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Simulation of Indoor Positioning System Based on Radio Frequency

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Abstract : *Indoor Positioning Systems (IPS) are rapidly increasing in dynamic working areas. The tags, reader and server module, that constitute the IPS systems; generally communicate with technologies such as radio frequency, ultra-wideband, ultrasonic, and infrared. In this study, IPS simulation software, which can generate possible scenarios related to the behavioral modules of modules, have been realized in the IPS systems that use radio frequency as communication technology. Ambient noise, room walls, and other disruptive factors encountered in real applications have been modeled on scenarios. In the developed IPS simulation software, the modules related to the system and the parameters related to the application environment are ensured to be used very flexibly. The system, that uses the trilateration algorithm for positioning can also be operated as Monte Carlo simulations. However, the performance of this simulation software has been tested under different ambient conditions.*

Keywords: *IPS, Log-normal shadowing, RF, Simulation software, Trilateration*

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I. Introduction

Indoor Positioning Systems (IPS) attract the interest of researchers because of the rapid development of technology and the increase in demands for these systems [1]. Test and prototype phases contain many problems due to the dynamic nature and complexity of IPS systems that use communication technologies such as radio frequency (RF), ultra-wideband (UWB), ultrasonic (US) and infrared (IR), Naturally, simulation methods are resorted to cope with the above-mentioned problems before these systems are developed. In the simulation phase, the behavior of the system must be analyzed by uploading all features of the IPS system into the simulation environment. However, there is not any simulation platform having a general usage to make behavior analysis for all the systems which are desired to be realized. On the other hand, this situation results in the situation, in which the researchers realize their simulations specific to their own systems. Therefore, in academic studies, only the simulation systems, which can realize special-purpose systems, are mentioned. The simulation system, which has the capability to realize all IPS systems, which are desired to be realized, is realized within the scope of this study.

When the academic works on indoor positioning systems are examined, it will be seen that the designed system is realized before it is developed. For example; Y. Alvarez et al. have made studies in order to determine the position of the personnel in large industrial warehouses. Before developing the positioning system, they made a special simulation study that could be used only for their systems in the computer environment by creating a tag, that sends the RF signal that the personnel will carry on theirselves, and, a warehouse model on which they will make study. They performed the performance analysis of the system using general optimization techniques in the simulation. As a result, they stated that the study that they correctly positioned with a 2.5% error rate in detection the location of the personnel [2]. Adam K. Jastrzebski and his colleague made studies in order to present a practical approach in positioning by realizing the simulation of statistical variations of the signal power received indoor wireless personal area networks. Although in this simulation, however, there are not any obstacles (walls, etc.) that we use to add noise to the signals as in our study. In the study, they compared on the RSS data created in the simulation environment by using the Gamma distribution and log-norm (Gaussian) methods. At the end of the study that they made, they stated that there was a standard deviation of 10-15% in Gamma distribution but it showed better performance than the Log-norm method [3]. Feng Wang et al. conducted a simulation study in order to position the people or objects by using SRS (sounding reference signal) signals from mobile phones indoor by using the UTDOA positioning algorithm. As a result of the study, they stated that the system performs well under the correct configuration. In addition, they emphasized that it is important for environment parameters to be determined very well by being planned very carefully for the system analysis, as it is in our study [4]. Tuo Xie et al. performed an experiment of an advanced TDOA approach based on the RSS-supported cross-collation method and compared it with

Super-resolution techniques (SRTs) method. In their study, they did not develop a general simulation but a special simulation based on the environment parameters. As a result of the study, the system performance was analyzed in simulation and improvements were made on it and they stated that they provided superiority in position accuracy, calculation complexity, and noise prevention performance compared to the SRTs method [5]. In his study, Mohamed Khalaf-Allah made a study by using Differential Ultra-Wideband technology to increase the location estimation accuracy indoor. They worked their simulations in a fixed environment and parameters. As a result of the study, it was stated that system performance has increased in line-of-side (LOS) case [6]. Farhan Manzoor et al. developed a simulation environment for the performance analysis of the IPS system that they have developed. The simulation that they have developed does not have a dynamic structure due to that they used a fixed number of tags and readers. In the study, they used 2 RFID readers, RFID tags, the locations of which are known previously, and RFID tags, the locations of which are not known. They used the Angle of Arrival (AOA) algorithm in the study. They stated the working area of the simulation as 10 meters x 10 meters. As a result of the study, they stated at they found the tag position correctly with the error margin of 1.23 meters from the first RFID reader and 3.14 meters from the second RFID reader [7].

