Multi-Path Routing Algorithm for Inclusive Mobility in an Urban Environment

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***Abstract*—The concept of smart city is frequently used nowadays to refer to the level of integration of cities with citizen services. Mobility and navigation are some examples. When considering disabled users, in a temporary or permanent way, the challenges to provide such services in an efficient way are even bigger. This paper is an extension of a previous work where a mobile application to recommend the most suitable route for citizens was implemented with both Dijkstra and A-Star algorithms. The presented work describes a multi-path approach considering the user might want to choose several destinations in the mobile application and obtain the most suitable route that goes through all of them. Results are presented using the Genetic and the Simulated Annealing Algorithms. Both were evaluated with 100 runs and 2, 4, 8 and 16 destinations. The average algorithm execution time, standard deviation, median value, maximum and minimum execution times were assessed. The Simulated Annealing Algorithm presented better results and always suggested the shorter, or equal, path when comparing to the Genetic Algorithm.**

Index Terms - Inclusive Mobility. Routing Algorithms, Disabled People, Multi Path routing.

I. Introduction

Currently, nearly 15% of the global world population have some type of disability that limits mobility [1]. The use of applications to support the mobility of citizens is a reality and majority of the cities [18]. These applications have more relevance for people with some kind of mobility disability due to the constant growth and changes that happen in the cities and that require accessibility reformulation. Therefore, the interest of developing newer and improved mobility applications has been growing exponentially, mainly with regard to assistance to people with permanent or temporary mobility disabilities [3].

Urban orientation is intrinsically linked to mobility and it refers to the ability of a citizen to know at every moment exactly where he is, whether or not he knows the city, and to be able to get directions to a desired location [4]. Permanent or temporary mobility disabilities includes several types of segments such as visually impaired people, wheelchair users, people with autism spectrum disorder, deaf people, pregnant ladies, elder or people with toddlers. For each of these segments, the concerns and precautions to take during a route are quite different. For visually impaired people, the lack or total absence of vision makes them less aware of what is happening around them. Adding the fact that they have limited or no access to positioning information using vision, all information given to them must be as precise as possible. Based on previous studies, people belonging to this segment should not be redirected to routes where emergency vehicles exist. On the other hand, when referring to people using a wheelchair, the main concerns are related with the type of surfaces on which they move and also the slope. In these cases, the preferred surfaces for mobility must be uniform, firm and smooth while generating adequate friction for a comfortable and stable ride [5]. In turn, when talking about people with autism spectrum disorder the main concerns are related to the bustle of the streets and here there is a need to avoid these types of places during a route.

In previous works [6] [18], a mobile application named Viana+Acessível was developed in order to assist disabled people to move around the streets of Viana do Castelo. The application allows the user to choose his segment and to receive a personalized route considering his current location and intended destination, using the A-Star algorithm. The main contribution of this paper is an extension of the initial work with a multi-path routing algorithm, considering that allowing the choice of a single destination might be limited in several scenarios. In this paper, several algorithms are used and tested to understand which one has a better performance in this situation.

The paper is organized as follows: Section II presents related works associated to algorithms used by navigation applications as well as the current available applications. Section III briefly introduces the system, layout changes and evaluation. Section IV presents the conclusions and future work.

II. Related Work

In this section, some algorithms that can potentially be used to implement the multi-path approach are presented and then some mobility aid applications are introduced.

