



MyPath: Accessible Route Generation Using Crowd-Sensed Surface Information

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Abstract. Wheelchair users often find it difficult to navigate unfamiliar areas both built and natural. Although routing applications have been designed for cars and bikes, accessible routing for wheelchair users is a non-trivial problem that has been scarcely investigated. Wheelchair navigation is obstructed by several barriers such as broken or uneven path surfaces, steep inclines, absence of curb ramps and access slopes, etc. An accessible route enables wheelchair users to avoid such barriers while navigating familiar and unfamiliar environments. In this paper, we propose MyPath - an accessible routing system that leverages crowd-sourced surface vibration data captured through smartphones carried by wheelchair users. Data contributed by the users are then used to automatically recognize surface types and to populate the OpenStreetMap (OSM). Our efficient routing algorithms leverage rich OSM information to generate end-to-end accessible routes and present them through an interactive user interface. MyPath system has been extensively evaluated by a dedicated expert group of wheelchair users and other participants to ensure the seamless operation of the proposed system.

Keywords: Mobile app development · Tracking and localization · Accessible routing · Wheelchair users

1 Introduction

Traveling on sidewalks and paths, especially in unfamiliar areas, is challenging for wheelchair users because of unpredictable barriers, such as uneven surfaces, discontinuous sidewalks, insurmountable stairs, steep slopes, or missing curb ramps. These routes can become more challenging in varied weather conditions such as

heavy rains and snow. For someone using a wheelchair, an inaccessible route can quickly become an overwhelming impediment resulting in a failed outing, delayed arrival, and physical exhaustion. Additionally, attempts to analyze and identify suitable routes may become too difficult or time-consuming, which reduces a wheelchair user’s desire to go on future excursions. Consequently, knowing the most optimal route to any destination is essential for a user’s successful community participation. Due to the variable nature of the accessibility of paths, some regulations such as [1, 2] have been introduced that lay down clear guidelines for the accessibility of surfaces. ADA mandates accessible surfaces to be stable (resist movement), firm (resist deformation by applied forces), slip-resistant, and should have enough integrity and resilience.

The research on accessible routing has developed in many different paths. The major challenge in the domain of accessible routing is tackling the problem of unpredictable barriers through mapping technologies. Crowd-sourcing is a popular method of easily identifying inaccessible barriers in public areas [3, 4]. Satellite-based geographic information systems (GIS) [5, 6] and GPS [7] are also utilized along with smartphones with embedded accelerometers and gyroscopes [8–11]. Path accessibility information databases such as OpenStreetMap (OSM) [12, 13] have also leveraged crowd-sourcing to collate valuable information about accessibility barriers [14–19]. The actual routing process can be initiated only after these barriers have been categorically identified.

However, there are fewer attempts to develop an accessible routing algorithm that generates custom routes based on the accessibility of the path. In this paper, we introduce the MyPath accessible routing system for wheelchair users which works by crowd-sourced surface vibration data collected by wheelchair users in an unobtrusive manner through the MyPath app. Our MyPath app is an accessible app by itself and is thoroughly verified by a team of wheelchair users, blind and low vision (BLV) users, and rehabilitation and mobility experts. The app has both Android and iOS versions and is tested for many hours for correct functioning.

The MyPath system consists of three interconnected modules - sensor data collection, ML-based surface classification, and accessible route generation (see Fig. 1). We model the accessible routing problem in the built environment as a graph-theoretic problem on a weighted road network and propose a tree-based path routing algorithm for estimating the optimal path for wheelchair users. The path-finding algorithm uses the accessibility score calculated from the surface type and incline of a path to generate the optimal route. We have already validated the effectiveness of our ML models for surface classification through prior work [20–22] and in this paper, we only discuss the system design aspects.

In summary, this paper makes the following contributions.

- We designed and developed an accessible app for collecting surface vibration data from wheelchair users through smartphone sensors.
- We proposed two accessible routing algorithms. The first algorithm generates the optimal route for the highest accessibility. The second algorithm generates multiple accessible routes between a pair of source and destination

coordinates. We developed a web-based application to find accessible routes from point to point for wheelchair users.

- We conducted extensive testing involving stakeholders to make sure our MyPath app is accessible. The app and the routing modules are tested thoroughly for functional correctness using modular testing involving real users.