In the study, a multi-purpose IPS simulation software was developed in order to observe the analysis and performance tests of a radio frequency based positioning systems indoor. In the software, the values of the reader, tag, and environment components which constitute the basis of IPS systems can be changed according to ambient conditions. Thus, the simulation environment is planned to be as close as possible to the real world. In the simulation, the performance of the study is observed by using the trilateration algorithm for positioning indoor. In addition, the communication data between the tag and the reader is recorded in the file as the simulation output. In the simulation, it is planned to avoid the time and cost spent to develop the test equipment used in positioning indoor.

The organization of the topics to be described in the article is as follows. In the second part, the input parameters are described by mentioning the interface of the simulation. In the third section, the trilateration method is mentioned for the positioning indoor. In the fourth chapter, it is worked with a test scenario which is previously known for simulation. On the other hand, in the last part, the results of the study are examined.

II. Simulation Interface

When examining the academic studies in the field of positioning indoor, it will be observed that the simulations performed are generally specific to the study made. On the other hand, in studies that claim to implement a general IPS simulation software system, it is seen that the software is not flexible enough, and therefore it cannot simulate the situation that would occur by changing any parameter in real systems. The software developed within the context of the study is a general IPS simulation software that is not specific to the study. Simulation software within the scope of the study was developed as flexible as possible. Thus, the system analysis can be performed by running the system closest to the real system. In addition, the simulation interface, which is much easier to use than its counterparts, is presented in Fig. 1.

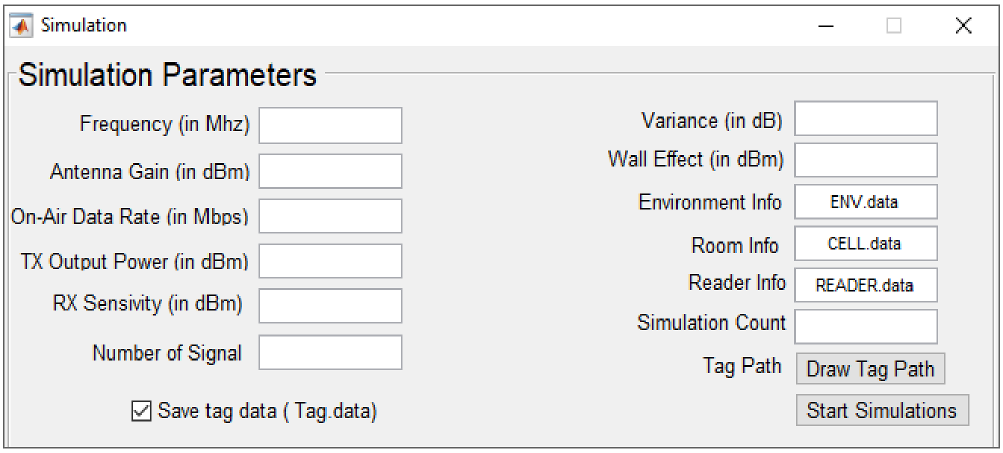

Figure 1: Developed simulation software interface

The IPS simulation software can measure the system performance by using the values obtained at the end of the simulation as well as the actual position values. In addition, all steps and data in the simulation are recorded. Therefore, it is possible to implement different positioning algorithms on this data. The parameters used in the simulation system are explained below in details.

- Frequency: It is used to determine the frequency, in which the tag and reader will communicate, in the system desired to be developed. The input value must be in MHz.

