Navigation Infrastructure for People with Disabilities

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Abstract—**The importance of navigation support for people with disability has been demonstrated by convention on the Rights of Persons with Disabilities. This paper presents the navigation infrastructure for people with disabilities. The infrastructure includes map generation service, web interface, mobile services. Also we purpose method of target area examination by volunteers. Using a modified Openstreetmap road graph allows you to build more precise routes. Introduced classification of obstacles types allows you to identify problems in the path of a person with disabilities. Application of Dijkstra's-based algorithm with modified edge weights allows you to find safe traffic routes. The results of testing on the pilot region allow us to estimate the amount of work required to improve the quality of people's live with disabilities.**

I. INTRODUCTION

One of the important problems of modern society is to provide all rights for people with disabilities, including the rights to freedom of movement. According to convention on the Rights of Persons with Disabilities, "Persons with disabilities have access to a range of in-home, residential and other community support services, including personal assistance necessary to support living and inclusion in the community, and to prevent isolation or segregation from the community" [1]. Accessing to community services requires indoor and outdoor availability.

Commonly the indoor availability is achieved by installation support devices like ramps, elevators, markers and so on. The another way is to use special assistant person who helps to access community services. In any case, indoor availability provides by community service administration independently and it is required to provide information about social object availability for person with disabilities access. In Russia the project "Accessible environment" aims to collect information about social objects accessibility [2].

The outdoor availability requires more comprehensive approach because the outdoor infrastructure is served by various organizations. Commonly a person with disabilities requires to move from start point (e.g. home) to the final point (e.g. community service building). It can be solved by several ways:

- Using special transport. It requires relevant service, limits of time and loads traffic network, but effective for long distances.
- Using special staff. It requires relevant service, it is expensive but it is effective for people with high disabilities.
- Using special devices and applications. It requires corresponded devices and application, detailed information about the visited area, moreover it is cheaper than other options and provides more freedom of movement.

In paper [3] we provides an approach and methods which are used for the development of navigation services for people with disabilities. The environment includes several applications with utilizing unified database and provides the information support for disabled people. The service "Accessibility Passports" was developed to collect information about accessibility of objects. "Accessibility map" service visualizes the information on the geographical map. The paper is focused on the development of the essential service of the environment — "Social navigator".

Standard navigation solutions and route planning services are generally oriented to people traveling in vehicles. The walking routes are represented without taking into account the set of features of the way. Such features may be the existence of walkways, possibilities of crossing the carriageway and moving from house to house. Navigation service for disabled people should takes into account various pits and bumps in the road, narrowing of the road, the presence of steps, stairs, ramps, crossroads, etc. The developing Navigation Infrastructure is able to make journey planning considering individual restrictions of a person according to the actual road situation. This is possible due to the creation and filling of road obstacle database, using of adapted methods of routes building and special road graphs with pedestrian ways.

In this paper we improve presented approach and methods to describe the navigation infrastructure for people with disabilities. The infrastructure includes map generation service, web interface, mobile services and method of target area examination by volunteers.

The rest of paper is organized as follows. Section II contains analysis of related work. Section III describes route graph building procedure. Section IV introduces of procedure for the collection of road obstacles. Section V contains route constructing algorithm. Section VI describes infrastructure implementation and evaluation. Section VII summarizes and discusses the contribution of the paper.

II. RELATED WORK

Generally, the geoinformation service provides maps with ability to construct walk routes without disability restrictions: Google (https://www.google.com/maps), Yandex.Map (https://yandex.ru/maps), Openstreetmap (http://www.openstreetmap.org/directions), etc. It shows distance, expected time, list of turning points. Created routes are intended for peoples without disabilities: the way may include stairs, curbs, crosswalks and so on.

Kasemsuppakorn and Karimi in paper [4] present a routing method suitable for wheelchair users by taking into account sidewalk obstacles such as slope, steps, sidewalk condition and sidewalk traffic as are preferred by users.

Ren and Karimi in paper [5] provide users movement pattern recognition algorithm to improve map matching efficiency and accuracy in pedestrian/wheelchair navigation systems/services. The algorithm integrates GPS positions, orientation data from compass, and movement states recognized from accelerometer data in a client/server architecture.

