Shaded Router Using Dynamic Shade Simulation

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ABSTRACT

Particularly in metropolitan locations exposed to sunlight, the growing severity of heatwaves poses serious health concerns to cyclists and pedestrians. We solve this by putting forth ShadeRouter, a unique route planning system that optimizes routes according to shade coverage. Our method integrates shaded areas into a multi-layered road graph by applying sophisticated segmentation models to high-resolution satellite photos. Our approach uses a modified Dijkstra algorithm to allow users to prioritize routes based on their preferred distance and shade balance. By lowering heat exposure, this device not only improves outdoor comfort but also supports sustainable urban mobility. Using a dataset of 2925 satellite photos segmented for shading data at different times of the day, preliminary tests show the efficacy of our approach in the city of Tempe, Arizona. Future research will concentrate on improving the dynamic shade simulations to take temporal fluctuations into consideration and extending the model to additional urban environments.

KEYWORDS

Shaded Route Planning, Satellite Image Segmentation, Dynamic Sunshade Mapping, Pedestrian Thermal Comfort, Sustainable Urban Mobility

CCS CONCEPTS

1. Information systems Geographic information systems
2. Computing methodologies Image segmentation; Machine learning algorithms
3. Applied computing Transportation; Environmental sciences
4. Human-centered computing User interface design; User-centered design

ACM REFERENCE FORMAT

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INTRODUCTION

Global warming is causing more and more problems for metropolitan areas, especially in the form of intense heat waves and urban heat islands. These heat episodes are becoming more intense and frequent due to a number of factors, including decreasing green spaces, high-density development, and climate change. Because of this, bikers and pedestrians are frequently subjected to extended sun exposure, which can have a negative effect on their general mobility, comfort, and health. This problem is especially important in crowded cities with inadequate shade and an urgent need for sustainable urban mobility solutions.

Heatwaves are made worse by the urban heat island effect, particularly in areas with large amounts of heat-absorbing and heat-retaining concrete and asphalt surfaces. As a result, ground temperatures rise, making outdoor activities uncomfortable and even dangerous, especially for vulnerable groups including the elderly, young people, and people with underlying medical conditions. According to recent research, limiting exposure to direct sunlight can improve urban quality of life by lessening the negative health impacts of excessive heat. Intelligent solutions that can optimize routes for bikes and pedestrians while accounting for environmental aspects like shade and thermal comfort are desperately needed as cities continue to grow and become denser.

Conventional route planning methods frequently ignore environmental aspects like the availability of shade while optimizing for variables like time, distance, and traffic congestion. Because of this, users are often led along paths that may be quicker or shorter, but they are subjected to high amounts of sun radiation, which can cause heat stress. In cities with hot and dry climates, the neglect of shade in route planning becomes a serious problem during the hottest summer months. This flaw in current route planning methods emphasizes the necessity of a fresh strategy that gives thermal comfort equal weight with more traditional measures like distance.

We address this issue by introducing ShadeRouter, a dynamic route planning system that incorporates satellite imagery shade information into conventional route optimization algorithms. ShadeRouter's goal is to provide bicycles and walkers with personalized routes that strike a compromise between travel efficiency and shade covering. Through the utilization of sophisticated image segmentation methods and the incorporation of shade data into a multi-layered road graph, our system offers users route choices that minimize exposure to direct sunlight. By using a modified Dijkstra algorithm, the system enables users to prioritize shorter distances or colored paths according to their preferences.

The fundamental innovation of our method is the use of foundation models such as the Segment Anything Model (SAM) to dynamically extract darkened areas from satellite photos. Our method dynamically changes shade information based on satellite imagery, which makes it flexible enough to adapt to different urban environments and times of day, unlike existing methods that rely on static data sources like LiDAR or predetermined shading maps. This adaptability is especially helpful in urban areas where shade circumstances vary during the day as a result of things like building shadows, tree cover, and the sun's location.

Our research intends to offer a scalable, data-driven solution that improves the comfort and safety of cyclists and pedestrians by overcoming the shortcomings of current shaded route planning systems. An important benefit of ShadeRouter is its ability to dynamically integrate shadow data into route planning, particularly in areas without extensive LiDAR datasets or intricate microclimate models. Furthermore, our method may be easily implemented in cities across the globe by using publicly available satellite imagery, making it a useful tool for encouraging heat adaptation and sustainable urban transportation.

