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Developing a Hybrid GPS/Wi-Fi Navigation System for User Guidance

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Abstract

Today, location based services are offered by different organizations such as Google, MapQuest, open trip planner, and etc., but in most cases current services do not provide seamless operations between indoor and outdoor environments;
Development of a hybrid navigation system with the capability of continuously positioning in both indoor and outdoor environments is important. This paper, presents architecture for developing a hybrid navigation system that includes five main subsystems: routing, positioning, database, user interface and mapping. In the positioning part, the combination of Global positioning system (GPS) and Wi-Fi finger print technique are proposed to determine the position of users in outdoor and indoor environments respectively. Also, the data related to the movement history of user is suggested to be used for improving the accuracy of obtained positions in indoor part. The evaluation of proposed method was done by implementation of prototype system. The obtained result shows the possibility of utilizing the suggested method in most location-based services in indoor/outdoor environments.

Keywords: *indoor/outdoor hybrid navigation, Global positioning system, received signal strength (RSS), Wi-Fi finger print*

1. Introduction

In the recent decades, the development occurred in the field of information technology has resulted in expanding a wide range of positioning technologies [1]. Nowadays, the mobile devices with the capability of connection to internet, powerful processors, access to global positioning system and screens with high quality graphic in the form of smart phones and pocket pcs etc. have prepared the context for further expansion of positioning services in various fields [2].

Also, presenting navigation services are performed via different institutions like Google, MapQuest, OpenTripPlanner etc., but in most presented services, the main focus has been made in outdoor environments and the capability of positioning and navigating users in indoor and outdoor environment is not continuously possible [1]; while most users are spending more than 70% of their times in indoor environment; hence, with regard to the increasing development of urban space and the sets of buildings and the need of different users in the displacement between different indoor/outdoor environments, the necessity of developing a hybrid navigation system which is accountable for the needs of users' navigation continuously in indoor/outdoor environments is important.

2. Related Work

Many of today's handheld devices include both navigation and communication capabilities, e.g., GPS and Wi-Fi. This convergence of communication and navigation functions is driving a shift in the device market penetration from GPS only navigation devices (90% in 2007) to GPS-enabled handsets (78% by 2012)[1]. This trend is the reason why many researchers have focused on improving hybrid positioning navigation methods in past years [2].

Baus et al.[3] in a project under the name, REAL, developed hybrid navigation system in order to positioning the users in indoor/outdoor environments. In this study, infrared transmitters and global positioning system were used for positioning in indoor and outdoor environment respectively.

Hung et al. [4] used the combination of observation from received signal strength and inertial navigation system for positioning of indoor users and presented an experimental model for modeling the process of signal distribution Wi-Fi access points in indoor environments. They saved walls as a set of linear threads in a database for modeling multi-path effect and the influence of walls on the observation of signal strength, and by overlapping the presented experimental model with building geometric situation tried to remove the stage of training and modeling in continuous signal distribution.

Mok and Kong developed a hybrid algorithm to convert received signal strengths to distances in Wi-Fi positioning systems. The main idea in Mok's and Kong's research was compounding raw distances obtained from GPS with distances obtained from Wi-Fi signal strengths and calculating user position from these resources[5]. The proposed method by Mok and Kong increases the degree of freedom, but the empirical method that converts RSSs to distance has considerable errors. Hung et al developed an indoor navigation system that compounded from Inertial navigation system and Wi-Fi signal strengths.

In 2010, Saeed et al.[6] developed a hybrid positioning system which used global positioning system for determining the position in outdoor, and RFRD tags for determining the position in indoor environment in Liverpool and the obtained results were presented in the environment of virtual city. In 2010, Zirari and Spies [7] developed a hybrid algorithm for determining position of indoor/outdoor users by combining raw observation of global positioning system like observation pseudo-ranges with the receivers of mobile systems and the distances from the observation of receiving signal from access points of Wi-Fi network. The suggested method by them has disadvantages like unavailability of range observations between satellite-receiver in mobile devices and also lacking the existence of stable relation for converting the observations of received signal strength to range.

