Towards Ubiquitous Accessibility Digital Maps for Smart Cities (Vision Paper)

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ABSTRACT

Designing indoor and outdoor spaces to become accessible for people with disabilities is of paramount importance. Accessibility leads to improvements in human rights and business outcomes; due to inclusion of a broader range of the population. For example, adding braille writing to signs and installing ramps allow visually-impaired people and the wheel-chaired to navigate on their own.

While digital-maps have evolved in recent years to become a part of our everyday life, available ones primarily cover vehicular roads only with limited, if any, accessibility information. This highly limits the range of applications they can support. In this paper, we present our vision for ubiquitous accessibility digital-maps for smart cities; where the maps' indoor and outdoor spaces are *automatically updated with the various accessibility-features and marked to assess their accessibility levels* for the different disability types such as vision-impairment, wheel-chaired, deafness, etc.

To realize this vision, we describe an architecture for a crowd-sourcing-based system to automatically construct the accessibility maps. In addition, we discuss the multi-disciplinary challenges that have to be addressed to materialize it as well as the current pioneering efforts in the research community related to our vision.

CCS CONCEPTS

•Information systems → Location based services; •Human-centered computing → Ubiquitous and mobile computing systems and tools;

KEYWORDS

accessibility, crowd-sourcing, digital maps, pedestrian navigation, indoor localization, outdoor localization, smart cities

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(a) Sign with Braille (b) Sidewalk Ramp

Figure 1: Example for accessibility features added to the different entities: (1) Braille writing added on a sign to help individuals with sight-impairment and (2) Ramps installed on walkways to help wheel-chaired individuals.

1 INTRODUCTION

Designing indoor and outdoor spaces to ensure people who experience disabilities have direct (i.e. unassisted) or indirect (i.e. supporting the person's assistive tool/technology) access to these spaces is of paramount importance for any community [20]. Individuals can experience different types of impairment, temporally or permanently, including physical, sensory or a combination of them. Hence, accessibility requires installing various features to support the different disability groups; such as adding braille writing to signs to help individuals with visual impairment find places or installing curb ramps on sidewalks to aid wheel-chaired individuals to move onto or off the sidewalk (Figure 1). Making smart cities accessible leads to improvements in their citizens' human rights, business results and civic engagement; due to inclusion of a broader range of the population (persons with disabilities and the elderly) [4]. In addition, this will lead to more innovation, social justice and impactful outcomes across key services such as healthcare, transportation, and education.

In this paper, we present our vision for ubiquitous accessibility digital-maps; where spaces of the indoor and the outdoor maps are *automatically updated with the various accessibility features and marked with assessment of their accessibility levels* for the different disability types; such as vision-impairment, wheel-chaired, sensory disorder, deafness, etc. Digital maps have evolved in recent years to become a part of our everyday life as they play a key role in enabling a wide range of location-based services (LBS), including navigation systems, traffic estimation services, asset tracking applications, and many more. However, available commercial (e.g. Google Maps [2], Bing Maps [1] and Here [3]) and open-source (e.g. OpenStreetMap [5] and Wikimapia [8]) digital-maps primarily cover vehicular roads only with limited accessibility information;

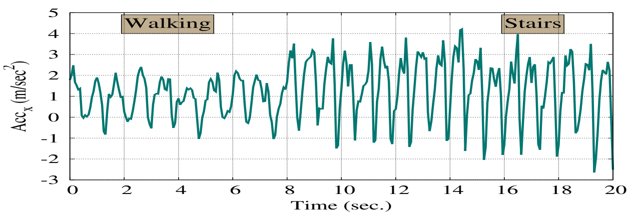

Figure 2: Climbing stairs causes higher acceleration variance as compared to walking on a straight surface.

if any; this highly limits the range of applications they can support [13, 15, 16]. Adding accessibility information to digital maps, both indoors and outdoors, opens the doors for new set of services targeting better support for individuals with disabilities and gives incentives for enhanced spaces accessibility and inclusive design, among others. For example, an enhanced navigation service can provide accessible routes suggestions based on the user's disability type, instead of the current shortest-route or shortest-time based algorithms. Specifically, a wheel-chaired individual can get suggestions for routes with curb-ramps and without stairs; and individuals with sensory processing disorder (SPD) can get route suggestions away from areas with loud noise (e.g. construction sites).

