University of West Hungary

Thesis of PhD dissertation

Network Analysis Methods for Mobile GIS

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1. INTRODUCTION

The mobile GIS emerged at the intersection of the evolution of mobility with development of geoinformatics, it represents the user demand and ambition to exploit the geographic knowledge in decision support everywhere and anytime. Network analysis is a major requirement for more than half of the world population moving with mobile devices, they need to comprehend their nearby location and manage their trips and movement.

This research defines the mobile GIS, its architecture and major applications with focus on the network analysis and optimal path. Also, it presents a new approach for the Travelling Salesman Problem (TSP) and tackles the multi-objective navigation problems, and finally it covers the mobile geovisualization.

Aims of Study

1) **Exploit the power of mobile GIS**

   The mobile GIS is a new paradigm in Geography and it has the power to deliver the geospatial data to the mobile user everywhere and anytime.

2) **Emphasize the role of network analysis in mobile geoinformation**

   The network analysis provides the quantitative base for the decision support in transportation and public utilities. Also, the study presents a new approach to solve the travelling salesman problem.

3) **Analyse the optimal path for mobile user**

   The mobile user is always moving, and his/her time and energy are limited, and it is required to determine the optimal path in realtime to minimize the time and energy consumed in navigating from origin to destination.

2. BACKGROUND

The mobile GIS is a new paradigm in geoinformatics that has a unique feature, it is held by the user anytime and everywhere. The mobile user knows its location, has a small screen, and may be connected to the internet or other device/networks or in offline mode and this normal user is a consumer and source for geospatial data. Although in some literature they may refer to the same system, two differences exist between mobile GIS and Web-GIS. The Web-GIS does not have any GIS software neither application at the client side, and needs to be connected to the internet for functionality. The mobile GIS requires GIS applications and software to be installed on the mobile device, and from communications aspect, the mobile GIS can be online (connected mode) or offline (standalone mode).

The criteria for mobile GIS problem are: 1) geodatabases are matured and available (locally or remotely), 2) mobile device is aware of its position, and 3) geospatial functions and algorithms are available on mobile device. The mobile GIS was developed as an extension to classical GIS systems and is a part from it. The mobile device is spreading, and the demand on mobile GIS is increasing.

The mobile GIS is evolving and its advancement will be in several aspects like hardware, geodatabases, positional techniques, wireless networking and algorithms. The areas of applications will increase also, in both directions vertically and horizontally. Horizontally, new applications areas for mobile GIS will be applied, such as medical applications and education, while vertically, in the penetration of mobile GIS as main tool same as notebook and PC for enterprises with heavy geoinformatics applications like public utilities and oil companies.

The privacy of location is violated by mobile devices, and the protection of the privacy required special considerations. This issue is beyond the scope of this research and it requires a dedicated research.

3. ARCHITECTURE OF MOBILE GIS

The mobile GIS system is a micro-level cloning of GIS systems. It has the main components of classical GIS systems with obvious differences. The main components of desktop GIS are hardware, software, data, applications, and users, Figure (1) describes the main components of mobile GIS.

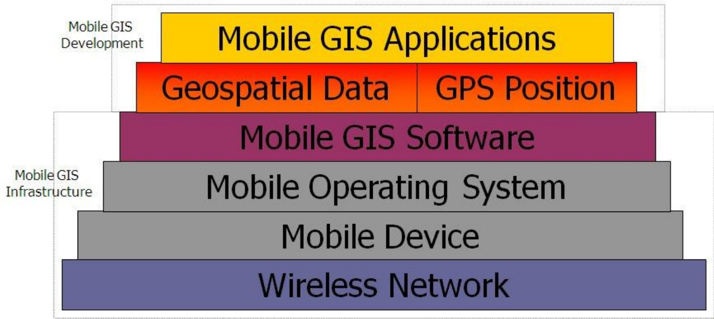

Figure (1) General architecture of mobile GIS system

The mobile device is rich with its communications technologies. Mainly, it has its GSM voice and data communications, in addition to Wi-Fi, infrared, and bluetooth communications. Also, it has positional capabilities, outdoor positioning where the mobile device is free to air, and indoor positioning, where the mobile device is inside building. There are several outdoor positioning techniques for mobile GIS such as GPS, Assisted-GPS (A-GPS), and the mobile GSM network. The position of mobile device can be delivered quantitatively in the format of three or two independent coordinates or qualitatively as near of or close to a landmark or a point of interest (relative position). The mobile GIS requires a generic portion of geodatabases such as limited portion of geodatabase, detailed data for specific locations, topological data for pedestrian, realtime traffic data, vehicle and public transportation, overview for the whole area of interest and environmental and weather data.

