RFID-Based Mobile Positioning System Design for 3D Indoor Environment

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Abstract In this study, an RFID based indoor positioning system has been proposed. In the system, while RFID readers have been considered to be mobile, RFID tags have been attached on fixed positions inside building. Performance of various types of readers and tags on indoor positioning has been investigated and most appropriate tag/reader couple has been used. In the experiments of this study, geographical proximity approach has been used. As the results of tests performed on three different model proposed for indoor positioning, it has been shown that best rate for position estimations without error have been obtained from third model with the rate of approximately 76% and in the worst case, position estimation error has been obtained 2 meters.

Keywords: RFID, Indoor, Positioning, Mobile, Geographical Proximity

1 Introduction

The number of high, complex and wide spread buildings increases with each passing day in modern cities of today's world. These buildings with dozens of floors, hundreds of corridors, rooms and passages are almost like a city in terms of their complexity and number of people occupied. Depending on the size and complexity of buildings many problems arise which need to be solved. One of the leading problems is developing personalized navigation applications for performing safe and quick evacuation of buildings in case of emergency. Beside, guiding visually impaired people, security, visitor tracking, finding addresses, service organizations and guiding tourists are some other application areas. In widely used 2D applications such as car navigation systems, location of a user is determined using Global Positioning System (GPS). However, GPS cannot be used directly in indoor spaces and we need accurate indoor positioning systems.

There are many technologies and systems proposed for indoor positioning. RFID technology is a step ahead from other current technologies in terms of accuracy and other advantages. Today, there are some RFID readers and tags which are plug and play on smart phones. These portable RFID readers and tags which can be easily found in market are not widespread because of some disadvantages such as short read ranges, causing mobile devices run out of charge quickly and making attached mobile device grow in size. Beside, with the advancement of technology it is expected that RFID readers and tags are placed inside mobile devices in production just like integrated WIFI adapters and this advancement will provide a more effective use of RFID in the near future. Hence, mobile phones will be able to use RFID based indoor positioning systems and serve various personalized services.

1.1 Positioning Systems for Indoors

There are several technologies addressed for indoor positioning. These are Ultrasound, RFID, Bluetooth, WLAN, Pseudo-GPS and Infrared. There are major disadvantages of using these systems except RFID such as requirement of direct line of sight between receiver and transmitter in Ultrasound and Infrared technologies, delays in data transmission and limited bandwidth in Bluetooth and signal reflection and varying signal strength due to the dynamic network structures in WLAN. However, there is no need of direct line of sight between receiver and transmitter in RFID technology. RFID offers the opportunity of working in any environment and interaction between receiver and transmitter is fast, but we should keep in mind that RFID readers are expensive (Lemieux 2009, Candy 2008). Advantages and disadvantages of indoor positioning technologies are summarized in Table 1.

Table 1 Indoor positioning technologies (Lemieux 2009, Candy 2008)

Technology	Advantages	Disadvantages	Accuracy
Ultrasound	-Simple and cheap equipment -Precision measurement possibilities	- The necessity of the establishment of the recipients in every room -Negative influence of a high density-tone. -Receiver and transmitter need to see each other directly.	a few centimeters when it is placed frequent enough
RFID	-The transmitter and receiver don't need to see each other	-Passive tags have low precision than active tags.	1 cm-2 meters.

	directly. -Opportunity to work in all types of environments. -Fast interactions. -Passive tags are cheaper and smaller than active tags and it doesn't need batteries.	-RFID Readers are expensive.	(Depending on the placement of RFID readers and tags)
Bluetooth	-Any kind of Bluetooth device can be monitored (cell phone, mp3 player, laptop) -Variable reading distance (1 m. vicinity) -Relatively cheap for small scale installations.	-Cost effective for large scale installation -Limited bandwidth. -Transmission delay. -The possibility of a maximum of seven sub-links corresponds to main connection.	2-15 meters.
WLAN (Wifi)	-The possibility of use the infrastructure of IEEE 802.11. -Low cost.	-Poor performance for multi-layered and very dense areas. -Due to signal reflection and dynamic network structure variable signal strength.	1-3 meters. (in range of 50 meters)
Pseudo-GPS		-Necessity of establishment of small satellites similar to GPS satellites into-building -Mobile devices have got GPS receiver -High cost	About 1 meter
Infrared	-Compact. -Low power consumption.	-Sensitive to daylight. -Receiver and transmitter need to see each other directly. -Installation and maintenance is cost.	5-10 meters.

