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A New Method for Path Finding of Power Transmission Lines in Geospatial Information System Using Raster Networks and Minimum of Mean Algorithm

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Abstract: Currently path-finding methods, which are widely used in GIS, rely on finding a path, which the sum of pixels' weights on the path would be less than the other paths. According to dependency between sum of pixels' weights and length of path, decrementing of sum of pixels' weights can not considered as a proper criterion for optimum path finding. In addition, path length is not regarded as an independent criterion in selecting a path. Therefore, in path finding, it is not possible to optimize the other parameter by changing the sum of pixels' weight parameter or path length. In this paper, a new algorithm so-called minimum of mean algorithm for finding the optimum path in Geospatial Information System (GIS) is presented. Based on this algorithm, the mean of pixels' weight is minimized. This criterion is independent of path length and the path length is considered as an independent parameter. The result of the aforesaid algorithm tends to find a path which crosses pixels with low weight and length of path is lower than a threshold. The mentioned algorithm has been applied on path finding of High Voltage Transmission lines located between Tabriz and Ahar cities in Iran and the produced outcomes have been compared to the results of conventional methods.

Key words: Path finding . Dijkstra algorithm . minimum of mean algorithm . high voltage transmission lines

INTRODUCTION

Dijkstra in 1960 proposed an algorithm in which was based on finding the shortest path between an origin node and other nodes of a graph [1]. This algorithm has been utilized in various disciplines such as transportation, telecommunication and computer for finding the shortest path between two nodes in a graph. Moreover other algorithms have been developed on the basis of the foresaid algorithm, regarding to the specific requisition [2, 3].

This algorithm has been used in GIS in two fields, namely network analysis and route designing. On account of analysis which is exploited in vector network like network of roads of cities, the mentioned algorithm is applied in favour of finding the most optimum path between two nodes on the subject of parameters as traffic intensity, speed and path length [4]. Contrary to the previous topic, path designing is performed in a raster network. This subject is applied in GIS as efficient means for designing the path of a road, power transmission line, pipelines and etc. Furthermore, this subject is used in path finding of an agent in the artificial environment of a computer game.

Related to the path finding of roads using GIS in a raster network, many researches have been carried out, which by considering various parameters, one or several paths would be selected for road construction [5-7]. For instance, one of the related applied investigations can be cited to the path finding in arctic all weather in Canada using Dijkstra algorithm in GIS [8]. Another investigation was accomplished in the USA on behalf of finding the optimum path to achieve ancient and historical sites from sets of origin points [9].

Also, investigations in the scope of gas pipe lines designing and their path finding by the aid of GIS have been performed. For example, in order to design a petroleum pipe line from the Caspian sea to the Black sea, GIS and path finding analysis in a raster network have been utilized and criteria such as altitude, geological characteristics, ground workability and road crossing to the pipe line network have been considered [10].

The current path finding approaches used in GIS are based on finding a path which its sum of the weight of situated pixels on the path is less that the other paths. Being lessened of the sum of the weight of pixels is not a proper criterion for choosing the optimu m path. This is because of the sum of the weight of pixels

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is dependent on path length parameter. In addition, path length is not considered as an independent parameter in choosing the path. Therefore, it is not possible to optimize one of the sum of the weight of pixels and path length by changing another one. In the present paper, a new algorithm namely minimum of the mean algorithm is proposed for finding the optimum path based on in GIS analysis.

In this algorithm, the average weight of path pixels would be minimized. This criterion is independent of path length and as a result, the path length would be considered as an autonomous parameter in path finding process. The outcome of this algorithm tends to find a path which traverses slight value pixels As well as and the length of path is in the specific range. The foresaid algorithm was applied in path finding of power transmission line in a case study between Ahar and Tabriz cities in Iran and the obtained results are compared to the previous conventional methods.