Conceptual Framework for Standalone Mobile GIS

The mobile GIS framework is designed to extend the functionalities of GIS to mobile users even in offline mode. The proposed framework is based on sending the area of interest from the geodatabase in the GIS Server to the mobile device where it will be stored, and the second thing is to build GIS applications for mobile device to access the local stored partial geodatabase in the hard disk of mobile device instead of using the application at the server side as shown in Figure (2).

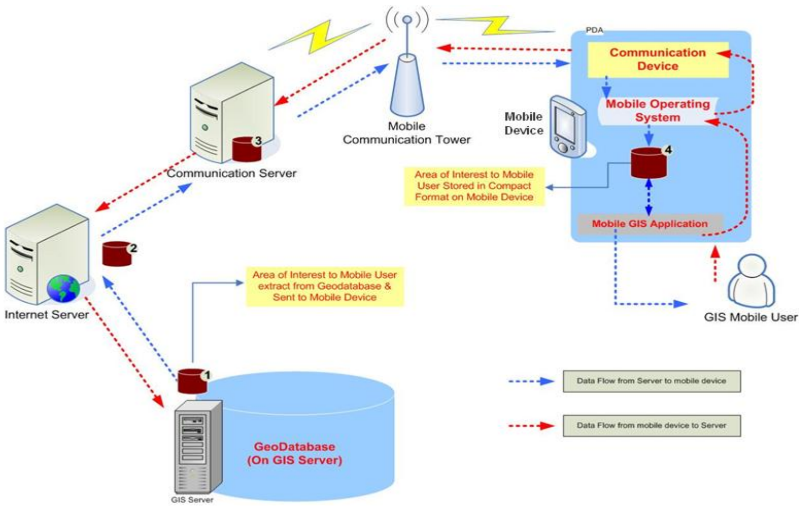

Figure (2) Proposed Framework for Standalone Mobile GIS

This framework has several advantages, it allows the mobile GIS user to work in offline mode, which leads to reduce the bandwidth load on the communication network. The performance of the GIS operation will increase. The GIS user can perform the required analysis, edits the geospatial data, and executes the required tailored GIS applications according to her/his needs. The security of the mobile GIS user is achieved in the proposed framework, since only the transmission of data from server to client can be monitored not the requests nor the results of mobile GIS operations.

4. MOBILE GIS APPLICATIONS

The mobile GIS has a wide range of different applications such as spatial query, proximity analysis, navigation, optimal path, communications and many others. The mobile GIS is a tool to acquire the long travelled roads as it is the only available device for this task. The trajectory of the road from Kuwait to holly Muslim places in Saudi Arabia and back to Kuwait is around 2850km as shown in Figure (3). This road and its points of interests were collected using mobile GIS.

Figure (3) Road from Kuwait to Mekkah

Intelligent Landmark for Mobile GIS

Although the absolute position of a geographic object is of extreme importance, its main usage is for spatial analysis and relationships with its nearby environment within a geographic database. From the theoretical point of view, the geodatabase is stored in absolute coordinates, and the position of moving object is acquired in absolute coordinates, and then by overlaying both of them, the relative position (theoretically) is determined and the semantic of the geographic position is created, but (practically) this not the case. The uncertainty in the geodatabases and the errors in GPS measurements deviate the relative position of moving object from its actual position as shown in

Figure (4). This deviation overloads the system by a map-matching requirement to find the precise relative position of the moving object.

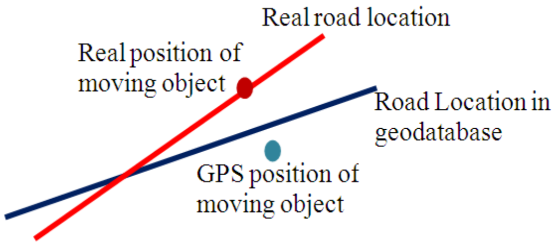

Figure (4) The map-matching problem

The urban transportation network has dense number of landmarks and points of interests. By adding a bluetooth device to landmarks so that each landmark is broadcasting its data to other devices and moving objects, the relative position for moving objects can be resolved with higher accuracy. In Figure (5), a bluetooth device is attached to a traffic signal, and it is broadcasting its data to moving cars. The transmitted message from landmark will include (ID, Name, Type, X, Y, h, time) as the data model described in Figure (5).

