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Automatic vehicle location tracking system based on GIS environment

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Abstract: Recently, automatic vehicle location (AVL) has become more widely used, affordable and popular than ever before. AVL is used for different tracking purposes, especially for those related to tracking one vehicle or a fleet of vehicles. Tracking system technology was made possible by the integration of three new technologies: navigational technologies such as global positioning system (GPS), database technologies such as geographic information system (GIS) and communication technology such as general packet radio service (GPRS). The proposed software design 'tracking system' is used to pinpoint the position, ground speed and fuel level of a given vehicle. This improves fleet management by making it secure and more efficient. The system has the ability to detect the optimal path between source and destination, depending on many factors such as travel time, jam, topography and number of traffic lights. The authors applied greedy techniques (GT) such as Dijkstra's and Kruskal's algorithms to a graph weight depending on the proposed cost function (CF). The geofencing technique is applied to the system based on real coordinates and grants security and safety to the fleet of vehicles. The designed software offers more flexibility in loading digital maps. This proposed software has the ability to visualise the real position of vehicles on maps and to take decisions according to real-time information.

1 Introduction

Automatic vehicle location (AVL) is a system that enables companies to trace and coordinate the movements of their fleet of vehicles. Much of the AVL software has been created for fleet management and vehicle location purposes. The AVL communications software system was built based on the geographic information system (GIS) environment, but these types of systems use short message service (SMS) technology [1–4].

The main contribution of this proposed software is to apply the pre-published computer algorithms with GIS application and its concepts. This system is based on a known technique in computer algorithms called greedy technique (GT). This approach suggests constructing a solution through a sequence of steps, each expanding a partially constructed solution obtained until an optimal solution is reached. At each step of this technique the choice is made as follows: feasible, locally optimal and irrevocable. The main task of the proposed software is to compute the optimal path between two real GIS coordinates. The authors used single-source shortest path algorithm 'Dijkstra's algorithm (GA)' and made it compute the optimal path but not the shortest. This depends on the proposed cost function (CF); it considers many parameters such as travel time, street condition, topography, average speed, distance and number of traffic lights. The second task is to find the minimum spanning tree (MST) based on Kruskal's algorithm (KA) on GIS digital maps with the proposed CF as graph weight. The third task is to apply the geofencing technique based on global positioning system (GPS) readings. A buffer zone area as a rectangle was made to compute the borders of this fencing as real coordinates, and if the fleet steps out of the border the system will raise an alarm.

2 Designed software

The main contribution in this paper is to design the fleet vehicle tracking software; this software was designed using VB6 and map object programming tools. The objective of this software is to interface between GPS/general packet radio service (GPRS) modem and GIS environment by receiving GPRS packets from the GPRS/GPS modem. The designed software is called 'Track it Software', and it appears to be user friendly for different clients' needs and requirements. In this system a new technique was used, with the position correction processed by the tracking software. The main station receives data from the GPS receiver and makes the correction process. The corrected vehicle position is calculated by adding the difference position between the GPS modem position calculated by the base station and the position at a fixed point.

2.1 Software characteristics

The tracking system software contains many features to make the tracking software more reliable. The main features of this proposed software are database, alarm parameters, tracking tools and load map.

- Database is designed in a specific procedure to give permission for the administrator to be able to add, edit and remove the member data. In addition, the database provides the ability to dial up with a multi-user to trace a fleet of vehicles at the same time. This makes the tracking software more reliable and efficient.

- Alarm parameters represent the signal received from the sensors of the GPS/GPRS modem to give an indication of vehicle status. The criteria of the alarm parameters in the designed software are as follows:

– *Speed alarm*: The speed signal of the tracked vehicle received from the GPS/GPRS modem allows the administrator to make a note of it, and therefore maintains control over the vehicle driver. For instance, if the vehicle speed exceeds a certain limit, then the alarm turns on.