- Antenna Gain: It is used to determine the antenna gain of the tags and readers in the system. Antenna gain can be described as the signal output power transmitted into the environment by the antenna. The input value must be in dBm.
- On-Air Data Rate: It is used to determine the rate details between the tag and the reader in the system. The input value must be in Mbps.
- Signal Output Power: It is used to indicate with how much signal power the tags send to the environment. The input value must be in dBm.
- Reader Sensitivity: It is used to determine the lowest signal power that the readers can perceive. The input value must be in dBm.
- Variance: It is used to determine the standard deviation value. The input value must be in dB.
- Wall effect: It is used to determine how much the rooms in the simulation area in the system will be affected while the signal is passing. The input value must be in dBm.
- Simulation Environment Size: It is used to determine the minimum, height and height values of the environment, in which the system will run. The input value must be in the format E[(x1,y1,z1)....(x4,y4,z4)]. Input value must be entered into the interface in the specified file format.
- Rooms in the Simulation Environment: It is used to determine the width, height, and height of the rooms in the study environment in which the system will run. The input value must be in C1 [(x1, y1, z1) .... (x4, y4, z4)], C2 [(x1, y1, z1) [(x1, y1, z1) ... (x4, y4, z4)]. format. Input value must be entered into the interface in the specified file format.
- Numbers and locations of Readers: It is used to determine the number and location of readers to be used in the system. The input value must be in R1 (x1, y1, z1), R2 (x1, y1, z1), ..., RN (x1, y1, z1) format. Input value must be entered into the interface in the specified file format.
- Tag Route Information: It is used to determine the route that the user will go in the system. The X and Y coordinates of the route can be drawn on the screen with the Mouse of the computer.
- Number of Signals: It is used to determine the number of signals to be sent by each tag in each simulation. The input value must be entered as a positive whole number.
- Number of Simulations: It is used for the information on how many times the simulations performed for the system will be repeated. The input value must be entered as a positive whole number.
- Save Tag Data: At the end of the simulation, the route tracked by the tag is used for information for communication with the readers and the simulation result information. The tag must be marked to save the tag data.

III. Trilateration Method

In this study, trilateration is a method that is used to estimate the unknown point [8]. This method is used to find the intersection point of at least two circles whose radiuses are known equation (1) and equation (2). In Fig. 2 the intersection point found is accepted to be the location of the tag.

$$x = \frac{r_1^2 + r_2^2 + d^2}{2d} \tag{1}$$

$$y = \frac{r_1^2 + r_3^2 + i^2 + j^2}{2j} - \frac{ix}{j} \tag{2}$$

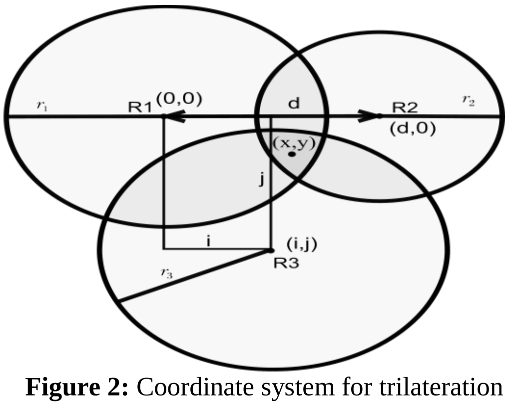

Figure 2: Coordinate system for trilateration method

Also, Log-normal Shadowing Model is used to provide causes fluctuations in the signal strength by adding some noise on the signals in the simulation. This model is used by adding on the Free Space Path Loss

Model (FSPL). FSPL model is written in the equation (3). The Log-normal Shadowing Model is depicted in the equation (4) and equation (5) [9].

$$FSPL(dB) = PL_0 = 20\log_{10}(d) + 20\log_{10}(f) + F - G_t - G_r \tag{3}$$

$$X_g = e^{\mu + \sigma Z} \tag{4}$$

$$PL(dB) = P_{Tx_{dBm}} - P_{Rx_{dBm}} = PL_0 + 10\gamma \log_{10}\frac{d}{d_0} + X_g \tag{5}$$

PL0 is the path loss at the reference distance. d is the length of the path in meters. f is the signal frequency in megahertz. As the operation is carried out with the units, meter, and MHz, the constant F value in the path loss model. Gt and Gr are transmit and receive antenna gains in dBm. PL is the total path loss measured in dB. PTx is the transmitted power in dBm. PRx is the received power in dBm. d0 is the reference distance. γ is the path loss exponent. Xg is a Gaussian random variable with zero mean. μ and σ that are, the mean and standard deviation of the variables natural logarithm respectively. Z is standard normal random variable.

IV. Test Scenario

It is required to enter all the features of the system into the IPS simulation software in order to be able to observe the analysis and performance tests related to the IPS systems that the researchers desire to develop. A known test scenario is followed to observe the outputs produced by the IPS software according to the entered parameters. The parameters used in the test scenario are shown in Table 1. The route information related to route that the tag in the test scenario will move is shown in Fig. 3 with red triangle mark. Each red triangle indicates the true position of the tag. As seen in Fig. 3, the tag goes back to where it started after all the rooms have been toured.