Analyzing various sources we have found that several services have provided routes taking into account wheelchair accessibility: OpenRoute-Service (http://www.openrouteservice.org/), Routino (http://www.routino.org/), OpenTrip-Planner (http://www.opentripplanner.org/). These services extend traditional walk routes by analyzing additional information if it is available. In this case person has not been warn about possible problems on the route, for example, curbs and crosswalks.

At present the Openstreetmap project is working to create an opportunity for creation application for disabled people (http://wiki.openstreetmap.org/wiki/Wheelchair_routing). The goal is to develop a route planner especially for wheelchair users based on Openstreetmap data. Thus, they have developed the new tag “wheelchair” which can mark locations and roads adapted for wheelchairs. It can be set only with the full confidence that this is true, with appropriate indicators or by human’s recommendation, who uses the wheelchair. Using this tag, several levels of availability can be specified: “Wheelchairs have full and unimpeded access”, “Wheelchairs have partial access” and “Wheelchairs have no unrestricted access”.

The presented services are not oriented to people without limited mobility. The databases of presented services have enough information for moving by automobile or by public transport, but have a lack of description of features of pedestrian ways. During the building process of pedestrian route for disabled people some insignificant features for ordinary people should be accounted. For example, the height and number of steps on the way, availability of ramps have a great influence on the accessibility of the route for disabled people.

The navigation service for peoples with limited mobility should be able to make route planning considering individual restrictions of a person and availability of pedestrian paths. To create such service we should collect the database of obstacles and features of pedestrian ways and only after the filled base will start to build the routes. The routes have been built for disabled people can be different with the traditional walk routes provided by the Openstreetmap, Yandex.Map and Google services. In this way the route building issue can be formulated as the task of searching obstacle-avoiding way. It can be solved by finding a smooth, obstacle-avoiding curve on the plane [6]. Other solution is to build polygonal path taking into account simple obstacles in a form of intersecting polygons [7]. Nonetheless the graph performance of paths is implemented in the most common route planning algorithms.

III. Route graph

In accordance with target group the routing service should be cheap, configurable and available on mobile and desktop platforms without stable Internet connection. There are several services provided ability to construct routes.

- The Google Directions API (https://developers.google.com/maps/documentation/directions) is a service that builds routes between locations using an HTTP request. It allows searching for routes for several modes of transportation, including transit, driving, walking or cycling. The route could be specified as a text description of waypoints or as latitude/longitude coordinates. The Directions API can return multi-part route using series of waypoints in JSON and HTML formats. The service uses static (known in advance) coordinates for placement the route on a map. This service is not designed to respond in real time to users input. The service can be used only with Google Maps.
- JavaScript API Yandex.Map (https://tech.yandex.ru/maps) is a set of JavaScript components targeted to creation of interactive maps. API provides the opportunity of automobile route building. The route is calculated automatically, the arbitrary number of stopping and transit waypoints could be determined before the calculation.
- The Openstreetmap is a project with various offline, embedded (http://wiki.openstreetmap.org/wiki/Routing/OfflineRouters) and web-based (http://wiki.openstreetmap.org/wiki/Routing/online_routers) routing services and software. It combines sophisticated routing algorithms with open and free road network data of the OpenStreetMap project. One of fast and memory efficient open source routing library for Openstreetmap is GraphHopper (https://graphhopper.com/).
- API 2GIS (http://api.2gis.ru) - provides access to a directory of organizations and city maps (more than 80 cities in Russia). Mobile application allows to get information on 600000 organizations including non-commercials (addresses, phones, e-mail, hours of work, etc.) The 3D map shows number of building stores, driveways, kiosks and fences. The stops and routes of public transport are presented on the 3D-map. 2GIS navigation focused only on major streets and highways, ignores the small alleys and passages that are often reduce and accelerated way. 2GIS route builder is not focus on pedestrians.

For “Social navigator” project we select GraphHopper library with Openstreetmap data. The library is available on server, desktop and mobile platforms, can be easily modificated and free for use. The Openstreetmap data also can be easily modificated, stored in various formats and also free for use.

To provide route for disabled people we need to select types of used roads. In Openstreetmap data the road type is defined by attributes like “highway=footway”. Let us consider that disabled people uses roads for pedestrians. Therefore the routing service should prefer to use roads for pedestrians and other types of roads only if it has required. The attributes of preferred and undesirable roads are shown on Tables I and II.

