Towards Deriving Incline Values for Street Networks from Voluntarily Collected GPS Data

John, S.[1,2], Hahmann, S.[1], Zipf, A.[1], Bakillah, M.[1], Mobasheri, A.[1], Rousell, A.[1]

[1] Chair of GIScience, Department of Geography, Heidelberg University, Germany

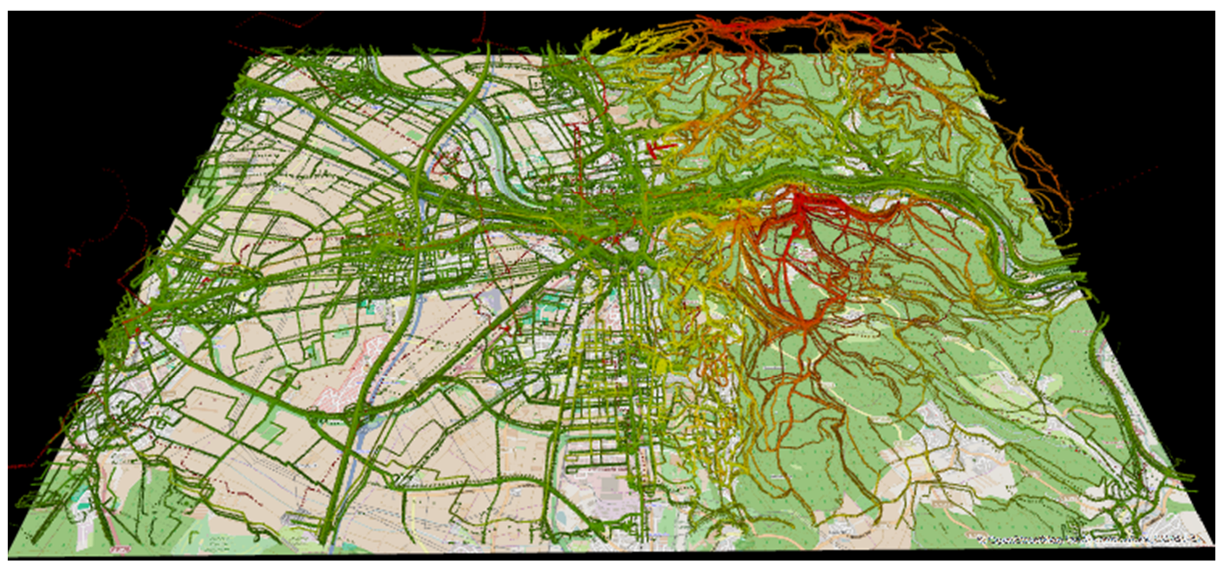
[2] Institute of Geodesy and Geoinformation Science, Technical University of Berlin, Germany

