Accessible Area Mapper for Inclusive and Sustainable Urban Mobility: A Preliminary Investigation of Airborne Point Clouds for Pathway Analysis

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ABSTRACT

We introduce the “Accessible Area Mapper,” a novel system designed to map accessible pathways using airborne point clouds. By harnessing the 3D terrain information from these point clouds, our system delineates physically navigable areas that are customized to suit individual mobility requirements. This allows for a comprehensive understanding of pathways suitable for active mobility methods, like walking and bicycling. In addition, it can also identify accessible routes for individuals with disabilities, thereby promoting sustainable urban mobility as a whole. While it’s currently in early stages, our work marks a transformative step towards reshaping 3D urban pathway mapping, making strides towards a more sustainable and inclusive transport ecosystem. We demonstrate our system’s preliminary capabilities and discuss its potential.

CCS CONCEPTS

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

KEYWORDS

Pathway Accessibility, Inclusive Navigation, Sustainable Mobility, Spatial Connectedness, Airborne Point Clouds, UAV, LiDAR

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1 INTRODUCTION

Modern urban mobility faces dual challenges: ensuring accessibility for citizens with diverse mobility needs and driving sustainable mobility solutions to reduce the carbon footprint of their commuting patterns [1, 12]. Unfortunately, traditional navigation and pathway mapping systems often fail to deliver the necessary information on pathways like slope and width, vital for ensuring accessibility and promoting active mobility like walking or cycling. This hinders the broader goal of sustainable urban mobility.

The prime sources for creating pathway networks have been GPS or image data. These tools, while invaluable, have largely been focused on mapping roadways for motor vehicles [7, 10, 18]. With vehicular transport accounting for a significant percentage of greenhouse gas emissions, there’s a pressing need to encourage alternative, sustainable modes of transport like walking. To promote this shift, comprehensive pathway data is essential. While there have been recent strides in sidewalk mapping [5, 8, 11], they often yield simplified centerlines tailored for able-bodied walkers, overlooking critical dimensions like width and slope that are essential for accommodating a wide spectrum of urban mobility.

Recent advances in vehicle-mounted LiDAR systems offer the potential to capture detailed pathway information, including aspects like width and slope. However, since these systems are often tied to vehicles, they predominantly provide a vehicular perspective [3, 13, 17]. This limits their potential for promoting active and sustainable mobility. While newer systems are available that target sidewalks using mobile LiDAR [6] and photogrammetric point clouds [16], their ground-based data acquisition confines them to smaller areas, preventing a comprehensive understanding of city-wide pedestrian networks.

Some studies have specifically focused on enhancing accessibility for people with disabilities by crafting navigation tools tailored to specific mobility needs. Some of these tools either integrate slope data into pathways [2, 4, 9] or employ crowdsourcing to determine pedestrian accessibility [14]. While these efforts enhance navigation for disabled individuals, these often focus only on existing vectorized paths, missing opportunities for exploring new pathways and capturing width information. Furthermore, while mobility needs vary greatly, many tools are designed for a singular mobility need

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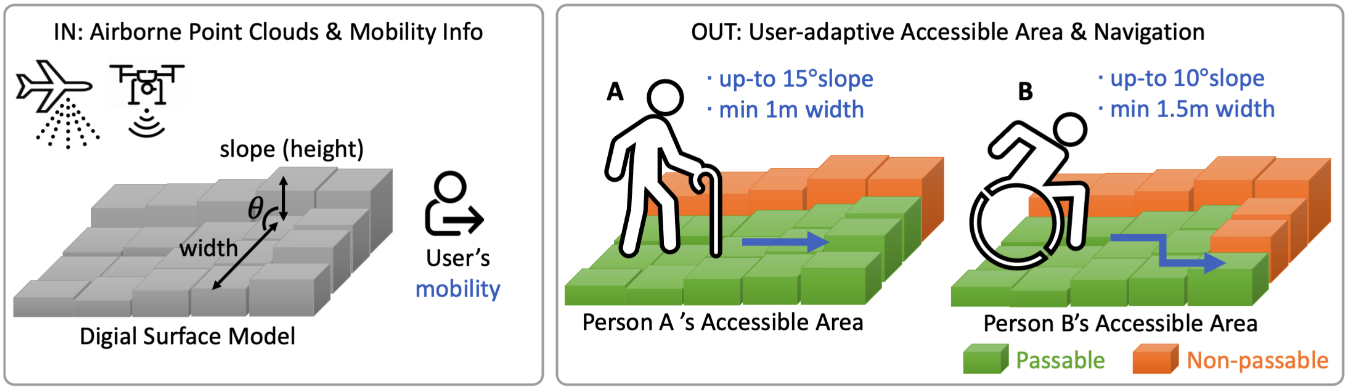

Figure 1: The DSM, derived from airborne point clouds, is utilized to identify regions compatible with a user's abilities. Specifically, the Accessible Area Mapper evaluates slope and width and shows areas that align with the user's travel capabilities.

