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Research Paper

An Improvement on the Topological Map Matching Algorithm at Junctions: A Heuristic Approach

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Abstract

Nowadays, there is a growing demand for transportation and location-based services. The rapid progress in wireless and positioning systems caused an ever-increasing use of these systems in vehicles and transportation. Navigation of vehicles relies on matching received positions by Global Positioning System (GPS) or other sensors with the map of road networks to show the user which part of the road they are on. There is a possibility that the algorithm can't recognize the correct link out of the candidate links due to errors in positioning sensors, digital maps, and map matching algorithms. Location-based services, intelligent transportation systems, and users may be misled by incorrect road detection. By combining a topological map-matching algorithm with the Analytic Hierarchy Process (AHP) optimization method, a compound method has been devised. As the material of the study, we have used Garmin GPS data and a 1:2000 urban map of the national cartographic center. We conducted a case study in a dense part of Tehran City in order to test the efficiency of the algorithm. There are three components to the algorithm, one being an initial map match, two being a mapping on a link, and three being a mapping at a junction through the AHP method. The algorithm has been executed in a dense urban network. Because of the presence of high buildings in urban areas we have the most errors in this area. From 906 positioned points the link has been successfully realized in 97.3% of cases. The results are acceptable, and in 2.7% of the remaining cases, error in the positioning system is responsible for the error and it is recommended to improve positioning system errors.

Keywords: Topological Map-matching, Analytical Hierarchy Process (AHP), Intelligent Transport System (ITS), Location-based services (LBS)

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1. Introduction

Map matching algorithms developed to integrate positioning data with spatial road map network data, have been devised to provide reliable, precise, and real-time positioning data needed for Intelligent Transport System (ITS). It is required for services like routing, navigation management, and emergency reaction. (Chen et al., 2003; Kim et al., 1996; Phuyal, 2002; Li and Chen, 2005; Li and Fu, 2003; Ochieng et al., 2004; White et al., 2000; Yin and Wolfson, 2004; Zhao et al., 2003; velage , 2009).

Map matching of moving objects is usually applied to locate the exact position of the vehicle in a set of road networks (Juan et al., 2021). Thus, it is required to do map matching for a vehicle in its exact location on a way. Map matching attributes a certain object from a spatial dataset to the location of that object in another spatial dataset.

Today, location-based services and transportation systems are a major part of unbans services (e.g. Huang, et al., 2021; Zhang, et al., 2021). One of these services is management and monitoring of public transportation and automatic pay catch of passing through special routes and in this condition positioning is a crucial factor declaring the presence of the user.

There are different algorithms for map matching of moving objects which can be classified as Geometrical, Topological, Probabilistic, and Advanced (Vafaeinejad 2017).

Many studies are so far conducted to enhance the precision of map-matching algorithms, but less attention is paid to the optimization methods (Rasekh and Vafaeinezhad, 2012). In 2002 the topological weighted algorithm based on parameters of proximity, heading, and the junction was outlined to specify the link. In the following years, some new results were found by additions or removal in the parameters of the algorithm (Fallah-Zazuli et al., 2019). In 2009, two parameters of turn restrictions injunctions and connectivity of links were added to the algorithm and got the successful results of 96.7 % in suburban areas. Analyzing errors and resolving them, the algorithm got the precision of 97.8% in low-density areas.

The purpose of the research was to improve the results of map matching algorithms by the use of optimization methods which is a heuristic approach. Heuristic approaches in network analysis is (e.g. Vafaeinezhad 2009; Mahpour et al., 2018; Vahidnia et al., 2018; Mahpour et al., 2020) and Analytical Hierarchy Process (AHP) technique in Mapping problems (e.g. Masih et al., 2018; Mahpour et al., 2021; Ahadi et al., 2018) are considered widely in recent studies. To address to this issue, we have chosen the topological map-matching algorithm and optimization method of the Analytical Hierarchy Process (AHP) and found considerable conclusions. To explore the efficiency of the algorithm, a case study has been conducted in a dense area of Tehran City and obtained good results.

The rest of the study is organized as follows. Section 2 reviews and discusses the relevant Literature. Section 3 represents the study methodology, containing the characteristics of the study area, modelling framework and the data collected for this study. Section 4 indicates the model specification and results. Section 5 provides an in-depth discussion of the results and key findings and offering plans for implementations.