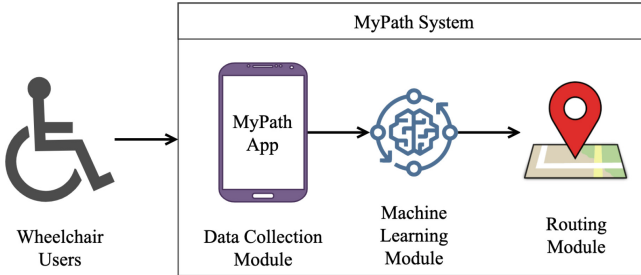


Fig. 1. Workflow of the MyPath system with three interconnected modules. In this paper we focus on the Data Collection and Routing Modules.

2 Related Works

In this section, we discuss the related research papers that deal with accessible routing and navigation techniques for wheelchair users. These include data recognition and analyzing methods for detecting real-time street obstacles and conditions, route generation, recommender systems, and routing algorithms.

2.1 Accessible Routing and Navigation Systems

Plenty of researchers have explored the socially and technically relevant problem of accessible routing and navigation in different contexts. We have identified three unique approaches that use mobility assistants, crowd-sourced knowledge, as well as well-defined accessibility criteria to determine accessible routes.

Mobility Assistants. Some researchers have focused on developing a map of the built environment using GPS and GIS technologies to properly identify various barriers and facilities in the built environment for wheeled mobility-aid users. Mobility assistants were software systems that created GIS models for the surrounding environment. Some well-known GIS-based mobility models are MAGUS [5, 6] and U-Access [23]. MAGUS assigned different impedance scores to different routes based on the number of barriers, distance, slopes, surface type and the number of road crossings. U-Access [23], also considers different types of environmental objects as well as the physical abilities of the users while choosing the best routes.

Several systems [8–11] utilize embedded smartphone sensors such as gyroscope, accelerometer, and location information. Karimanzira et al. [24] applied machine learning algorithms to generate accessible routes for wheeled mobility.

Crowd-Sourced Recommendation Systems. Crowd-sourcing helps to populate information about the built environment on an accessibility map using the knowledge of many users. Extensive use of mobile phones fueled the use of crowd-sourcing and user-generated contents (UGC) (like geo-tagged pictures) for routing and navigation purposes [25]. The RouteCheckr system [26] also allows collaborative data annotation to generate personalized routes for its users. Mobile Pervasive Accessibility Social Sensing (mPASS) [27] also creates personalized routing paths but their crowd-sourced data also involves sensory data collected via geo-referencing. OpenStreetMap [12,13] has emerged as leading source of up-to-date mapping database, whose data was incorporated by intelligent navigation systems such as eNav [28]. A crowd-sourced mobility assistant for wheelchair users - WheelShare [29–31], was developed to generate end-to-end routes based on surface types identified by a robust machine learning system.

Defining Accessibility Criteria. The main challenge in modeling accessibility to generate optimal routes comes from the erratic and ever-changing features of routes due to man-made obstructions or inclement weather. Accessible routes can quickly become uncomfortable due to flooding, lack of maintenance, and not adhering to improving accessibility regulations such as having a slope beyond one-in-twenty or having a path narrower than 915 mm [1]. The authors of [32] proposed an algorithm for building a routing networks based on multiple accessible criteria collated from OpenStreetMap (OSM) data. Kawabata [33] proposed a context-adaptable pedestrian navigation system, which is capable of generating user-preferred routes. However, the author considered only blocking stairs and road surfaces but not existing slopes and ramps. Rahaman et al. [34] extended Kawabata’s work by also considering the slope of the path, and implemented a multi-objective A* search algorithm (CAPRA) [35] that reports distance and elevation. Sahelgozin et al. [36] introduced a novel optimization method, Ubiquitous Pedestrian Way Finding Service (UPWFS) that defined length, safety, difficulty, and attraction as four criteria that must be met for a personalized path that suits users.

