

Scalable Methods to Collect and Visualize Sidewalk Accessibility Data for People with Mobility Impairments

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Figure 2: Our proposed data collection methods will provide unprecedented levels of street-level accessibility information. I will use the information to develop map-based accessibility tools such as RouteAssist (mockup shown above), a mobile-phone based tool that personalizes route suggestions based on a user’s reported mobility-levels.

ABSTRACT

Poorly maintained sidewalks pose considerable accessibility challenges for mobility impaired persons; however, there are currently few, if any, mechanisms to determine accessible areas of a city *a priori*. In this paper, I introduce four threads of research that I will conduct for my Ph.D. thesis aimed at creating new methods and tools to provide unprecedented levels of information on the accessibility of streets and sidewalk. Namely, I will (i) conduct a formative study to better understand accessibility problems, (ii) develop and evaluate scalable map-based data collection methods, (iii) integrate computer vision algorithms to increase the scalability of the methods, and (iv) develop accessible-aware map-based tools that demonstrate the utility of our data (Figure 1 and 6).

KEYWORDS

Crowdsourcing accessibility; Computer Vision; Accessible Urban Navigation; Google Street View

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Figure 1: I design, develop, and evaluate tools to locate, identify and assess sidewalk accessibility features in GSV (The latest version of the interface shown above).

ACM CLASSIFICATION KEYWORDS

H5.m. Information interfaces and presentation

INTRODUCTION

According to the most recent US Census (2010), roughly 30.6 million adults have physical disabilities that affect their ambulatory activities. Of these, nearly half report using an assistive aid such as a wheelchair (3.6 million), cane, crutches, or walker (11.6 million) [11]. Despite comprehensive civil rights legislation for Americans with disabilities many city streets and sidewalks in the US remain inaccessible. The problem is not just that sidewalk accessibility fundamentally affects where and how people travel in cities but also that there are few, if any, mechanisms to determine accessible areas *a priori*.

The overarching goal of my thesis is to create new methods and tools to provide unprecedented levels of information on the accessibility of streets and sidewalks (Figure 2). Using a combination of crowdsourcing, computer vision (CV), and online map imagery such as Google Street View (GSV), I will design, develop, and evaluate methods and tools to collect and visualize street-level accessibility information (Figure 1, 2, 3, 5, and 6).

BACKGROUND AND RELATED WORK

There are three primary components related to my thesis: (i) taxonomy of street-level accessibility features and existing

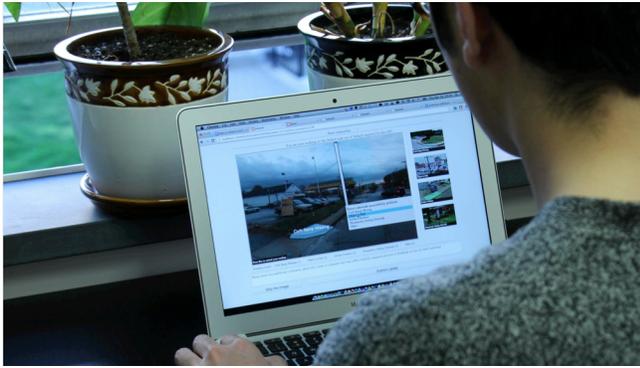


Figure 3: The labeling tool allows users to remotely identify sidewalk accessibility features by inspecting GSV images and drawing labels on them. These labels are useful both as raw data for my proposed accessibility applications as well as for training computer vision (CV) algorithms.

accessibility audit methods; (ii) crowdsourcing image labeling; and (iii) CV techniques.

Sidewalk Accessibility Factors and Audit Methods

As I develop the novel methods and tools to collect sidewalk accessibility information, it is crucial to understand how the design aspects of streets and sidewalks can limit the access of people with mobility impairments. A list of common accessibility problems include: lack of sidewalks, missing curb ramps, poor walking surfaces, blocked pathways, difficult street crossings, and narrow sidewalks [10].

In the US, state and federal departments conduct and encourage the use of street audits to find and assess the aforementioned deficiencies. But audits are often time-consuming and expensive, thus more efficient auditing methods have been explored including the use of GSV to audit characteristics of neighborhoods [8]. Reported benefits of these remote methods include time-savings and the ability to monitor cities from a central location. In contrast, applications such as *SeeClickFix.com* allow citizens to report accessibility problems directly via their mobile phone. While I focus on remote, virtual methods for auditing, mobile phone data-collection techniques could be integrated as well.