In 2011, Alonso et al addressed the investigation of indoor positioning methods for robots and stating that one of the most important faults existing in this field is lacking the possibility of signal distribution modeling, divided the entered errors on the amount of received signal strength to two parts of errors from small changes in signal scale and errors from large changes in signal scale and addressed the attempt in modeling the errors from small changes in signal scale by fuzzy methods [8]. In 2011, Woo et al by investigating using fingerprint method addressed the observation of received signal strength in closed workshop environments like tunnels etc. and reached an accuracy of 5 meters [9]. In 2011, Yim et al using Kalman filter investigated interpolation methods of users' position in outdoor environments. They presented a method for more appropriate updating of indoor users' position in database of mobile instruments by relying on movement differences and existing environment between the users of indoor environment and outdoor environment like smaller displacement velocity, smaller environment etc. [10]

During the last few years, different hybrid positioning systems are offered by commercial companies. For example, Skyhook, Navizon and Ekahau. Skyhook Wireless developed a Hybrid Positioning System, called XPS, combining the benefits of GPS, Cell Tower triangulation, and Wi-Fi Positioning. XPS delivers a range accuracy of 10m- 20m whether in indoors or outdoors, in rural areas or urban areas [11, 12]

3. indoor/outdoor Positioning techniques

Today, there are different positioning technologies with different capabilities and limitations such as GPS, Cellular, RFID, Wi-Fi, and Infrared. Among these different technologies, Global Navigation Satellite Systems (GNSS) is the standard generic term for satellite navigation systems that are used widely. GNSS provides autonomous geo-spatial positioning with global coverage. It provides reliable positioning, navigation, and timing services to worldwide users on a continuous basis in all weather conditions, day and night [2]. GNSS do not work in indoors and the fact that the user may be in environments poorly covered or not covered at all (indoor, urban canyons, etc.) makes the satellite signals reception difficult. This constraint significantly impacts the accuracy, the Quality Of Service, and the service continuity that ensure that positioning can be realized in an agreed time scale and respond to a satisfactory level of service availability, other methods are in need of utilizing additional hardware like installing pseudolites. Cellular communication system is another positioning method that determines the position of mobiles cell phones. This method is based on a technique named Cell tower in which the position of user's cell phone is determined by the position of cell tower the user locates within. Cell towers have not enough accuracy and in many rural areas the desired accuracy is very low so This method cannot be used in many other navigation and positioning systems that need higher accuracies, however it has some advantages like great coverage network in the range of a state, country etc. and servicing different mobile devices [4]. RFID, Wi-Fi, infrared transmitters and ultra wide band are other methods that are usually used for determining user's position in closed environments. Applying ultra wide bands has advantages like access to the accuracy of a better than centimeter level and lower level of waves interference, but in the other hand, it needs buying additional hardware and has more complex computations. The method of using infrared transmitters is also another alternative for the existing methods that has the accuracy smaller than 10 meters and the most important disadvantage of it is being sensitive to solar light and needs buying additional equipment. Using Wi-Fi network access point is another method that because of spreading the use of access point in urban areas and increase of mobile devices with capability of receiving Wi-Fi signals, its application is dramatically increased.

Since, it is not enough to measure the performance of a positioning technique only by observing its accuracy. Selection of different positioning technologies is function of different criterions that could affect system performance directly. Considering the differences between the indoor and outdoor positioning, we provide the following performance benchmarking for hybrid navigation system: accuracy, coverage, and cost as shown in table1 [4].

Table 1. Comparison between different methods of positioning [4]

Positioning technique	**Coverage range**	**Accuracy (m)**	**Cost**
GPS	World(except indoors)	Smaller than 10m	cheap
Pseudo-lite	2cm-2m	local	very expensive
Cell towers	City-region	50-150m	moderate
Wi-Fi	Building-Campus	1-5m	cheap
Bluetooth	Building-campus	1-5m	expensive
Ultra wide band(UWB)	Building	Smaller than 1m	expensive
RFID	Building	1-10m	Cheap-moderate

Since cost is one of the important factors in applying positioning systems, using expensive methods is not cost effective. Regarding the expansion of Wi-Fi access point in urban areas, there is no need of buying additional hardware in many of these areas and this issue decreases the cost of applying Wi-Fi networks considerably and hence is an appropriate option for indoor positioning part. In the other hand, since GPS has benefits like world coverage (except indoors), free charge that installed in most of mobile devices, it seems to be a good choices to be implemented in outdoor positioning part of system. With regard to these benefits and spreading mobile apparatuses having the ability to receive Wi-Fi network waves and satellite positioning, the suggested method in this research is based on determining hybrid position using access points of Wi-Fi networks for indoor environments and satellite positioning in outdoor environment.