MINIMUM OF MEAN ALGORITHM

In various applications of path finding like path finding of pipe lines, power transmission lines and etc, users are appeal to find a path which cross low weight regions and length of path be shorter than a specific value. In different application, pixels weight demonstrates the cost of path construction regarding to the region topographic characteristics. However, a part of construction cost is related to the line length that should be entered in calculations as an independent parameter.

In view of the mentioned characteristics, finding such a path with available algorithms is impossible. for the reason that in such algorithms, the only selected path has been chosen which depends on the minimum of sum of the pixel's weight and finding the optimum path by changing path line is impractical. Thereafter requisition for other algorithms to cope with this shortcoming has been received some demands. Illustrations of the minimum of the mean algorithm using a simple sample are as follows.

Given that the aim is finding the best path for water pipe line on the basis of region slope (Fig. 1). In such a way that pipe crossing on a milder slope will be tended to a better designing concerning the path length less than six units. The digits on the pixels in Fig. 1 show the slope percent of the region of interest.

According to the Fig. 1, if algorithms such as Dijkstra would be utilized for path finding, the A path would be opted with the following characteristics.

$$\text{Path A}\begin{cases} l = 5.2 \\ \sum w_i = 16 \\ \dfrac{\sum w_i}{n} = 4 \end{cases}$$

Now you can suppose that paths B and C have the following characteristics:

$$\text{Path B}\begin{cases} l = 5.8 \\ \sum w_i = 17 \\ \dfrac{\sum w_i}{n} = 3.4 \end{cases}$$

$$\text{Path C}\begin{cases} l = 7 \\ \sum w_i = 17 \\ \dfrac{\sum w_i}{n} = 2.43 \end{cases}$$

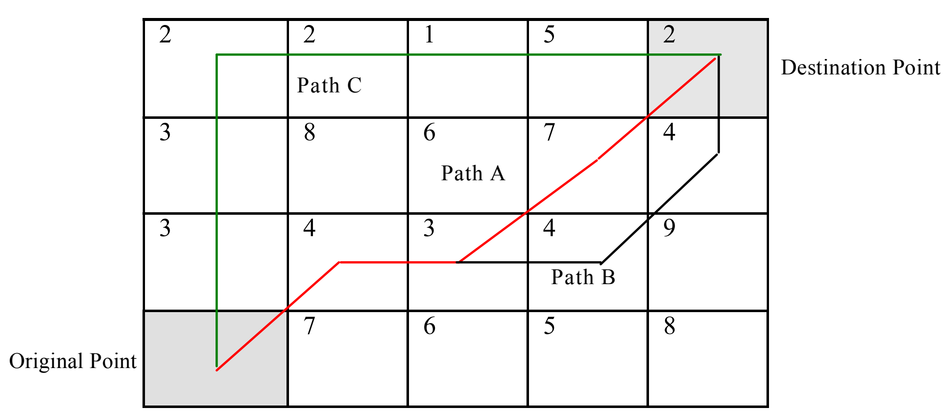

Fig. 1: Three paths resulted from three different parameters

By evaluating the paths A, B and C it is clear that, A and B paths are shorter than 6 units but path B is the optimum answer of the problem regarding its crossing on pixels with a slighter slope. Moreover, although the path C has been crossed on pixels with slighter slope but, because of its length which is more than 6 units could not be opted as the optimum answer. The reason that the sum of weight of path A is less than path B is that the sum of pixels of path A is fewer than those of path B, therefore by appending a little length to the path line, a more optimum path could be chosen. This matter would tend to select path B in return of path A.

The above example illustrates that a balance can be created between sum of pixels weight and path length parameters in order to choose the optimum path as regards to its characteristics.

In order to implement this idea, the mean of pixels weight should be minimized instead of the sum of pixels weight. But paths with minimum pixels weight have usually long paths which causes that they can not be optimum paths (path C).