(e.g., wheelchair user) [4, 9], which narrows their adaptability and overall utility.

To address these challenges, we propose a novel approach to accessible pathway mapping, dubbed **Accessible Area Mapper**. This system identifies accessible pathways based on physical surface information and their connectivity, using 3D terrain data derived from airborne point clouds. Using airborne point clouds allows accessible routes to be determined over large areas, even areas without previous route databases. Features that hinder the accessibility of pathways are directly measured from 3D terrain data, allowing our system to delineate navigable areas tailored to individual mobility needs, supporting active mobility in alignment with the sustainable urban vision.

2 THE DESIGN OF ACCESSIBLE AREA MAPPER

The Accessible Area Mapper is designed to answer the question, "What areas of the terrain are accessible to me?" In contrast with existing systems that analyze accessibility along predetermined pathways based on a one-size-fits-all definition of a user's abilities, our system shows the user all accessible areas of the surrounding environment based on the user's custom mobility settings. This holistic and customizable approach is made possible by leveraging 3D terrain information derived from airborne point clouds.

By converting airborne point clouds into a digital surface model (DSM), our system creates a seamless representation of the ground elevation. This allows our system to analyze any potential route, whether it exists in a routes database or not, and determine if it is suitable for the user to safely and comfortably navigate.

For instance, a steady increase in the elevation captured by the DSM suggests a hilly region, while abrupt changes might point to curbs, stairs, or some other barrier. By using this elevation data, our system can determine which neighboring portion of the DSM is navigable based on the user's mobility by assessing the slope and the width of the path linking one part to another. This process mirrors the user's potential movement across the virtual landscape, modeled by the DSM, and determines if such a move would be feasible for the individual in the real world.

In our system, "mobility" is defined according to individual travel requirements. Figure 1 shows how the width and slope parameters are determined from the DSM and how these parameters relate to determining an area's accessibility. Person A (Figure 1) requires a pathway at least 1m wide and can navigate slopes up to 15 degrees. These parameters establish person A's mobility and are used to delineate the passable areas in the environment. In contrast, other individuals, like Person B, possess different capabilities.

Specifically, the system computes the pixel-level slope using the Sobel operator and recognizes impassable objects via the object-based ground filtering algorithm [15] that uniquely defines grounds as smoothly connected areas. Concurrently, this system employs morphological openings with varied kernel sizes to gauge width as the opening procedure disconnects narrowly linked regions. These operations, rooted in "spatial connectedness," facilitate the identification of accessible areas. Ultimately, the system integrates user-specific mobility parameters to dynamically identify accessible pathways by assessing the interconnectedness of navigable regions.

Thus, our system, unlike previous methods that define accessibility along existing vectorized pathway networks, identifies passable areas seamlessly across large areas with high resolution raster. It uses detailed slope and width information to determine the terrain's accessibility for any potential movement direction. Also, by considering the user's mobility, our system provides customized navigable space, ensuring its usefulness for a wide set of needs and transportation modes.

3 DEMONSTRATION OF THE ACCESSIBLE AREA MAPPER SYSTEM

3.1 Datasets and Experimental Areas

We demonstrate our system using a UAV image-based high-point-density (1600pts/m^2) point clouds constructed from a Structure from Motion (SfM) procedure, and also explore its scalability with low-point-density (20pts/m^2) but widely available airborne LiDAR data. Both datasets cover an urban area in Lakewood, Ohio, USA. The UAV images were captured using a DJI Zenmuse P1, and SfM was executed using Agisoft's Metashape. The LiDAR point clouds were sourced from the U.S. Geological Survey's 3D Elevation Program.