Crowdsourcing Image Labeling Tasks

Our image labeling task is analogous to that often performed in training CV systems (Figure 1 and Figure 3). For example, *LabelMe* [9] provides granular segmentation by allowing users to draw polygonal outlines around objects that are publically viewable and editable. Our proposed image labeling work is different not only in focus (accessibility) but also in the unique integration of both crowdsourcing and CV to increase scalability and control for quality. In addition, our labels do not just identify features, they also describe their quality.

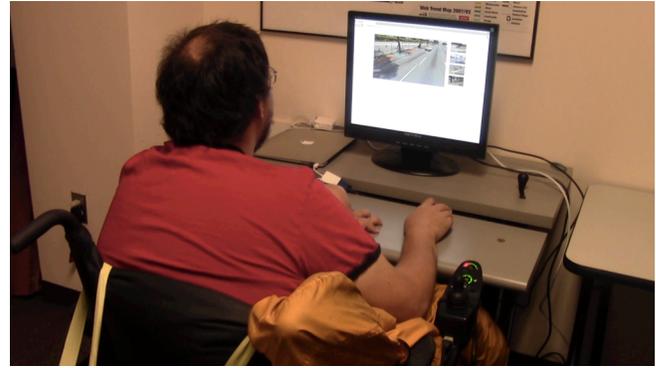


Figure 4: Our research team conducted semi-structured interviews with three wheelchair users (two males with spinal cord injury and one male with cerebral palsy). Each wheelchair user also took part in an image labeling session. They were asked to “think-aloud” during the session so that we could better understand the rationale behind their labeling decisions.

Computer Vision

Work in analyzing outdoor scenes via CV algorithms is also relevant. For example, [3] use edge-based cues to trigger rectangular objects in man-made environments. I will apply and adapt these methods towards our aims, primarily (i) automatically detecting accessibility features in GSV images and (ii) triaging scenes and adapting crowd workflows.

RESEARCH GOALS AND METHODS

My thesis is comprised of four primary threads of research: (i) a formative study to better understand the accessibility problems via interviews and surveys; (ii) the development and evaluation of scalable map-based data collection methods and interactive labeling tools to acquire street-level accessibility data; (iii) the integration and use of CV algorithms to further increase the scalability of the data collection methods; and finally, (iv) the design, development, and evaluation of two accessible-aware map-based tools that demonstrate the utility of our data.

i. Formative Inquiry

To inform our designs, I will conduct three formative inquiries. First, I will interview sidewalk design experts to understand current practices around accessible design. Second, I will interview mobility impaired persons to gain deeper insight into how street-level accessibility affects their lives. I will also interview caregivers to understand their perspective on managing travel and what technologies they use for determining accessible routes.

In the summer of 2012, our research team conducted semi-structured interviews with three wheelchair users (Figure 4) [5]. Using this as a foundation for future interview studies, I will turn to a grounded theory approach to categorize, group, and contextualize the interview results.



Figure 5: I explored initial approaches to scalably detect accessibility problems in GSV images by combining automated approaches and crowdsourcing. Green boxes in the image show automatically detected curb ramp labels. A user of this validation interface can delete automatically detected labels by clicking the ones that are not on curb ramps.

ii. Crowdsourcing Accessibility Data Collection

The primary goal of my thesis is to design scalable methods and interactive tools to collect street-level accessibility information from GSV. Ultimately, I will create a volunteer-based crowdsourcing system similar to *SnapshotSerengeti.org* where any online user can contribute to collecting accessibility information. As a starting point, however, I have been developing and deploying interactive tools on Amazon Mechanical Turk.

I have conducted three preliminary studies centered on exploring new data collection methods using GSV. First, because inspecting sidewalk accessibility in streetscape imagery is a potentially ambiguous task, I investigated its feasibility with six motivated and diligent labelers, and showed that the labeling approach is reliable [5]. Second, I piloted a range of labeling interfaces and examined the effect of three different labeling interfaces on task performance including labeling time and accuracy [4]. Third, I performed preliminary experiments using a manually curated database of 229 GSV images demonstrating that minimally trained crowd workers could correctly determine the presence of accessibility problems with 81% accuracy. With simple quality control methods, this accuracy increased to 93% [5].