– *Temperature and fuel alarm*: The sensors of the GPS/GPRS modem are connected with the vehicle to read the status of temperature and fuel level to alarm the administrator of the vehicle's current status.

- *Tracking tools*: The toolbar of the designed software contains main tracking tools to make different functions on the map related to geographical property, such as zooming, identifying, extent, measure distance and refresh map tools. These tools make the displaying process more reliable.

- *Load map*: A new procedure is designed to load maps, where the users import the map from the hard disk automatically and then the software saves the maps in a database and enables the users to restore or remove it at any time.

2.2 Discussion

2.2.1 Optimal transportation movement with real-time information

2.2.2 Cost function parameters: The proposed CF will compute the time required to move from source to destination. The proposed design 'tracking system' receives real-time or historical information from Geo Database and then it computes the optimal path of tracking depending on the following parameters:

1. *Time*: First of all, the proposed CF will compute the time depending on the distance between source and destination and the average speed on the streets as follows:

$$T1 = \frac{\text{Distance}}{\text{AVG speed}}$$

2. *Travel time*: CF divides a day to four intervals and the travelling time will affect the time as shown in Table 1.

3. *Number of traffic lights*: The time after this factor is shown in Table 2. Each traffic light will increase the time with 30 s.

4. *JAM factor*: The time after this factor is shown in Table 3.

5. *Street condition*: The time after this factor is shown in Table 4.

6. *Topography*: The time after this factor is shown in Table 5.

The results of CF will be the weight between two points; the authors used graph theory and Dijkstra's routing algorithm to compute the optimal path between source and destination. Modifications to Dijkstra's algorithm were made as follows:

- The network may have cycles, but all arc lengths must be non-negative.

Table 1 Travel time

Travel time	Effect
(6–12) AM	$T2 = T1^{*}0.05 + T1$
(12–6) PM	$T2 = T1^{*}0.12 + T1$
(6–12) PM	$T2 = T1^{*}0.3 + T1$
(12–6) AM	$T2 = T1^{*}0.01 + T1$

Table 2 Trafficlights against effect

No of traffic lights	Effect
0	$T3 = T2$
1	$T3 = T2 + 30$
2	$T3 = T2 + 60$
3	$T3 = T2 + 90$
4	$T4 = T2 + 120$

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Table 3 Residential against effect

Residential	Effect
dense	$T4 = T3^{*}0.13 + T3$
medium	$T4 = T3^{*}0.08 + T3$
Low	$T4 = T3^{*}0.01 + T3$

Table 4 Conditions against effect

Condition	Effect
extra	$T5 = T4$
medium	$T5 = T4^{*}0.05 + T4$
bad	$T5 = T4^{*}0.1 + T4$

Table 5 Topography against effect

Topography	Effect
hill	$T6 = T5 + 0.1 + T5$
flat	$T6 = T5$
sharp	$T6 = T5^{*}0.03 + T5$

- Maintains a partition of N into two subsets:

Set P: permanently labelled nodes
Set T: temporarily labelled nodes

- Move nodes from T into S one at a time in non-decreasing order by the minimum path from the source node

begin
  $P := \{\}$; $T := N$;
  $d(i) := \infty$ for each node i in N
  $d(s) := 0$ and pred$(s) := 0$;
  while $|P| < n$ do
    begin
      pick i in T with minimum $d(i)$ value; // the value will be taken from our CF
      move i from T to P;
      for each (i, j) in A do
        if $d(j) > d(i) + cij$ then
        $d(j) := d(i) + cij$ and pred$(j) := i$
    end;
end;

An example of Dijkstra's algorithm and how to determine the minimum cost is shown in Fig. 1. The modification to

