Smart Environment for Ubiquitous Indoor Navigation

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***Abstract*—Mobile navigation service is one of the most important Location Based Services. With the rapid advances in enabling technologies for ubiquitous computing, more and more active or passive devices/sensors are augmented in the indoor environment, indoor environment has become smarter. This paper proposes that by introducing the notions of Smart Environment and Ambient Intelligent, a ubiquitous indoor navigation service can be built to provide an adaptive smart wayfinding support and enhance users with a new experience during indoor navigation. In this paper, we set up a smart environment with a positioning module and a wireless module. Based on this smart environment, we design a ubiquitous indoor navigation system with interaction and annotation module (for user generated content), user tracking module (for collaborative filtering) and context-aware adaptation to illustrate some potential benefits of combining indoor navigation and Smart Environment.**

Keywords- smart envrionment; context-aware adaptation; user generated content; collaborative filtering; ubiquitous indoor navigation

I. INTRODUCTION

With the gradual maturating of ubiquitous computing and the rapid advances in mobile devices and wireless communication, Location Based Services (LBS) have gained high interest as one of the potential mobile "killer-applications" in the near future.

Mobile navigation service is one of the most important LBS applications. It aims at providing wayfinding guidance in an unfamiliar environment. One of the successful mobile navigation systems is car navigation which has been widely used and trusted by car drivers. Recently, the increasing ubiquity of personal mobile devices (such as cell phones and PDAs) triggers a move towards mobile pedestrian navigation systems. However, most of the current pedestrian navigation systems are designed to assist outdoor navigation. After arriving at a destination by using outdoor navigation services, a pedestrian usually needs to enter a building (indoor) and requires indoor navigation. Also people tend to lose orientation a lot easier within buildings than outdoor [1, 2]. Indoor navigation systems are designed to meet this need.

Currently, computing has become increasingly mobile and ubiquitous, which implies that mobile services must be capable of recognizing and adapting to the highly dynamic environments while placing fewer demands on user's attention [3]. In order to meet these requirements, mobile indoor navigation services should be context-aware and adapt to the dynamic environment (context). However, most of the current mobile indoor navigation services only employ location as context parameter and provide location-related services/information to users [4]. More work should be done to introduce context-awareness into indoor navigation services. Additionally, most of the mobile indoor navigation systems are limited to provide richer, just-in-time information (navigation instructions) for users [5]. However, a lot of users are not satisfied with simply being passive consumers of information, but rather want to be active contributors. By enabling user generated content, users can share their personal experiences with other navigators, which will fulfill users' intrinsic desire to share their personal experiences (with friends, or even with other tourists they do not really know) and thus provide users with a new experience during indoor navigation.

Also with the rapid advances in enabling technologies for ubiquitous computing, more and more active or passive devices/sensors are augmented in indoor environment, indoor environment has become smarter. This abundance of technologies has given place to the new notions of "Smart Environment (SmE)" and "Ambient Intelligent (AmI)". The basic idea behind SmE and AmI is that "by enriching an environment with technology (sensors, processor, actuators, information terminals, and other devices interconnected through a network), a system can be built such that based on the real-time information gathered and the historical data accumulated, decisions can be taken to benefit the users of that environment" [6]. One of the most popular instantiations of these areas is the concept of smart home.

In this paper, we propose that by introducing the notions of SmE and AmI, a ubiquitous indoor navigation service can be built to provide an adaptive smart wayfinding support and enhance users with a new experience during indoor navigation. To our knowledge, there is little work focusing on that.

This paper is structured as follows. In section II, we augment some devices/sensors to our office and set up a smart environment as a testbed for ubiquitous indoor navigation. Based on this smart environment, we develop a ubiquitous indoor navigation system to illustrate the benefits of combining indoor navigation and Smart Environment in section III. Section IV draws some concluding remarks and presents the future work.

II. SMART ENVIRONMENT

According to Weiser [7], Smart Environment (SmE) is “a physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives and connected through a continuous network”. Based on this understanding, we set up a simple smart environment with a positioning module, which provides adequate positioning information, and a wireless infrastructure module, which interconnects mobile clients (such as cell phones and PDAs) and devices installed in the environment (such as server, sensors, etc.). In this section we will focus on these two modules.

