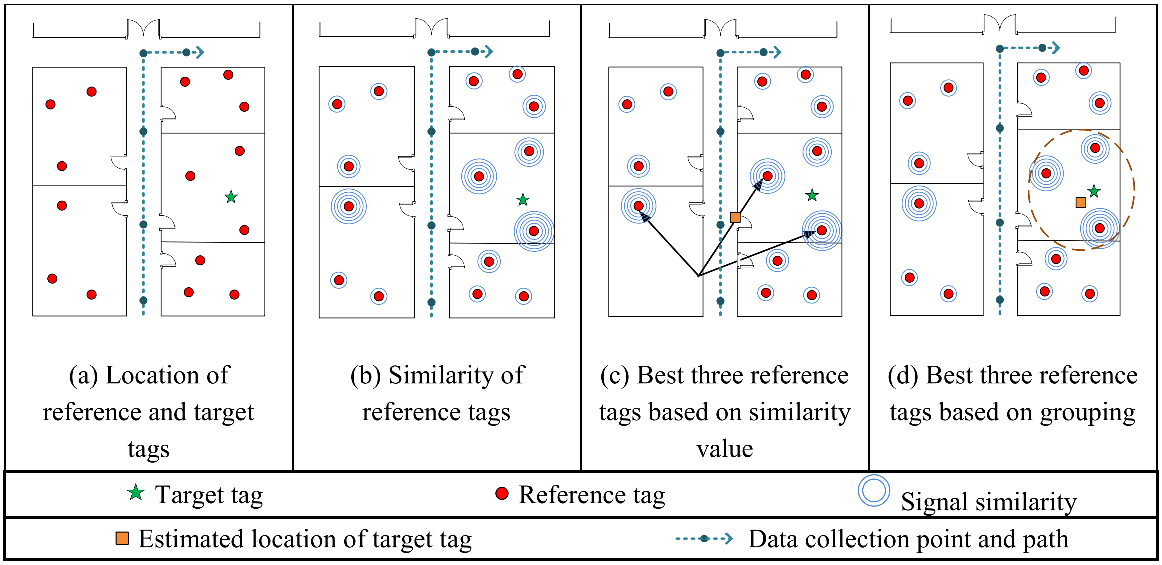


Figure 4-3 Reference tags clustering (Motamedi et al., 2013b)

The solution to this problem is to form clusters of reference tags that are spatially close. The target localization can be performed within the selected cluster, as shown in Figure 4-3(d). However, clustering of reference tags based only on spatial closeness of the tags does not necessarily lead to best results. For example, Figure 4-4(a) shows a case where spatial clustering will not lead to the optimum selection of reference tags for localization (Motamedi et al., 2013b).

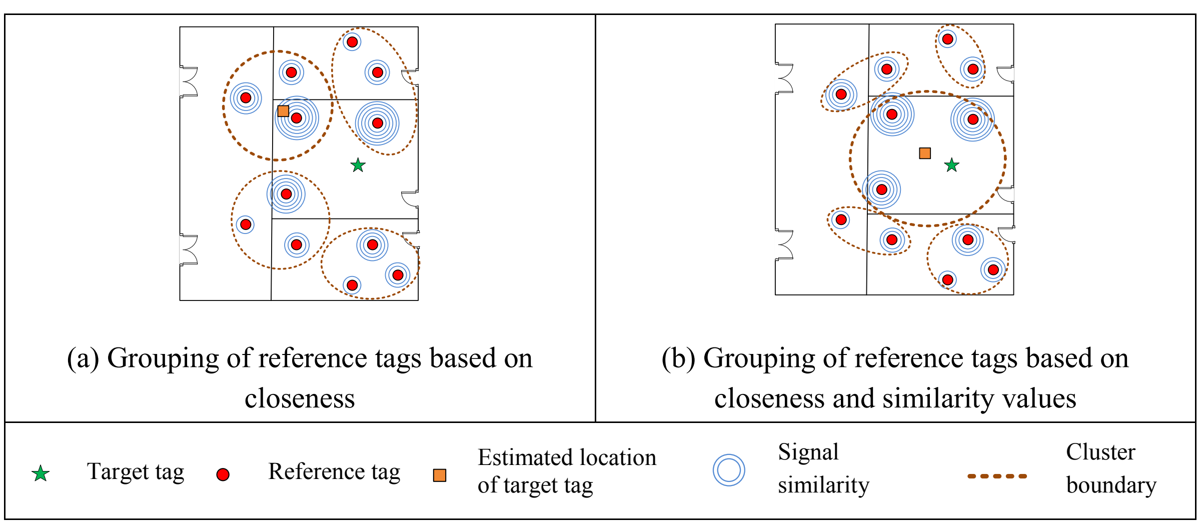


Figure 4-4 Multi criteria clustering vs. single criterion (Motamedi et al., 2013b)

There are several methods to form clusters. Clustering of tags can be *static* using a predefined fixed number of tags or can be *dynamic*. Moreover, the clustering can be uni-dimentional (e.g. closeness) or multi-dimensional (e.g. closeness and similarity) (Chen et al., 2012). The proposed method for clustering uses combination of two criteria for selecting members of each cluster: (1) *closeness of reference tags*: by selecting the reference tags that are spatially close to each other using algorithms such as k-means (Kanungo et al., 2002), and (2) *similarity of reference tags to the target*: by selecting tags that have similar signal pattern to that of the target tag using β values. Consequently, by using CMTL, target tags that show similar signal pattern to the one of the target and at the same time are in close proximity of each other are chosen as the target cluster. However, additional criteria such as zone number, floor number, or types of material surrounding the tags can be added to the clustering algorithms. Figure 4-4(b) shows how this clustering method chooses a group of tags that is spatially close and at the same time shows high signal pattern similarity. Motamedi et al. (2013b) introduced the following steps to form clusters and chose the target cluster:

4.2.4.1 **Calculating spatial closeness of clusters' members**

It was assumed that there are z clusters (number of combinations containing k distinct elements out of a set with n elements) available in the environment (Equation 4-4). G_r $[r \in (1, z)]$ denotes the r^{th} cluster and k_{G_r} denotes the total number of reference tags in the cluster. First, the x and y coordinates of the centroid point for each group are calculated. $x^C_{G_r}$ and $y^C_{G_r}$ denote the coordinates for the centroid point of r^{th} group. $x_{R^{G_r}_e}$ and $y_{R^{G_r}_e}$ denote the coordinates of the e^{th} member of the group. The total of the distances of each group member to the centroid of the group is calculated using Equation 4-5 and normalized using Equation 4-6.

$$z = \frac{n!}{k! \times (n-k)!} \qquad \textbf{Equation 4-4}$$

$$D_{G_r} = \sum_{e=1}^{k_{G_r}} \sqrt{\left(x_{R_e^{G_r}} - x_{G_r}^{C}\right)^2 + \left(y_{R_e^{G_r}} - y_{G_r}^{C}\right)^2} \qquad \textbf{Equation 4-5}$$

$$\acute{D}_{G_r} = D_{G_r} / Max\,\{D_{G_r}\} \qquad \textbf{Equation 4-6}$$

4.2.4.2 Calculating the signal pattern dissimilarity of clusters' members and selecting the target cluster

In this stage the average signal pattern dissimilarity (*β*) of each member of the group ($R_e^{G_r}$) to the target tag (T_u) is calculated using Equation 4-7 and the value is normalized using Equation 4-8.

$$\beta_{G_r}^{T_u} = \left(\sum_{e=1}^{k_{G_r}} \beta_{R_e^{G_r}}^{T_u}\right) \Big/ k_{G_r} \qquad \textbf{Equation 4-7}$$

$$\acute{\beta}_{G_r}^{T_u} = \beta_{G_r}^{T_u} / Max\,\{\beta_{G_r}^{T_u}\} \qquad \textbf{Equation 4-8}$$

The target cluster is selected based on two values calculated using Equation 4-6 and Equation 4-8. K_{G_r} denotes the score of each multi-dimensional cluster based on two criteria (i.e. spatial closeness of members and the signal pattern similarity of members to the target) as shown in Equation 4-9. The weights, w_D and w_β , can be adjusted based on the layout of the building, density of tags and their spatial distribution. The best cluster with the smallest score is chosen as the *target cluster* using Equation 4-10.

$K_{G_r} = w_D \times \acute{D}_{G_r} + w_\beta \times \beta_{G_r}^{\acute{T}_u}$ **Equation 4-9**

$K_{G_r}^{Best} = Min\ \{K_{G_r}\}$ **Equation 4-10**

4.2.5 Localization based on clustering results using ANN and VRTs

Applying CMTL for localization in a large area (e.g. construction sites) brings the problem of maintaining the required accuracy without adding more real reference tags. Empirical weighted averaging equation presented in Ni et al. (2004) adopted for a specific environment in which their test was performed. Additionally, applying weighted averaging in large areas with high level of noise, and scattered reference tags (not in rectangular mesh) causes large errors (Jiang et al., 2012). To overcome these limitations, adding VRTs to increase the density and applying ANN to create a flexible positioning method are proposed in this research. Zhao et al. (2007) used VRT, and Jiang et al. (2012) applied ANN separately to improve the mentioned limitations of LANDMARC. Zhao et al. (2007) and Ng et al. (2011) used interpolation for rectangular mesh form of reference tags' placement. The main idea of the method proposed in this paper which is named CMTL+, is to use a combination of VRT and ANN considering the clustering algorithm introduced in Section 4.2.4.

4.2.5.1 Virtual Reference Tags

Figure 4-5 illustrates schematically, when there are five reference tags in an area of 4m × 5m and the approximate error is *e*. However, using the same number of tags in an area of 12m × 15m will result in an error of *e'* which is a function of the area's size scale change.

To reduce the value of *e'*, more reference tags are required to be deployed that results in a higher implementation cost.

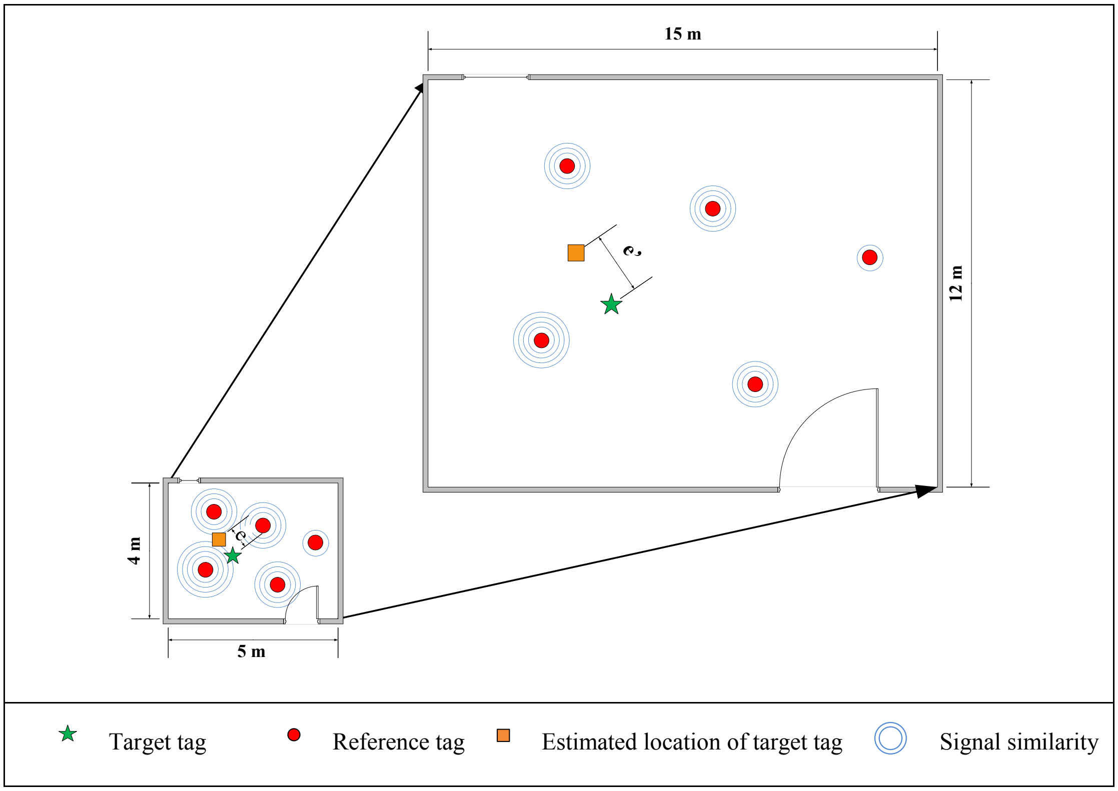


Figure 4-5 Scale change limitation of methods based on weighted averaging

As explained in Section 2.3.3.3, adding virtual nodes can avoid the density problem. Figure 4-6 shows how adding a grid of VRTs surrounded by the four chosen real reference tags in a cluster can provide more input data to the system to be trained more precisely.

The coordinates of the newly added VRTs are known. Yet, the RSSI values should be calculated. An irregular bilinear interpolation is used in this paper to estimate the RSSI of each VRT based on the RSSI values of the surrounding real reference tags. In our method, the reference tags are placed randomly (not in a triangular or rectangular mesh).

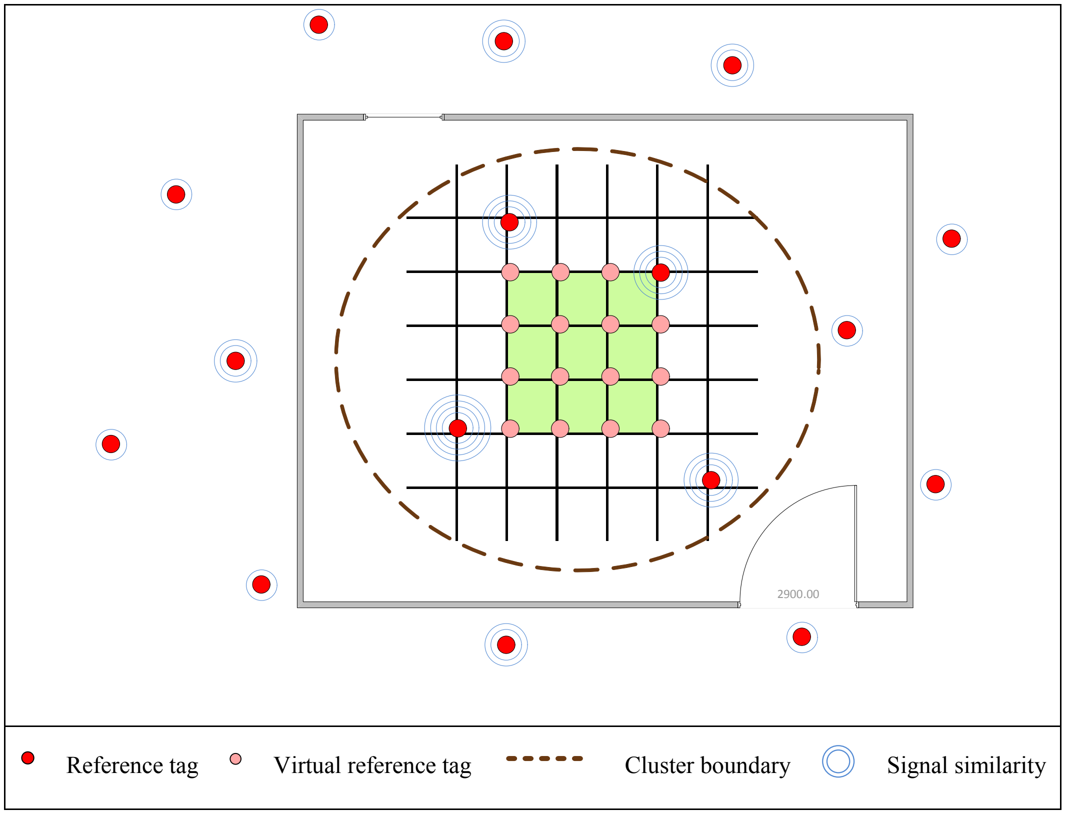


Figure 4-6 Fixed density limitation in LANDMARC method

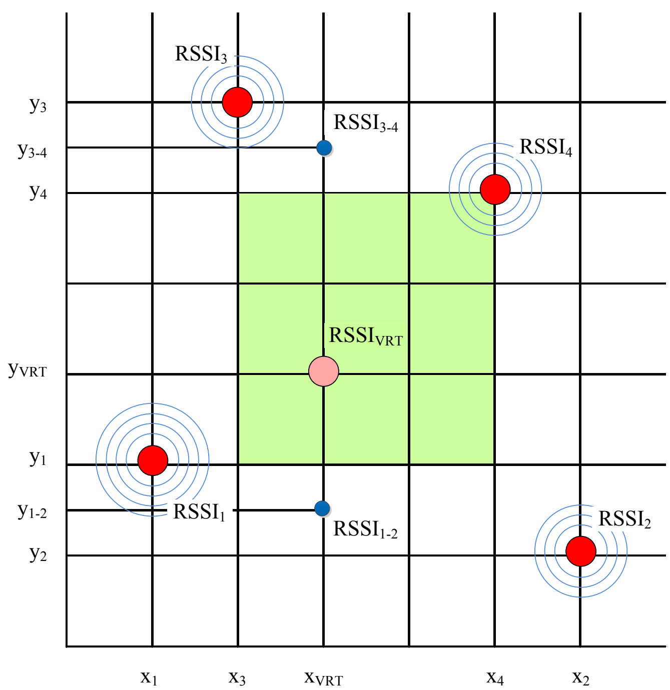


Figure 4-7 Calculation the RSSI of VRTs using irregular bilinear interpolation

As shown Figure 4-7, for the case that the winner cluster includes four real reference tags, a linear interpolation in the *x*-direction is performed in the first step. Applying Equation 4-11 between $RSSI_1$ and $RSSI_2$ results in $RSSI_{1\text{-}2}$ and applying Equation 4-12 between $RSSI_3$ and $RSSI_4$ results in $RSSI_{3\text{-}4}$. Next, the *RSSI* of the VRT can be obtained by using Equation 4-13 which interpolates in the y-direction between

$$RSSI_{1-2} = \frac{x_2 - x_{VRT}}{x_2 - x_1} RSSI_1 + \frac{x_{VRT} - x_1}{x_2 - x_1} RSSI_2 \qquad \textbf{Equation 4-11}$$

$$RSSI_{3-4} = \frac{x_2 - x_{VRT}}{x_2 - x_1} RSSI_3 + \frac{x_{VRT} - x_1}{x_2 - x_1} RSSI_4 \qquad \textbf{Equation 4-12}$$

$$RSSI_{VRT} = \frac{y_{3-4} - y_{VRT}}{y_{3-4} - y_{1-2}} RSSI_{1-2} + \frac{y_{VRT} - y_{1-2}}{y_{3-4} - y_{1-2}} RSSI_{3-4} \qquad \textbf{Equation 4-13}$$

4.2.5.2 **Artificial Neural Network for positioning**

As mentioned in Sections 2.3.3.2 and 4.2.4, LANDMARC and CMTL use weighted averaging of the selected reference tags coordinates to calculate the location of the target tag. The weights are calculated based on an empirical function using the distance indicators. Weighted averaging presented by Ni et al. (2004) is adopted to the size, the environment, and the topology of the reference tags in their tests. Consequently, it does not provide the best positioning for all settings.

