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Design of a Social Collaboration and Precise Localization Services for the Blind and Visually Impaired

Mohammed Elbes[a], Ala Al-Fuqaha[b]
[a]Computer Science Department, Alzaytoonah University of Jordan, P.O.Box 130 Amman 11733 Jordan
[b]Computer Science Department, Western Michigan University, 4601 Campus Drive
Kalamazoo, MI 49008, USA

Abstract

The Blind and Visually Impaired (BVI) encounter various difficulties during their daily activities like path planning, navigation and obstacle avoidance. Many BVI still trust and rely on the white cane to explore their environments. The state-of-the-art white canes have audio systems to guide the BVI through their environment. In this paper, we present a top-down design approach for a social collaboration service especially designed for the BVI. We also present a precise localization approach for indoor and outdoor environments which serves as the underlying foundation for the social collaboration environment.

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1. Introduction and Background

The Blind and Visually Impaired (BVI) usually lack the information needed to bypass obstacles and hazards. They also have little knowledge about the landmarks in their surrounding environment and about appropriate routes that need to be followed from a source to a destination. In this work, we propose a social collaboration service that provides such information to make this important segment of our society more independent.

Research and development efforts that focus on the use of technology to help the BVI started not long time ago. These efforts focused on building tools to avoid obstacles. The regular white cane (which is used by most of the blind) is supplemented with laser and ultra sound to efficiently help the blind avoid

*Ala Al-Fuqaha. Tel.:+1 -269- 276-3868; fax: +1-269-276-3122.
E-mail address: ala@ieee.org.

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obstacles. However, these tools are not enough to help the BVI navigate complex environments without the assistance of others.

In the last two decades, research and development efforts have focused mainly on the navigation component of assistive devices. Location identifiers were affixed on places with known locations to help the blind identify land marks in the environment. Those identifiers are then equipped with sensors and the blind can sense these identifiers using special equipments [1]. The disadvantage of this approach is that individuals have to scan the entire surrounding environment to search for these identifiers.

An example of systems that use location identifiers is the Talking Signs System [2]. In this system, infrared transmitters are spread throughout the environment and continuously send digital speech signals in a range of 15-40 meters depending on their battery power. The receiver held by the user picks up these signals and the user can listen to these voice commands. Transmitter localization can also be achieved using a hand-held receiver for maximum efficiency. The disadvantage of using such systems is their high installation cost and maintenance relative to the limited coverage they provide [1].

A group of researchers at the University of Rome developed a system called Project II [3] to help the blind navigate their environment. The system is comprised of a network of RFID tags, an RFID tag reader and a PDA with a system installed especially for this purpose. The RFID tags are spread all over the test floor to provide the system with all kinds of needed information. The reader is installed in a cane and the antenna is installed in the extremity of the cane close to the ground. The antenna is directly connected to the reader which connects to the PDA using Bluetooth. The reader continuously reads the signals from the tags and transmits them to the PDA which in turn converts them into speech signals that can be heard by the user through the use of headsets. The disadvantage of using such systems is the high cost of installation

Most recent systems like iNAV [4] is based on a compass and consists of many sensors to provide location and orientation. Using a compass to provide a decentralized location service allows iNAV to separate navigation and positioning into two separate problems. Cricket motes by MIT [5] utilize the speed difference between light and sound to compute the distance between a sender called "*Beacon*" and a receiver. In another work, a system called DOLPHIN [6] uses a collection of ultra-sound sensors to determine the absolute location of the user. SWAN [7] determines the location of the user using the signal strength of the radio signals observed at the smart phone. Finally, the Active Bat [8] system uses the reflections of ultrasonic pulses to determine the position and the orientation of the blind person.

All of the aforementioned systems provide position coordinates and/or orientation details needed as a foundation to provide a comprehensive social collaboration environment for the blind. What these systems do not provide is a collaboration environment that enables its users to easily associate and share data with location coordinates and orientations. In this work, we present a complete social collaboration environment for the blind and visually impaired and demonstrate how the user experience can be collected over time and shared among the users; thus, leveraging the power of the crowd to quickly build and mine a database that associates data with location coordinates and orientations.