1 Motivation

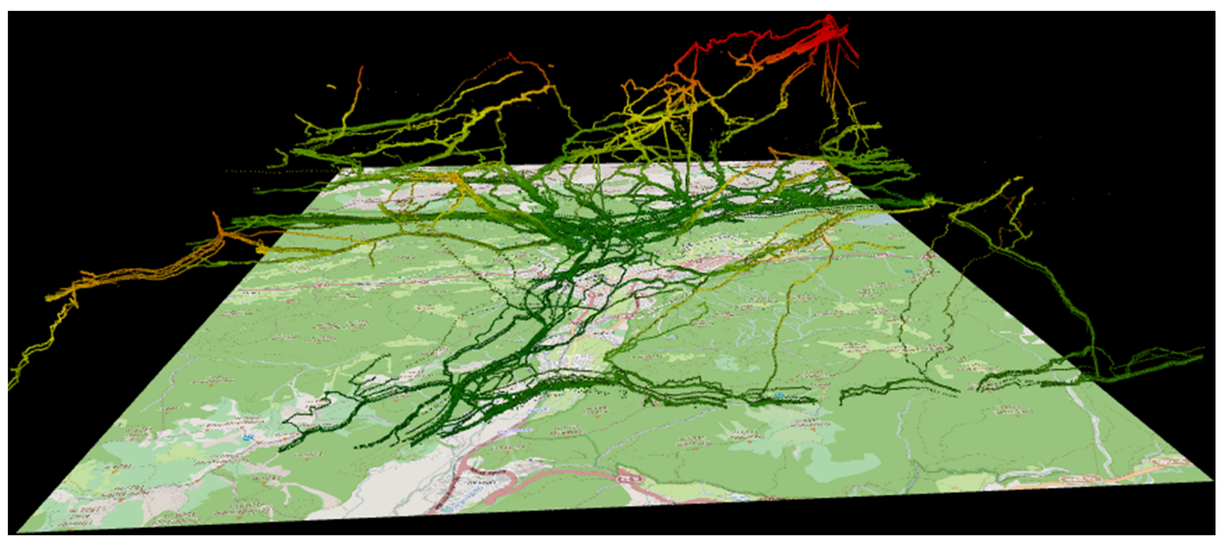
When producing **optimal routes** through an environment, considering the **incline** of surfaces can be of great benefit. For instance, incline should be considered when computing the most **energy efficient routes**, which is relevant for electric cars and bicycles. Likewise, pedestrians with **restricted mobility** (such as wheelchair users, parents with pushchairs, and the elderly) often have to and/or want to avoid steep ways.

Such information may be derived from different types of digital elevation models (DEM). Capturing methods for **high-resolution DEM** (e.g. airborne LiDAR, photogrammetry, terrestrial surveying) are **expensive**. **Low-cost** and/or open licensed **DEM** (e.g. SRTM, ASTER) generally **do neither have sufficient horizontal resolution** (SRTM-1 and ASTER: 30m) **nor sufficient vertical accuracy** (SRTM RMSE: 6m in Eurasia [1], ASTER RMSE: 9m overall [2]).

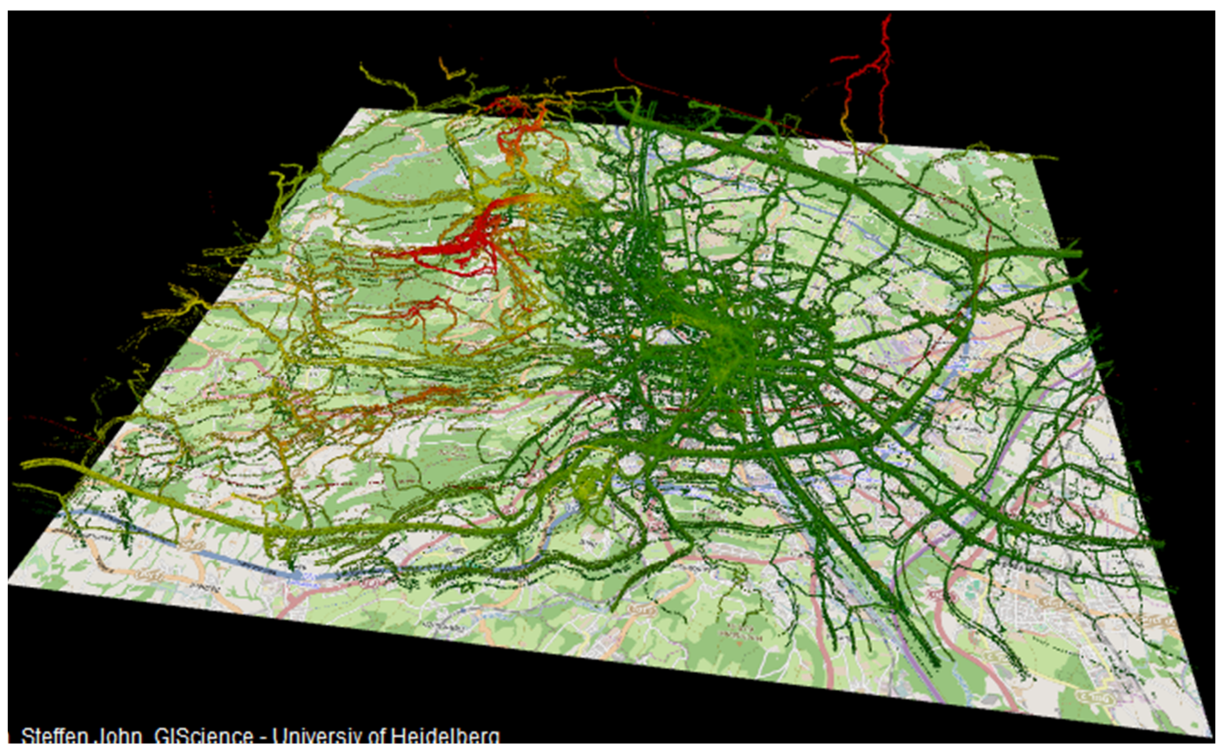
We therefore investigate an alternative **low-cost approach** which **derives street incline values from GPS traces** that have been voluntarily collected by OpenStreetMap (OSM) contributors.



