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Smoothing the Ride: A Surface Roughness-Centric Approach to Bicycle Routing

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Abstract. This study addresses the impact of surface roughness on bicycle route planning, emphasizing the combination of vertical acceleration and speed. The approach introduces an index derived from surface roughness that is used as an impedance in existing routing algorithms. The study evaluates bike routes based on real and modified edge lengths, revealing differences in surface roughness. Challenges, including bike variability and accelerometer limitations, are discussed. The method effectively captures regions with higher surface roughness, offering valuable information for bike route planning. Its reliance on smartphone accelerometer data makes a step towards widespread applicability.

Keywords. Bikeability, Smartphone-accelerometer data, Routing, Open-source

1 Introduction

The 2022 Intergovernmental Panel on Climate Change (IPCC) underscores the transition to biking as a viable CO2 mitigation strategy. It aligns with multiple Sustainable Development Goals (SDGs) (Lee et al., 2023). This alignment is confirmed across ten of eleven assessed SDGs with medium to high confidence. It highlights the significance of promoting bicycles over cars to alleviate congestion and enhance overall citizen well-being.

Augsburg, located in southern Bavaria, actively embraces this shift towards biking, recognizing benefits such as minimal spatial demand, noiseless mobility, and positive impacts on well-being beyond CO2 reduction [1]. Additionally, biking integrates well with public transport (Willberg et al., 2021). However, achieving ambitious biking goals in cities necessitates addressing resource limitations.

Various scientific studies on bikeability have approached this challenge from different perspectives, utilizing surveys to understand bikers' experiences (Jonietz and Timpf, 2012; Wahlgren and Schantz, 2012; Handy et al., 2010; Joo et al., 2015) or deriving indexes from sensor data to identify key factors (Krisp et al., 2021; Bíl et al., 2015; Gao et al., 2018). The common goal is to comprehend the factors influencing bicycle usage, facilitating effective city planning and improvement processes.

Crucial to these planning processes is high-quality data, with accelerometers being a valuable source. When combined with Global Navigation Satellite System (GNSS) data, accelerometers measure road surface roughness. The relationship between road comfort and cyclist perception is then assessed through questionnaires (Bíl et al., 2015; Gao et al., 2018). This data connection has two implications: first, identifying roads or segments for improvement, and second, enhancing existing routing systems.

Cities aiming to provide such services face challenges in obtaining widespread, high-quality data at regular intervals. Current methods rely on laboratory bicycles, specific measurement devices, and instructed personnel maintaining certain speed levels (Bíl et al., 2015; Gao et al., 2018; Joo et al., 2015), limiting data collection to smaller areas due to the associated effort.

We propose changes to make accelerometer data collection more feasible for bike route planning. These changes include A) accessible, affordable, and easy-to-use measurement tools, B) addressing data quality concerns through increased quantity, and C) extending the index to accommodate different individual travel speeds, impacting vertical acceleration significantly.

The goal of this short paper is to explore options that such an index offers to enhance existing routing algorithms with the information of surface roughness. The idea being to enable eventual cyclists to chose their next route with or without regards to the unevenness of road surface.

[1]https://www.augsburg.de/buergerservice-rathaus/verkehr/radverkehr, last access: February 16, 2024

2 Background

In their work on bikeability Jonietz and Timpf (2012) develop a methodology to calculate an index for the bicycle friendliness of a given road network. They highlight the importance of the subjective perception of the factors influencing a bicycle road networks level of service. That has been assessed in the meantime by some researchers (Bíl et al., 2015; Gao et al., 2018).

Bíl et al. (2015) developed a new method for objectively measuring bicycle vibration called the dynamic comfort index (DCI). They applied this method on various road sections with different surface pavements. By testing the DCI on three different bicycles and eleven road sections, they demonstrated the simplicity and robustness of their data capturing method, which can be widely applied. The study highlights the importance of objective vibration measurement in assessing cycling comfort and route suitability, providing a valuable tool for planning and managing bicycle facilities.

Gao et al. (2018) conducted field tests to measure cycling vibration data using a Dynamic Cycling Comfort Measure System. They collected data on pavement conditions, weather, road geometry, congestion, and traffic conditions to assess cyclists' comfort levels. Seventeen volunteers participated in the study, providing feedback on vibration perception, overall comfort, and road conditions. Their study aimed to understand how vibration affects cyclists' comfort and how this information can be used to enhance cycling infrastructure in urban areas.

