INSAR: Indoor Navigation System using Augmented Reality

Ahmed Alnabhan
Department of Information Sciences and Technologies
Rochester Institute of Technology RIT
amn5948@rit.edu

Brian Tomaszewski, Ph.D.
Department of Information Sciences and Technologies
Rochester Institute of Technology RIT
bmtski@rit.edu

ABSTRACT

Indoor navigation applications for mobile devices are being more common and needed for people who want to find inside building destinations. Many indoor navigation applications utilize different technologies, such as Wi-Fi fingerprinting, have been suggested. Most of these applications use a fixed background map and pre-calculated paths to lead the user to their destinations. Users of these systems need general map reading skills and understanding how specifically indoor maps work. In addition, these system types need to implement complex and accurate calculations to determine routing paths before navigation starts - which could be affected by unstable Wi-Fi signals. In this paper, we suggest INSAR or Indoor Navigation System Using Augmented Reality, which utilizes Wi-Fi fingerprinting, augmented reality (AR), and digital compass technologies in an integrated Android-based app. Specifically, we used a Wi-Fi fingerprinting method to determine user position, augmented reality to display real-time navigation information, and a compass to determine destination direction. Additionally, digital compass use to read the destination direction of each reference point (RP) helps direct the users ”on the fly” thus reducing potential Wi-Fi signal instability effects.

Keywords

Indoor navigation, augmented reality AR, Wi-Fi fingerprinting, indoor positioning, compass

1. INTRODUCTION

People may visit new enclosed places such as large buildings, and need to reach specific locations and rooms inside these buildings. They may need an easy and friendly navigation tool to find their end destination. Nowadays, most people use mobile devices such as smart phones and tablets. Important to this research, modern smart phones are equipped with powerful processors, expandable memory, cameras that capture video and still views, networking and Wi-Fi technologies, and advanced sensors that provide the ability of determining the position and the orientation of the device such as Global Positioning System (GPS), accelerometer, compass, and gyroscope [16]. Adding such powerful tools and capabilities to smart phones allows them to run high performance functionalities such as augmented reality technology [29]. Augmented reality (AR) is the technology that superimposes the computer generated objects over a real scene that is captured in real-time by the camera so that they seem like one environment [22]. The computer generated objects may be 2D or 3D graphics, text, audio, point of interest (POI) or video which augment and integrate with the physical world to reveal useful information to the user and help him to interact with the application in an easy and comfortable way. Smart phones users can use their phones for navigation to specific places. Most navigation apps use the Global Positioning System (GPS) to determine both the user and destination positions. These app types are perfect to guide the user outdoors by revealing the directions and distance between the user and their destination [5]. In enclosed places such as buildings, airports, and markets, however, GPS satellite signals become weak or non-existent; therefore, GPS is not suitable for indoor positioning and navigation [12]. There are many indoor positioning techniques that can be used instead of GPS in augmented reality systems such as ultra-sound, optical marker-based, optical markerless, magnetic, inertial, ultra wide-band (UWB), hybrid, accelerometer, active RFID, passive RFID, and Wi-Fi fingerprinting [8, 23, 31]. The feasibility of using a specific approach to locate the user indoors depends on several factors such as accuracy, infrastructure, cost, complexity of implementation, delay time, updates rate, operating range, portability, and tracked target mobility [2]. Wi-Fi fingerprinting can be used to locate the position of the user because Wi-Fi networks already exist and most of the modern smart phones are equipped with Wi-Fi chips so that they can communicate with each other. Furthermore, Wi-Fi fingerprinting provides a high-accuracy, low-cost indoor positioning solution [32]. For these reasons, we used Wi-Fi fingerprinting methods in the INSAR system. In this paper, we suggest expandable Android software that uses augmented reality technology for indoor navigation. The software relies on the Wi-Fi fingerprinting technique to determine user location and a compass to determine the destination direction at specific reference points. All data is stored locally on the same device that implements the calculations so that the software does not need to connect with a server. Using augmented reality in the app provides interactivity between the user and the app because the user feels like he is acting in-

ISA'14, November 04-07 2014, Dallas/Fort Worth, TX, USA

http://dx.doi.org/10.1145/2676528.2676535

side the real environment. Furthermore, displaying the real view along with the related information on the screen during the navigation process presents all the required information in one view and physical place. Therefore, the user can recognize where they are with no need for understanding the how to read the reference maps that traditional navigation systems use as a background.

2. RELATED WORK

Wi-Fi indoor positioning is divided into two types: The first type is the wave propagation, e.g. trilateration, which computes the distance between the Access Point (AP) and the user (or the device). The second type is the Wi-Fi fingerprinting by measuring the Received Signal Strength (RSS) [6, 10]. This project uses the Wi-Fi fingerprinting as a positioning technique.