2. Literature Review: Types of Map Matching Algorithms

The map matching algorithms match the positioning data from the global positioning system on the map. The matching aims to determine the exact location of a vehicle on the road link and also the exact position of that vehicle on the same link. The algorithm is divided into four different categories of geometric, topological, probabilistic, and advanced (Aghakhani et al., 2018).

The first group contains geometric algorithms as the primary and the simplest types of algorithms. They just consider geometric information related to the network and positioning points and perform mainly based on distance (ZHAO et al., 2003). This paper has used a compound method by which a topological map-matching algorithm is improved by the Analytical Hierarchy Process (AHP) optimization method. As the material of the study, we have used Garmin GPS data and a 1:2000 urban map of the national cartographic center. To explore the efficiency of the algorithm, a case study has been conducted in a dense area of Tehran City. Flowchart of map matching algorithm outlined in this study presents in figure 1.

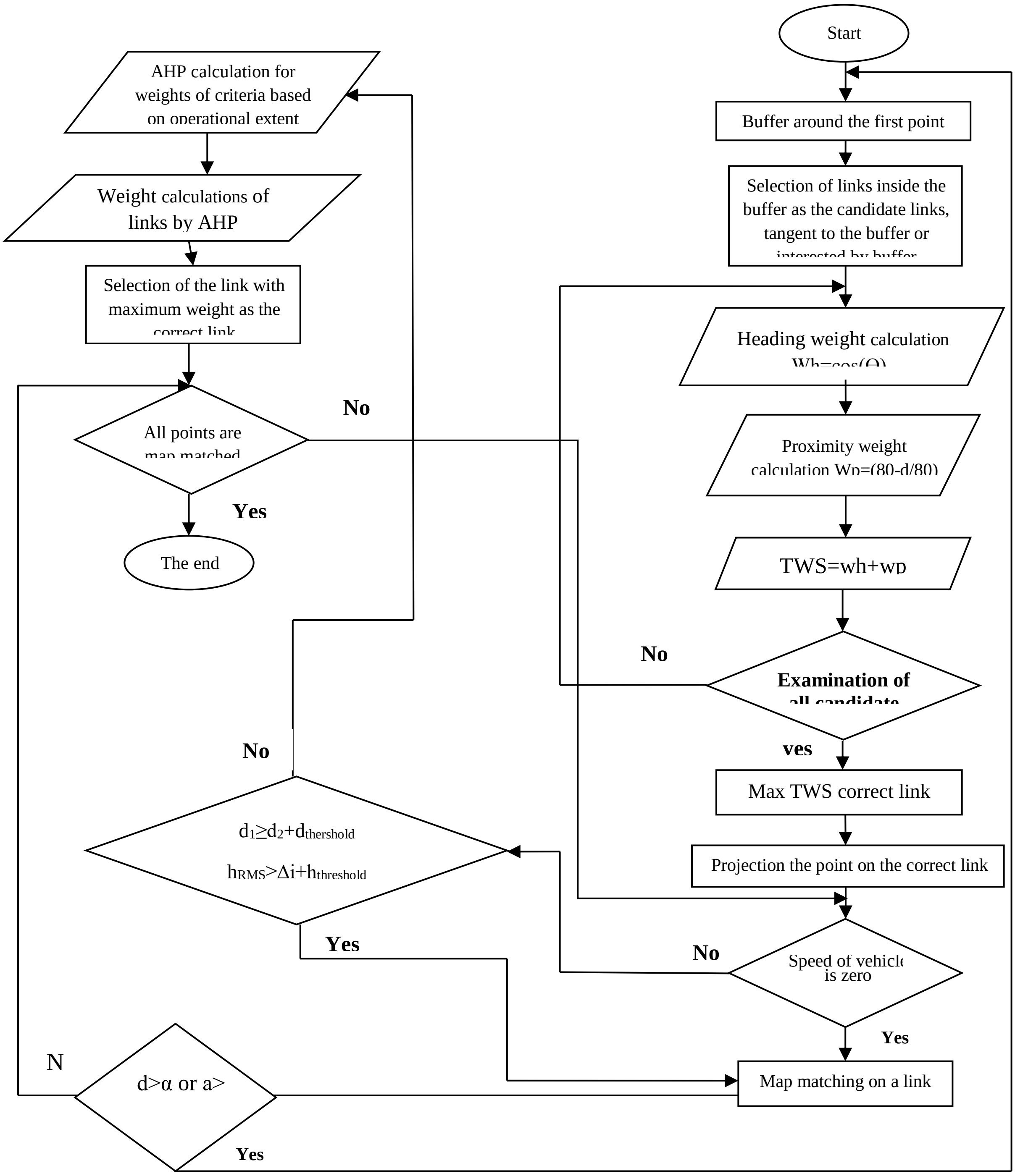

Figure 1. Flowchart of map matching algorithm outlined in this study

The geometric map matching algorithms have many problems and uncertainties that make them inapplicable for urban areas and dense networks. Because they are very sensitive to the errors in positioning data, disregard the precedent data about the vehicle, and also disregard the topology of the network and link connectivity. To eliminate these problems and difficulties, map matching algorithms related to the topological information of networks are developed.

The topological map-matching algorithm is defined as an algorithm that uses connectivity and proximity of links with geometric information of network (C. A. Blazquez et al,2005, Y. Meng et al.,2002, ZHAO et al.,2003, B. Baella and M. Pla, 2005).

Application of topological information of networks can contribute to the map matching particularly in dense networks and downtowns with networks close together. Using this information, it is possible to avoid abrupt skips in matching on unrelated but close networks. Accordingly, in a shift of route in the vehicle, the algorithm can avoid a route that is unrelated to the previous route in a search for new networks, and do the searching just for the networks that are connected to the previous network.

The probabilistic algorithms of map matching utilize probability theory to specify a set of candidate links by sources of error data of navigation sensors and spatial data of roads (Velage et al, 2009).

The advanced algorithms of map matching import a vast set of data in the calculations as input and render more advanced processing for map matching. The algorithms include applications of techniques of extended Kalman Filter, belief theory, fuzzy logic, and artificial neural network (Yang et al. 2003, Syed and Cannon. 2004, Quddus et al, 2006. Pyo et al, 2001, Velage et al. 2009). An advanced algorithm needs more data for processing and is slow and difficult in execution while a topological algorithm is can be run very fast and easily (Velage et al. 2009). Therefore, topological algorithms have more potential for real-time application and need lower memory space.