To overcome this limitation, ANN is applied as an alternative method for positioning in the literature as explained in Section 2.3.3.4. However in most of the research, ANN was used to map the RSSI to the coordinates. In this research, RSSIs are processed and then summarized into dissimilarity indicators (β values). Furthermore, the benefit of VRTs is added to the input of ANN during the data processing phase. The proposed network has to learn the relationship between the dissimilarity of each reference tags (with respect to the other reference tags) and its known coordinates, when considered as an imaginary target tag. In other words, if there are *n* reference tags with known coordinates, in each learning loop, each reference tag becomes a candidate as a target at an unknown position and the dissimilarities of its signal pattern to the other reference tags are calculated and provided as inputs to the network. The known coordinates of the reference tag are provided as output of the network. The network learns the relationship of the dissimilarity patterns and the coordinates in each loop. Then the network can estimate the coordinates of an unknown target based on its signal dissimilarity pattern with all leant reference tags.

A supervised, feed-forward ANN is used for mapping the inputs to outputs with a BP algorithm. The algorithm has the task of minimizing the errors of the network weights. The "tan-sigmoid" function is used as the transfer function of the model (Hudson et al., 2012). The size of the network depends on four main parameters including the number of input nodes, output nodes, hidden layers, and neurons in each hidden layer. The number of the network's input nodes is equal to the number of participant reference tags during localization (i.e. *n*, where *n* is the total number of reference tags) and the number of output nodes is equal to the coordinates of a reference tag.

The architecture of the proposed network is illustrated in Figure 4-8. If the input of the network is considered as a *n* by *n* matrix, then the values in each row show the signal dissimilarity between i^{th} reference tag and each other reference tags. Similar to Equation 4-2, γ_{Rj}^{Ri} is the *distance indicator* (*pattern dissimilarity*) value between the i^{th} reference tag and the j^{th} reference tag (temporary target for training) after *m* data collection steps. The matrix of γ_R (Equation 4-14) is constructed using the calculated values from Equation 4-15. Obviously, the signal dissimilarity of each reference tag with itself is equal to zero; therefore, the main diagonal entries are zeros.

$$\gamma_{Rj}^{R_i} = \sqrt{\sum_{s=1}^{m}\left(RSS_s^{R_i} - RSS_s^{R_j}\right)^2}$$ **Equation 4-14**

$$\gamma_R = \left[\gamma_{R_j}^{R_i}\right]_{i=1,..n;j=1,..n}$$ **Equation 4-15**

The number of hidden layers is set to one. Since there is no specific guideline for choosing the number of hidden neurons (N_{hidden}), an empirical equation (Equation 4-16) is proposed which can provide the optimum number of hidden layer neurons considering the number of input layer and output layer nodes.

$$N_{hidden} = \left(\left(N_{input} + N_{onput}\right) \times \frac{2}{3}\right) + 2$$ **Equation 4-16**

For instance, in the network shown in Figure 4-8, if N_{Input} is 19 (including four real and 15 virtual *reference tags*) and N_{Output} is two, the number of hidden neurons is equal to 16.

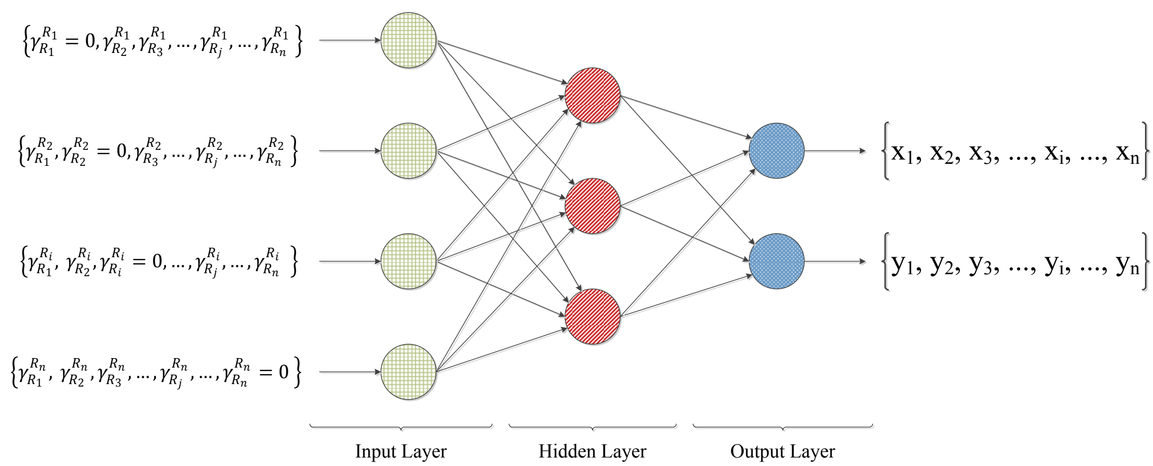


Figure 4-8 Proposed network architecture overview

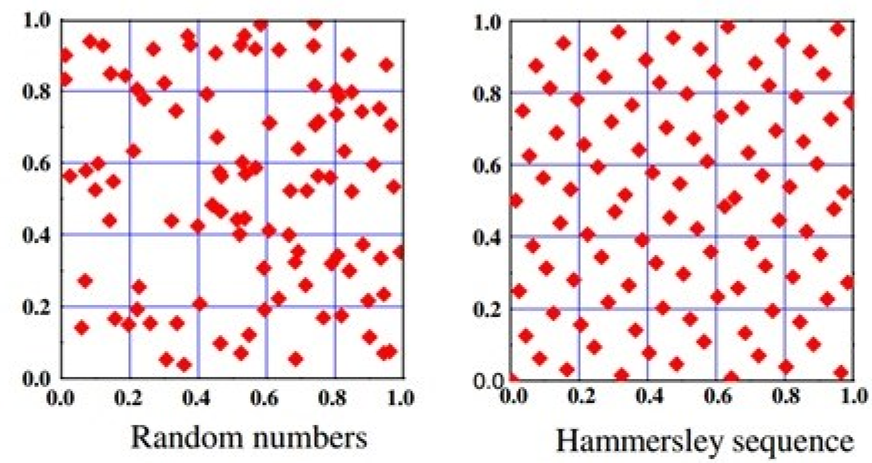
4.3 Case study

4.3.1 Development of a simulation environment

A simulation environment is developed in Matlab (MathWorks, 2012) in order to evaluate the proposed method for various distributions of reference and target tags, data collection points, RSSI behaviors, and the number of readings at each data collection point. The simulation platform provides a flexible environment to define and place multiple reference and target tags. The simulation can help evaluating the impact of a large number of parameters, such as the number, distribution and RF behavior of tags. It also provides the convenience of performing a large number of tests with less time and cost compared to field tests because it does not require the set up and data collection time needed in the field tests.

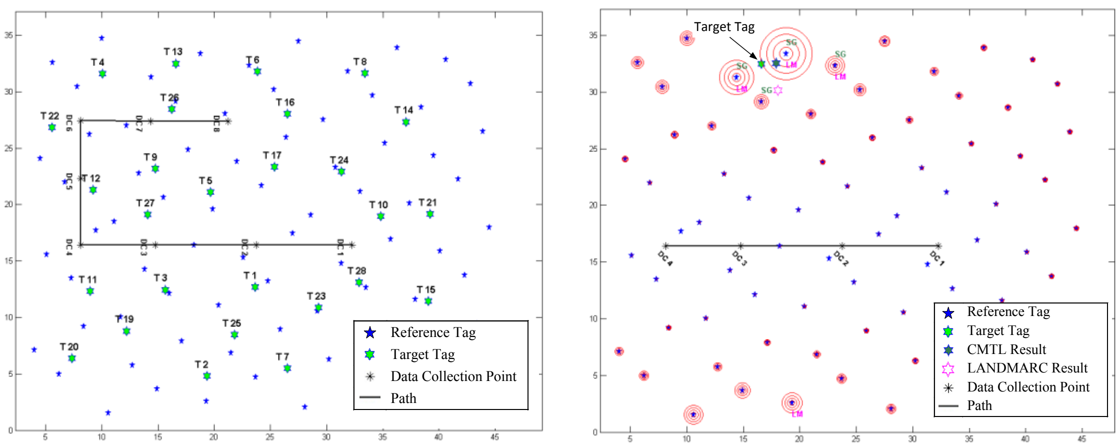
The simulator comprises different modules, such as: (1) parameters definition; (2) RSSI generator; (3) pattern similarity assessment; (4) clustering; (5) localization using neural network and Irregular bilinear interpolation; (6) data comparison and sensitivity analysis; and (7) field test data processing.

Generating random coordinates for the reference and target tags may result in inhomogeneous area from the layout point of view. Therefore, the *Hammersley* algorithm (Hammersley, 1960; Dai and Wang, 2009) is used to distribute the tags homogeneously in the layout.



Equation 4-17 Layout comparison of the scenarios using random numbers and hammersley sequence (Dai and Wang, 2009)

The generation of RSSI values in the simulation uses Monte Carlo approach based on our field test results explained in Section 4.3.2. The signal similarity between target and reference tags are calculated for a set of data collection points that are specified in the simulation input. The clustering module finds the best group of reference tags based on signal pattern similarity score and geometric proximity of reference tags in each selected cluster as explained in Section 4.2.4 However, the simulation environment does not consider the effect of obstacles on the propagated radio signals. Hence, the current version of the simulator simulates an obstacle-free environment where the behavior of the RFID signals follow the results of our field test in a similar environment. Consequently, the simulator does not provide the validation for the proposed method of localizing moveable tags in cluttered indoor environments. In order to validate the method in such environments, field tests are performed (Section 5.4). Additionally, an irregular bilinear interpolation is performed between all the members of the winner cluster. The result feeds the network defined in Matlab Neural Networks Toolbox™.



(a) Defining reference and target tags and data collection points

(b) Simulation results for sample target tag (T13)

Figure 4-9 Sample simulation input data and results

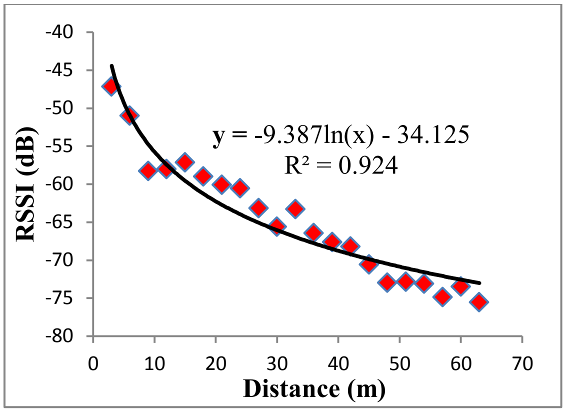
Figure 4-9(a) shows a snapshot of a sample simulation input data with 75 randomly distributed reference and 25 target tags. The small and large stars show the location of reference tags and target tags, respectively. The path that the user with a handheld reader took to localize the target tags is shown by a line. Stars on the path show the data collection points. As shown in the figure, there are eight data collection steps. Figure 4-9 (b) shows the results of one case where target tag 13 is localized with four data collection points. The dark large star is the estimated location of the target based on the clustering method and the white star represents the position of the target calculated by the LANDMARC method. The diameters of the circles around reference tags are inversely proportional to the β values. Hence, the bigger the diameter of the circle, the closer the associated reference tags to the target tag. As shown in the figure, the simulation tool is able to identify the closest reference tags to the target and to estimate its location. Table 4-1 summarizes the setup of network defined in Matlab 2012b (MathWorks, 2012).

Table 4-1 ANN setup in Matlab

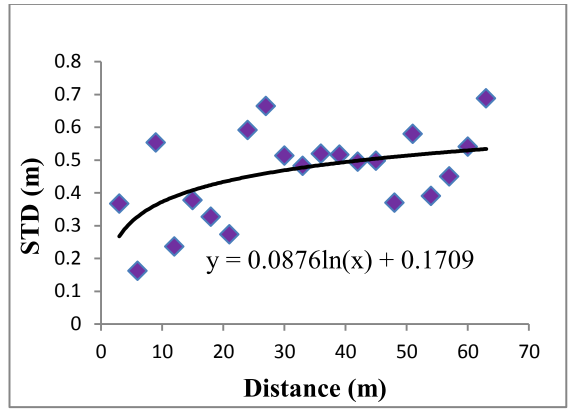
Functions	Description		Matlab Command
Processing Functions	Mapping row minimum and maximum values to [-1,.1]		'mapminmax'
	Removing rows with constant values		'removeconstantrows'
Data division functions	Divide data randomly		'dividerand'
	Divide up every sample		'sample'
Train function	Bayesian regulation backpropagation		'trainbr'
Performance function	Mean squared error		'mse'
Transfer functions	Hidden layer	Tan-Sigmoid	'tansig'
	Output layer	Linear	'purelin'

4.3.2 Testing RFID characteristics

In order to realize the proposed method for locating moveable objects (i.e., CMTL), the characteristics of an available RFID system are analyzed. Active RFID tags from Identec Solutions (Identec Solutions, 2012) with relatively long nominal range (100 m), operating frequency of 915 MHz, and 32 KB of storage are used together with a handheld reader. Available tag's antenna are omnidirectional (1/4-wave monopole with 2/3 vertical element and 1/3 horizontal element).



(a) Average values



(b) Standard deviations

Figure 4-10 RSSI vs. distance relationship

In order to perform the tests, a .Net application is developed to log received signals by the RFID reader and to store them in data tables. The frequency of reading and the power of the antenna are customizable. Several tests were conducted to test the readability range and the effect of various environment factors on the RFID tags. The first test was performed at Concordia Stinger Dome (120m × 70m) to examine the readability range and signal attenuation of tags in an obstacle-free environment. An RFID tag was placed on a tripod and RSSI values were collected at various distances from the tag. Figure 4-10(a) shows the decrease of RSSI values by increasing the distance. It is also observed that the gain is higher in front on the same long axis of the tag. Figure 4-10(b) shows that the standard deviations of RSSI values slightly increase as the distance between the tag and the reader (l) increases. Equation 4-18 shows the relationship between the distance and RSSI value based on our field test. Equation 4-19 formulates the relationship between the standard deviation of the RSSI values and the distance where RSSI measured in decibels milliwatt (dBm) and l in meters.

$RSSI = -9.387\ ln(l) - 34.125$ **Equation 4-18**

$\sigma_{RSSI} = 0.0876\ ln(l) + 0.1709$ **Equation 4-19**

4.3.3 Localization accuracy comparison using simulation

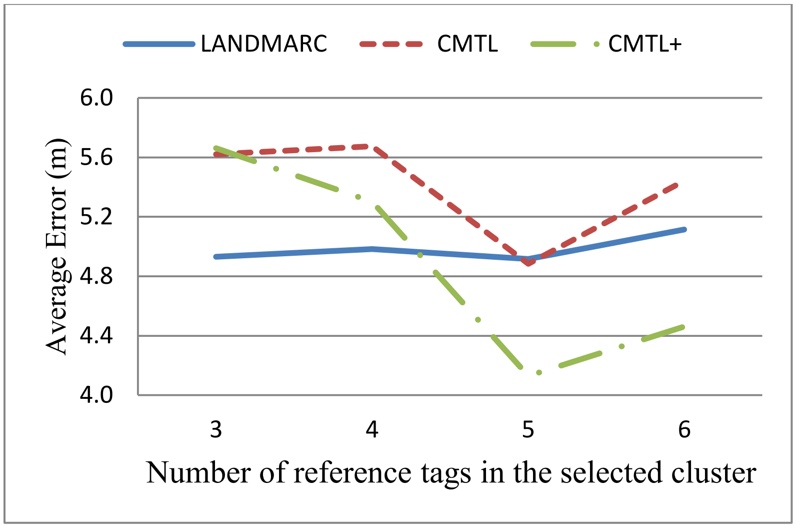
In order to compare the applicability of the proposed method, a comparative study has been performed using the simulation environment. The accuracies of localization using CMTL+, CMTL and LANDMARC methods are compared by developing all approaches in the simulation environment. For static clustering (with fixed number of tags), a list of all combinations of groups with k members can be formed. Equal weights of one (Equation 4-4) are used in the simulation environment. The following variables are changed in the simulation to find the sensitivity of the results to each or combination of the variables: density of total reference tags (real and virtual), number of cluster's member, number of data collection points, test bed size, number of real reference tags, and path of data collection points. It can be noticed that there can be two meanings of density in the simulation. The first one is the density of the total reference tags (including virtual and real tags) and the second one is the density of real reference tags placed in the simulation. To distinguish these two meanings, the word of density in the simulation is used for the total number of reference tags.

4.3.3.1 Effect of the number of reference tags in the selected cluster and the shape of data collection paths

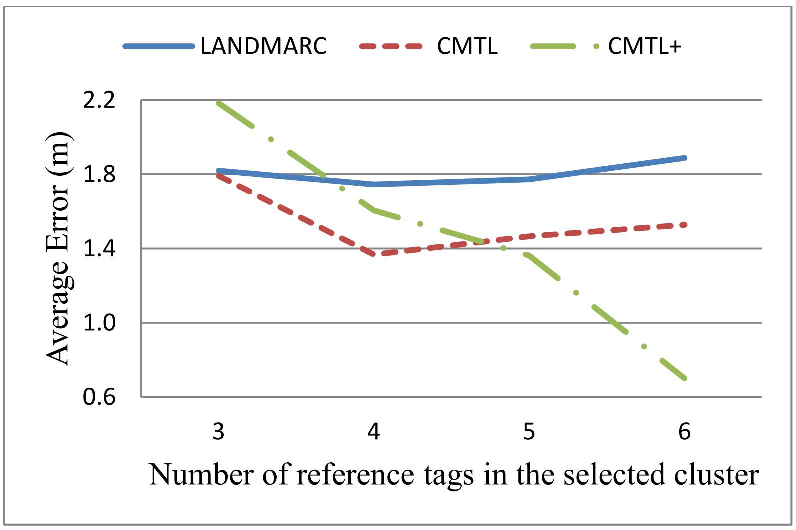
Concerning the effect of the number of reference tags in the selected cluster and the shape of data collection paths on the accuracy of localization, the simulation is run for 49 real *reference tags* in an area of 30m × 30m, and is repeated 20 times for 20 target tags.

The number of data collection points is set to 4 with paths of I shape, L shape, and U shape. A minimum reference tag density of 0.2 per square meter is considered as the threshold for adding VRTs inside the winner cluster. In case that the actual density of real reference tags is below this threshold, the algorithm adds some virtual tags to reach that density. The set number of target tags and the value of density are fixed for all the following simulation results in this chapter. Finally, the results of the proposed method using CMTL+ are compared by LANDMARC and CMTL methods.

