Accessible Navigation Mapping for UVA Engineering Buildings: Supporting People with Mobility Disabilities for Wayfinding

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I. INTRODUCTION

In an interview with NBC News, Kyle Cox, a graduate student at Texas A&M who uses a wheelchair to travel through campus, stated that he "still faces challenges navigating the campus." Kyle continued and said, "Problems like this do happen on campus, and I end up missing class or getting there late even when I leave, sometimes up to an hour before class to give myself enough time to make it" (Ali, 2020). Although Texas A&M states that their campus complies with all ADA regulations, navigating through a college campus can still be difficult. For example, while a path might be wheelchair-accessible, it could take considerably longer to navigate compared to other options, resulting in schedule conflicts or other barriers.

Wayfinding is defined as the cognitive and physical process of navigating. However, it is more than just simply following a directional route. It is an essential skill that is interconnected with independence, quality of life, mental health, and economic prosperity (Parker et al., 2021). Furthermore, wayfinding is incredibly important in order to allow people to get to know their surroundings, as well as to build a good sense of comfort and familiarity with their environment for all pedestrians, regardless of the level of disability (Gupta, 2020).

Effective wayfinding, crucial for navigating any environment, can be particularly difficult on college campuses for students, faculty, and staff with mobility-related disabilities (Parker et al., 2021). For example, with their frequent construction and high foot traffic, college campuses can present navigation difficulties due to blocked and/or narrow paths. Furthermore, many schools have historic buildings constructed well before the Standard of Accessible Design came into effect, which set minimum requirements for public and commercial facilities to be accessible (ADA Standards for Accessible Design Title III Regulation 28 CFR Part 36 (1991), 2014). All these different factors can result in wayfinding at college campuses becoming an additional barrier for those with mobility-related disabilities.

Finding accessible routes and building entrances can be difficult to find using popular navigation apps like Google Maps, Apple Maps, and Waze. These apps often lack the functionality to find these routes and entrances entirely, or the information they provide might not always be accurate (Carole Martinez, 2020). Additionally, these popular apps are often not equipped for wayfinding within buildings themselves (Parker et al., 2021). While there are specific apps designed for people with mobility-related disabilities, many of these apps primarily rely on crowd-sourced data to populate information about accessible routes and buildings (Carole Martinez, 2020). This approach can be problematic in areas with a limited user base, as there may be fewer contributions and, consequently, less data available (Gupta, 2020). Furthermore, the lack of built-in verification methods to guarantee that user-imputed accessible routes are indeed accessible can lead to potential inaccuracies in the information provided (Gupta, 2020). One potential solution to these accessibility challenges on college campuses lies in developing a wayfinding app that uses both real-time information and institutionally populated data to guarantee day-to-day accuracy.

Our team aims to create the foundation for a wayfinding app specifically designed for users with mobility-related disabilities on college campuses. We will begin by exploring these objectives in the context of the University of Virginia, a public university in the mid-Atlantic. We envision that this app will offer information on permanent accessibility features of the built environment and guide users along accessible routes in ways that move beyond simple ADA compliance. Our current project seeks to lay a foundation for building this app by determining key data elements and providing guidance on a method to collect a subset of these data elements efficiently.

II. METHODOLOGY

Overview Our team sought to achieve the dual objectives of 1) determining appropriate data elements required for wayfinding for people with mobility-related disabilities, and 2) conducting an early assessment of approaches to collecting a subset of these data elements through three approaches. We first conducted a thorough literature review to assess the range of existing approaches as related to the dual objectives. Second, a survey, with approval from the University of Virginia Institutional Review Board for Social and Behavioral Sciences (protocol 6351) was used to assess the needs of students, faculty, and staff with mobility-related disabilities. Finally, we conducted a pilot test to assess the feasibility and effectiveness of sensor-based data collection for a subset of data elements. We regularly convened with an advisory committee consisting of different department heads and individuals across the University of Virginia, including members from the UVA Geospatial Engineering Services, the UVA Provost Office, UVA Facilities Management, Student Disability Access Center (SDAC).

Literature Review

We conducted a review of literature written about existing apps to determine approaches to data element definition and data collection. To find our sources, we used search terms such as "accessibility applications," "wayfinding," and "accessible navigation apps" in academic search engines such as Google Scholar, IEEE Xplore, and ResearchGate to find papers about wayfinding apps designed, built, and deployed for use in small cities, universities, and/or public spaces. In each paper and article, we looked specifically for more applications dedicated to mobility disabilities, but we were open to applications that targeted other or multiple disabilities as well. We made sure to pay close attention to what data elements were being collected in order to understand which elements seem to make the most impact and studied the unique data collection methods of each application.