2. Social Networking for the Blind

A survey [9] conducted by researchers at the University of Birmingham in 2012 targeted a group of blind and visually impaired students at the age of 14 years and up. The goal of the survey was to understand how this segment of students access the Internet and whether they are interested in using known social networking sites or not. Furthermore, the work intended to know why the blind uses social networking sites and whether they use their phones to access these sites and whether accessibility to these sites is easier through cell phones or computers.

Almost all of the participants in the survey access the Internet at home from their own computers and about 69% access the Internet through their mobile phones. About 15% of the participants were unable to register in the social networking website on their own because of their visual impairment. The website that most of the participants were unable to register on was Facebook which is expected because Facebook was the most popular site among all participants. Participants with severe visual impairments were those who face more difficulty during the registration process. Only about fifth of the 70 participants said that the accessibility of the website determines whether or not to register in the website [9].

3. Software Architecture of a Social Network Environment for the Blind and Visually Impaired

In this section we present a software architecture for a social collaboration environment for the blind. This network provides assistance for the blind and visually impaired while they travel from a source Point of Interest (PoI) to a destination location PoI. The social collaboration environment provides route planning services, obstacle avoidance services (i.e. what kind of obstacles available on a specific route and how to navigate around them), route alternatives service and the ability to tag a certain PoI both by audio and text.

3.1 Proposed Social Collaboration Features

The user is given the ability to create PoIs and register them on the collaboration server. The user can tag each PoI by providing textual or audio metadata that provides details about the PoI. The PoI is then registered on the server with its location and orientation information. PoIs can be public or private based on the user preference. This gives the user the ability to tag places in his/her own private environment (home, office, etc.) and will allow the user to navigate between these PoIs. If the user creates and tags a public PoI, then the PoI will be accessible by other users using the collaboration network.

Keyhole Markup Language (KML), a product of Google Earth [10], is used to represent the PoI tags through XML. KML provides the ability to provide meta-data about a certain location using XML. The user can provide a description and exact location information for the PoI. Figure 1 shows an example of a tag created for the Waldo Library at Western Michigan University.