2.1 Indoor Positioning using *Wi-Fi Fingerprinting*

In last few years, many studies have presented different methods to implement indoor positioning system utilizing the pre-existing Wi-Fi networks. In general, these studies and systems divided the positioning procedure into two phases: The first phase is the offline phase, called training phase, that includes collecting fingerprints (measuring signal strength) in specific points called reference points (RP) in the indoor environment and building a database to store those fingerprints (radio map). The second phase is the online phase, sometimes called estimation phase, in which the device reads the Wi-Fi signals strength on the fly at RPs and compares them to the stored radio map to determine the current user location of the user [4, 11, 19, 20, 24]. This fingerprinting method does not need to install new network hardware and its functionality can be built programmatically. RADAR [3], developed by Microsoft, was the first system that used the two-phase fingerprinting method and its accuracy was up to three meters. Many algorithms were proposed and applied during implementing the steps of two phases to increase the accuracy of the system such as weighted k-nearest neighbor (KNN) [25] and Bayesian [33]. Technically, building and maintaining the database that contains the measured fingerprints is not an easy task because it is affected by several outliers such as the changes in the environment (e.g. adding, moving, removing, or changing access points), access points attack, and weakness of signal strength [20]. There are two recognized approaches to estimate the unknown location when creating the database: the first and simplest way is the deterministic that takes the average of signal strength for each access point AP in each reference point RP. RADAR utilized deterministic and KNN algorithm in its offline phase [3, 4]. The second way is the probabilistic that provides more information for the average of signal strength in a given RP such as the probability distribution function (PDF) estimate [7, 17, 33]. Our system uses the two-phase approach to locate the user. However, we did not use any of the methods that calculate the whole path between a starting point and a destination.Instead, our system stores the direction from each single reference point toward the destination taking in account the shortest path. The shortest path is determined by calculating the number of reference points on the path from the current reference point to the destination reference point on both sides. The shortest path is the one with fewer reference points on it because the distance between each two reference points is equal. We made the calculations of the shortest path manually on the map before storing the related direction from each reference point toward other reference points in the database. Making these calculations once and storing the directions in the database gave us two advantages. First, we avoid complex calculations to determine the current location. Second, if the system could not determine the current location because of Wi-Fi signal instability, it would not recalculate the whole path again but rather would show the right direction at the same or the next reference point in the following reading. Commercially, there are several products on the market use Wi-Fi technologies as an indoor positioning system. In 2000's, Ekahau developed Ekahau positioning engine EPE that used the signal strength pattern recognition in conjunction with user's history and its accuracy was 1-5 meters [4]. Ekahau now produces real-time location system (RTLS) for staff and equipment positioning based on Wi-Fi fingerprinting technology [9]. Skyhood wireless [27] is another product that utilizes Wi-Fi fingerprinting to provide a positioning service similar to GPS [14]. However, these solutions are expensive, need more hardware, and use servers to store databases and implement calculations.

2.2 *Augmented reality*

Several indoor navigation systems using augmented reality have been proposed over last few years. These systems utilize a variety of positioning techniques such as a marker-based, vision-based, markerless, RFID, and activity-based instruction. Marker-based technique requires putting pre-defined markers inside the indoor environment and generating and showing the signage and orientations depending on those markers [20]. There are several projects that can be used to develop the marker-based augmented reality on Android platforms such as the AndAR project [1]. Vision-based technique requires comparing the captured images by the camera with pre-defined set of pictures stored in a database and locating the place by matching [15]. Activity-based instructions technique selects information points in the building and shows info depending on the activities of the user [21]. Some researchers suggested hybrid navigation system that use RFID and markerless augmented reality [30]. All the previous mentioned systems use positioning techniques other than Wi-Fi fingerprinting which we have used in INSAR. However, AVANTI [18], an experimental Fire Evacuation Drills augmented reality system, uses the Wi-Fi fingerprinting technique as an indoor positioning approach and the accelerometer sensor to determine the speed and location of the user. AVANTI uses the server-client paradigm for navigation implementation. Our system is designed to implement all the work in the app with no need for connecting to remote servers. This makes the performance faster because there is no need to set a connection and exchange the information with a remote computer back and forth.

