Detecting, Mapping, and Grading Sidewalks using Street View Images and Secondary Sources for the city of Dallas

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**Abstract.** Access to sidewalks represents an improvement in mobility for city residents and visitors. For persons in wheelchairs, the availability of curb ramps is vital to independent navigation of an urban area. In this paper, we use machine learning methods to find and map curb ramps and to then assess their quality and accessibility. Using a dataset shared by researchers at the University of Maryland, we create a training set of images that is used to train a convolutional neural network to correctly identify and grade Street View images. The model correctly identifies the presence or absence of curb cuts in 80% of examples presented in the data presented.

1 Introduction

For persons using wheelchairs, availability of sidewalks and curb ramps represent a necessity in navigating a city or urban environment. In the absence of consistent availability, wheelchair users rely on their own experience and knowledge of a specific part of a city to navigate. Without this knowledge, a wheelchair user may be required to take much longer routes through a city to reach a destination.  
Documentation and mapping of sidewalks and curb cuts has previously been carried out through in-person (subjective) “Neighborhood Audits” or through information cataloged in Geographic Information Systems. The completeness, timeliness, and quality of the information gathered in these methods may be lower than what is needed for a comprehensive view of the availability of a feature like sidewalks across a city.

There is a myriad of reasons for the city of Dallas to focus a portion of spending on sidewalk creation and repair. For the mobility impaired, availability of sidewalks is an essential requirement for moving about the metropolitan area. Additionally, sidewalks allow citizens to move in a safe manner around the city without the risks associated with walking in the streets amongst cars driven by ever-increasingly distracted drivers. Sidewalks also provide health benefits since they provide a means of pedestrian travel to near-home destinations for those who may otherwise choose to not travel. Lastly, sidewalks in disrepair tend to contribute to the “broken-windows” theory surrounding many under-privileged areas of the metroplex. Overall, sidewalks represent a worthwhile investment for the city and provide a means of safe and healthy travel for those who choose pedestrian transportation.

Despite the obvious benefits of accessibility to a city and its citizens, the problem of documenting and mapping current levels of accessibility is persistent. This represents a problem for the city in allocation of resources to the proper parts of the city. It also represents a problem to the citizens and visitors: difficulty navigating the city despite gaps in the availability of sidewalks and curb ramps for wheelchair users.

In the fiscal year 2015, Dallas had a proposed budget for infrastructure projects, such as sidewalks, of $7,135,208. That number has grown each of the past several years as the city has increased in size. The city of Dallas has grown in both its inhabited sprawl and in the density of the population at double-digit rates over the past 5 years. This growth can be explained by the city’s pro-business mentality and the relative value proposition that such a large city provides. Dallas boasts a centrally located position in the country, and the city’s status as a transportation hub allows businesses to send employees to any destination in the world with relative ease and efficiency. The City and State have pro-business tax and incentive policies, which have encouraged this growth. With this growth, the city must acquire a better way of allocating the budget for sidewalks and other infrastructure. Today, the city of Dallas essentially responds to complaints about sidewalks through its street services program. As inquiries come in, the city will generally put that particular inquiry on a list for assessment. There is no priority granted for severity of the situation. Additionally, maintenance in suburban areas is the responsibility of the home or property owner and this is not necessarily considered in the ranking process. The current process takes 2-3 months in order to get an assessment and cost estimate for each incident or property owner. Once the assessment has been done, either the city or the property owner will plan and fund the project. One program in Dallas allows the city to reimburse homeowners up to $500 or 50% of the repair cost, whichever is less.

Under these circumstances, the city spends significant time and resources just doing the assessments. Using the algorithmic approach that this paper describes, the city would be able to feed images of these incidents into the model and immediately receive a grading of the sidewalk in question. The city officials could then compare this grading to the grading of previous works to know whether this sidewalk was an immediate issue, who owns the sidewalk, and how much the repair may cost. This would allow the city to prioritize project desires into bins such as: critical, severe, moderate, and low-risk. Therefore, Dallas could dispatch crews to the areas where their services will be the most impactful to the safety and health of the public.