TABLE I. TAGS OF PREFERRED ROADS FOR PEDESTRIAN

Attribute	Description
highway=residential	This tag is used for roads accessing or around residential areas but which are not a classified or unclassified highways.
highway=service	This tag is used generally for access to a building, service station, beach, campsite, industrial estate, business park, etc.
highway=living_street	This tag is used to tag living streets, which generally have lower speed limits, and special traffic and parking rules.
highway=pedestrian	This tag is used on areas of a city or town reserved for pedestrian-only use and in which some or all automobile traffic may be prohibited.
highway=footway	This tag is used for mapping minor pathways which are used mainly or exclusively by pedestrians.
highway=steps	This tag is used for flights of steps on footways.
highway=path	This tag is used for generic path, either multi-using or unspecified usage, open to all non-motorized vehicles.

TABLE II. TAGS OF UNDESIRABLE ROADS FOR PEDESTRIAN

Attribute	Description
highway=primary	This tag is used for a major highway linking towns, in developed countries normally with 2 lanes.
highway=secondary	This tag is used for a highway which is not part of a major route, but nevertheless forming a link in the national route network.
highway=tertiary	This tag is used for roads connecting smaller settlements, and within large settlements for roads connecting local centres.
highway=trunk	This tag is used for high performance roads that don't meet the requirement for motorway.
highway=motorway	This tag is used only on ways to identify the highest-performance roads within a territory.
highway=unclassified	This tag is used for minor public roads typically at the lowest level of the interconnecting grid network.
highway=bus_guideway	This tag is used for guide buses roads.

The main problem of this approach is roads with sidewalks. The routing algorithm cannot define the correctness of turning because it uses sidewalks and carriageway as a single line. For example, the road with both sidewalks has two "T" crossroads in different directions and one "X" crossroad with footpath (see Fig. 1). The correct pedestrian way from point A to point D goes throw point E, but routing algorithm suggests route A-B-C-D.

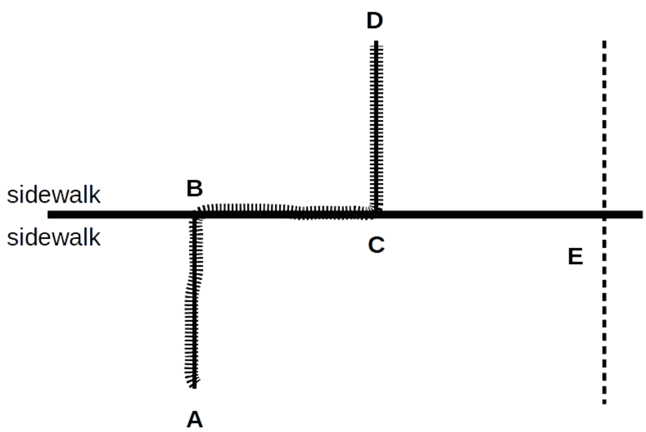

Fig. 1. Example of routing in road with sidewalks

The solution is to create separate roads for pedestrians in parallel with carriageway and disable access pedestrian to carriageway. New roads intersects with all crossroads and pedestrian can cross the road by default. The restrictions for crossing the roadway can be installed by using obstacles (see next section). The produced graph is shown on Fig. 2 and the routing algorithm suggests correct route.

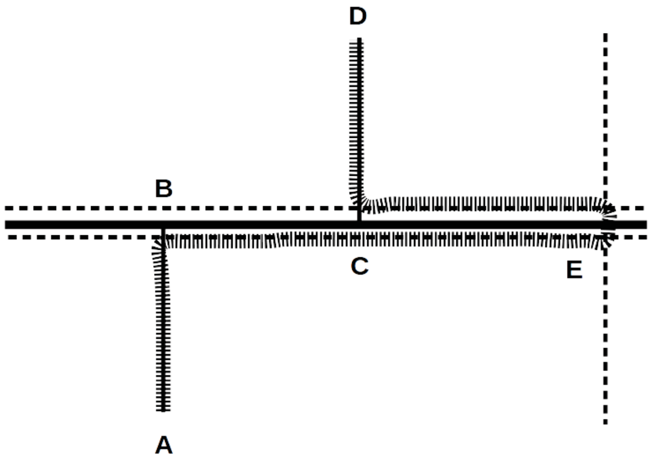

Fig. 2. Correct route in road with sidewalks

The another problem is a square with pedestrian zones. By default, Openstreetmap describes a square polygon and routing algorithm sends a pedestrian along the edge of square area. The example of routing in a square with pedestrian zones is shown on Fig. 3.

