Towards accessible and inclusive navigation and wayfinding

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ABSTRACT

This paper presents a brief overview of the various (related) research the author has been involved with in the area of navigation and wayfinding for people with visual impairments. The first major piece of research presented is that of the building and deployment of a beacon-based indoor navigation and wayfinding system called GuideBeacon for people with visual impairments. The second major piece of research presented is a broader community-based effort called CityGuide to enable various location-based services (including navigation and wayfinding) in both indoor and outdoor environments for people with disabilities. The paper concludes by summarizing a specific challenge in the area that warrant future research attention.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility systems and tools**.

KEYWORDS

wayfinding; navigation; blind; visually impaired; beacons; computer vision

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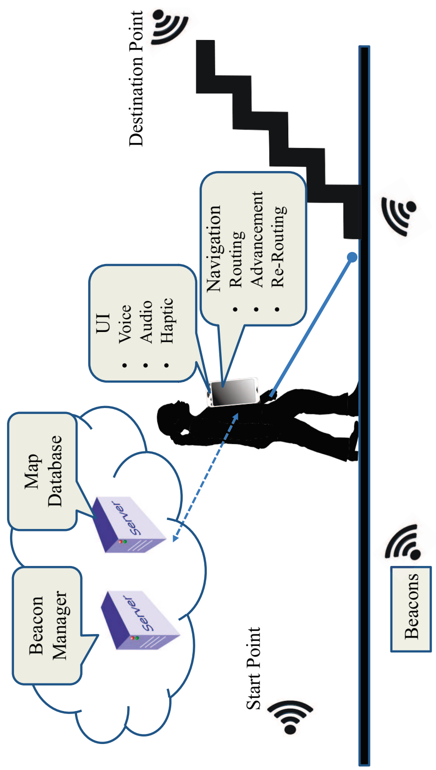

Figure 1: A system diagram depicting the GuideBeacon system and its components.

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AUTHOR'S RESEARCH PLANS ON ACCESSIBLE NAVIGATION AND WAYFINDING

This section provides an overview of the author's past and ongoing research in navigation and wayfinding for people with visual impairments. These are categorized as (i) a core accessible indoor navigation and wayfinding system called GuideBeacon, and (ii) a broader, community-wide effort to be inclusive to people with all disabilities called CityGuide that expands the focus of navigation and wayfinding to include many location-based services in both indoor and outdoor spaces.

Indoor Navigation and Wayfinding for People with Visual Impairments

There are currently few options for navigational aids in large indoor spaces for individuals who are blind or visually impaired (BVI). Such indoor spaces can be difficult to navigate even for the general sighted population if they are disoriented due to unfamiliarity or other reasons. Work done in this direction by the author has the objective of building and deploying indoor wayfinding systems for BVI individuals that assists them in navigating between any two points within indoor environments. There are two main directions of ongoing research the author is interested in related to the topic of indoor navigation and wayfinding for people with vision impairments. The first direction is perfecting the design of indoor navigation and wayfinding systems, minimizing false or missed point of interests (POI) and improving the timing and delivery of information. The second direction is that of preparing the infrastructure needed (such as indoor maps, beacon placement) employing computer vision and machine learning techniques through software tools.

GuideBeacon: Indoor Navigation System. The GuideBeacon indoor navigation system consists of a smartphone app that interacts with Bluetooth Low-Energy (BLE) beacons strategically placed to provide location context to indoor environments [9]. The system allows for users to navigate from one point to another specified point like a GPS-based navigation system with turn-by-turn instructions provided to guide the user along a path. In addition to BLE beacons, the system utilizes a combination of compass and step counter information, beacon proximity and filtering algorithms. Quantitative evaluations show that GuideBeacon can cut the time required for a BVI individual to navigate unfamiliar indoor spaces by 30-50% and cut the associated distance walked by more than 50% in most cases. Qualitative evaluations show a general satisfaction with the UI design and navigation functions while providing valuable feedback for future improvement. There exists some recent related work in the area of indoor accessible wayfinding systems [1, 2, 4–6, 11]. The major difference between these and GuideBeacon is that the latter is a pure BLE approach utilizing proximity detection at all POIs for better accuracy, and does not attempt to localize at areas away from POIs. GuideBeacon system aims to achieve the greater precision and sophistication required for turn-by-turn navigation through optimal beacon placement and configuration, mutual interference resolution between beacons, accurate proximity detection, and fine-grained user movement tracking. A fully functional implementation of GuideBeacon now exists at the Envision Research Institute in Wichita, KS for use by visitors.

IBeaconMap: Automated Indoor Space Representation for Beacon-Based Wayfinding. One major challenge facing beacon-based indoor wayfinding is that of creating fast and accurate representations of indoor spaces that can be used for beacon-placement and subsequent navigation computations. Manual determination of beacon placement locations and path computations is time-consuming and labor-expensive, especially for large indoor spaces. Such an approach requires the manual identification of walking paths on a floor plan, marking of points of interest, determining the distance between any two POIs, determining the orientation between them for navigation, computing shortest paths between points of interests, and subsequent adjustments to optimize the resulting paths that may require further iterations of the entire process.