Figure (5) The intelligent landmark: Traffic signal with bluetooth device

The intelligent landmark system has the ability to enhance the positioning of moving objects in realtime as it will deliver the relative position and eliminate the map-matching step. As well, it will ensure the user awareness of the surrounding geospatial environment and directions.

5. OPTIMAL PATH

Network Analysis is an essential requirement for mobile GIS. The graphs were among the main models used in geoinformatics. In mobile GIS, two main objectives are essential for mobile user, the first is the spatial query about place and direction: where am I now? Where is a specific location? The second is the optimal navigation path for a trip from an origin to one or more destinations. The first objective can be achieved by visual inspection of the display of the current position (relative or absolute) on a map of the area of interest displayed in the background, while the second objective requires the storage of transportation network as graph, and apply the relevant algorithm for the trip purpose.

New Approach for Travelling Salesman Problem (TSP)

The proposed approach for TSP is based on minimizing the cost of passing through each node. Connecting these minimum traveling costs for each node should theoretically lead to the required least cost tour.

$$C_i = \min C_{incident} + \min C_{outgoing} \quad (1)$$

Where C_i is the least travel cost of node i, $C_{incident}$ is the edge cost from node k to node i, and $C_{outgoing}$is the edge cost from node i to node j. By applying this approach on the full graph described in Table (1), minimum $C_{incident}$ for node 1 will be $C_{4,1}$ of edge (4,1) which has the least cost to arrive to node 1, while the minimum $C_{outgoing}$ of node 1 is $C_{1,5}$ which has the least cost to move from node 1.

Table (1) Cost of edges (Origin-Destination Matrix)

	1	2	3	4	5
1	9999	5	10	10	4
2	8	9999	9	15	22
3	14	17	9999	11	1
4	6	28	14	9999	9
5	7	13	14	16	9999

Table (2) presents the minimum travel cost array for the full graph in Table (1).

Table (2) Minimum travel cost of each node

$C_{incident}$	From	Node	To	$C_{outgoing}$	C_i
6	4	1	5	4	10
5	1	2	1	8	13
9	2	3	5	1	10
10	1	4	1	6	16
1	3	5	1	7	8
31				26	57

Node (4) has the same node (1) as incident and outgoing, and this is not allowed, so the second least cost is used, and the final array is shown in Table (3).

Table (3) Adjusted minimum travel cost of each node

$C_{incident}$	From	Node	To	$C_{outgoing}$	Sum
6	4	1	5	4	10
5	1	2	3	9	14
9	2	3	5	1	10
11	3	4	1	6	17
1	3	5	1	7	8
32				27	59

From Table (3), the following are concluded:

$${}_{1}^{N} C_{outgoing} = 27$$

$${}_{1}^{N} C_{incident} = 32$$

$${}_{1}^{N} C_{incident} > {}_{1}^{N} C_{outgoing}$$

Cost of least tour > 32

By arranging the node sequence of the incident side, the optimal path can be achieved, as shown in Table (4).

Table (4) Second Convergence

$C_{incident}$	From	Node
6	4	1
5	1	2
9	2	3
1	3	5
16	5	4
37		

Algorithm for TSP Problem

In this section, the algorithm for this solution is presented, and it has the following steps:

1. Create node, link, and sub-graph arrays
2. Assign a status of “new” for all nodes
3. Create the minimum travel cost array
4. Exclude the part with minimum sum and start from the maximum sum
5. Join possible nodes from minimum travel cost array
6. Fill sub-graph array with joined nodes
7. Update the status of nodes to be “new” for non-processed nodes, “start” for nodes at the start of sub-graph, “end” for nodes at the end of sub-graph, and “finished” for nodes at the middle of sub-graph.
8. Create a new minimum travel array by excluding “finished” nodes considering the status of nodes
9. Exclude the part with minimum sum and start from the maximum sum
10. Join possible nodes and sub-graphs from minimum travel cost array
11. Go to step 8 until the existence of single sub-graph which is the required solution of the problem

The algorithm discovers also the possible realizations for the minimum cycle.

