eNav:

A Suitable Navigation System for the Disabled

Dženan Džafić, Pierre Schoonbrood, Dominik Franke, and Stefan Kowalewski

RWTH Aachen Embedded Software, Ahornstraße 55 52074 Aachen
{dzafic, schoonbrood, franke, kowalewski}@embedded.rwth-aachen.de

Abstract Navigation for disabled people in wheelchairs is a huge challenge: stairs and curbstones can already hinder a wheelchair to pass the route. The availability of affordable increasingly powerful smartphones and Internet allows for smart applications, which can help wheelchairs users to find a valid and accessible route. In this paper eNav is presented, which is such an application. It brings together different features to help routing for wheelchairs. eNav links big data from areas of maps, incline and different disability databases to compute the most energy-efficient route between two points. The complex and cumulated data is presented to the disabled in a very simple and understandable manner via desktop PCs or smartphones. By using crowd sourcing technology, eNav users have the possibility to increase the map data used by eNav. An evaluation between the energy-efficient and the shortest route shows that in 41% of all tested routes, the efficient route uses less energy than the shortest.

Keywords: disabled, wheelchair, navigation, eNav, energy efficiency, crowdsourcing, OSM, POI, accessibility

1 Introduction

There are 7.5 million people living in Germany which are severely disabled. This corresponds to 9.4% of Germany's total population [1]. This community should not be ignored during the development of navigation systems.

A specific routing system requires more than accessible routing. Electric wheelchair user not only have problems judging whether a route is barrier free or not, they also need to determine whether the battery level of their wheelchair suffices to bring them to their destination and, even more importantly, back home.

Battery indicators of electric wheelchairs are generally not reliable. On one hand, they behave in the same way as battery indicators of old cellphones. The battery level is indicted as full most of the discharge time. If the battery is discharged to a certain level, the battery indicator quickly depicts the battery as depleted. On the other hand, even if the battery indicator would depict depletion linearly, it is hard to determine the reach of a certain battery charge level. This is caused by the strong dependency between the incline and the energy consumption of electric wheelchairs [21].

To tackle these challenges, the map-data used in common navigation systems needs to be enriched with relevant data like altitude and surface information.

In this work, the eNav navigation system is presented. It proposes smart and innovative solutions to these challenges. It is basically founded on a wide collection of different maps extended with detailed information about the nature and the quality of the roads which hinder wheelchair user. To collect the necessary map-data for this task, several distinctive sources and methods are used.

In the next section, basic notions and definitions are given. Afterwards, the architecture of eNav is discussed, followed by a detailed explanation of the components of the architecture as well as the methods used in eNav for computing the energy efficient route. Finally, the profitability of the most energy efficient route is evaluated in contrast to the shortest route.

2 Preliminaries

This section gives a short definition of accessibility with regard to handicapped people. It furthermore describes the nature and reveals the source of road or rural maps upon which our special navigation system eNav is build. In addition, it introduces the A^*-algorithm adopted for the eNav distance computation. It finally concludes with an overview of the crowd sourcing concept which is used to enhance data fed into eNav.

2.1 Accessibility

To guarantee for equal rights between physically handicapped and non-handicapped people, the German law defines the notion of accessibility as follows:

> “Building works and other constructions are accessible […], if they are usable and accessible by the disabled in the usual way, without any unusual complications principally unaided.” (BGG § 4)

This legislation consequently imposes an environmental infrastructure allowing disabled people to use it at least with the same effort as persons without handicaps would do. This work focuses essentially on accessibility notion related to mobility impaired people.

2.2 Map sources

To enable accessible routing, eNav uses a three-dimensional map which is enriched with additional information from several distinct sources. OpenStreetMap (OSM) is used as a main source of base maps. These maps are extended with laser scan data and surface type information, which is provided by the municipality of Aachen.

2.2.1 OpenStreetMap (OSM)

The OSM platform was the best free source found to acquire maps for eNav. According to [2], no other open source project exists with a comparable world map data density and reliability like OSM. Additionally, OSM provides a good basis, to extent its data, available in XML-Format, with project specific data. There are tags for this purpose, which describe a property and are stored as a key-value pair in the OSM-files. For three-dimensional routing, especially the tags with the key altitude and elevation are of interest. These tags store height information of nodes. Considering eNav and its routing, several other tags like “wheelchair”, “step”, etc. are of interest as well.

2.2.2 Laser scan data

The height information indispensable for eNav is only sparsely available in the OSM-maps [3]. The integration of this information into the OSM-maps is of decisive importance not only to eNav but also to other projects, like a simple 3D illustration of OSM-maps [4]. This crucial height information with which the OSM-maps are enriched is provided by laser scan data.