In order to navigate between various PoIs, the user is equipped with our indoor/outdoor localization system that provides precise position and orientation information and continuously sends it to the collaboration server. Our precise localization system allows the user to create PoIs with sub-meter accuracy. As the server receives this information, it provides textual or audio assistance to the user about the assigned route and the PoIs located on the route from the source to destination. Users are able to configure their preferences on whether they like to be provided with audio or tactile instructions to allow them to navigate through the details of the followed route. Furthermore, the system allows the user to interact with other users (using text or audio) within a certain distance to share their experiences.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://www.opengis.net/kml/2.2">
<Document>
<Placemark>
 <name>Waldo Library </name>
 <description> Waldo Library located at West Michigan Avenue in Kalamazoo,
MI. The best way to arrive to this library is to follow Aracadia Rd and head
north-west as this route has minimum number of obstacles and has special road-
way for pedestrians along all the way. </description> <Point>
<coordinates>42°16'56.21"N, 85°36'49.24"W</coordinates></Point>
</Placemark></Document></kml>
```

Fig. 1: An *example of a PoI tag using KML.*

3.2 Social Networking for the Blind

In this section we provide generic software architecture of the proposed social collaboration services. Figure 2 shows the block diagram for the overall system while a detailed discussion is provided in section 3.2.

The system components are hosted on the server which the users will connect with while using the collaboration services. The User Interface (UI) provides the user with the ability to tag locations and pass it to the Rule-Based Expert System (RBES) which is considered the "*Brain*" of the system. The RBES analyzes all the rules that are related to the user's current location and orientation and provides the proper assistance to the user.

All the rules and user accounts are stored in the system's database. The user must be authenticated to the system first before starting to use the collaboration services. Users can connect to the server from any device and uses Google maps augmented with audio/tactile instructions to navigate indoor environments (floor plans augmented with audio/tactile instructions are utilized for indoor environments).

The system also provides some reporting services functionality through the reporting services system. This reporting service provides some statistical reports about all network services (i.e. the number of current online users, the number of visually impaired users logged in the system in the past three months, etc.). The location tagging sub-system interacts with the user through the UI that provides the user with the ability to create public or private location tags in the form of text or audio.

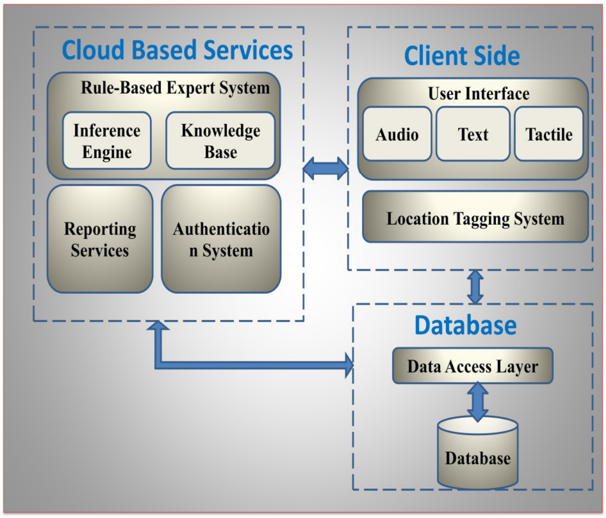

Fig.2: *Block diagram of the proposed system.*

3.3 System Objects

In this section we provide a description of the various system objects and describe their functionality:

The Cloud Based Services Object: This object will host our social collaboration services. All other system objects will be part of this object. Users connect to this object through the Internet and interact with it as they move between PoIs.

- **Point of Interest (PoI) Object:** A PoI can be any place with known location. The user can create a PoI of interest, tag it with textual or audio information and register it on the system. As mentioned earlier, PoIs can have public visibility (i.e. a cafe on a route, restaurant, bookstore, mall, etc) or can have private visibility (i.e. parent's house, desk location in the living room, etc.).
- **User Object**: This object is created once a user gets registered on the collaboration network.
- **Profile Object:** Each user has a profile object that contains the user's preferences and details.
- **Tag Object:** This object contains description about a certain PoI and is created by the user and represented using KML. The Tag can contain textual or audio description about the PoI. For example, if the PoI is for a hotel, the tag can be a textual review about the hotel's customer reviews, etc.
- **Location Object:** This object has 3D location information about a certain PoI.
- **Database Object:** All user profiles, PoI tags, Rules, PoI locations and orientations are stored in the database object
- **Route Object:** The route object contains detailed directions from a source PoI to a destination PoI. It also has information about the route details including its associated obstacles and PoIs.
- **Rule-Based Expert System:** This system analyzes the users' tags and PoIs and provides consultation and advice for the user. This system interacts with audio analysis system which analyzes the user audio input and extracts rules from the input. The user interacts with the Rule-Based expert system through an interface especially designed for this purpose. The user

experience is stored in the knowledge object in the form of a set of rules. Sample rules can be of the form:

- "*Avoid routes having obstacles when navigating from point A to point B"*.
- *"Go from Point A to Point B and Pass by a pizzeria"*.
- *"Go to a hotel in downtown Chicago that has a* review *score of 4 out of five or more"*.
- *Go to a coffee shop in downtown Kalamazoo that has at least 50 reviews about it"*.
- *"Follow the route with least traffic from point A to point B"*.
- *"Only use routes where traffic lights have a speech system installed on*".

4. Our Precise Localization System

The fast growing manufacturing of mobile devices instrumented with positioning technologies stimulated the development of Location Based services (LBS) [11]. These services provide users with their geographical location as they navigate through their environment. Many technologies are already available to develop these services like Wi-Fi [12], Angle-of-Arrival (AoA) based systems [13] and Ultra Wide Band (UWB) [14]. In our work we utilize low cost MEMS sensors along with Time Difference of Arrival (TDoA) based sensors to perform Pedestrian Dead Reckoning (PDR).