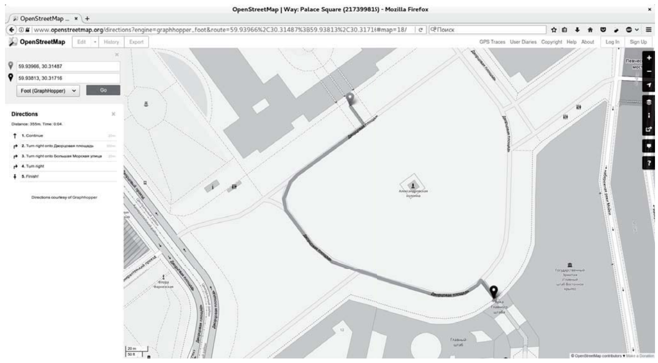

Fig. 3. Example of routing in pedestrian zone

The solution is to create roads between all points of square polygon. It requires analysis of pedestrian zone configuration to avoid crossing paths with different objects.

The result of source road graph analysis allows to construct more precise pedestrian routes. The extension of road graph allows to set any movement restrictions more accurately.

IV. ROUTE OBSTACLES

The main difference between ordinary pedestrian and person with disabilities is that regular pedestrian can pass any road obstacles without causing difficulties. For example, high curb at a crossroads are passed by ordinary pedestrian without any problems, but for person on wheelchair it can cause a serious problem. Unfortunately, these obstacles are not described centrally and person learns about an obstacle only when it occurs in his/her way. Therefore the task of collecting and classifying information on obstacles is actual. The results of performed analysis for the disability categories are presented in the Table III.

TABLE III. CATEGORIES OF DISABILITY

Name	Core problems
(A) Moving on a wheelchair persons	Elevation changes, inclined surfaces, narrow passages
(B) Persons with hearing impairments	Sound signals, intense traffic
(C) Persons with visual impairments	Signs, visual signals, protrusions, elevation changes
(D) Persons with impaired musculoskeletal system	Elevation changes, inclined surfaces, narrow passages
(E) Persons with impaired mental development	Signs, signals, intense traffic

During the process of gathering information we have defined a 9 types of obstacles and described them in the Table IV. Each obstacle can be classified by a type and the difficulty of overcoming (from 0 to 5). The coefficients of influence of obstacles on the category of disability are presented in Table V. Difficulty rating is based on an expert-volunteer own experience and normative documents.

TABLE IV. TYPES OF OBSTACLES

Name	Description
(1) High curb	A single drop of height is associated with the intersection of the borders of the road surface, for example, the transition from the sidewalk into the roadway. The difficulty of overcoming high curb depends on the height difference.
(2) Stairs without ramps	Flights of stairs have two or more steps without bypass routes in the neighborhood. Complexity without overcoming stair ramp depends on the number of steps, their height and their depth availability handrail.
(3) Unregulated pedestrian crossing	Pedestrian crossing the roadway have only the presence of "pedestrian crossing" sign without adjusting the intersection of the order with the help of a traffic light. The difficulty of overcoming the unregulated pedestrian crossing depends on the width of the roadway, traffic density and the availability of funds, warning traffic accident (information and warning signs, humps on the road, etc.).
(4) Various pits and bumps in the road	The road has a local height differences with affecting passage. Typically, unpaved roads that category is identified obstacles due appearance roughness over time. The difficulty of overcoming irregularities and pits depends on their size, the height difference of magnitude, their amount, etc.
(5) Stairs with ramps	The road has a flight of stairs with the adjacent ramp. Flight of stairs can be separated from the ramp with handrails. The difficulty of overcoming the stairs with a ramp depends on the number of stages, their height, their depth, the angle of the ramp and the presence of handrails.
(6) Adjustable pedestrian crossing	Pedestrian crossing the roadway has the a sign "pedestrian crossing" with the regulation by a traffic light. The difficulty of overcoming the controlled pedestrian crossing depends on the width of the roadway, traffic intensity, audio-visual warning and the availability of funds, warning traffic accident (information and warning signs, humps on the road, etc.).
(7) Steep climbs and descents	The road has a prolonged drop height of the roadway. The difficulty of overcoming steep ascents and descents is dependent on the length of the drop, tilt angle, the presence of handrails and other mobility aids.
(8) Object on the road	The road has a single obstacle on the road (nightstand, a flower bed, column, etc.) that interferes with the direct movement.
(9) Narrowing of the road	The road has a decrease in the width of the pedestrian zone by the installation of separators available projections, etc.