1.2 RFID Technology

RFID is a term used to define wireless non-contact use of radio frequency electromagnetic fields to transfer identification data of an object for the purposes of identifying and tracking (Khong and White 2005). The data is stored in tags which is an electronic data storage device (Transponder tag) like smart cards. On the other hand, unlike smart card systems the power needed for both tags and transferring data between reader and tag is provided by use of non-contact electromagnetic field. A reader is required to receive data from a tag (Finkenzeller 2003). A reader loads energy to its antenna in order to make it transmit radio signals for activating tags and receiving data from tags. An activated tag transmits its data (Khong and White 2005). The antenna provides communication between reader and tag and some properties differ such as frequency range which affects the performance of the system depending on the shape and size of the antenna (Dziadak et al. 2009).

RFID tags can be either active or passive according to the power source. An active tag has its own power source generally obtained from a battery and this kind of tag transmits its ID periodically. A passive tag gets its power from the signal of the reader (Manish and Shahram 2005).

Two fundamental components of an RFID system are reader and tag. Beside this, antennas, computers and database systems are used in order to make system more effective. Components of an RFID system are shown in Figure 1. Another important issue is the frequency range of the reader. Available frequencies are LF (Low Frequency), HF (High Frequency) and UHF (Ultra High Frequency) (L. Wang et al. 2007). In addition, frequency ranges such as SHF (Super High frequency) or microwave can be used. Properties of radio frequencies are shown in Table 2.

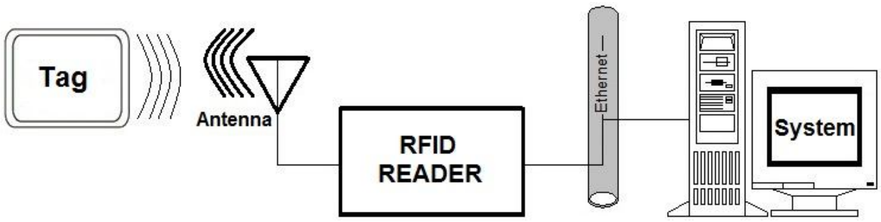

Fig. 1 Components of an RFID System

Table 2 Properties of Radio Frequencies (Era Build 2006, N. Li and B. Becerik Gerber 2011)

	Low Frequency(LF)	**High Frequency(HF)**	**Ultra High Frequency(UHF)**	**Microwave**
Frequency Range	125-135 kHz	13.56 MHz	400-960 MHz	2.45-5.8 GHz
Read Range	<0.5 meter (passive)	<1.0 meter (passive)	<10 m. (passive) >10 m. (active)	>100 m (active)
Standards	ISO 11784/5, 14223, 18000–2	ISO 14443, 15693, 18000–3	ISO 18000–6/7, EPCGen1 and 2	ISO 18000–4/5
Impact of Metal/liquid	Very Low	Low	High	High
Data Transfer Speed	Low	Average	High	High
Multiple Readings	-	50 tags/sec.	150 tags/sec.	-
Usage	Farming, Security, Beverage Factory	Medicine Industry, Healthcare Sector	Production, Logistics and Construction Sectors	Military, Shipping, Airlines

2 RFID Based Positioning Techniques

2.1 Distance Estimation

In this approach, position of a target is estimated based on the geometric features of triangle. Determining the position of a target is possible with two ways. One of them requires measuring the angle between the unknown position and at least two reference points. Intersection of lines drawn according to these angles points the estimated location. The other one requires knowing the distances between the target and three reference points in order to estimate the target position.