4. Development of indoor/outdoor hybrid navigation algorithm

In the suggested algorithm, users positioning uses the combination of global positioning system in outdoor environments and received signal strength observation of Wi-Fi access points in indoor environments. Figure 1 shows the suggested algorithm in this research. In the mentioned algorithm, three possible states were investigated with regard to the receiving signals from global positioning system and Wi-Fi network access points.

In the first case, some conditions are studied in which only one positioning method is available. In these conditions, if GPS is the only available method, the final positioning is determined by this method. Also, when only Wi-Fi network access point signals are available, observation signal intensity is sent to server and the best estimated position using indoor positioning algorithm and Wi-Fi network access points is selected as the final position of user.

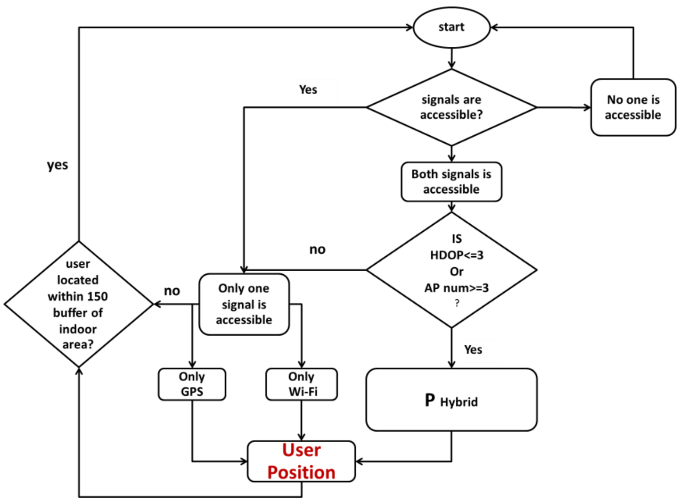

Fig. 1. Proposed hybrid positioning algorithm

The second case includes the conditions that the signals of both systems are available and valid. In this situation, two possibilities are investigated with regard to Horizontal dilution of precision (HDOP) and Wi-Fi access points. If HDOP of GPS is lower than 3 or the number of Wi-Fi access points is more than 2, the position of user is determined using relation 1.

$$P_{Hybrid} = \frac{W_{GPS} \times P_{GPS} + W_{wifi} \times P_{wifi}}{W_{GPS} + W_{wifi}} \qquad (1)$$

Where, P_{wifi} is the obtained position from positioning using Wi-Fi access points and P_{GPS} is the obtained position from GPS and the coefficients W_{wifi} and W_{GPS} are the weights applied on the obtained situations from Wi-Fi access points and GPS. If HDOP of GPS is more than 3 or Wi-Fi access points is lower than 2, the positioning method is changed to the first state.

In the third case, when no signal is accessible, system searches signals until one of the previous cases occurs. After the user position is obtained, another condition is checked to see whether the user is located within the 150 meters of indoor area or not. If this condition is satisfied, the system continues to search for the Wi-Fi signals, otherwise the system waits until the user is located in this area.

5. The algorithm of positioning in indoor environment based on received signal strength observation

Figure 2 depicts the proposed Wi-Fi fingerprint positioning algorithm. In the first step, the received signal strengths of available access points averaged at time t, and then these averages along with physical addresses of access points are send to server.
At the server, signal differences between the received observation and the offline received signal strengths in the database are calculated as follows:

$$d_{obs} = \sum_{i=1}^{N} \left| SS_{obs}{}^{i} - SS_{Av-Train}{}^{i} \right| \qquad (2)$$

Where, $SS_{obs}{}^{i}$ and $SS_{Av-Train}{}^{i}$ are received observation signal and mean received signal strength in training phase, also N is the number of observed access points and d_{obs} is the sum of training and observed signal distances.
At this point, the system checks to see whether the previous location of user is known or not.
If the previous location of user is known, a buffer is created around its location, and then candidate positions that located within this buffer zone are selected as remained candidate positions.