A. Algorithms

In [7], the *Neuro-fuzzy* algorithm is studied in order to understand its behaviour when the main concern is to avoid obstacles collision when they are moving in a randomly way in a specific area. This algorithm explores approximation techniques from neural networks. The *Bayesian Recursive* algorithm is tested in [8] where authors try to use it to calculate the free space estimation for an autonomous wheelchair using stereoscopic cameras by severely disabled people. In this case, a 3D point map is generated through geometric projections and then converted to a 2D distance map. *Neurogenetic* algorithms have been tested in several studies [9], [10], [11] using the *Gilbert-Johnson-Keerthi* algorithm and the *Participle Swarm Optimization* algorithm. The first one is used to determine the distance between two convex sets. The second one intends to optimize relative positions between objects. These specific studies are aimed at visually impaired people or wheelchair users. For visually impaired people, it focus on obstacle avoidance. On the other hand, for wheelchair users it tries to focus on identifying several obstacles as well as facilities such as crosswalks with traffic signs in order to reach the best paths to follow based on the surfaces he could face with. The use of *Ant Colony Optimization* algorithm is described in [12] where the authors try to solve computational problems involving path-finding in graphs. In computer science, a graph is an abstract data type which consists of a finite set of vertices and edges. Compared to the real life, a graph represents a set of paths which an user can take. Combined with Ant Colony Optimization algorithm, the authors suggest to use the *Dynamic Window Approach* algorithm which is tested to avoid collisions between obstacles. The *A-Star algorithm* is characterized by its relatively simple implementation and it reaches a considerably satisfactory time when planning the shortest path of a map with obstacles [13]. In addition to the use of the previous algorithm authors in [6] and [14] describe *Dijkstra algorithm* as the recommended to find shortest paths in a graph. The use of *Machine Learning* algorithms [5], [15] is suggested to help to optimize the entire best route decision process using the *Support Vector Machine algorithm* and the *Naive Bayes algorithm*. *Computer Vision algorithms* is also tested with the purpose of data processing such as image classification, object detection and tracking, semantic segmentation and image reconstruction.

B. Mobility aid applications

The OpenStreetMap application and the OpenTripPlanner application are mentioned in [16] to develop a framework which aims to assist people with mobility impairments to use routing services such as car, train, public transport, bike, or even foot. Through these applications, a road graph is created with different levels of detail that can be modified at run-time by users if an obstacle obstructs the pre-planned route. OpenStreetMap[1] is used to manage and model the road graph while OpenTripPlanner[2] is used to plan a dedicated path considering different constraints and mobile platforms for real time navigation and obstacle detection. The Wegoto application [15] uses several smartphone sensors such as accelerometer, gyroscope and GPS (Global Positioning System) and processes all these data using a data fusion algorithm called Kalman algorithm. The algorithm is used to merge records from sensors and counterbalance their respective defects.

The work presented in this paper is an extension of the Viana+Acessível app [6]. It was built to work specifically in the city of Viana do Castelo, in Portugal, where the streets of the historic center of the city were classified in a Geographic Information System (GIS) by the City Council together with the institutions that represent each one of the segments. The main purpose of the Viana+Acessível application is to help people with some type of disability to walk around the city using the most suitable route provided by the app based on the suitability of the streets classification in the GIS. When starting the application, the user can choose one of the previous segments and then all suggestions made by the app will take into account the chosen disability. After choosing the segment, the user can choose to show the points of interest of the city on a GIS map of Viana do Castelo, divided into five categories: culture, health, public services, transport or tourism. In addition, the user can also check parking spaces for people with disabilities and all taxi locations. For each of these locations, he can obtain specific information by clicking on the desired point or start navigating towards the chosen destination.

III. System Overview and Evaluation

This section starts by presenting the Viana+Acessível app, the main changes made to the layouts to allow for multi-path selection. Finally, the evaluation made is also presented.

A. Viana+Acessível application

Figure 1 depicts the main architecture of Viana+Acessível app. The application, developed in React Native, is available for devices which runs an Android operation system or an Apple operation system. The initial version of the app allows users to select a point of interest as intended destination whereas the starting location is always the user's current location. The A-Star algorithm is used to calculate the most suitable route based on his mobility segment.

