Towards Disability-Aware Sidewalk Routing

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ABSTRACT

This study presents a novel approach to designing a system for disability-aware sidewalk routing that considers the specific needs and preferences of individuals with mobility impairments. The study involves creating a multi-objective personalized routing service that uses multi-sensors and an artificial intelligence fusion approach to identify sidewalk distresses on a surface level. The preliminary model is used to rapidly deploy big spatial data management systems, providing the Department of Transportation (DoT) and Americans with Disabilities Act (ADA)-compliant services to various desired domains. This research contributes to the broader goal of creating smarter and more inclusive cities by harnessing technology to address the unique mobility requirements of all community members.

CCS CONCEPTS

• **Mathematics of computing** → **Paths and connectivity problems**; • **Information systems** → *Data structures*; **Spatial-temporal systems**; **Crowdsourcing**; • **Computing methodologies** → **Artificial intelligence**;

KEYWORDS

Sidewalk mapping, feature detection, smart navigation

1 INTRODUCTION

Sidewalks are an irreplaceable component of everyday infrastructure used by millions of users as they provide convenient and safe transportation access to pedestrians. However, according to Governors Highway Safety Association (GHSA), fatalities on sidewalks have increased by 77% within a decade. Moreover, as sidewalks become more crowded with sidewalk transportation (i.e., E-scooters and delivery robots), reports have suggested that many sidewalk segments are kept non-ADA compliant. The safety of sidewalks can be reinforced by thorough monitoring and continuous maintenance. Still, the construction and management of sidewalks are mostly comprised of manual processes that must meticulously adhere to the DoT and ADA standards. In such cases, an artificial intelligence (AI)-driven approach is necessary to eliminate subjectivity and laborious procedures in sidewalk maintenance and provide disability-aware routing to vulnerable sidewalk users.

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We studied harmonizing several components in this study to devise a full-fledged solution. Recently, in computer vision, studies involving multi-sensor fusion [5] and vision transformer [3] have shown outstanding performances in object recognition and detection. Additionally, effective sidewalk routing needs an efficient path-planning method to handle big spatial datasets [6]. Yet, none of the studies explicitly focuses on detecting sidewalk features and providing smart, safe routing to people with mobility impairments. Hence, strongly inspired by the lack of optimal solutions in automated sidewalk management and ADA-compliant sidewalk routing, this paper proposes a novel disability-aware sidewalk routing system fused with the combination of multi-sensors, vision transformers, and multi-objective path-planning algorithms. To offer appropriate sidewalk path suggestions for individuals with mobility impairments, it's necessary to acquire precise information regarding the specific characteristics of the sidewalk surface, such as cracks, potholes, and slopes. With the extracted sidewalk features, the proposed sidewalk routing system stores and queries the spatial information in an appropriate big spatial data structure to efficiently create a precise sidewalk map integrated to provide a personalized disability-aware routing service.

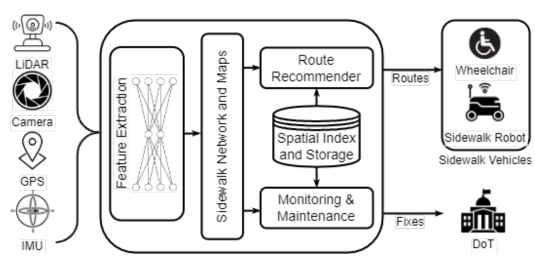

Figure 1: Proposed System Architecture

2 SYSTEM ARCHITECTURE

To achieve a completely automated sidewalk management system that offers disability-aware routing and contemporary innovative services, the outline of the proposed system is depicted in Figure 1. The system is divided into multiple components: (1) *Feature Extraction*. (2) *Sidewalk Network and Maps*, (3) *Spatial Index and Storage*, (4) *Monitoring and Maintenance*, (5) and *Route Recommender*. First, the *Feature Extraction* component collects and combines datasets from various sensors (i.e., light detection and ranging (LiDAR), RGB camera, GPS, and inertial measurement unit (IMU)). These datasets train vision transformer models for sidewalk surface feature extraction. Second, in the *Sidewalk Network and Maps* component, the extracted features are arranged and mapped to create sidewalk network graphs, which devise an entire sidewalk map in a designated area. Next, the sidewalk network and maps are used to create *Route Recommender* that finds and outputs the most optimal, safe routes. Last but not least, in the *Spatial Index and Storage* component, we have devised a big spatial data indexing, database management system, and a query engine, which extend the usability of our sidewalk routing system to other usages, such as automated sidewalk inspection.