3. INSAR SYSTEM OVERVIEW

Our software, INSAR, was implemented and tested on a college campus. The user needs to do no more than choosing their destination from the dropdown list(Figure 1(b)), tapping the (START NAVIGATION!!) button(Figure 1(a)), and following the directions to find their destination (Figure 1(c)). Developing INSAR system consisted of two phases: the first phase is offline (training) phase and the second is

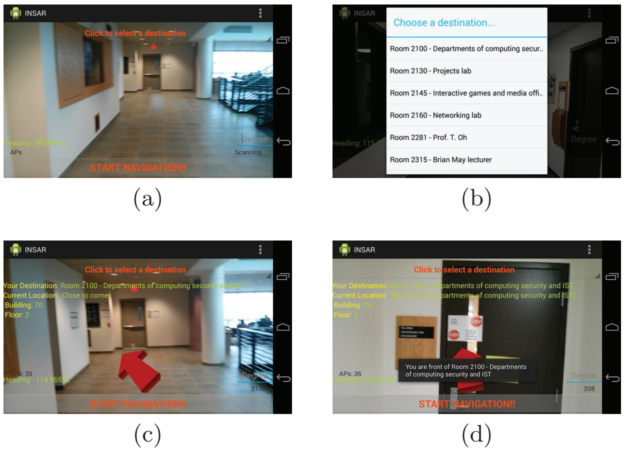

Figure 1: Screnshots of INSAR. (a) Is the main user interface before starting navigation. (b) A menu of the available destinations in the work area. (c) The user interface during the navigation process. (d) The toast message that tells the user when they access their destination.

online (estimation) phase. Each of these phases was implemented as a series of tasks (Figure 2).

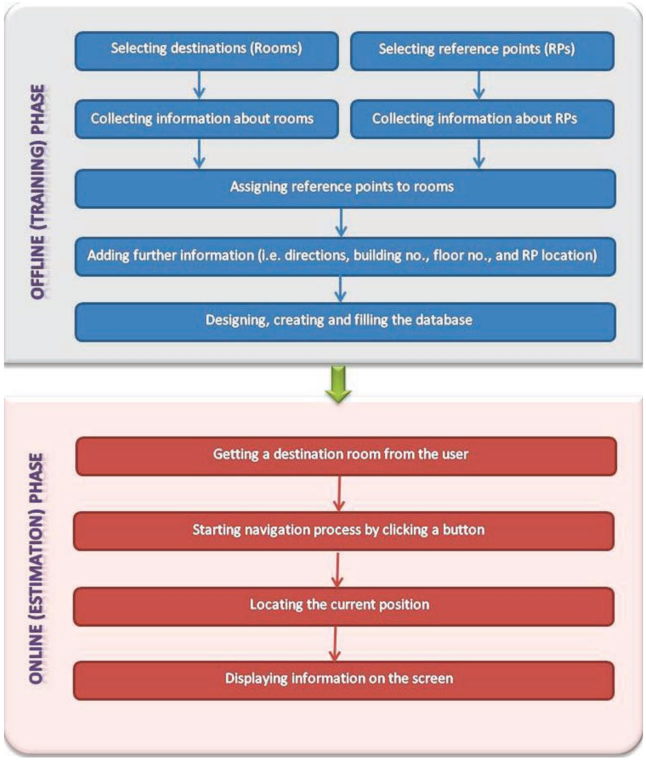

Figure 2: INSAR developing phases

3.1 Offline *(Training)* Phase

INSAR uses a Wi-Fi fingerprinting technique for positioning. This technique requires creating a database that contains information about selected reference points (fingerprinted points), selected destinations (rooms), and the relationships between them such as assigning reference points to rooms, and directions from each reference point towards each room (Figure 3). The result of the offline phase was creation of the INSAR database or radio map. The distance between reference points is important to get better results. Short distances may lead to getting similar readings of the Wi-Fi signals and that affects the accuracy of localization. On the other hand, long distance may not cover some destinations especially in the environment where the rooms, for example, very close to each other. Unlike systems that precalculate the route to the destination from the beginning, our system stores the direction toward the selected destination at each reference point in the database along with the Wi-Fi signals. If the system could not determine the exact situation at a specific reference point due to the instability of Wi-Fi signal, it should not recalculate the whole path again. In the next reference point, rather, the system will correct the direction depending on the new readings of the Wi-Fi signals and the calculations.

3.2 Online *(Estimation)* Phase

Each time the user taps the start navigation button, INSAR scans the Wi-Fi signals on the fly, compares them against the signals stored in the database for each reference point, determines the current location, retrieves the related information from the database, and displays the information on the real scene that is captured by the camera. Depending on the current location, INSAR retrieves the related direction from the database and uses the digital compass of the phone to make the arrow on the screen points toward the destination. INSAR runs Wi-Fi scanning every three seconds during the navigation process.

4. IMPLEMENTATION

We developed INSAR software to work on Android smart phones and tablets. We used Android SDK and eclipse IDE to implement the functionality and testing. INSAR consists of four components: Positioning system, navigation system, database and user interface UI (Figure 4).