This data is acquired during an earth surface scanning done by an airplane using laser tracking with a frequency of approximately 200 kHz. The laser pulses send from the airplane are reflected on the earth’s surface and then captured again by the airplane sensors. From the resulting elapsed time, the relative distance between the laser scanner on the airplane and the earth’s surface is calculated. Using other sensors on the airplane, like GPS and IMU, the relative distance to the absolute height of earth’s surface is recalculated.

During scanning of large areas, the airplane flies striped patterns possessing a width of several hundred meters. In eNav, a digital surface model with a 1m raster (DOM1) is used. DOM1 has an accuracy of ±20cm, which suffices for the route calculation used in eNav [5]. The district government of Cologne provided the laser scan data of Aachen for the eNav project, which must be used solely for research purposes.

2.3 A^*-algorithm

The A^*-algorithm calculates the shortest path from A to B. It adopts a similar approach to that of the Dijkstra's [6] algorithm. However, A^* uses a heuristic in addition to path weights to conduct a targeted search and reduce thereby the execution time. An example of such a heuristic is the linear distance between intermediate nodes and the target [6, 7].

2.4 Crowdsourcing

Crowdsourcing is a web-based business model originally proposed by Jeff Howe in 2006 [8]. It is the action of an institution to outsource a task, usually done by an employee, to a network commonly with a large user base in an open tender. On the one hand, the task can be designed to gather new knowledge contributing to the solution of a problem; on the other hand, it can be a contribution to the marketing or the configuration of a product [9].

Part of crowd sourcing is crowd testing. The latter notion originates from software development field. This special test finds software faults by daily monitoring and analyzing th**e** activity of a large user base [10]. In eNav, this technique is not used to detect software faults, but rather to discover inaccuracies in the data used by the software.

3. Related work

In this section, recent projects are listed, which are based on approaches similar to the method adopted for eNav. The projects mPass [11], Easywheel [12], and Path2.0 [13] are excluded from this overview because of their similarities to the OpenRouteService [14] project. Projects like inDAgo [15] incorporate accessible routing as well, but their target group are the elderly.

3.1 OpenRouteService

OpenRouteService (ORS) is an open source route planner based on OSM-maps. The University of Bonn is the original developer of this project, which is currently under active development at the University of Heidelberg. Since the OSM-data used is popular and widespread, the resulting routes are highly reliable. The modes that ORS supports are car, bicycle and pedestrian, which generally suites only common users. However, incline information is only sparsely available. Since

ORS applies the classical A^* search algorithm, incline information is not taken into account during the route computation. That results in distance and time being the unique determining factors for such a computation. For the disabled, a new computation approach *rollstohlrouting.de* is developed. This approach involves the sparsely available incline information, the level of a curbside, the pavement and the width of a carriageway as important factors in route planning.

The ORS service is accessible for users via the *openrouteservice.org*. In addition, other application and clients can use the service via an API. As usual, the user can decide to travel the fastest or the shortest route. This choice influences the calculation. The user is supported by an adequate route description including an output of the route on a map.

3.2 Wheelmap

The founder of *Wheelmap* is the registered association *Sozialhelden e.V*, which is headed by Raul Krauthausen. The main contribution of *Wheelmap [16]* is the ability to tag points of interest (POI) whether they are wheelchair accessible or not and additionally, whether a wheelchair accessible toilet is available or not. In contrast to eNav, *Wheelmap* does not provide any routing functions. The API of *Wheelmap* is used to integrate POI into the eNav navigation system.

4. eNav

eNav is a navigation system for the disabled, which enables them besides accessible routing, to choose a route which improves driving comfort. Additionally, eNav grants electric wheelchair users a better overview of the reach of the battery pack. Usually, battery indication on electric wheelchairs is as inaccurate as those of cellphones. During most of time, the battery is indicated as being full. After some usage time, the battery is quickly indicated as being depleted. An electric wheelchair user can easily make a miscalculation because of this problem. Although he can easily reach his destination, he may not be to go back home.

eNav provides the possibility to calculate the shortest route to a destination, as well as the most energy efficient. Moreover, it presents a course overview about how much of a charged battery is used during the planned trip. Furthermore, by using the *SpiderWebGraph* algorithm [17], eNav is one of the first navigation systems allowing direct routing across flat areas like squares.

A complete software architecture description of eNav is given is the next section followed by a detailed description of single components.

4.1 Architecture

The architecture of eNav is based on the classical client-server architecture. That means the user queries the client for a route. This query is then sent as request to a server. The server in its turn calculates the routes and sends them back as answer to the requesting client, where they are presented to the querying user.