Both come to the conclusion that accelerometers mounted on bicycles are a good option of measuring surface roughness of roads. Further both papers mention the importance of travel speed and the kind of bicycle used for the measurement.

Aultman-Hall et al. (2012) emphasize the significance of having a readily applicable method, stressing that the absence of standardized procedures has resulted in data collection occurring sporadically and on a project-specific basis at isolated sites. This fragmentation hinders the ability to extrapolate findings across entire systems. Overcoming this challenge is crucial, as conventional data collection methods such as interviews have proven to be cumbersome and project-specific. Thus, it remains imperative to explore the possibilities of data acquisition and processing.

3 Data

The region chosen for this study is called the Jakobervorstadt in Augsburg. Figure 1 shows the region of the case study and the raw speed and acceleration data visualized as heat maps. The heat map showing the travel speed exemplifies that the speed is highest on the big streets around the living space of the Jakobervorstadt-Süd. There are many specific bicycle lanes where it is easier to go faster. When looking at the data statistically the speed in the north is relatively high. That is not depicted in the heat map, because of the search radius of the heat map that does not find as many points because the roads in the north the are not as dense as in the south.

The area was selected because of the heterogeneous road network with all kinds of different surfaces. In tendency the southern and central part of the region features roads that are smaller and narrower than in the north. In the south some roads have cobblestones, or are laid with gravel around the river of the park. That can be seen in figure 1 as there are more spots with higher linear acceleration in the south than in the north.

Table 1. Network statistics between north and south

category	north	south
nr. of edges	994	285
nr. of nodes	428	144
edge length avg	36.91	35.38
edge length total	36697	10083
intersection count	304	100
intersection density	417.12	456.20
street length avg	37.53	37.53
street length total	19933	6156
street segment count	531	164

In this work *OSMnx* is used to obtain a road network and calculate the shortest route based on a weight that can be specified (Boeing, 2017). It also offers the option to download a network for bicycles. In case study region no underpasses exist, which could cause problems with the routing. *OSMnx* also allows a statistical evaluation of the downloaded networks, from which a selection of values can be seen in table 1. As can be seen the overall count of edges and nodes and the total street- and edge length is higher in the north. Yet, the density of intersection is higher in the south which points at more smaller streets. The rest of the relative values (density, average) are comparable, because of the difference in size of the two regions.

4 Methodology

The data was collected with a simple rubber holder for the handlebar of a bicycle as is shown in figure 3. Thus, the smartphone is mainly affected by the roughness beneath the front wheel of the bicycle.

The software used to collect and store the resulting acceleration data in csv-files is the *physics toolbox suite* [2] by *Vieyra Software*. It saves the linear acceleration in X / Y / Z directions (compare figure 3) together with a GPS point among other data. Because the measure frequency of the accelerometer is higher than that of the GPS many measure points share the same geotag.