4.1 *Positioning* System

The positioning system is the core of INSAR and it is responsible for determining the current user location. It runs Wi-Fi reading every three seconds and temporarily stores the scan results in a temporary table. Next, it compares the content of that table against each single reference point in the database to determine the position of the user. During the development process, we applied three positioning algorithms:

1. Highest number of MACs and signals matching (NM) [28]: INSAR reads the MAC address and the Wi-Fi signals "on the fly" and compares them against the stored information for each reference point to find the matching. The condition of matching is that the signal read on the fly should be within a range of Âś4 of the signal already stored in the database. INSAR considers the reference point (RP) that has the highest number of matches as the current location.

2. Least sum of square (SS) [26, 28]: INSAR calculates the difference between the signal that is read on the fly and the signal that is stored in the database for

Figure 3: The map of the work area with the selected reference points (fingerprints). The distance between each two adjacent points is 2.4 meters. Each blue dot in the map represents a destination room and it is located in front of the door of that room.

the same MAC address and calculates the square of difference for each Access point. Then it calculates the summation of all squares for each reference point (RP). The reference point (RP) with the smallest summation is returned as the current location.

3. Least average of square AS: INSAR calculates the difference between the signal that is read on the fly and the signal that is stored in the database for the same MAC address and calculates the square of difference for each Access point. Then it calculates the average of all squares for each reference point (RP). The reference point (RP) with the smallest summation is returned as the current location.

We chose to work with the highest number of MACs and signals matching method because it gave the more accurate results during the testing and evaluation phase. We proposed the least average of square method as a new positioning technique to improve the results of the least sum of

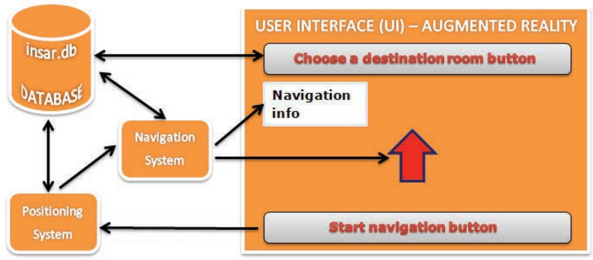

Figure 4: INSAR's components: Positioning system, navigation system, database, and user interface UI and how they work with each other

square method. However, the improvement was not enough to accept it as positioning method in INSAR.

4.2 *Navigation* System

INSAR starts the navigation process as the user tabs the button (START NAVIGATION!!). The navigation system is built on the top of the positioning system. Every three seconds, the navigation system receives the number of the current reference point, i.e. the current position, and it retrieves information related to that reference point from the database and sends them to the user interface to be displayed on the screen. INSAR uses the Android class SensorManager to determine the heading of the phone or tablet (0 - 359 degrees) and subtracts that heading value from the direction value that is retrieved from the database. This process produces the direction of the arrow image on the screen as illustrated in the following formula:

$$DA^\circ = DD^\circ - H^\circ$$

Where the DA is the direction of the arrow image displayed on the screen. DD is the direction measured in degrees. It represents the orientation from the current location (reference point) toward the destination room and it is retrieved from the database. H means the heading of the smart phone or the tablet measured in degrees. This step makes the arrow point toward the same direction even though the user turns the phone around.
To obtain the best navigation results of INSAR, the user should hand-hold the smart phone or the tablet as illustrated in Figure5.

4.3 *Database*

We used SQLite to create and deal with the database (radio map). INSAR builds the database during the offline phase of the system. To obtain better navigation process results, data needs to be refined and filtered before storing into the database. During the data filtering process, we eliminated the weak and unstable Wi-Fi signals. We stored information for the strongest 15 access points that show up in each single reference point. The database is stored on the same device that runs INSAR and all data manipulations are implemented locally. Reading data is almost the only operation that is executed against the database repeatedly. When the database tables were initially created, they draw their data from corresponding XML files. We added building name and floor number to the database to make the system

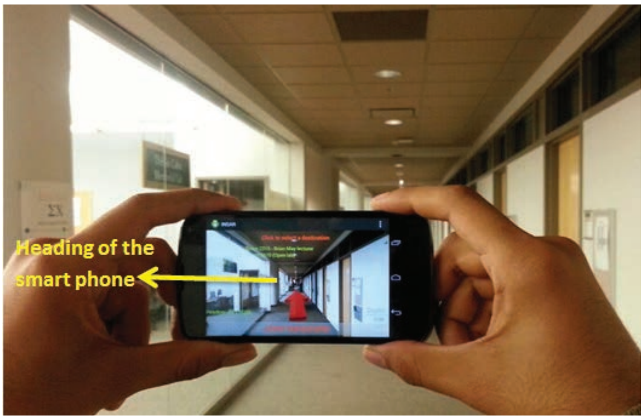

Figure 5: The typical hand holding of the smart phone during the navigation process

scalable.