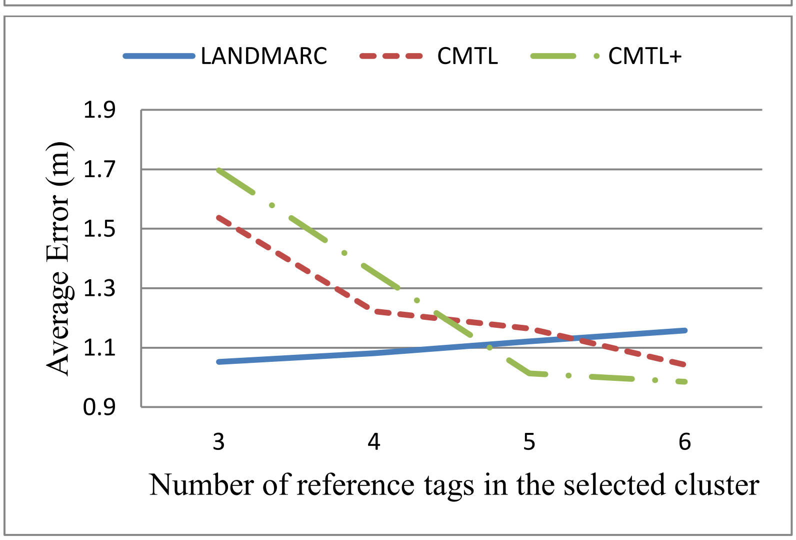
Figures 4-11 (a), (b), and (c) show the localization average error using cluster sizes of three, four, five, and six tags. From Figure 4-11 (a) it can be shown that the cluster size of five tags provides mostly better accuracy when the path of data collection is I-shape. Increasing the size of the cluster helps decreasing the average error for L and U shape paths (Figures 4-11 (b) and (c)). Based on these results, the number of *reference tags* in the selected cluster is set to four in the following section since LANDMARC performs best when using four reference tags for positioning.



(a) I shape path



(b) L shape path



(c) U shape path

Figure 4-11 Accuracy comparison for different number of reference tags in selected cluster and different shape of data collection paths

4.3.3.2 Effect of number of reference tag densities and data collection paths on the accuracy

Another parameter which can have effect on the both average error and computational load is the density of total number of reference tags including real and virtual reference tags. As it was mentioned in Section 4.2.5.1 after selecting the winner cluster based on the defined criteria it may be needed to add VRTs within the area surrounded by the selected cluster's members. The simulation checks the minimum required density within the area surrounded by the tags selected in the winner cluster to find how many virtual tags must be added. The density can improve the accuracy of the localization but at the same time it imposes a great computation load on the simulation. Therefore, considering the required accuracy and computational capacity of the machine used for computing, the minimum density should be defined properly.

The results shown in the Figure 4-12 come from five rounds of simulation for the density of 0.2, 0.6, 1.0, 1.4, and 1.8 per square meter. The simulation is performed for 49 real reference tags in an area of 30m × 30m. Furthermore, the simulations are done for I, L, and U-shape and the random data collection paths. Analyzing the results shows that, for I-shape path, increasing the density not only cannot improve the accuracy but also degrades it which can be because of the mentioned symmetric problem in Section 4.3.3.6. In the all next scenarios, increasing the density above 0.2 leads to an improvement between 38% to 46% and the average error is less than one meter which is acceptable.

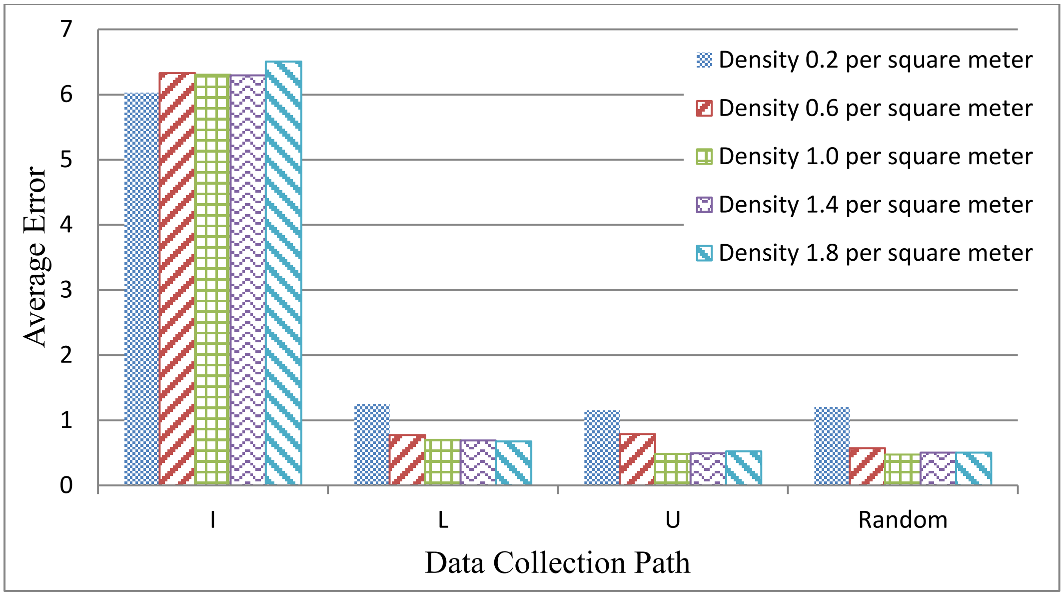


Figure 4-12 Accuracy comparison of CMTL + ANN localization for different reference tag densities (real and virtual)

4.3.3.3 Effect of the number of data collection points on the localization accuracy

In order to identify the effect of increasing the data collection steps on the accuracy of localization, an area of 75m × 75m with 81 reference tags is used. The data collection points follow a random pattern. Test cases with 2, 4, 8, and 16 collection points are performed. Figure 4-13 shows that increasing the number of data collection points improves the accuracy of localization, especially from two points to four points with 87% improvement. However, the results do not show major improvement after four data collection steps.

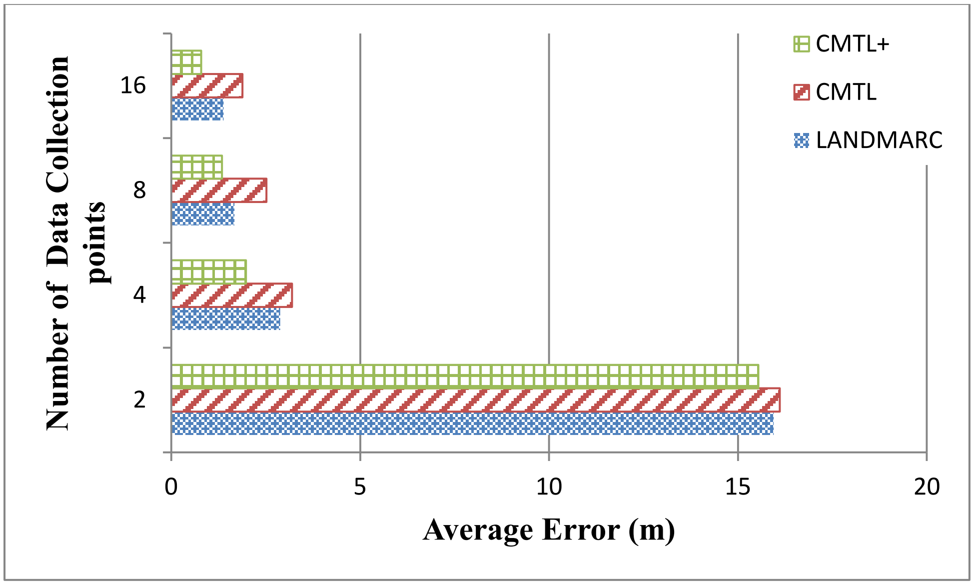


Figure 4-13 Accuracy comparison for different number of data collection steps

4.3.3.4 Effect of the shape of data collection paths using 49 reference tags

In order to identify the effect of the shape of the data collection path on the accuracy of localization, the simulation setup for 49 real *reference tags* in an area of 75m × 75m is used. The data collection follows the I-shape, L-shape, and U-shape with four data collection points. The results of localization using CMTL, CMTL+, and LANDMARC are compared in Figure 4-14. As shown in Figure 4-14, a major improvement in accuracy happens when the shape of data collection path diverges from the straight line. This is due to the fact, that the chance of selecting a better cluster, in case of symmetric distribution of the *reference tags* with respect to the path, is increased when the data are collected on any paths other than I-shape. Moreover, using CMTL+ leads to increasing the accuracy between 3% and 46% compared to LANDMARC and CMTL.

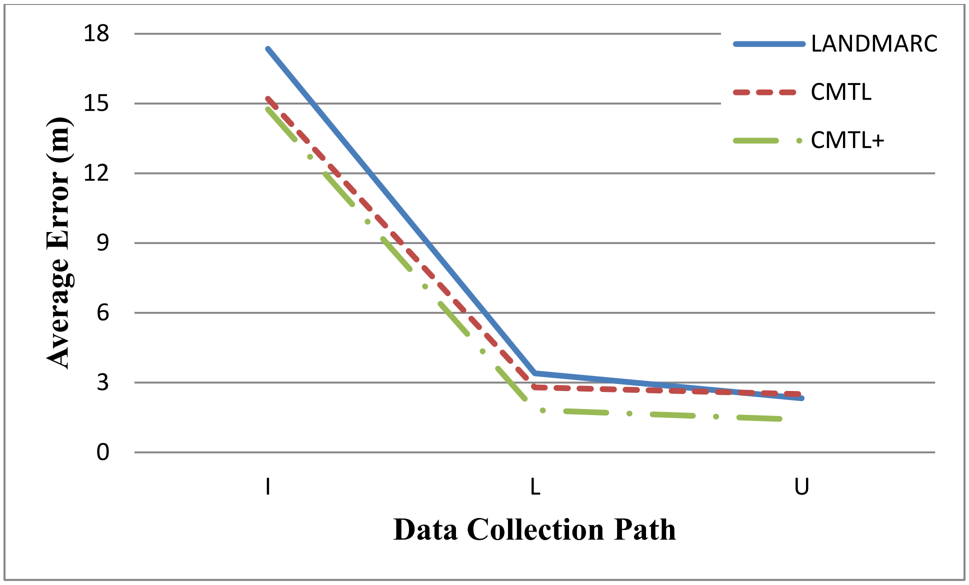


Figure 4-14 Accuracy comparison for different shape of data collection paths using 49 reference tags

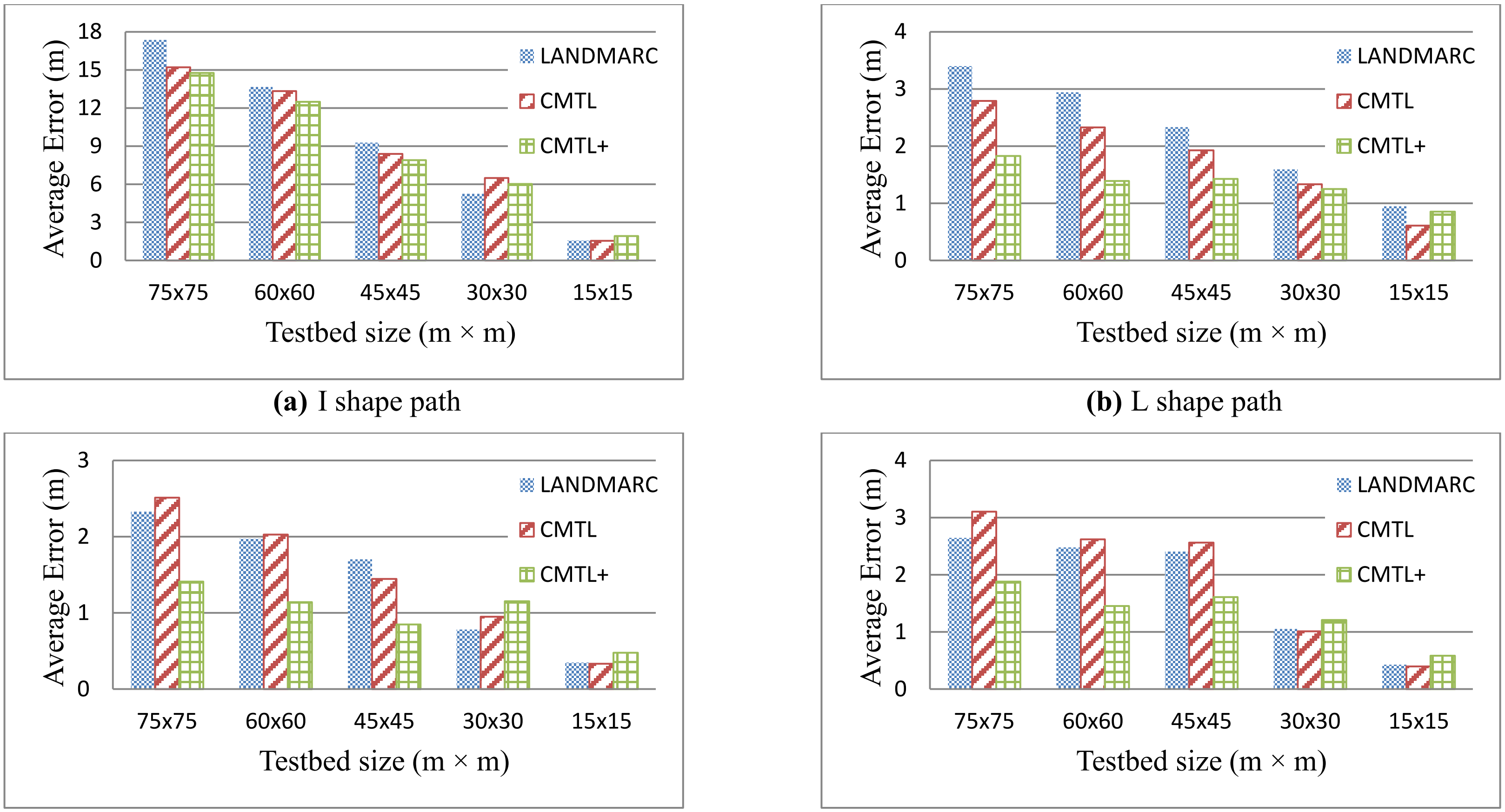
4.3.3.5 Effect of the shape of data collection path and test bed size on the accuracy

Concerning the effect of the shape of data collection path and the size of the test bed on the accuracy of localization, the simulation is run for 49 real *reference tags* in areas of 75m × 75m, 60m × 60m, 45m × 45m , 30m × 30m and 15m × 15m , using I shape, L shape, U shape, and eight random data collection points.

As shown in Figure 4-15(a), the proposed method improves the accuracy compared to LANDMARC and CMTL in the area of 75m × 7m5 by 15% and 3%, respectively. Moreover, an improvement of 6% and 15% is achieved over the LANDMARC method for the areas of 60m × 60m and 45m × 45m, respectively. However, the results for area of 30m × 30m and 15m × 15 m show an increment of the average errors for such small areas which will be discussed later about the source of error and possible recommendations. The range of errors is from 1.93 meters to 14.75 meters by increasing the size of test bed CMTL+). The same scenarios are repeated for L and U shape data collection paths.

Figures 4-15 (b) and (c) show considerable improvements for the L-shape and U-shape paths (even 30m × 30m for L shape path).

Compared to I-shape path, the errors range for L-shape is from 0.85 to 1.83 meters and for U shape is from 0.48 to 1.41 meters. It is obvious that we can achieve better results in L and U-shape paths because of lower chance of symmetric data collection cases compared to L-shape path. Additionally, random data collection points are used to find the accuracy regardless of the data collection's path. There are significant improvements for larger test areas than area of 30m × 30m and 15m × 15 m (Figure 4-15(d)).



(a) I shape path

(b) L shape path

(c) U shape path

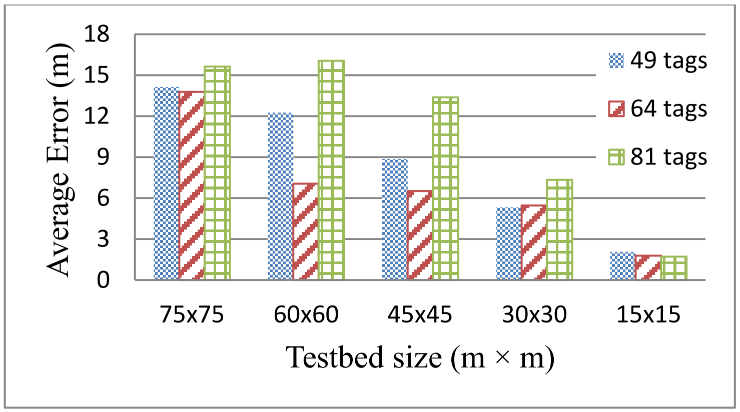
(d) Random points

Figure 4-15 Accuracy comparison of CMTL+ localization for different data collection paths using 49 reference tags

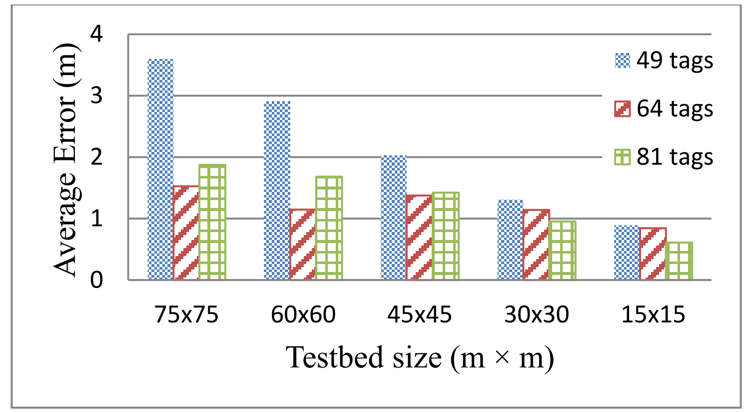
4.3.3.6 **Effect of number of real reference tags, data collection paths, and test-bed sizes on the accuracy**

In order to identify the effect of the number of real reference tags, data collection path, and test bed size using the proposed method, a sensitivity analysis was done based on the aforementioned parameters and the results are shown in Figure 4-16. Logically, it was expected that less error can be achieved by increasing the number of real reference tags. Focusing on Figures 4-16 (a), (b), (c), and (d), it is found out that expectation works for the 49 and 64 real reference tags and usually in scenario of 64 tags there is less error compared to 49 tags. However, the average errors dramatically increase by using 81 tags and I shape path which means that placing more tags can increase the chance of selecting wrong tags in the winner cluster when there is a symmetric tags' placement. Therefore, it is understood that placing more real reference tags without eliminating symmetric placement of the reference tags may result in larger errors.

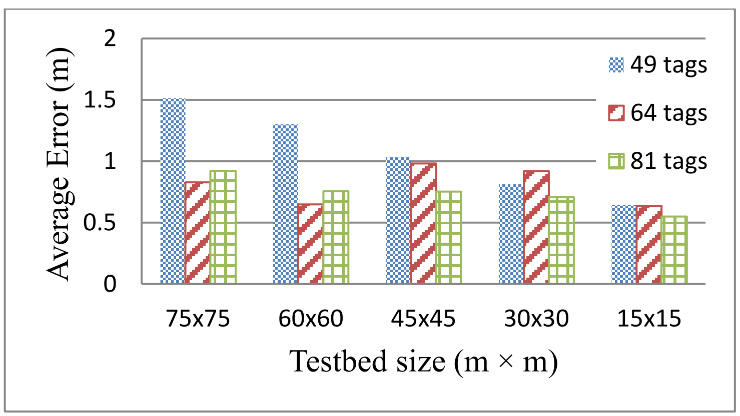
The exceptions for achieving better accuracy when adding more reference tags mostly happened when using the U-shape path and random data collection points. For instant, the average error for the area of 30m × 30m with 64 tags and a U-shape path are greater than the same area size and path but with 49 tags. It can be noticed from Figures 4-16 that if the density of the real reference tags is more than 0.02 per square meter, the error is less than one meter and there is no benefit of increasing the density.