[2]https://www.vieyrasoftware.net/; last access: February 16, 2024

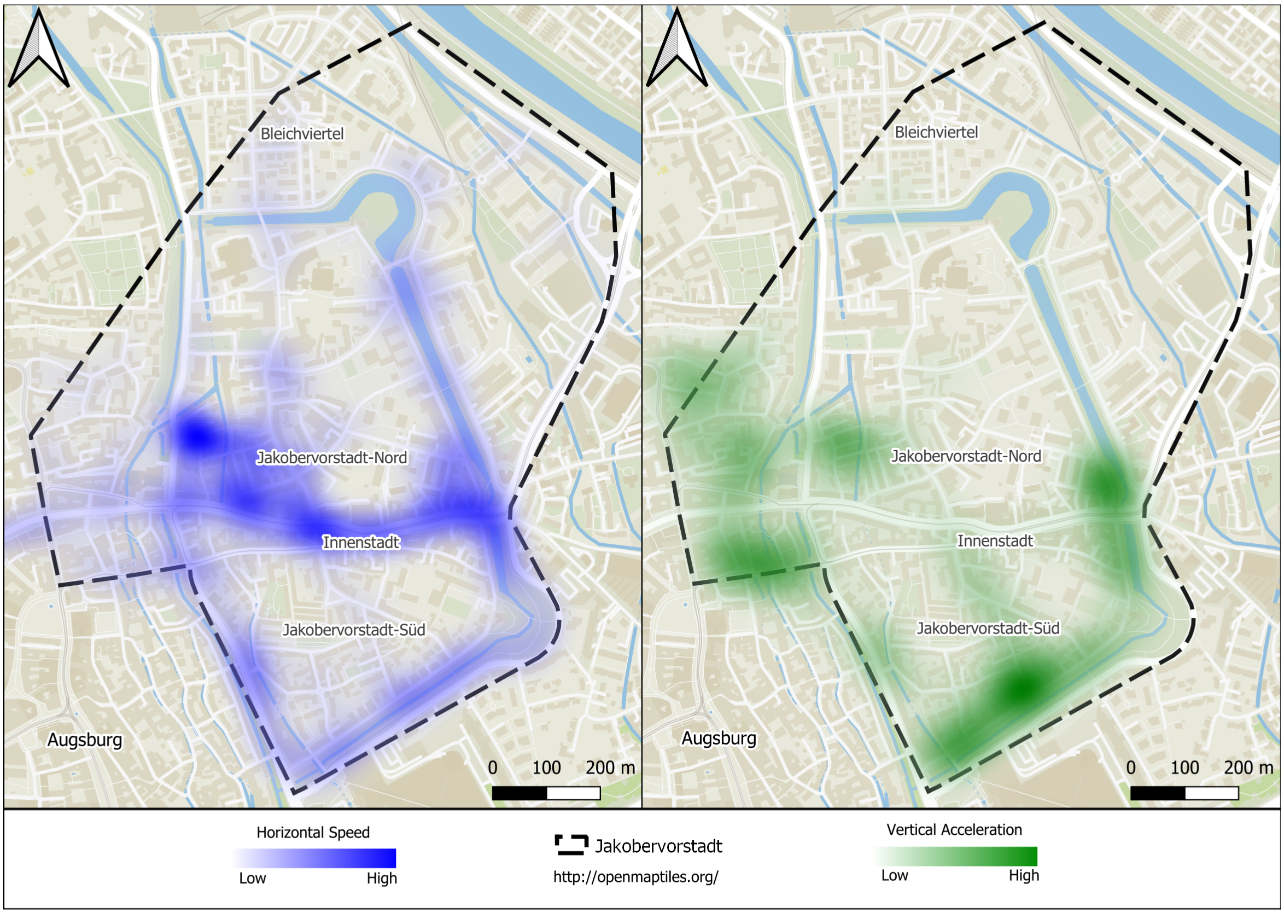

Figure 1. Overview of the region Jakobervorstadt of the case study and giving an overview of the collected data in form of heat maps

For the data accumulation each edge of the network was measured twice, each time with a different type of bicycle. One being a mountain bike with suspension the other a normal bicycle that is rentable at many points in the city. The latter having no suspension and thinner wheels. The same rubber holder and smartphone is used for all of the measurement tours.

The index value is calculated differently from those of other works. Its formula is as follows:

$$I(i) = \frac{\alpha * \frac{(|a_i| - \bar{a})}{std(a)} * \frac{1}{\exp(\beta * \frac{v_i}{max(v)})}}{max(|I(i)|)} \quad (1)$$

- $I(i)$ is the index of measure point i
- a is the Z-acceleration
- v is the travel speed
- $\bar{x}$ is the total mean
- $std()$ is the standard deviation
- β, α are factors that were obtained by testing

In formula 1 the acceleration in vertical direction is damped by the travel speed. It is then divided by the highest index value, such that the index ranges between -1 and 1. The idea behind the damping is that at higher travel speed the vertical acceleration caused by a unevenness is bigger than that of the same unevenness, but with lower travel speed. This is one possibility how to tackle the issue with different speeds, which was mentioned in section 1. Its impact can further be adjusted with varying values for the β factor. The index value with which the edge length is manipulated in a later step can be seen in figure 2.

This index is small when the roughness of the surface is low and vice versa. It is then added to one so that it potentially ranges from 0 to 2 and subsequently multiplied with the *real-length* of the edge. The altered length is called *felt-length*. The network contains two different lengths, which can than be used as an impedance for routing algorithms. *OSMnx* brings along a function to calculate such routes based on a given impedance.

