# Indoor Map Learning for the Visually Impaired

Hao Tang, Tayo Amuneke, Juan Lantigua, Huang Zou, William Seiple, Zhigang Zhu

Department of Computer Information Systems, CUNY

Borough of Manhattan Community College

The Graduate Center, CUNY

Department of Computer Science, CUNY City College

Lighthouse Guild

htang@bmcc.cuny.edu, tayo.amuneke@gmail.com, juanlantiguajr@gmail.com, zouh520sdo@gmail.com, wseiple@lighthouseguild.org, zhu@cs.ccny.cuny.edu

## Abstract

Trip planning is useful for every traveler, especially for visually impaired people because they can learn maps and routes prior to their upcoming journey. Research on trip planning for the visually impaired has been more attention in the past decade. However, past methods have some limitations: (a) the methods usually made use of special visualization interfaces that are costly; (b) the methods mainly focused on outdoor navigation due to existing online map and GIS databases. Although this approach could be extended to indoor navigation, it would need substantial additional effort to generate indoor maps. Therefore, the above limitations make trip planning unfeasible to most of visually impaired people. In this paper, we propose a novel trip planning framework by applying gamification concept, which particularly deals with indoor scenarios. First indoor accessible maps are automatically generated, and then, a mobile app will be designed and implemented for the visually impaired. This will allow users to learn building layouts and routes prior to their travel. The proposed trip planning method can be easily adapted to other indoor scenes, and it will encourage the visually impaired users to travel easily and independently.

## Keywords

Assistive Technology, Accessible Map, Trip Planning, Visually Impaired, Gamification, Map Learning, Cognitive Map

**Introduction**

Traveling in unknown environments presents significant challenges for visually impaired people (VIP). Though a lot of efforts have been made to develop navigation systems and algorithms for VIP, many of them need additional infrastructures (Ganz et al. 33-44, Dias 1-20, Paisios 2012, Ahmetovic et al. 1). Hence, they are not easy to scale up. Methods using computer vision with mobile devices (Manduchi 9-12, Hu et al. 600-614) do not need infrastructure changes, but they are error-prone, especially in indoor environments. Therefore, they are unreliable for VIP to use for localization. As an alternative or supplementary solution, a trip planning approach allows VIP to learn spatial environments and plan route priors to their upcoming journey.

Research on trip planning for the visually impaired has been more attention in the past decade (Zeng and Weber. 54-60, 466–473 Kumar 1, Ivanchev 81-88, Meneghetti 165-178 and Poppinga 545-550). However, past methods have some limitations: (a) the methods usually made use of special visualization interfaces that are costly; (b) the methods mainly focused on outdoor navigation due to existing online map and GIS databases. Although this approach could be extended to indoor navigation, it would need substantial additional effort to generate indoor maps. Therefore, the above limitations make trip planning unfeasible to most of VIP.

In this paper, we propose a novel trip planning framework, particularly dealing with indoor scenes. Figure 1 shows the system work flow. First an indoor accessible map is automatically generated using AutoCAD architectural floor plan, and then a mobile app is designed and implemented for the visually impaired to learn maps and plan trip prior to their travels. VIP user can play the app, and learning progress can be evaluated and reported automatically. The app allows a VIP to play as many times as need to feel familiar with the building layout and build a cognitive map. The proposed trip planning method is easy to be applied to other indoor scenes and encourages the visually impaired to travel independently.