4.4 *User Interface*

The interface of INSAR is the real scene of the work environment and it is built on the top of the positioning and the navigation systems. Using augmented reality makes the user see the real scene during navigation. INSAR uses the phone's camera to show the view. This real-time displaying of the real views in the environment of the user represents a part of the information displayed by INSAR because the user could see their actual location and the related information. INSAR displays information to the user as graphics, text, and notifications (Figure 1(d)). The direction toward the destination is represented by an arrow which is drawn on the fly based on the current location and the related angle. In addition, user interface displays the selected destination, the current location of the user, building name, and the floor number in text format. When INSAR finds the destination, it issues a two seconds user notification vibration. At the same time it displays a message on the screen telling the user that they are in front of the destination.

5. EVALUATION

INSAR was tested and evaluated on a variety of Android smart phones and tablets and Android OS versions (Figure 6).

Two versions of the INSAR prototype have been used in the testing process; the first version used the algorithm (highest number of matches NM), and the second version used the algorithm (least average of square AS). Seven users, who are unfamiliar with the work area, participated in INSAR prototype testing. Each user used a different Android smart phone (or tablet) to navigate to three different destination rooms for each INSAR prototype version. Tables 1 and 2 summarize the results of INSAR prototype testing.

As for the positioning system, the results varied when users used a Samsung smart phone. The difference of hardware from one manufacturer to another or the versions of smart phones from the same manufacturer might affect the positioning system. Wi-Fi signal fluctuation is still a main reason for getting accuracy error even though the user used the same INSAR hardware and software implementation. We measured the Wi-Fi signals and the directions at each reference point using Google LG Nexus 4 smart phone. Regarding the navigation system, which depends on the compass to show the direction during the navigation tour, testing showed that the direction retrieved from database displayed the wrong direction on some devices. This means that the compass sensor in some Samsung smart phones has different abilities than other Android devices such as the Google LG Nexus 4 that was used to measure the directions and to write them into the database. The difference in Android device power sensors seems to be true in the same family of devices from the same manufacturer. For example, the results of the positioning system (that uses Wi-Fi adapters) and the navigation system (that uses Wi-Fi adapters and compass) were different in Samsung Galaxy S3, Samsung Galaxy S4 smart phones, and the Samsung Galaxy Note 10 tablet.

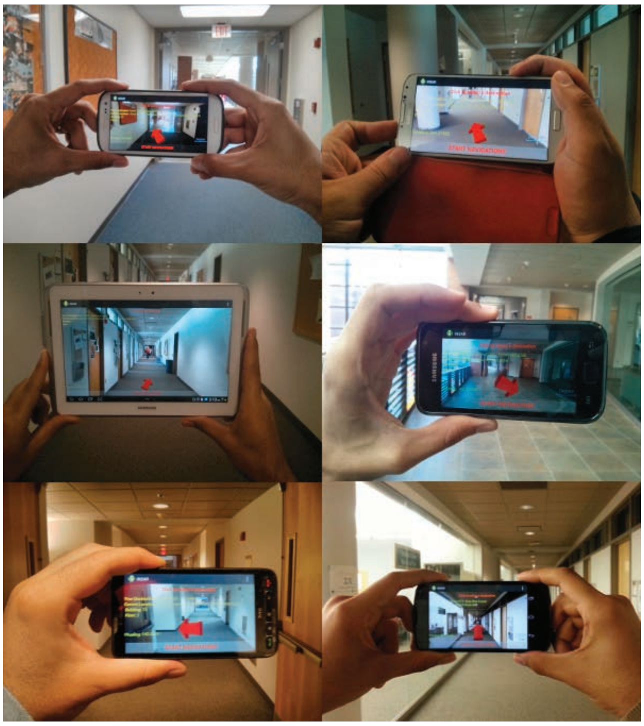

Figure 6: Testing INSAR using different Android devices with different versions of Android OS

NOTES from Table 2:

1. Positioning accuracy means locating each fingerprint at a given time. The positioning process is the base of the navigation process. The positioning accuracy error is measured by meters.

2. Navigation Info accuracy means the accuracy of displayed textual, graphic information and the notifications. This depends on the positioning system.

3. The distance between each two fingerprints is 2.4 meters. The accuracy error is calculated by multiplying the number of fingerprints by 2.4 meters. For example, 7.2 means that INSAR found the selected destination before or after three fingerprints from the actual location.