B. Layouts

The main contribution presented in this work focuses on the possibility of the user to select several destinations and to obtain a the most suitable route that goes through all of them. This required some changes to the layouts. As illustrated in Figure 2 (a), the user has two buttons available when accessing a point of interest. The 'Go' button allows him to find the most suitable route to that specific location. The new 'Add' button allows the user to add that point of interest to a list of intended destinations. Figure 2 (b), that represents the initial page of

[1] https://www.openstreetmap.org/map=7/39.602/-7.839

[2] https://www.opentripplanner.org/

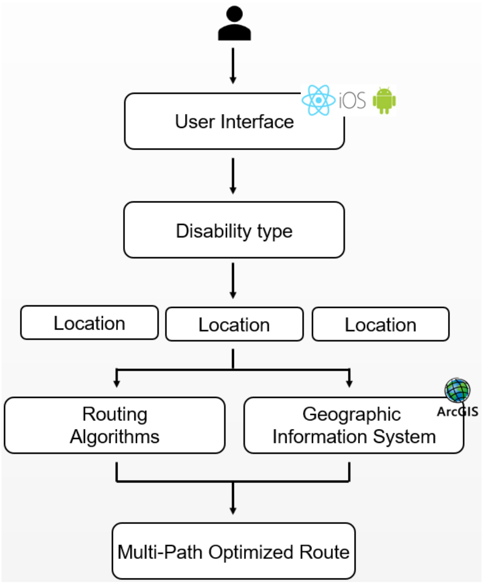

Fig. 1: System's architecture and workflow

the app, now has an option menu entry that allows the user to check all chosen destinations (Figure 2 (c)) that will be considered by the multi-path algorithm when calculating the best route.

C. Evaluation

This section presents the execution time results and the suggested path results of two algorithms used to implement the multi-path functionality.

The first algorithm tested was the Genetic Algorithm which is a search heuristic that is inspired by Charles Darwin's theory of natural evolution.

The second algorithm tested was the Simulated Annealing Algorithm with linear and exponential approaches and is characterized by being a stochastic global search optimization algorithm.

In order to evaluate the performance of each algorithm, 100 runs were performed for 2, 4, 8, and 16 destinations.

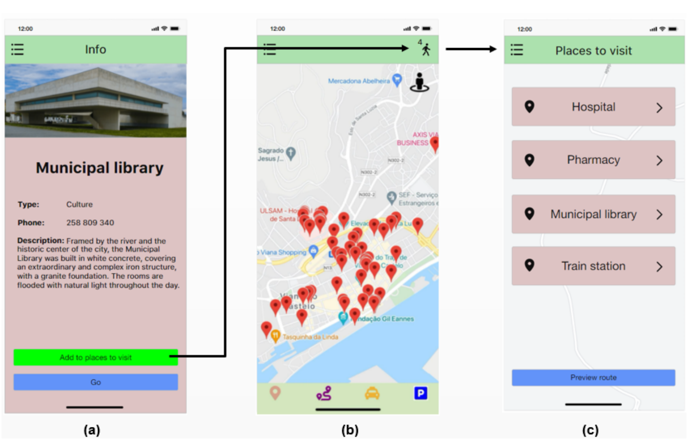

Fig. 2: Multi path functionality incorporated in the layouts

For all scenarios some metrics were registered such as the average algorithm execution time (AT) in ms, the standard deviation (SD), the median value (MedT), minimum execution time (minT) and the maximum execution time (MaxT).

	AT	SD	MedT	MinT	MaxT
2 destinations	70.35	10.92	66.75	58.5	117.8
4 destinations	89.74	21.04	86.4	78.1	284.7
8 destinations	114.38	9.82	112.35	102.8	178.8
16 destinations	171.71	10.66	169.9	159.3	233.3

TABLE I: Execution time values for Genetic Algorithm

As expected, results in Table I show us that Genetic Algorithm presents higher values as the number of destinations increases. The higher standard deviation was verified for 4 destinations (21.04) having registered a minimum execution time of 78.1ms and a maximum execution time of 284.7ms.

In Tables II and III are presented the results for Simulated Annealing Algorithm with linear and exponential approaches. Registered results are pretty similar being that for the linear approach the higher standard deviation is 20.43 for 2 destinations and for exponential approach is 20.75 for 8 destinations.