The follow-up study that were submitted to UIST2014 complemented the previous study; I addressed some of the limitations by improving the labeling interface and analyzing the effect of images' age [7]. The new interface queries images from GSV API instead of using manually curated street scape imagery and allows users to pan around the 360-degree view (Figure 1). I investigated workers' labeling performance with a new labeling interface, where the tasks involved identifying the presence and absence of curb ramps—an important sidewalk accessibility attribute [1]. To provide feedback to workers about their performance, I included some scenes with ground truth. If a worker makes mistakes at a ground truth scene, after hitting



Figure 6: I will design, develop, and evaluate two applications that utilize the collected data: *RouteAccess* (Figure 1) and *AccessibilityScore* (mockup shown above). *AccessibilityScore* is an easy-to-understand visualization of the accessibility of cities that will be available via a computer or mobile device. Red areas are least accessible and green areas are most accessible.

the submit button, the interface provides visual feedback about the error and show the proper corrective action. We observed, even with the increased task complexity, workers were capable of identifying accessibility attributes in GSV.

GSV images' age is a potential issue as what we find could be obsolete. However, I found that there was high concordance between curb ramp infrastructure in GSV and physical world through in person audit described in [7]. Future work should extend this study to other types of accessibility attributes.

III. Increasing Scalability with Computer Vision

Crowdsourcing accessibility data collection is labor intensive, and is not readily scalable to large areas. At the same time, automatic methods are unlikely to identify accessibility problems with a sufficiently high level of accuracy to create a useful system. I will therefore explore methods of combining the two. I plan to use CV to produce improved labeling in several distinct ways. First, I will design methods and tools for humans to *verify* and *fix* computer detection results (rather than provide the raw labels themselves). Second, I will use CV algorithms to automatically scan large regions for potential accessibility problems. The goal is to focus human efforts on a small set of streets that are most likely to contain problems (*i.e.*, scene triaging). Finally, I will propose methods to increase human labeling efficiency and accuracy using automated methods. For example, CV can play roles in locating and positioning the GSV camera in geographic space and selecting an optimal viewpoint, and estimate “scene complexity” to smartly allocate workers to different workflows.

Thus far, I have developed a preliminary accessibility feature detector using state-of-the-art CV techniques, and proposed a method of controlling a workflow to allocate workers to increase time-efficiency. As a starting point, I have focused solely on detecting curb ramps because of

their visual salience in images as well as their significance to accessibility [1]. Our research team has explored various object detection algorithms [6,7]. The one that performed best in internal assessments was implemented using Deformable Part Model (DMP) [2]. The detection precision and recall were 29% and 67%. Although human verification can increase the detection precision to 68% (2.3x the original) as humans reject false positive labels (Figure 5), our false positive rate is still too high compared to the performance of human labelers (84%) [7].

To overcome insufficient performance of current CV and human verification approach, I have designed and developed a “smart” system, Tohme, that combines machine learning, CV, and custom labeling/verification interfaces to find curb ramps [7]. Tohme consists of two workflows, a human labeling pipeline and a CV pipeline with human verification, which are scheduled dynamically based on predicted performance. I showed that Tohme could provide curb ramp detection accuracy comparable to manual labeling approach at a 13% reduction in cost. This figure will only increase as the performance of automated methods improve. Future work includes improving the performance of the detector by, for example, taking contextual cues into account, and using the detector for triaging. In addition, we will examine how CV can be used to speed up the labeling task itself (e.g., via smart labeling where the outline “pen” sticks to edges).

IV. Proof of Concept Accessibility Applications

There will be multiple ways to incorporate the collected accessibility information. As a proof of concept, I will design: *AccessibilityScore* (Figure 6) and *RouteAccess* (Figure 2). For both applications, the key research question is how to incorporate new data related to mobility access. Employing a user-centered design process, I will design the tools to allow end-users to easily discover both areas of high accessibility in cities as well as areas that are particularly inaccessible.

RESEARCH SITUATION AND DISSERTATION STATUS

In the fall of 2014, I will be a fifth year Ph.D. student in the Department of Computer Science at the University of Maryland, College Park. Although I have not proposed my dissertation, I have been committed to this project over two years and am well into the dissertation stage. I plan to propose my dissertation this fall based on feedback from the UIST doctoral symposium. I expect the remaining proposed work to take 1-2 years.

EXPECTED CONTRIBUTIONS TO UIST/CHI COMMUNITY

This research will contribute to the UIST/CHI community by: (i) extending the knowledge of how people with mobility impairment interact with technology to navigate through cities; (ii) introducing the first work that demonstrates that GSV is a viable source for learning about the accessibility of the physical world; (iii) introducing scalable methods that combine crowdsourcing and CV to

collect accessibility information; and (iv) presenting and evaluating tools that empower people with mobility impairments as well as city governments.

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