While determining the positions with the methods mentioned above, several measured features are used related to communication between readers and tags such as received signal strength (RSS), transfer time (TAO), transfer time difference (TDOA), received signal phase (RSP) and angle of approach (AOA).

2.2 Scene Analysis

Scene analysis approach consists of two main steps. First of all, environmental information (finger print) is gathered. Then location of the target is estimated by comparing the finger print set and online measurements. Generally RSS based finger prints are used. First of two fingers print based methods is the k-Nearest Neighbors (kNN) also known as (radio wave mapping) and the second one is probability method. Nearest neighbors method is realized using first RSS measurement on stations with known locations in order to create RSS database defined as radio wave map. Later in the online phase, k nearest matches is searched in the signal space produced by existing RF devices using RSS measurements directed to target points. Later, mean squared error is applied on the selected adjacent points to estimate the target point's location. In the probability approach, location of the target is determined assuming that target point has n possible locations and there is a signal strength vector observed by experimental probability and Bayes formulation in the online phase. Therefore, the location with highest probability is selected. Typically, probability methods consist of calibration, active learning, error prediction and tracking phases.

2.3 Proximity

This approach depends on the distribution of receiver/transmitter. It is assumed that point is in the same location with receiver/transmitter when the target enters the domain of receiver/transmitter. If more than one target is detected, it is assumed that target is in the same location with the receiver getting the strongest signal. This approach is fundamental and easy to apply. In addition, accuracy is proportional to the size of cells.

3 Materials and Method

3.1 Determination of the Reader and Tags to be used in the Study

Basic components of the RFID systems are RFID readers and RFID tags. The target that is required to be determined of its location could be an RFID reader or an RFID tag. In other words, the tags could be fixed and the readers could be in motion, and vice versa. In our study, since the requirement of equipment independent buildings (eg. in emergency situations), a system which the RFID readers are in motion and passive tags are attached to predetermined points on the surfaces of building has been suggested. Usages and performances of various types of readers and tags have been investigated. Considering the usability and functionality, ATID AT 870 model has been preferred for the mobile RFID Reader. On the other hand, 14 different types of passive tags have been tested in various aspect. Their performances have been compared regarding to the range of reading, independency from aspect of reader, and response time. After these detailed tests, TE34 Gain model passive tag has been preferred.

3.2 Settlement Patterns of the Tags

The tags have been attached in three different design models to the application area. In the first model, the tags have been consecutively attached within one meter intervals as a straight line to the ceilings of corridors and a room in application area. Height of the ceiling is 320 cm. Figure 2 shows a corridor having tags plugged on ceiling.

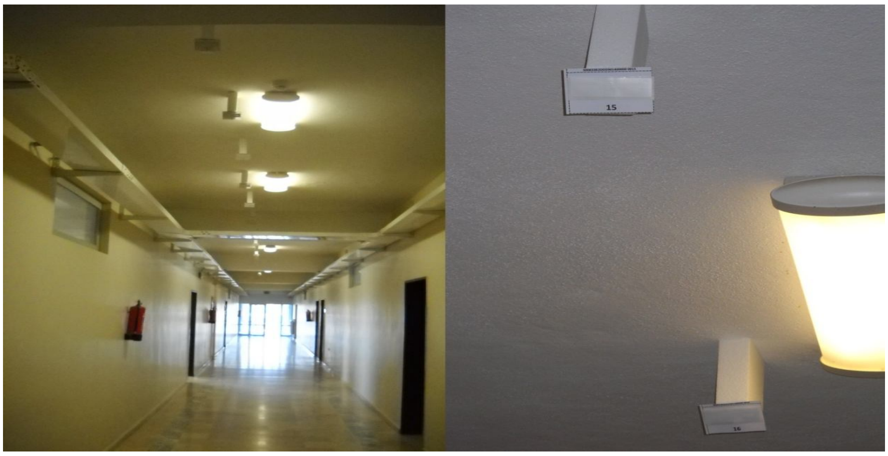

Fig. 2 Image of the corridor having tags plugged on ceiling in which Model 1 has been installed

In the second model, the tags have been attached up to the 220 cm height on the surfaces of two opposite walls of a room. Figure 3 shows the room in which Model 2 has been installed.