We describe our project's methodology, present state, and initial findings in this progress report. We also talk about the difficulties in incorporating dynamic shadow data into algorithms for route optimization and how our study can affect public health and urban mobility. ShadeRouter is a forward-thinking solution that not only meets the immediate needs of urban dwellers but also fits in with larger sustainability and resilience objectives as cities continue to struggle with the consequences of climate change.

RELATED WORK

Research on improving the comfort of cyclists and pedestrians in urban settings by optimizing shaded routes has increased as a result of urban heat islands and the growing frequency of heatwaves. To reduce heat stress and encourage sustainable urban mobility, several researchers have put forth various strategies for integrating shade into route planning systems.

In order to optimize routes for bicycles and pedestrians, Da et al. (2024) [1] developed the ShadeRouter system, which uses high-resolution satellite data to identify shaded regions and incorporates them into a multi-layered road map. In order to provide route recommendations based on user preferences for shade versus distance, the system uses a modified Dijkstra algorithm and sophisticated image segmentation algorithms to dynamically extract shaded zones. This technology is especially helpful for cities that experience high temperatures since it lets users personalize their routes by giving priority to areas that provide shade, which lowers exposure to heat during hot weather. Accuracy in areas with low picture resolution may be impacted by the system's heavy reliance on high-quality satellite imagery.

A heat-sensitive routing tool was created by Foshag et al. (2024) [2] with the goal of safeguarding susceptible groups in cities such as Heidelberg. This tool finds routes with higher thermal comfort during heatwaves by integrating user surveys and micro-climate models. In order to improve urban resilience, the study highlights how crucial it is to take user preferences into account when developing routes. However, its scalability to other places that might not have access to comprehensive environmental data is limited by its reliance on localized data and micro-climate simulations.

Weidmüller et al. (2024) [3], on the other hand, investigated the application of tree-based shading solutions in urban design to create routes that are shaded. Their research focuses on Velika Gorica, Croatia, where trees were strategically planted to shade about 50% of the city's roads using GIS models. By using natural materials to reduce heat, this nature-based solution supports the objectives of sustainable urban development. Seasonal changes in tree cover and the sustained investment needed for urban green infrastructure, however, present difficulties for the strategy.

The CoolWalks study by Wolf et al. (2024) [4] is another noteworthy contribution. It created the CoolWalkability index to optimize shaded routes based on differences in street layouts and building heights across several cities, such as Manhattan, Barcelona, and Valencia. According to this study, towns with asymmetrical street layouts and a range of building heights can provide more shaded walkways, which will increase pedestrian thermal comfort. The method might not, however, take into consideration real-time variations in shade brought on by elements like the time of day and the weather because it depends on static shading data from buildings.

Deilami et al. (2020) [5] created the Shadeways smartphone app with the goal of giving bicycles and pedestrians in Greater Bendigo, Australia, shaded paths. In order to improve user comfort during intense heat, the software finds shaded routes using geotagged data and input from community polls. Using real-time environmental data to inform route decisions, the method is user centric. Its usefulness is restricted to locations with comprehensive spatial data, which may not be accessible in places with fewer resources.

Morrison (2018) [6] introduced the Parasol Navigation system, which optimizes walking routes according to user preferences for sun or shade exposure using LiDAR data and a modified Dijkstra algorithm. Parasol gives users the ability to select routes that strike a balance between distance and sun exposure by using LiDAR-derived sun/shade maps. The system's reliance on LiDAR data restricts its scalability, particularly in regions lacking extensive LiDAR coverage, despite its creative use of solar modeling.

In cities like Rome and London, Vasilikou and Nikolopoulou (2020) [7] used a technique known as "thermal walks," which combines subjective surveys with microclimate monitoring, to examine how urban shape affects pedestrian thermal comfort. The sequence of locations that pedestrians pass through, such as streets and squares, affects how they perceive heat, according to the study, underscoring the significance of spatial diversity in urban planning. The applicability of this approach is restricted to particular metropolitan environments and climates, which limits its generalizability to areas with varying climatic circumstances.