2.2 Routing Algorithms

There are many notable approaches taken to tackle the problem within some constraints. First of all, we need to note that all the shortest path finding algorithms cannot be utilized in this new problem because there’s a lack of optimal substructure. Thus, many approaches go in either reducing the complexity of the problem with assumption or creating a heuristic for the estimated result. One approach by Quang Dung Pham and Yves Deville [37] tackles the problem

with a constraint-based technique. They re-define the problem within eight constraints about the graph’s property and provide two approaches. One uses the idea of DFS to search for the exact solution while the another utilizes a local search path where the next optimal move is calculated given the previous one in a tabular manner. Also, Wong [38] mentioned the longest simple path on graphs within the domain of information retrieval on peer-to-peer networks where vertices are labeled with weights. A genetic algorithm is proposed in the paper to solve the problem. However, most papers here either proposed an approximate solution without proof of optimum or a restraint-ed exact solution applied on special graph. In this paper, we come up with a solution with high performance in time and correctness.

3 MyPath System

The MyPath project is currently divided into three modules: 1) MyPath Data Collection App, 2) MyPath Surface Classification, and 3) MyPath Accessible Routing. These three modules are connected to produce a crowd-sourced data collection and routing system to assist wheelchair users in navigating the built environment. MyPath system efficiently integrates both the data collection and routing algorithm to present a comprehensive and self-sufficient intelligent system capable of generating accurate accessible routing solutions. Figure 2 depicts a schematic diagram of the proposed system architecture with its internal components that are distributed between client and server-side operations.

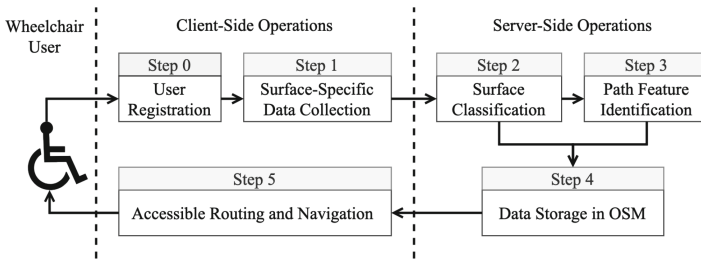


Fig. 2. Complete MyPath System Architecture. Client-side: User registration (step 0), Data collection (step 1), and Accessible route generation and navigation (step 5). Server-side: Surface classification (step 2), Path feature identification (step 3), and Data upload to OSM (step 4).

3.1 MyPath System Functionality

The MyPath system was built in two phases: an internal training phase, and an external live phase. In the training phase, path data from various indoor and outdoor surfaces were manually collected and used to train a robust machine-learning model for surface detection. The detected surfaces were verified and

further used as input data for the initial testing of the routing algorithms. The live phase consists of recruiting real wheelchair users who will collect vibrational data in their local community in an unobtrusive manner which will be stored and used to generate personalized end-to-end routes. Figure 2 illustrates the functional workflow of the MyPath system. Step 1: A wheelchair user registers an account with the system which is used to return personalized routes. Step 2: The user collects data using a smartphone which is automatically uploaded to our server. Step 3: The collected data is fed into the surface recognition model which predicts the surface type. Step 3–4: The surface type and inclination features of the paths are accumulated and uploaded to OSM. Step 5: The routing algorithm pulls the data from OSM to generate personalized routes which are displayed on the smartphone to assist the wheelchair user.

3.2 MyPath System Architecture

In this section, we describe the MyPath system architecture from an operational perspective by dividing the various functionalities discussed in Sect. 3 into *client-side* and *server-side* modules. The client-side operations of the MyPath system consist of two modules - a *data collection module* and a *routing and navigation module*. The Data Collection Module is developed as a cross-platform mobile (Android and iOS) application whereas the Routing and Navigation Module can be accessed through a web application. In the future, we aim to integrate all working modules into a seamless smartphone application with web functionalities. The MyPath server performs multiple tasks, 1) pre-processing and hosting the de-identified collected data, 2) classifying surfaces using deployed machine learning model, and 3) generating accessible routes using our algorithm. It provides several APIs to securely communicate with our smartphone application.