In order to prevent this matter, the length parameter must be considered as a limiting parameter. For this reason, a path will be opted which its length would be less than a specific amount besides of minimization of the sum of the pixels weight (Eq. 1).

$$\begin{cases} \frac{\sum w_i}{n} \rightarrow \min \\ l < L_{max} \end{cases} \qquad (1)$$

If in the above equation, $L_{max} = 6$ would be placed, it would be prescribed that by choosing a proper value for L_{max} the optimum path will be selected. Also, by changing the values of L_{max}, various paths with different characteristics could be assigned.

IMPLEMENTATION OF MINIMUM OF MEAN ALGORITHM

In order to implement the minimum of mean algorithm, Dijkstra algorithm should be modified to find the optimum path on the basis of mentioned criterion in Eq. 1. Optimization of the Dijkstra algorithm is carried out in such a way that instead of calculating the sum of pixels weights in each level, equation 1 would be minimized.

Various methods exist for implementing Dijkstra algorithm. One of the methods which is faster than the others, was selected for implementation of minimum of mean algorithm,

This method is based on the foundation of the nodes relation among themselves according to the pixels neighbours. As regards to the Fig. 2, those nodes which are related to the origin node would be given code 1, which means that they are situated in the first layer of the origin distance. Furthermore, nodes of the second layer (pixels with code 2) are related to the layer one's nodes. Third, fourth and subsequent layers are defined on the same way.

5	4	4	4	4	4	4	4	4	4
5	4	3	3	3	3	3	3	3	4
5	4	3	2	2	2	2	2	3	4
5	4	3	2	1	1	1	2	3	4
5	4	3	2	1		1	2	3	4
5	4	3	2	1	1	1	2	3	4
5	4	3	2	2	2	2	2	3	4
5	4	3	3	3	3	3	3	3	4
5	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5

Fig. 2: Depiction of various layers in a raster network

Intended for calculating the least cost for reaching to the entire nodes of the network from the origin node, calculating the least cost from the first layer for each existent node on that layer regarding to the equation 1 in comparison to the adjacent nodes in the prior layer or the present nodes in the layer should be applied.

By assuming that the values of the all nodes are positive, the stages for executing the algorithm are as below:

- Set the origin node weight and the layer inside equals to zero
- Consider the counter layer as k = 1
- For each node placed in layer k, path length L_{max}^{k} would be calculated from origin to the node of interest.
- For each pixel (node) situated in layer k which

$$k(\sqrt{2} + \alpha) > L_{max}^{k} \qquad (2)$$

Then, the minimum of mean weight criterion to origin is calculated. In Eq. 2, parameter α is the path length controlling parameter which should be determined based on the project condition.

- Put the counter layer as k = k + 1
- Stages 3 and 4 would be repeated until cost of entire nodes will be calculated.

If the aim is finding a path with the minimum cost from a node in layer n to origin node, it is obvious that this path has been passed over nodes of n-1, n-2, …1 layer and eventually terminated to the origin node. At this moment so as to seek those nodes which are placed on this path in every layer, assigning cost of the destination node regarding to the calculated node in layer n-1 would be sufficient and subsequently by finding these nodes, path with the least cost from the origin node to an arbitrary node would be determined.

APPLYING MINIMUM OF MEAN ALGORITHM IN PATH FINDING OF POWER TRANSMISSION LINES

Currently, path finding of power transmission lines is carried out based on the conventional manner and as regards to its incompetence such as the incapability in considering the entire required information simultaneously, time consuming, high expenses in field monitoring, not ability in integrating different data and etc, the opted paths have several shortcomings.

To overcome this problem, Geospatial Information System (GIS) is utilized in path finding of power transmission lines which employs several parameters simultaneously in finding the finest path. At this part, various stages for using minimum of mean algorithm meant for path finding of power transmission lines are explained and results are described with Dijkstra algorithm. Figure 3 illustrates the various stages for path finding of power transmission lines using minimum of mean algorithm in GIS.