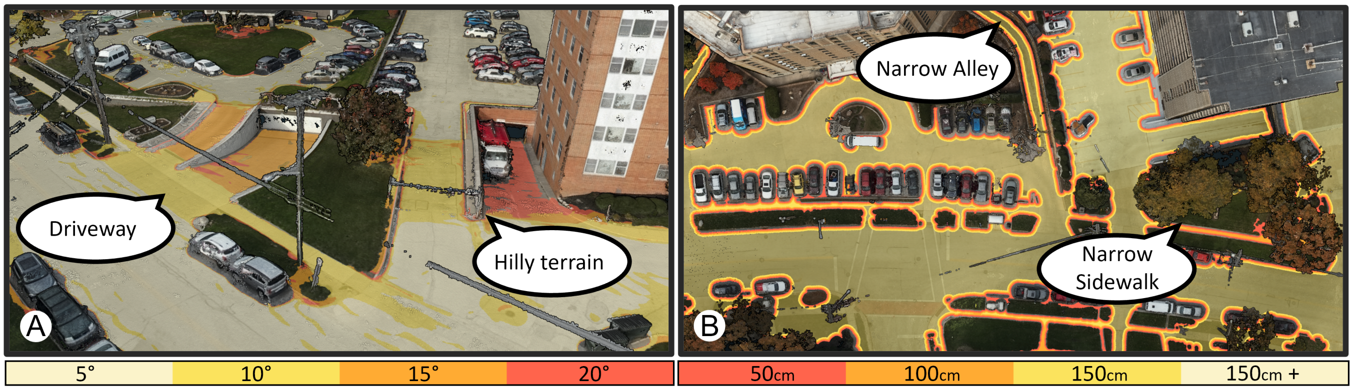

Figure 2: (A) The slope gradation map indicates the degree of slope which must be overcome to access each area. (B) The proximity (width) map shows the available clearance between a position and a barrier to travel.

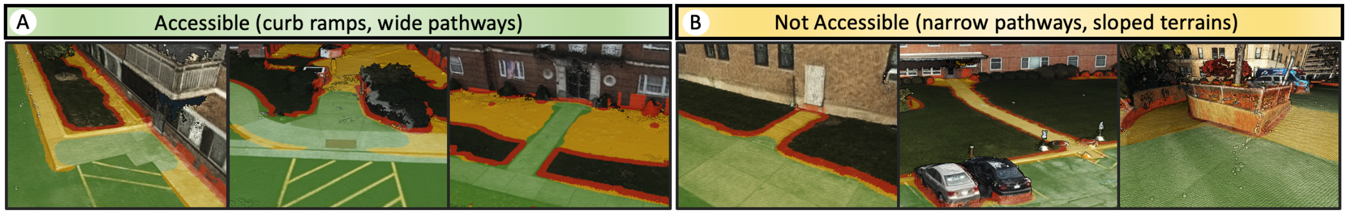

Figure 3: (A) illustrates areas accessible to wheelchair users, while (B) depicts cases where wheelchair access may be restricted.

3.2 Demonstration 1: Slope and Proximity Maps

Our first demonstration showcases our system's capability to visualize the slope and width information of navigable spaces. Figure 2-A shows the slope gradation map, indicating how our system interprets terrain slope. Figure 2-B shows the proximity (width) map, illustrating how it gauges proximity to impassable objects. Specifically, colored areas in the slope gradation map indicate spaces where specific mobility is needed. Each color represents successively increasing slopes that must be surmounted to access that area. Conversely, the proximity map represents the proximity to impassable barriers. Each color indicates the clearance available by width if a user were to try to access the area.

As shown, our system can filter both the slope gradation and proximity maps to highlight areas that align with the user's mobility needs. This unique capability allows users to understand and plan their routes better, based on their requirements. Consequently, this mapping system has the potential to revolutionize pathway mapping and navigation systems, ultimately contributing to a more inclusive and accessible urban environment.

3.3 Demonstration 2: Adaptable Navigation Scenario

Figure 3 illustrates how our system identifies accessible areas tailored to specific mobility requirements. Yellow and green show passable spaces for able-bodied pedestrians, but wheelchair users may be able to access only green spaces. For these computations, we defined user-specific mobility capabilities: the pedestrian needs a 0.5m width and can pass up to 50-degree slopes, while the wheelchair user needs a 1.5m width and can handle up to 10-degree slopes.