A. *Indoor Positioning*

Most of the outdoor navigation systems employ GPS for positioning. Unfortunately, GPS can only be used outside of buildings because the employed radio signals cannot penetrate solid walls. For positioning in an indoor environment, additional installations (e.g., WiFi or sensor networks) are required.

There exist numerous different positioning techniques that vary greatly in terms of accuracy, costs and used technology. After comparing different positioning techniques, we choose a Bluetooth-based beacon positioning solution, which uses Cell of Original (CoO) as signal metric, proximity as positioning algorithm, and adopts passive position calculation. In our smart environment, we use BlueLon BodyTag BT-002 [8] as Bluetooth beacon because we can adjust the range of BodyTag BT-002 by changing its transmit power. Bluetooth beacons are placed in different places actively broadcasting their unique IDs. Mobile devices passively receive the broadcast message when they are within the range of a beacon. After receiving a beacon ID, mobile devices look up the current position from a mapping table. This mapping table can be cached in the mobile devices or accessed from a server.

After choosing the positioning technique, we have to consider the sensor placement which tries to optimize the placement to balance the signal coverage and development cost. Different applications may have different coverage requirements. For indoor navigation, complete coverage is not necessary. As decision points (decision area, where the navigator must make a wayfinding decision, such as whether to continue along the current route or to change direction) and landmarks are essential for wayfinding [9], we adopt a simple placement solution: beacons are placed at every decision point, and every landmark. For deriving the positions of decision points and landmarks, we use the methods suggested in our previous project NAVIO (Pedestrian Navigation Systems in combined Indoor/Outdoor Environment) [10]. And then, in order to avoid overlapping, we adjust the range for every beacon.

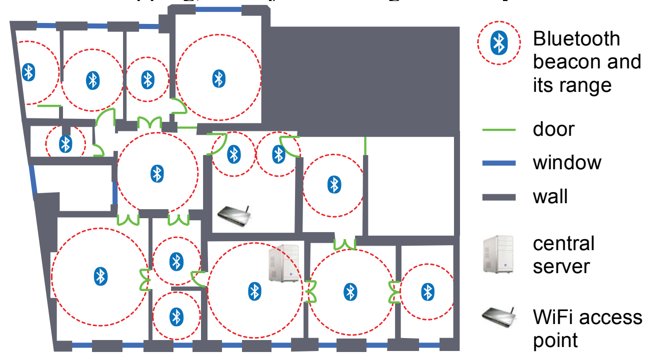

Figure 1. Layout of our smart environment.

B. *Wireless Infrastructure Module*

The wireless infrastructure module interconnects mobile clients and devices installed in the environment. To establish a wireless infrastructure, several technological solutions are possible: IrDA, WiFi, Bluetooth, UWB, ZigBee, etc. They differ in operating frequency, range, data transfer rate, connection type, etc. After carefully analyzing and comparing different technologies, we establish a wireless infrastructure based on WiFi technology because of its highly availability, its high data rate, and its wide coverage range.

We also introduce a center server to the smart environment. The center server is responsible for providing indoor navigation services, gathering and recording real time messages (such as users’ moving track, user generated content, etc).

Fig. 1 depicts the layout of our smart environment. This smart environment is very simple, but it is enough as a testbed for effectively supporting the entire indoor navigation process, including indoor positioning, route selection, and route presentation. For other applications, different other sensors such as temperature sensors and noise sensors may be also integrated into the smart environment to facilitate context gathering.

III. UBIQUITOUS INDOOR NAVIGATION IN A SMART ENVIRONMENT

In this section, we apply the basic idea of Smart Environment and Ambient Intelligent to design a ubiquitous indoor navigation system for the above smart environment. We believe that with the support of a smart environment, we can gather “the real-time information” and accumulate “the historical data”, and then “decisions can be taken to benefit the users of that environment”, such as providing adaptive smart wayfinding support and enhancing users with a new experience during navigation. In order to illustrate these benefits of combining indoor navigation, Smart Environment and Ambient Intelligent, we design some modules based on the smart environment.