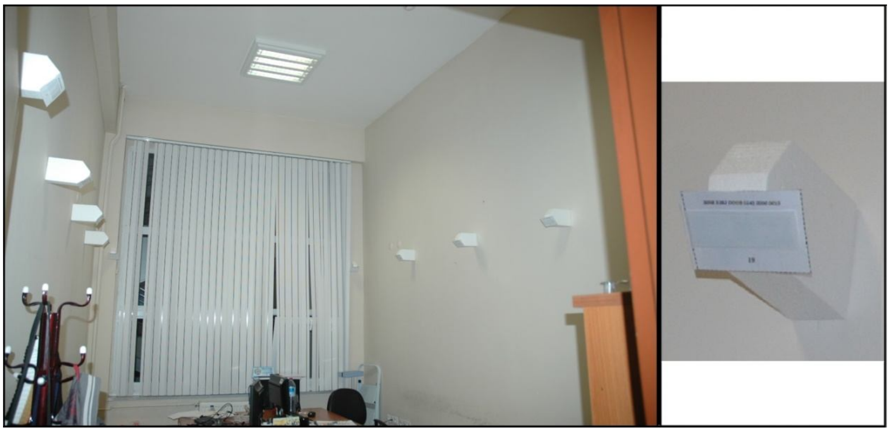

Fig. 3 Image of the room in which Model 2 has been installed and close view of tag on wall

In the third model, the tags have been attached to the ceiling of a room which has 4 m x 4 m dimension. 16 different tags have been placed to the centers of 1 m dimensional quadratic cells. Height of the ceiling is 250 cm. Figure 4 shows the room in which Model 3 has been installed.

Fig. 4 Image of the room in which Model 3 has been installed

3.3 Developed Software

In the study, a software for the mobile RFID devices has also been developed. Geographical proximity approach has been used in this program. In every two seconds, RFID reader receives data from the tags within the reading range. Receiving data period also can be set by the user in "Configuration" tab (Figure

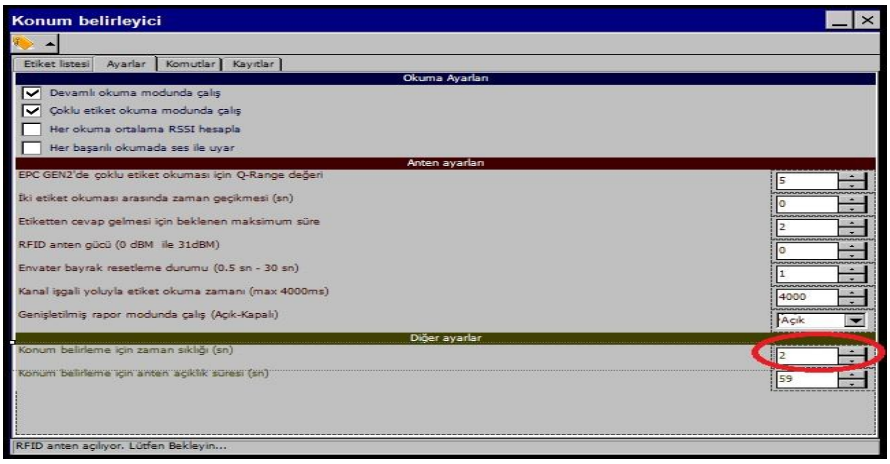

Fig. 5 Configuration (Ayarlar) Tab

At the end of every period, the tag which has the strongest signal is determined by the software based on collected data. Then the predefined coordinates of this tag are sent to the user. The software has been tested in three different design models as mentioned above.