In earlier research, we presented a novel approach for performing data fusion between multiple sensor technologies including accelerometers, gyroscopes, Wi-Fi, AM radio signals of opportunity and TDoA sensors to achieve precise localization in indoor and outdoor environments. In this paper, we present an overview of our approach to perform indoor/outdoor localization listing some of the results obtained in our localization research. The details and technicalities of our localization approach is the subject of earlier research. The proposed Inertial Navigation System (INS) [15] is comprised of tri-axial accelerometer, gyroscope and an MIT Cricket system [5] for gyroscope drift correction. This INS system provides the distance that the moving object travelled and the direction of that distance. Figure 3 shows the installation of our INS system on the feet of the user.

Our indoor localization approach utilizes the Received Signal Strength Indicator (RSSI) measurements collected from known locations called *"Location Fingerprints*" to perform precise indoor localization.

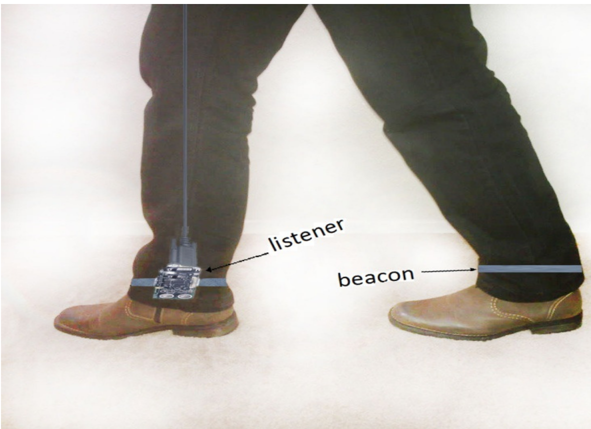

Fig. 3: *Installation of Cricket beacon and listener in support of PDR*

These location fingerprints are stored into a database. Online RSSI measurements obtained from the moving object are compared with the location fingerprints in the database to obtain user location. We devised a budgeted dynamic exclusion heuristic to exclude RSSI measurements from noisy access points. Further location accuracy was obtained by fusing the online RSSI measurements with the data from our INS using the Particle Filter for data fusion.

The particle filter's dynamics are controlled by the RSSI location fingerprints and the distance and orientation measurements obtained from our INS system. If the tracked object's position was estimated at time *k*, the INS guides the generation of particles at time *K+1*. For each particle $\boldsymbol{X_i}(k) = [x_i(k), y_i(k)]$, the next particle $\boldsymbol{X_i}(k+1)$ is obtained by:

$$x_i(k+1) = x_i(k) + d \cos(\Theta) + N(\mu, \sigma) \tag{1}$$

$$y_i(k+1) = y_i(k) + d \sin(\Theta) + N(\mu, \sigma) \tag{2}$$

Where d is the absolute distance traveled by the tracked object during the time interval $[k, k+1]$ and Θ is the direction of d. $N(\mu, \sigma)$ is a normally distributed noise with μ-mean and σ-standard deviation.

The weight of each particle $\boldsymbol{X_i}(k)$ depends on the RSSI distance between the closest location fingerprint to $\boldsymbol{X_i}(k)$ and the RSSI vector on the tracked object. The smaller this distance, the higher weight $\boldsymbol{X_i}(k)$ will have.

$$D^T_{FP_{closest}} = \sqrt{\sum_{j=1}^{M} \left(RSSI_j^{FP_{closest}} - RSSI_j^T\right)^2} \tag{3}$$

Where $D^T_{FP_{closest}}$ is the closest location fingerprint to particle $\boldsymbol{X_i}(k)$ and M is the number of access points. The weight of $\boldsymbol{X_i}(k)$ is then given by:

$$w_i(k) = \frac{1}{D^T_{FP_{closest}}} \tag{4}$$

Figure 4 illustrates our indoor localization approach using PF for data fusion. Our earlier research on outdoor localization utilizes the phase shifts between AM radio signals to obtain the distances between nearby locally deployed Low Power AM radio base stations and the Software Defined Radio receiver installed on the moving object. Given the location of only one AM base station, we use Particle Swarm Optimization (PSO) to estimate the location of the moving object.