TABLE V. COMPLEXITY COEFFICIENTS FOR DIFFERENT TYPES OF DISABILITY

Obstacle	(A)	(B)	(C)	(D)	(E)
(1)	1,2,3,4,5	—	1,1,2,3,4	1,1,2,3,4	—
(2)	1,2,3,4,5	—	1,1,2,2,3	1,1,2,2,3	—
(3)	—	1,2,3,4,5	1,2,3,4,5	—	1,2,3,4,5
(4)	1,2,3,4,5	—	1,1,2,3,4	1,1,2,3,4	—
(5)	1,2,3,4,5	—	—	1,2,3,4,5	—
(6)	—	1,2,3,4,5	1,2,3,4,5	—	1,2,3,4,5
(7)	1,2,3,4,5	—	—	1,1,2,2,3	—
(8)	—	—	1,2,3,4,5	—	—
(9)	1,2,3,4,5	—	1,2,3,4,5	—	—

If obstacle is not a problem for person with disabilities, then coefficients are zero ("—"). Otherwise, the 5 coefficients are presented (from easy till difficult passable obstacle):

1: independent movement;

2: independent movement difficult;

3: independent movement requires preparation;

4: moving only with assistance;

5: insurmountable obstacle.

These coefficients are show obstacle passage complication speed depending of types of obstacle and disability. For example, if volunteer found the steep slope of the road and marks with coefficient 3, then for persons with impaired musculoskeletal system the coefficient will be 2 that is third in order. It means that for this type of disability considered obstacle has not a great complexity and he/she can pass this obstacle independently.

In "Social Navigator" project loaded points and categories are placed in GeTS server and displayed on a map which is accessed through OpensStreetMap. The server's database provides access to the collection and management of obstacles by software and web interface. Users are classified according to the level of access and an opportunity. Obstacles points are grouped into categories. The database maps of roads and maps of the area are saved in a file storage. Maps of roads and areas are divided into regions. GeTS is Geo2tag-based server, which combines Open source Geo2tag LBS platform (http://geo2tag.org)[8] and application programming interface for accessing via web.

Web interface (http://gets.cs.petrsu.ru/obstacle/web-client) includes map and list of nearest objects and set of tabs with obstacle points, social objects and administrative functions. The fragment of obstacle point edit form is shown on Fig. 4. User can edit common fields like point's name, coordinates and description, add confirmation photo and add or edit additional fields. Also web interface provides more accurate positioning and user can clarify it if necessary.

Mobile application GeTS Supplement provides the ability to add and edit obstacles points on the map, publish them on the public map. This application allows to simplify manual input by detecting user's location. The application displays a window with a map on which the user specifies a point and a set of parameters to it. The user enters the name of the point, then choose a category and puts the rating at 5 point scale. Web-based interface is an analogue of mobile obstacles editing application.

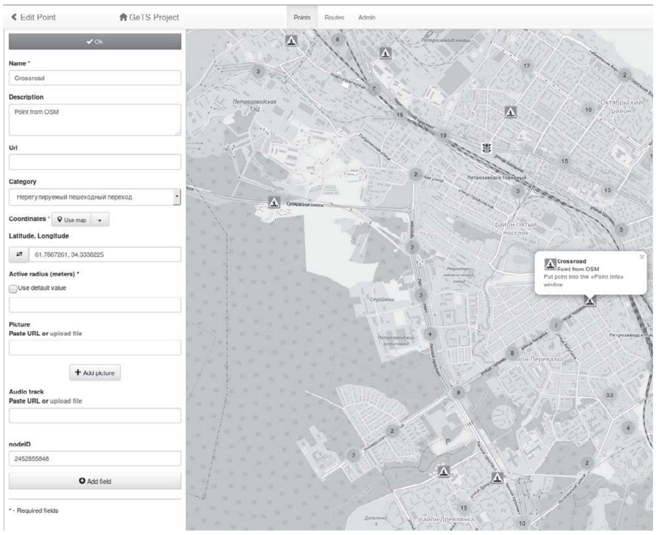

Fig. 4. Fragment of GeTS obstacle point edit form

There are several ways to gathering information about obstacles.