4 Experimental Results

4.1 Model 1: Placement of Tags as a Straight Line

In the first design model, the height of ceiling is 320 cm and the length of corridor is approximately 30 m (Figure 6). The program has been tested in the test area including corridor and classroom and results given below has been obtained. In the test phase, each point with installed tags are considered as a node. The position of a person is accepted equal to the position of a tag (node) with the strongest signal received. The node number is passed to the user as the position data. Node numbers are set through the corridor from 1 to 31 incremented by one and from 32 to 35 in the classroom. Distance between nodes installed through the corridor is 1 meter.

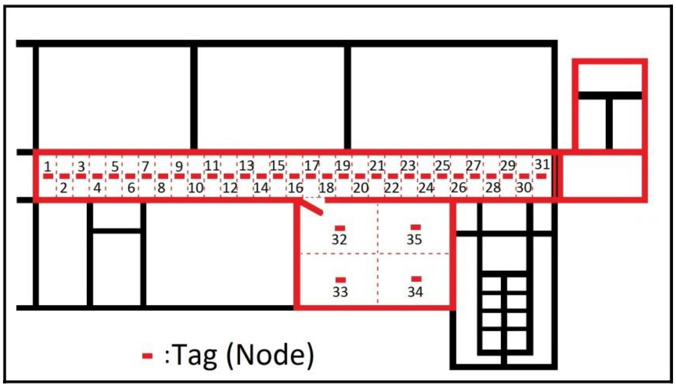

Fig. 6 The points of tags which are attached in study area (shown on the floor plan)

Different results have been obtained in cases such as the carrier person is stable or in motion. Firstly, the case in which the carrier person is stable in a point has been tested. For this purpose, we have waited in the point 2 for 1 minute. During this time, direction of the reader's antenna has been set towards the nodes with increasing node number through the corridor. Time period for reading has been set to be 2 seconds. In other words, position estimation is repeated every 2 seconds.

The position of the person is accepted as one of three points which have numbers 3, 4 and 5 just after point 2 and one of these points is estimated as the person's position. It is thought that direction of the antenna affects the quality of signal and results have been obtained like this. Another factor that affects the signal is thought to be human body. A person who blocks the signal by standing between reader and tag makes the signal quality worse.

While the person is stable, the position accuracy has been obtained between 1 m and 3 m depending on the direction of reader's antenna (ie horizontal or vertical) (Table 3).

Table 3 Positioning test results for Model 1 while the person is stable

Error Value (meters)	Explanation	Results	Percentage (%)
3	Estimated position is in front of the actual position 3 m.	5	16,66
2	Estimated position is in front of the actual position 2 m.	13	43,33
1	Estimated position is in front of the actual position 1 m.	12	40
0	Estimated position is equal to actual position.	0	0
Total		30	

While in motion, the test has been performed in rooms and corridors during four minutes in average walking speed (aprx 6 m/s). During this time, direction of the reader's antenna has been set towards the direction of the person's motion. Time period for reading has been set to be 2 seconds same as previous test. There has been taken estimation data for 112 points during the test of the program. Error rates for these measurements are given in Table 4.

Table 4 Positioning test results for Model 1 while in motion

Error Value (meters)	Explanation	Results	Percentage (%)
-6	Estimated position is behind the actual position 6 meters.	1	0,89
-5	Estimated position is behind the actual position 5 meters.	3	2,68
-4	Estimated position is behind the actual position 4 meters.	0	0
-3	Estimated position is behind the actual position 3 meters.	4	3,57
-2	Estimated position is behind the actual position 2 meters.	10	8,93
-1	Estimated position is behind the actual position 1 meter.	12	10,71
0	Estimated position is equal to actual position.	51	45,54
1	Estimated position is in front of the actual position 1 m.	22	19,64
2	Estimated position is in front of the actual position 2 m.	9	8,04
Total		112	