Survey

We created a survey in Qualtrics to distribute to the students, faculty, and staff of the University. Recruitment for the survey was administered via listservs at the University that were focused on the disability community. The aim of this survey was twofold: firstly, to gain insight into the perspectives of eligible participants (specifically, individuals associated with the University who have experienced or are currently experiencing mobility-related disabilities or impairments) regarding the University's accessibility and wayfinding initiatives, and secondly, to explore participants' opinions on the types of data elements they consider essential for effective wayfinding. The questions were created using information gained from the literature review and conversations with people at the university who work in the accessibility space. The survey consisted of eighteen questions that began with questions about available accommodations, transitioned to questions about barriers experienced and ended with questions about opinions on wayfinding apps. Data were analyzed using descriptive statistics.

Sensor Data Collection

In order to collect data, we piloted a robot that had built-in LiDAR sensors. We wish to highlight a method to collect that data through sensor-based approaches. The LiDAR technology measures distance by emitting a light pulse that hits the target and then reflects back to the sensor. The time between when the light signal is sent and received by the LiDAR sensor calculates the distance. The decision to use LiDAR sensors was based on the sensor's capabilities of collecting and storing concrete data that has the ability to produce a two dimensional map of the area. The robot with mounted LiDAR sensors collected data from both inside and outside a building at the university. The sensor was able to measure distance, angles, and surface changes. The robot was then mounted with an Azure Kinect sensor to collect RGB (Red-Green-Blue) data of the same path where the LiDAR sensor was used. RGB data produces a video color model of the mapped area, while the Azure Kinect data output is a high-quality depiction of the built environment. The team realized that a combination of these two sensors would be very helpful with wayfinding, considering that a combination gives two-dimensional and three-dimensional visuals of an environment. A difference between the action of collecting data from the LiDAR sensor and the Azure Kinect sensor was the need for a laptop. The robot was able to store all of the LiDAR data since it was already built in. However, for the Azure Kinect sensor, it had to be taped to the top of the robot and connected to a laptop. This created the need for someone to walk right behind the robot with a laptop that was connected to the sensor via wires.

Data Analysis

The survey results were recorded and analyzed through the Qualtrics platform. The team looked for overarching trends across both the closed-ended and open-ended questions. Descriptive statistics, summarizing data with measures like frequency, proportions, and central tendency, were employed for the closed-ended responses. For the open-ended questions, we employed directed content analysis to systematically group similar responses. This dual-approach helped us develop a comprehensive understanding of participants' perspectives on accessibility.

To assess the effectiveness of different sensors in mapping built environments, the team conducted a two-step approach. First, the team analyzed data outputs from the LiDAR sensor by utilizing a Python program to transform the data into a map. The map was used to evaluate how well the LiDAR sensors capture the floor plans and building features. The successful creation of this map confirmed LiDAR's suitability for this task. The team then analyzed the Azure Kinect data output, which is an RGB video that provided a direct visual representation of the built environment. The team then analyzed how effective the video would be paired with the LiDAR sensor in collecting the desired features and creating a map.

III. RESULTS

Literature Review Results

The following table displays our literature review findings in detail, including each application's goal, user population, collected data elements, and data collection process.

We identified 2 wayfinding apps that met our inclusion and exclusion criteria, which were Applications 1 and 3, Project Sidewalk and NavCog (Saha, 2019; Asakawa, 2015). Only Applications 1 and 2, Project Sidewalk and CityGuide, used crowdsourcing and open-source data, while the other Applications 3 and 4, NavCog and Guide Beacon System, required the installers to manually enter and program data (NavCog, 2016; Lin, 2015). All four applications collected essential data elements. The common elements between all four include curb ramps, missing ramps, obstacles on paths, accessible doorways, accessible bathrooms, location of elevators, signage, and traffic.

Application	1- Project Sidewalk	2- CityGuide	3- NavCog	4- Guide Beacon System
Goal	To provide a quick overview of all physical accessibility issues at any location selected by the user at the street level	To serve as a navigational tool tailored to find accessible routes within major urban areas	To meet the navigational needs of the visually impaired when navigating indoor environments	To enhance accessibility navigation and improve overall museum display experience
User Population	People with mobility-related disabilities	People with mobility-related disabilities	People with vision-related disabilities	All
Data Elements Collected	curb ramps, missing ramps, obstacles on paths (sidewalk obstructions that are difficult for persons in wheelchairs to pass), surface problems (ex. degradation of pathways over time due to weathering), etc.	accidents, road conditions, traffic jams, speed cameras, and police presence	ramps, accessible bathrooms, traffic, other physical barriers, etc.	ramps, accessible bathrooms, traffic, other physical barriers, etc.
Data Collection Process	volunteer-based participation model. Users sign up to contribute to the data set by identifying and marking locations on Google Maps with different accessibility labels	relies on OpenStreetMap (OSM) data, a collaborative project that creates and distributes free geographic information globally, for updates on path changes	populated and programmed by the installers to give real-time audio cues to direct individuals with mobility disabilities in the direction of ramps, accessible bathrooms, or other physical barriers	populated and programmed by the installers to give real-time audio cues to direct individuals with mobility disabilities in the direction of ramps, accessible bathrooms, or other physical barriers