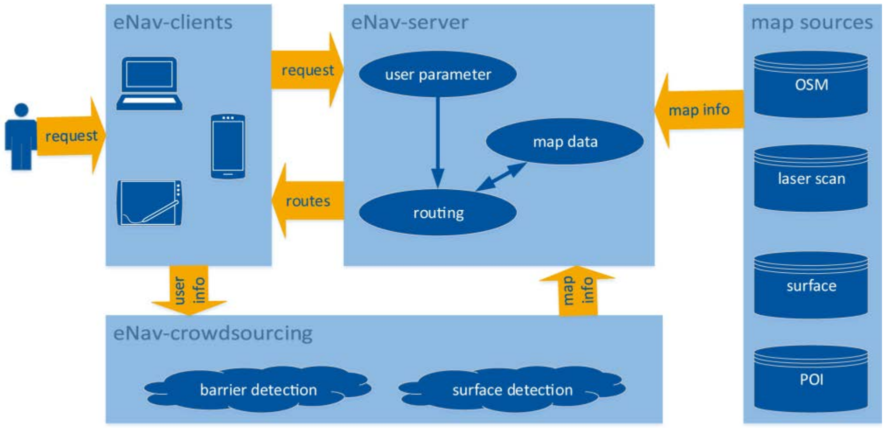

Fig.1. eNav architecture and its components.

The map-data used for the route calculation is gathered from several data sources, as seen in figure 1. Furthermore, the map-data is constantly updated with the help of crowdsourcing.

The next section presents the detailed concept of the client part architecture.

4.1.1 Client

Currently, there is a web-based client for desktops and one for smartphones (figure 1). Both enable the user to enter additional parameters, as can be seen in figure 2 on the left side. A part of these parameters is reserved for properties of the electric wheelchair with which the user wants to travel. These parameters enable, besides the calculation of the shortest route, the calculation of the most energy efficient route.

Figure 2 in the middle shows the choice the user can have, when the shortest and the most energy efficient route differ. If the user selects the energy efficient route, then the distance is increased by 230m, but the energy consumption is reduced by ca. 25% in contrast to the shortest. After selecting one of the two choices, navigation is started and the screen shown in figure 2 on the right can be seen.

The surface type can also be added as an optional parameter for planning the route. A wheelchair user can, for example, choose to avoid cobblestone. This will increase energy consumption, in addition to a possible increase of driving comfort.

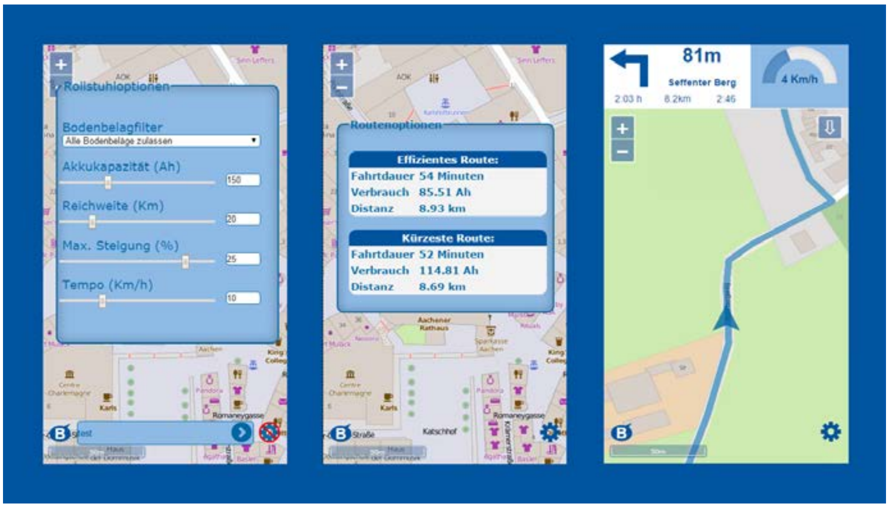

Fig.2. The user interface of eNav. (1) Routing options. (2) Choice between shortest and efficient route. (3) eNav output during navigation.

The parameter incline can be explained twofold. For electric wheelchair users, this parameter can be translated to the maximal incline the wheelchair can cope with. For hand-operated wheelchair users, this parameter can be interpreted as the maximal incline the user can or wants to overcome. During the route calculation, the server rules out any route that includes an incline greater than the maximal incline set by the user.

4.1.2 Server

The server (figure 1) takes care of every aspect of route calculation. Clients can request route calculations using a REST API. These calculations are based on an especially for eNav designed directed graph object, in which the edges are annotated with their energy consumption in addition to surface type information. For calculation of the edges energy consumption, every node is enriched with height information. Information about this calculation can be found in Chapter 4.2.

The route calculation is conducted with an especially for eNav modified A*-algorithm, which requires a heuristic suitable for considering energy efficiency. A more detailed explanation of the modification of this algorithm can be found in [18].

The information required for the graph object used for routing, is collected from several sources. Several sources apart from crowdsourcing, which is described in section 4.1.4, are explained in more detailed in the next section. The data collected using crowdsourcing is send directly to the server, which then evaluates them.