A. *Interaction and Annotation*

One of the great advantages of ubiquitous systems is the potentiality to directly interact with the environment. Similar to the notion of Web-as-participation-platform in Web 2.0 [11], our smart environment allows users to do more than just retrieve information (receiving navigation instructions). They are encouraged to add comments, feedbacks, or annotations to the smart environment while they use it.

During navigation in this smart environment, users can annotate their personal preferences, comments or experiences to different landmarks and decision points (areas), e.g., users may annotate a comment to the navigation instructions provided at the current decision point ("The navigation instruction here is really unclear, I can't understand it"). As landmarks and decision points are georeferenced by the Bluetooth beacons, the annotated messages posted by users during navigation can be viewed as User Generated Georeferenced Content [12].

In our smart environment, this message can be text, photo, image, etc. In default case, the message is dedicated for everyone (public) and has a permanent availability. Users can also specify the target and the duration of the message, for example, this message is only showed to Mary, and is only available on April Fools' Day. In order to protect the privacy, users can send the messages anonymously.

When posting their message, users also have to specify the message type. We define several message types for our smart environment: comment, announcement and management. Users submit a comment message to express their feelings, experiences, and feedbacks to a place, or navigation instructions provided at this place, for example, "This place is dirty, I don't like it", "The shop here always has some very nice clothes." or "The navigation instructions provided on my PDA at this place is really poor, I can't understand it". Comment messages are similar to the ratings and reviews in rating systems of Web 2.0 applications. Messages with announcement type are always used for announcing some information to the public or private, for example, "There will be a lecture at this place in the afternoon" and "The store discounted all clothing for the sale" for the public, or "I would like to meet you at 5 pm." for a specific person. Management messages can only be sent by authorized persons, such as staff members of our institute, to manage the smart environment, for example, "this corridor" will be "blocked" on "April 1st" which means that when providing navigation instructions, the system should avoid guiding the navigator crossing that corridor at that time.

These kinds of user generated content benefit the indoor navigation in the following ways:

1) Enhance users with a new navigation experience: During moving in the smart environment, users can not only receive the navigation instructions, but also some other relevant information, such as other users' interesting experiences, comments and feedbacks at the current place, or some announced information ("This store discounted all clothing for the sale") at the current place. They can also make comments to other users' annotations, and make their own annotations to the current place. As users (vistors /tourists) "want to learn more about its history (previous users' experiences) and make an impact on its future (sharing their personal experiences)" [5], this kind of interaction and annotation will enhance users with a new navigation experience, and then improve the performance of navigation in this smart environment.

2) Real time update: With user generated content, the smart environment can constantly be updated by users themselves without any time-consuming and cost-intensive processes. For example, from some real time user generated content, some of the "traffic information" for the smart environment can be automatically obtained (e.g., some of the corridors in the environment are blocked). Based on this real time "traffic information", indoor navigation systems can provide the navigator a traversable route, and successfully guide him to his destination.

3) Qualitative evaluation of the system: By analyzing user generated messages, some important conclusions regarding the navigation system or smart environment can be drawn. For example, if there are a lot of bad or negative messages at some place, navigation instructions provided by the smart environment at that place should be enhanced, for example, by providing more detailed wayfinding guidance at that place, or placing some active landmarks at this place, and thus help users to make wayfinding decisions easier at this place. This can be viewed as a new method for qualitative evaluation of software in software engineering.

B. *User Tracking*

We also design a module to record users' wayfinding behaviors in our smart environment. Before starting navigation, users are asked to provide some personal information such as age, gender, profession, and familiarity with the environment. The system also records users' destinations. This information can be used to classify different users and tasks. During navigating in the smart environment, users' moving tracks are recorded, such as "2009-03-30 15:23:40, placeA", "2009-03-30 15:23:45, placeB".

This module provides the following benefits for indoor navigation:

1) Quantitative evaluation of the system: For every navigation, we calculate some statistical data for the moving track, such as users' moving duration at every decision point, and error points (if the user moves from A to B, and then B to A, A to C, we will consider the navigator made some wrong decision at point A). For all the navigation tracks, if the duration at a specific decision point is too long, or users make wrong decisions, we may consider we have poor navigation support at this decision point. As a result, information services provided by the navigation and smart environment at that place should be enhanced. This can be viewed as a new method for quantitative evaluation of software in software engineering.