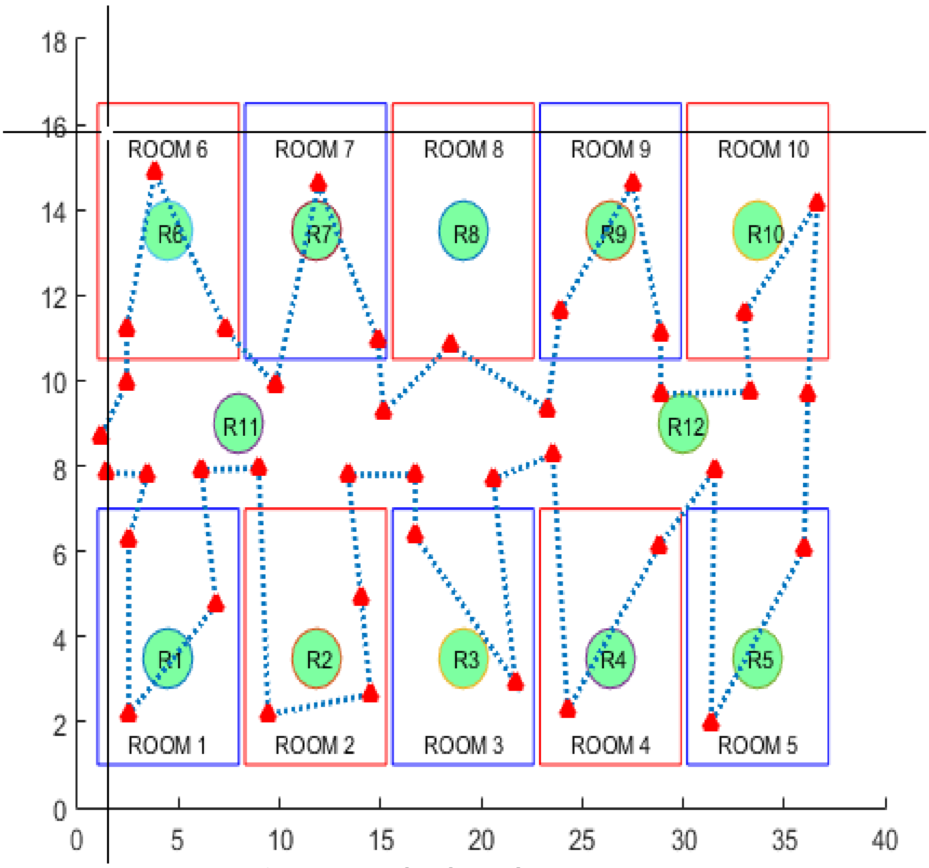

Figure 3: Tag path in the simulation environment

Table 1: IPS system parameters for the test scenario

Parameter	Value	Measured in
Frequency	2400	Mhz
Antenna Gain RX-TX	2	dBm

On-Air Data Rate	1	Mbps
TX Output Power	-12	dBm
RX Sensitivity	-82	dBm
Variance	7	dB
Wall Effect	6.9	dBm
Environment Info*	E[(1,1,3),(38,1,3),(38,17,3),(1,17,3)]	Coordinate
Room Info* *(Point to Point is 1 meter.)	C1[(1,1,3),(8,1,3),(8,7,3),(1,7,3)] C2[(8.3,1,3),(15.3,1,3),(15.3,7,3),(8.3,7,3)] C3[(15.6,1,3),(22.6,1,3),(22.6,7,3),(15.6,7,3)] C4[(22.9,1,3),(29.9,1,3),(29.9,7,3),(22.9,7,3)] C5[(30.2,1,3),(37.2,1,3),(37.2,7,3),(30.2,7,3)] C6[(1,16.5,3),(8,16.5,3),(8,10.5,3),(1,10.5,3)] C7[(8.3,16.5,3),(15.3,16.5,3),(15.3,10.5,3),(8.3,10.5,3)] C8[(15.6,16.5,3),(22.6,16.5,3),(22.6,10.5,3),(15.6,10.5,3)] C9[(22.9,16.5,3),(29.9,16.5,3),(29.9,10.5,3),(22.9,10.5,3)] C10[(30.2,16.5,3),(37.2,16.5,3),(37.2,10.5,3),(30.2,16.5,3)]	Coordinate
Reader Info*	R1[(4,3.5,3)], R2[(12,3.5,3)], R3[(19,3.5,3)], R4[(26,3.5,3)], R5[(34,3.5,3)], R6[4,13.5,3)], R7[(12,13.5,3)], R8[(19,13.5,3)], R9[(25,13.5,3)], R10[(34,13.5,3)], R11[(8,9,3)], R12[(30,9,3)]	Coordinate
Number of Signals	10	Integer
Simulation Count	100000	Long Integer
Tag Path*	40 samples shown in Fig. 3 TS1[(1,8.7,1)] to TS40[((1,7.9,1))]	Coordinate
Save Tag Data	True	Boolean