4.1.3 Map sources

To create the graph object mentioned in the last section, several sources are used. On the bottom layer, the OSM-maps (see section 2.2.1) are situated. These provide eNav with information about addresses, accessibility, street- and track positions, length of streets and other conditions related to traffic.

Fig. 3. Map-layers.

The second layer is formed by the laser scan data described in section 2.2.2. This data is combined with the laser scan data from the first layer in such a way that every node from the bottom layer is matched to a data point of the laser scan data layer using clustering. This combination produces a three-dimensional map and allows the calculation of the incline information at every edge.

After the creation of a three-dimensional map, the third layer, which consists of the surface type information delivered by the municipality of Aachen, can be stacked on top of it. This data entails information about every track on a street, which requires matching of two surface types at one edge. This constitutes a challenging task. In fact, consider an edge with a footway and a bicycle tag on the first level. On the third level, the footway has a different surface type than the bicycle track. Currently, only one surface type can be matched with an edge. As a solution, a best of strategy in terms of comfort is used, as a wheelchair user may use both tracks.

The last layer is comprised out of the *Wheelmap* database (section 3.2), which supplies eNav with information about the accessibility of POI.

4.1.4 Crowdsourcing

Crowdsourcing serves eNav on three aspects of data refinement:

1. **Barrier detection:**
   In section 2.2.1 it is stated that the quality of data in OSM is very high, nevertheless this data is incomplete in regard to several aspects. As a consequence, several steps and other barriers exist, which are not marked as such in OSM. To make this date more complete, the eNav GUI enables users to report barriers in the way illustrated in figure 4. Thereby a distinction is made between permanent and temporal barriers. A permanent barrier definitely blocks the passage for a wheelchair user, as for example stairs. Temporal barrier block the passage for a limited time. A car parked on the sidewalk would be an example of such a barrier. This differentiation is made to hinder temporal barriers to block edges for a long time. If temporal barriers, like roadworks, are reported, then the concerning edge is blocked only for a predefined period of time.

Fig.4. The barrier detection interface.

   In addition to manual barrier detection, crowd-testing is used to scan barriers automatically. The client is able to detect where and when users deviate from the proposed route and then reports this information to the server. Whenever the server detects a large number of such deviations confined in a certain spot, it alarms an Administrator group. The attending administrator then decides if the concerning edge is excluded from routing or not. Over time, the reliability of the data in terms of accessibility is improved by this procedure.

2. **Surface detection:**
   The quality of surface type data delivered by the municipality of Aachen is very good. In rural areas, however, this information is not as detailed as in urban areas or in some cases not available at all. To ensure a high quality of surface type information outside the district of Aachen, eNav uses a surface detector. This detector measures the linear acceleration along the z-axis using a smartphone. The acceleration is then used to differentiate between cobblestones and asphalt. Several other projects take a similar approach for collecting this type of data [19]. The user constantly stores the linear acceleration in the z-axis during the trip. By comparing the acceleration of edges from which the surface type is known beforehand and of those which are unknown, the surface type of the unknown area can be deduced. This enabled automatic calibration of the detector and that potentially differentiates eNav from other projects.

A distinction is made between surface types which have a noticeable impact on driving comfort. As explained in section 4.1.3, the problem of matching surface type of different tracks on one edge is an emerging problem, which is actually well solved with a “best of”-approach.

3. **The POI**
   The POI are only indirectly integrated into eNav by outsourcing them to *wheelmap.org*, managed by *the Sozialhelden e.V*. (section 3.2). Thereby the information entered by eNav users concerning the POI are relegated to *Wheelmap.org.*

4.2 Energy consumption function

In this section the consumption function used by the modified A*-algorithm to calculate the most energy efficient route is explained. This function takes two influencing factors into consideration. First, the incline influencing factor will be described. Afterwards, surface types and their friction coefficients are discussed.

4.2.1 Incline

To examine the influence incline has on energy consumption; sensors have been installed on a wheelchair, which constantly measure energy consumption during

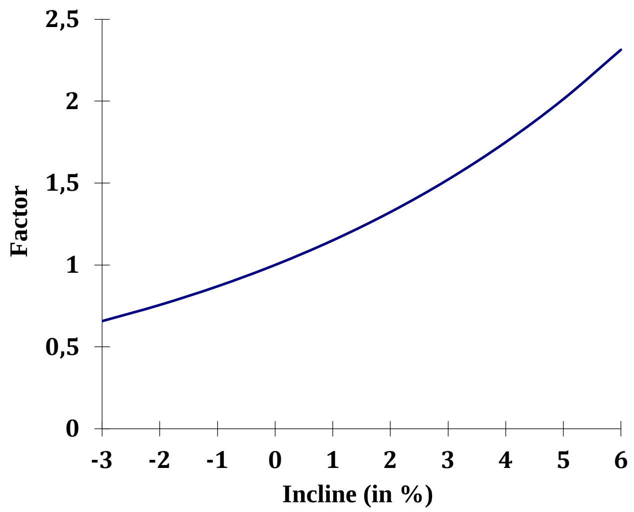

Fig. 5. Relation between energy consumption and incline.