Finally, using the SOLWEIG model, Buo et al. (2023) [8] created high-resolution heat exposure maps for Phoenix-Tempe, Arizona, to help with pedestrian shaded corridor planning. In order to help municipal planners create cooler urban environments, the study focuses on producing intricate maps that distinguish the shade contributions from trees and structures. However, the method depends on high-resolution spatial analysis and a large amount of LiDAR data, which could not be practical for cities without such access.

The availability of high-quality data, the static nature of shade information, or the localized application of their methodologies frequently limit these research, despite the fact that they provide insightful information about incorporating shade into urban route planning. Our suggested ShadeRouter method seeks to overcome these constraints by dynamically detecting shaded areas using real-time segmentation models and freely available satellite images. Our approach provides adaptable, shade-optimized routes that may be tailored to different urban environments by incorporating this data into a road graph and optimizing routes using a modified Dijkstra algorithm. Without requiring specific data, this method promotes sustainable mobility and improves pedestrian comfort while offering a scalable solution that can be implemented in cities all over the world.

DATASETS

A dataset is created with 2925 images which are 3D models of the Tempe city map(partial city). It consists of images of various buildings with the shade during different times of the day starting 6 am in the morning till 6 pm in the evening, marking shades of each building for 13 different hours per week.

There are two other sets of images that would be used here other than the ground truth mentioned above. One of them being the satellite image of the ground truth, followed by the ground truth image without no sunlight – in order to get the shape of the building so that the model can distinguish between the building and the shade with ease.

Figure 1: Satellite Image(left most), ground truth (Centre) and Image with no sunlight(Right most)

METHODOLOGY

In our method, we use ControlNet to augment the ShadeRouter system's segmentation capabilities. ControlNet is a neural network augmentation that provides extra control signals to picture segmentation algorithms. ControlNet improves the accuracy of detecting darkened patches in satellite pictures by conditioning the segmentation model with spatial information such as building outlines and edge maps.

This model is especially useful in complicated metropolitan areas where shadows shift throughout the day owing to variations in the sun's position and the presence of various structures. We use ControlNet to guarantee that the segmentation process distinguishes shaded regions from other urban components such as highways and buildings.

This enhanced segmentation data is critical for properly mapping shaded pathways, which are then included into our dynamic routing algorithm to optimize itineraries for heat-sensitive individuals.

As shown in Figure 2, Stable Diffusion uses a U-net design with a ControlNet for encoder and intermediate blocks. The gray blocks represent the structure of Stable Diffusion V1.5.ControlNet is built by combining trainable blue blocks and white zero convolution layers.

In the current architecture we use Control Net for generating the images with the shade, as the model goes text to image generation, the input parameters would be the area the user would select, the image of that followed by the time of the day which would generate the image of the shade. Currently we are working on tweaking the parameters during the training process by looking at the term C_i where we are currently planning to add the image with no sunlight, so as the model understands with better clarity resulting in increased performance.