3.3 MyPath Smartphone Application

MyPath is a cross-platform Android and iOS mobile application that aims to improve accessibility and navigation for people with limited mobility. Its primary purpose is to collate data from diverse wheelchair users through crowd-sourcing which will facilitate accessible navigation for individuals with limited mobility. MyPath leverages the distributed data generated by a large number of wheelchair users from geographically diverse communities to create personalized routes for individual users' specific needs and requirements. The app collects accelerometer, gyroscope, and location data using device sensors, which are stored locally alongside session information to maintain data context. MyPath also provides navigation assistance and data visualization features that allow users to view and track their collected data. Figure 3 shows the welcome, data collection, and data visualization screen of the MyPath app.

3.4 MyPath Route Generation

We model the accessible route generation for wheelchair users as a graph problem where the graph G has a set of edges E connecting a set of vertices V . We formally define the accessible routing problem as follows. Given an undirected weighted graph $G(V, E, W)$, with $E = \{\{x, y\} | x, y \in V\}$, and W is a set of edge weights in the form of $W = \{w(e) | e \in E\}$, we aim to find the simple path S_p such that the max edge weight in S_p is minimum. We developed two algorithms to generate end-to-end routes between a source and a destination point. Single-Route-Generation Algorithm generates a single optimal route from a weighted graph using a variation of Prim’s Minimum Spanning Tree (PMST) algorithm. Multiple-Route-Generation Algorithm applies the Depth-First Search (DFS) approach to generate multiple routes between the source and the destination nodes. The first algorithm utilizes the accessibility score to generate an optimal path while the second one generates all possible paths within a boundary. Thus, the output of the second algorithm might or might not contain the output of the first algorithm.

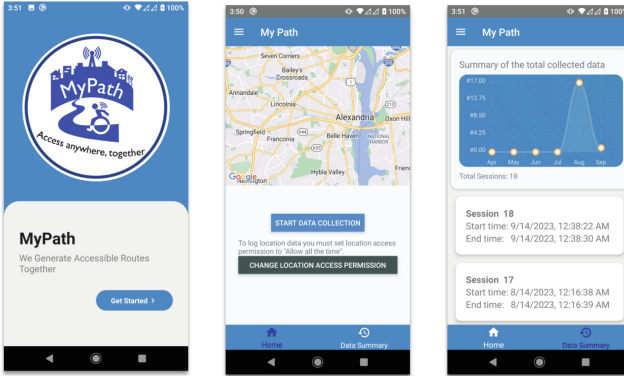


Fig. 3. MyPath App UI Flow

4 Performance Evaluation

Each module of the MyPath system has been rigorously evaluated to ensure seamless working of the MyPath data collection and routing modules. The testing has been performed in three different project sites across the United States (location hidden for anonymity) covering more than 150 paths and walkways. The evaluation of the systems was done as a two-part process.

4.1 Part 1: Evaluation of the MyPath Data Collection App

We have evaluated the MyPath smartphone app based on the accuracy and precision of the GPS localization and the accessibility of the App to wheelchair users and others with low vision, and mobility experts.

- The data collected by the GPS sensors was analyzed to ensure the correctness and high accuracy of real-time localization that is displayed in the app. The precision of the mapped coordinates was tested by collecting data from opposite sidewalks of the same road as shown in Fig. 4. The localization shows a high degree of accuracy in identifying the different sidewalks.
- To evaluate the accessibility of the MyPath smartphone app, a participatory action research (PAR) and advisory group was created consisting of wheelchair users, stakeholders, and technical experts. The progress of the research team was monitored and discussed every three months by the PAR group, and every 6 months by the Advisory group. These groups provided us with valuable insight into enhancing the usability, accessibility, and overall performance of the MyPath system. Figure 5 shows the changes made to the app display after consulting with the PAR and advisory groups.

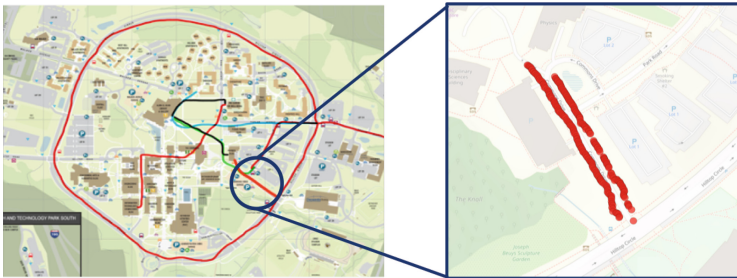


Fig. 4. Accuracy of localization for identifying left and right sidewalks of the same road