When the simulation is completed, the estimated position value shown by the blue triangle for each sampling value of the tag is shown in Fig. 4. There is a blue triangle for each red triangle. The line between the red and blue triangles indicates the distance between the real value and the estimated value of the tag. At the end of the simulation, the samples taken from the tag results and their estimated position values are compared and their mean value is calculated as 0.8 meters and the standard deviation is calculated as 1.9 meters. Also, as a simulation output, the records of the communication between the tags and the reader are submitted to the researcher as in Fig. 4. Although, it is possible to improve the system by changing the parameters related to this test scenario.

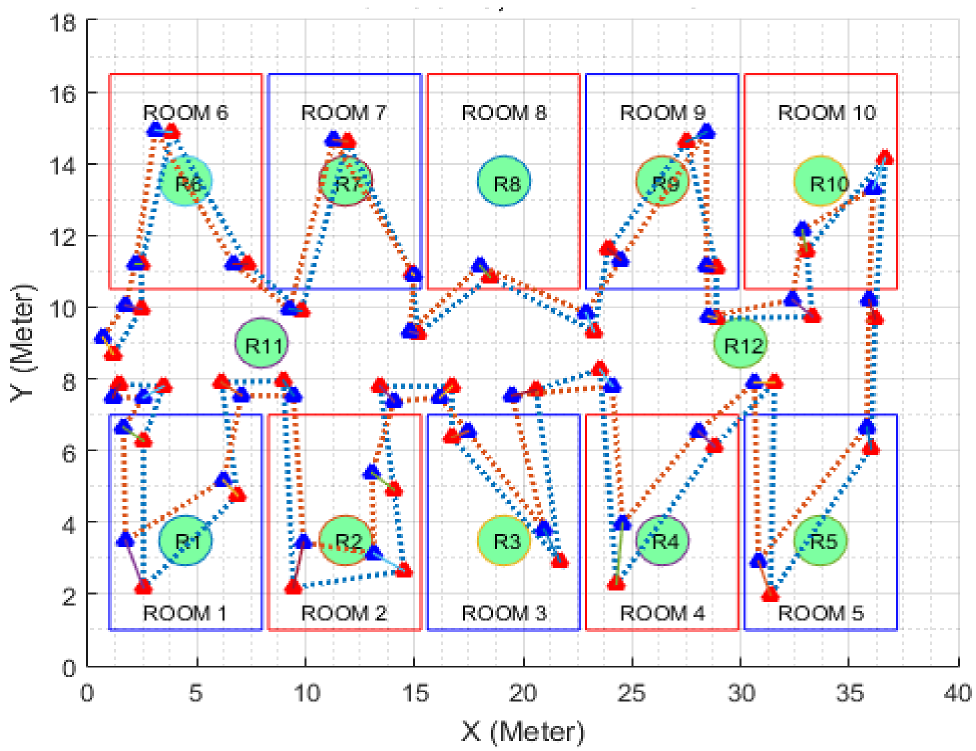

Figure 4: Test scenario results

V. Conclusion

In the study, a general IPS simulation software was developed that can include all systems which communicate with RF technology and run in the form of Monte Carlo simulations, as different than the simulations used for positioning indoors. Thus, the researchers do not only have to develop a special purpose simulation for the analysis of their systems. The developed simulation environment can run independently from room, and reader numbers. However, since parameters do not take fixed values in simulation, it is possible to enter flexible data. The researcher can design the desired environment, room and reader numbers as he/she desired, and can observe the running performance of the IPS system. Researchers are also ensured to predict the realizability status of the system before passing to hardware testing of software researchers. As a result of the simulation, the communication data between the tags and the readers are provided to the researcher as output. The system can be improved by applying this data on different indoor positioning algorithms.

For the future studies, it is planned to use more than one tag at the same time and to integrate the algorithms used indoors into the system except the trilateration algorithm.

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