As seen in Table 4, in the worst case, position estimation error has been obtained 6 meters. In 4 measurements out of 112 which approximately correspond to 3% of total, position estimation error has been observed between 4 and 6 meters. In the case that position estimation error has been considered ± 1 meter, 85 measurements out of 112 which approximately correspond to 75% of total has provided the criteria. Beside, in the case that position estimation error has been considered ± 2 meters, 104 measurements out of 112 which approximately correspond to 93% of total has provided the criteria (Table 5). The position accuracy depends on the walking speed in this model.

Table 5 Position estimation errors and percentages

Position Estimation Error (meters)	Estimation Count	Percentage (%)
±1	85/112	75,89
±2	104/112	92,85

4.2 Model 2: Placement of tags to Side Walls Oppositely

In the second model, the tags have been attached up to the 220 cm height on the walls (Figure 2). The dimension of the room is 3 m x 5 m. Unlike Model 1, tags are installed on wall not on ceiling. The height of ceiling in Model has been set 320 cm. In Model 2, height of tags attached on wall is 220 cm. In this model, distance between reader and tag is reduced 1 meter compared to previous model. It is aimed to improve accuracy of RSSI by reducing the distance. On the other hand, there have been performed tests in two different periods. Period with 2 seconds which has been applied for Model 1 has also been applied to Model 2. Beside, 1 second period has also been tested.

We have used the room shown in Figure 7 for the test with motion. Tags attached on the same wall have been labeled with the same letter. Tags have been given consecutive numbers. There has been attached totally 12 passive tags in the room. Each point with attached tags is considered as a node. The position of a person is accepted equal to the position of a tag (node) with the strongest signal received. In this model, an area on the room plan is shown to the user for indicating position instead of passing node number to user. This process is performed by the "Map" tab in the program. The area in which user can get signal from tag labeled with B5 is shown in the program interface as seen in Figure 8. Size of an area is set to be 1,5 m x 1m according to the position of a tag or 1,5m x 0,5 m for corners of the room.

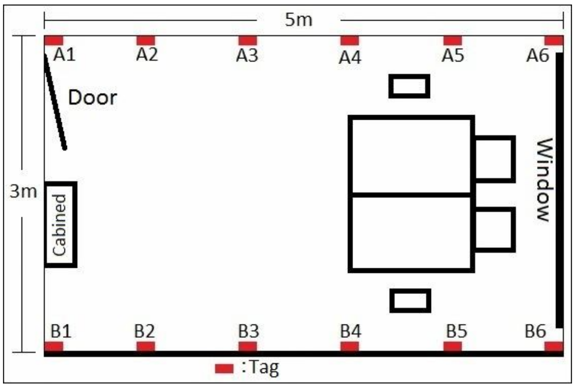

Fig. 7 Model 2

Fig. 8 The program was running on mobile device

Totally 106 position data have been obtained in the test with period set to be 1 second. In the other test with period set to be 2 seconds there have been obtained 110 position data. Error rates for these measurements are given in Table 6.

Table 6 Positioning test results for Model 2

Error Value (meters)	Explanation	1 Second Period		2 Seconds Period	
		Results	Percentage (%)	Results	Percentage (%)
±3	The distance between the estimated position and the actual position is 3 meters.	7	6,6	4	3,67
±2	The distance between the estimated position and the actual position is 2 meters.	8	7,55	0	0
±1	The distance between the	26	24,52	26	23,64

	estimated position and the actual position is 1 meters.				
0	Estimated position is equal to actual position.	65	61,32	80	72,72
Total		106		110	

As seen in Table 6, while the rate of estimated positions which equal to actual positions (without error) has been about 61% in the test with 1 second period, it has been obtained as 73% for the test with 2 seconds period. In the case that position estimation error has been considered ± 1 meter in test with 1 second period, 91 measurements out of 106 which approximately correspond to 86% of total has provided the criteria. Beside, with the same position error consideration in test with 2 second period, 106 measurements out of 110 which approximately correspond to 96% of total has provided the criteria (Table 7).