4.2 Part 2: Evaluation of the MyPath Routing Module

To evaluate the overall routing module on a real map, we collected surface type and incline data covering an area of 0.3 km² and over 100 paths. To facilitate the testing of the routing application, inclination data was collected manually by measuring the incline level on all pathways for every 10–20 ft. of distance. These inclines and the surface types of each path were uploaded to Open Street Maps (OSM). The routing application pulls the data from OSM to generate the routes rendered on the map. Not all wheelchairs can access steep inclines and consequently, each wheelchair has a maximum threshold of inclination it can handle without slipping, tipping over, and the user losing control. This accessibility (or

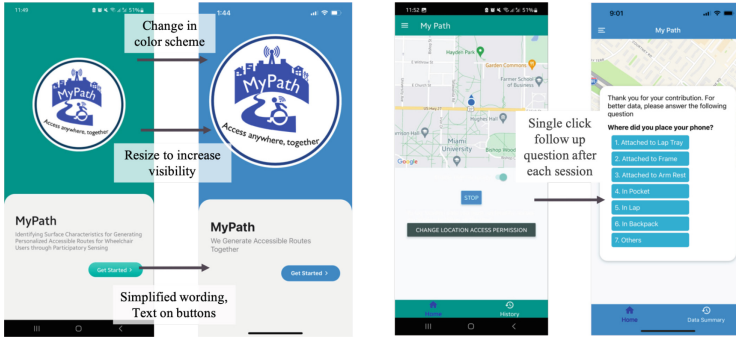


Fig. 5. UI changes in the MyPath App based on PAR recommendations

inaccessibility) of the paths based on the inclination of the path generates a heatmap which is shown in Fig. 6. Figure 7 shows two examples of the routing application.

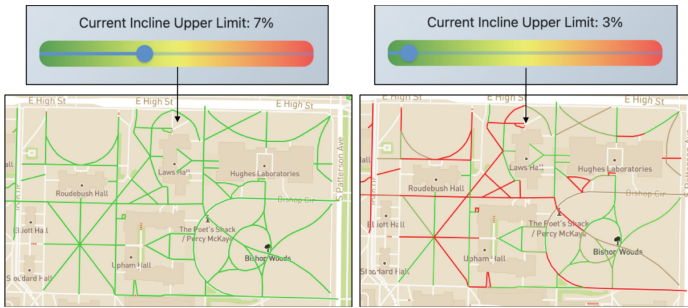


Fig. 6. Heatmap of incline accessibility

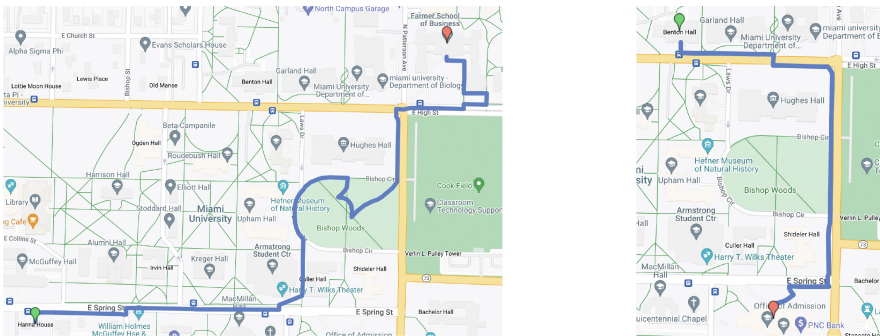


Fig. 7. Optimal route generation from surface type and incline data

5 Conclusion and Future Works

In this paper, we introduce MyPath which is an accessible route generation system for wheelchair users based on surface vibration information captured through their smartphones. MyPath system has a data collection app and a routing web service. The data collection app uses built-in sensors in smartphone to capture surface vibration and user location. This information is then used to automatically classify surfaces and to determine their accessibility through a scoring mechanism. Surface accessibility is then used to generate end-to-end accessible routes for wheelchair users through the built environment. Evaluation with real wheelchair users establishes the accessibility and effectiveness of the MyPath system. In the future, we plan to test the MyPath system with a wider audience and include step-by-step navigation information using textual and voice-based interaction.

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