5 Results

The first part of the results is the comparison of the two maps of figure 1 and 2. In the southernmost edges the in-

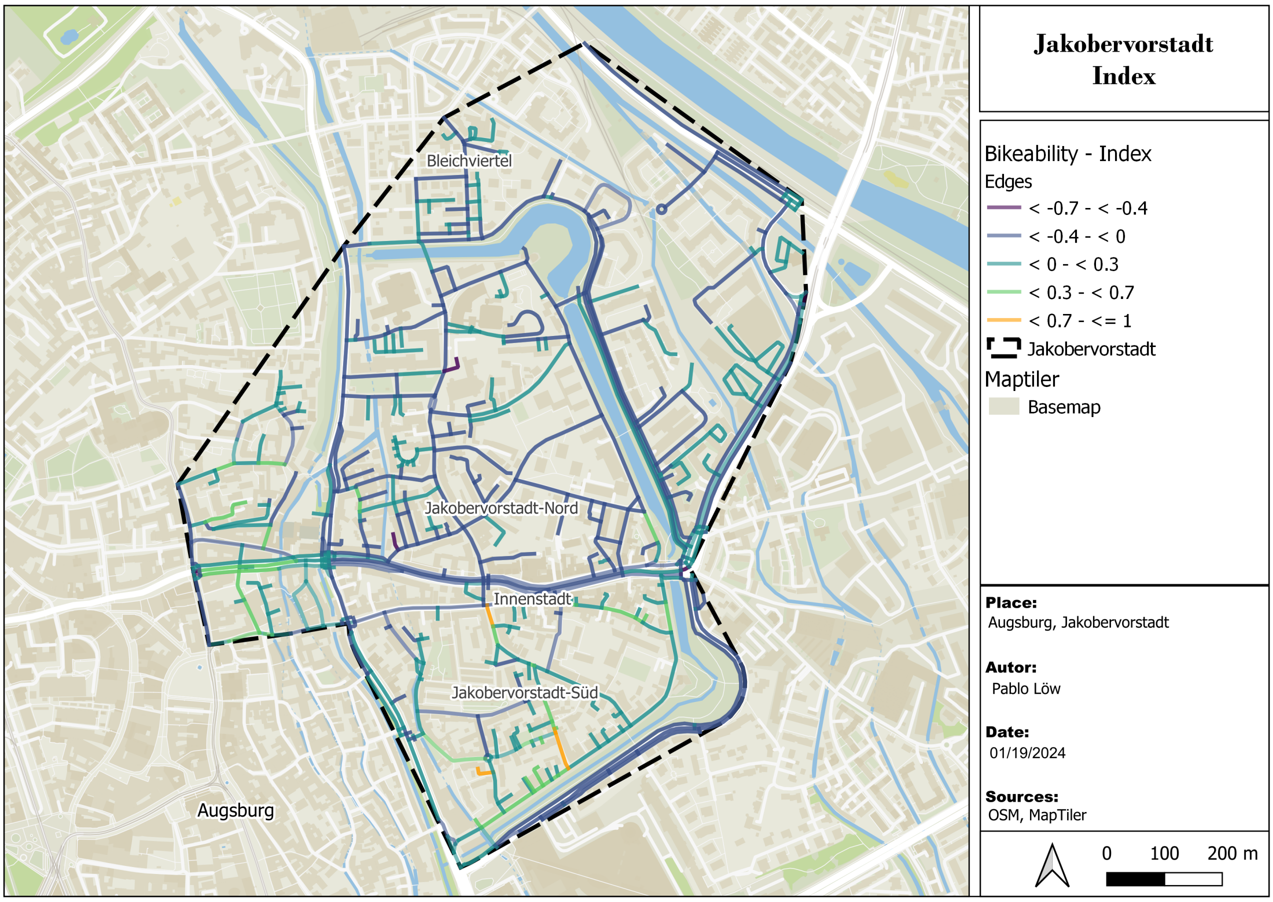

Figure 1. Overview of the region Jakobervorstadt of the case study featuring the street network coloured by the bikeability index