Case study: In the present research, by choosing an available power transmission line (230 KV), path finding between origin and destination substations has been applied and merits of the selected path to the existence path has been evaluated and compared.

The selected area in the present study includes a region with the area of 1680 square kilometres located between Ahar and Tabriz cities (North West of Iran). The origin substation so called Shafa substation is situated in seven kilometres of south east of Tabriz city and Ahar substation as the destination substation is placed in 3 kilometres of south east of Ahar city. The maximum altitude above sea level between origin and destination points is 2830 metre and the minimum altitude is 1300 metre.

The maximum and minimum slope of the region is 29 and 0.9 percent respectively. Also, between the substations, features like cultivation, orchard, woods, river, residential and military areas, fault, road and etc exist. Figure 4 shows the origin and destination location of substations in Tabriz and Ahar cities and also location of these two cities and roads connecting them.

Determination of the effective factors: After investigating electrical industry's critics' outlook and analyzing electrical industry standards in path finding of power transmission lines context, the effective parameters in path finding of power transmission lines where designated. The effective parameters in choosing the optimum path for power transmission lines have been categorized in five main classes as:

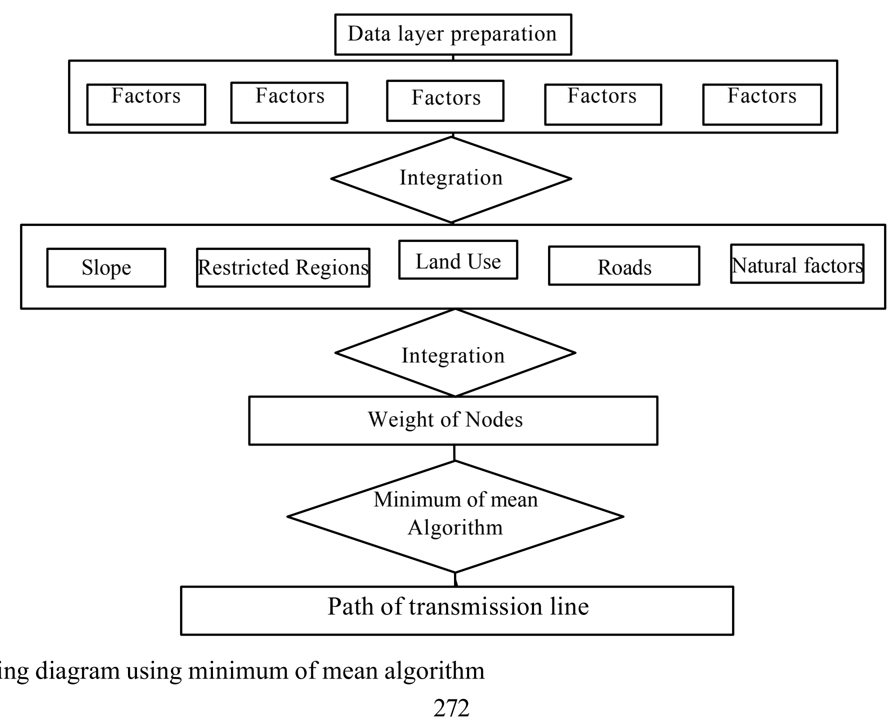

Fig. 3: Path finding diagram using minimum of mean algorithm

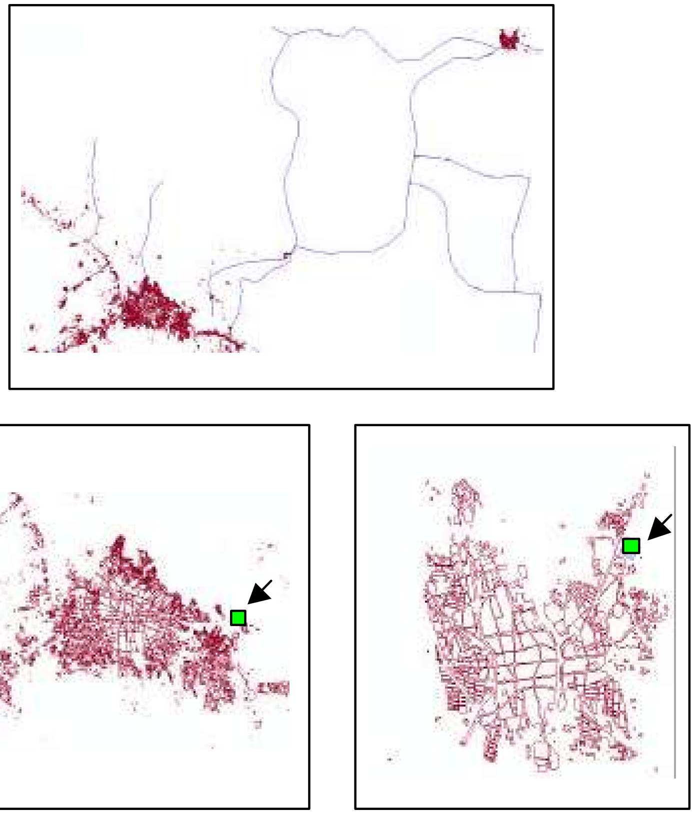

Fig. 4: Depiction of origin and destination substations in the selected study area. a) Location of Tabriz and Ahar cities and roads between them. b) Location of Ahar substation in comparison with Ahar city. c) Location of Shafa substation in comparison with Tabriz city