- Automatic import known obstacle from third-party source. This way can be passed for some types of obstacles like crossroads. The obtained data should be verified by expert-volunteer.
- Manual input obstacles. It can be passed throw GeTS web interface. This is a very slow but reliable way and requires expert-volunteer with good memory and/or preliminary data collection.
- Using GeTS Supplement application for Android platform to input obstacles. The application is available on Google Play market for free download (https://play.google.com/store/apps/details?id=org.fruct.oss.getssupplement).

According to the survey's results of the pilot area it is preferred combines ways in the following sequence:

1) automatic import known obstacles from Openstreetmap, getting data about stairs, crossroads and traffic lights for pedestrian roars;
2) generation of plan of area survey by voluneets, drawing up a list of road naming;
3) inspection target area and input found obstacles by using GeTS Supplement application, obstacle's description includes its rating, commentary thereto, photos and audio with an explanation;
4) manual correction of gathered obstacles throw web-interface, performing as needed to clarify the location of obstacles, its relation to the pedestrian road and adjoining buildings, to correct rating or commentary.

The usage of collected obstacles in routing algorithm requires binding points with roads. Unfortunately, if we use automatic location detection in GeTS Supplement application we have error in determining the location of gps module. Also user can set point aside from the the road.

To solve this problem the GeTS Supplement application includes "magnet" function which moves new point to nearest road line. This function requires road graph to determine nearest roads. User can enable or disable "magnet" depending on the situation (see Fig. 5). By using "magnet" function we get more exactly point coordinates and can clearly define corresponded road.

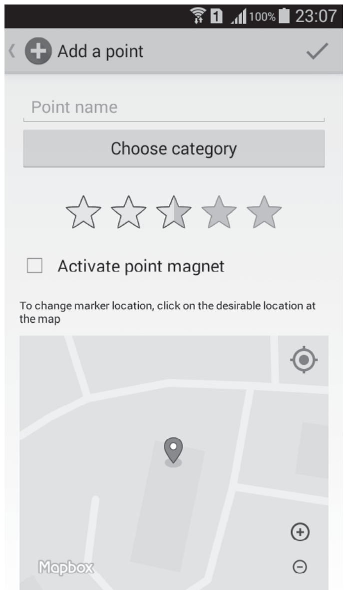

Fig. 5. GeTS Supplement input form with magnet

V. ROUTE CONSTRUCTING ALGORITHM

To create a route we use GraphHopper routing engine. GraphHopper is an open source road routing library and server written in Java and provides a web interface called GraphHopper Maps as well as a routing API over HTTP. GraphHopper uses Dijkstra-based algorithm which is using weights of the edges to determine shortest path.

In "Social Navigator" project we use algorithm, described on [9] with road types and available obstacles to calculate edge weight. For preferred types of road (see Table I)) we set road weight $R = 0.6$, for undesirable types of road (see Table II.) we set road weight $R = 5$ and set road weight $R = 1.7$ for other types of road.

The weight O_i for obstacle i calculates as following:

$$O_i = D_i * K_i,$$

where D_i is a difficulty of overcoming and K_i is a coefficient of influence of obstacles on the selected category of disability. The total edge weight E calculates as following:

$$E = R + \sum_{i \in I} O_i,$$

where I is a set of nearest obstacles. The road weight includes into used road graph during data generation (see section VI). The obstacle weight and edge weight calculates on each request.

In “Social Navigator” project we try to produce three types of routes for each request:

- “Save route” with weight of each included obstacle less than 1 or equal;
- “Moderately dangerous route” with weight of each included obstacle less than 5;
- “Fast route” is a route with shortest path.

If it is impossible to build a “safe route” or “Moderately dangerous route”, then they are not present in output.