Table. 1 Literature Review Results

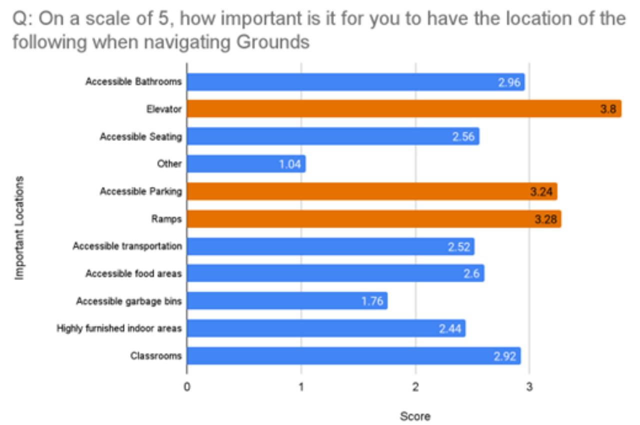

Figure.1 Survey Results for Importance of Accessible Locations

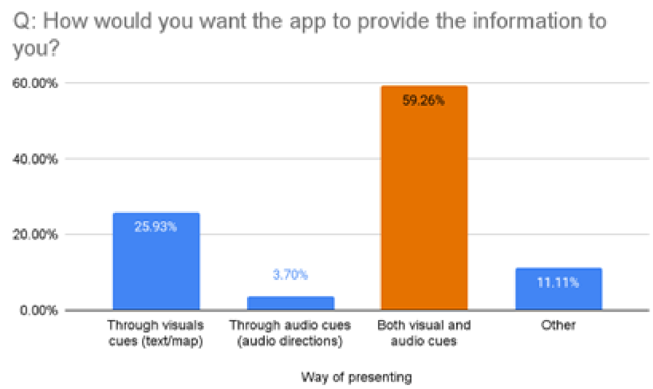

Figure.2 Survey Results for Method of Information Presentation on Application

Survey Results

We received a total of 25 complete survey responses. Participants ranked the importance of each listed accessible location on a scale of 0 to 4 in the survey. The results for this question indicate that most important accessible features they would like to know about around grounds include the location of elevators (3.8 out of 4), locations of ramps (3.28 out of 4), and accessible parking (3.24 out of 4), which can be seen highlighted in orange in Figure. 1. In the survey, participants also noted that buildings with more elevators and ramps are the most accessible and easiest for them to navigate. Figure.2 displays the results for how users would prefer the information to be presented within the wayfinding application. Out of all responses, 59.26% of the participants express the desire for the aids to incorporate both visual and audio cues, also highlighted in orange in Figure.2.

Participants provided valuable feedback on various aspects of campus navigation, particularly on the everyday challenges faced by the participants with mobility disabilities. One common area that many participants mentioned was to enhance campus space and facility accessibility. The survey results revealed significant accessibility concerns among participants. In response to a question about specific inaccessible features at the University, 12% of participants reported encountering issues with accessible transportation and parking options near buildings. Additionally, 32% of participants indicated challenges with accessible entrances and pathways, particularly the absence of ramps on routes solely consisting of stairs. Furthermore, another 32% of participants reported encountering buildings that were only accessible via stairs and lacked ramps or signage for the location for ramps, indicating a need for easier access and more ramps around the campus. Respondents suggested increasing floor space and elevators in academic buildings, enhancing signage visibility, and strategic planning for future renovations. Improved signage was also desired, particularly for directing individuals to elevators in buildings as well as directions for general accessible pathways.