- Slope: the most important parameter in determining the optimum path for power transmission lines and their construction cost is ground slope. This parameter would be attained from DTM.
- Restricted area: this layer consists of an integration of building blocks, military districts, protected areas and public facilities. Considering this factor would tend to reduce environmental influences due to high voltage of power transmission lines on human beings as well as reduction in interference in public facilities and services buffer such as gas and petrol pipe lines and also their dire influences on human beings and nature.
- Roads: this parameter includes highways, freeways, first, second and third class of asphalted road, gravel road, as well as railway. The cost of transportation of materials to the construction site of transmission line is dependent on this parameter.
- Land use: this factor contains orchards, woods, cultivations like wheat, grain and rice. Non-passing of lines through these areas would make considerable abatement in buying fields meant for tower and other subsidiary matter related to field premises.
- Natural factors: these parameters include all rivers, faults and glacier and avalanched regions. This class of factors has direct influence on magnitude of transmission lines incidents in time of utilization and coerces immense costs to the local electrical institutes [1].

Preparation of data layers: In order to integrate data in GIS environment, preparing operation of input maps using common data processing methods in GIS (like integrating several layers as one layer, converting vector format into raster format, preparing slope map, preparing distance map, reclassification and format conversion) were applied on data. Then, classified (valued) maps of each sub-classes (features) were produced. These maps were integrated which formed related map to the main classes. Reclassification of feature maps, were assigned on the basis of importance of each class to the other classes regarding to its effectiveness in path finding. The importance of each class is enhanced from zero to one and negative number