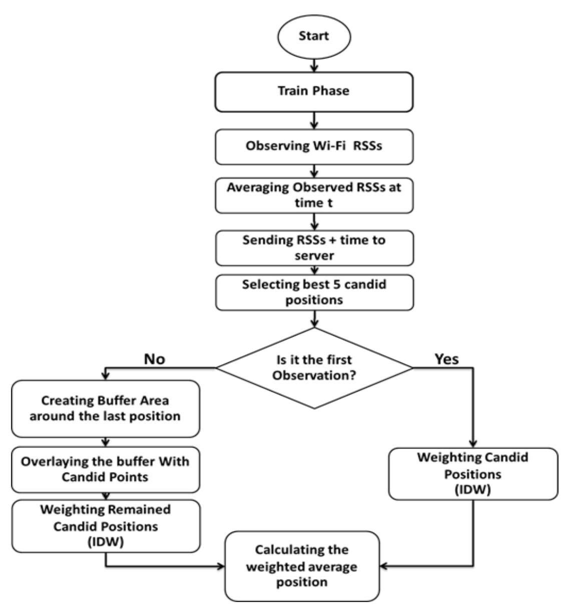

Figure 2. Positioning algorithm in indoor environment based on received signal strength observations

In the last step, final positions are calculated through weighed average position of new candidate positions. Here, weight of candid positions obtained from square of inverse difference of observed and train received signal strengths as follows:

$$P_{Wifi} = \frac{\sum_{i=1}^{c}(W_i \times P_i)}{\sum_{i=1}^{c}(W_i)} \quad (3)$$

$$W_i = \frac{1}{\sum_{i=1}^{c}\left(\left(\left|SS_{obs}{}^{i} - SS_{Av-Train}{}^{i}\right|\right)^2\right)} \quad (4)$$

Where, C is equal to the number of refined candidate positions, $SS_{obs}{}^{i}$ and $SS_{Av-Train}{}^{i}$ is observed received signal strength and the average received signal strength in training phase respectively and P_{Wifi} is equal to estimated final position.

6. Creating a database of received signals in outdoor environment

The received signal strengths database is another important part of the database that is used in Wi-Fi positioning. Whereas signal strength observations depend on parameters such as direction of observation and time of observation, they need to be included in the database. The RSS database is composed of five main columns: id, received signal strength, direction, time and Mac addresses. id is used as the key between the network database and the RSS database. RSS is expressed as negative numbers that indicates observed received signal strengths. Direction indicates north, south, west and east. Figure 5 shows this scenario. Time is time of observations. Mac address is a unique id of access points.

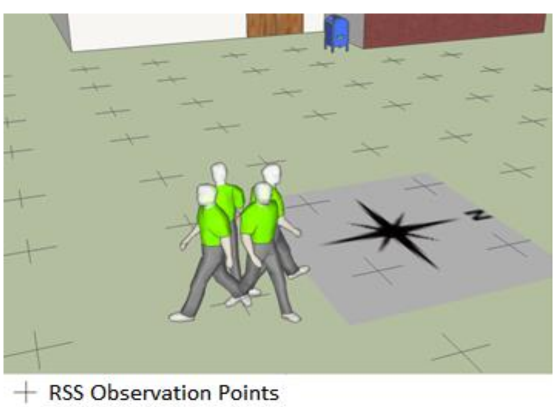

Figure 3. Observing RSSs in different directions

7. Area of study

In order to implement the suggested system, there is a need to select one region as the study area; hence, the campus area of Kerman's graduate university of advanced technology was considered as the study area. WGS84 ellipsoid and UTM projection system were selected as reference coordination system.

The study area includes; area of Kerman's graduate university of advanced technology as the outdoor study area and the first floor of Block two in ICST as the indoor study area. The world geodetic system 84 and UTM are datum and projection for both indoor and outdoor study areas.

7.1. Outdoor network data

The outdoor network of the study created from open street map data with osm format [13]. A raw osm data could not be used in the data base directly as outdoor network, some preparations like; GIS ready, modifying format, classification and assigning proper coordinate system were performed. Figure 4 shows the data used in this part.