Figure 4 envisions how our system could shape future navigation by offering individualized route suggestions. For instance, a curb ramp on the sidewalk, too narrow for wheelchair users requiring at least 1.5m in width, prompts the suggestion of a detour (transitioning from the red path to the blue one in Figure 4). While our current system automatically identifies impassable objects, including vegetated areas, it lacks the ability to discern permissible spaces (e.g., private property, vehicle-only roads). Hence, we manually exclude such areas from navigation.

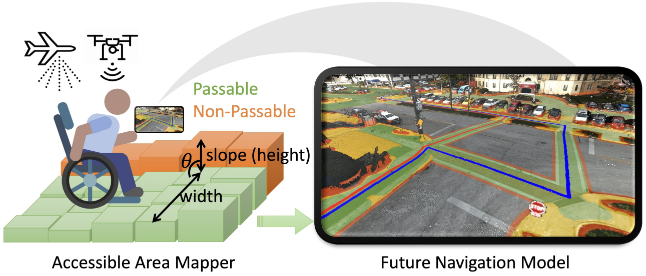

Figure 4: Contrary to existing navigation systems, our system offers the potential to suggest routes specifically tailored to a user's mobility needs. The blue path in the figure indicates a route deemed passable for wheelchair users.

4 LIMITATIONS AND FUTURE WORK

Our proposed system, while innovative, is still evolving and has several challenges that need addressing. These include:

- **Permissibility Understanding:** Our current system, while able to assess physical accessibility from 3D surfaces, doesn't discern permissibility like pedestrian *vs.* vehicle routes or public *vs.* private property.
- **Slope Calculation:** The system uses the Sobel operator to provide pixel-level slope estimates. However, this method does not distinguish between uphill and downhill gradients.
- **Route Optimization:** Our current system finds accessible areas but can't consider pavement quality and lacks automated navigation or route optimization feature.
- **Data Quality and Scalability:** Our system's performance hinges on the quality of airborne point clouds, with factors like noise and tree occlusions potentially affecting outcomes. Although UAV-based systems provide superior precision and detail, their scalability is limited. Airborne LiDAR data, on the other hand, offers greater scalability but may deliver lower point density and precision (Figure 5). Additionally, auxiliary optical imagery might be necessary to discern non-accessible vegetated areas, particularly under tree canopies.

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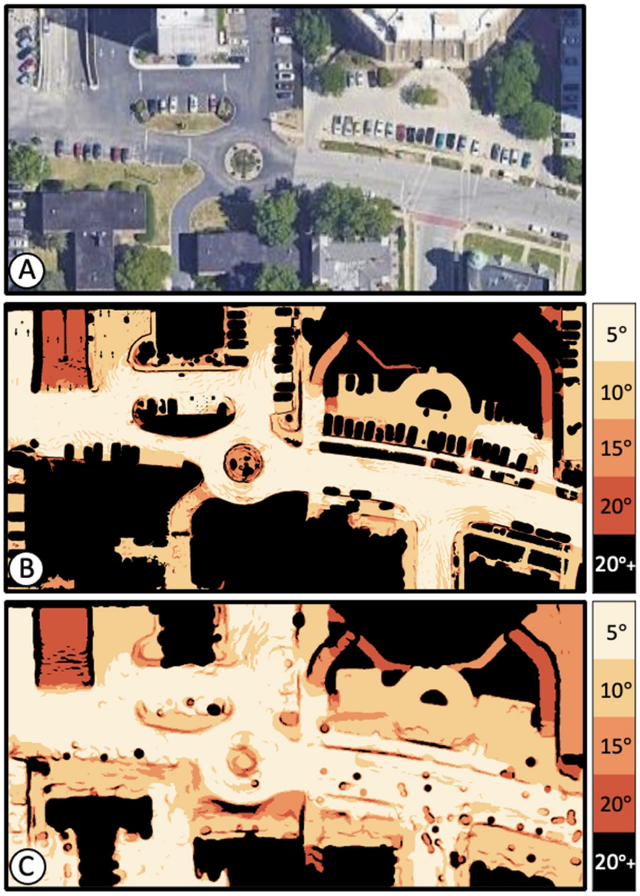

Figure 5: (A) Google Maps, the slope gradation maps from (B) UAV-based system and (C) airborne LiDAR-based system. While the airborne LiDAR-based system holds promise for its scalability, it may necessitate auxiliary optical imagery to mask vegetation.

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