Table 1: Reclassification of subclass layers in the main class layers

	Building blocks		Military districts		Conserved areas		Public facilities	
Restricted area class	Distance (m)	value	Distance (m)	value	Distance (m)	value	Distance (m)	value
	0-100	-1.00	0-100	-1.0	0-100	-1.0	0-100	-1.00
	100-200	0.00	100-200	0.0	100-200	0.1	100-200	0-30
	200-400	0.20	200-400	0.2	200-400	0.3	200-500	0.60
	400-700	0.40	40-700	0.4	40-700	0.6	500-1000	0.85
	700-1200	0.70	700-1500	0.6	700-1000	0.8	<1000	1.00
	1200-2000	0.85	1500-3000	0.8	>1000	1.0	-	-
	>2000	1.00	>3000	0.9	-	-	-	-
	Asphalted roads		Non-asphalted roads					
Roads class	Distance (m)	value	Distance (m)	value				
	0-100	1.00	0-100	1.00				
	100-500	0.95	100-500	0.90				
	500-1000	0.85	500-1000	0.70				
	1000-3000	0.60	1000-3000	0.50				
	3000-5000	0.35	3000-5000	0.20				
	5000-10000	0.10	5000-10000	0.10				
	10000-20000	0.05	>10000	0.05				
	>20000	0.00	-	-				
	Cultivation		Orchard		Woods			
Land use class	Distance (m)	value	Distance (m)	value	Distance (m)	value		
	0-100	0.2	0-100	0.10	0-100	0.05		
	100-200	0.5	100-200	0.40	100-300	0.45		
	200-500	0.8	200-500	0.75	300-500	0.75		
	>500	1.0	>500	1.00	500-1000	0.90		
	-	-	-	-	>1000	1.00		
	River		Fault		Avalanched regions			
Natural factors class	Distance (m)	value	Distance (m)	value	Distance (m)	value		
	0-100	0.00	0-500	0.00	0-100	0.0		
	100-300	0.20	500-1000	0.10	100-300	0.3		
	300-500	0.35	1000-2000	0.35	300-500	0.6		
	500-1000	0.55	2000-5000	0.65	500-1000	0.8		
	1000-2000	0.75	5000-10000	0.85	1000-2000	0.9		
	2000-5000	0.90	10000-20000	0.95	>2000	1.0		
	>5000	1.00	>20000	1.00	-	-		
Slope class	Slope percent	value						
	0-2	1.00						
	2-5	0.90						
	5-8	0.80						
	8-12	0.70						
	12-16	0.55						
	16-20	0.30						
	20-25	0.10						
	25-30	0.00						
	30-100	-1.00						

present illicit location for towers. Table 1 depicts the reclassification of subclasses in the main classes.

Table 2: Weight of main class layers in integration with each other for obtaining output raster map

Restricted areas class	Building blocks	Military district	Conserved area	Public services
	0.4	0.3	0.15	0.15
Roads class	Asphalted road	Non-asphalted road	Railway	
	0.5	0.3	0.2	
Land use class	Cultivation	Orchard	Woods	
	0.3	45	0.25	
Natural factors class	River	Fault	Avalanched regions	
	0.45	0.35	0.2	

Table 3: Related weights to integrated classes in index overlay model

Class	Class's value
Slope	25
Land use	21
Restricted areas	18
Natural factors	15
Roads	21

Data integration: At this section, firstly existing sub-classes in every main class are integrated together and related map to each class are generated. At this level, intended for integrating sub-classes and creating main classes, index overlay model is used. In this method, data layers are integrated according to Eq. 3.

$$S = \frac{\sum W_i S_{ij}}{\sum W_i} \quad (3)$$

In the above equation, W_i stands for the i^{th} map's weight, S_{ij} represents the j^{th} class of the i^{th} map and S describes pixel's value in the output map [15].

Table 2, shows the weight of each sub-class meant for main class layer creation. In the next step, main class's layers have been integrated on the basis of Index overlay model. The result is a raster map where its pixel's values equals to raster network's nodes weight. Table 3 shows the weight of main class layers in integration with each other for obtaining output raster map or node's weight.

Software design for path finding in raster network: In order to execute Dijkstra algorithm and minimum of mean algorithm in power transmission lines path finding, a software has been designed and written for receiving data layers, execution of Dijkstra and minimum of mean algorithm, displaying location of towers as a series of points of transmission lines path.

In software designing stage, issues such as management of data structure, inputting data layers, a display environment qualified for introducing initial and last points (substations) and depiction of towers location and also recommending two optimum paths and refining selected points and assigning towers locations, have been considered.

