Comparative Analysis of Indoor Positioning Systems Based on Communications Supported by Smartphones

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Abstract

In this paper, common trends of architectural design, technologies, properties, and drawbacks of indoor positioning systems based on communications supported by smartphones are analyzed. The main idea of such kind of systems is that their users can use them through their mobile devices because such systems include positioning functionality based on such technologies as Wi-Fi, Bluetooth, and GSM. For example, museums might not need to buy expensive audioguides, but instead can provide their visitors with appropriate software for their smartphones. The paper presents a comparative analysis of most promising at the moment systems and solutions.

Index Terms: Indoor positioning system, Fingerprinting, Triangulation, Wi-Fi, GSM, Bluetooth.

I. INTRODUCTION

Creating systems and solutions for solving the problem of indoor positioning and navigation is a promising and complex task. This problem requires of creating maps based on floor plans of indoors, choosing the effective positioning technology and algorithms, deploying the appropriate positioning devices inside buildings. Modern systems can offer much more than just positioning with acceptable accuracy. For example, the tasks of navigation, providing context information in text-, audio- or video- format, collection statistical information about the movements of people in buildings. The functions of these systems are depending on location type. Thus, the developing companies have great potential for creating various services.

II. INDOOR POSITIONING SYSTEMS

Dutch company IWAY [1] creates mobile navigation system with special modules separately for different types of objects and buildings according their destination: supermarkets, offices, museums, airports, etc. Such applications are focused on positioning and solutions specific for each object. Customer can download and install the application from the Internet. For example, the shopping center customers can find a map of interests to obtain information about discounts and special offers. In addition, there is an opportunity for the administration to process the data for the analysis of visitors' movements' trough the shopping center. The system provides a set of functions to evaluate the efficiency of the shop work. Using such system makes it possible to coordinate the work of the shopping center. The system developed by this company includes mobile and desktop modules for public facilities, staff and administration. Desktop part of the system is responsible for the analysis, statistical data processing, and

HR management. The positioning method used in the system is based on fingerprinting technology and uses Wi-Fi signals, 3G/4G. This method provides the accuracy of 1-5 meters. Calculated coordinates can be displayed on Google Maps. However, there is no information available whether the system uses its own maps or not. Furthermore, the system is able to determine the user's altitude.

The Wifarer's [2] indoor positioning system has the similar concept as the IWAY's solution. This system offers a set of maps for positioning indoors, which can provide various content (for example, descriptions of exhibits in museums). In addition, Wifarer also provides some statistics regarding the movement of people. The system uses Wi-Fi fingerprinting technique with an accuracy of about 1.3 m. The system is designed for iOS and Android, and provides for indoor navigation. Wifarer use individual maps and Wifarer has developed software that will disrupt the Wi-Fi fingerprints that other mapping companies use to determine location, making accurate coordinate readings impossible.

Applications, which use API (Application Programming Interface) of Walkbase [3], have a different core approach in compare with another systems described above. For example, an application "Checked" for Android devices doesn't display client coordinates on the map, but determines if a user is located in a particular location or not with accuracy about 3-5 meters. The application allows adding different content with reference to a particular location which will be displayed on the mobile device screen when a user will be in the location. The approach is used A-GPS approach, which requires at least 10 measurements per location. It is also possible to determine the use location floor. The application uses a machine learning algorithm for adaptation of changing Wi-Fi hotspots signal (their movement). Applications users can add new locations and their descriptions in a common Walkbase database. The Walkbase API can be used by Android OS versions 2.1 and above.