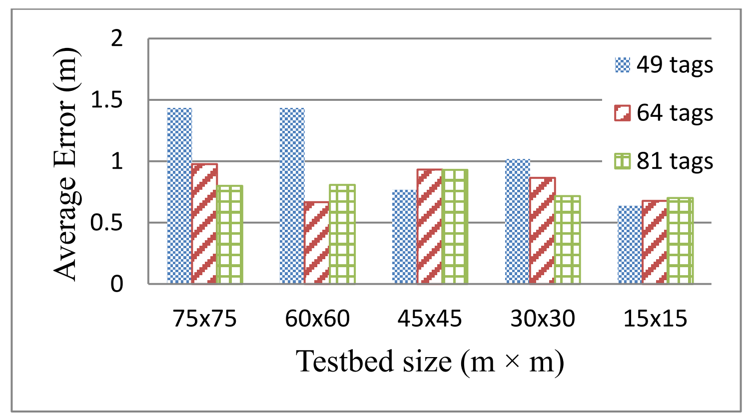
(a) I shape path



(b) L shape path



(c) U shape path



(d) Random points

Figure 4-16 Accuracy comparison for different number of reference tags, data collection paths, and test-bed sizes

From another point of view, the sensitivity of the average error to the number of the real reference tags is analyzed. I shape data collection path was selected as the most critical path and the different test bed sizes were considered in this simulation and the data of this simulation are generated for four data collection points. Figure 4-17 illustrates that increasing the number of reference tags from 49 to 64 improved the accuracy in general but from 64 to 81 reduced it. The reason could be because of the higher chance for choosing a wrong symmetric cluster when there are a larger number of reference tags placed in an area.

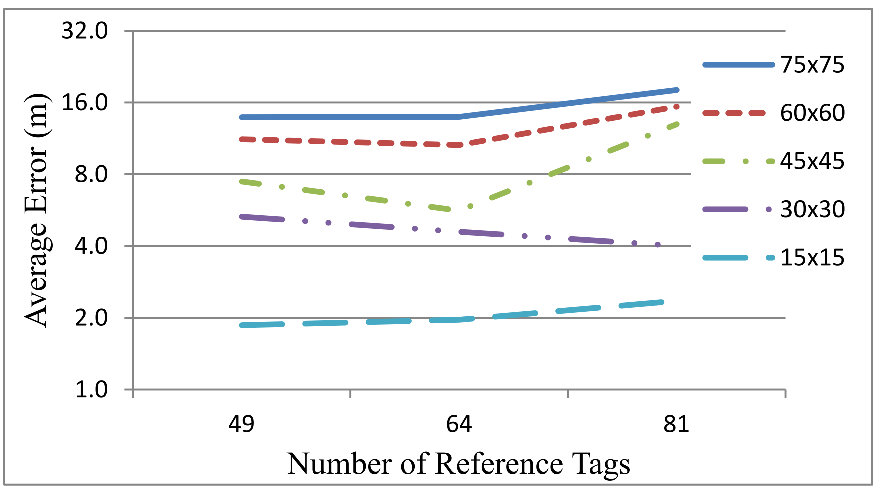


Figure 4-17 Accuracy comparison of CMTL+ localization for different number of real reference tags and test-bed size

4.3.4 Field test

In the next sections, two field tests were performed to validate the results of simulator, and applicability of the CMTL and CMTL+ algorithms. The first test was done in an obstacle-free environment where the reader had line-of-sight to the all reference tags during the data collection period. The second test, which is more complicated, was done in an noisy environment with lots of obstacles.

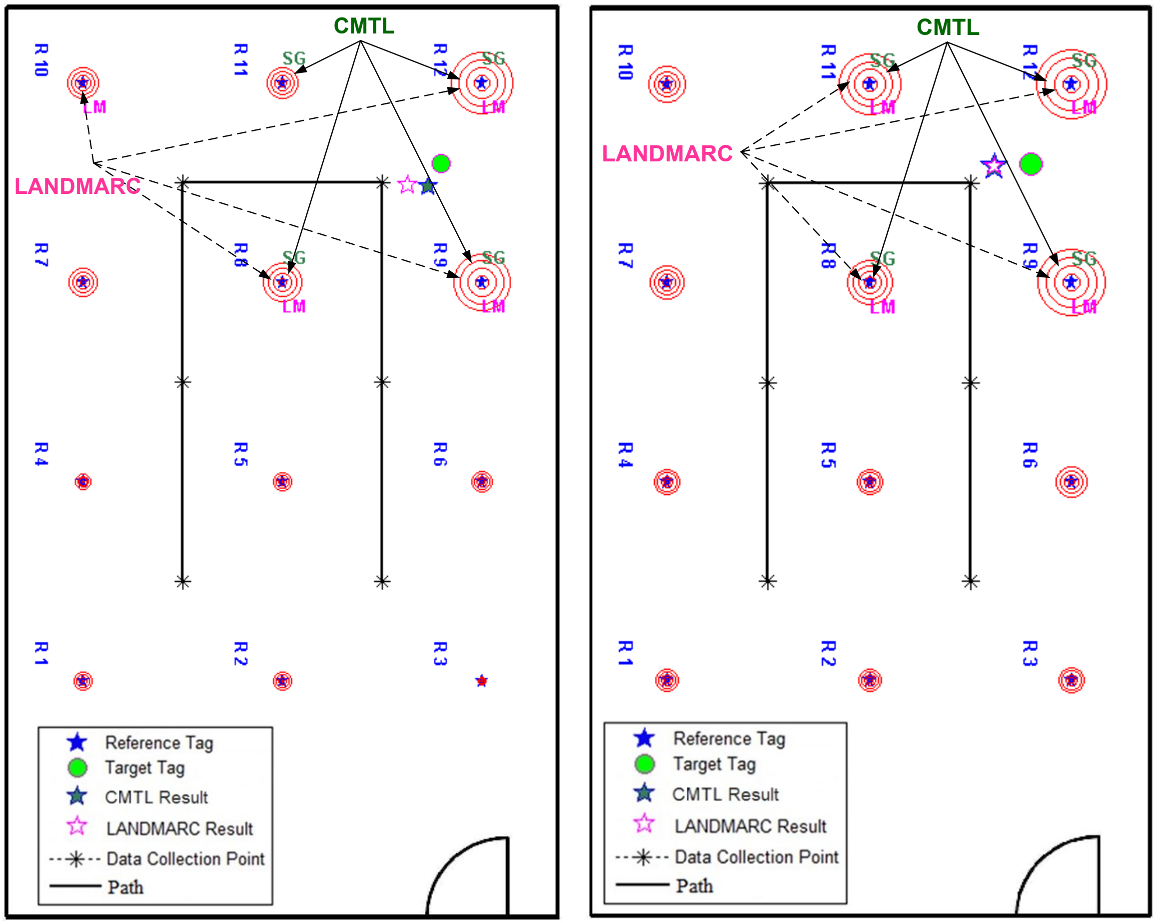
4.3.4.1 Obstacle-free environment (with line-of-sight)

This case study is performed to test the applicability of the CMTL+ algorithm explained in Section 4.2.4 for selecting the closest reference tags to track the objects in an indoor/outdoor environment. The test was conducted in an obstacle-free environment where all tags were placed inside one room. The tags were placed on the ground in a grid of 5 m ×7.5 m. A target tag was placed randomly in the room with the distance of 70 cm from the closest reference tags (R_9 and R_{12}) and data were collected using a handheld reader at the six data collection steps forming a U-shaped path for 30 seconds at each data collection step. The setting of this test is illustrated in Figure 4-18 (a) and the calculated β values for all reference tags are presented in Table 4-2. Figure 4-18 (b) shows the same setup in the simulation environment. The reason of doing the simulation with the same setting is to compare the real results in an indoor environment with the result of simulation based on clean environment with the minimum noise. The RSSI values were generated using our signal propagation model (Equation 4-18 and Equation 4-19) and they were compared with the real measured data.

Table 4-2 β value for field test and one instance of the simulation (obstacle-free environment)

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}
Field Test	13.5	13.2	33.1	15.4	13.7	12.2	8.7	6.2	4.3	8.1	8.3	4.1
Simulation	11.1	11.3	10.5	10.2	10.3	8.6	8.2	6.1	4.1	7.6	4.4	3.8

In Figures 4-18, the diameters of circles around reference tags are inversely proportional to their β values. The results show that R_{12} has the least β value in both field test and simulation environment. As can be seen in Table 4-2, the simulated β values are systematically less than those of the test values. This can be explained by the fact that the space used in the test is much smaller than the one used in the test explained in Section 4.3.2. Moreover, CMTL was applied to find the four nearest reference tags. The result illustrated in Figures 4-18 shows that CMTL chose the closest four reference tags while LANDMARC chose one of the reference tags incorrectly.



(a) Test results (b) Simulated results

Figure 4-18 Obstacle-free test

4.3.4.2 Environment with obstacles (without line-of-sight)

The case study test is performed using 20 long range active RFID tags placed inside four different rooms on the 9th floor of the EV Building of Concordia University. The area for the test is approximately 35m × 25m. The test is done in a cluttered and noisy environment where tags were attached to various assets in the rooms. The placement layout of the tags is shown in Figure 4-19 where four rooms were selected with five tags in each room. The density factor of total reference tags was set to 0.5 tags per square meter. The number of tags selected for clustering is set to four.

The active tags used in this case study have long nominal read range (250m) and stable RSSI values (Identec Solutions, 2013). The data were collected at six different data collection points in the corridors using a handheld device. About 100 readings for each tag were collected at each data collection point and the data were then filtered and processed for localization.

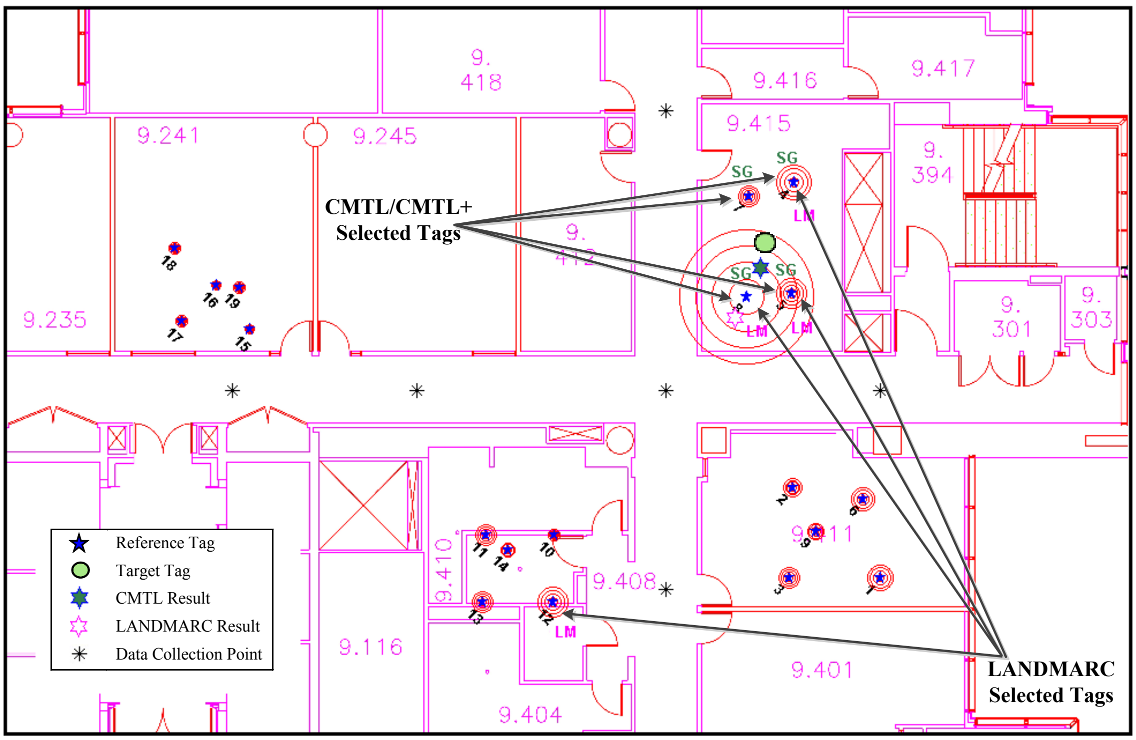


Figure 4-19 Field test in cluttered and noisy environment

The analysis for the accuracy of localization is performed for the two scenarios. In the first one, the accuracy of localization is performed for centered tags inside each room surrounded by four tags. In this test, each centered tag is selected as a target tag and it is localized using data collected from the other tags. The comparative analysis is performed to evaluate the results of localization using the LANDMARC method, CMTL, and CMTL+. As shown Figure 4-19, using CMTL leads to choosing better group of reference tags. The improvement in the results compared to LANDMARC is related to the fact that in most of cases, CMTL choses spatially close tags for localization. However, LANDMARC may select tags from other rooms due to their signal pattern similarity with the target tag because of the random noise or symmetry.

Figure 4-20 shows the results for the target tag localization using CMTL+, CMTL, and LANDMARC. This figure illustrates that the CMTL method chose tags inside the same room as the target tags for localization. Additionally, ANN and VRT help CMTL method to localize the target better than weighted averaging method used by LANDMARC. The average errors are 1.55 m, 0.77 m, and 0.38 m for LANDMARC, CMTL, and CMTL+, respectively.

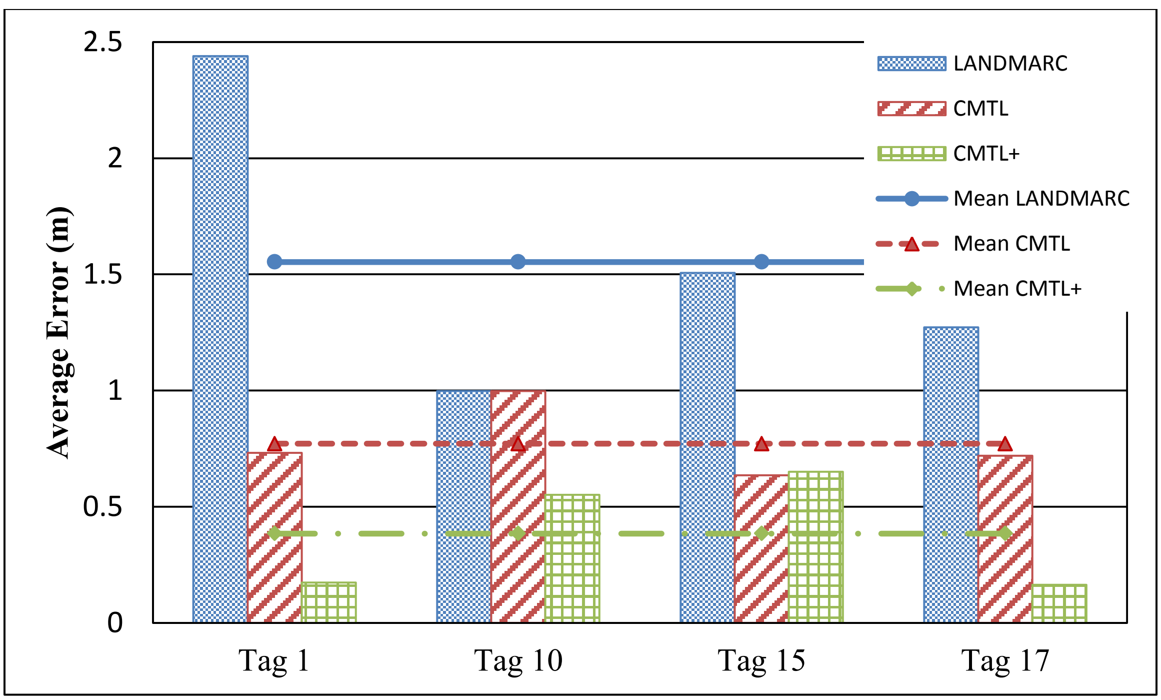
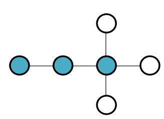
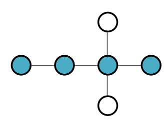
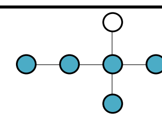
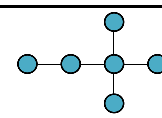


Figure 4-20 Accuracy comparison of LANDMARC, CMTL, and CMTL+ANN methods (considering centered tags)

In the second scenario, the results for 20 target tags show an improvement of 40% by using CMTL+ compared to CMTL and LANDMARC (Figure 4-21). However, the improvement of CMTL+ compared to CMTL is about 5%. One of the reasons for this low improvement could be the limited number of the tags per room. In other words, when any tag other than the centered tag is considered as target tag, there is not enough tags around the target tag. Another possible reason can be the small size of test area. As mentioned in Section 4.2.5, CMTL+ is more effective in large areas.

Another analysis is performed to find the effects of the number data collection points and their paths. Four scenarios introduced in Table 4-3 show data collection with 3, 4, 5, and 6 points with different paths.