3. Methodology: Topological Map-Matching Algorithms by AHP

The algorithm includes three parts including 1- initial map matching, 2- map matching on a link, and 3- map matching at a junction through the AHP method. To run the algorithm we need three sets of data. Link data involve unique ID of link, starting node, and ending node of link. Nod data consist of unique ID and geographic coordinates. Also, Location finding data from a navigation sensor consist of geographic coordinates, heading and speed of the vehicle, and turn restriction data at junctions restored as turn restriction matrices.

Initial map matching aims to discern the accurate link for the first located point. The process is in a way that following the initial map matching, the algorithm qualify three conditions to match the other points:

1: Does the vehicle have a stationary situation? (Map matching on a link)

2: Is the vehicle traveling on the previous matched link? (Map matching on a link)

3: Is the vehicle close to a junction? (Map matching at the junction)

If the speed of a vehicle is zero in a positioned point, thus, that vehicle will be stationary and the position of the vehicle will be determined on the previous matched link. If the vehicle is not stationary, the algorithm explores whether the positioned point is near the junction. If the vehicle is at a distance to the junction, the positioned point will be matched on the previous matched road. If the vehicle is close to the junction, it will go to the matching stage at the junction and the correct link will be selected amongst the candidate links. In all the mentioned situations, following the specification of a correct link for a point, an orthogonal projection system determines the position of that vehicle on the link.

3.1. Initial Map Matching

The initial map matching is very important in a map matching process. Because any error in the primary process lead to the errors in the next stages. The initial map matching is performed in three stages.

1: Identification of a set of candidate links

2: Specification of correct links from candidate links using weights of heading and proximity

3: Estimation of the position of the vehicle on the correct link

In order to reduce the calculations, the algorithms, using a mechanism, consider a number of road segments as the candidate for each positioning. This makes it possible not to calculate the distance of positioned point for each given link.

For the initial matching, a bulb of error as a buffer is generated around the first positioned point. The bulb is generated based on the quality of positioning data. (Variance and covariance of latitude and longitude of coordinates) all the links inside the bulb of error or tangent and intersected by the bulb are considered as candidate links for the first positioned point.

An extent of confidence is defined for each positioned point regarding the precision of the GPS receiver and any road segment that pass from inside that extent will be considered as candidate road segment.