In scope of European project Smartmuseum [4] a recommendation system for visitors of museums has been implemented. This system supports indoor and outdoor excursions with positioning. System provides information on the various kinds of cultural places and other objects. The main features of the architecture of this system are the mechanisms of content creation that can be interest for a user. The mechanism is based on user's search requests in the scope of the system and information of user's profile. Profile is created when a user registers into the system and provides information about his/her interests. Moreover, the system can provide advice to the user and information about places of interest based on user's location defined using GPS if the user location is open area. If the user location is inside the building RFID technology is used for positioning. Each RFID tag stores the URL of the web page with information about the subject of the cultural heritage. The architecture of this system consists of user profiles server, annotation server that contains information about cultural values and issue recommendations server, which processes the user profiles information and their requests. Custom application developed for Windows Mobile 5 and 6 versions, Symbian versions 9.3 and 9.4.

Google Maps [5] application can solve the problems of positioning navigation in open areas and in the indoors. It provides possibility to calculate the route inside the building between several floors, navigate, view photos, and panoramas at 360 degrees. There is also the ability to view a notification about nearby locations and accompanying content. For orientation it is used Wi-Fi and cellular networks with the positioning accuracy

ranges from 5 to 10 meters. Outdoor is used GPS and cellular networks. Google Maps application supports the following popular platforms as iOS, Android, Blackberry, Windows Phone 7, and etc. Google is releasing a self-serve tool for venue owners to upload their floor plans to Google for inclusion in Google Maps.

One of the main competitors of Google is a company Skyhook Wireless [6], which offers SDK to build positioning services (Skyhook Location SDK) and their own positioning system (Skyhook Location Performance, SpotRank). The company works with MapQuest using their maps. To determine user location hybrid algorithms that process signals from the Wi-Fi network, mobile networks and GPS is used. This solution achieves an accuracy of 10 meters. The using of different sources of signals allows provide for the user quick positioning with corresponding accuracy. From a complete cold start, Skyhook determines a user location in 4 seconds. In addition, the system can provide navigation for the user. Skyhook uses a massive network of more than 700 million known Wi-Fi access points and cellular towers. An interesting solution is the application SpotRank that keeps track of the density of people in different buildings, for example, which can provide information on the busiest sites in the area.

The platform developed by Qubulus [7] specializes in solving problems of navigation in indoor and outdoor and uses fingerprinting technology. Recording Tool allows to the users recording network data (Wi-Fi, 2G, 3G) in a particular location and adds it to the total base. These results are compressed into the special FPD file. Further, this information is used for positioning in the format of Geo-coordinates and displays on Google Maps or Bing maps. The company provides the ability for customers to write applications with the cloud API to gather intelligence necessary for effective business and advertising.

Nokia Research Center has developed Indoor Navigator [8] to provide precise indoor location information on a mobile device without needing GPS. This indoor positioning technique based on Nokia high accuracy indoor positioning technology (HAIP). This technique uses Bluetooth 4.0 and Wi-Fi triangulation method and requires to mounting Bluetooth beacons in the each location. The system architecture consists of positioning server, global location database and positioning beacons in a number of locations. The beacons are working in receive and broadcast mode. This approach provides the 0,3 m accuracy. But the system is not released, and Nokia Research Center did not published new reports about this project.

Place Lab [9] project's aim is to determine user location indoor and outdoor. Technically, the system is based on radio beacons, which periodically sent radio signals by Wireless LAN access points, fixed Bluetooth stations, and GSM towers. Accuracy of the presented approach is 13-30 meters.

The Horus [10] is a WLAN Location Determination system, characterized by high accuracy: through a probabilistic location determination technique and low computational requirements: through the use of clustering techniques.

RADAR [11] is a radio-frequency based system for locating and tracking users inside buildings. RADAR is based on empirical signal strength measurements as well as a simple yet effective signal propagation model. Accuracy of the RADAR is 2-3 meters.

In [12], an indoor localization application leveraging the sensing capabilities of the current state of the art smart phones is presented. Application is implemented for the using on smart phones and it integrates offline and online phases of fingerprinting. Accuracy of presented approach is up to 1.5 meters.