OpenStreetMap GPS tracks in the region of Garmisch-Partenkirchen, Germany
Vertical exaggeration: 2
http://cap4route.geog.uni-heidelberg.de/hd-osm-gps-webgl/gap-osm-gps-webgl.html



OpenStreetMap GPS tracks in the region of Garmisch-Partenkirchen, Germany
Vertical exaggeration: 2
http://cap4route.geog.uni-heidelberg.de/hd-osm-gps-webgl/gap-osm-gps-webgl.html



OpenStreetMap GPS tracks in the region of Salzburg, Austria
Vertical exaggeration: 2
http://cap4route.geog.uni-heidelberg.de/hd-osm-gps-webgl/salzburg-osm-gps-webgl.html

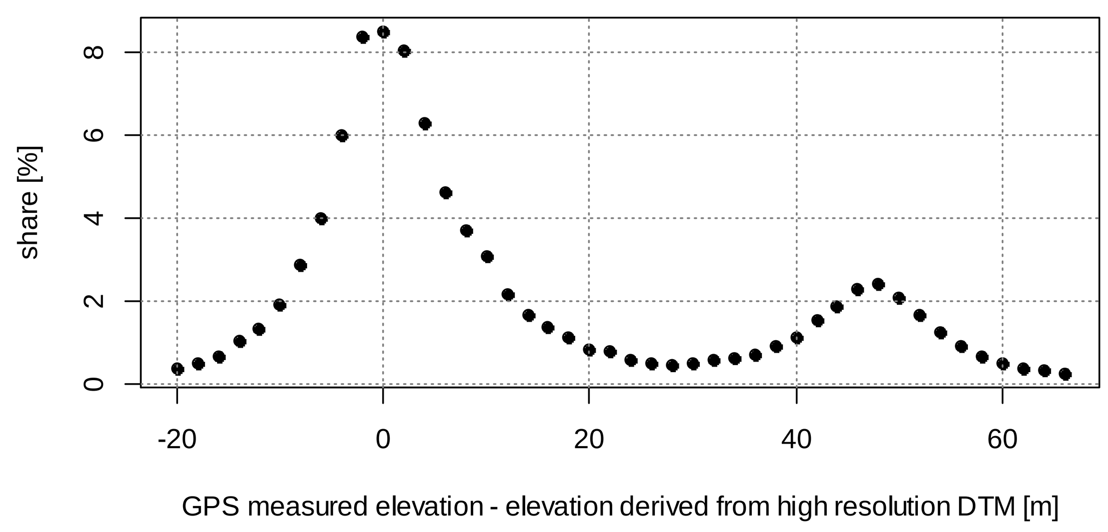
2 Input Data

GPS data uploaded to the OSM servers is a popular example of what has been termed Volunteered Geographic Information (VGI) by Goodchild [3]. The data has been (and is still) collected by the project contributors primarily to support mapping. As the inclusion of roads and paths in the map is a major goal of the project, the collected GPS data often follows such man-made structures.