To rectify the lack of city-wide mapping of sidewalks and curb cuts, this paper will demonstrate a machine learning based solution to this problem. Using a training set of images from Project Sidewalk at the University of Maryland, several machine learning methods will be evaluated for performance. A method to extend the trained model to the full geography of the city of Dallas will be outlined. Finally, discussion of how this information can be leveraged to help wheelchair users, as well as plan remedial action within the city will be discussed.

2 Previous Research

Image recognition is not a new field. The use of machines to recognize images has been around for decades. As early as 1963, the electrical engineering department at MIT began using computers to recognize 3D images. While these initial applications were somewhat simple compared to those that we currently use today, they paved the way for what has now become a commonplace practice across industries.

Bahlman, Zhu, and Pelkofer’s work [3] provided meaningful advancements in image element detection and classification. In this paper, the authors built upon their previous research involving shape and color recognition to help classify street signs and traffic signals. Their work is interesting in that it has a 2-step approach where if the model fails on the first classification step, the image is thrown out. This model is important to our work, because it shows how an algorithm such as Adaboost can be used to detect both anomalous and important features for an image-based problem proposal.

Another important piece of research is Perona’s “A Bayesian Hierarchical Model for Learning Natural Scene Categories” [4]. In this paper, the authors provided an approach that allowed for very hands-off model building. This model will potentially provide a structure for our model should we encounter any issues with sparse image objects that are hard to classify correctly. In the model, the computer attempts to use human-based rules to classify image objects. Essentially, each image is broken down into a series of codebook images and reoccurring elements are scanned and classified. Each of these codebook images is additionally clustered using k-means clustering. This portion of the model is used to eliminate features that occur with low frequencies in the training data. The remarkable aspect of this paper is that the model was able to achieve a 78% accuracy rate with such a low amount of supervision. While there are many applications of image classification models, the models outlined above provide a solid basis for our understanding of the evolution of image recognition and model application. Our next area of concentration has been on the specific use of neural networks for problem solutions in the image recognition and classification space.

An aspect of previous work that is of high importance for this work is the use and application of convolutional neural networks. As this is our model of choice, it was important for us to research the application of convolutional neural networks and their potential pitfalls. Goodfellow and a team from Google [5] showed an application of neural networks for image recognition. In this work, Goodfellow applied the DistBelief method for neural networks combined with Google Streetview images to recognize multi-digit numbers, namely street addresses. In the model, the researchers first addressed training the model to identify house numbers. This was a very important step as many variables come into play with these image captures. For instance, lighting, obstructions, and changing conditions can provide potential issues when identifying numbers from images. Additionally, varying font sizes, colors, and styles can impact the ability of the algorithms to correctly identify an image. An important aspect of this type of recognition is that if a single digit is misidentified, the entire interpretation is irrelevant and meaningless. Once the model was trained on house numbers, a more complete Streetview dataset was used. The final approach involved subtracting the mean from each image. In the end, the researcher’s models were able to achieve a 97.84% accuracy with this approach, which was just short of the human benchmark of 98% that was the target of the project. This piece of research and the approach acted as an important catalyst for our approach to identifying sidewalk obstructions and sidewalk grading.

Convolutional neural networks have also been used to improve the solutions submitted in the ImageNet Large-Scale Visual Recognition Challenge. In the work of Simonyan, Karen, and Zisserman [6], the team used convolutional neural networks combined with several other approaches to achieve one of the highest accuracy levels seen in the competition. Their application of multiple models to solve the problem provides a solid reference point for the problem that we solve in this model.

Logistic Regression and Artificial Neural Networks have become benchmarks in classification tasks across problem types. Dreiseitl and Ohno-Machado [19] researched the methodology of machine learning methods across more than 70 papers. The authors state that the two methods, Logistic Regression and Artificial Neural Networks, both have similar basis: statistical pattern recognition in large data sets. The authors reviewed 72 papers that compared outcomes of implementations of both logistic regression, and artificial neural networks. Artificial neural networks outperformed logistic regression in 51% of the studies, but 42% of the studies provided no difference in outcome between the methods. The underlying context, and understanding the authors are seeking is the ability to implement a model to a medical context. They label logistic regression and several other methods as a “White box” method, where the parameters are clearly stated and the method that the model uses to assign importance and come to a conclusion are clearer. In contrast, Artificial Neural Network and support vector machines are labeled as “black box” methods that do not provide interpretable markers of importance or provide methods to be verifiable.