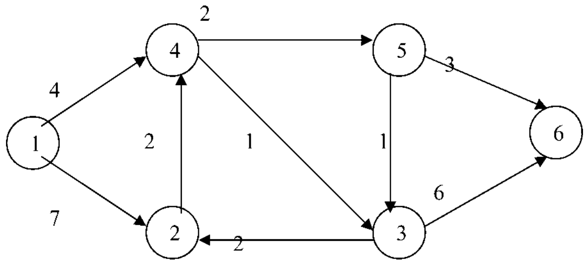

Figure 1 *Example of Dijkstra's algorithm*

Dijkstra's algorithm was made as follows:

$$P = \{\},\ T = \{1, 2, 3, 4, , 6\}$$
$$P = \{1, 4\},\ T = \{4, 5, 5, 6\}$$
$$P = \{1\},\ T = \{2, 3, 4, 56\}$$
$$P = \{1, 4, 5\},\ T = \{5, 6\}$$
$$P = \{1, 4, 5, 2\},\ T = \{1, 2, 3, 4, 5, 6\}$$
$$P = \{1, 4, 5, 2, 6\},\ T = \{\}$$

For each link, there are associated weight graphs computed with the proposed CF as shown in Fig. 2.

2.2.3 Compute the minimum cost map traverse depending on the proposed CF: In this section, the authors used Kruskal's algorithm to do this task with the proposed CF to compute the weight between two points.

The algorithm begins by sorting the map street weights in non-decreasing order and then starting with the empty sub-graph. It scans this sorted list adding the next edge on the list to the current sub-graph if such an inclusion does not create a cycle; it simply skips the edge otherwise.

Algorithm MinimumCostTraverse(Map G)
{
//Kruskal's algorithm for constructing the minimum spanning tree
//input: a weighted connected graph $G = (V, E)$
//output: ET, the set of edges composing the minimum spanning
tree of G. Sort E in non-decreasing order of the edge weights
ET = 0; counter = 0;
$K = 0$;
While ecounter $< |V| - 1$
$K = k + 1$
If ET $U\{$eik$\}$ is a cyclic
ET = ET $U\{$eik$\}$;
ecounter = ecounter + 1;
return ET;
}

The weight graph of the proposed CF is shown in Fig. 3.

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Figure 2 *Weight graph of the proposed CF*

Figure 3 *Weight graph of the proposed CF*

2.2.4 Geofencing: The authors developed this process to apply the geofencing technique to generate a buffer zone that the fleet cannot go out of. The response of the proposed system is shown in Fig. 4.

2.3 The designed software

The designed software is responsible for receiving GPRS packets from the GPS/GPRS modem, which contains the GPS data, analyses and data management, and then displaying data into a GIS environment [5]. The overall system design is shown in Fig. 5. This designed software contains three phases:

1. Management phase (database).

2. Communication phase (GPRS server).

3. Map phase.

2.3.1 Management phase (database): The management phase contains functions of organising members (drivers) information, received data from the GPS/GPRS modem (tracking data) and GIS data (checkpoints) [6, 7].

This phase was built using Microsoft Access Database and is improved using structured query language (SQL), which interacts with the system software. Administrator records can be easily added, edited and removed from the database. The management window contains three main tabs: user tab, tracking tab and checkpoints tab, as shown in Fig. 6.

1. User tab: The user tab contains members (drivers) information, with functions like 'Add', 'Edit' and 'Delete' concerned with the member's information. The 'Reports' button allows browsing reports for available members.

2. Tracking tab: This tab contains the core of the system, which is divided into 'online track' and 'offline track', as shown in Fig. 7. By using tools of this tab, the administrator can perform several functions such as:

- start a new online tracking session for a selected member,

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Figure 4 *Response of the proposed system*

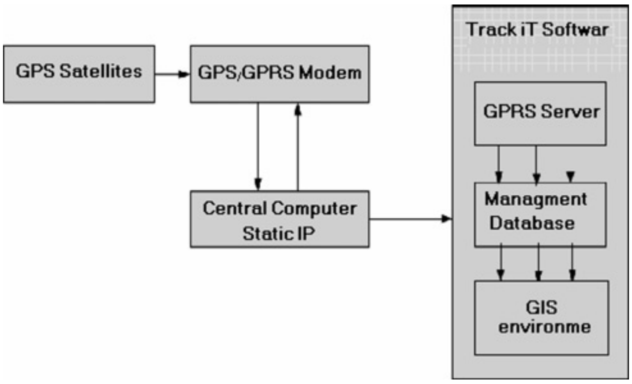

Figure 5 *Overall system design*

- save or remove online tracking session,
- run an offline tracking session,
- manage an archived tracking session.