2) Smart wayfinding support (collaborative filtering): With more and more navigation carried out in this smart environment, we will have a lot of navigation tracks. Based on these numerous navigation tracks, we may draw some interesting wayfinding patterns by using the notion of collaborative filtering. Collaborative filtering is "the method of making automatic predictions (filtering) about the interests [behaviors] of a user by collecting taste [behaviors] information from many users (collaborating)" [13]. One of the most successful collaborative filtering is Item-based filtering popularized by Amazon.com (users who bought x also bought y).

For every navigation, user' moving track consists of origin, destination and a list of continuous decision points. As a result, we take these origins, destinations and decision points as items. Because we also record users' personal information, we classify users into several groups. After applying the notion of Item-based collaborative filtering, we draw some interesting wayfinding patterns for different user groups, such as

a) Route based pattern: when navigating from place A to place B, user group G always chooses a route with decision points C and D. Next time, when a new visitor with the same profile as group G wants to navigate from A to B, the system recommends a route containing C and D for him.

b) Destination based pattern: after navigating to place A, users also go to place B, or users who go to place A always go to place B.

When applying these two patterns for indoor navigation, the system can provide smart wayfinding support to users.

C. Context-Awareness

Mobile indoor navigation should be context-aware, and adapt to the dynamic changing environment. Before discussing the context-awareness providing by our indoor navigation system, we want to introduce the notion of context used in this paper. We adopt the definition provided by Huang and Gartner [14]: "1) Something is context because it is used for adapting the interaction between the human and the current system. 2) Activity is central to context. 3) Context differs in each occasion of the activity."

Based on the above two modules and the smart environment, our indoor navigation system provide the following context-aware adaptations.

1) Context-aware adaptation for software architecture: We can classify navigation systems into services-side (connecting) and client-side (local caching) solutions according to where the data (spatial data and route instructions) is stored and the calculation (mainly route selection) is executed. These two solutions have different requirements in CPU's processing performance, memory capability, battery consumption, network availability, etc. In fact, it is not suitable to simply assign the calculation and data to the server side or the client side. In order to have an extensible and adaptable system, the decisions on where the calculation is executed and data is stored should depend on the current context, such as mobile devices' processing performance, memory level, power (battery) level, network availability etc.

In our navigation system, we provide a context-aware adaptation for software architecture. Some of the context parameters we used are: mobile devices' processing performance, memory level, power (battery) level, and network availability. Where to execute the calculation and where to store the data are adapted based on these context parameters. We develop an empirical function for determining the distributions of data (spatial data and route instructions) storing and calculation (route selection) executing. This context-aware adaptation will start (by invoking the empirical function) when users enter the smart environment.

2) Context-aware adaptation for the destination selection: At this moment, most of the navigation systems always guide users to a destination, which is always a place. However, users' destination may also be a person. We provide this function in our indoor navigation system. Usually, people don't always stay in one place (for example, at their desks in the office), e.g., they may move to another room for a meeting. Based on the tracking module, we can get the current position of the target person from the smart environment, and guide the user to the target person's current position. If the target person's current position can not be provided by the smart environment (for some privacy reason), the indoor navigation system will guide the user to the usual place (for example office).

3) Context-aware adaptation for route selection: For navigation, there are different kinds of "best" routes: fastest, shortest, least traffic, most scenic, etc. In fact, the "best" route should fit the current context. For this smart environment, we calculate the route according to the current context (such as availability of some corridors) and users' preferences. From the interaction and annotation modules, we may get the real time availability of the smart environment, and calculate the route according to the current "traffic information".

IV. CONCLUSIONS AND FUTURE WORK

Technology available today is rich. With more and more active or passive devices/sensors being augmented, indoor environments have become smarter. This paper focused on introducing the notion of Smart Environment and Ambient Intelligent to mobile indoor navigation services. In this paper, we set up a smart environment with a positioning module and a wireless infrastructure module for ubiquitous indoor navigation. Based on this smart environment, the paper designed a ubiquitous indoor navigation system with interaction and annotation module (for user generated content), user tracking module (for collaborative filtering) and context-aware adaptation to illustrate some potential benefits of combining indoor navigation and smart environment.