Application of TSP Algorithm on A-TSP17 Problem

The TSP algorithm will be implemented manually and was developed as C program and applied on the problem A-TSP17 from TSPLIB website which origin-destination cost is shown in Figure (6). Figure (7) presents the possible realizations for the minimum cycle. Each group can have any sequence and will lead also to the same cost of minimum cycle, and their number is 27648 possible minimum cycle.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	9999	3	5	48	48	8	8	5	5	3	3	0	3	5	8	8	5
2	3	9999	3	48	48	8	8	5	5	0	0	3	0	3	8	8	5
3	5	3	9999	72	72	48	48	24	24	3	3	5	3	0	48	48	24
4	48	48	74	9999	0	6	6	12	12	48	48	48	48	74	6	6	12
5	48	48	74	0	9999	6	6	12	12	48	48	48	48	74	6	6	12
6	8	8	50	6	6	9999	0	8	8	8	8	8	8	50	0	0	8
7	8	8	50	6	6	0	9999	8	8	8	8	8	8	50	0	0	8
8	5	5	26	12	12	8	8	9999	0	5	5	5	5	26	8	8	0
9	5	5	26	12	12	8	8	0	9999	5	5	5	5	26	8	8	0
10	3	0	3	48	48	8	8	5	5	9999	0	3	0	3	8	8	5
11	3	0	3	48	48	8	8	5	5	0	9999	3	0	3	8	8	5
12	0	3	5	48	48	8	8	5	5	3	3	9999	3	5	8	8	5
13	3	0	3	48	48	8	8	5	5	0	0	3	9999	3	8	8	5
14	5	3	0	72	72	48	48	24	24	3	3	5	3	9999	48	48	24
15	8	8	50	6	6	0	0	8	8	8	8	8	8	50	9999	0	8
16	8	8	50	6	6	0	0	8	8	8	8	8	8	50	0	9999	8
17	5	5	26	12	12	8	8	0	0	5	5	5	5	26	8	8	9999

Figure (6) Data of ASTP-17 nodes

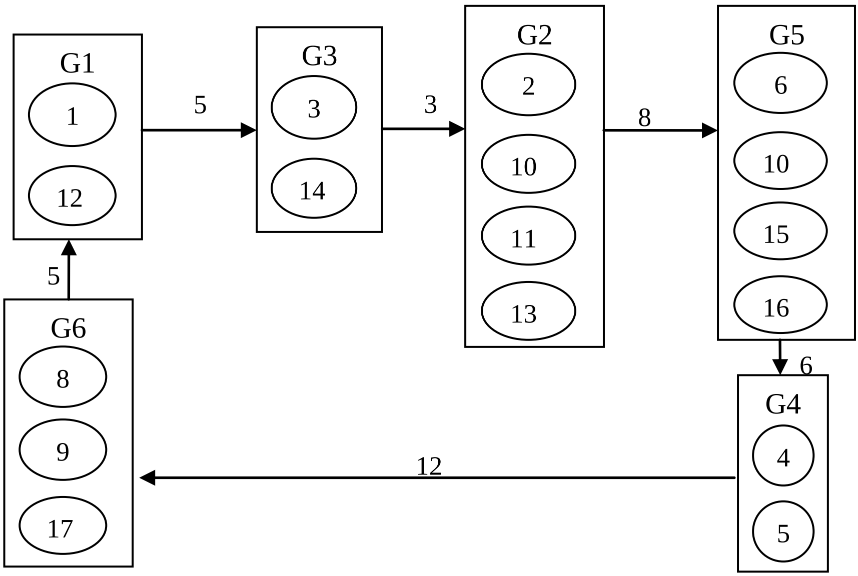

Figure (7) The possible realizations for the minimum cycle for A-TSP17 problem

Multi-objective Navigation Problems

The optimization problems in navigation are multi-objective problems not single objective as traditionally approached in discrete mathematics. If the decision function f(cost) represents the different criteria for the navigation problem, then the optimization requirements can be expressed mathematically as minimizing the partial derivatives for the cost function. For example, if the function f(cost) = f(Distance, energy, time, safety), then optimal path conditions are minimize(distance, energy, time) and maximize(safety), and could be expressed as follows:

$$\text{minimize}\left(\frac{\partial\, \text{f(cost)}}{\partial\, distance}\ ,\ \frac{\partial\, \text{f(cost)}}{\partial\, energy}\ ,\ \frac{\partial\, \text{f(cost)}}{\partial\, time}\right) \text{ and maximize}\left(\frac{\partial\, \text{f(cost)}}{\partial\, safety}\right)$$

Figure (8) displays the result of applying this methodology on a sample from Kuwait metropolitan area optimizing length and time in peak hours. The cost was assumed to depend on time and length only.