Table 4-3 Order of selected data collection points

Order of data collection points				
Number of data collection points	3	4	5	6

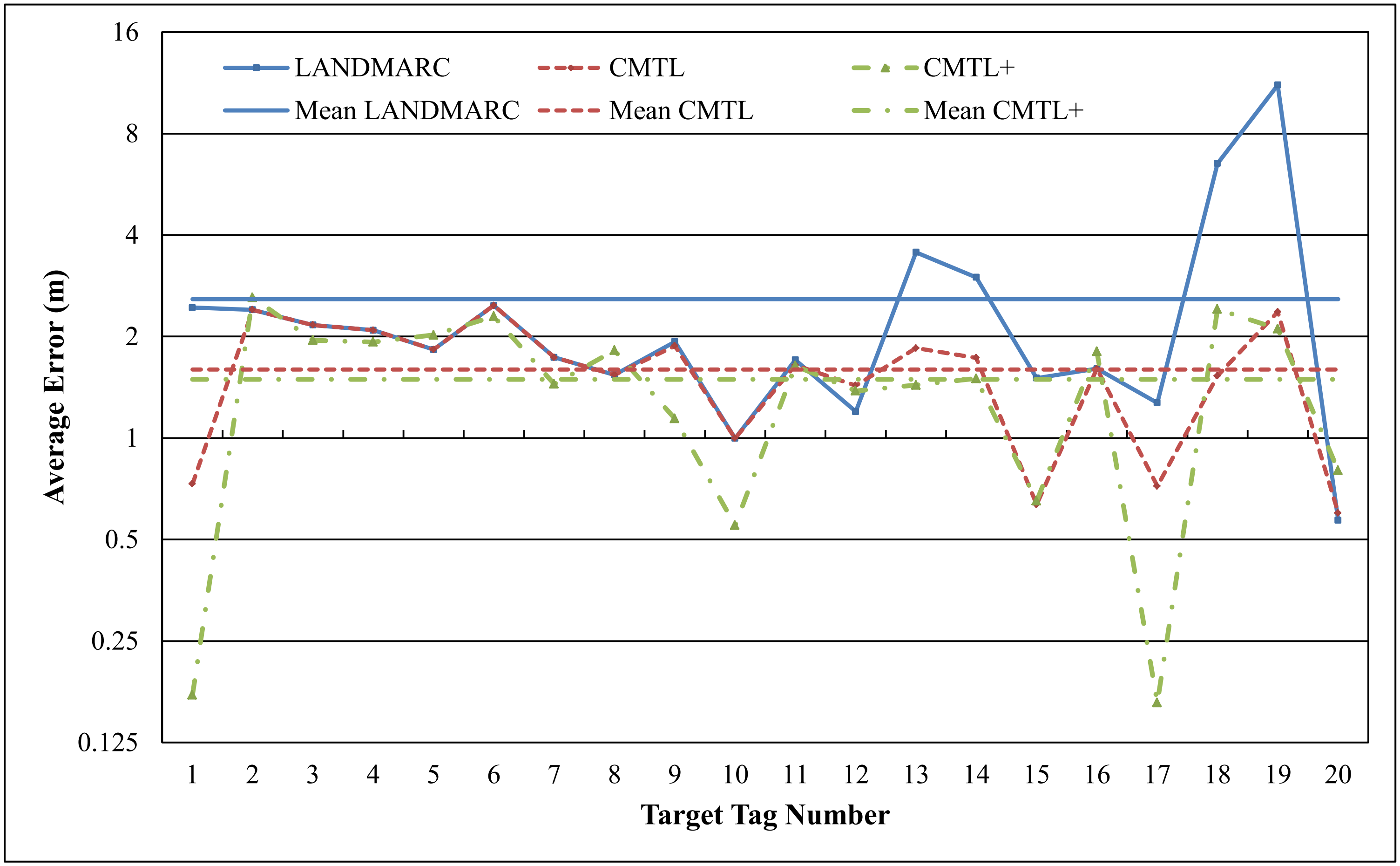
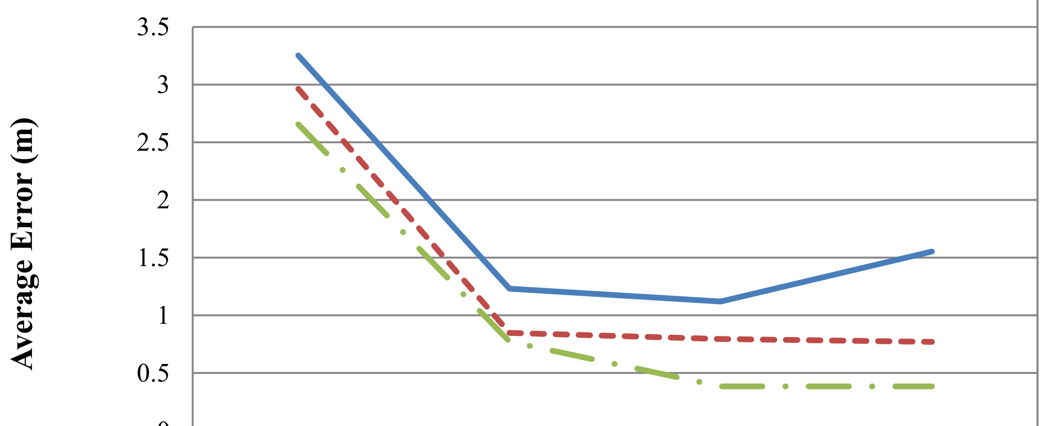


Figure 4-21 Accuracy comparison of LANDMARC, CMTL, and CMTL+ methods (considering all tags)

The effect of increasing the number of data collection points on the accuracy of localization is presented in Figure 4-22. In each column, the error is calculated based on the data gathered in the set of data collection points shown in the first row. The number of data collection points is increased from three. The results in the figure show that by increasing the number of data collection points, the accuracy of CMTL-based methods always improves but LANDMARC started to increase the accuracy after five data collation points. However, the improvement rate for CMTL-based methods decreases by adding data more collection points. Unfortunately, because of space limitation it was not possible to investigate increasing the reference tags density factor as area of each room was not large enough to analysis the sensitivity of this factor on the results.



	3	4	5	6
LANDMARC	3.25	1.23	1.12	1.55
CMTL	2.96	0.85	0.80	0.77
CMTL+	2.65	0.77	0.38	0.38

Number of Data Collection Points

Figure 4-22 Effect of increasing the number of data collection points

4.4 Summary and conclusions

This chapter investigated several methods to localize RFID-equipped objects in a construction site using handheld RFID readers. It discussed a sample scenario to assist users (e.g. site supervisor or workers) estimate the location of movable objects they are looking for. The main advantages of the CMTL+ is that it can adapt itself to the changes in the environment; it utilizes RFID tags in the construction site or in the building, and does not require a fixed RTLS infrastructure for localization. The conclusions of this chapter are as follows: (1) The proposed method for locating movable objects (i.e., CMTL and CMTL+) is based on the neighborhood methods. However, CMTL/CMTL+ use a handheld reader instead of a fixed number of fixed readers in similar LANDMARC-based methods. Using a handheld reader provides the flexibility to choose the number of data collection points and paths; (2) VRTs are added to the CMTL in the case of low reference tags density to keep the density at the desired level without using more real reference tags; (3) ANN was applied on the CMTL method and more reliable results are achieved compared to weighted averaging method used by LANDMARC; and (4) The results of simulations and case studies showed that CMTL+ is able to estimate the location of the target object with higher accuracy compared to LANDMARC and CMTL methods. Moreover, the results showed that in order to have a better accuracy, the density of total reference tags should be set above 0.2 per square meter; however increasing the density imposes higher computational load to the system. Additionally, considering five tags within the winner cluster causes lower error for CMTL+. Using any data collection paths other than the straight path (I-shape) has a significant effect on the accuracy while the major improvement happens when the shape of the data collection path diverges from the straight line. Regarding the number of data collection point, the results shows that having minimum four data collection points is necessary to achieve better results.

CHAPTER 5 CONCLUSIONS AND FUTURE WORK

5.1 Summary of research

The research proposed a comprehensive approach for applying RFID in the construction site for the localization of available resources. It elaborated on the needs, motivations and benefits of including standard definitions of RFID systems in the BIM as a stable foundation to reach to a reliable localization system. A conceptual model together with a requirements' gathering are performed in order to identify the related attributes and relationships for RFID system components. The modularity and extensibility of the design are taken into account to accommodate the possible future types and properties of RFID systems. Furthermore, new IFC entities, property sets and ports are defined for the RFID system. Moreover, this research investigated several methods to localize various types of RFID-equipped objects in a construction site using handheld RFID readers. It discussed possible scenarios to assist site supervisor or workers estimate the location of movable objects they are looking for. The main advantages of the proposed system are that it can adapt to the changes in the environment, it utilizes available RFID tags on the construction site, and does not require a fixed RTLS infrastructure for localization.

5.2 Research contributions and conclusions

The conclusions of this research are as follows: (1) The properties of RFID systems were defined by reusing the available property sets or by adding separate property sets to include RFID type-specific information and the different relationships including physical attachment, decomposition type, and logical assignment were investigated and standardized to cover all possible relationships between RFID tags and different entities of BIM; (2) A sample model of a construction site was developed using the existing and newly added definitions and relationships in IFC to validate the applicability of the proposed model. Moreover, to realize the proposed extension of IFC, various IFC-compatible tools were utilized and tested; (3) The proposed method for locating movable objects (i.e., CMTL and CMTL+) is based on the neighborhood methods. However, CMTL/CMTL+ use a handheld reader instead of a fixed number of fixed readers in similar LANDMARC-based methods. Using a handheld reader provides the flexibility to choose the number of data collection points and paths; (4) VRTs are added to the CMTL in the case of low reference tags density to keep the density at the desired level without using more real reference tags and ANN was applied on the CMTL method and more reliable results are achieved compared to weighted averaging method used by LANDMARC; and (5) The results of simulations and case studies showed that CMTL+ is able to estimate the location of the target object with higher accuracy compared to LANDMARC and CMTL methods.

5.3 Limitations and future work

For the case study regarding BIM extension, various IFC-compatible tools were utilized and tested to realize the proposed extension of IFC. The results showed that the current tools have several limitations for extending the definitions. Moreover, the exported IFC file of a model that is created in a certain tool lacks several details of the same model when opened in standard IFC viewers. Additionally, the exported IFC file has compatibility issues when opened by other BIM tools. Although the tested tools claim to be fully compatible with certain versions of IFC implementation, they were unable to utilize existing properties and relationship types available in that IFC version. This shows that the current state of practice has major limitations for adding new objects, relationships and properties as well as utilizing existing classes of IFC. In our case study we used the combined approach of utilizing IFC tools as well as manually adding EXPRESS code and finally visualizing the model using standard viewers.

The future research includes proposing the newly defined objects to the building SMART to be added in upcoming versions of the IFC standard. Moreover, the same methodology can be used to add the definitions of other types of sensors to BIM. The compatibility of the proposed extension can be investigated for other construction industry sectors (BrIM, RIM, MIM, and IDM).

The proposed localization method can be further improved by applying dynamic segmentation techniques and more advanced signal processing methods for removing noise from logged data. Moreover, other pattern matching techniques can be employed and compared. In order to form the clusters, dynamic clustering methods can be employed. Extracting more information from BIM can also be used to enhance the selection of the target cluster by considering spatial constraints, building materials and hierarchical location information (e.g., room number). Additionally, methods to identify the convergence of the localization should be investigated in order to find the optimum number and location of data collection steps. Finally, the simulation environment can be further enhanced to include the effect of building materials on radio signals.

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APPENDICES

Appendix A – List of RFID-related researches in construction

Research Area		Authors
Supply chain management and logistics		Chin et al. (2008); El Ghazali et al. (2011), (2012); Guven et al. (2013); Helmus et al. (2009); Radosavljevi (2007); Sarac et al. (2010); Majrouhi Sardroud and Limbachiya (2010); Shin et al. (2011); van Gassel and Glenco (2008); Yin et al. (2009); Wang et al. (2007b);
Object tracking	**Material**	Cheng et al. (2008); Ergen et al. (2007a); Furlani and Pfeffer (2000); Jaselskis et al. (1995); Jaselskis and El-Misalami (2003); Kim et al. (2010), Ren et al. (2007); (2011); Tzeng et al. (2008); Song et al. (2007); Swedberg (2009); Yin et al. (2009)
	Equipment and tools	de la Garza et al. (2009), Goodrum et al. (2005), Swedberg (2005), (2007)
Project and Progress management		Chin et al. (2008), GoStructural (2008), Lee et al. (2006b), Lu et al. (2011), Hammad and Motamedi (2007), Montaser and Moselhi (2012b), Atkin et al. (2006), Yagi et al. (2005), Yoon et al. (2005)
Localization		Bosche et al. (2006), Dziadak et al. (2009), Jang and Skibniewski (2009), Jiang et al. (2009), Luo et al. (2011), Montaser and Moselhi (2012a), Motamedi et al. (2012), Pradhan et al. (2009), Razavi et al. (2012), Razavi and Haas (2010), Rüppel and Stübbe (2008), Rüppel et al. (2010), Song et al. (2004), (2006); Taneja et al. (2010a), Torrent and Caldas (2007), (2009); Vossiek et al. (2010), Wireless Vision (2006), Xiong et al. (2013), Yabuki and Oyama (2007)
Quality Control		Akinci et al. (2006); Jaselskis et al. (2003); Jehle et al. (2009); Kang and Gandhi (2010); O'Connor (2006); Philips (2004); Reisbacka et al. (2008); Wang (2008); Yabuki et al. (2002)
Lifecycle management		Ergen et al. (2007a), (2007b); Helmus et al. (2011a), (2012); Hentula et al. (2005); Jehle et al. (2008); Ko (2009); Kiritsis et al. (2008); Lee et al. (2012); Motamedi and Hammad (2009a), (2009b), (2009c); Motamedi et al. (2011), (2013); Peyret and Tasky (2002)
Safety		Chae and Yoshida (2010); Friedlos (2008); Helmus (2007); Helmus et al. (2011b); Kelm and Laussat (2010); Swedberg (2008); Soltani (2010)

Appendix B - Technical specifications for RFID tags, readers, and handheld device used in the Research

Table B-2 Technical Specifications for RFID Tag: i-Q32 (Identec Solutions, 2007)

Identec Solutions: i-Q32		
Performance	Read rate	p to 100 tags/s (Identification Code only) Up to 35 tags/s @ 128 bit data reading
	Max. response time	< 150 ms (single tag)
	Multiple tag handling	Up to 2,000 tags in the read zone
Communication	Read/Write range to i-PORT 3	Up to 100 m (300 feet) @ free air
	Operating frequency	868 MHz (EC) or 915 MHz (NA) ISM Band
	Data rate (download to tag)	115.2 kbits/s
	Data rate (upload to reader)	115.2 kbits/s
	Maximum transmission power	0.75 mW ERP
	Standards / Certification	EN 300 220 (EC); FCC Part 15 (US); Industry Canada
Electrical	Power source	Lithium battery (not replaceable)
	Expected battery life	6 Years @ 600 times 128 bit readings/day
	Battery monitoring	Yes
Data	Data retention	10 years without power
	Write cycles	100,000 writes to a tag
	Memory size	32,431 bytes user definable (i-Q32)
	Identification code	48 bit fixed ID
Environmental	Operating temperature	–40°C to +85°C (–40ºF to +185ºF)
	Shock	50 G, 3 times DIN IEC 68-2-27 Multiple drops to concrete from 1 m (3 ft)
	Vibration	3 G, 20 sine wave cycles, 5 Hz to 150 Hz, DIN IEC 68-2-6 5 G, noise 5 Hz to 1000 Hz, 30 minutes DIN IEC 68-2-64
Physical	Dimensions	131 mm × 28 mm × 21 mm (5.2 in. × 1.1 in. × 0.85 in.)
	Enclosure	Plastic (ASA / Luran®S)
	Weight	50 g
	Enclosure rating	IP 65

Table B-1 Technical Specifications for RFID Tag: i-Q350L (Identec Solutions, 2013)

Identec Solutions: i-Q350L RTLS		
Category	**Type**	**Specification**
Communication Broadcast 350	Operation Mode	Transmits Sensor ID and user data in pre-defined interval
	Read Range	up to 500m
	Compatibility	i-PORT M350, i-CARD CF 350 and i-PORT 4-350
	Operating Frequency	868 MHz (EU) or 920 MHz (NA)
	Transmit Power	<1mW
Communication Response 350	Operation Mode	Bi-directional communication (reading log, blink LED, write/read data)
	Read Range	up to 250m
	Compatibility	i-PORT M350 and i-CARD CF 350
	Operating Frequency	868 MHz (EU) or 920 MHz (NA)
	Transmit Power	<1mW
Communication Marker	Operation Mode	Receives Marker ID and transmits marker information several times via Broadcast 350 telegrams
	Read Range	up to 5m
	Compatibility	i-MARK
	Operating Frequency	125 kHz
Data	Data Retention	> 10 years without power
	Write Cycles	100,000 writes
	Memory Size	10,000 Bytes user definable
	Identification Code	48 bit fixed ID
Configuration	Device	i-PORT M350 or i-CARD CF350
	Ping Rate	Configurable from 0.5 to 300 seconds insteps of 0.5 seconds
	Number of Bursts	Configurable from 0 to 15
	Broadcast	User Data Up to 50 Bytes
Electrical	Power Source	Lithium Battery (replaceable)
	Battery Monitoring	Yes
Environmental Conditions	Operating Temperature	–40 °C to +85 °C (–40 °F to +185 °F)
	Humidity	10% to 95% relative humidity @ 30°C
	Shock	Multiple drops to concrete from 1m (3ft), 3 times DIN IEC 68-2-27
	Vibrations	3G, 20 sine wave cycles, 5 to 150 Hz, DIN IEC 68-2-6 5G, noise 5 to 1.000 Hz, 30 minutes, DIN IEC 68-2-64
Standard/Certification	Europe	CE (EN 300 220-1, -3; EN 301 489-1,-3; EN 60950)
	North America	FCC Part 15 (US); Industry Canada
Physical	Dimensions	137 x 37.5 x 26.5 mm (5.4 x 1.48 x 1.04 in.)
	Enclosure	Plastic
	Weight	50g
	Enclosure Rating	IP65

Table B-3 Technical Specifications for RFID Reader: i-CARD CF 350 (Identec Solutions, 2012)

Identec Solutions: i-CARD CF 350		
Communication Broadcast	Operation mode	Receiving sensors ID's and data
	Read range	Up to 500m (1600ft)*
	Compatibility	i-B350 and Q350 series of sensors
	Operating frequency	868 MHz (EU) or 920 MHz (NA)
Communication Response	Response mode	Bi-directional communication (reading log, blink LED, write/read data)
	Communication range	up to 250m (800ft)*
	Compatibility	i-Q350 series of sensors
	Operating frequency	868 MHz (EU) or 920 MHz (NA)
	Transmit power	< 1mW
Antennas	Broadcast/Response (350)	1 MMCX connector for external antenna at 868 (EU) or 920 MHz (NA)
Performance	Multiple sensor handling(Response)	Up to 500 sensors per read zone
Interfaces	Data interface master/host	CF Type 1
Electrical	Power source	Dual 3.3 V and 5 V
	Power consumption	< 250 mW (50mA)
Environmental Conditions	Operating temperature	-20°C to +60°C (-4°F to +140°F)
	Storage temperature	-40°C to +80°C (-40°F to +176°F)
Standard/Certification	Europe	CE (EN 300 220-1, -3; EN 300 328, EN 301 489-1, -3; EN 60950)
	North America	FCC Part 15 (US); Industry Canada
Physical	Dimensions	55 × 43 × 3.3/6 mm (2.2 × 1.7 × 0.13/0.24 in.)
	Enclosure material	ABS / Metal
	Weight	15 grams (0.52 ounces)

Table B-4 Technical Specifications for RFID Reader: i-CARD 3 (Identec Solutions, 2005)

Identec Solutions: i-CARD 3		
Compatibility	ILR i-Q tags and ILR i-D tags.	ILR i-Q tags and ILR i-D tags.
Performance	Read/write range (adjustable)	Up to 100 m (300 ft) with i-Q tag*
	Read/write range (adjustable)	Up to 6 m (20 ft) with i-D tag*
	Read rate – ID only	100 tags/s
	Read rate – 128 bit data	35 tags/s
	Multiple tag handling	Up to 2,000 tags in the read zone
Communication	Frequency	868 MHz (EU) or 915 MHz (NA)
	Certification	EN 300 220 (EU); FCC part 15 (US); Industry Canada
	Data rate (up-/download)	115.2 kbits/s (i-Q Tag)
	Data rate (upload to tag)	38.4 kbits/s (i-D Tag)
	Data rate (download from tag)	115.2 kbits/s (i-D Tag)
	Number of antennas	1
	Output power	≤ 27 dBm, digitally adjustable
	Sensitivity	-85 dBm/high sens., -55 dBm/low sens., digitally adjustable
User Interfaces	Parallel interface	PCMCIA
	Option serial interface	RS-232, JTAG via PGM 15 connector
	Number of status indications	3 LEDs (Host TxRx, RF Tx, RF Rx)
Electrical	Input power	5 VDC ±5 %
	Power consumption	≤ 500 mW (100 mA @ 5V)
	Standards / Safety	CE and EN 300 220
Environmental	Operating temperature	-20 °C to +60 °C (-4 ºF to +140 ºF)
	Storage temperature	-40 °C to +80 °C (-40 ºF to +176 ºF)
	Humidity	90 % non-condensing
Physical	Dimensions	Standard Type II PC Card (86 × 54 × 5 mm) (3.38 in. × 2.12 in. × 0.19 in.)
	Enclosure	Metal
	Weight	32 grams (1.13 oz)

* The communication range depends on the antenna type, the antenna cable runs and the environmental conditions.