Comparing results of Dijkstra algorithm and minimum of mean algorithm: Both Dijkstra and minimum of mean algorithms have been implemented in the mentioned software application. Opted paths are different according to the two approaches. In the minimum of mean algorithm by changing various values of α in Eq. 2, different paths are chosen which smaller amount of α tends to shorter paths and larger amount of α results in longer but more optimum paths. In the current research, different amount of α has been utilized in which a value of 0.7 generated the best results.

In following sections the attained results of the two algorithms on the basis of index overlay method is described and compared.

Evaluation of the results: Prepared data using diverse integration methods was entered in Dijkstra and minimum of mean algorithms and for each data integration approach, a path has been assigned. In order to probe the results, both algorithms workability in index overlay method are evaluated.

Obtained results showed that the opted path using Dijkstra algorithm has 91.6 kilometres length and the attained path from minimum of mean algorithm has 95 kilometres length (Fig. 4). However, results cite that minimum of mean algorithm have the following advantages to the Dijkstra algorithm:

- The opted path by minimum of mean algorithm contrary to Dijkstra algorithm does not pass through steep regions. The produced path resulted from Dijkstra algorithm has crossed part of mountainous areas with high altitude and slope, while the resulted path using minimum of mean algorithm has traversed the entire length of areas with low slope (Fig. 4).

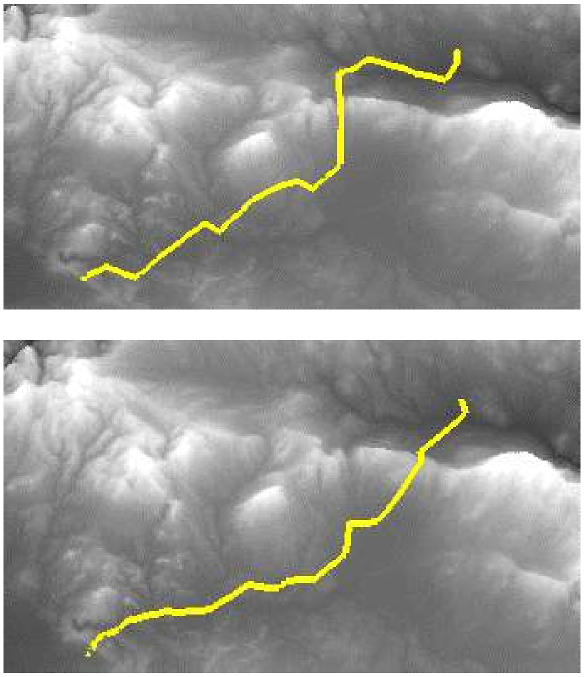

Fig. 5: a) The opted path using Dijkstra algorithm b) The opted path using minimum of mean algorithm

- The related path to minimum of mean algorithm has not traversed residential areas and has gotten the maximum distance during traversing these areas (Fig. 5).
- Regarding cultivations and orchards features, the minimum of mean algorithm has not crossed these regions as far as possible.

CONCLUSIONS

On account of the indirect effect of length parameter in path finding using Dijkstra algorithm and influence of other parameters, the opted paths are not appropriate choices and in many cases dos not concern parameters of interest. To cope with this problem an algorithm has been proposed which minimizes the mean of nodes' weight rather than minimizing sum of nodes' weight with a condition which the length of proper path should be shorter than a known value. The most important results of using this method in path finding of power transmission lines are as below:

- Independency of sum of pixels' weight effectiveness from path length parameter.
- Considering path length parameter as an independent parameter in selecting the optimum path.
- Possibility for determining different paths by changing the effect of length parameter, compared to Dijkstra algorithm which opts one path solely.
- Satisfying effective parameters during path finding in most of the times and being optimum of the resulted path of this algorithm compared to the Dijkstra algorithm.

Finally using this method is considered as an efficient and reliable method for path finding of power transmission lines. Development and enhancement of the mentioned algorithm using additional parameters and criteria is ongoing research.

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