From the above discussions, we can draw the conclusion that by introducing the notion of Smart environment and Ambient Intelligent, a smart ubiquitous indoor navigation system can be built such that based on "the real-time information gathered and the historical data accumulated", an adaptive smart wayfinding support combined with new navigation experiences can be provided to users.

1) As users can directly interact and annotate with the smart environment, they can not only passively receive

navigation instructions, but also actively add comments, feedbacks, or annotations to the smart environment while they use it. This will enhance users' navigation experiences, and improve the performance of navigation.

2) By gathering user generated content, the smart environment (for example, the real-time "traffic information" of the environment) can be constantly updated by users themselves without any time-consuming and cost-intensive processes.

3) By monitoring users' wayfinding behaviors, we can use the notion of collaborative filtering to draw some interesting wayfinding patterns, which can be used for providing smart wayfinding guidance, such as Amazon-like recommendation.

4) By analyzing the user generated content and users' behaviors, we can make a quantitative and qualitative evaluation of our navigation system, which will assist the iterative design during the process of system development (software engineering).

5) Some of the context parameters gathered from the smart environment can be used to introduce context-aware adaptation to indoor navigation.

Our next step is to recruit some people to test and evaluate our smart environment. Furthermore, we will also focus on applying the notions of User Generated Content and Collaborative Filtering to design our ubiquitous indoor navigation services.

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REFERENCES

[1] V. Radoczky, "Kartographische Unterstuetzungsmoeglichkeiten zur Routenbeschreibung in Fussgaenger Navigationssystemen im In- und Outdoorbereich," Master Thesis, Vienna University of Technology, 2003.

[2] F. Hohenschuh, "Prototyping eines mobilen Navigationssystems für die Stadt Hamburg," Master Thesis, Hamburg University, 2004.

[3] K. Henricksen, J. Indulska, and A. Rakotonirainy, "Modeling context information in pervasive computing systems,". Proc. International Conference on Pervasive Computing (Pervasive 2002), Springer Lecture Note in Computer Science 2414, Aug. 2002, pp. 167–180, doi: 10.1007/3-540-45866-2_14.

[4] H. Huang, and G. Gartner, "A Survey of Mobile Indoor Navigation Systems," Report of UCPNavi Project, Vienna University of Technology, 2009.

[5] Y. Kang, J. Stasko, K. Luther, A. Ravi, and Y. Xu, "RevisiTour: Enriching the Tourism Experience With User-Generated Content," In Proc. International Conference on Information and Communication Technologies in Tourism 2008, 2008, Springer, pp. 59-69, doi: 10.1007/978-3-211-77280-5_6.

[6] J. Augusto, and H. Aghajan, "Editorial: Inaugural issue. Journal of Ambient Intelligence and Smart Environments," vol. 1(1), pp. 1-4, 2009.

[7] M. Weiser, "The computer for the 21st century," Scientific American, vol. 265(3), pp. 94-104, 1991.

[8] Bluelon, BodyTag BT-002. http://www.bluelon.com/index.php?id=263, Accessed 4.2009.

[9] R.G. Golledge, "Wayfinding behavior: cognitive mapping and other spatial processes," The Johns Hopkins University Press, Maryland, 1999.

[10] B. Brunner-Friedrich, and V. Radoczky, "Active landmarks in indoor environments," In Proc. Visual Information and Information Systems (VISUAL 2005), 2005, Springer Lecture Note in Computer Science 3736, pp. 203-215, doi: 10.1007/11590064_18.

[11] Wikipedia, Web 2.0, http://en.wikipedia.org/wiki/Web_2.0, Accessed 4.2009.

[12] Wikipedia, User-generated content, http://en.wikipedia.org/wiki/User-generated_content, Accessed 4.2009.

[13] Wikipedia, Collaborative filtering, http://en.wikipedia.org/wiki/Collaborative_Filtering, Accessed 4.2009.

[14] H. Huang, and G. Gartner, "Using activity theory to identify relevant context parameters," In Proc. 5th International Symposium on LBS & TeleCartography (LBS 2008), Nov. 2008, Springer Lecture Note in Geoinformation and Cartography, pp. 35-45, doi: 10.1007/978-3-540-87393-8_3.

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