Feature Extraction. This component handles the challenges of combining multiple sensory datasets into an embedded spatial dataset. Each sensor used in the data collection has its unique purpose. The LiDAR applies a three-dimensional, volumetric perspective to the sidewalk dataset recorded by the RGB camera. The IMU calibrates and verifies the depth calculation collected by the LiDAR sensor, and the GPS sensor collects geolocational information every second. Our multisensory approach enriches the spatial interpretability of the areas examined. The combined dataset is modified and trained under vision transformer models. In this study, various vision transformer models are fine-tuned and tested to achieve the highest accuracy of the feature extraction model. The feature extraction component is comprised of AI models for (1) crack identification, (2) pothole identification, (3) slope estimation, and (4) sidewalk width estimation. The feature extraction aims to detect sidewalk surface features and store the information in a spatial database in real-time streaming.

Sidewalk Network and Maps. The extracted sidewalk surface features are used to create sidewalk graph networks. Unlike the traditional weighted network graphs, our sidewalk network graphs contain nodes and edges embedded with spatial information from feature extraction that precisely denotes the sidewalk's underlying surface conditions at each segment. We devise big data spatial data structures to properly access and manage spatial information to create sidewalk network graphs and maps.

Spatial Index and Storage. An efficient, continuous management of sidewalk maps is necessary. This component integrates sidewalk maps within a big spatial data index and framework for rapid update and retrieval. We explored various spatial indexing techniques, such as the Pyramid and R- tree Index [2]. The preliminary results indicate that both the R-tree and Pyramid structures can be effectively utilized for efficiently indexing the sidewalk network. While improving this component, we will investigate how these index structures can be adjusted to match their suitability, effectiveness, and capacity to handle and search through sidewalk maps with embedded features and the positioning of objects (users).

Route Recommender. Inspired by personalized route recommenders such as PreGo [4], we develop and evaluate multi-objective path planning algorithms in this component. The algorithm is tested on the sidewalk map produced in *Sidewalk Network and Maps* component, which recommends safe, personalized sidewalk routes to people with movement impairments. The recommended routes should suit different disability conditions of users (i.e., wheelchairs and crutches) and various sidewalk vehicle categories (i.e., manual and electric wheelchairs and sidewalk robots). These routes should consider the anticipated combined effectiveness attained at sidewalk segments and intersections, emphasizing safety and comfort while considering conventional measures like distance and time.

Monitoring and Maintenance. As the *Spatial Index and Storage* continuously updates and stores underlying spatial indices, this component aims to communicate with the municipality or local DoT directly for fixing and maintaining the integrity of sidewalks.

3 DEPLOYMENT

This section describes two use cases of the sidewalk routing system:

Personalized-Safe Sidewalk Routing Assistant is a deployable mobile application specifically designed to assist people with motor disabilities. Personalized-Safe Sidewalk Routing Assistant is ADA-compliant, and depending on the user's preference setting, it scales to provide the best routing for the user through multi-objective path-finding algorithms. This application is aware of ongoing constructions and minor to significant sidewalk damages that are updated in real-time.

Sidewalk Analyzer is a serviceable program that monitors and reports the current health of sidewalk segments. To conduct automated sidewalk surveys, the Sidewalk Analyzer can be deployed on unmanned ground vehicles such as Jackal [7]. Collected information that contains sidewalk features is transmitted to the database server, where the database management system will index the features and sort them by the severity metric system. For instance, if multiple large potholes are found in an area, the analyzer will alert the user and provide an organized report that prioritizes repairing the potholes over a small crack found in another area.

4 PRELIMINARY RESULTS

For the Multi-Object Routing, the preliminary tests conducted on an actual network map consisting of 535,451 nodes and 1,2823,539 edges reveal that our proposed multi-objective optimal path calculation algorithm demonstrates a twofold enhancement in performance compared to its initial baseline. As the project progresses, the envisaged algorithms will be further refined and compared against state-of-the-art methods. We collected 16,000 sidewalk images for Surface Feature Extraction and conducted the preliminary test on the image sets. These images were combined with other sensor datasets using timestamps. We created a unique image processing pipeline that projects and trims the images on a hue, saturation, and value (HSV) scale. We employed and fine-tuned Mask2Former's [1] basic architecture to train a model. Our initial sidewalk feature detection and segmentation model achieved its peak performance with a mean intersection over union (mIOU) of 0.9680 when applied to our curated dataset of sidewalks. These initial findings lay the foundation for the algorithms, data structures, and AI models outlined in our research objectives.

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