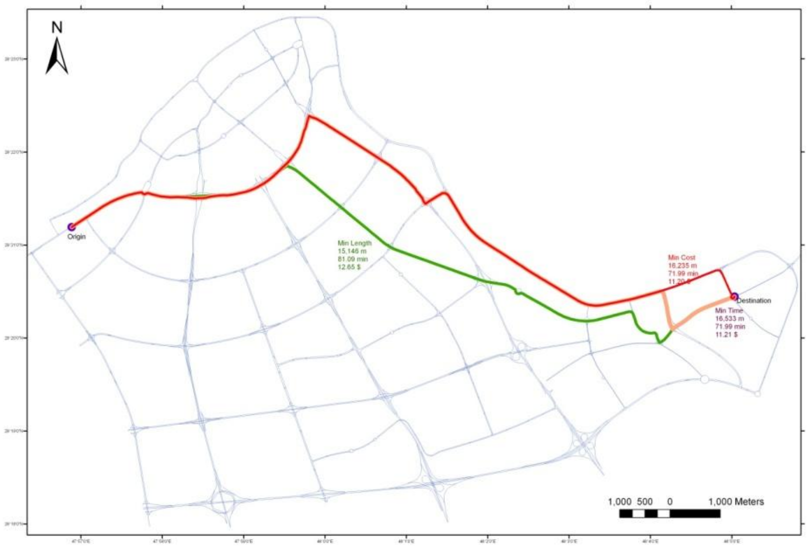

Figure (8) Different solution for multi-objective problem of Kuwait City with the minimum length (in green), minimum time (in orange) and minimum cost (in red) from origin at the West to the destination at the East.

6. MOBILE GEOVISUALIZATION

The visualization of the geospatial data is the main concern of the mobile user. In 1990, the Cartography faced up the challenge of displaying the geographic information on the small size screen of mobile device for mobile GIS applications. The main objective of mobile cartography is to make the user aware of his/her location, direction, and important features around, and this is for the realtime display of geographic information. Figure (9) displays the two orientations in mobile GIS.

Figure (9) North direction in mobile GIS

Holography

Holography is an active imaging senor technique that creates for a 3D object its hologram which is a 2D storage for the 3D data and it can be retrieved and rendered as 3D image such as the 3D surface in Figure (10). The holography is a promising technique expected to provide mobile GIS with an important 3D geovisualization tool.

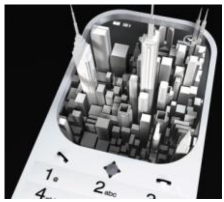
Figure (10) Holography display on mobile device

Metric System for Geographic Coordinates in Mobile GIS

The geoinformatics inherited an ancient sexagesimal system for geographic position from Babylon civilization. The use of this system for mobile user is not suitable as he/she requires a simple quantity that reflects the accuracy of navigator GPS. The latitude (or longitude) on earth surface is defined as three quantities, which are degrees, minutes, and seconds, and most often 100 parts of a second or as decimal degree. The South-West corner of great pyramid of Khufu in Giza, Egypt has geographic coordinates realized on WGS84 as N 29° 58’ 44.3830” latitude and E 31° 07’ 57.0194” longitude as shown in point P in Figure (11) left.