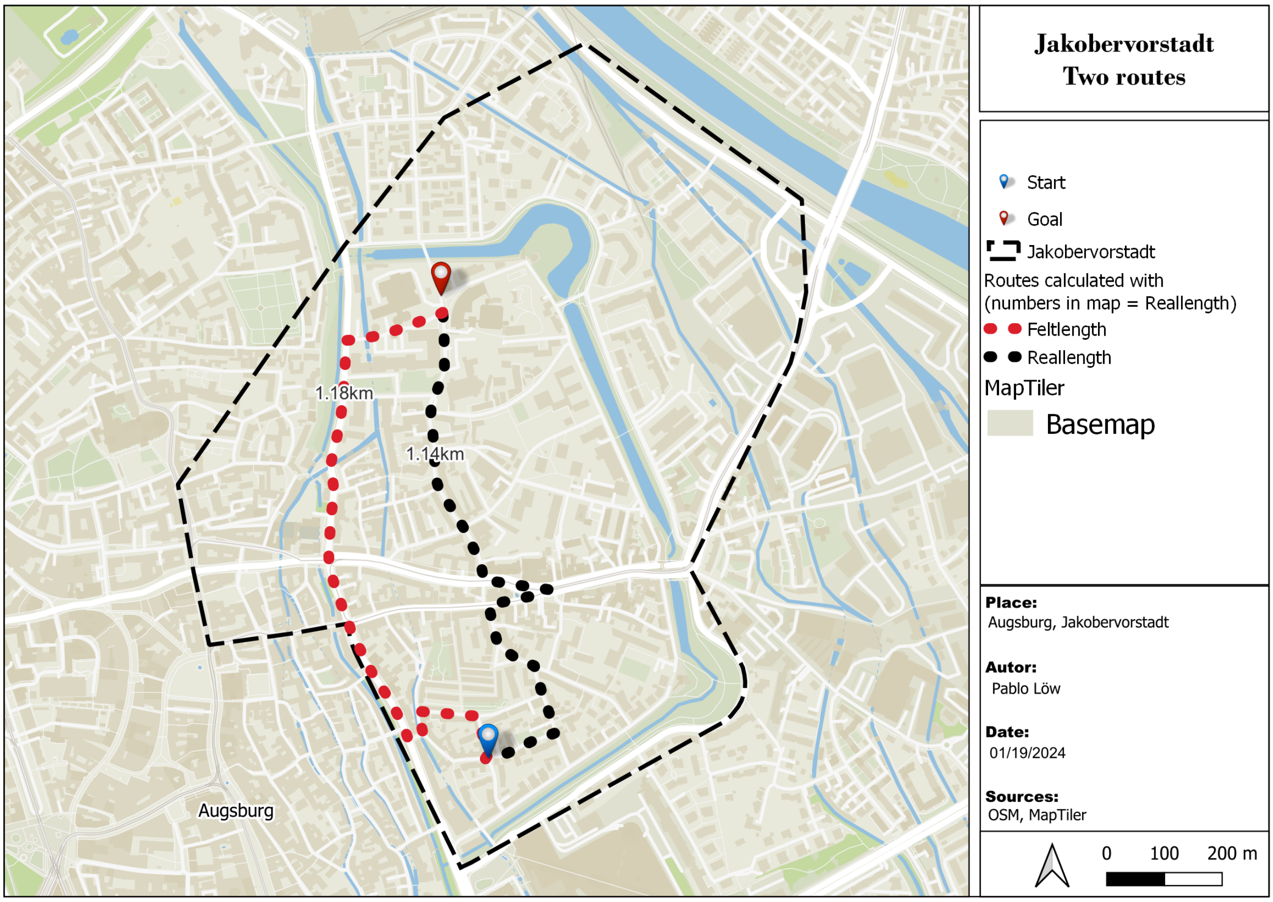

Figure 2. Two different routes from the same start- and end- point. The black one calculated with the real length and the red with the felt length

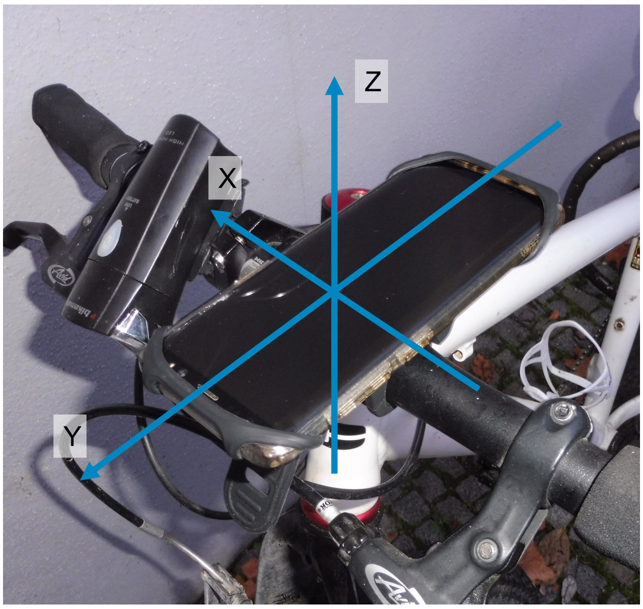

Figure 3. Rubber mounting of the smartphone to the handlebar

dex is above zero, but not very high. Even though the heat map of the acceleration is comparable high there. That can be attributed to the high travel speed, which is also high at these roads as can be seen in the corresponding heat map.