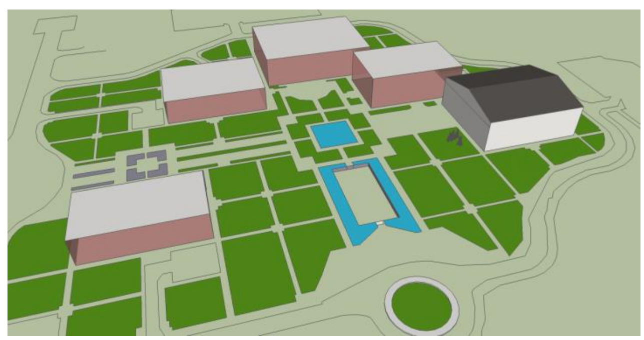

Figure 4. The outdoor study area

7.2. Indoor network data

The first floor of block two in international center for advance science and technology and environmental sciences located in 30km southeast Kerman city was selected as the indoor study area and the map of this area was created in Autodesk dwg format. Since the outdoor and indoor networks didn't have the same coordinate system, thus the indoor coordinate system transformed to outdoor coordinate system (wgs84).

. Figures 5 and 6 show the indoor study area and the related network respectively.

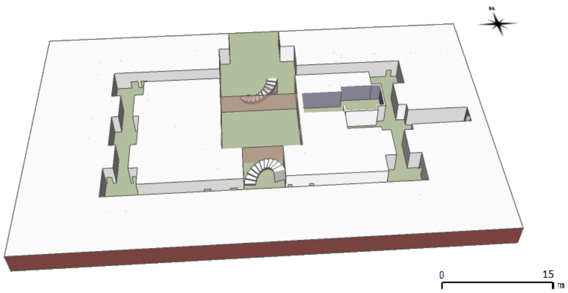

Figure 5. The study area of indoor section

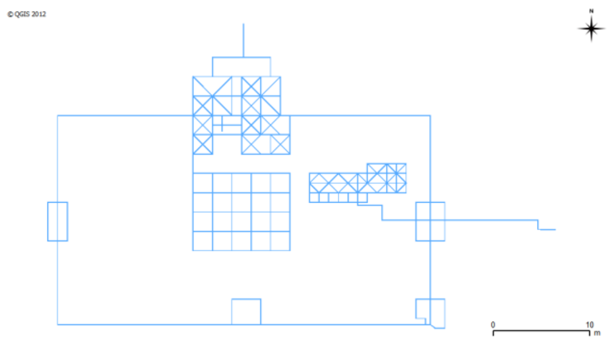

Figure 6. indoor network

7.3. Collecting received signal strength data in outdoor environment

Collecting correct received signal strength in different points for preparing a reliable database has a great influence in accuracy of indoor positioning. Hence, based on proposed method, RSS data was collected with 2 meter resolution in four main directions; north, south, east and west at 3 different times; morning, noon and after noon. Figure 7 shows locations that RSS data are collected. An application was developed according to reduce errors in collecting RSS data as Wi-Fi trainer with C#.NET in windows mobile platform. Figure 8 shows Wi-Fi trainer interface.

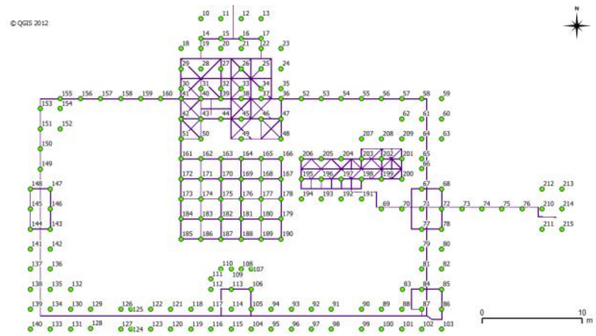

Figure 7. received signal strength observation points(green dots)

Figure 8. GUI of developed application for collecting received signal strength data

Collected Data in includes: point id, direction, time, access point name, received signal strength and Mac address. After collecting these data, all obtained data uploaded in text format and prepared for inserting in the database.

8. System architecture

According to the proposed method, the system and its five subsystems are: user interface, navigation, positioning, mapping and database. Figure 9 shows the system architecture.