4. The following terms are used to evaluate the accuracy of the navigation system:

Table 1: The mobile devices and Android versions used in testing INSAR

Device No.	Device Manufacturer	Category	Model Number	Device Type	Android Version
1	LG	Nexus	Nexus4	Smart phone	4.3 Original
2	Samsung	Galaxy S	19000	Smart phone	4.1.2 Custom ROM
3	Samsung	Galaxy S2	19100	Smart phone	4.2.2 Custom ROM
4	Samsung	Galaxy S3	SGH-T999	Smart phone	4.1.2 Original
5	Samsung	Galaxy S4	SGH-M919	Smart phone	4.2.2 Original
6	Samsung	Galaxy Note 10.1	GT-N8013	Tablet	4.1.2 Custom ROM
7	Samsung	Galaxy Note 10.1	GT-N8013	Tablet	4.1.2 Original
8	HTC	HD2	NexusHD2	Smart phone	4.0.4 Custom ROM

Table 2: The results of testing INSAR on corresponding devices in table 1

Device No.	Positioning Accuracy[1] in Highest No. of Matches (NM) Algorithm[3]	Positioning Accuracy[1] in Least Average of Square (AS) Algorithm[3]	Navigation Info Accuracy[2] in Highest No. of Matches (NM) Algorithm[4]	Navigation Info Accuracy[2] in Least Average of Square (AS) Algorithm[4]	Preferred algorithm
1	0 - 7.2 meters	0 - 9.6 meters	Good	Acceptable	NM
2	2.4 - 9.6 meters	Did not work	Not acceptable	Did not work	NM
3	0 - 9.6 meters	Has not been tested	Acceptable	Has not been tested	NM
4	0 - 7.2 meters	0 - 9.6 meters	Good	Acceptable	NM
5	0 - 9.6 meters	0 - 7.2 meters	Acceptable	Good	AS
6	0 - 7.2 meters	Has not been tested	Average	Has not been tested	NM
7	0 - 9.6 meters	0 - 7.2 meters	Average	Average	AS
8	7.2 - 14.4 meters	Did not work	Average	Did not work	NM

Good means that the user is comfortable with the information and this information is correct.

Acceptable means that the information displayed on the screen is helpful but sometimes it gives wrong information.

Average means that the user finds it hard to find their way easily. For example, the user is guided to the wrong way and then he is told to go the opposite direction. This cause confusion for the user.

Not Acceptable means that the positioning system makes wrong positioning guesses and displays wrong information to the user.

Did not work means that the positioning system did not work. As a result, there is no information to display to the user

It is worth mentioning that the Custom ROM version of Android produced low accuracy in both positioning and navigation systems. Furthermore, older smart phone versions showed weaknesses in determining the location of the user and telling the correct direction. This means that the differences in the hardware and software of the Android smart phone may affect the results of INSAR.

6. LIMITATIONS

During the process of developing INSAR prototype, we experienced some limitations that affected system results that have been previously identified in the literature as being issues affecting indoor navigation performance [13, 20, 28]. These challenges are summarized in the following points:

1. The changes in the infrastructure of the work area such as removing, adding, moving, or changing one or more of the access point.
2. The changes in the environment such as adding, or removing the furniture, or upgrading the building.
3. The signals fluctuation in short period of time.
4. Multipath effects that are caused by signal reflections on the surfaces in the work area.
5. Interference with signals of other devices that work at the same frequency of the access pointsâĂŹ signals such as smart phones and microwaves.
6. Human bodies can block the signals when they are moving between the access point and the reference point.
7. The timestamps of the received signal strength are variable during the daytime. For example they are different in the crowded place during the work and study hours.

The following subsections explain the challenges we experienced during the process of INSAR development and the methods we used to handle each issue:

6.1 Heavy labor

Fingerprinting requires much effort and time to be implemented. To register the information at each fingerprint, the developer needs to run the scanning using a third party application for a specific period of time (20-second period used in INSAR). The larger the number of reference points, the greater the effort and time is needed to register information. Furthermore, the conversion of data and putting it in the required formats needs more time and applications to get it done. We did not find software that make the conversion; Therefore, we developed the required applications to implement data conversion into the required format.

6.2 Wi-Fi signal fluctuation and instability

Wi-Fi signal fluctuation caused by many factors such as the reflection from the walls, furniture, and other objects located inside the environment, magnetic fields inside the building, people moving inside the building, working electronic devices such as PCs and microwaves, adding, removing, or changing one or more access point in the environment, and opening and closing doors in the work area. To reduce the effect of Wi-Fi signal fluctuation, we filtered the data by eliminating the access points that have big difference between the highest and lowest signals registered during the 20-second scanning process. Moreover, we eliminated the access points that did not show in more than one second during the 20-second scanning process. In addition, we registered the information of only 15 access points at each fingerprint in the database. This filtration process reduced the effect of Wi-Fi signal fluctuation in the radio map that is stored in the database.