Table B-5 Technical Specifications for Handheld Device: WORKABOUT Pro S (Psion, 2011)

Psion Teklogix: WORKABOUT Pro 3 C	
Platform	PXA270 624 MHz Processor
	1 GB Flash ROM, 256 MB RAM
Expansion Slots	One SD/MMC memory card slot
	End-cap USB interface supports GPS expansion module
	100-PIN expansion interface: supports PCMCIA (type II), GPRS/ EDGE and other third-party expansion modules developed using Psion Hardware Development Kit
	Flex cable interface supports scanner (serial) and imager (USB) modules
	One Type II CF card slot
Operating System	Microsoft Windows Mobile® 6.1 Classic, Professional
Physical Dimensions	8.78" × 2.95"/3.94" × 1.22"/1.65" (223 mm × 75/100 mm × 31/42 mm)
Approvals	Safety: CSA/UL60950-1, IEC 60950-1, EN60950-1; EMC: FCC Part 15 Class B, EN 55022, EN 55024, EN301 489
	Laser: IEC 60825-1, Class 2, FDA 21 CFR 1040.10., 1040.11 Class II
	Bluetooth: 1.2
	In-vehicle cradle: e Mark
Environmental	Withstands multiple drops from 6 ft (1.8 m) to concrete
	Rain/dust: IP65, IEC 60529
	Operating temperature: -4°F to 122°F (-20°C to +50°C)
	5%-95% RH non-condensing
	Storage temperature: -40°F to 140°F (-40°C to +60°C)
	ESD: +/- 8kVdc air discharge, +/-4kVdc contacts

Table B-5 Technical Specifications for Handheld Device: WORKABOUT Pro 3 C (Psion, 2011)

Psion Teklogix: WORKABOUT Pro S	
Platform	PXA270 520MHz Processor
	256 MB Flash ROM, 128 MB RAM
Expansion Slots	One SD/MMC memory card slot
	End-cap USB interface supports GPS expansion module
	100-PIN expansion interface: supports PCMCIA (type II), GPRS/ EDGE and other third-party expansion modules developed using Psion Hardware Development Kit
	Flex cable interface supports scanner (serial) and imager (USB) modules
	One Type II CF card slot
Operating System	Microsoft Windows Mobile® 6.1 Classic, Professional
Physical Dimensions	7.87” × 2.95”/3.94” × 1.22”/1.65”(200 mm × 75/100 mm × 31/42 mm)
Approvals	Safety: CSA/UL60950-1, IEC 60950-1, EN60950-1; EMC: FCC Part 15 Class B, EN 55022, EN 55024, EN301 489
	Laser: IEC 60825-1, Class 2, FDA 21 CFR 1040.10., 1040.11 Class II
	Bluetooth: 1.2
	In-vehicle cradle: e Mark
Environmental	Withstands multiple drops from 6 ft (1.8 m) to concrete
	Rain/dust: IP65, IEC 60529
	Operating temperature: -4°F to 122°F (-20°C to +50°C)
	5%-95% RH non-condensing
	Storage temperature: -40°F to 140°F (-40°C to +60°C)
	ESD: +/- 8kVdc air discharge, +/-4kVdc contacts

Appendix C – Matlab code of the simulation

```
function [LMErr,KBestGRErr,GRErrAnn,LMErrMean,KBestGRErrMean,...
    GRErrAnnMean,LMRECORD,CLRECORD,LMErrStd,KBestGRErrStd...
    ,GRErrAnnStd]= CMTLVIRE()
%%  Initial Setting

%   k = Number selected reference tags
%   sn = Number of inputs' reference tags for training the ANN
%   dens = Number of Tags per Square Meter
%   sm = Default number of hidden neurons
%   r = Number of Reference Tags
%   t = Number of Target Tags
k=4;
sn=4;
dens=0.2
sm=20
r=49
t=20;
LMRECORD=0;
CLRECORD=0;
Xmin=0;
Xmax=30
Ymin=0;
Ymax=30
%   Reset Seed Number
se = RandStream('mt19937ar','Seed',1);
RandStream.setGlobalStream(se);
 %   Reading the Building Map
Rx=[(Xmin-1),  (Xmax)+1];
Ry=[(Ymin-1),  (Ymax)+1];
plot(Rx,Ry,'.','markersize',1);
hold on
RefXY=HSS(r,2)';
RefXY(:,1)=(Xmax-Xmin)*RefXY(:,1);
RefXY(:,2)=(Ymax-Ymin)*RefXY(:,2);
Refxyb(:,1)=linspace(1,r,r);
Refx=RefXY(:,1);
Refy=RefXY(:,2);
Refxyb(:,2)=RefXY(:,1);
Refxyb(:,3)=RefXY(:,2);
n=size(Refxyb(:,1),1);
plot(Refxyb(:,2),Refxyb(:,3),'p','markersize',8,'markerfacecolor','b');
%   Generating Target Points
pita=0;
XYminmax(1,1)=min(Refxyb(:,2))+4;
XYminmax(1,2)=max(Refxyb(:,2))-1;
XYminmax(2,1)=min(Refxyb(:,3))+3;
XYminmax(2,2)=max(Refxyb(:,3))-3;
XY=[];
XY=HSS(t+1,2)';
XY(:,1)=(XYminmax(1,2)-XYminmax(1,1))*XY(:,1)+XYminmax(1,1);
XY(:,2)=(XYminmax(2,2)-XYminmax(2,1))*XY(:,2)+XYminmax(2,1);
XY(t,:)=[];
t=length(XY');
```

```
plot(XY(:,1),XY(:,2),'h','markersize',10,'markerfacecolor','g');
for j=1:t
    text(XY(j,1)-0.5,XY(j,2)+0.5,sprintf('%g', j), 'fontsize',7,...
        'color','K','Rotation',-45,'FontWeight','Bold','Fontsize',10);
end
XYminmax(1,1)=Xmin+((Xmax-Xmin)./4);
XYminmax(1,2)=Xmax-((Xmax-Xmin)./4);
XYminmax(2,1)=Ymin+((Ymax-Ymin)./4);
XYminmax(2,2)=Ymax-((Ymax-Ymin)./4);
LMRC=1;
CLRC=1;
%   Running for t number of Target Points
for l=1:t
%   Running 4 loops for I, L, U shape data collection path and Random
points
%   m = Number of Data Collections
%   p = Number of Target Points
%   n = Number of Reference Points
    for iluz=1:4
        if iluz == 2
            minie=3;
        elseif iluz == 3
            minie=3;
        else
            minie=1;
        end
        for ie=minie:5
            %   m = Muximum Number of Data Collection Points
            m=2^(ie-1);
            LXY=[];
            switch iluz

                %   I Shape
                case 1
                    LXY(:,1)=linspace(XYminmax(1,2),XYminmax(1,1),m)';
                    LXY(:,2)=((2.*(XYminmax(2,2)-XYminmax(2,1)))./4)...
                        +XYminmax(2,1);

                %   L Shape
                case 2
                    LXY(:,1)=linspace((XYminmax(1,1)-((XYminmax(2,2)...
                        -XYminmax(2,1))./2))+1,XYminmax(1,2),m)';
                    LXY(:,1)=flipud(LXY);
                    for q=1:m
                        if(LXY(q,1)<XYminmax(1,1))
                            LXY(q,2)=(LXY(q-1,2)+(LXY(1,1)-LXY(2,1)));
                            LXY(q,1)=LXY(q-1,1);
                        else
                            LXY(q,2)=((2.*(XYminmax(2,2)-XYminmax...
                                (2,1)))./4)+XYminmax(2,1);
                        end
                    end

                %   U Shape
                case 3
```

```
                    LXY(:,1)=linspace(XYminmax(1,2),XYminmax(1,1)...
                        -((((XYminmax(2,2)-XYminmax(2,1))./2))...
                        +(XYminmax(1,2)-XYminmax(1,1)))),m+1)';
                    LXY(m+1,:)=[];
                    for q=1:m
                        if(LXY(q,1)<XYminmax(1,1) && LXY(q,1)>...
                                (XYminmax(1,1)-(((XYminmax(2,2)...
                                -XYminmax(2,1))/2))))
                            LXY(q,2)=(LXY(q-1,2)+(LXY(1,1)-LXY(2,1)));
                            LXY(q,1)=LXY(q-1,1);
                        elseif(LXY(q,1)<(XYminmax(1,1)-
((XYminmax(2,2)...
                                -XYminmax(2,1))./2)))
                            LXY(q,1)=LXY(q-1,1)+(LXY(1,1)-LXY(2,1));
                            LXY(q,2)=LXY(q-1,2);
                        else
                            LXY(q,2)=((2.*(XYminmax(2,2)-
XYminmax(2,1)))...
                                ./4)+XYminmax(2,1);
                        end
                    end

                %   Randomly
                case 4
                    LXY(:,1)=((XYminmax(1,2)-
XYminmax(1,1))*rand(1,m))...
                        +XYminmax(1,1);
                    LXY(:,2)=((XYminmax(2,2)-
XYminmax(2,1))*rand(1,m))...
                        +XYminmax(2,1);
            end
            plot(LXY(:,1),LXY(:,2),'*','markersize',10,...
                'markeredgecolor','K');
            if iluz ~=4
                plot(LXY(:,1),LXY(:,2),'K','LineWidth',2);
            end

            lx=LXY(:,1);
            ly=LXY(:,2);
            dt=[];
            d=0;
            RSSt=[];
            RSSr=[];
            rita=[];
            spot=[];
            RSSI=[];
            %% RSSI Generator Core
             %   Number of Random Noise for RSSI
            z=100;
             %   Reset Seed Number
            se = RandStream('mt19937ar','Seed',1);
            RandStream.setGlobalStream(se);
             %   Generating RSSI for Target Tags on different Colletion
Points
            for i=1:m
```

```
            dt(i)=sqrt(((lx(i)-XY(l,1)).^2)+((ly(i)-XY(l,2)).^2));
            d=dt(i);
            RSSt(i) = -9.387.*log10(d) - 34.125;
            e = 0.0876.*log(dt(i)) + 0.1709;
            RndRSSt=e.*randn(1,z)+RSSt(i);
            RSSt(i)=mean(RndRSSt);
        end
         %   Generating RSSI for Reference Tags on different
Colletion Points
        for i=1:m
            for j=1:n
            dr(i,j)=sqrt(((lx(i)-Refx(j)).^2)+((ly(i)-
Refy(j)).^2));
            d=dr(i,j);
            RSSr(i,j) = -9.387.*log10(dr(i,j)) - 34.125;
            e = 0.0876.*log(d) + 0.1709;
            RndRSSr=e.*randn(1,z)+RSSr(i,j);
            RSSr(i,j)=mean(RndRSSr);
            end
        end

        %% LANDMARC Method

        %   Calculating Beta Value
        %   Using all RSSIs on one Matrics
        RSSI=RSSt;
        for s=2:n+1
            RSSI(s,:)=RSSr(:,s-1);
        end
        %   Euclidean-Based Beta Value
        minkowski2=squareform(pdist(RSSI,'minkowski',2));
        minkowski2=minkowski2(1,:);
        minkowski2(1)=[];
        EU=minkowski2;
        Refxyb(:,4)=0;
        Refxyb(:,4)=EU';
        %   Selecting k best references based on Beta value sorting
        SRefxyb1=[];
        KBest1=[];
        SRefxyb1=sortrows(Refxyb,4);
        KBest1=SRefxyb1(1:k,:);
        %   Calculating the position of the target using LANDMARC
        %   weighted averaging using KBest Matrix
        E=[]; W=[]; LMX=[]; LMY=[];
        E=1./(KBest1(:,4).^2);
        W=E./sum(E);
        LMX=sum(KBest1(:,2).*W);
        LMY=sum(KBest1(:,3).*W);
        LMErr(l,iluz,ie)=sqrt((((LMX-XY(l,1)).^2)+((LMY-
XY(l,2)).^2)));
        LM=  LMErr(l,iluz,ie);

        %% CMTL

        %   Calculation of Beta Value for Selected Reference Tags
```

```
%   Selecting Group of Reference Tags for Training
%   Selecting k reference tags based on Exhaustive Grouping

KBest3=[];
SelectedGroup=[];
KBest3=[];
Selectedxyb1=[];
KBest3=Refxyb(1:(ceil(r)),:);
SelectedGroup=Grouping(KBest3,sn,1,1);
for i=1:sn
    Selectedxyb(i,:)=Refxyb(SelectedGroup(i),:);
end
pita=0;
SBeta=0;
KBest3=Selectedxyb;
%   Calculating the position of the target using GROUPING
%   weighted averaging uses GrRef Matrix
E=[]; W=[]; KBestGRX=[]; KBestGRY=[];
E=1./(Selectedxyb(:,4).^2);
W=E./sum(E);
KBestGRX=sum(Selectedxyb(:,2).*W);
KBestGRY=sum(Selectedxyb(:,3).*W);
%   Calculating the error for the GROUPING weighted
averaging
KBestGRErr(l,iluz,ie)=sqrt((((KBestGRX-XY(l,1)).^2)+...
    ((KBestGRY-XY(l,2)).^2)));
RES4=KBestGRErr(l,iluz,ie);

%% VIRE + CMTL Neural Network

num(k)=sn;
ANNTBeta=[];
pita=0;
xq=[];
yq=[];
xq=[];
nxq=[];
nyq=[];
nzq=[];
Annq=[];
nAnnq=[];
minkowski2=[];
ej=0;
IntRSSr=[];
A=(max(KBest3(:,2))-min(KBest3(:,2)))*(max(KBest3(:,3))...
    -min(KBest3(:,3)));
if A<dens
    sm=2;
else
    sm=ceil(sqrt(A*dens));
    if sm >10
        sm=10;
        CLRECORD=[l,iluz,ie];
        CLRC=CLRC+1;
    end
```

```
            end
            a=linspace(min(KBest3(:,2)),max(KBest3(:,2)),sm);
            b=linspace(min(KBest3(:,3)),max(KBest3(:,3)),sm);
            [xq,yq]=meshgrid(a,b);
            nxq=xq(:)';
            nyq=yq(:)';
            nxq=[nxq';KBest3(:,2)]';
            nyq=[nyq';KBest3(:,3)]';
            for i=1:m
                IntRSSr(i,:)=RSSr(i,KBest3(:,1));
                zq =
griddata(KBest3(:,2),KBest3(:,3),IntRSSr(i,:),xq,yq);
                if isnan(zq)
                    break;
                end
                plot3(KBest3(:,2),KBest3(:,3),1./KBest3(:,4),'o')
                nzq(i,:)=zq(:)';
            end
            if isnan(zq)
                nxq=[];
                nyq=[];
                nzq=[];
                nxq=[KBest3(:,2)]';
                nyq=[KBest3(:,3)]';
                for i=1:m
                    IntRSSr(i,:)=RSSr(i,KBest3(:,1));
                end
                nzq=IntRSSr;
            else
                nzq=[nzq,IntRSSr];
            end
            i=length(nxq);
            while i>0
                if isnan(nzq(1,i))
                    nzq(:,i)=[];
                    nxq(:,i)=[];
                    nyq(:,i)=[];
                end
                i=i-1;
            end
            ANNTBeta=KBest3(:,4);
            Annq = griddata(KBest3(:,2),KBest3(:,3),ANNTBeta,xq,yq);
            nAnnq=Annq(:)';
            minkowski2=squareform(pdist(nzq','minkowski',2));
            nRSSI=[RSSt;nzq'];
            EU=squareform(pdist(nRSSI,'minkowski',2));
            EU=EU(1,:);
            EU(1)=[];
            inputs=[];
            targets=[];
            net=[];
            outputs=[];
            errors=[];
            inputs = minkowski2;
            targets(1,:) = nxq';
            targets(2,:) = nyq';
```

```
             %   Create a Fitting Network
            hiddenLayerSize = ceil((sm+2).*(2/3)+2);
            net = fitnet(hiddenLayerSize);
            %   Choose Input and Output Pre/Post-Processing Functions
            %   for a list of all processing functions type: help
nnprocess
            net.inputs{1}.processFcns = {'removeconstantrows',...
                'mapminmax'};
            net.outputs{2}.processFcns = {'removeconstantrows',...
                'mapminmax'};
            net.numLayers=2;
            %   Setup Division of Data for Training, Validation,
Testing
            %   For a list of all data division functions type: help
nndivide
            net.divideFcn = 'dividerand';  % Divide data randomly
            net.divideMode = 'sample';  % Divide up every sample
            net.divideParam.trainRatio = 70/100;
            net.divideParam.valRatio = 15/100;
            net.divideParam.testRatio = 15/100;
            % For help on training function 'trainlm' type: help
trainlm
            % For a list of all training functions type: help nntrain
            net.trainFcn = 'trainbr';  % Bayesian regulation
backpropagation
            net.trainParam.epochs=500;
            % Choose a Performance Function for a list of all
            %   performance functions type: help nnperformance
            net.performFcn = 'mse';  % Mean squared error
            net.layers{1}.transferFcn = 'tansig';
            net.layers{2}.transferFcn = 'purelin';
            %   Choose Plot Functions
            %   for a list of all plot functions type: help nnplot
            net.plotFcns = {'plotperform','plottrainstate',...
                'ploterrhist','plotregression', 'plotfit'};
            net.trainParam.showWindow=1;
            %   Train the Network
            [net,tr] = train(net,inputs,targets,'useParallel','yes');
            %   Test the Network
            outputs = net(inputs);
            errors = gsubtract(targets,outputs);
            GRANNResult(:,ie) = net(EU');
            GRErrAnn(l,iluz,ie)=sqrt((((GRANNResult(1,ie)-
XY(l,1)).^2)...
                +((GRANNResult(2,ie)-XY(l,2)).^2)));
            RES5=GRErrAnn(l,iluz,ie);
            %   Recalculate Training, Validation and Test Performance
            trainTargets = targets .* tr.trainMask{1};
            valTargets = targets  .* tr.valMask{1};
            testTargets = targets  .* tr.testMask{1};
        end
    end
end
for i=1:5
    LMErrMean(i,:)=mean(LMErr(:,:,i));
    KBestGRErrMean(i,:)=mean(KBestGRErr(:,:,i));
```

```
    GRErrAnnMean(i,:)=mean(GRErrAnn(:,:,i));
    LMErrStd(i,:)=std(LMErr(:,:,i));
    KBestGRErrStd(i,:)=std(KBestGRErr(:,:,i));
    GRErrAnnStd(i,:)=std(GRErrAnn(:,:,i));
end
hold off
end

%   Hammersley Sequence Sampling
function m=HSS(n,k)
%   n=Number of samples
%   k=Dimension of sample space
%   radix-R
R=primes(2^k);
mi=[];
for i=1:n
    mij=i/n;
    for j=1:k-1
        mij=[mij,RX(i,R(j))];
    end
    mi=[mi;mij];
end
m=ones(k,n)-mi';
end

function Radix=RX(n,R);
nn=dec2base(n,R);
v=floor(log(n)/log(R));
phiR=0;
for i=v:-1:0
    x=nn(v-i+1);
    if x=='A'
        x='10';
    elseif x=='B'
        x='11';
    elseif x=='C'
        x='12';
    elseif x=='D'
        x='13';
    elseif x=='E'
        x='14';
    elseif x=='F'
        x='15';
    elseif x=='G'
        x='16';
    elseif x=='H'
        x='17';
    elseif x=='I'
        x='18';
    end
    ph=str2num(x)/(R^(i+1));
    phiR=phiR+ph;
end
Radix=phiR;
end
function [Result] = Grouping(Ref,k,wd,wb)
```

```matlab
Ref(:,4)=Ref(:,4)./max(Ref(:,4));
SR=0;
%   Co=Combination of References in group of k
%   SR=Selected Reference
Co=combnk(Ref(:,1),k);
[m,n]=size(Co);
parfor i=1:m
    SR=[];
    SR(:,1)=Co(i,:);
    for j=1:k
        R=SR(j,1);
        SR(j,2:4)=Ref(Ref(:,1)==R,2:4);
    end
    cx=mean(SR(:,2));
    cy=mean(SR(:,3));
    c=SR;
    SR=[0 cx cy 0];
    SR=[SR;c];
    %   CD=Centroid
    CD=squareform(pdist(SR(:,2:3),'euclidean'));
    %   MCD=Mean of CD
    MCD(i)=mean(CD(2:k+1,1));
    %   MB=Mean of Beta
    MB(i)=mean(SR(2:k+1,4));
End

MCD=MCD./max(MCD);
%   TCo=Total of each combination
TCo=(wd.*MCD)+(wb.*MB);
%   BG=Best Group
BG=find(TCo==min(TCo));

while BG ~= 0
  Result=Co(BG(1),:);
  BG(1)=[];
end

end
```