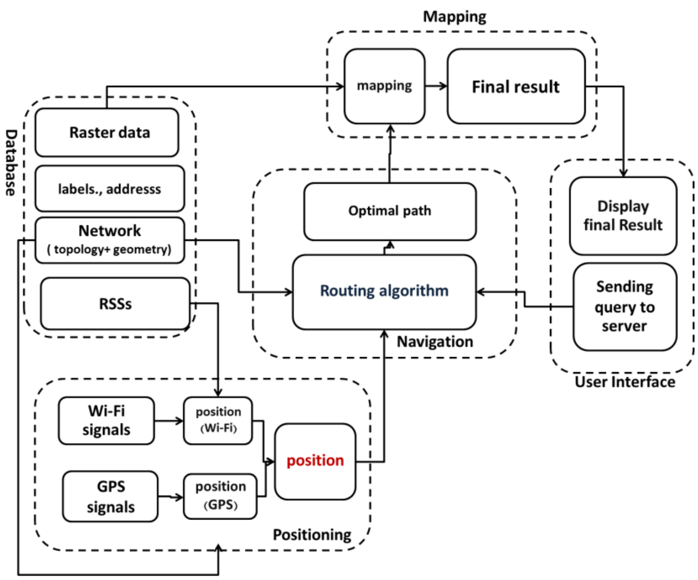

Figure 9. system architecture of hybrid navigation

8.1. User interface subsystem

The main objective of this subsystem is to create a user interface that is intuitive. The user should be able to look up a desired destination and the system should be able to display the computed route to the user a route . This subsystem has three main parts:; signal status, getting target, and display the results.

After getting user information, the information is sent to the server with POST method along with GPS and Wi-Fi observed RSSs. Figure 10 shows the developed user interface. The main other objective of this subsystem is to display the result to the user. The final result is a PNG image that includes three layers: background image, optimal path, and user current location. Background images differ in indoors and outdoors; open street maps are used as background images in outdoors and simplified building maps are used as background images in indoors.

Figure 10. User interface subsystem

8.2. Positioning subsystem

One of the main objective is to be able to locate the handheld device in a building and outdoor. The device should be able to use signal strength measurements of the available wireless networks and GPS signals to accurately locate itself according to the proposed hybrid positioning algorithm in both indoors and outdoors. Equation 5 shows hybrid positioning equation;

$$P_{Hybrid} = \frac{0.4 \times P_{GPS} + 0.6 \times P_{wifi}}{0.4+0.6} \quad (5)$$

Where, P_{wifi} is the obtained position from positioning using Wi-Fi network access points and P_{GPS} is the obtained position from GPS.

Here, 0.4 and 0.6 are weighs of GPS and Wi-Fi positioning techniques. The radius of the buffer area is 8 meters and the numbers of initial candidate positions are equal to five. Figures 11 A and B show the idea of considering user location history.

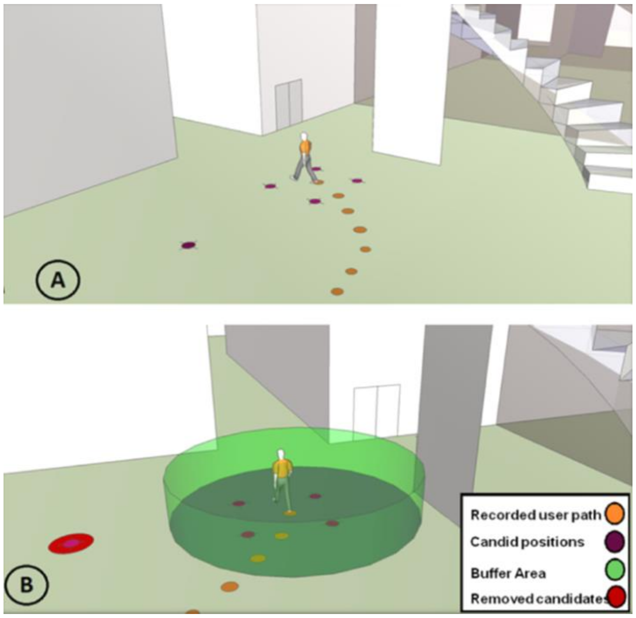

Figure 11. Considering user movement history for improving positioning accuracy

8.3. Database subsystem

This subsystem implemented with Postgresql 9 database[14]. This database is not a spatial database and needs postgis 8.4 to be installed on it. According to the proposed method, this subsystem has two main parts: network database and RSS database.