driving [20]. Several test drives have been conducted with a C500 electric wheelchair of the company Permobil, to gather empirical data for several different slopes. This is data is used to deduce following consumption function:

$$\text{consumption} := \text{normal consumption} * \text{distance} * 1.16^{\text{incline}}$$

The normal consumption denotes the energy usage consumption while driving on an even surface, which is calculated by dividing the full load capacity of the battery by the lower limit of the maximum reach of the electric wheelchair. As it can be seen, the energy consumption has an exponential behavior in regard to incline, which can be explained by the discharge time of a battery. Figure 5 shows this exponential behavior. A more detailed description can be found in [21].

4.2.2 Friction coefficient

To take the friction effect of surfaces into consideration during the computation, a friction coefficient should be assigned to each surface type. These coefficients have been determined with the help of the research group of *Professor Oeser* from the *Institute of road engineering of the RWTH Aachen*. A detailed description and complete table of friction coefficients can be found in [22, 23]. The consumption function is expanded to incorporate these coefficients:

$$\text{consumption} := \text{normal consumption} * \text{distance} * 1.16^{\text{incline}} * \text{friction coefficient.}$$

The factor for the incline has been determined on asphalt, which is used as the reference surface type and therefore assigned the factor 1 as a friction coefficient. Another coefficient is for example cobblestone coefficient with the factor 1.05. However, the surface type has a minimal effect on the overall energy consumption when compared with the incline. The modification of the heuristic of the A^*-algorithm to incorporate this consumption function is discussed in [18].

5 Evaluation

In this section presents an eNav evaluation based on different tests. During these the shortest route is compared against the most energy efficient one. During this evaluation the focus set on the energy consumption reduction the efficient route yields in contrast to the shortest one. A more specific test is not conducted yet. Nevertheless, indicators exist which show that the profitability of the most energy efficient route is clearly higher than the profitability of the shortest one.

5.1 Test procedure

For the test, 100.000 routes have been calculated with randomly generated start points and destinations. All these points are situated within Aachen city. The deepest point is at 125 MASL and the highest at 410 MASL. For every 100.000 routes, both the shortest as the most energy efficient route is calculated. For data evaluation, the start point and destination, as well as the distance and the energy consumption for both routes is recorded. Using a *PostgreSQL* database, this data is evaluated. The consumption function including both incline and surface type (section 4.2) is used for the calculation of the most energy efficient route.

5.2 Shortest vs efficient route

First, the number of routes where the energy consumption of the efficient route is lower than the shortest route is counted. Figure 6 shows the percentage of efficient routes which consume less energy than the shortest route. In 41% of the cases energy can be saved by choosing the efficient one. In the other 59%, the energy consumption of the efficient one equals that of the shortest route.

To better judge the quality of these measurements, it should be mentioned that urban area of Aachen has up to 285m difference in altitude. In more flat areas the percentage differs. By calculating the average of the energy saving in percentage, an increase of efficiency of 2% can be observed. The main cause of this value is that the major part of shortest and efficient routes only differ 1% in terms of energy efficiency. A switch between the sides of the street is responsible for this phenomenon.

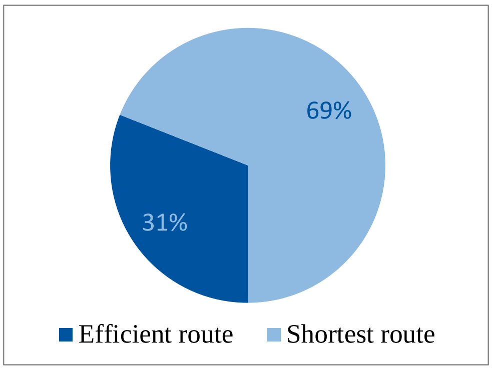

Fig.6. Route comparison of test cases.

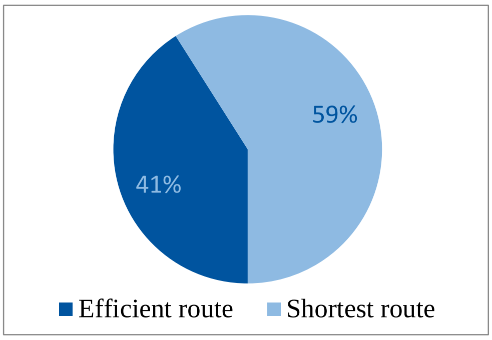

Fig.7. Route comparison of test cases including < 1% cases.