Sensor Results

The program processed the data that was collected and it depicts a grayscale image depicting the robot's path (Fig.3). During the data collection the robot started inside of the building and was taken to a specific point outside. AThe intended route involved the robot starting indoors, navigating to a specific outdoor location, and then returning directly to the starting point. However, the image reveals a distinct overlap, suggesting the robot's return path deviated from its initial outward path. Several

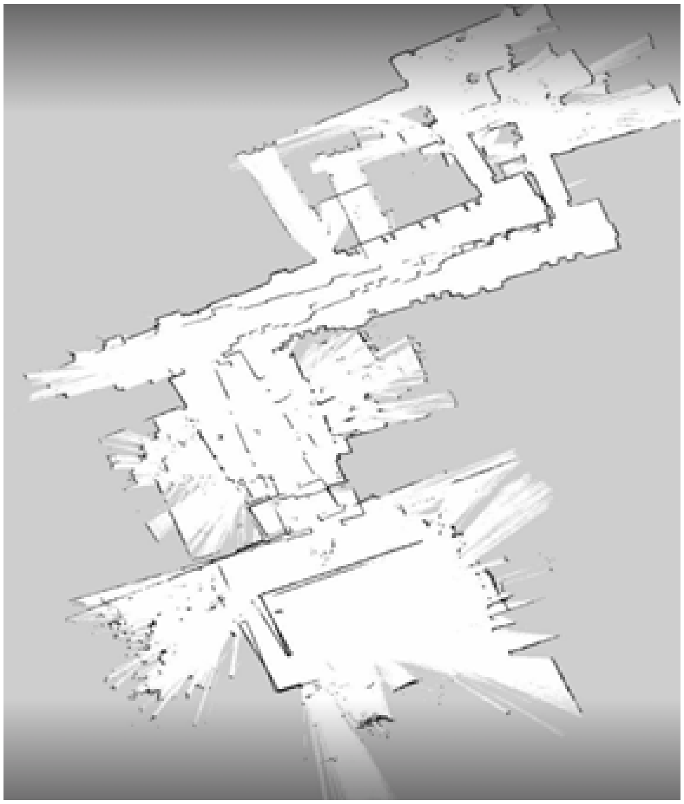

Figure.2 LiDAR Sensor Mapping Output

factors likely contributed to this deviation. The robot encountered various surface changes that caused unintended shaking and directional shifts, as evidenced by the shaking in the Azure Kinect sensor's video output whenever the robot traversed bumps, particularly the doorway threshold. The generated map and video data demonstrate the capabilities of the sensor system for environmental mapping. This combined approach can be used to create comprehensive maps of both indoor and outdoor environments. These maps can be further enhanced by incorporating points of interest (POIs) such as barriers and accessibility features. Additionally, the sensor data demonstrated its capabilities to extract valuable measurements like doorway widths and ramp slopes, providing crucial information for accessibility assessments.

IV. DISCUSSION

Summary of Key Findings

Our survey highlighted several essential features for a comprehensive wayfinding app. The most important feature, according to the survey, was having accurate information about elevators, accessible parking, and ramps. For better accessibility, participants strongly preferred a dual approach where the app displays information both visually and audibly, such as using both maps and voice instructions. Incorporating both modes of instruction would help accommodate for a wider range of users. Moreover, users emphasized the need for improved signage and additional informative features such as travel time, distance, steepness, and surface changes (e.g., tile to carpet) within the wayfinding app.

In terms of sensor results, our use of the LiDAR sensors and its resulting data demonstrates its potential for effective mapping, yielding a two-dimensional representation. The code used during data analysis is able to transform the raw data into a gray-scale mapping representation of the environment. However, the robot's deviation from its path during both outbound and return trips creates an issue during the mapping. The Azure Kinect sensor produces a precise visual representation of the environment, so any bumps or jostling of the sensor can result in static or imperfect mapping. Maintaining the robot's centering and path consistency would enhance map precision and readability. Moving forward, the robot should be used to separately collect data inside and outside as well as along the same path in order to avoid these limitations. An app that synthesizes the strengths of each of these sensors is more likely to enhance wayfinding and ensure a user-friendly navigation experience.

Implications

The findings from our literature review, survey results, and sensor evaluations have significant implications for enhancing campus accessibility and wayfinding aids for individuals with mobility-related disabilities. We highlight the need for a wayfinding app that goes beyond conventional wayfinding apps such as Apple and Google Maps. Integrating environmental data-gathering sensors suggests a method for creating dynamic maps that allow users to view the environment in its entirety while also adapting to changes in the surrounding landscape and environment. Using such technology would reflect up-to-date changes in the environment, including foot traffic and temporary obstacles. For example, if the sensors could be set stationary at a place where data is constantly being measured throughout the day, any changes could be reflected to the back-end and create updates on the map accordingly. However, since the current method requires manual operations on raw data from the sensors, the amount of data collected on a daily basis would pose a significant burden for processing data, leading to an increase in the workload for maintaining such a dynamic system. The dynamic maps could also incorporate real-time updates that allow users to avoid sudden environmental changes.