8.4. Mapping subsystem

The main role of this subsystem is overlaying the final map result and considering cartographical operations on the final image. This subsystem was implemented by means of UMN Mapserver [15].

9. Evaluating system functionality

Evaluation of system's functionality is performed in two cases, at the first case, user located in indoor and select a target in outdoor. This condition was checked at eight locations and Table 2 shows the errors. The average RMSE were 2.13 for x and 2.85 for y. Figure 12 A shows the returned result in this condition.

Table 2. Results of testing hybrid positioning at indoor

Point Number	Element	Real position (m)	Estimated position (m)	Difference (m)	Error (m)
1	X_1	523862.3294	523863.943	1.6136	2.1667
	Y_1	3324011.947	3324010.501	-1.446	
2	X_2	523846.3294	523844.002	-2.3274	2.70
	Y_2	3324003.947	3324005.316	1.369	
3	X_3	523834.3294	523830.738	-3.5914	7.717
	Y_3	3324016.947	3324010.116	-6.831	
4	X_4	523872.3294	523874.255	1.9256	٧4.11
	Y_4	3323994.947	3323991.307	-3.64	
5	X_5	523858.3294	523857.048	-1.2814	1.287
	Y_5	3324017.947	3324018.071	0.124	
6	X_6	523846.3294	523844.861	-1.4684	3.053
	Y_6	3324022.947	3324020.27	-2.677	
7	X_7	523870.3294	523872.412	2.0826	2.097
	Y_7	3324006.947	3324006.701	-0.246	
8	X_8	523832.6713	523831.4665	-1.204789	5.637
	X_8	3324003.633	3323998.126	-5.5076	

In the second case, user was located in outdoor and a destination in indoor was chosen. As figure 12 B shows, this situation.

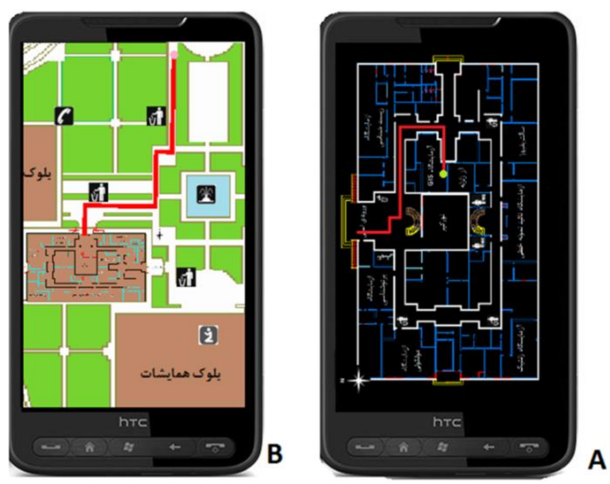

Figure 12- A sample of system's operation in two positions of indoor and outdoor

10. Conclusion and future works

Development of an indoor/outdoor hybrid navigation system was investigated in this paper. At the First step, the selection of appropriate positioning technologies has been made according to three criterions: cost, accuracy and coverage.

In the second step, Wi-Fi and GPS positioning techniques compounded to develop a hybrid positioning algorithm. User location history and inverse distance weighting used along with the Wi-Fi fingerprinting method for robust Wi-Fi positioning algorithm. The movement history data of user is suggested to be used for improving the accuracy of obtained positions in Wi-Fi fingerprinting method. In the last step, the main parameters that should be considered in designing database were expressed. According to this process a system with five subsystems designed which was including five systems: routing, positioning, database, user interface and mapping. According to the proposed architecture a prototype system was developed in the study area. Finally, the system functionality in terms of positioning and navigation was evaluated. The obtained results showed the capability of proposed method. Since, one of the most important aspects of this paper that needs to be worked on is the overall accuracy of the indoor navigation system. The application currently works with moderate accuracy, which is sufficient enough but not ideal.

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