Figure 7 shows the relation between the efficient route and the shortest route using a filter. The filter sorts out every case where the efficient route only differs up to 1% in energy efficiency in comparison with the shortest one. This filter is necessary, because the occurrence of this 1% difference is very high and therefore can distort the result.

Now, only 31% of the test cases generate an efficient route which consumes less energy than the shortest. The increase of efficiency, calculated by the average of energy saving in percentage, is increased to 6% in contrast to the 2% without filter.

A detailed distribution of efficiency from the 41% more efficient routes can be seen in figure 8. The distribution of the energy saving in percentage is displayed in intervals. Between the parentheses, the relative frequency of the number of routes, contained in the interval, is listed. It is interesting to note that some routes save more than 50% energy. The maximum saving detected is equal to 61% with a distance of 1.8km and a detour of 160m.

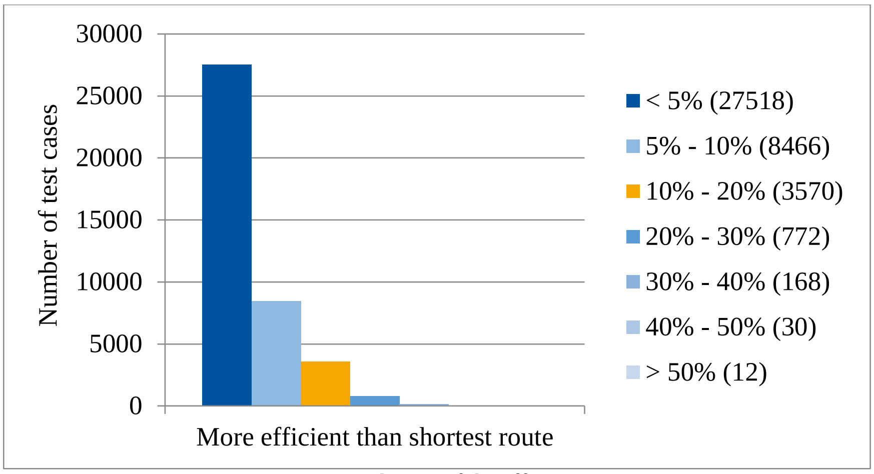

Fig. 8. Distribution of the efficient routes.

Striking is the prevalence of the routes belonging to the first interval, which is equal to 67%. For this reason, this interval is split as shown in figure 11. The aforementioned phenomenon, caused by switching of the sides of the road can be observed in 9.7% of the test cases. The prevalence of this phenomenon clearly reduces the average reduction of energy consumption.

From the boxplot in figure 9, can be observed that both quantiles are below the 10% mark. The filter cannot increase the quantiles above the 10% mark.

It is noteworthy that efficient route can save more than 7% for the half of the test cases, which reaffirms the benefit of the efficient routes. Especially if the short detours are taken into con-

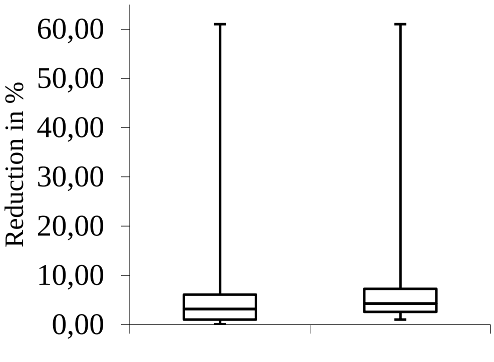

Fig. 9. Efficient route without (left) and with (right) filter.

sideration, the savings should be evaluated positively. Noteworthy are the outliers that save more than 50% on energy consumption, figure 10 shows the height

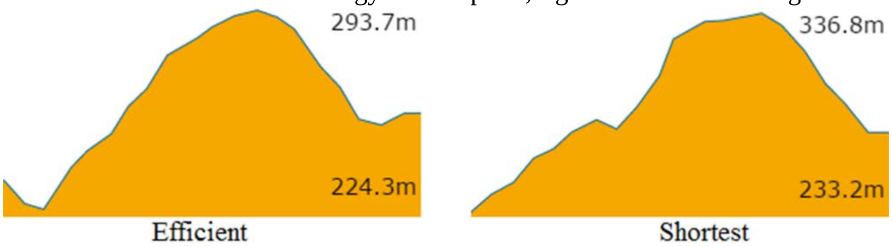

Fig. 10. Comparison of the height profile between the efficient and shortest route of an outlier

profile of the efficient and shortest route belonging to such an outlier. The height difference of the shortest route is clearly higher than the difference of the efficient route. The exponentiality of the consumption function (section 4.2.1) explains the savings of the efficient route.