The author has contributed to designing a software tool called IBeaconMap to largely automate this process [8]. IBeaconMap employs indoor space representation techniques using a combination of image processing, machine learning, and computational geometric techniques to automate the process of extracting the necessary information from an indoor space for subsequent beacon placement and path computations for navigation. These techniques should only need as input an architectural floor plan of the indoor space of interest be able to provide a connectivity graph representation of the space upon which path computations for navigation could be performed. None of the previous work on indoor space representations focused on providing outputs catering to the special needs for beacon-based wayfinding (e.g., [7, 12–16]). The web-based mapping tool developed as part of NavCog [5], the only other tool with a similar objective as IBeaconMap, requires a user to mark all beacon locations and walking paths first on a floor plan image. This higher-level of manual involvement is expected to not scale well thus rendering the tool not as desirable in many situations. The recent work on using crowdsourcing to deploy beacons in [10] assumes that beacon locations are already known; thus, IBeaconMap can serve as a useful first tool to create markings where beacons can then be placed in a crowdsourced fashion.

Figure 2: Extracted indoor path using IBeaconMap on a floor plan provided as input.

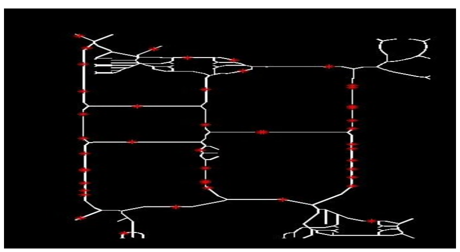

Figure 3: Skeleton output from IBeaconMap.

Figure 4: Final connectivity graph constructed by IBeaconMap.

CityGuide: Community-Wide Inclusive Wayfinding and Related Location-Based Services

How can technology make cities more accessible to people with special needs? Wayfinding remains a challenge for people with disabilities in our communities. In addition to the challenges noted earlier about wayfinding in indoor spaces, there remain many outdoor areas such as sidewalks

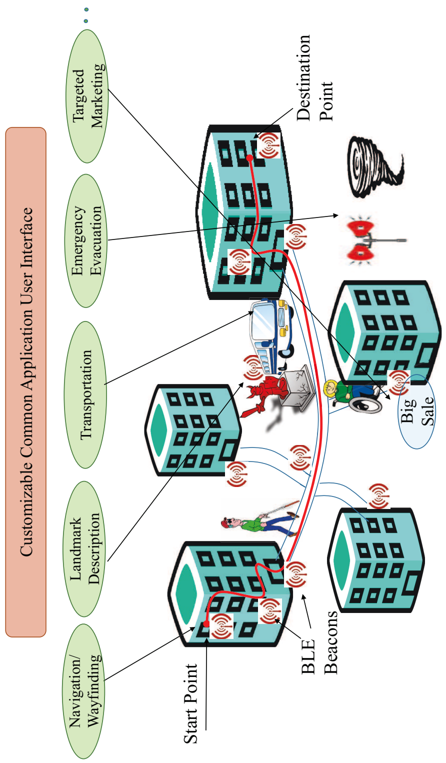

Figure 5: The CityGuide concept. Various location-based services/applications can be enabled utilizing a technology infrastructure that enables accessible navigation and wayfinding within and across indoor and outdoor spaces.

within and around office buildings, public recreational areas, and university campuses, for which the effectiveness of GPS is limited or non-existent. This puts people with vision impairments at a big disadvantage in accessing such spaces. Similarly, for those with mobility impairments requiring the use of wheelchairs, the determination of accessible pathways to a destination remains inefficient. For example, upon entering indoor spaces, wheelchair-accessible paths are not always marked. Moreover, outdoor sidewalks do not typically indicate the absence of curbs and wheelchair accessibility. Similar challenges exist for people with cognitive impairments. Thus, there still remains a great need to provide a low-cost, easy to use, and reliable *auxiliary* wayfinding system within indoor and outdoor spaces complementing GPS-based systems. A solution to the wayfinding problem for people with disabilities in our communities also has broad applications for the general population in unfamiliar, disorienting spaces.

The long-term goal of work in this direction is to design, deploy, evaluate, and refine a wayfinding system in communities called CityGuide [3] that (i) supplements outdoor GPS systems (in an integrated smartphone app) to provide fine-grained, customized, turn-by-turn navigation within or across indoor and outdoor spaces for those with visual or physical impairments, older adults, and the general population, (ii) complements existing signage city-wide to improve the safety of the citizens and provide customized information about landmarks, transit stops, and other features of interest in the community. This infrastructure will further enable vital emergency notification and evacuation alert systems to all citizens and visitors to the city. Underlying positioning technologies (complementing GPS) used towards building such auxiliary wayfinding systems will eventually leverage a combination of: wireless information emitters such as Bluetooth BLE beacons and/or Wi-Fi, AI-based systems, and wide-area wireless networks such as 5G.

ONE CHALLENGE OF INTEREST

Given the author's background work on accessible navigation and wayfinding, one challenge of interest to him is the following: "Given that there may be a multitude of technology options to design and deploy accessible navigation and wayfinding systems, how does one arrive at an optimal mix for a specific environment?". For example, BLE beacons can be utilized in some scenarios where creating and maintaining such an infrastructure is feasible. In other scenarios, utilization of computer-vision based techniques may be more feasible, even if accuracies may be lower, due to reduced infrastructure costs. Other technology options such as Wi-Fi, 5G, GPS, etc. also come into the mix. This requires the creation of a framework in the future that considers the following factors to arrive at a recommendation: (i) various characteristics of the deployment environment (such as dimensions of the space, materials present, its planned use, maintenance ease, indoors/outdoors, urban/rural), (ii) user characteristics (nature and level of impairments due to disability, familiar or unfamiliar, comfort-levels with using the technology), (iii) costs of deployment and maintenance, and (iv) local regulations and laws. Creating a better understanding of the various trade-offs that will go into such a framework will perhaps help create a roadmap for increasing the number of accessible and inclusive navigation and wayfinding deployments around the world.

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