In the second stage, the correct link must be selected from candidate links, thus, the weights of heading (Table 1) and proximity (Table 2) will be calculated for all the candidate links. In the attribute table of links, all links have a specified azimuth as well as the GPS point position of the vehicle travelling is specified for each given point. It is obvious that the closer is the heading of the travel of the vehicle, the more the probability of locating the vehicle on that link, and vice versa. Therefore, it is required to calculate first the azimuth of the travel of the vehicle and the azimuth for each of the candidate links. Finally, a link will be selected that its heading has the most proximity to the heading of vehicle. Azimuth differences to determine the heading weights is obtained from cos(θ), i.e., the angle between the link and the heading of the vehicle.

$$W_h = \cos(\theta) \quad (1)$$

The weight of proximity is calculated by the vertical distance of the positioned point up to the link. The link closer to the positioned point gets higher weight.

After the candidate road segments were specified for each positioned point, the distance of that point to all the road segments is calculated. To calculate the distance there are two states (Figure 2).

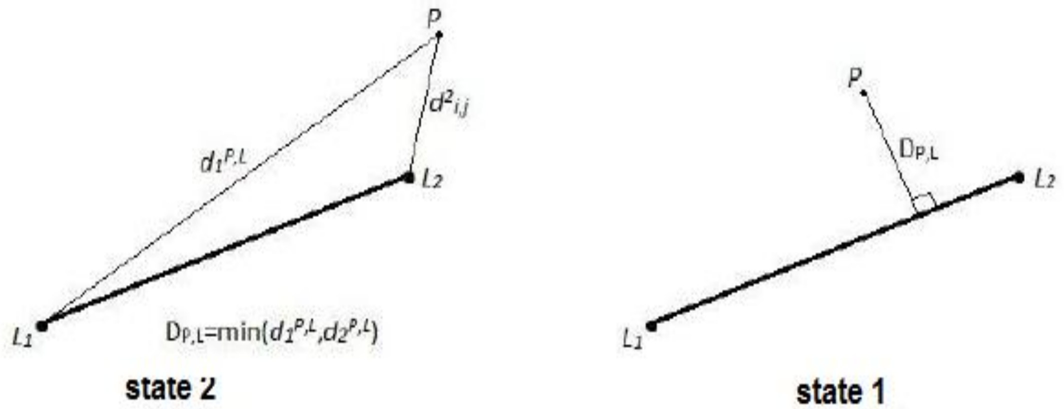

Figure 2. Calculation of distance of user to a candidate link in different states

The first state is in a situation that the top view of user on the edge corresponding to the road segment is located between both the start and the end nodes. In this state distance to coordinates of image is calculated. The second state is when the top view of user on the edge corresponding to the road segment, is out of both the start and the end nodes. In this state, the distance of the situation of the user to both the start and end nodes is measured and the minimum of the distance is considered as the distance of the user to the road segment. The proximity weight has a linear relationship with distance.

$$W_P = (\frac{80 - D}{80}) \quad (2)$$

The sum of both these values is calculated for all the candidate links and the link with the most TWS value is assumed as the correct link.

$$TWS = \cos(\theta) + (\frac{80 - D}{80}) \quad (3)$$

It is also required to determine the position of moving object on its traveling route. The vertical projection of the user on the selected link is as the place of the user. As the vertical projection of the user position is not located on the selected link, the node closer to the user position is assumed as the place of user.

3.2. Map Matching on the Link

After the success of initial map matching, the next stage is to do map matching on a link. Thus, the algorithm examines the speed of the vehicle. If the speed of the vehicle is zero, the algorithm transfers its position to the previous map matched road segment. If the vehicle is travelling (the speed is more than zero), it calculates whether the vehicle is close to the junction or not. So it explores two below options:

- Distance of the previous map matched point to the next junction
- The heading of the vehicle relative to the heading of the previous map matched link

To specify whether the vehicle is close to a junction, it compares the distance that the vehicle traveled in the last time interval with the distance of the previous map matched point to the junction.

$$d_1 \geq d_2 + d_{thershold} \quad (4)$$

Where d_1 is the distance between the previous map matched positioning point to the next junction, and d_2 is the distance traveled by the vehicle during the last time interval, and $d_{threshold}$ is a threshold distance that is a positive value.