– Online tracking: Online tracking implements the interface between both software and hardware. This part is concerned with tracking real-time data of vehicle positions, where the data received from the GPS/GPRS modem are displayed directly on the related map.

When clicking on the 'start track' button, the GPRS server starts listening on port number '554' for any GPS/GPRS modem request to make a connection with the server [8, 9]. When the connection is established (between the modem and server), the modem starts sending National Marine Electronics Association (NEMA) data that contain the location, speed, time and sensor parameters to the server, as shown in Fig. 8.

The sample of received data is shown in Fig. 9.

The GPRS server reads these data and then processes them to obtain necessary data such as longitude and latitude coordinates (3216.4838, 03613.9412) that represent the location of the vehicle, which can be displayed directly on the map [10]. The sequence of points

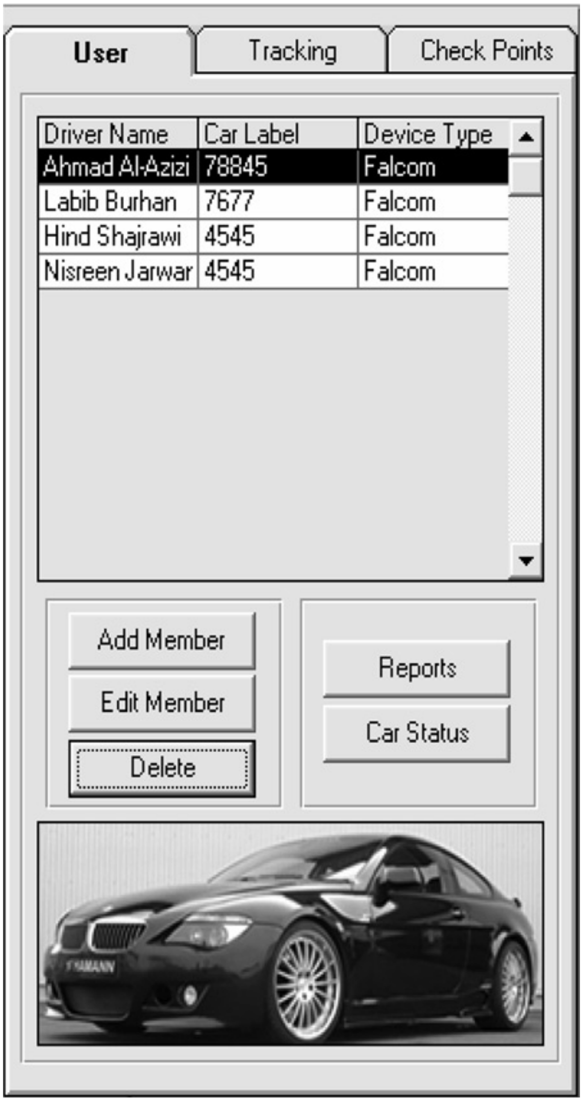

Figure 6 *Management tap*

representing the dynamic locations of the vehicle is shown in Fig. 10. On the 'online track' the designed software is able to manage a fleet of vehicles, where the control station can monitor more than one vehicle at the same time. The data received from the GPS/GPRS modem contain a unique number for each modem, shown in Fig. 9. This number is the identifier for each vehicle when the modem sends data for the main station; the tracking software checks the identifier number to identify the driver of the vehicle.