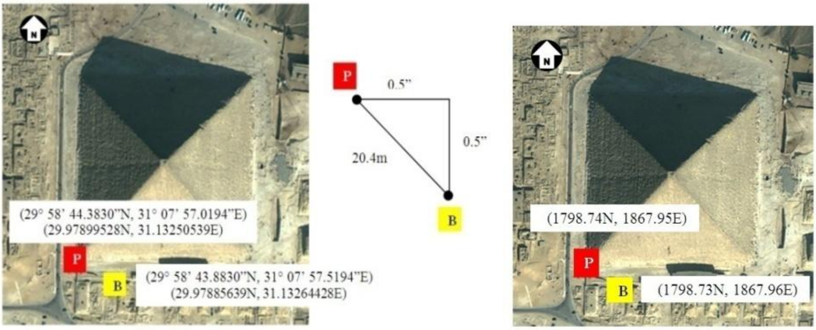

Figure (11) Khufu Pyramid in Giza, Egypt

The advancement in geoinformatics requires a modern metric system for geographic coordinates that is easy to use and has a single unit and quantity for the latitude and longitude without need of conversion when used in calculations and in the same time easy for oral and written communication by normal user. The proposed metric system based on minutes defines the position with the two quantities latitude and longitude using minutes and 1% of minute. Each quantity is composed of 4 integer digits and two digits after the decimal point. The number is easy to use by normal users, and it has nominal accuracy of 20m which is accepted for navigation purposes and daily use of mobile GIS as shown in Table (5) and Figure (11) right.

Table (5) the proposed coordinates of Pyramid corner and point B (20.4m from Pyramid) for mobile GIS with 20m nominal accuracy based on minutes

	Sexagesimal degrees, minutes, seconds		**Proposed minutes system**	
Point	***Latitude (DD MM SS.s)***	***Longitude (DD MM SS.s)***	***Latitude mmmm.mm***	***Longitude mmmm.mm***
P	29° 58’ 44.4”	31° 07’ 57.0”	1798.74	1867.95
B	29° 58’ 43.9”	31° 07’ 57.5”	1798.73	1867.96

7. CONCLUSION

The mobile GIS is evolving and is driving the science and technology to a new horizon. The mobile device is rich in its communications capabilities with the increasing bandwidth of present wireless networks, and it is a handy tool to geospatially transfer knowledge online as it connects the owner of the knowledge to the requester.

The mobile GIS is an important tool in the acquisition of geospatial data, gathering its attributes data, and collecting the trajectories of moving objects even by non-experts. The acquisition of accurate 3D coordinates in realtime, the orthometric height, indoor coordinates, and the discovery of surrounding location environment are challenges facing mobile device and require more research. The mobile GIS software requires adding more spatial functionalities and specifically network analysis and multi-objective optimal path modules to enable the user to control these functions in mobility. The holography is a promising 3D visualization tool and will have important role in the future of mobile GIS.

The standalone framework was presented as a concept to release the GIS functionality in mobility from the dependency on the communications network and to allow the mobile user to perform geospatial functions in offline mode. The intelligent landmark was proposed as relative positioning tool for tracking vehicles precisely and to avoid the map-matching required in traditional tracking. The current sexagesimal system for the quantitative representation of geographic position in longitude and latitude requires revision to a more generic system based on the contemporary decimal system. In this study, a new metric system based on geographic minute was proposed to overcome the difficulties associated with the sexagesimal system. However, the proposed system needs to compute the lengths and areas from this metric system, and it requires new mathematical handling. The research presented a new approach for the Travelling Salesman Problem (TSP) and multi-objective navigation problems.

8. NEW SCIENTIFIC RESULTS

1) Conceptual framework for standalone mobile GIS

The use of mobile GIS in offline mode is vital, and the standalone framework provides the solution for this problem.

2) Intelligent landmark for relative positioning

The relative position of the moving object provides the geospatial semantic to the user, and it can be acquired using intelligent landmark.

3) New approach for Travelling Salesman Problem (TSP)

The least travel cost for each node is a new approach for tackling the TSP.

4) Multi-objective navigation problems

The function model for the representation of navigation should optimize all the criteria for optimal path not only single criterion.

5) Metric minutes system for geographic coordinates

The use of metric minutes as a base for geographic coordinates is easier for normal user and will expand the use of geographic data.

Applications Presented

1. The geospatial acquisition of the international road from Kuwait to Mekkah and returning back using mobile GIS.
2. The design and data model for intelligent landmark.
3. The application of the algorithm for solving the Travelling Salesman Problem (TSP) using the least travel cost approach.
4. A C program was developed to implement the algorithm and applied on 17-nodes problem.
5. The application of multi-objective optimal path on sample from Kuwait City metropolitan area.
6. Example on metric geographic minute application in pedestrian movement.