TABLE I
COMPARATIVE ANALYSIS OF INDOOR POSITIONING SYSTEMS

Solution	Type	Positioning technology	Declared Accuracy	Architecture	Context information	Navigation functions	3D positioning	Statistic information	Supported Platforms	Using Maps
IWAYtours	IPS	Cell and Wi-Fi fingerprinting	1-5m	Standalone	+	-	+	-	Android	Google Maps
Wifarer in-venue navigation	IPS	Wi-Fi fingerprinting	1,3m	Client-Server	+	+	+	+	iOS, Android	Individual Maps
Walkbase	API	A-GPS	10-50m	Client-Server	+	-	+	-	Android	-
Smartmuseum	IPS	RFID	0.5m	Client-Server	+	-	+	+	Windows Mobile, Symbian	-
Google Maps (indoor module)	IPS	Cell and Wi-Fi triangulation	5-10m	Client-Server	-	+	+	-	iOS, Android, Blackberry	Google Maps
Skyhook Location	API	Cell and Wi-Fi triangulation	10m	SDK	-	-	+	+	Android, Linux, Windows, Mac OS	MapQuest
Qubulus LocLizard	API	Cell and Wi-Fi fingerprinting	1m	SDK	-	-	+	+	Android	Google Maps, Bing Maps
Qubulus Gecko	IPS	Cell and Wi-Fi fingerprinting	3-5m	Standalone	-	-	+	-	Android	Google Maps, Bing Maps
Nokia Indoor Navigator	IPS	Bluetooth 4.0 and Wi-Fi triangulation (HAIP)	0.3-1m	Client-Server	+	+	+	-	Windows Phone 7, Symbian	Navteq Destination Maps
Microsoft RADAR	IPS	Wi-Fi fingerprinting	2-3m	Client-Server	-	-	+	+	?	Bing Maps
Horus	IPS	Wi-Fi fingerprinting with location clustering	2-3m	Client-Server	+	-	+	-	Windows XP, Linux	Individual Maps
Indoor Localization Application (by Eladio Martin et. al.)	IPS	Cell and Wi-Fi fingerprinting	1.5	Standalone	-	-	+	-	Android	Individual Maps
Place Lab	IPS	Cell, Bluetooth, and Wi-Fi centroid, fingerprinting, particle filter	13-30m	Client-Server	+	-	+	-	?	Individual Maps

There are several systems and services which solve the problem of indoor positioning are considered (see Table I, where IPS − Indoor Positioning System). Some considered systems provides API for developers. There are two types of algorithms for indoor positioning: signal propagation model and information about the geometry of the building and location fingerprinting. Fingerprinting approach which is more sophisticated and promises better adaptability those systems that need an extra infrastructure. The accuracy of positioning system which uses fingerprinting technique is higher. The maximum accuracy is 1 m and is provided by Qubulus solutions. Some systems provide context information to the user depending on location (e.g. it can be exhibition description in the museum). Some systems provides navigation indoor functionality to the user, other systems provide only location in the map. Most systems have opportunity to define the floor of user location. Some systems allow collecting the statistical information about users' movement, density and personal information. This feature can be used by organizations to personalized provided services. There are following main platforms by considered indoor positioning system developers: iOS, Android, Blackberry, Linux, Windows, Mac OS, Windows Phone 7, Symbian. The most popular platform is Android. Some systems use external maps (Google maps, Bing Maps, Navteq Maps, and other), but some systems has own maps and provides possibilities for the user create own maps.

III. CONCLUSION

Based on results of this study it can be concluded that the main modern indoor positioning systems has been studied. The companies successfully implement their platforms, mobile applications and API for creation positioning systems. The most popular indoor positioning technology is the Wi-Fi fingerprinting. The accuracy of positioning system which uses this technique is higher than the system which uses other techniques. The maximum accuracy is 1 m and is provided by Qubulus solutions. There are several systems which support of members of contextual information. For example, the information about discounts and special offers for shopping center customers or the information about museum pieces. The most considered systems has "client-server" architecture which allows to make some calculations in server side and use maps provided by several services.

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