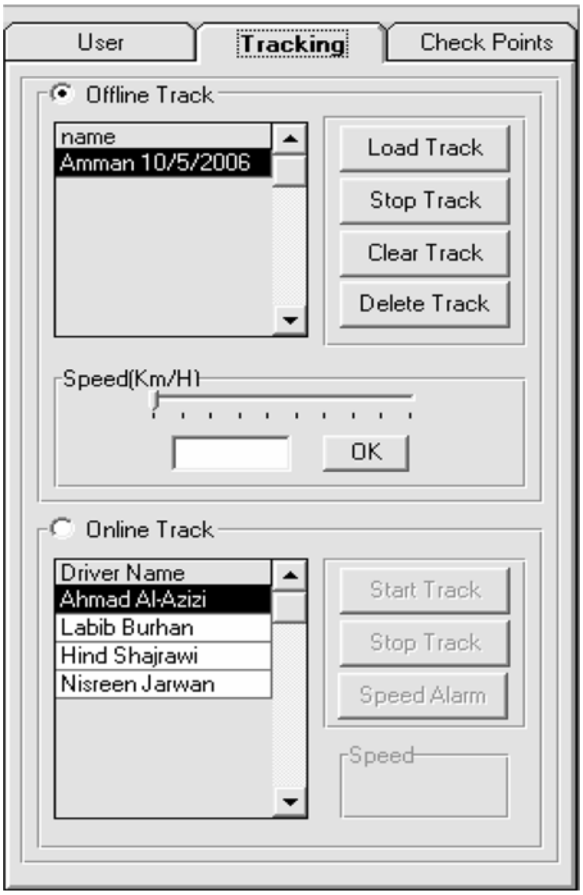

Figure 7 *Tracking tab*

Figure 8 *Start tracking*

- Offline tracking: This part does not have a real-time transmission of data. Offline tracking is used to review the data stored in online tracking (archived data). The data will be shown on the map in sequence as in the online track, as shown earlier in Fig. 10.

- Checkpoints tab: Checkpoints are important in any map; they represent references added by the user for better understanding and easy map readings. The points can be schools, restaurants, hospitals etc. In the system software the checkpoint can be added by entering the point value in the information box by the user, or by using the mouse pointer to the main map and then clicking on the desired point on the map. The checkpoints can be displayed on the map by selecting the point from the list menu and then clicking on the 'Activate' button. The point will be displayed as a red circle, as shown in Fig. 11.

2.3.2 Communication phase (GPRS server): The GPRS server is the base of communication operation between the system software and the GPS/GPRS modem. This phase is related directly to the management phase, since it is responsible for making connection with the GSM modems, fetching the received GPRS packets and performing some processing and data management [11]. These data will be inserted into the database tables to be displayed in the loaded map.