6.3 Magnetic fields inside the work area

The existence of magnetic fields affects both the using of the compass and the Wi-Fi signal stability. As for the compass, we noticed a difference in compass directions within a small area due to the interference of the magnetic fields inside the building which affects directions read by the compass sensor of the smart phone. To avoid the influence of magnetic fields on the results of the navigation system of INSAR, we read the directions at each fingerprint separately. We repeated the reading process several times at each fingerprint and registered the directions that looked stable.

6.4 Android hardware devices differences

The power of sensors and Wi-Fi adapters differs in Android smart phones depending on the manufacturer. These differences in standards may cause different results on different devices.

7. CONCLUSIONS AND FUTURE WORK

In this paper, we have presented INSAR, Indoor Navigation System Using Augmented Reality, which utilizes Wi-Fi fingerprinting technique as a positioning system and displays the information to the user using augmented reality AR technology. Our system determines the direction toward the destination on the fly using the smart compass of the mobile device. INSAR was tested on different Android mobile devices, smart phones and tablets, with different Android operating system versions. The difference in Android hardware and software affected the results of the system during the navigation process. In general, INSAR worked very well and gave an accuracy between 0 and 7.2 meters on some devices. However, it did not work on some old versions of Android software and hardware. We will work to improve the performance of INSAR on all Android versions in the future.

INSAR is a standalone system. Thus, it stores, manipulates, displays data locally without need to connect to a server. This makes the system faster during the navigation process because it does not need to spend extra time to exchange data with a remote server. Furthermore, our system does not need to be connected to the Internet.

Augmented reality technology normally uses GPS as a positioning system. Using Wi-Fi fingerprinting with augmented reality technology presented in INSAR to determine the phone position and other objects indoors may make it a good alternative to GPS which does not work inside buildings. However, Wi-Fi fingerprinting accuracy needs to be improved in order to be used for more complex augmented reality applications.

INSAR runs on Android smart phones and tablets and it is designed to be extended in the future so that it can run in all floors of the building and in other buildings. Another addition could be implemented on our system which is running it on iOS mobile devices in the future. One of the possible valuable improvements which could be added to INSAR in the future is audible description of the navigation information. Further research and improvement will make our system more accurate and scalable on variety of devices and operating systems

8. REFERENCES

[1] *AndAR - Android Augmented Reality*. June 2014. `https://code.google.com/p/andar`.

[2] D. Anzai and S. Hara. Does particle filter really outperform low pass filter in indoor target tracking? In *2010 IEEE 21st International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)*, pages 882–886, September 2010.

[3] P. Bahl and V. N. Padmanabhan. Radar: An in-building rf-based user location and tracking system. In *INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, volume 2, pages 775–784, March 2000.

[4] D. R. Brown and D. B. Dunn. Classification schemes of positioning technologies for indoor navigation. In *Southeastcon, 2011 Proceedings of IEEE*, pages 125–130, March 2011.

[5] Y.-C. Cheng, J.-Y. Lin, C.-W. Yi, Y.-C. Tseng, L.-C. Kuo, Y.-J. Yeh, and C.-W. Lin. AR-based positioning for mobile devices. In *2011 40th International Conference on Parallel Processing Workshops (ICPPW)*, pages 63–70, September 2011.

[6] M. Cypriani, F. Lassabe, P. Canalda, and F. Spies. Wi-Fi-based indoor positioning: Basic techniques, hybrid algorithms and open software platform. In *2010 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, pages 1–10, September 2010.

[7] B. Dawes and K.-W. Chin. A comparison of deterministic and probabilistic methods for indoor localization. *Journal of Systems and Software*, 84(3):442–451, March 2011.

[8] S. DiVerdi and T. Höllerer. Groundcam: A tracking modality for mobile mixed reality. In *Virtual Reality Conference, 2007. VR '07. IEEE*, pages 75–82, March 2007.

[9] Ekahau. *real-time location system (RTLS)*. June 2014. `http://www.ekahau.com/real-time-location-system/technology/how-rtls-works`.

[10] T. Gallagher, B. Li, A. G. Dempster, and C. Rizos. Database updating through user feedback in fingerprint-based Wi-Fi location systems. In *Ubiquitous Positioning Indoor Navigation and Location Based Service (UPINLBS)*, pages 75–82, October 2010.