Although we focused on mobility-related disabilities, participants of the survey expressed their desire for accessibility features such as audio cues and visual representations of obstacles, bringing a cross-disability lens to this work. Therefore, we deemed it necessary that any features or mechanisms included in a wayfinding app be multi-modal for full accessibility and be as inclusive as possible. Other sensory cues, such as wearable technology or vibration on personal devices, could also be considered to inform the users about the environmental conditions ahead. These preferences laid the groundwork for the fundamental development of wayfinding aids. Applying the same methods and considerations to a broader context and understanding the specific challenges faced by individuals with mobility-related disabilities, university administrators could make more informed decisions regarding infrastructure implementations, construction planning, and accessibility policies. Our wayfinding apps and other health technologies can be enhanced by approaching disability from a more holistic framework, which accounts for different forms of disability and the way the community interacts with the environment (Valdez, 2022). Our study's implications touch such broader concepts of community engagement and technology innovation, aiming to create a more accessible and inclusive campus environment for all. By involving university officials and other stakeholders throughout the process, the developed technologies could better meet the actual user demands and improve the overall efficacy of such apps (Ozkaynak, 2021).

Limitations

One limitation of our study is the number of responses that our survey received. The small sample size limits our ability to engage in any meaningful subgroup analysis that might provide further insight into the community's needs. It is possible that a shortened timeline for the completion of this project may have limited the number of survey respondents. The survey instrument is also subject to recall bias during completion, however, given that engaging with the environment and engaging in wayfinding is a regular activity for those at the University, we expect this bias to be minimal.

Another notable limitation stems from the inherent potential for human error. The two most suitable sensors that this project focused on are LiDAR and Azure, both of which require extensive human interaction. During the data collection phase, the LiDAR sensor was mounted on a robot, and the data were collected via the manually operated robot. The sensor captured raw data regarding range and intensity which required further analysis using programming scripts to calculate and plot the necessary information—the same process was followed with the Azure sensor. The data were also collected through manual measurements, with raw data requiring further analysis. The subjective nature of data analysis could impact the interpretation and overall accuracy of the environment plot generated, for example, removing potential error data (N/A or outlier). The involvement of human operators was an impactful variation to the reliability and consistency of the data collected and analyzed. This human error was displayed on the map produced by the LiDAR sensor data. The map was off-centered as a result of the robot not returning to the initial starting point.

Future Research

Future research should prioritize more extensive data collection gathered from the disability community to ensure a more comprehensive understanding of the range of specific needs and preferences regarding wayfinding on campus. Additional data might be obtained through a multi-institutional study, allowing not only for a larger sample size but also a broader diversity of experiences. A second area of future research is the development of a functional prototype of a wayfinding app created in collaboration with the members of the disability community. This prototype should incorporate the fundamental work so far, with user feedback, environmental data, and identified accessibility features needed on campus. Once the prototype is developed, comprehensive usability testing should be conducted to ensure the wayfinding app is effective and meets the specific needs of the intended users. This test should focus on the ease of use, usefulness, accuracy, and instantaneity of campus geographic information and overall user satisfaction. Feedback from these tests can then be used for the app's interactive development.

Another field for further research would be to explore more efficient ways for collecting and analyzing data from the sensors, possibly leveraging AI or machine learning to automate the interpretation of the raw data. More advanced technology will also reduce labor requirements and, therefore, increase the scalability of solutions. Finally, the most effective way of conveying such information and implementation methods should also be assessed in future research. The goal would be to develop a wayfinding aid that provides the most intuitive, accessible, and efficient guidance for the disability community.

After the app is developed and a more advanced process for collecting and analyzing data is defined, a subsequent research phase could be adapting and testing the entire development cycle at other universities. This expansion should take the research further to a broader understanding of general university campus accessibility challenges and solutions. Through these future steps, this project can achieve and expand its goal of enhancing campus accessibility and promoting accessible wayfinding for the disability community.

V. CONCLUSION

In order to create a more accessible campus at the University of Virginia, we conducted a literature review, administered a survey, and tested the feasibility and accuracy of two sensor technologies to inform the development of a wayfinding app for those with mobility-related disabilities. Based on the feedback received from students, faculty, and staff, we identified key areas and barriers for those with mobility disabilities. Additionally, we tested different technologies for automated mapping for a wayfinding application and made recommendations for our stakeholders. Future research for the creation and implementation of this wayfinding application will enable those with mobility-related disabilities and the UVA community to easily navigate throughout the campus, creating a more accessible space.

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