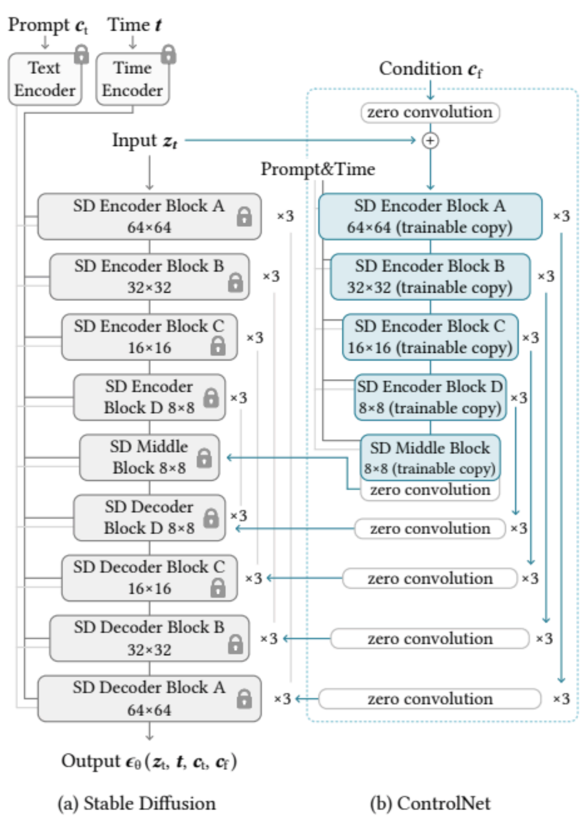

Figure 2 : ControlNet

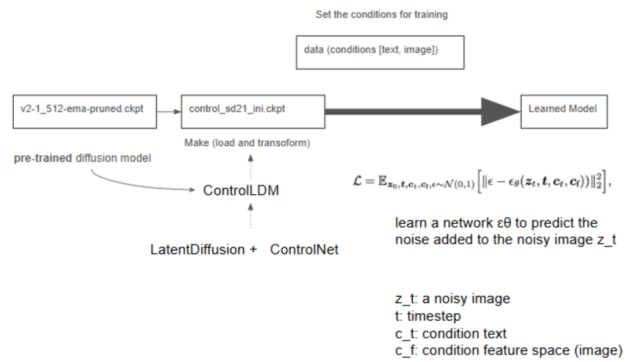

Figure 3 : Current Architecture

RESULTS

The model has been divided into train and test datasets with about 832 images in the train set and 208 in the train set.The back bone model shown the structural similarity index(SSIM) of 0.383(Scale being [-1,1]) and the mean squared error is 45.76. The below image shows us the time slot performance in the Average SSIM v/s MSE over time.

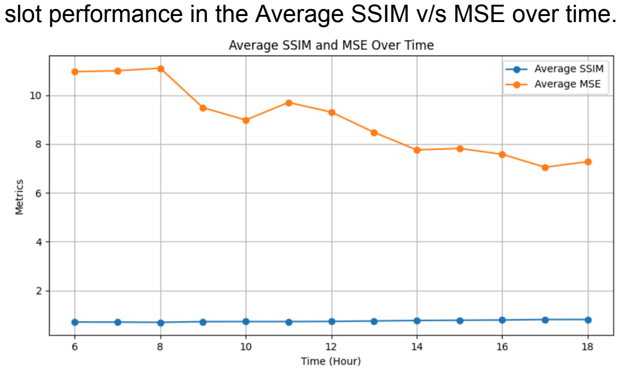

Figure 4 : Current Performance

The below graphs depict Average MSE over time(Figure 5) and Average SSIM over time(Figure 6). As depicted in the images the error is decreasing as the model trains on more and more data, probably because the parameters during initialization weren't the perfect ones.

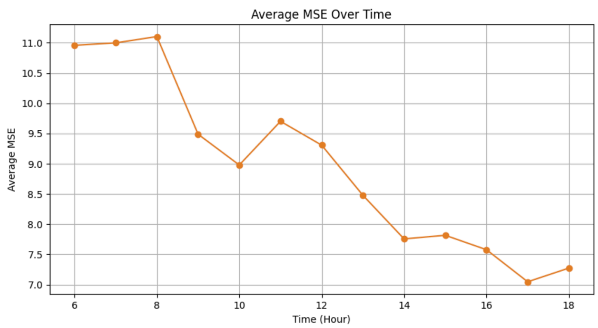

Figure 5: Average MSE Over Time

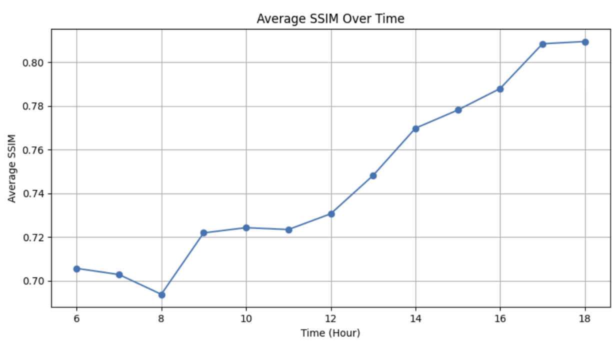

Figure 6 : Average SSIM Over Time

Also as the initial performance is comparatively worse than the later time, it also indicated that the model isn't doing good in learning the features of the images recorded at 6 am in the morning, as when the dataset is passed these images contribute towards the initial performance of the model. To resolve this problem running the model by shuffling the images would be an efficient solution to look at the possible ways to increase the performance of the model.

CONCLUSION

TBD

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