Appendix D – Matlab code of test analysis

```
function
[LMErrStd,KBestGRErrStd,GRErrAnnStd,LMErrMean,KBestGRErrMean,...
    GRErrAnnMean]= CaseStudy()
%%  Initial Setting

%   k = Number selected reference tags
%   sn = Number of inputs' reference tags for training the ANN
%   dens = Number of Tags per Square Meter
%   sn = Default number of hidden neurons
%   r = Number of Reference Tags
%   t = Number of Target Tags
%   ML = Type of RSSI (1 or 2)
%   TT = List of Target Tags
k=4;
sn=4;
dens=0.2;
sm=20;
TT=[1 10 20 28];
ML=2;
FIXDATA=xlsread('TEST1-TEST2', 'Ref');
DC1=xlsread('TEST1-TEST2', '1');
DC2=xlsread('TEST1-TEST2', '2');
DC3=xlsread('TEST1-TEST2', '3');
DC4=xlsread('TEST1-TEST2', '4');
DC5=xlsread('TEST1-TEST2', '5');
DC6=xlsread('TEST1-TEST2', '6');
Target=1;
n=size(FIXDATA(:,1),1);
Refxyb=FIXDATA;
DC1(:,all(isnan(DC1),1))=[];
DC2(:,all(isnan(DC2),1))=[];
DC3(:,all(isnan(DC3),1))=[];
DC4(:,all(isnan(DC4),1))=[];
DC5(:,all(isnan(DC5),1))=[];
DC6(:,all(isnan(DC6),1))=[];
FIXDATA(all(isnan(FIXDATA),2),:)=[];
Refxyb=FIXDATA;
[r sm]=size(FIXDATA);
hold on
XYminmax(1,1)=min(Refxyb(:,2));
XYminmax(1,2)=max(Refxyb(:,2));
XYminmax(2,1)=min(Refxyb(:,3));
XYminmax(2,2)=max(Refxyb(:,3));
%   Reset Seed Number
se = RandStream('mt19937ar','Seed',1);
RandStream.setGlobalStream(se);
%   Reading the Building Map
Rx=[(XYminmax(1,1)-1), (XYminmax(1,2))+1];
Ry=[(XYminmax(2,1)-1), (XYminmax(2,2))+1];
plot([33.134,0],[21.493,0 ],'.','markersize',1);
img = imread('EVR.png');
image([0,33.134],[21.493,0 ],img);
n=size(Refxyb(:,1),1);
```

```
plot(Refxyb(:,2),Refxyb(:,3),'p','markersize',8,'markerfacecolor','b');
LXY=xlsread('EV-9.xls', 'DC');
[m sm]=size(LXY);
plot(LXY(:,2),LXY(:,3),'*','markersize',10,'markeredgecolor','K');
lx=LXY(:,2);
ly=LXY(:,3);
%   Running for t number of Target Points
Refxyb=[];
Refxyb=FIXDATA;
%   Reading Target Points
for t=1:4
    Refxyb=[];
    Refxyb=FIXDATA;
    Target=TT(t);
    XY=Refxyb(Refxyb(:,1)==Target,2:3);
    RSSt=[];
    RSSr=[];
    rita=[];
    spot=[];
    RSSI=[];
    %   Running 3 loops for I, L and U shape Route
    %   m = Number of Data Collections
    %   p = Number of Target Points
    %   n = Number of Reference Points
    for i=1:m
        switch i
            case 1
                for j=1:n
                    %   Reading RSSI for Target Tags on different
                    %   Colletion Points
                    if DC1(1,(3*(j-1)+1))==Target
                        RndRSSt=DC1(:,(3*(j-1)+ML));
                        RndRSSt=RndRSSt(isfinite(RndRSSt(:, 1)), :);
                        RSSt(i)=mean(RndRSSt);
                    %   Generating RSSI for Reference Tags on different
                    %   Colletion Points
                    else
                        RndRSSr=DC1(:,(3*(j-1)+ML));
                        RndRSSr=RndRSSr(isfinite(RndRSSr(:, 1)), :);
                        RSSr(i,j)=mean(RndRSSr);
                    end
                end
            case 2
                for j=1:n
                    %   Reading RSSI for Target Tags on different
                    %   Colletion Points
                    if DC2(1,(3*(j-1)+1))==Target
                        RndRSSt=DC2(:,(3*(j-1)+ML));
                        RndRSSt=RndRSSt(isfinite(RndRSSt(:, 1)), :);
                        RSSt(i)=mean(RndRSSt);
                    %   Generating RSSI for Reference Tags on different
                    %   Colletion Points
                    else
                        RndRSSr=DC2(:,(3*(j-1)+ML));
                        RndRSSr=RndRSSr(isfinite(RndRSSr(:, 1)), :);
                        RSSr(i,j)=mean(RndRSSr);
```

```
        end
    end
case 3
    for j=1:n
        %   Reading RSSI for Target Tags on different
        %   Colletion Points
        if DC3(1,(3*(j-1)+1))==Target
            RndRSSt=DC3(:,(3*(j-1)+ML));
            RndRSSt=RndRSSt(isfinite(RndRSSt(:, 1)), :);
            RSSt(i)=mean(RndRSSt);
        %   Generating RSSI for Reference Tags on different
        %   Colletion Points
        else
            RndRSSr=DC3(:,(3*(j-1)+ML));
            RndRSSr=RndRSSr(isfinite(RndRSSr(:, 1)), :);
            RSSr(i,j)=mean(RndRSSr);
        end
    end
case 4
    for j=1:n
        %   Reading RSSI for Target Tags on different
        %   Colletion Points
        if DC4(1,(3*(j-1)+1))==Target
            RndRSSt=DC4(:,(3*(j-1)+ML));
            RndRSSt=RndRSSt(isfinite(RndRSSt(:, 1)), :);
            RSSt(i)=mean(RndRSSt);
        %   Generating RSSI for Reference Tags on different
        %   Colletion Points
        else
            RndRSSr=DC4(:,(3*(j-1)+ML));
            RndRSSr=RndRSSr(isfinite(RndRSSr(:, 1)), :);
            RSSr(i,j)=mean(RndRSSr);
        end
    end
case 5
    for j=1:n
        %   Reading RSSI for Target Tags on different
        %   Colletion Points
        if DC5(1,(3*(j-1)+1))==Target
            RndRSSt=DC5(:,(3*(j-1)+ML));
            RndRSSt=RndRSSt(isfinite(RndRSSt(:, 1)), :);
            RSSt(i)=mean(RndRSSt);
        %   Generating RSSI for Reference Tags on different
        %   Colletion Points
        else
            RndRSSr=DC5(:,(3*(j-1)+ML));
            RndRSSr=RndRSSr(isfinite(RndRSSr(:, 1)), :);
            RSSr(i,j)=mean(RndRSSr);
        end
    end
case 6
    for j=1:n
        %   Reading RSSI for Target Tags on different
        %   Colletion Points
        if DC6(1,(3*(j-1)+1))==Target
            RndRSSt=DC6(:,(3*(j-1)+ML));
```

```
                        RndRSSt=RndRSSt(isfinite(RndRSSt(:, 1)), :);
                        RSSt(i)=mean(RndRSSt);
                    %   Generating RSSI for Reference Tags on different
                    %   Colletion Points
                    else
                        RndRSSr=DC6(:,(3*(j-1)+ML));
                        RndRSSr=RndRSSr(isfinite(RndRSSr(:, 1)), :);
                        RSSr(i,j)=mean(RndRSSr);
                    end
                end
        end
    end
    RSSr(:, ~any(RSSr,1) ) = [];

    %% LANDMARC Method

    % Calculating Beta Value
    % Using all RSSIs on one Matrics
    RSSI=RSSt;
    for s=2:n
        RSSI(s,:)=RSSr(:,s-1);
    end
    % Euclidean-Based Beta Value
    minkowski2=squareform(pdist(RSSI,'minkowski',2));
    minkowski2=minkowski2(1,:);
    minkowski2(1)=[];
    EU=minkowski2;
    Refxyb(Refxyb(:,1)==Target,:)=[];
    Refxyb(:,4)=0;
    Refxyb(:,4)=EU';
    TBeta=[];
    TBeta=EU';
    for j=1:r-1
        text(Refxyb(j,2)-0.5,Refxyb(j,3)+0.5,sprintf('%g',
Refxyb(j,1)),...
        'fontsize',7,'color','K','Rotation',-45,'FontWeight',...
        'Bold','Fontsize',10);
    end
    E=1./(EU.^2);
    for u=1:r-1
    plot(Refxyb(u,2),Refxyb(u,3),'r:o','markersize',3000*E(u));
    end
    % Selecting k best references based on Beta value sorting
    SRefxyb=[];
    KBest1=[];
    SRefxyb=sortrows(Refxyb,4);
    KBest1=SRefxyb(1:k,:);
    % Calculating the position of the target using LANDMARC weighted
    % averaging using KBest Matrix
    E=[]; W=[]; LMX=[]; LMY=[];
    E=1./(KBest1(:,4).^2);
    W=E./sum(E);
    LMX=sum(KBest1(:,2).*W);
    LMY=sum(KBest1(:,3).*W);
    LMErr(t)=sqrt((((LMX-XY(1)).^2)+((LMY-XY(2)).^2)));
```

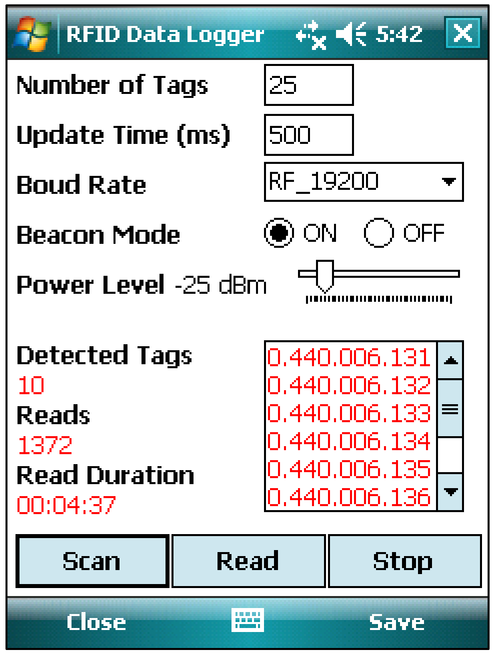
```matlab
%% CMTL Method

SRefxyb=[];
Selectedxyb=[];
SRefxyb=sortrows(Refxyb,4);
Selectedxyb=SRefxyb(1:k,:);
[sn sm]=size(Selectedxyb);
%   Calculation of Beta Value for Selected Reference Tags
%   Selecting Group of Reference Tags for Training
%   Selecting k reference tags based on Exhaustive Grouping
KBest=[];
SelectedGroup=[];
KBest=[];
Selectedxyb=[];
KBest=SRefxyb(1:(ceil(r-1)),:);
SelectedGroup=Grouping(Refxyb,k,0.5,0.5);
for i=1:k
R=SelectedGroup(i);
Selectedxyb(i,:)=Refxyb(Refxyb(:,1)==R,:);
end
pita=0;
SBeta=0;
%   Calculating the position of the target using GROUPING weighted
%   averaging uses GrRef Matrix
E=[]; W=[]; KBestGRX=[]; KBestGRY=[];
E=1./(Selectedxyb(:,4).^2);
W=E./sum(E);
KBestGRX=sum(Selectedxyb(:,2).*W);
KBestGRY=sum(Selectedxyb(:,3).*W);
%   Calculating the error for the GROUPING weighted averaging
KBestGRErr(t)=sqrt((((KBestGRX-XY(1)).^2)+((KBestGRY-XY(2)).^2)));

%%  VIRE + CMTL Neural Network

KBest3=Selectedxyb;
num(k)=sn;
ANNTBeta=[];
pita=0;
xq=[];
yq=[];
xq=[];
nxq=[];
nyq=[];
nzq=[];
Annq=[];
nAnnq=[];
minkowski2=[];
ej=0;
IntRSSr=[];
A=(max(KBest3(:,2))-min(KBest3(:,2)))*(max(KBest3(:,3))...
    -min(KBest3(:,3)));
if A<dens
    sm=2;
else
```

```
    sm=ceil(sqrt(A*dens));
    if sm >10
        sm=10;
    end
end
a=linspace(min(KBest3(:,2)),max(KBest3(:,2)),sm);
b=linspace(min(KBest3(:,3)),max(KBest3(:,3)),sm);
[xq,yq]=meshgrid(a,b);
nxq=xq(:)';
nyq=yq(:)';
nxq=[nxq';KBest3(:,2)]';
nyq=[nyq';KBest3(:,3)]';
for i=1:sn
TEMP(i)=find(Refxyb(:,1)==KBest3(i,1));
end
for i=1:m
    IntRSSr(i,:)=RSSr(i,TEMP);
    zq = griddata(KBest3(:,2),KBest3(:,3),IntRSSr(i,:),xq,yq);
    if isnan(zq)
        break;
    end
    plot3(KBest3(:,2),KBest3(:,3),1./KBest3(:,4),'o')
    nzq(i,:)=zq(:)';
end
if isnan(zq)
    nxq=[];
    nyq=[];
    nzq=[];
    nxq=[KBest3(:,2)]';
    nyq=[KBest3(:,3)]';
    for i=1:m
        IntRSSr(i,:)=RSSr(i,KBest3(:,1));
    end
    nzq=IntRSSr;
else
    nzq=[nzq,IntRSSr];
end
i=length(nxq);
while i>0
    if isnan(nzq(1,i))
        nzq(:,i)=[];
        nxq(:,i)=[];
        nyq(:,i)=[];
    end
    i=i-1;
end
ANNTBeta=KBest3(:,4);
Annq = griddata(KBest3(:,2),KBest3(:,3),ANNTBeta,xq,yq);
nAnnq=Annq(:)';
minkowski2=squareform(pdist(nzq','minkowski',2));
nRSSI=[RSSt;nzq'];
EU=squareform(pdist(nRSSI,'minkowski',2));
EU=EU(1,:);
EU(1)=[];
inputs=[];
targets=[];
```

```
    net=[];
    outputs=[];
    errors=[];
    inputs = minkowski2;
    targets(1,:) = nxq';
    targets(2,:) = nyq';
    %   Create a Fitting Network
    hiddenLayerSize = ceil((sm+2).*(2/3)+2)+1;
    net = fitnet(hiddenLayerSize);
    %   Choose Input and Output Pre/Post-Processing Functions
    %   for a list of all processing functions type: help nnprocess
    net.inputs{1}.processFcns = {'removeconstantrows',...
        'mapminmax'};
    net.outputs{2}.processFcns = {'removeconstantrows',...
        'mapminmax'};
    net.numLayers=2;
    %   Setup Division of Data for Training, Validation, Testing
    %   For a list of all data division functions type: help nndivide
    net.divideFcn = 'dividerand';  % Divide data randomly
    net.divideMode = 'sample';  % Divide up every sample
    net.divideParam.trainRatio = 70/100;
    net.divideParam.valRatio = 15/100;
    net.divideParam.testRatio = 15/100;
    %   For help on training function 'trainlm' type: help trainlm
    %   For a list of all training functions type: help nntrain
    net.trainFcn = 'trainbr';  % Bayesian regulation backpropagation
    net.trainParam.epochs=1000;
    %   Choose a Performance Function for a list of all
    %   performance functions type: help nnperformance
    net.performFcn = 'mse';  % Mean squared error
    net.layers{1}.transferFcn = 'tansig';
    net.layers{2}.transferFcn = 'purelin';
    %   Choose Plot Functions
    %   for a list of all plot functions type: help nnplot
    net.plotFcns = {'plotperform','plottrainstate',...
        'ploterrhist','plotregression', 'plotfit'};
    net.trainParam.showWindow=1;
    %   Train the Network
    [net,tr] = train(net,inputs,targets,'useParallel','yes');
    %   Test the Network
    outputs = net(inputs);
    errors = gsubtract(targets,outputs);
    GRANNResult(:,t) = net(EU');
    GRErrAnn(t)=sqrt((((GRANNResult(1,t)-XY(l,1)).^2)...
        +((GRANNResult(2,t)-XY(l,2)).^2)));
    RES5=GRErrAnn(t);
    %   Recalculate Training, Validation and Test Performance
    trainTargets = targets .* tr.trainMask{1};
    valTargets = targets  .* tr.valMask{1};
    testTargets = targets  .* tr.testMask{1};
end
LMErrStd=Std(LMErr);
KBestGRErrStd=Std(KBestGRErr);
GRErrAnnStd=Std(GRErrAnn);
LMErrMean=mean(LMErr);
KBestGRErrMean=mean(KBestGRErr);
```

```
GRErrAnnMean=mean(GRErrAnn);
hold off
end
```