VI. Implementation and Evaluation

The architecture of “Social Navigator” project was introduced in papers [9], [3]. The extended version of architecture by adding map service which implements road graph generation and map tiles generation is shown on Fig. 6. GeTS server is used to store obstacle data. Users can save founded obstacles by using GeTS Supplement application or through special web interface. Accessibility passports service provides accessibility information for social objects. OSM storage provides reprocessed Openstreetmap road graphs for mobile applications. Social navigator application provides ability to construct routes and navigates through mobile device.

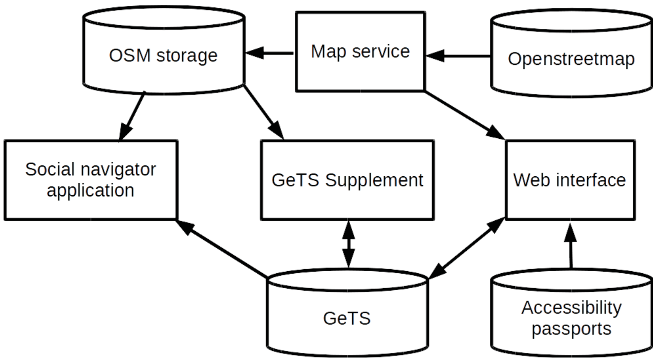

Fig. 6. Social navigator project high level architecture

Map service uses the data source from Openstreetmap service and generates results of data files for each selected area using following scheme (see Fig. 7):

1) Convert Openstreetmap “area.pbf” file to “area.o5m” format by osmconvert tool.
2) Extract road graph from O5M file to “roads.o5m” by osmfilter tool.
3) Extract other data from O5M file to “other.o5m” by osmfilter tool.
4) Convert sidewalks to separate footpaths and generates road graph without sidewalks by own tool (file “roads-without-sidewalks.osm”).
5) Merge “roads-without-sidewalks.osm” and “other.o5m” files by osmconvert tool.

Produced results are used to generate road graph for “Social Navigator” mobile application, GeTS Suppliment application, web-interface navigation and map generation service. The data generation requires a lot of time and computing resources. For

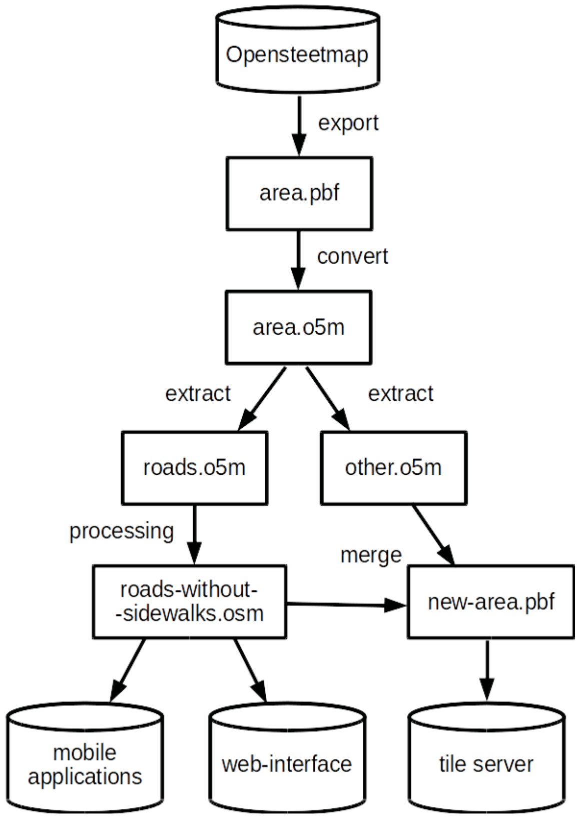

Fig. 7. Openstreetmap data transformation

example, graph generation for Karelia region takes 73 seconds (4x1GHz, 4Gb RAM, OS Ubuntu 16.04).

The web-interface contains modified Graphhopper application to construct routes. When user selects start and finish points and type of disability, he or she sends the request to server-side script. The script receives the list of corresponded obstacles and calls Graphhopper application. The result sent back to web-interface. The screenshot of web-interface is shown on Fig. 8. User can see found routes, route estimates in points, list of obstacles in selected route with descriptions.