The latest version of the **GPX planet-file** is dated **August 2013** and contains around **2.7 billion points worldwide**, although most of the data contributions are located in Europe, e.g. according to our findings there are **0.2 billion GPS points** in **Germany** (7% of total points).

In our study region of Heidelberg we have computed the differences between GPS elevation measurements and a high resolution DEM (1m horizontal resolution, ≤0.5m vertical accuracy). We have found an **RMSE of 27m**. The **horizontal accuracy** can be assumed to be better – according to Liu et al. [4] it is **between 5 and 10 meters**.

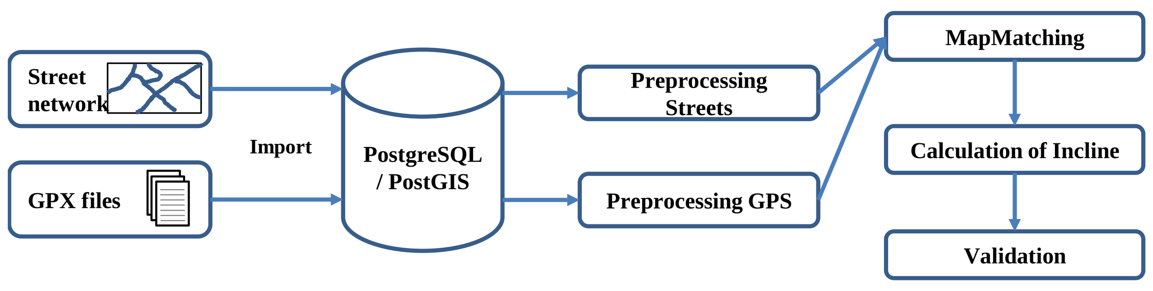
Distribution of errors of GPS elevation measurement. The peak at ~48m may be explained by the difference of 48m between WGS84 ellipsoid used by some GPS devices for elevation measurement and the EGM96 geoid used by the reference data for elevation values above sea level.



OSM GPS Planet file:
http://planet.openstreetmap.org/gps/
Regional extract:
http://zverik.osm.rambler.ru/gps/files/extracts/index.html
Tool for conversion to 3D Shape Files:
https://github.com/GIScience/osmgpxfilter

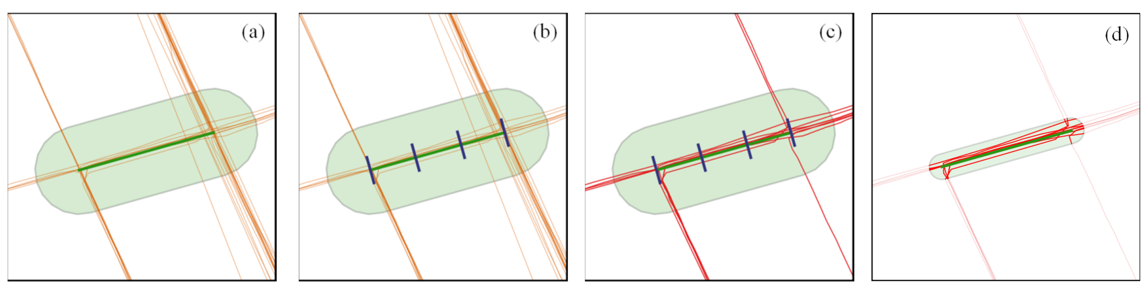
3 Methods

The approach is to match GPS tracks to the street network, where they serve as input for the computation of incline per street segment. For the validation we use a high resolution (1m) DEM.



3.1 Map Matching

Simplified process of [5]: (a) Select candidate tracks using a buffer (light green) around a street segment (dark green), (b) create profile lines (blue), (c) select GPS tracks (red) which intersect at least 70% of the profile lines and (d) clip GPS tracks at buffer.