To realize our vision, we describe a crowd-sourcing-based system to automatically construct the accessibility digital-maps. Digital-maps have been traditionally constructed through satellite images, road surveyors, and/or manual entry by trained personnel [16, 28]. However, with the dynamic changes and richness of the physical world, it becomes hard to keep the maps up-to-date and capture the numerous accessibility measures using these techniques. Thus, a crowd-sourcing solution is inevitable to achieve ubiquitous coverage efficiently. The envisioned system makes use of the ubiquitous mobile devices; such as smart-phones, smart-watches and fitness trackers; that come equipped with a wide-range of sensors including accelerometer, magnetometer, gyroscope, camera, etc. In particular, as the users navigate through the indoor and outdoor areas, the system collects multi-modal saptio-temporal sensor traces from their mobile devices and fuses them to detect the various accessibility features. For example, the acceleration force excreted while walking on a straight surface is different from the one when the user is climbing stairs (Figure 2). Therefore, one can leverage the accelerometer to detect the stairs on the road. Similarly, computer vision techniques can be employed to detect braille dots from the phone's camera snapshots [29]. In addition, we can have different map-feature types based on their adopted accessibility measures. For instance, stairs can have different types based on the number of steps, steps' height, handrail availability, tactile-warnings installation and its placement; road intersections can have different types based on curb-ramps and tactile-warnings installation; etc. These map-features can then be used to rate the accessibility level of the different areas for a given disability type. However, there are multi-disciplinary challenges that have to be addressed for this vision to become true including inferring the various accessibility features accurately using the crowd-sourced traces while handling the traces heterogeneity, the high accuracy location requirements for both indoor and outdoor spaces, and the massive accessibility information visualization, among others.

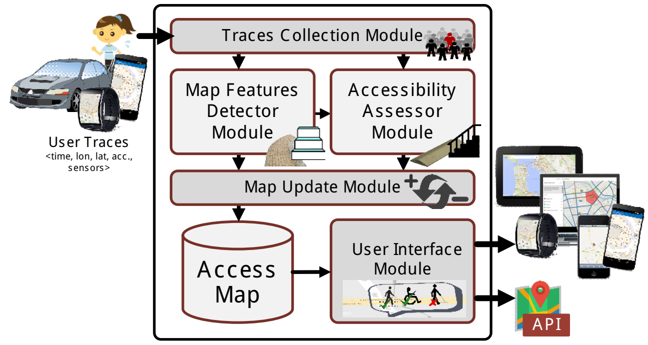

Figure 3: Proposed system architecture.

The rest of the paper is organized as follows: Section 2 discusses our vision and a proposed system for realizing ubiquitous indoors and outdoors accessibility digital-maps. Then, we explore possible opportunities enabled through our envisioned maps in Section 3. Section 4 highlights the multi-disciplinary research challenges to attain our vision and the current related pioneering efforts in the research community. Finally, we conclude the paper in Section 5.

2 VISION AND ARCHITECTURE

In this section, we describe our vision for realizing the ubiquitous accessibility digital-maps. This vision is based on leveraging the users' sensor-rich mobile devices (e.g. smart-phones, tablets, smart-watches, etc) as ubiquitous computing devices in a crowd-sourced manner. The crowdsourced multi-modal sensors information can be employed to automatically infer the users' different surrounding semantics as well as rate the spaces' accessibility level through their effect on the collected sensor measurements. For example, using the higher/stronger acceleration signals to detect the stairs (Figure 2), we can update the map to include stairs at the user's position where they were detected. Routes containing these stairs can then be marked as *inaccessible* for wheel-chaired and *low-accessibility* level for individuals that have hard-time climbing stairs.

The proposed system architecture (Figure 3) consists of five main modules:

The Traces Collection Module: runs on the user mobile device and collects time- and location-stamped measurements from its different sensors such as the acceleration, compass readings, gyroscope readings, WiFi and cellular information (signal strength and heard APs or cell towers), camera images, sound signals, outdoor GPS signal, etc. The traces are forwarded to the other modules in the cloud for processing. The user can configure the module to achieve different privacy/energy-efficiency/high-accuracy goals.