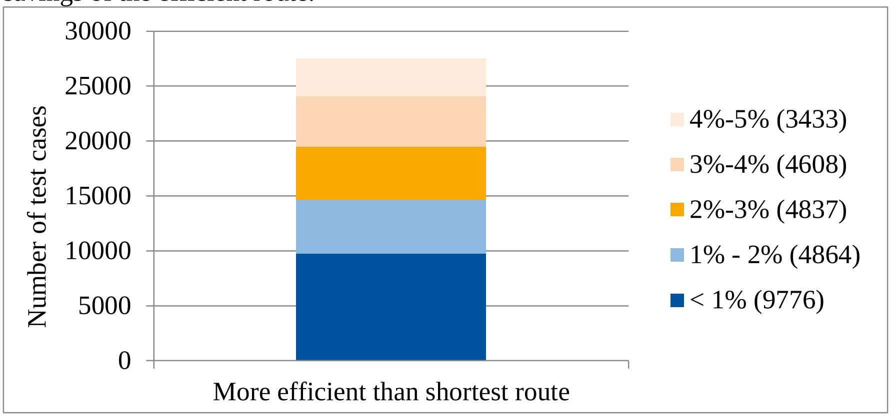

Fig. 11. Distribution of the efficient routes with up to 5% savings.

The same phenomenon as with energy saving can be observed in figure 12, which depicts the increase in travel distance of the energy efficient route in contrast to the shortest route. Switching of the sides of the road leads to short detours of several meters and are excluded if the difference is less than 10 m.

On average, the detours required for the efficient route only increase travel distance by 1%. By applying the filter that rules out the test cases in which only the sides of the road are switched, the detours induce an increase of travel length by 5% on average. Interestingly, the average increase in travel length in percentage is very similar to the average energy saving in percentage. But no relation between the length of detour and the saving can be recognized.

The efficient route with the longest detour, increases travel distance by 180% and achieves an energy consumption reduction of 30% in contrast to the shortest route. On the other hand, an efficient route, calculated during the test, lengthens travel distance by 160%. But only 5% energy is saved in contrast to the shortest route. Because of this phenomenon, it is sensible to allow the user to choose between taking the shortest or the most efficient route.

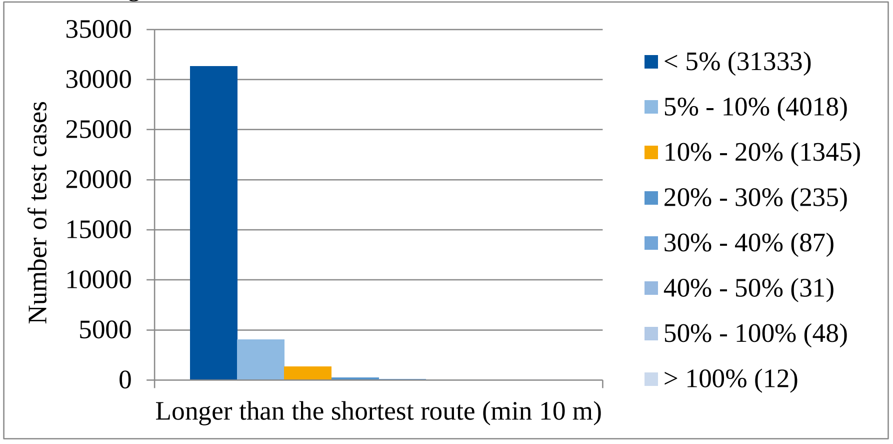

Fig. 12. Detour of the efficient route.

6. Conclusion

In this work, a navigation system for the disabled is proposed. The eNav project not only makes accessible routing and an increase in driving comfort for wheelchair users possible, but also enables users to get a course estimations whether the battery capacity of their electric wheelchair suffices to finish a planned trip or not.

By using a three-dimensional map, eNav can deliver the shortest and the most energy efficient route from a start to a destination point, allowing users to choose one of the two available options. During testing, efficient routes have been found which reduce energy consumption by more than 60% in contrast to the shortest route. The detour required in this case is usually less than 5% of the total length of the shortest route.

On account of the usage of crowdsourcing, the quality of accessibility information is increased permanently, utilizing manual as well as automatic data collection methods. Furthermore, the eNav App uses a surface detector, which recognizes surface types by their linear acceleration along the z-axis when a user drives over a specific type of surface. This surface information is then added to the map-data of eNav.

A next extension of eNav will be the integration of other disabled road users, like those in need of a walking frame. For this group of the disabled different requirements apply as well. The requirements can be fulfilled by using the map-data from eNav. We thank the Center for European Research on Mobility (CERM)[1] for their support.