Tool for Map Matching of OSM network and GPS tracks
https://github.com/GIScience/osmgpxmapmatcher

The table shows the share of covered way segments and the average number of tracks covering a way segment per feature class.

feature class	covered segments [%]	avg # of tracks
motorway	100	121
primary	100	24
secondary	98	13
cycleway	93	13
residential	62	4
path	57	5
footway	40	5

3.2 Calculation of Incline

Prior to incline computation, the (noisy) elevation values of the GPS tracks are smoothed using a weighted average filter. The incline is then computed as follows:

$$m^t = \sum_{i=1}^{n-1} \left(\frac{h_i - h_{i+1}}{d_{i,i+1}} \right) \left(\frac{d_{i,i+1}}{l} \right) ,$$

m^t .. incline of GPS track segment in %
n .. number of nodes in GPS track segment
h .. elevation of track point
d .. horizontal distance between two track points
l .. horizontal length of GPS track segment

4 Results

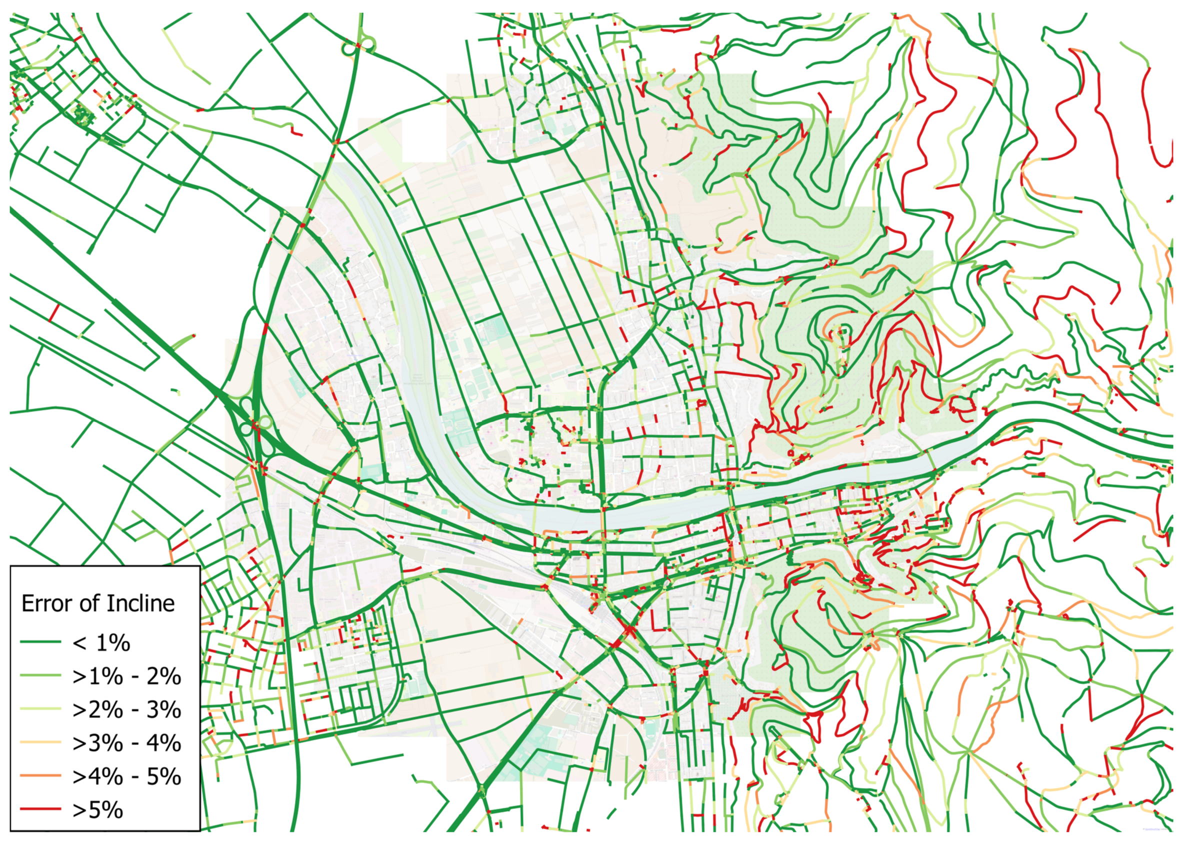
The **inner accuracy** of the elevation values measured with low cost GPS devices is better than their absolute accuracy. The **RMSE** of the **elevation differences** between 2 consecutive GPS points (smoothed data) and the high resolution DEM is **0.3m** resulting in an average error of the estimated incline of **2.4%**.