The Map Features Detector Module: takes the collected raw traces and fuses them to estimate the different accessibility map features that the users have encountered using machine learning techniques. For example, it can identify different types of intersections; such as one with a curb-ramp, one with a curb-ramp and tactile warnings, etc. Similarly, it differentiates between normal signs and signs with braille writing; stairs and stairs with handrail; walkways with and without directional/guidance tactile; and so on.

The Accessibility Assessor Module: takes as an input the detected *fine-grained* map-features and a list of disability types and health issues along with their accessibility requirements. The module then assesses the accessibility levels for every route or area based on these inputs for the given disability-types/health-issues. For instance, for a wheel-chaired person, a space has to have a minimum width, curb-ramps are required, bridges should have ramps and/or elevators, etc. Thus, the module can then asses bridges with elevators as *accessible* and bridges with stairs only as *inaccessible* for the wheel-chaired.

The Map Update Module: is responsible for updating the map with the detected map features and accessibility information. The updates include adding a new feature; refining an existing feature's location and/or updating its accessibility assessment; and removing outliers and outdated ones to maintain the map's integrity.

The User Interface Module: interacts with the system's users. We classify our users into two types: individual users and automated services. The individual users query the service and expect to have a visual result on a map showing the accessibility features or routes based on the defined disability type(s). Similarly, the automated services send location-based accessibility queries. However, the results are returned through a web-service API.

3 OPPORTUNITIES

In this section, we discuss opportunities enabled through our envisioned ubiquitous accessibility indoor and outdoor digital maps. First, adding the accessibility information to the map can help highlight issues to governments and decision makers such as areas with low accessibility support for a certain disability type. Previous crowdsourcing-based projects have been used to report road surface issues, e.g. potholes, to authorities [6, 7, 24]. In addition, accessibility maps can help individuals choose more suitable areas to move in, or visit, that are accessible for them. A user with special accessibility requirements can use it as a factor while choosing different services (e.g. restaurant or store). Similarly, providing accessibility information through APIs would enable location-based services to use them to improve their offerings. For example, Yelp [9] can provide additional filters based on the area and/or the restaurant building's accessibility.

Another prominent opportunity would be in navigation applications. Currently, navigation systems provide shortest-route or shortest-time suggestions. However, this route can be inaccessible; e.g. if it does not contain a ramp, contains stairs, is a steep uphill path, etc. With accessibility information available, better navigation systems can be built to avoid such paths according to the user disability type and/or health issues.

All in all, these opportunities; among others; aim at further improving the quality of life for people with disabilities in multiple ways as discussed earlier.

4 REALIZATION CHALLENGES

In this section, we discuss the multi-disciplinary research challenges that need to be addressed to realize our vision; as well as the related current efforts in the research community. We group the different challenges into two categories: mapping-related and application-related. This is in addition to the traditional challenges for crowdsourcing-based systems such as incentives, heterogeneity, energy-efficiency, and scale.

(a) Ramp Ex. 1 (b) Ramp Ex. 2 (c) Ramp Ex. 3 (d) Ramp Ex. 4

Figure 4: Example for different type of ramps installed within the same area.

4.1 Mapping Challenges

4.1.1 Accessibility Features Detection. Automatic detection of indoor and outdoor semantics using the phone's sensors has gained attention from researchers recently [13, 16, 19, 23, 26, 27]. However, detecting accessibility features is currently limited in literature. In addition, there is a wide variation of the same accessibility measure type, even in the same area. For example, Figure 4 shows different type of ramps installed in the same area. This makes the detection problem much harder. To address this, in [25], authors focus on a specific accessibility measure, the curb-ramps at intersections and they propose a framework that fuses computer-vision-algorithms with human users to label intersections as having a curb-ramp or not on Google street-view images. We believe that a truly ubiquitous system, through fusing the different multi-modal sptaio-temporal traces, can eliminate the need for the manual interventions and detect a wide variety of accessibility features. However, further research is needed to develop machine-learning models to fuse the sensor measurements and detect the vast accessibility information robustly and accurately.