Because there are some errors in the previous map matched positions, digital maps and width of roads, it is required to have a threshold distance to ensure that the vehicle is at the junction.

If $d_1 = d_2$ so the vehicle is at a junction. If the heading of the vehicle shifts considerable relative to the heading of the link of the selected road segment, it shows a turn and it can be determined that it has reached a junction.

$$h_{RMS} \geq \Delta i + h_{threshold} \quad (5)$$

Where, h_{RMS} is the second power of average errors for all headings related to the map matching of the positions on the recognized previous link. Δ i is the angle between the heading of the vehicle and the heading of the recognized previous link. And $h_{threshold}$ is a positive threshold value. The values of $h_{threshold}$ and $d_{threshold}$ were determined empirically 60 degrees and 1 meter for a dense urban area. If the two explorations in equations 4 and 5 are satisfying, the algorithm will choose the previous map matched link and snap the positioning point on the same road segment; if not it the algorithm goes to the junction.

3.2.1. The Threshold to Exit from Map Matching on the Link

In the initial map matching just a geometric method is used and there is the possibility to recognize the link by mistake. If it goes on by the pam matching without any other examination, it may have incorrect results. Thus, by adding two conditions it can to prevent occurrences of errors in map matching algorithm. One of the conditions is related to the distance. It states that if the distance of positioning point to the map matched point is more than α, the algorithm should do the initial map matching again. The second condition is related to the heading difference. If the angle between the heading of traveling and the map matched link is more than β, the algorithm should return to the initial map matching stage. The values of α and β are 22 meters and 30 degrees for a dense urban area.

3.3. Map Matching at the Junction by AHP

About junction, AHP method is applied to select the candidate link. The stages here are to some extent like initial map matching section. Buffers are first generated around the point of interest and the candidate links are specified. Then, the heading is determined by using the current point and the last positioned point restored. The criteria are delivered into nine categories since the AHP method is applied to select the candidate link. The angle between each link and the heading is determined, and then they are divided equally. The classification is that the higher weight is for the link in the same heading with the positioned point. (Table 1).

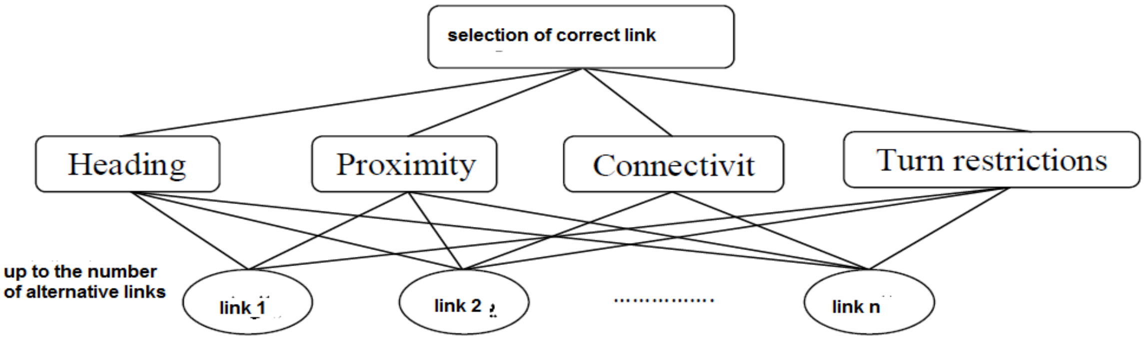

Figure 3. Selection of correct link by AHP method

Table 1. Weighting of the link between the heading of the travel and heading of the link based on AHP

Value	ϴ Angle
0≤ ϴ≤20	9
20<ϴ≤40	8
40<ϴ≤60	7
0<ϴ≤80	6
80<ϴ≤100	5
100<ϴ≤120	4
120<ϴ≤140	3
140<ϴ≤160	2
160<ϴ≤180	1

The proximity to the positioned point is another influencing parameter. The weight of proximity is calculated by vertical distance (D) of the positioned point to the link and the link closer to the positioned point get higher weight (Table 2). If the vertical line of positioned point has no physical intersection with the link of interest, the distance to the nearest node of that link will be considered.