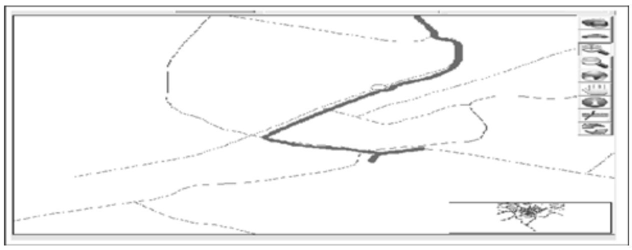

Figure 10 *Tracking path of vehicles*

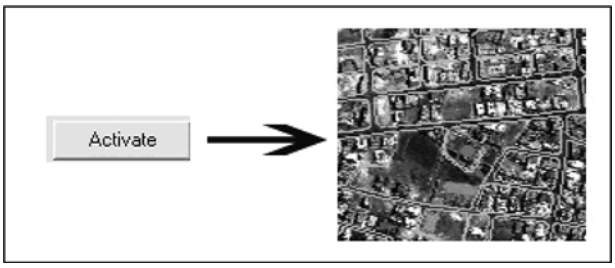

Figure 11 *Active checkpoint*

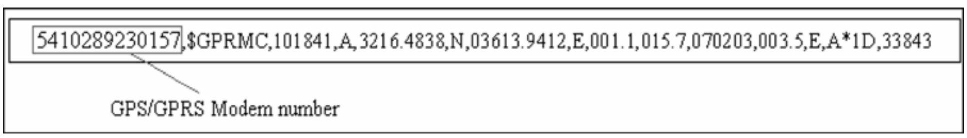

Figure 9 *Sample of received data*

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The GPRS has two modes: transmission control protocol (TCP) mode and user datagram protocol (UDP) mode [12, 13]. This makes the system software more efficient and compatible, as the user will be able to switch between TCP or UDP modes coupling with the server settings or the importance of the received data.

In the TCP mode, the GPRS server is turned on when the user chooses the 'start track' button from the tracking tab, so that the GPRS server changes its status from 'closed' status to 'waiting' status. It opens a specific port (554) on the central computer and starts listening (waiting) to any request from the modems to hold a connection with the central computer, as shown in Fig. 12.

During the listening status, if any GPS/GPRS modem sends a request data to make a connection with the central computer, the GPRS server changes its status from 'waiting' status to 'connected' status and a connection will be established [14]. This can be demonstrated as shown in Fig. 13.

Then the NEMA data received are as follows:

$GPRMC, 122831.742,A,3156.1921,N,03555.3342,E, 0.00,,020506,,*1C

The NEMA data are received by the GPRS server until the vehicle is switched off as the modem is switched off, or when the administrator stops the tracking session by clicking on the 'stop track' button.

In the UDP mode, the GPRS server is not required to make conversation with the modem, and the received data will be fetched and inserted in the database table directly. For the UDP mode, there is no way to guarantee the connection status to be connected or not compared with the TCP mode [15].

2.3.3 Map phase: The map phase is a GIS environment used to load digital maps and monitors geographical data on the loaded map. This window is built using two main programming tools:

- Visual Basic (v6.0) programming language.
- Map Objects (v2.0): is a set of mapping and GIS components for developing applications under VB6 environment.