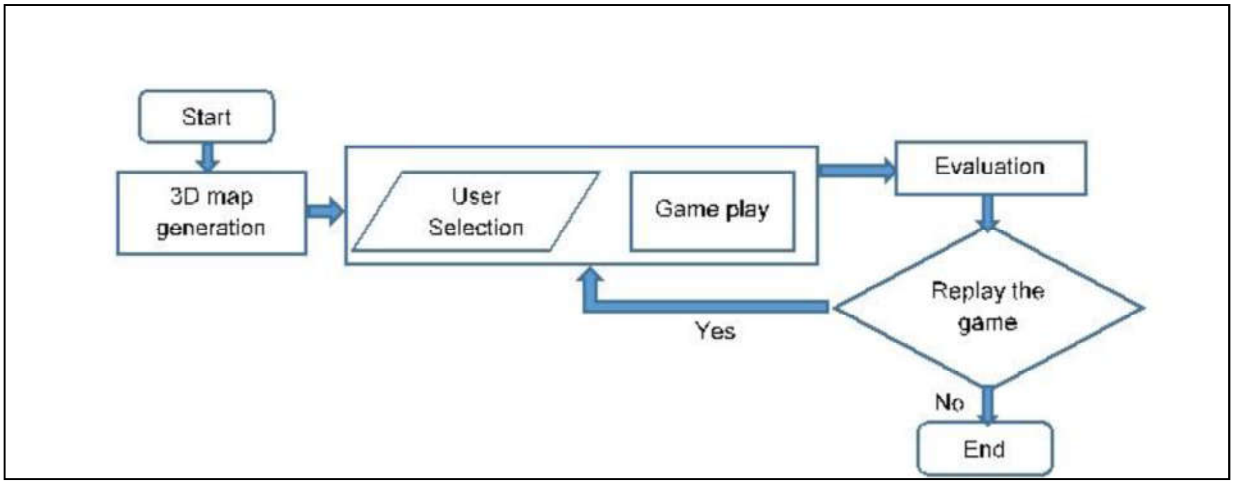


Fig. 1. Flow Chart of the Mobile App

**Discussion**

*Related Work*

Many efforts have been made to develop navigation algorithms and systems for VIP, however, most of them are GPS-based accessible navigation systems that aim at outdoor scenes, Example of such accessible systems are Ariadne GPS (Ariadne), BlindSquare (BlindSquare) and Sendero Seeing Eye GPS (Sendero). However, none of the aforementioned systems works in indoors due to the lack reliable and available GPS signals. However, research shows that on average people spend around 87% of their time in indoor environments (Klepeis et al. 231–252), and indoor spatial knowledge acquisition could play a very important role to improve the quality of daily life of VIP. In the last decade, researchers have been working on Wi-Fi or Bluetooth-based localization and navigation approaches, and a few public facilities have tested such approaches (e.g. SFO airport and The American Museum of Natural History). Most of the approaches, however, usually provide rough localization of users and cannot navigate them to their destinations. Ahmetovic (Ahmetovic et al. 1) proposed a method which navigates the visually impaired in a campus building, but it requires large-scale infrastructure changes and tedious sensor installations and calibrations procedures, thus making such kinds of requirements very costly and not easy to scale up.

VIP typically plan their routes prior to their journey, especially when they have to travel to an unfamiliar environment. As a result of the lack of reliable and accurate indoor navigation systems, any advances in safe and easy indoor trip planning could have significant impact on the quality of life for VIP. Many approaches (ClickAndGo and Das 1-20, Sánchez et al. 365-371 and Sanchez et al. 970-981, Ganz et al. 33-44) offering trip planning features provide narrative maps, which are verbal or text-based descriptions of the navigation instructions between two locations. However, trip planning feature only offers a step-by-step guidance between two pre-defined locations, and does not help the visually impaired to build a complete cognitive map. They will not work if temporary changes of building layout (renovation) or a special event cause a detour. Cognitive maps are part of our daily lives, as they are the basis for all spatial behavior (Downs and Stea 8–26). They contain knowledge about landmarks, route connections, distance and directions (Montello 14771–14775). Without the cognitive map, it's very difficult for VIP to travel independently, especially when they get lost from the route they planned in advance or need a detour. This need for a layout learning was emphasized in interviews we conducted with VIP. Therefore, building a cognitive map is important to enhance the safety and independence of VIP navigating unfamiliar indoor environments.

Although building a cognitive map for the visually impaired is important, it's not easy. (Brock 1-361) gave an excellent review of building spatial cognition for VIP. Some approaches build interactive maps (Zeng and Weber 54-60, 466–473, Kaklanis et al. 59-67, Brock et al. 117-129), and VIP can explore these maps to build up their cognitive maps. This requires special visualization interfaces and costly devices are usually needed. In addition, most of the systems focus on outdoor maps and are not easy to translate to indoor maps due to the lack of accessible maps for indoor environments.