Table 2. Weighting of proximity in AHP

Value	Proximity
0≤D≤1.8	9
1.8<D≤3.6	8
3.6<D≤5.4	7
5.4<D≤7.2	6
7.2<D≤9.0	5
9.0<D≤10.8	4
10.8<D≤12.6	3
12.6<D≤14.4	2
14.4<D	1

The connectivity is a parameter in which the highest weight, i.e., number 9, is given to the links that are connected to the previous link and the lowest weight of 1 to the link with no connection to the link (Table 3) The other parameter is turn restriction (Table 4). If vehicle approximate to the junction at which it is not allowed lawfully to turn to the right or left, the link got the lowest weight; if it is allowed the link gets the highest weight.

Table 3. Weighting of connectivity in AHP

Connectivity	Value
Connected	9
Disconnected	1

Table 4. Weighting of turn restriction in AHP

Turn restriction	Value
Turn allowed	9
Turn not allowed	1

For each of the parameters, the pairwise comparison matrix of links is completed.

An examination of the map matching performed off-line revealed that the coefficients in must be different in varying operational extents, including urban, suburban and rural, to get more accurate results in map matching.

In this stage the coefficients are imported from the work of Nagendra R. Velaga et al. (2009). In this article the coefficients are calculated by Constrained Nonlinear Minimization optimization method. In the following sections we change the coefficients for improved results Finally the weight parameter is calculated for all candidate links and the link with highest weight get recognized as the correct link.

Final Weight of Link= (the weight from the table of links for heading)×(weight of heading criterion)+ (the weight from the table of links for proximity)×(weight of Proximity criterion)+(the weight from the table of links for connectivity)×(weight of connectivity criterion)+ (the weight from the table of links for turn restrictions)×(weight of turn restriction criterion)

In the next section the whole executive method for this research is explained. For a map matching analysis first the data must be prepared. The preparation includes digitizing of maps, preparing GPS maps. Coefficients, parameters and weights must be prepared to algorithm can perform map matching.

4. Results

To do map matching it is required to have user positioning data and digital road networks. The maps of national cartographic center of Iran, 1:2000 at scale, were used as the data. The study area was selected so that it contains both urban regions of dense textures and also highway textures. The coordinate of the northwest and southeast corner of the area are 531000, 3946800 and 532600, 394440 in UTM coordinate system.

The roads were digitized based on their centerline. This is worthy to note that two sides of boulevards and highways were digitized as none coincident for more precise and more accurate digitization.

As one of the hypotheses of the research is to regard traffic parameters in modeling road networks, traffic data were needed for this research. The data about the heading of the traffic and one-way or two-way streets have been imported from the urban map database. One-way streets have been drawn according to the traffic flow. The one-way and two-way lines have been restored in two separate layer files.

To prepare the positioning data of the user, a road segment have been selected for transverse of the user car. The road segment has been selected so that firstly has the ability to meet the research requirements in terms of volume of data and secondly transverse different textures of the city not to limit the results to a certain type of roads (Figure 4).

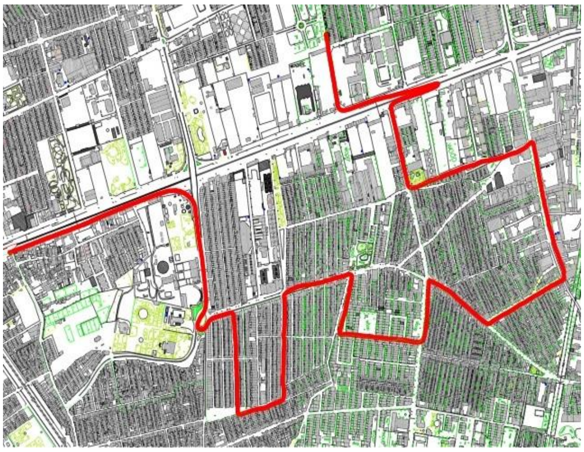

Figure 4. The road segment for positioning data in the study area

A GPS receiver of Garmin 62s has been applied in the research to provide input data for map matching process. The positioning error of the device as claimed is less than 15 meters in 95% of cases.

The map matching algorithm has been encoded by Visual Basic Programming in order to join with ArcGIS software. In the output two layers of map matched points and buffers around the points are added that represent what map matching method has been used for each point.