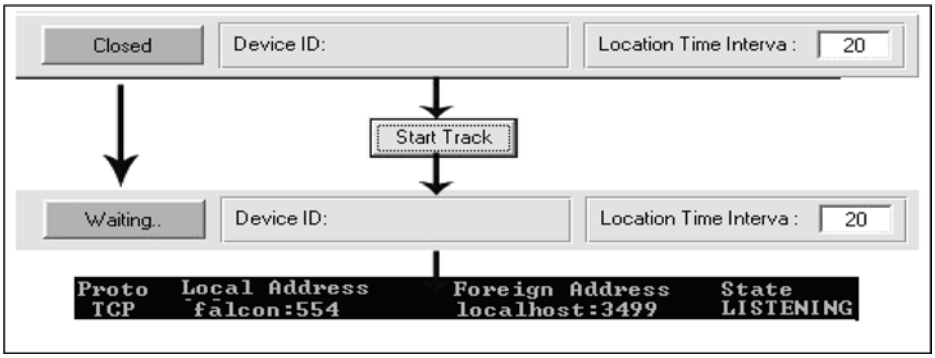

Figure 12 *GPRS server status when start tracking*

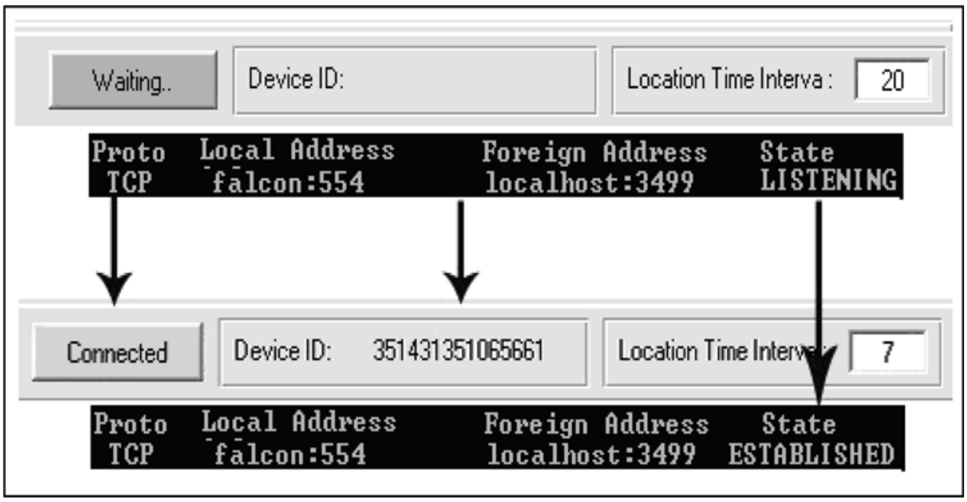

Figure 13 *GPRS server status when connection accepted*

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Certainly, this window is related the management phase, and precisely relates to the tracking and checkpoints tabs for monitoring data functions (that is displaying the main map, checkpoints, tracking the selected vehicle and points that correspond to the location of the selected vehicle) [16]. In addition, it provides some map tools such as zooming, panning, identifying and measuring distance. As shown in Fig. 14, the map window contains four main parts:

Map window, Tool bar, Map legend, Secondary map.

- Map window: This is the core of the GIS operation and the main part in the map section, as it is used as a GIS environment for digital maps and geographical data. The map window is used to display the loaded map, activates checkpoints, and tracks the selected vehicles and points to the location of the selected vehicle.

- Tool bar: Contains tools to make different functions on the map related to geographical property. The main function of this tool is:

– Zooming, full extent, pan, and identifier: This tool is essentially to browse a map and is required in any map browsing.

– Measuring distance: This feature measures the distance between two specific points on a map and gives the distance in miles or kilometres; this can be demonstrated as shown in Fig. 15.

– Refresh: The map will be drawn in random colours; the 'Refresh' tool can change the colour of the loaded map to a more comfortable one.

– Geofencing: Is used to make a buffer zone, where the main control station can alarm the administrator if the vehicle moves out of the fence area.

- Map legend: The map legend is one of the digital map properties where the layers of a loaded map will be displayed. It makes it easier to display and control a loaded map by showing or hiding layers, as shown in Fig. 14.