Our proposed AM radio based localization system operates using locally deployed Low Power AM Radio (LPAM) transceivers as permitted by the FCC. The proposed system operates in a frequency band around 1MHz. This band is chosen to minimize the multipath delay spread effects that are encountered in the 2.4 GHz ISM band (e.g., Wi-Fi, Bluetooth, etc.).

In the basic approach, we use phase shifts from radio signals obtained from all nearby AM radio base stations regardless of whether these signals are noisy or not (EUC approach). Our Budgeted Dynamic Exclusion (BDE) heuristic excludes the signal phase shifts obtained from noisy AM radio signals. After identifying the noisy AM radio signals using BDE, we use Particle Filter (PF) to fuse signal phase shifts with data obtained from our INS obtaining high location accuracy of less than one meter. Particles are generated by the same way in equations (1, 2), however, the particle's weight depends on the differences between the phase shifts observed at the tracked object location and at the particle's location according to the equation:

$$w_i(k) = \frac{1}{\sum_{l=1}^{N-1}\sum_{j=l+1}^{N} |R_{\theta_{BS_j}}^{BS_l} - P_{\theta_{BS_j}}^{BS_l}|}, \quad \forall\ l < j \tag{5}$$

Where $R_{\theta_{BS_j}}^{BS_l}$ is the received phase shift between signals from BSl and BSj on the receiver R and $P_{\theta_{BS_j}}^{BS_l}$ is the observed phase shift between signals from BSl and BSj for the particle $X_i(k)$.

In this paper, we present results obtained for both indoor and outdoor localization approaches. The details of these approaches are outside the scope of this paper. Figure 5 shows the location accuracy obtained in our indoor localization approach compared to the classic probabilistic methods (EUC) using RSSI measurements for localization. The figure also shows the location accuracy enhancement achieved using our BDE heuristic. Further location accuracy obtained using our data fusion technique between RSSI measurements and INS data using the Particle Filter (PF).

Figure 6 shows the results for our outdoor localization approach. The figure shows how our data fusion using PF outperforms the classic EUC method that utilizes phase shifts between signals obtained from all nearby AM radio towers.

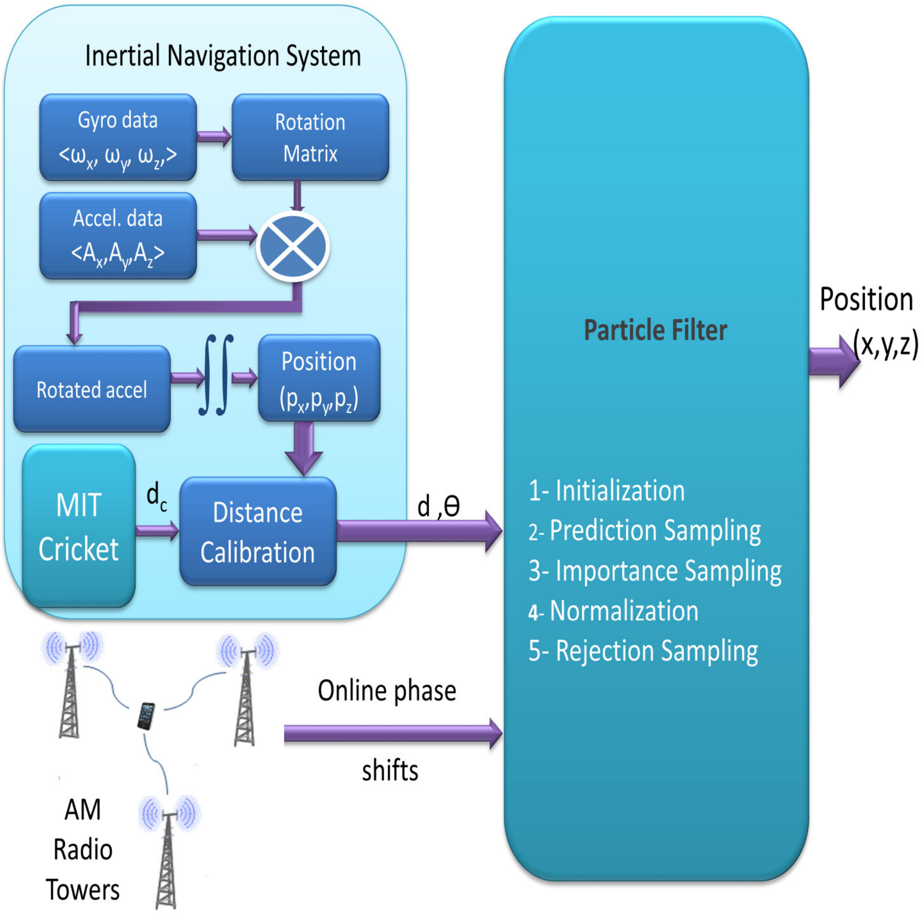

Fig. 4: *The overall localization system architecture*

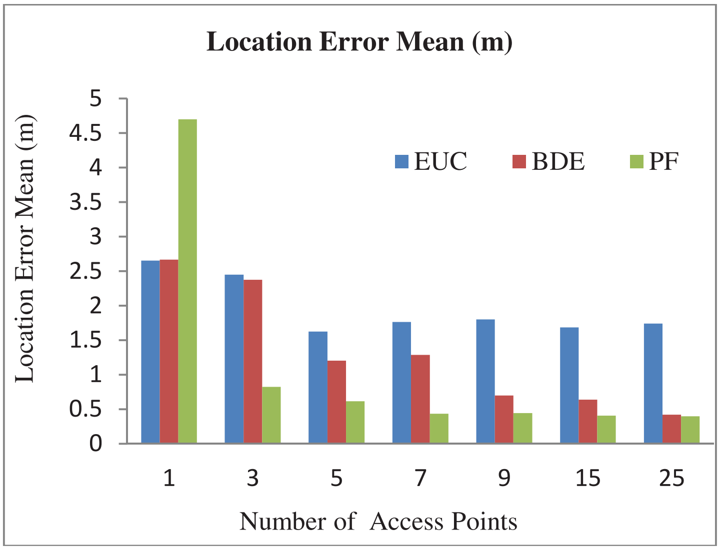

Fig. 5: *Our indoor localization approach performance*

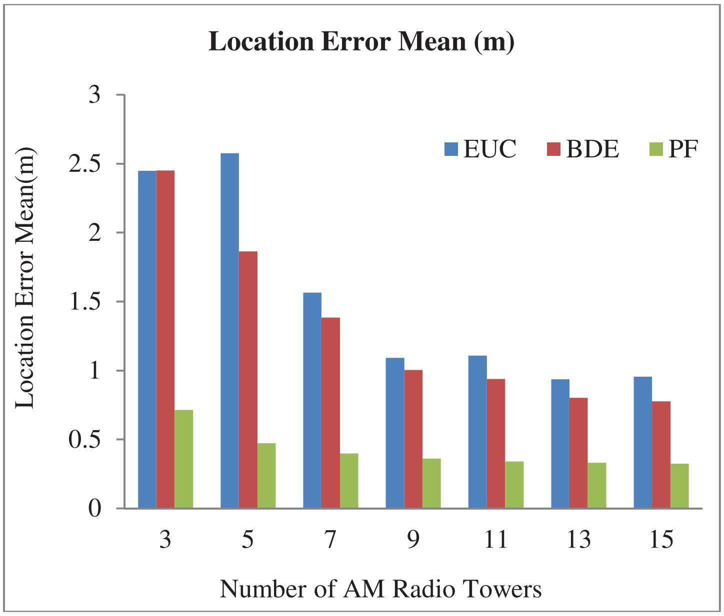

Fig. 6: *Our outdoor localization approach performance*

5. Conclusion

In this paper, we presented a software architecture for social collaboration services especially designed for the blind and visually impaired. Our proposed social collaboration services are different from other generic social services offered by providers like Facebook and Twitter in the sense that it is especially designed and developed from the ground up to enable the blind and visually impaired to exploit the benefits of data sharing.

We also presented our indoor-outdoor precise localization approach that provides a solid foundation for the proposed social collaboration services. The users are equipped with this precise localization system to provide the server with their precise coordinates and orientation. Based on this information, the server provides the necessary assistance to the user as they navigate through indoor or outdoor environments.

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