[11] M. Gunawan, B. Li, T. Gallagher, A. G. Dempster, and G. Retscher. A new method to generate and maintain a Wi-Fi fingerprinting database automatically by using RFID. In *2012 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, pages 1–6, November 2012.

[12] L. C. Huey, P. Sebastian, and M. Drieberg. Augmented reality based indoor positioning navigation tool. In *2011 IEEE Conference on Open Systems (ICOS)*, pages 256–260, September 2011.

[13] L. Jiang. A WLAN fingerprinting based indoor localization technique. Master's thesis, Dept. Computer Science, University of Nebraska, NE, 2012.

[14] K. Jones and L. Liu. What where wi: An analysis of millions of Wi-Fi access points. In *IEEE International Conference on Portable Information Devices, 2007. PORTABLE07*, pages 1–4, May 2007.

[15] J. Kim and H. Jun. Vision-based location positioning using augmented reality for indoor navigation. 54(3):954–962, August 2008.

[16] S. Kurkovsky, R. Koshy, V. Novak, and P. Szul. Current issues in handheld augmented reality. In *2012 International Conference on Communications and Information Technology (ICCIT)*, pages 68–72, June 2012.

[17] B. Li, Y. Wang, H. Lee, A. Dempster, and C. Rizos. Method for yielding a database of location fingerprints in WLAN. 152(5):580–586, October 2005.

[18] E. L. Mañas, J. P. Herrero, G. Méndez, and P. Gervás. Augmented reality and indoors Wi-Fi positioning for conducting fire evacuation drills using mobile phones. In *4th Symposium of Ubiquitous Computing and Ambient Intelligence UCAmI*, September 2010.

[19] N. Marques, F. Meneses, and A. Moreira. Combining similarity functions and majority rules for multi-building, multi-floor, Wi-Fi positioning. In *International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, pages 1–9, November 2012.

[20] W. Meng, W. Xiao, W. Ni, and L. Xie. Secure and robust Wi-Fi fingerprinting indoor localization. In *International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, pages 1–7, September 2011.

[21] A. Mulloni, H. Seichter, and D. Schmalstieg. Handheld augmented reality indoor navigation with activity-based instructions. In *the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*, pages 211–220, 2011.

[22] T. Olsson and M. Salo. Online user survey on current mobile augmented reality applications. In *10th IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pages 75–84, October 2011.

[23] G. Papagiannakis, G. Singh, and N. Magnenat-Thalmann. A survey of mobile and wireless technologies for augmented reality systems. 19(1):3–22, February 2008.

[24] C. Pei, Y. Cai, and Z. Ma. An indoor positioning algorithm based on received signal strength of WLAN. In *Pacific-Asia Conference on Circuits, Communications and Systems, 2009. PACCS '09*, pages 516–519, May 2009.

[25] P. Prasithsangaree, P. Krishnamurthy, and P. Chrysanthis. On indoor position location with wireless LANs. In *The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 2002*, volume 2, pages 720–724, September 2002.

[26] K. C. Y. Shum, K. J. Cheng, J. K. Y. Ng, and D. Ng. A signal strength based location estimation algorithm within a wireless network. In *IEEE International Conference on Advanced Information Networking and Applications (AINA)*, pages 509–516, March 2011.

[27] Skyhook. *skyhook wireless*. June 2014. `http://www.skyhookwireless.com/`.

[28] J. Stook. Planning an indoor navigation service for a smartphone with Wi-Fi fingerprinting localization. Master's thesis, GIMA, Univ. of Utrecht, Netherlands, 2011.

[29] S. Vert and R. Vasiu. School of the future: Using augmented reality for contextual information and navigation in academic buildings. In *IEEE 12th International Conference on Advanced Learning Technologies (ICALT)*, pages 728–729, July 2012.

[30] C.-S. Wang, D.-J. Chiang, and Y.-Y. Ho. 3D augmented reality mobile navigation system supporting indoor positioning function. In *International Conference on Computational Intelligence and Cybernetics (CyberneticsCom)*, pages 64–68, July 2012.

[31] J. Xiao, Z. Liu, Y. Yang, D. Liu, and X. Han. Comparison and analysis of indoor wireless positioning techniques. In *International Conference on Computer Science and Service System (CSSS)*, pages 293–296, June 2011.

[32] W. Xiao, W. Ni, and Y. K. Toh. Integrated Wi-Fi fingerprinting and inertial sensing for indoor positioning. In *International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, pages 1–6, September 2011.

[33] M. A. Youssef, A. Agrawala, and A. U. Shankar. WLAN location determination via clustering and probability distributions. In *Proceedings of the First IEEE International Conference on Pervasive Computing and Communications, 2003. (PerCom 2003)*, pages 143–150, March 2003.