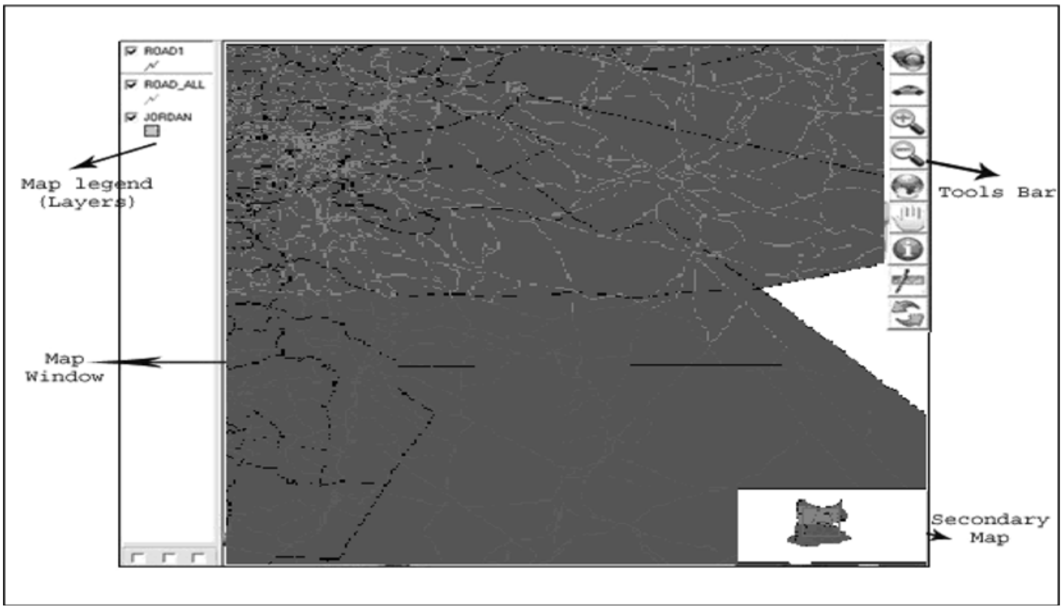

Figure 14 *Map window*

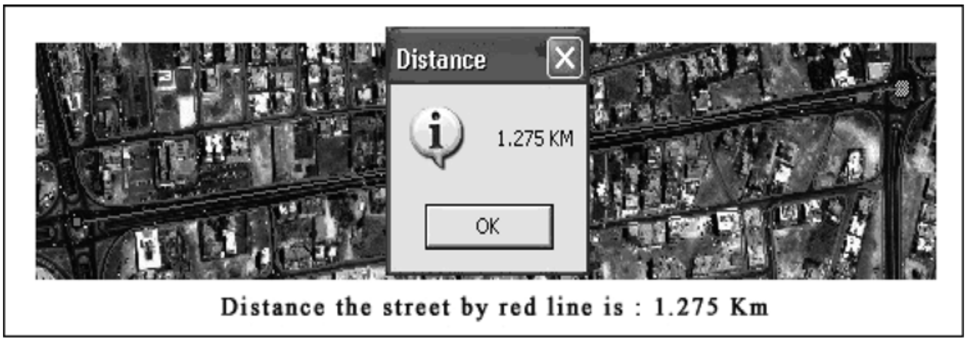

Figure 15 *Distance result*

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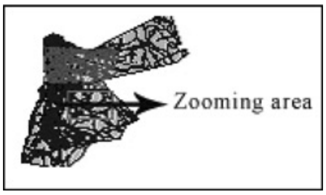

Figure 16 *Secondary map zooming*

- Secondary map: This is a small map shown in the window corner; its function is to specify the area, where the map is zoomed, as demonstrated in Fig. 16.

3 System verifications

Several tests of the designed software were performed to check out system performance and operation. The final validation process was done by tracking more than one vehicle at the same time: one at specific streets in Greater Amman Municipality in Jordan and one at Hashemite University campus streets. The vehicles' positions were tracked at specific points and the results of using our tracking system were compared with the real positions; the comparison results were within accuracy limits, which are almost 95%.

4 Conclusions

The tracking system has the ability to trace and coordinate a fleet of vehicles, with integration of GPRS/GPS technology. It ensures that the tracking process is within an accurate and acceptable range, since it allows managers to supervise vehicle status (i.e. fuel, temperature and door status); the system provides reliable and precise information about the amount of work by all employees, so the administrator will make sure that his/her fleet is working in location and being monitored efficiently and effectively.

The proposed system provides the fleet an ability to take decisions according to real-time information, in addition to historical data. The geofencing technique applies grants safety and security to the fleet throughout the trip.

The designed software offers more flexibility, especially in loading digital maps; it has improved taps such as the 'Tracking' tap and the 'Parameters' tap, which makes the software more reliable. The main features and advantages of this proposed system are the ability to transfer between WGS84 and any other geographical system in order to visualise the real position of vehicles on the map. In addition, all acquired information about the fleet and tracking process is stored in the system database archive. The software system can report all information about the fleet of vehicles and users.

This proposed system can be used in monitoring and controlling applications. The software system was applied in the power industry (such as in power substations) to control a variety of parameters (e.g. coolant temperature alarm, fuel alarm and power factor correction alarm) that are critical in the process of power faults detection in power transmission and substations fields.

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