[1] http://www.cerm.rwth-aachen.de/

References

1. Statistisches Bundesamt (2014) 7,5 millionen schwerbehinderte Menschen leben in Deutschland. Statistisches Bundesamt. Available online: https://www.destatis.de/DE/PresseService/Presse/Pressemitteilungen/2014/07/PD14_266_227pdf.pdf?__blob=publicationFile, lastly checked on 26.04.2016.
2. Ramm F, Topf J (2010) OpenStreetMap –Die freie Weltkarte nutzen und mitgestalten. Berlin.
3. Franke D, Dzafic D, Weise C, Kowalewski S (2011) Entwicklung eines mobilen Navigationssystems für Elektrofahrzeuge auf Basis von OpenStreetMap-Daten. In: Konferenz für Freie und Open Source Software für Geoinformationssysteme (FOSSGIS), Heidelberg.
4. Franke D, Dzafic D, Baumeister, D, Kowalewski S (2012) Energieeffizientes Routing für Elektrorollstühle. In: 13. Aachener Kolloquium Mobilität und Stadt (ACMOTE), Aachen.
5. Bezirksregierung Köln (2011) Topographische Reliefinformationen, Köln.
6. Norwig P, Russell S (2009) Artificial Intelligence – A Modern Approach, München.
7. Hart PE, Nilsson NJ, Raphael B (1968) A Formal Basis for the Heuristic Determination of Minimum Cost Paths. IEEE, Transactions on Systems Science and Cybernetics. Menlo Park, California, USA.
8. Howe J (2006) The Rise of Crowdsourcing, Wired Magazine, 14.
9. Kleemann F, Voß GG, Rieder K (2008) Crowdsourcing und der arbeitende Konsument. In: Arbeits-und Industriesoziologische Studien 1, Nr. 1, S. 29–44.
10. Gregor K, Mlynarski M (2013) Mobile Testing und Usability Testing?
11. Prandi C, Paola S, Silvia M (2014) mPASS: integrating people sensing and crowdsourcing to map urban accessibility. In: Proc. IEEE International Conference on Consumer Communications and Networking Conference, pp. 10-13.
12. Menkens C, Sussmann J, Al-Ali M, Breitsameter E, Frtunik J, Nendel T, Schneiderbauer T (2011) EasyWheel-A mobile social navigation and support system for wheelchair users. In Information Technology: New Generations (ITNG), pp. 859-866.
13. Palazzi C E, Teodori L, Roccetti M (2010) Path 2.0: A participatory system for the generation of accessible routes. In Multimedia and Expo (ICME), pp. 1707-1711.
14. Neis P, Alexander Z (2008) Openrouteservice.org is three times “open”: Combining Open-Source, OpenLS and OpenStreetMaps. GIS Research UK (GISRUK 08), Manchester.
15. Müller S, Kamieth F, Braun A, Dutz T, Klein P (2013) User requirements for navigation assistance in public transit for elderly people. In Proceedings of the 6th International Conference on Pervasive Technologies Related to Assistive Environments, pp. 55.
16. Sozialhelden EV (2016) wheelmap.org, lastly checked on 26.04.2016
17. Dzafic D, Klug S, Franke D, Kowalewski S (2015) Routing über Flächen mit Spider-WebGraph. In: Proc. Journal für angewandte Geoinformatik 1-2015, pp. 516-525.
18. Dzafic D, Franke D, Baumeister D, Kowalewski S (2013) Modifikation des A*-Algorithmus für energieeffizientes 3D-Routing. In: Proc. Angewandte Geoinformatik 2013 - Beiträge zum 25. AGIT-Symposium (AGIT), Wichmann Verlag, pp. 414-423
19. Kothgasser U (2012) Oberflächenbeurteilung von Radverkehrsanlagen mittels GPS und Beschleunigungssensoren. Universität für Bodenkultur Wien, Master thesis, Februar 2012.
20. Poppe D (2011) Design and Evaluation of a Hardware Platform for Precise State-Of-Charge Determination of Lead-Acid Accumulators. RWTH Aachen University, Bachelor thesis.
21. Franke D, Dzafic D, Weise C, Kowalewski S (2011) Konzept eines Mobilen OSM-Navigationssystems für Elektrofahrzeuge. In: Proc. Angewandte Geoinformatik 2011 - Beiträge zum 23. AGIT-Symposium (AGIT), Wichmann Verlag, pp. 148-157.
22. Schmitt S, Schlender D (2003) Untersuchung zum saisonalen Reifenwechsel unter Berücksichtigung technischer und klimatischer Aspekte. Bericht, Bergische Universität Wuppertal.
23. Dzafic D, Baumeister D, Franke D, Kowalewski S (2014) Integration von Bodenbelagsinformationen zum energieeffizienten Routen von Elektrorollstühlen. In: Proc. Angewandte Geoinformatik 2014 (AGIT), vol. 26 in Beiträge zum AGIT-Symposium Salzburg, pp. 451-460.