In this paper, we proposed a map-learning approach that allows the visually impaired to learn indoor maps, by playing a simple mobile game. The game guides the users navigate between two locations in an indoor environment. Unlike other existing trip planning methods, our system not only provides VIP a narrative map that users can virtually travel in the unknown facility with turn-by-turn navigation guidance, but it also allows the users to build up their cognitive maps (including landmarks, route connections and distance and directions).

*System Design and Implementation*

The paper seeks to provide an easy map-learning framework through gamification concept (Werbach 1). The approach consists of three major modules, 3D map generation, a trip planning game and assessment. When the game starts, a VIP user is prompted to choose a facility and his/her starting and ending positions in the facility. He/she then follows step by step guidance in the game play section until reach the destination. The user is then evaluated in each round, and he/she can replay the game until becomes confident enough to start the actual journey (Figure 1).

**3D Map Generation**

In this module, an architecture floor plan map, which is available in most building built within the last three decades, is used to construct a 3D map. Algorithms developed in our previous work (Tang et al. 176-191) automatically process an architecture map and produce a 3D accessible map, in which rooms, corridors, landmarks, doors, exits, elevators and stairs are labelled (Figure 2a). This map is then transcoded into the game with all the physics and collision features. The virtual avatar through these features can localize itself in the game. The maps that have more than one floor are connected through stairs, escalators and elevators.

Fig. 2a. The Generated 3D Accessible Map of a Facility with Three Floors.

Fig. 2b. An optimal path in blue is calculated using a pathfinding algorithm. The path is connected by a few waypoints (best viewed in the electrical version).

**Map Learning and Trip Planning**


Fig. 3. Interface of Our Mobile App: (a) three campus buildings are listed in the map selection; (b) Room numbers of one building are listed; (c) a configuration and setting page; (d) the third person perspective is displayed

The game is designed for VIP to learn indoor maps and plan trips. In this module, we import the 3D accessible map generated in the previous module to create 3D game environment. The 3D map is geo-referenced and all the rooms, including exits, staircases and other landmarks in the map have known 3D locations. The current game design focuses on training, which allows users to plan their journey, for example, the user plans to transfer from E train station to R train station at 34 street, or from the entrance of a campus building to the room 8/210. The optimal route is generated using a pathfinding algorithm (ref). The user then starts his/her virtual journey, with location-specific guidance provided by the game, based on the optimal route. The user applies various finger gestures (up, down, left and right) on the mobile device to move the avatar in the virtual environment. The game can also correct user whenever he/she does not exactly follow the guidance and is off from the optimal route.

## User Interface of the App

### *General User Interface*

The app user interface (UI) is able to work with the accessibility feature of the Android (TalkBack). The UI also display images in high contrast for those VIP users with some sight while have contrast sensitivity losses. Figure 3 shows some UI design, including a map selection page, a room selection page and a configuration and setting page. In the map selection page, all facilities available in the app are listed, and currently there are three campus building available. Once a facility is selected, the app proceeds to the room selection page, which allows users to select a specific room, users need to select a starting room and destination room before the training game actually launches.

*Configuration and Setting Page*

VIP often perceive information based on measurement they can easily interpret, hence we prepared a configuration and setting page. This page will allow them to choose what type of distance and movement representation they preferred, including feet, meters or steps. The amount of audio feedback is also controllable, since in interviews some VIP wanted more information while others wanted less.

The game-play mode has an audible music background that is turned on by default. The music was included to signify that the game play is still active, but it proved to be distracting to some VIP users, and a function to disable it was provided in the game.

a) Menu color option: The display module shown above is the default look of the application. The color selection is white text on black background because of the stated contrast preference of our group of initial VIP users. The color can also be inverted for users with different contrast polarity preferences. The color choice selection can be made in this module depending on the preference of the user.
b) Distance option: Observations from preferences discovered during experiments led to the design a distance module. We observed that users preferred the distance information feedback in a certain unit. To address this issue, we created a way to change the distance settings under the settings UI module. Feedback on distance is provided in terms of meters, feet or steps.
c) Level of feedback option: This option allows users to choose the level of details provided by audio feedback in the training.