The current reach of accessibility features in the urban landscape is central to the research that was performed for this paper. Bennett, Kirby, and MacDonald [17] surveyed 79 intersections in Halifax, Nova Scotia. Their scoring methodology asked 8 different questions that addressed both the presence and quality of curb ramps at these intersections. Each question required a binary response. Several of the questions would appear to be answerable from the research we propose – the presence of curb ramps, accessibility from the line of travel (that is, the chair user can access the ramp without exiting the crosswalk), that the ramp is “free from irregularities”, and free from drainage grates. Four additional questions address the question of slopes and dimensions of the curb ramp. Their findings in the limited scope of the survey was that 98.7% of intersections had curb ramps, but just more than half, 53.8, had a direct line of travel from the crosswalk. All of the ramps were free from drainage grates, and 85.9% were free from irregularity. The average intersection scored 5.6. The researchers proposed that wheelchair users must adapt to the lack of infrastructure by increasing their skill and dexterity in maneuvering the chair.

It is important to view the context of provisions for access as not special accommodations for persons with disability, but instead bringing the world to be equally accessible to all people. Bromley et al [18] noted in review of legislation in the United Kingdom seeks to provide access to goods and services to all persons, but not necessarily the facilities containing goods and services. It is a fine distinction between the two, and within this context it could be judged that this is the granular difference that describes how accessibility isn’t a special accommodation but provides equal access to all. Respondents in this survey-based study in Swansea, Wales found 60% thought that lack of curb ramps were a “major” or “prohibitive” obstacle to access. As a result, respondents had to use domain knowledge of the city to navigate around obstacles, and sometimes take much longer paths to access. Among the respondents, 60.8% agreed that “the way places are designed” is the major problem for wheelchair users. This attitude was somewhat more evident among younger users of wheelchairs than their older cohort. Wheelchair users recommended “more dropped kerbs” more often than any other improvement to the center city shopping experience.

Another important piece of research was Clarke et al’s [13] audit of Streetview images as compared with an individual’s in-person audit. The study involved researchers in neighborhoods in Chicago walking each block from the inside to the outside, essentially walking the block twice, and assessing the quality of the sidewalks. This study found that subjective measures like sidewalk quality have much lower consistency between observation via Streetview and in-person observation and grading. Essentially, the conclusion is that features requiring high levels of precision can be hard to attain via Streetview images. This poses an interesting aspect to our research. For instance, our model will need to stay informed of areas that have been treated in the previous time periods. Therefore, if a database of previously updated sidewalks does not exist, we will need to provide a means of storing projects within a database that allows for those items or coordinates to be referenced. This will prevent outdated Streetview images from being used in the classification and scoring process.

While it is important to see that our research problem can be solved via machine learning techniques, it is also important to see that there is indeed a reason for the application of these techniques to solve the task at hand. Therefore, it is important to see that improving sidewalk quality, coupled with other factors can lead to better health for society overall. In Haina et al [11], the researchers looked at signal data such as walkability of neighborhoods in relation to the overall health of the individuals in the area. The evidence used to provide insight into the improved environment of an area was sanitation practices and tobacco sales restriction. This coupled with increased walkability of an area leads to higher levels of physical activity and better health over time.

The fourth area of research for this project focused on the general health benefits of neighborhood walkability. Deehr and Shumann [7] provided work for five different neighborhoods in the Seattle area. Their research considered the incidence of pedestrian strikes by motorists, the health factors of walking, and the current modes of transportation that pedestrians were using. Their research led to the city adding additional walking paths, and trails. Additionally, much of the research sparked additional community involvement in the design of multi-model transportation infrastructure. Additionally, in Richardson,Troxel et al [10], the authors sought to understand whether factors such as green space and walkability resulted in “moderate to vigorous physical activity” for the residents of randomly selected neighborhoods in Pittsburg, PA. When controlling for factors such as crime, green space, and walkability in the selected targets, it was discovered that variables such as gender, age, education, and overall walkability of the neighborhood did play significant roles in the levels of physical activity for an area. This research helps us reaffirm that there is immense potential for identifying areas that need this sort of infrastructure. Ultimately the goals of helping people lead healthier and safer lives are potential outcomes of the modeling exercise laid out in this paper.