Fig. 8. GeTS web interface with routes

The produced results was evaluated on pilot zone: downtown area of Petrozavodsk city. The information was collected with the assistance of experts-volunteers from karelian regional public organization of motor impaired ”Petrosino”. After several surveys we have collected the information around 800 obstacle points in Petrozavodsk (420 points in pilot zone). The points distribution are shown on Fig. 9. During map service usage we have found around 40 streets requiring specification information about the sidewalks.

Fig. 9. Obstacle points in pilot zone

Routing algorithm evaluation has found set of problem situations.

- Unexplored territory. If this territory is located near start and end points, then routing algorithm prefers to use it because this territory is free of obstacles.
- Incorrect road graph. Some roads can be marked as available for pedestrian, but actually it is not.
- Passage to the wrong entrance to the building. Routing algorithm may set emergency exit as a last point.

These problems should be checked in corresponded applications.

VII. Conclusion

The presented work is a part of developed infrastructure that contains related mobile and web services. The infrastructure aims to improve quality of life of disabled people by the means of modern information and communication technologies. In this paper we describe navigation infrastructure for people with disabilities and improvements of previously presented approach and methods. The most important improvements are the following:

- building more precise routes due to using a modified Openstreetmap road graph containing data on pedestrian paths;
- using of classification of types of obstacles that allows users to identify problems in the path of a person with disabilities;
- obtaining of safe traffic routes due to implementation of Dijkstra’s-based algorithm with modified edge weights.

Routing algorithm evaluation has found set of problem situations, like unexplored territory, which can worsen constructed route. So, the results of testing on the pilot region allow us to estimate the amount of further work required to improve developed infrastructure. The presentation of testing results to the community-based organizations and authorities has shown a high interest in developing applications. Thus, the Navigation infrastructure will be improved by a filling database with new objects and increasing of route building quality in cooperation of developers with volunteers and representatives of community-based organizations.

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References

[1] “Convention on the rights of persons with disabilities,” United Nations, Jan. 2007, accessed 09 February 2016. [Online]. Available: https://documents-dds-ny.un.org/doc/UNDOC/GEN/N06/500/79/PDF/N0650079.pdf?OpenElement

[2] Y. A. Apanasik, I. M. Shabalina, and A. I. Shabaev, ““accessibility passports” service in information environment for persons with disabilities,” in *14th Conference of Open Innovation Association FRUCT*, Nov 2013, pp. 3–8.

[3] K. A. Kulakov, A. I. Shabaev, and I. M. Shabalina, “The route planning services approaches for people with disability,” in *Proc. 17th Conf. Open Innovations Framework Program FRUCT*. ITMO University, Apr. 2015, pp. 89–95.

[4] P. Kasemsuppakorn and H. A. Karimi, “Personalised routing for wheelchair navigation,” *Journal of Location Based Services*, vol. 3, no. 1, pp. 24–54, 2009. [Online]. Available: http://dx.doi.org/10.1080/17489720902837936

[5] M. Ren and H. A. Karimi, “Movement pattern recognition assisted map matching for pedestrian/wheelchair navigation,” *Journal of Navigation*, vol. 65, no. 4, pp. 617–633, 2012.

[6] Z. Li, D. Meek, and D. Walton, “A smooth, obstacle-avoiding curve,” *Computers & Graphics*, vol. 30, no. 4, pp. 581 – 587, 2006. [Online]. Available: //www.sciencedirect.com/science/article/pii/S0097849306000756

[7] V. Tereschenko, D. Yanchik, and D. Pustovoitov, “The optimal way searching task on obstacles multiplicity,” *Proc. of 20th International Conference on Computer Graphics and Vision GraphiCon2010*, pp. 280–284, 2010. [Online]. Available: http://graphicon.ru/html/2010/conference/RU/Se6/34.pdf

[8] M. Zaslavskiy and K. Krinkin, “Geo2tag performance evaluation,” *Proceedings of 12th Conference of Open Innovations Association FRUCT*, pp. 185–193, 2012. [Online]. Available: https://fruct.org/publications/fruct12/files/Zas.pdf

[9] K. A. Kulakov, Y. A. Apanasik, A. I. Shabaev, and I. M. Shabalina, ““accessibility map” and “social navigator” services for persons with disabilities,” in *Proceedings of 15th Conference of Open Innovations Association FRUCT*. ITMO University, 2014, pp. 69–76.