*Game-Play Mode*

There was a small change of view for one of our gameplay features; camera view to be exact. Switch from a bird's eye camera view to a third person perspective seemed to be more intuitive when giving instructions to the user. Previously implemented instructions gave the user directions from the perspective of the camera view (top down view), such as "Go Down" and "Go Up", which were not very user friendly. The third person camera view had a more egocentric perspective for more intuitive directional instructions like "Go forward", "Turn left", etc. Partially sighted VIP users benefit from this change of perspective (Figure 3d).

*Implementation*

The mobile app is implemented by integrating Unity 3D game development engine and Android Studio. The user Interface is implemented in Android Studio because of its provision of accessibility features. The game development is implemented in Unity 3D game development engine and therefore, requires an integration of both platforms. The rationale behind this is because of the TalkBack accessibility feature is not available on Unity 3D. Once the game part is completed, we export the project from the Unity platform and import it to Android Studio and complete the user interface design.

*Assessment*

The map learning is a self-learning process, so it is very important to include a self-assessment module. The game collects the statistics of game playing, including the time spent, the number of wrong turns and collisions that the user made during trip planning between two locations. The performance statistics allow the users to know how well they learned the map, and their learning progress. They can play many times to enhance their learning. They can select different sources and destinations, in order to construct a complete cognitive map of a facility.

In order to evaluate the effectiveness of the trip planning app, we conducted preliminary evaluations. The first prototype was tested with five blind users, who were all smartphone users. Two were totally blind, and three had low-vision. We asked them to complete a pre-test survey and a post-test survey.

In the pre-test survey, we ask general questions about their experiences using mobile app and independent travels, such as: Do you navigate alone indoors? Do you have trouble navigating alone? Do you use any app to get around/navigate or map learning? If so, how do you like the app? What places/facilities do you think should have an indoor accessible map made first? The survey results reveal they all have trouble navigating indoors. One participant used Google map before, but none of them used any indoor navigation app or map learning software. Their suggestions included making accessible maps for colleges, hospitals, government buildings, and public transportations.


Fig. 4. The interface of mobile app in previous version, (a) A floor selection interface with floor plans listed in a facility; (b) A room selection interface where user can move up and down to select rooms as starting or ending positions of the trip; (c) The game play interface.

In the post-test survey, we ask more specific questions about the experience of using our mobile app, including the interface design, the app features that they like or dislike, and any new features they suggest. Here are some of the feedback. (1) They preferred the portrait mode on the mobile device and a conventional app interface with accessible feature. Figure 4 shows the interface design of the previous version that we showed to the users, which is a in landscape mode, with some special design of map and room selection; (2) Some suggested a summary of the route before the game starts; some preferred more details – such as information of surrounding landmarks (rooms, exits, elevators, restrooms, water fountains, etc.); (3) Most of the users liked the idea of learning map from game play and want to see it further developed.

We then modified the app design and implementation based on their feedbacks. We changed the display mode to portrait, and change the interface to a conventional interface with Talkback features, and added a summary before the training starts. In addition, we also added a configuration and setting mode (Figure 3.c) which allowed users to select their preferred setting, please refer to the section C for more detailed descriptions (User Interface of the App).

## Conclusion

In this paper, we designed and implemented a mobile app for VIP to learn indoor map layout by planning trips. Trip planning will help them venture out into unfamiliar indoor environments easily. The app allows VIP users to practice trip planning as many times as need to feel familiar with the facility layout – building up a cognitive map. Such a learning process may be tedious, hence we apply the gamification concept in the app design to make the map learning easy and engaging. In the future, we will improve the user interface and enhance the game play experience to make the learning easier and more engaging. Our ultimate goal is to allow VIP users to easily plan and independent take trips, ultimately improving their quality of life.

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