Overall, our research helped us layout the precedent for image recognition, understand the application of the specific type of model that we are attempting to build, evaluate the effectiveness of proper infrastructure, and provide statistical affirmation of the health and societal benefits of proper infrastructure. With this knowledge established, we can make the case for our model to be used for the stated application problem.

4 Algorithm Design and Solution

For this model, we will be applying a convolutional neural network to train and ultimately score a series of Google Streetview images of the Dallas metropolitan area. This project will help the City of Dallas better prioritize infrastructure projects with potential extensions beyond applications to sidewalks. For this model, we have considered several inputs: the training data, the testing data, and the scoring algorithm used to correctly classify images.

The training data used in this model came from the University of Maryland’s Project Sidewalk. The University has agreed to share the data collected through this project with the SMU Walknet team. Project Sidewalk is part of a crowd-sourced approach to classifying images for potential issues in the image. This tool can be thought of as an application of the same methodology used by the Wayz application for smartphones, with the only difference being that users are not physically in the environment that they are assessing, rather they assess the sidewalk from their home computers. Users are dropped into a Google Streetview environment and then told to identify and grade a potential feature in the given image. The grading scale falls from a best value of “passable” or 1 to a worst value of “not passable” or 5. Of course, this grading schema is based off of subjective, visual inspection and not actual user experience feedback. Understandably, this does introduce the potential for some bias in the training data. However, it is believed that the data cleaning methods in place from the University of Maryland are sufficient for our model. Additionally, our model is more concerned with the obstacle identification in the actual image rather than the grade given. Our hope is that we can incorporate grading into the actual algorithm based on some sort of dispersion measure amongst the pixels in the image itself. The data has been shared via a Box repository on the cloud where a series of panoramic images have been dropped for our consumption into the algorithm. (**UPDATE** – we are currently working on a piece of code that is able to ingest these images and understand which pixel values constitute obstacles or sidewalk features that we are interested in for this study.)

The test data that we are using is an area of focus on the South side of the City of Dallas. This is an area where a great deal of funding and gentrification has been focused. To ensure that the neighborhoods are getting the correct amount of funding, we focus in on this area of the city to start. We use the Google Streeview API in Python in order to download the proper number of images to test for the area. (We have currently not decided on image spacing as we are still working on the process for loading the images into the environment appropriately. Once we have the data downloaded into the appropriate repository we will be able to test the data collected.)

The algorithm that we are using is a convolutional neural network. Convolutional neural networks have been applied to this sort of problem on many occasions and are basically the go-to approach to solving this sort of problem. These algorithms are especially strong when the training data is of the level of quality that we have from the University of Maryland. While the convolutional neural network approach is the approach that we start with, we may take an approach using different deep learning approaches such as Deep Believe Networks or stacked denoising autoencoders. However, we are still some time off with this approach for our project. We are still working on the best approach for ingesting images into memory in an efficient manner.

5 Project Plan

Domain Knowledge Research

Understand Social and Public Health considerations of sidewalks

Pedestrian Safety concerns

Persons with Physical Difficulties

Other Approaches to the Problem – Neighborhood Audits

Python Image Processing Knowledge

Google/Bing Street View API Knowledge

Machine Learning/Neural Networks with Images

Best Practices for improving performance in image classification problems

GIS (Geographic Information System) file formats and interchanges

Development of Machine Learning/Neural Network, Cross Validation, Testing

Documentation

Final Poster Presentation

6 Github

The address for this project’s Github page is: [github.com/dpmurraygt/CapstoneProject](file:///C:\SMU%20Data%20science\capstone\AppData\Local\Temp\Temp1_CapstoneProject-master.zip\CapstoneProject-master\github.com\dpmurraygt\CapstoneProject)

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