Accordingly in the north some streets have also indexes above zero even though the heat map did not show them as places with especially high vertical acceleration. But, because the travel speed is also not high there, even smaller spots with uneven road surface, result in a slightly higher index.

The second part is the actual calculation of routes in the modified network. The shortest routes between two points is calculated using a default function of the *OSMnx* package with different weights (real- and felt-length). The two different routes can be seen in figure 2.

When evaluating the two routes in terms of surface roughness one has to look at the index of the edges they are following. That is shown in the upper map of figure 2. Starting in the south, where the edges with the highest indexes can be found due to the slow travel speed and the cobblestones. The red route (felt-length) follows the two blue edges first to the north and then to the west, instead of going immediately along the green edge to the west. Which is only a minor detour compared to the total length of the route.

The black route (real-length) goes directly over some greenish and even a yellow edge to the east. This way has more uneven road segments in total, but is ca. 40 meters (real-length) shorter.

6 Discussion and conclusions

Measuring the roughness of the pavement via a phone attached to the handlebar as a method has its challenging parts. One is that every bicycle is different and in this case study two different ones were used, to reflect the wide range of available options. Interestingly the bicycle with suspension provides more extreme vertical acceleration values compared to the normal one. This finding aligns with the findings of Gao et al. (2018). The influence of tyre pressure and different types of suspensions could be subject to further research, but is beyond the scope of this short paper.

The accelerometer has a maximum acceleration value that can be measured, due to which a minor error between the different bicycles exists at points with extreme roughness. An important aspect of this method is that via crowd sourcing, more data for a region is acquired. Thus, such effects and measuring errors would be partly circumvented due to the averaging effect.

The rubber mounting is not firm, but relatively swingy and shakes at higher speeds on small disruptions of the street surface. If the position of the smartphone changes, that can lead to measuring errors on the Z-axis. It can affect the quality of the measurement. The test driver of this study was aware of that problem and put the smartphone back into the horizontal position whenever necessary.

With the exemplary aspect of crowd sourcing in mind there are two ways to deal with that issue. The first is to only consider data for the index that has less than a certain tilt angle, which would lower the amount of available data. The second is to use this angle and correct the values of the Z acceleration. The last option is computationally more complicated. Still, it is important to note that for the idea of crowd sourcing to be successful, the mounting of the smartphone should not be too complicated or expensive. Thus the error, especially because its possible to deal with it, is not outweighing the benefits. As the test data presented in this paper proves, the measurement yields relevant results.

The two different routes from which one is calculated with the normal edge length as weight and the other with the modified, show that the method successfully captures regions at which the surface roughness is higher and makes this information available for routing. That is interesting when bicycles with no- or little suspension are being used. With these the ride is more enjoyable on an even road surface. The knowledge of the surface roughness along the route is especially relevant for racing- and transport- bicycles.

The method is dependant on the existence and quality of a road network obtained with *OSMnx*. But because it is easy to obtain one for nearly anywhere on the planet that is not a problem in most of the cases. The quality of the OSM data is usually acceptable, especially in places where many people live (Boeing, 2017; Mooney et al., 2010).

Even though it already provides useful results future research on the behaviour of different bicycles and mounting tools and positions could lead to a more precise index. Another direction for research is the arbitrarily chosen factors α and β, which can be used to change the effect of the speed on the index and the stretching of the edge length.

The necessary data for this methodology is open source and can be gathered via crowdsourcing programs. It is thus applicable to most places of the world. Either the road network exists or it can be created by the inhabitants themselves via OpenStreetMap. Cyclists have their own interest in participating because it can improve their options of route finding.

A strength of this approach is that it creates an option. It can be chosen to consider the surface roughness or not when searching for a route, or calculating both and then selecting. The information it provides can be visualized as well in form of, for example, service areas.

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