Table 7 Position accuracy and percentage

Position Estimation Error (meters)	**1 Second Period**		**2 Seconds Period**	
	Estimation Count	**Percentage (%)**	**Estimation Count**	**Percentage (%)**
±1	91/106	85,85	106/110	96,36
±2	99/106	93,40	106/110	96,36

4.3 Model 3: Placement of Tags to the Center of 1 m Dimensional Quadratic Cells

In the third model, the tags have been attached to the ceiling of a room which has 4 m x 4 m dimension (Figure 9). They have been placed to the centers of 1 m dimensional quadratic cells. The height of the ceiling is 250 cm. In this model, room has been divided into 1 square meter cells. The estimated position is shown to the user as an area just like in Model 2. Size of each area is 1m x1m. Totally there have been used 16 passive tags and constructed 16 areas. The program has been tested only in 2 seconds period.

Room shown in Figure 9 has been used in the test with motion of this model. Tags have been labeled as shown in Figure 9. Totally 90 position estimation data have been obtained. Error rates for these measurements have been given in Table 8.

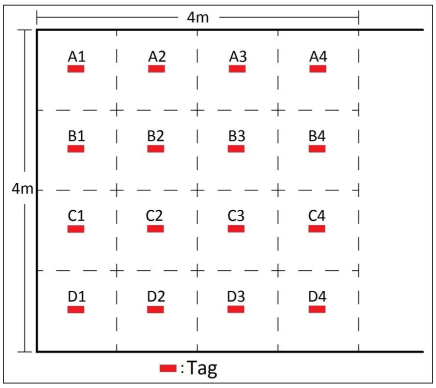

Fig. 9 Model 3

Table 8 Positioning test results for Model 3

Error Value (meters)	Explanation	2 Seconds Period	
		Results	Percentage (%)
±2	The distance between the estimated position and the actual position is 2 meters.	3	3,33
±1	The distance between the estimated position and the actual position is 1 meters.	19	21,11
0	Estimated position is equal to actual position.	68	75,56
Total		90	

In the test of Model 3 with motion, rate of estimated positions which equal to actual positions has been about 76%. In the case that position estimation error has been considered ± 1 meter, 87 measurements out of 90 which approximately correspond to 97% of total has provided the criteria. In the worst case, position estimation error has been obtained 2 meters. In 3 measurements out of 90 which approximately correspond to 3% of total, position estimation error has been observed 2 meters (Table 8).

In the second and third model, if the user stands in a fixed point and if exceptions are ignored, the position is determined correctly.

5 Conclusions

In this study, an RFID based indoor positioning system has been introduced. Usages and performances of various types of readers and tags have been investigated and the best combination has been selected. In general, in case of the tags were directly attached to the wall or ceiling, the interaction between tags and readers has been negatively affected and the performance of them has been decreased. To resolve this problem, the tags have been separated from the surfaces by using 20 cm long styrofoam material.

In the experiments of this study, geographical proximity approach has been used. As the results of tests performed on three different model proposed for indoor positioning, it has been shown that best rate for position estimations without error have been obtained from third model with the rate of approximately 76% and in the worst case, position estimation error has been obtained 2 meters.

In the study it has been observed that position estimation error is affected by several cases. One of them is the attachment frequency of tags. Increase of frequency reduces the error. Another factor is thought to be that direction of the antenna affects the quality of signal. The last factor that affects the signal is thought to be human body. A person who blocks the signal by standing between reader and tag makes the signal quality worse.

5 Acknowledgements

This study was supported by TUBITAK - The Scientific and Technological Research Council of Turkey (Project No: 112Y050) research grant. We are indebted for its financial support.

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