Appendix E – C# code of the active RFID tags data collection for handheld device and captured ccreen of the software




```
using System;
using System.Linq;
using System.Collections.Generic;
using System.Collections;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.IO;
using System.Text;
using System.Windows.Forms;
using IDENTEC;
using IDENTEC.ILR350.Readers;
using IDENTEC.ILR350.Tags;
using IDENTEC.Readers;
using System.Threading;

namespace NewRSSILogger
{
    public partial class Form1 : Form
    {
        private IDENTEC.ILR350.Readers.iCardCF350 m_reader;
        DateTime startTime;
        DateTime endTime;
        ArrayList IQTags = new ArrayList();
        ArrayList IQBeacon = new ArrayList();
        ArrayList NewList = new ArrayList();
```

```
        ArrayList OldList = new ArrayList();
        ArrayList MissedList = new ArrayList();
        IDENTEC.ILR350.RFBaudRate Baud = new
IDENTEC.ILR350.RFBaudRate();

        public Form1()
        {
            InitializeComponent();
            trackBar1.Maximum = 10;
            trackBar1.Minimum = -30;
            trackBar1.Value = trackBar1.Maximum;
            lblPower.Text = trackBar1.Value + "dBm";
            comboBox1.Items.Add("RF_19200");
            comboBox1.Items.Add("RF_38400");
            comboBox1.Items.Add("RF_57600");
            comboBox1.Items.Add("RF_115200");
            comboBox1.SelectedIndex = 3;

        }
        private void Call()
        {
            listBoxTags.DataSource = null;
            Cursor.Current = Cursors.WaitCursor;
            labelTags.Text = "";
            try
            {
                listBoxTags.DataSource = null;
                if (null == m_reader)
                    Connect();
                if (null != m_reader)
                {
                    iCardCF350 iqReader = m_reader as iCardCF350;
                    iqReader.SetRFBeaconBaudrate(Baud);
                    int tx;
                    tx=iqReader.GetAntennaTXPower(1);
                    iqReader.SetAntennaTXPower(1, trackBar1.Value);
                    tx = iqReader.GetAntennaTXPower(1);
                    iQ350TagCollection tags =
iqReader.ScanForTags(Int32.Parse(txtNTags.Text), true);
                    tags.Sort();
                    foreach (iQ350RTLS t in tags)
                    {
                        if
(!OldList.Contains(t.SerialNumber.ToString()))
                        {
                            OldList.Add(t.SerialNumber.ToString());
                            t.BlinkLED(m_reader,
IDENTEC.ILR350.Tags.LEDColor.ALL_LED, new TimeSpan(0, 0, 0, 1), 1);
                            t.WriteBeaconInterval(m_reader, new
TimeSpan(0, 0, 0, 0, 500));
                            t.WriteBeaconActivationState(m_reader,
true);
                            bool rt =
t.ReadBeaconActivationState(m_reader);
                            TimeSpan ff =
t.ReadBeaconInterval(m_reader);
```

```
                    }
                }
                listBoxTags.DataSource = OldList;
                labelTags.Text = OldList.Count + " tags";
            }
        }
        catch (iCardCommunicationsException)
        {
            try
            {
                Connect();
                Call();
            }
            catch (Exception)
            {
                MessageBox.Show("Could not connect to the selected
card");
                return;
            }
        }
        catch (CommPortException)
        {
            try
            {
                Connect();
                Call();
            }
            catch (Exception)
            {
                MessageBox.Show("Could not connect to the selected
card");
                return;
            }
        }
        catch (Exception ex)
        {
            MessageBox.Show(ex.Message);
        }
        finally
        {
            Cursor.Current = Cursors.Default;
        }
    }
    private void Read()
    {
        listBoxTags.DataSource = null;
        Cursor.Current = Cursors.WaitCursor;
        labelTags.Text = "";
        lblTime.Text = "00:00:00";
        IQTags = null;
        try
        {
            if (null == m_reader)
                Connect();
            if (null != m_reader)
            {
```

```
                    iCardCF350 iqReader = m_reader as iCardCF350;
                    iqReader.SetRFBeaconBaudrate(Baud);
                    iqReader.SetAntennaTXPower(1, trackBar1.Value);
                    ILR350TagCollection tags =
iqReader.GetBeaconTags();
                    tags.Sort();
                    listBoxTags.DataSource = tags;
                    labelTags.Text = tags.Count + " tags";
                    foreach (iQ350RTLS t in tags)
                    {
                            OldList.Add(t.SerialNumber.ToString());
                            IQBeacon.Add(t.SerialNumber.ToString() + "
" + DateTime.Now.ToString("hh:mm:ss.f") + "   " + t.MaxSignal.ToString()
                                   + "   " + t.LastSignal.ToString());
                            if (IQBeacon != null)
                            {
                                lblNRead.Text = "Read: " +
IQBeacon.Count.ToString();
                            }
                    }
                }
            }
            //Note that you may a have longer lasting battery if you
close the connection to the card when not in use
            catch (iCardCommunicationsException)
            {
                try
                {
                    Connect();
                    Read();
                }
                catch (Exception)
                {
                    MessageBox.Show("Could not connect to the selected
card");
                    return;
                }
            }
            catch (CommPortException)
            {
                try
                {
                    Connect();
                    Read();
                }
                catch (Exception)
                {
                    MessageBox.Show("Could not connect to the selected
card");
                    return;
                }
            }
            catch (Exception ex)
            {
                MessageBox.Show(ex.Message);
            }
```

```
            finally
            {
                Cursor.Current = Cursors.Default;
            }
        }
        private void Off()
        {
            listBoxTags.DataSource = null;
            Cursor.Current = Cursors.WaitCursor;
            labelTags.Text = "";
            IQTags = null;
            try
            {
                if (null == m_reader)
                    Connect();
                if (null != m_reader)
                {
                    iCardCF350 iqReader = m_reader as iCardCF350;
                    iqReader.SetRFBeaconBaudrate(Baud);
                    iqReader.SetAntennaTXPower(1, trackBar1.Value);
                    iQ350TagCollection tags =
iqReader.ScanForTags(Int32.Parse(txtNTags.Text), true);
                    tags.Sort();
                    foreach (iQ350RTLS t in tags)
                    {
                        if
(!NewList.Contains(t.SerialNumber.ToString()))
                        {
                            NewList.Add(t.SerialNumber.ToString());
                            t.WriteBeaconActivationState(m_reader,
false);
                            bool rt =
t.ReadBeaconActivationState(m_reader);
                            if (rt == false)
                            {
                                t.BlinkLED(m_reader,
IDENTEC.ILR350.Tags.LEDColor.ALL_LED, new TimeSpan(0, 0, 0, 1), 2);
                            }
                        }
                    }
                    listBoxTags.DataSource = NewList;
                    labelTags.Text = NewList.Count + " tags";
                }
            }
            //Note that you may a have longer lasting battery if you
close the connection to the card when not in use
            catch (iCardCommunicationsException)
            {
                try
                {
                    Connect();
                    Read();
                }
                catch (Exception)
                {
```

```
                    MessageBox.Show("Could not connect to the selected
card");
                    return;
                }
            }
            catch (CommPortException)
            {
                try
                {
                    Connect();
                    Read();
                }
                catch (Exception)
                {
                    MessageBox.Show("Could not connect to the selected
card");
                    return;
                }
            }
            catch (Exception ex)
            {
                MessageBox.Show(ex.Message);
            }
            finally
            {
                Cursor.Current = Cursors.Default;
            }
        }
        private void Scan()
        {
            listBoxTags.DataSource = null;
            Cursor.Current = Cursors.WaitCursor;
            labelTags.Text = "";
            try
            {
                if (null == m_reader)
                    Connect();
                if (null != m_reader)
                {
                    iCardCF350 iqReader = m_reader as iCardCF350;
                    iqReader.SetRFBeaconBaudrate(Baud);
                    int tx;
                    tx=iqReader.GetAntennaTXPower(1);
                    iqReader.SetAntennaTXPower(1, trackBar1.Value);
                    tx = iqReader.GetAntennaTXPower(1);
                    iQ350TagCollection tags =
iqReader.ScanForTags(Int32.Parse(txtNTags.Text), true);
                    tags.Sort();
                    listBoxTags.DataSource = tags;
                    labelTags.Text = tags.Count + " tags";
                    foreach (iQ350RTLS t in tags)
                    {
                       // t.BlinkLED(m_reader,
IDENTEC.ILR350.Tags.LEDColor.ALL_LED, new TimeSpan(0,0,0,1), 3);
                        t.WriteBeaconInterval(m_reader, new TimeSpan(0,
0, 0, 0, 500));
```

```
                        t.WriteBeaconConfiguration(m_reader,
IDENTEC.ILR350.Tags.BeaconInformation.None);
                        t.WriteBeaconActivationState(m_reader, true);
                        bool rt=t.ReadBeaconActivationState(m_reader);
                        IQTags.Add(t.SerialNumber.ToString() + "   " +
DateTime.Now.ToString("hh:mm:ss.f")  +"   " + t.MaxSignal.ToString());
                        if (IQTags != null)
                        {
                            lblNRead.Text = "Read: " +
IQTags.Count.ToString();
                        }

                    }
                    ILR350TagCollection btags =
m_reader.GetBeaconTags();

                }
            }
            //Note that you may a have longer lasting battery if you
close the connection to the card when not in use
            catch (iCardCommunicationsException)
            {
                try
                {
                    Connect();
                    Scan();
                }
                catch (Exception)
                {
                    MessageBox.Show("Could not connect to the selected
card");
                    return;
                }
            }
            catch (CommPortException)
            {
                try
                {
                    Connect();
                    Scan();
                }
                catch (Exception)
                {
                    MessageBox.Show("Could not connect to the selected
card");
                    return;
                }
            }
            catch (Exception ex)
            {
                MessageBox.Show(ex.Message);
            }
            finally
            {
                Cursor.Current = Cursors.Default;
            }
```

```
        }
        private void Connect()
        {
            if (m_reader != null)
                ((IDisposable)(m_reader)).Dispose();
            m_reader = null;
            ConnectCF();
        }
        private void ConnectCF()
        {
            try
            {
                if (m_reader == null)
                {
                    int i = CFReaderSearch.FindReaderComPort();
                    m_reader = new iCardCF350(new SerialPortStream(i));

                }
                if (m_reader != null && !m_reader.DataStream.IsOpen)
                    m_reader.DataStream.Open();
            }
            catch (Exception ex)
            {
                MessageBox.Show(ex.Message);
            }
        }
        private bool validateInput(string input)
        {
            bool isValid = true;
            if (String.IsNullOrEmpty(input))
            { isValid = false; return isValid; }
            char[] inputText = input.ToCharArray();
            foreach (char c in inputText)
            {
                if (!char.IsDigit(c))
                { isValid = false; return isValid; }
            }
            return isValid;
        }
        private void buttonScan_Click(object sender, EventArgs e)
        {

            if (!validateInput(txtNTags.Text.Trim()))
            { MessageBox.Show("Please, enter a decimal value for tags
in field"); return; }
            if (!validateInput(txtScanInterval.Text.Trim()))
            { MessageBox.Show("Please, enter a decimal value for scan
interval"); return; }
            lblNRead.Text = "";
            lblTime.Text = "00:00:00";
            buttonScan.Enabled = false;
            timer1.Interval = Int32.Parse(txtScanInterval.Text);
            timer1.Enabled = true;
            timer2.Interval = 1000;
            timer2.Enabled = true;
            startTime = DateTime.Now;
```

```
        }
        private void buttonRead_Click(object sender, EventArgs e)
        {
            if (!validateInput(txtNTags.Text.Trim()))
            { MessageBox.Show("Please, enter a decimal value for tags
in field"); return; }
            if (!validateInput(txtScanInterval.Text.Trim()))
            { MessageBox.Show("Please, enter a decimal value for scan
interval"); return; }
            lblNRead.Text = "";
            lblTime.Text = "00:00:00";
            buttonRead.Enabled = false;
            timer3.Interval = Int32.Parse(txtScanInterval.Text);
            timer3.Enabled = true;
            timer2.Interval = 1000;
            timer2.Enabled = true;
            startTime = DateTime.Now;
        }
        private void buttonStop_Click(object sender, EventArgs e)
        {
            timer1.Enabled = false;
            timer2.Enabled = false;
            timer3.Enabled = false;
            buttonScan.Enabled = true;
            buttonRead.Enabled = true;
            DialogResult save = MessageBox.Show("Do you want to save",
"Save", MessageBoxButtons.YesNo, MessageBoxIcon.Question,
MessageBoxDefaultButton.Button1);
            if (save.Equals(DialogResult.No)) return;
            string details = "Tags in Field: " + txtNTags.Text +
"\nInterval: " + txtScanInterval.Text + "ms\nGain: " +
trackBar1.Value.ToString() + "dBm\n\nID                Elapsed
RSSI";
            try
            {
                if (IQTags != null)
                {
                    Save(IQTags, details,false);
                    MessageBox.Show("Data saved");
                }
                else
                {
                    Save(IQBeacon, details, true);
                    MessageBox.Show("Data saved");
                }
            }
            catch (Exception ex)
            {
                MessageBox.Show(ex.Message);
            }
        }
        public void Save(ArrayList list, string details, bool B)
        {
            string path;
            DateTime.Now.ToString();
            if (B == false)
```

```
            {
                path = @"\Program Files\newrssilogger\RSSI
Logs.txt";//file Loc: *start->file explorer->Program Files-
>mobilereportingsystem->RFID.txt*
            }
            else
            {
                path = @"\Program Files\newrssilogger\Beacon RSSI
Logs.txt";
            }
            string text = details + "\n";
            foreach (string s in list)
            {
                text = text + s + "\n";
            }
            if (!File.Exists(path))
            {
                using (StreamWriter sw = File.CreateText(path))
                {
                    sw.WriteLine(text);
                    sw.Flush();
                    sw.Close();
                }
            }
            else
            {
                using (StreamWriter sw = File.AppendText(path))
                {
                    try
                    {
                        sw.WriteLine("");
                        sw.WriteLine(text);
                        sw.Flush();
                        sw.Close();
                    }
                    catch (Exception ex)
                    {
                        throw ex;
                    }
                }
            }
        }
        private void timer1_Tick(object sender, EventArgs e)
        {
            Scan();
        }
        private void timer2_Tick(object sender, EventArgs e)
        {
            endTime = DateTime.Now;
            TimeSpan elapsed = endTime - startTime;
            lblTime.Text = string.Format("{0:00}:{1:00}:{2:00}",
(int)elapsed.TotalHours, elapsed.Minutes, elapsed.Seconds);
        }
        private void timer3_Tick_1(object sender, EventArgs e)
        {
            Read();
```

```
        }
        private void trackBar1_ValueChanged(object sender, EventArgs e)
        {
            lblPower.Text = trackBar1.Value + "dBm";
        }
        private void menuItem1_Click(object sender, EventArgs e)
        {
            Close();
        }
        private void buttonBSet_Click(object sender, EventArgs e)
        {
            lblTime.Text = "00:00:00";
            Call();
        }
        private void buttonBUnSet_Click(object sender, EventArgs e)
        {
            lblTime.Text = "00:00:00";
            Off();
        }
        private void comboBox1_SelectedIndexChanged(object sender,
EventArgs e)
        {
            switch (comboBox1.SelectedIndex)
            {
                case 0:
                    Baud = IDENTEC.ILR350.RFBaudRate.RF_19200;
                    break;
                case 1:
                    Baud = IDENTEC.ILR350.RFBaudRate.RF_38400;
                    break;
                case 2:
                    Baud = IDENTEC.ILR350.RFBaudRate.RF_57600;
                    break;
                case 3:
                    Baud = IDENTEC.ILR350.RFBaudRate.RF_115200;
                    break;
            }
        }
    }

}
```

Appendix F – HP parallel-computing cluster (Cirrus) job submission code

```
#!/encs/bin/tcsh
#
# We use a locally installed version of TCSH because it has been
# tuned to our environment.
#
# Note that lines below, beginning with "#BSUB" are NOT comments,
# and must be included for this to work correctly.  These lines
# indicate directives to the job-submission agent.  Details of what
# other options are available can be found in the bsub manual page.

# load required modules:
module load matlab/2012b

# to help find our user's directory space:
set u = `echo mo_solta |cut -c1`

# Replace the path here with the correct path to the directory
# from which your job should be run:
cd /sfs/nobackup/m/mo_solta/MATLAB/HP

# give the job a reasonably meaningful name:
#BSUB -J "ClustANNSimBRHP.m"

#BSUB -o "ClustANNSimBR-Out.txt"
#BSUB -e "ClustANNSimBR-Err.txt"

# Send the job report by mail when the job finishes.
#BSUB –N

# Specify the number of processors required to run the job (note
# that you can have no more than 64 processors allocated to any of
# your jobs (combined) at any one time:
#BSUB -n 60

# Specify the queue to which the job will be submitted:
#BSUB -q long

# run the job, with appropriate options (be sure to replace
# $MatlabInputFile.m with the proper filename for your job input):

matlab  < ClustComp.m
```

Appendix G – Summary of computer hardware used for the tests

Name of hardware	Specifications
HP Z210 Workstation	Processor: Intel® Core™ i7-2600 CPU @ 4.30GHz; Memory(RAM): 8.00 GB
DELL PRECISION T7400	Processor: Intel® Xeon® CPU E5430 @ 2.66GHz; Memory(RAM): 8.00 GB
DELL PowerEdge T610	Processor: Intel® Xeon® CPU E5540 @ 2.53GHz (2 processors); Memory(RAM): 48.00 GB
HP Proliant DL145G2	Processor: AMD Opteron™ 200 (32 x 4 Cores); Memory(RAM): 8.00 GB
HP Proliant DL145G2	Processor: AMD Opteron™ 200 (32 x 4 Cores); Memory(RAM): 16.00 GB
HP Proliant DL585	Processor: AMD Opteron™ 6000 (17 x 8 Cores); Memory(RAM): 64.00 GB
HP Proliant DL585	Processor: AMD Opteron™ 6000 (1 x 8 Cores); Memory(RAM): 128.00 GB
HP Proliant DL585G2	Processor: AMD Opteron™ 8000 (8 x 8 Cores); Memory(RAM): 128.00 GB

Appendix H - List of Related Publications

Articles submitted/published in refereed journals:

1. Motamedi, A., **Soltani, M. M.,** Setayeshgar, S., and Hammad, A. **(2013)**. Incorporating Information of RFID Tags Attached to Building Components to the BIM, *Journal of Automation in Construction.* (Submitted)
2. Motamedi, A., **Soltani, M. M.**, and Hammad, A. **(2013)**. Localization of RFID-Equipped Assets During the Operation Phase of Facilities, *Advanced Engineering Informatics* (Available Online).

Articles submitted/published in refereed conference proceedings:

3. **Soltani, M. M.,** Motamedi, A., and Hammad. A. **(2013)**. Enhancing Cluster-Based RFID Tag Localization Using ANN and Virtual Reference Nodes, *Fourth International Conference on Indoor Positioning and Indoor Navigation, IEEE*, Montbeliard-Belfort, France. (Submitted)
4. Motamedi, A., **Soltani, M. M.**, and Hammad, A. **(2013)**. Indoor Localization of RFID-Equipped Movable Using Mobile Reader Based on Reference Tags Clustering, *International Symposium on Automation and Robotics in Construction (ISARC),* Montreal, Canada.
5. Motamedi, A., Setayeshgar, S., **Soltani, M. M.**, and Hammad, A. **(2013)**. Extending BIM to Incorporate Information of RFID Tags Attached to Building Assets, *International Conference on Computing in Civil and Building Engineering,* Montreal, Canada.
6. Motamedi, A., **Soltani, M. M.**, and Hammad, A. **(2012)**. Localization of RFID-Equipped Assets during the Operation Phase of the Building, *International Conference on Computing in Civil and Building Engineering,* Moscow, Russia.
7. Zhang, C., Hammad , A., **Soltani, M. M.**, Setayeshgar, S. and Motamedi, A. **(2012)**. Dynamic virtual fences for improving workers safety using BIM and RTLS, *International Conference on Computing in Civil and Building Engineering,* Moscow, Russia.