4.1.2 Accessibility Features Location Determination. Accessibility features require highly accurate fine-grained location estimation for full-usability. For example, while automatically guiding a blind-user, even small location errors can cause disturbance to the user who cannot see to fix the error by herself. Improved outdoor localization techniques that can provide higher level of accuracy while maintaining ubiquity and energy efficiency is an ongoing research area, e.g. [12, 14, 17, 21]. However, higher accuracy for pedestrian users is required for the accessibility maps. For indoor maps, the accessibility features location estimation is a much harder problem due to the unavailability of a global localization system indoors. While there are current pioneering work in the area, e.g. [10, 22], they are typically limited to certain, possibly experimental, test-beds, require floor-plan availability and/or fail to provide continuous location tracking with high accuracy[1]. Selecting the localization technology to use, fusing different technologies if available, increasing the ubiquity and the availability of the fine-grained location estimates, as well as balancing the techniques' accuracy and energy consumption is a vital research direction to achieve our vision.

4.1.3 Semantics-Rich Maps Construction. Currently available digital-maps primarily cover vehicular roads and there is no standard nor a worldwide database for indoor floorplans. To address this issue, there has been recent efforts towards improving the outdoor

[1]The typical accuracy estimates are based on the median error. However, accuracy deteriorates as we go to the 90-95 percentiles.

maps by automatically integrating various road semantics (such as tunnels and bridges) and completing missing roads, e.g. [13, 28]. Similarly, for indoor maps, researchers proposed crowd-sourcing algorithms to construct the floor-plans automatically [19, 30]. However, accessibility maps, for full usability, require more *fine-grained semantics* to be available in the digital maps such as street and indoors furniture and facilities. Constructing these semantics-rich maps using standard phone-sensors is a major challenge to attain the accessibility maps. One approach can be based on detecting the user's activities to infer the furniture she is interacting with and/or through the facilities effect on the sensors [12, 18].

4.2 Application Challenges

4.2.1 Hybrid Spatial Algorithms. The ubiquitous accessibility maps will enable a wide-range of novel LBS applications which will entail answering new various spatial queries. For example, instead of the typical shortest travel distance between two locations query, we can answer the shortest feasible path and/or the shortest preferable path based on set of disabilities or health issues. This can include considering the different accessibility levels, for a disability type or health issue, in the map—For an elder user, a route that includes a couple of steps' staircase should have different rank from a one with multiple steps' staircase or an elevator, etc. However, new algorithms and/or metrics will have to be deployed to answer these queries efficiently at scale for both indoor and outdoor spaces [11].

4.2.2 Confidence Estimation. Accessibility maps provide sensitive information to special users; a user with a disability may experience hard-time due to errors in the map and/or accessibility assessments. However, errors are inevitable for any machine-learning technique. Thus, we believe that estimating a confidence measure in the detected map-features and/or the assessments is another challenge to improve the maps usability. In [16], authors employ a fixed confusion matrix based on training data to estimate their detected map-semantics' confidence. However, dynamic estimates, based on the specific environment and condition, would be more meaningful to support the accessibility case.

4.2.3 Human-Computer Interaction. Realizing digital-maps includes representation, visualization and design. Our envisioned accessibility digital maps have to be tailored to two different user types: (1) *direct* users who view the map to explore it and (2) *indirect* users who use the accessibility information as a service (e.g. navigation apps). For the first type of users, adding enormous different semantics with various accessibility levels can lead to more cluttered and incomprehensible maps. HCI research studies will need to be conducted to verify suitable visualization methods. For example, these may include having different layers on the map based on the disability type and/or combinations of disability types, using accessibility heat-maps, having different icons with different accessibility interpretations (single icon per semantic) while allowing the user to click on it to check its accessibility compatibility, etc. More analysis; e.g. user studies and/or usability studies; needs to be conducted to identify appropriate visualization methods. In addition, supporting the different end-user platforms; e.g. laptops, tablets, smart-phones, smart-watches; and providing accessible visualization, for the accessibility maps, to the visually impaired users should be investigated. Similarly, for the second users' type, HCI and software engineering studies are needed for designing the APIs to support a wider range of users and providing more compatibility with existing services.

5 CONCLUSION

Mapping accessibility information opens the doors for enormous opportunities; aiming at improving the quality of life for people with disabilities. In this paper, we presented our vision for a system that *automatically* constructs ubiquitous indoors and outdoors accessibility digital maps. It allows users to check the areas' accessibility levels based on the different disability types. We highlighted the multi-disciplinary challenges that need to be addressed to materialize our vision and discussed current related research efforts.

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