5. Conclusion and Implications

In this research the road networks have been modeled with heading data; the road segments were digitized based on their traffic parameters. To enhance the accuracy, in the wide road segments (two-ways), the networks have been digitized separately and unmatched to each other. The conclusion of the research can be stated as following:

- The algorithm of the study uses a compound method. The method improves a topologic algorithm using an optimization method of AHP. Hence, it can obtain better results relative to the geometric and topological algorithm.
- Including the parameters of heading, proximity, connectivity and turn restriction have reduced errors in link recognition. For example, by turn restriction, the links that turn is not allowed are eliminated from the candidate links and this enhanced the detection of correct link (Table 5).
- Duo to capability in pairwise comparison of link matrices relative to the different criteria of heading, proximity, connectivity, and turn restriction, AHP method can obtain good results in junctions. Hence, it is possible to determine the importance and preference of each link by the extent of interest. The values are imported by user.
- In the compound algorithm, using geometric method in initial map matching, map matching on a link, and by AHP method in the junction, it is possible to reach an output of 97.3 percent of correct link recognition. That is, the algorithm can realize the link correctly in 97.3 % of cases. The results are from the following parameters:

Table 5. Parameters of the algorithm

Parameter	Value
Buffer range	20 m
Length threshold in map matching on a link	22 m
Angle threshold in map matching on a link	30 degrees
Length threshold in junction recognition	1 m
Angle threshold in junction recognition	60 degrees
Heading coefficient	0.3999
Proximity coefficient	0.0813
Connectivity coefficient	0.3640
Turn restriction coefficient	0.1548

Figure 5 represents that the algorithm performs well in link recognition. Link recognition at the junctions with many intersections is difficult but the algorithm acted successfully in detecting the correct link.

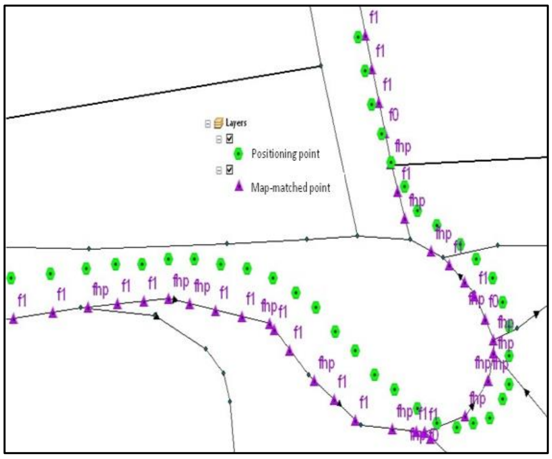

Figure 5. The output of map matching algorithm

- The 2.7 % error in map matched points is related to the low accuracy of GPS data and the algorithm performed correctly nearly in all cases. The errors can be eliminated by improvement in precision of GPS data and road network data.

Table 6 represents the characteristics and results of presented algorithm of this study and some other researches.

Table 6. A summary of map matching results in other studies

Researcher	Navigation sensor	Study area	Map scale	Data volume	Included parameters	Accuracy
White et al	GPS	Suburban	-	1200 meters	Heading, proximity, connectivity	85.8
Srinivasan et al	GPS	Campus road networks	-	242 GPS points	Heading, turn restriction	96.5
Blazquez Vonderohe	DGPS	City and suburban	1:24000	600 DGPS points	Connectivity, turn restriction	94.8
Greenfled	GPS	City and suburban	1:1250	500 DGPS points	Heading, distance, junction angle	85.6
Quddus et al	DR and GPS	City	-	700 DGPS points	Heading, distance, relative position	88.6
Velaga et al	GPS and DR	City and suburban	1:2500	2040 DGPS points	Heading, distance, turn restriction, link connectivity	96.8
Rahbar	GPS	City (street and highway)	1:2000	732 GPS points	Heading, distance, relative position, heading link, turn restriction, link connectivity	98.7*
Currect Research	GPS	City (dense area)	1:2000	906 GPS points	Heading, distance, turn restriction, link connectivity	97.3

*Our research area was a dense area of the city while the mentioned research study area was only streets and highways. On the other hand, we used 906 GPS points which are more than it

Map matching of moving objects has contributed a greatly in wireless networks and intelligent transportation networks and interested for researchers. For researches in this field, it is recommended that:

- The accuracy of GPS data increases using different methods
- Researchers use other optimization methods of genetic and artificial neural network in map matching
- To improve the results, case studies of errors in different data be conducted
- To avoid selection of wrong link delimit the candidate links.
- To involve parameter of speed in calculation of algorithm
- The algorithm must be executed in less complicated areas than urban dense area.

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