Due to the characteristics of the GPS measurement method there are better results in grass and residential areas than in forest areas.

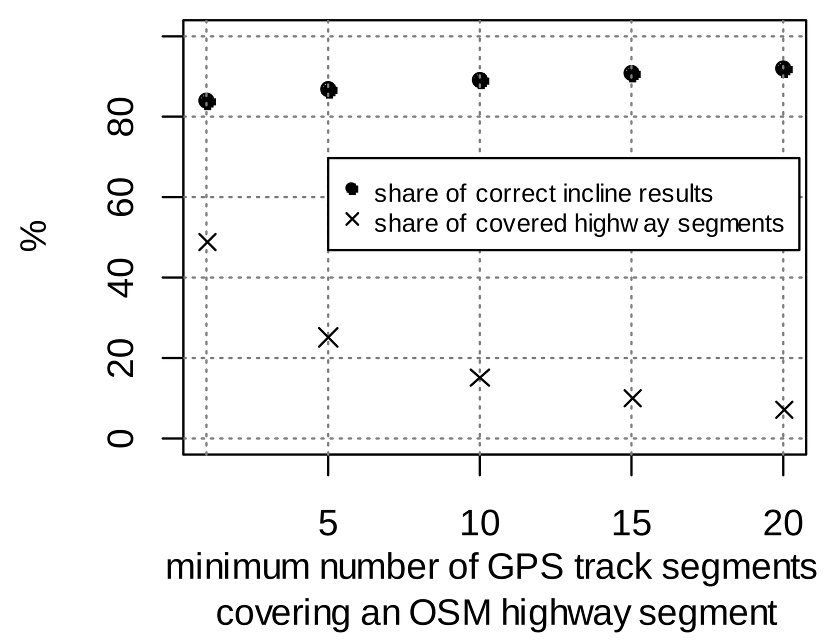
land use	RMSE Δh [m]	∅ distance [m]	≙ incline [%]
overall	0.3	13	2.4%
forest	0.5	11	4.4%
grass	0.2	29	0.8%
residential	0.3	10	2.7%

The table and the map show results for the incline calculation using only ways that are covered by at least 3 GPS tracks. The share of ways is computed where the error of the computed incline is less than 3% compared to incline values derived from high resolution DEM. Results using GPS are slightly better than results using SRTM. However, coverage for GPS is significantly worse.

data	incline error < 3% [%]	covered ways [%]
OSM GPS	86.3	37
SRTM	83.3	100



The share of street segments that have an error in the incline computation of up to 3% increases from 84% to 92%, if we consider only way segments that are covered by at least 1|5|10|15|20 GPS tracks. However, for the same scenario the share of covered way segments decreases from 49% to 7%.



References

[1] Farr, T. G.; Rosen, P. A.; et al. (2007): The Shuttle Radar Topography Mission. In: Reviews of Geophysics 45 (2).
[2] Meyer, D. J. (2011): ASTER Global Digital Elevation Model Version 2 – Summary of Validation Results. Online Report.
[3] Goodchild, M. F. (2007): Citizens as sensors: the world of volunteered geography. In: GeoJournal 69 (4), pp. 211–221.
[4] Liu, G.; Hossain, K.; et al. (2014): Beyond horizontal location context: Measuring Elevation Using Smartphone's Barometer. In : UbiComp '14, pp. 459–468.
[5] Zhang, L.; Thiemann, F.; Sester, M. (2010): Integration of GPS traces with road map. In : IWCTS '10, pp. 17–22.

MyAccessible.EU

A part of the research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 612096 (CAP4Access)