	AT	SD	MedT	MinT	MaxT
2 destinations	16.82	20.40	13.65	11	213.2
4 destinations	22.71	20.43	19	15.7	218.5
8 destinations	36.05	7.27	34.05	27.9	66.4
16 destinations	47.85	6.59	46.8	40.2	96.9

TABLE II: Execution time values for Simulated Annealing (linear)

	AT	SD	MedT	MinT	MaxT
2 destinations	17.17	20.65	13.3	11.4	213.2
4 destinations	21.92	19.92	19.8	16.2	216.9
8 destinations	33.15	20.75	30.6	26.2	231.8
16 destinations	48.53	8.78	46.3	39.5	110

TABLE III: Execution time values for Simulated Annealing (exponential)

The analysis of Tables I, II and III, allow to verify that Simulated Annealing Algorithm provides better results comparing to Genetic Algorithm based on average algorithm execution time and always obtains the shorter path.

	Path	Shortest Distance (km)
2 destinations	a,b	9.8
4 destinations	c,d,b,a	10.2
8 destinations	h,g,b,c,d,f,a,e	20.3
16 destinations	h,b,p,c,d,i,j,k,a,l,f,g,m,o,n,e	27.5

TABLE IV: Shortest distances for Genetic Algorithm

	Path	Shortest Distance (km)
2 destinations	b,a	8.8
4 destinations	c,d,b,a	10.2
8 destinations	h,c,d,b,f,a,g,e	18.8
16 destinations	h,b,p,c,d,i,j,k,a,l,f,g,m,o,n,e	27.5

TABLE V: Shortest distances for Simulated Annealing (linear)

	Path	Shortest Distance (km)
2 destinations	b,a	8.8
4 destinations	c,d,b,a	10.2
8 destinations	h,c,d,b,f,a,g,e	18.8
16 destinations	h,g,f,b,p,c,d,i,j,k,a,l,n,m,o,e	28.3

TABLE VI: Shortest distances for Simulated Annealing (exponential)

Tables IV, V and VI presents the shortest distances for all scenarios in both algorithms. The notation "a-p" represents the destinations that were used to explore the app development. Based on that, it is possible to conclude that Simulated Annealing Algorithm always suggest the shorter path when comparing to Genetic Algorithm. For 2 destinations the best path would be "b,a" with a distance of 8.8 km and is suggested by Simulated Annealing both linear and exponential approaches. For 4 destinations the best path is "c,d,b,a" with 10.2 km to go through suggested by all algorithms. For 8 destinations the best path would be "h,c,d,b,f,a,g,e" with a distance of 18.8 km suggested by Simulated Annealing Algorithm for both linear and exponential variants. Lastly, for 16 destinations the best path is "h,b,p,c,d,i,j,k,a,l,f,g,m,o,n,e" with a distance of 27.5 km. In this case, this is suggested by Genetic Algorithm and Simulated Annealing Algorithm with linear approach.

IV. Conclusions and Future Work

Currently, it becomes noticeable that the commitment to inclusive mobility has been growing every day. There are already plenty of solutions to support disabled people during their daily commutes within the urban environment. However, there are still some concerns about this topic. In this paper, an extension to a previous study made in the city of Viana do Castelo was presented, mainly through a mobile app to recommend the most suitable route to a set of segments of people with permanent or temporary disability condition. The main contribution had to do with the incorporation of the multi-path functionality, allowing the user to choose several intended destinations in the mobile interface and obtain the most adequate route that goes through them all. The described work makes use of a GIS that aggregates the classification of the suitability of more than 1000 street segments of the historical center of Viana do Castelo. This information fed two algorithms to test the multi-path implementation: Genetic Algorithm and Simulated Annealing Algorithm (two variants). Both were evaluated with 100 runs and for 2, 4, 8 and 16 destinations. The average algorithm execution time, standard deviation, median value, maximum and minimum execution time were assessed. In general, the Simulated Annealing Algorithm variants presented better results and obtains the optimal path when compared with the Genetic Algorithm.

As future work, it is planned to extend the multi-path choice to allow the user to assign a level of priority to each place. On the other hand, the use of machine learning algorithms to increase the effectiveness of the suggested route through user's feedback is also planned to be done.

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