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Highway Tracking and Mapping Using Mobile GPS Techniques

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Abstract- Mobile GPS instrument was used in this study for highway tracking and mapping within Duhok city. As many as 30 trips were made along the city street for this purpose. The data is downloaded and processed in a computer. Each track is converted into a vector line map. The many tracks along a single street consist of a bunch of adjacent lines. A group mean was derived and plotted. A network of the tracks mean representing the centerlines of the street within the selected test site was presented. The positional horizontal accuracy of these lines was checked with reference to a base map produced by a total station instrument. The standard deviation of the centerline deviation was $\pm 0.92\text{m}$. The derived tracks mean was successfully superimposed over a raster satellite Google Earth image.

Keywords: highway, mapping, tracking, GPS, mobile

I. INTRODUCTION

GPS applications play a wide rule in people's life at different level of sophistication. The system is used by millions of peoples starting from taxi drivers and mail delivery to the engineers who utilize complex precise systems which acquired coordinates with a few millimeters accuracy.

The aim of this paper is to explore the ability of using this system in highway mapping and navigation.

A mobile hand held instrument is used for acquiring the GPS data. A time lapse technique is used to record the vehicle track at fixed time interval. The raw data has to be edited, filtered, and processed to obtain a reasonably accurate result. Tracking of the same road has to be repeated as many as (30) times as a single track may contain a large amount of several errors.

A lot of work is needed to convert the raw data into a usable line map. The processes includes: editing, filtering, converting the track points into vector lines, representing a bunch of tracks with a single mean line, and finally producing a functional map. Figure (1) shows a raw observed data along the street of Duhok city. Obviously a lot of work is required on this data. The horizontal coordinates (Easting and Northing) were recorded. Elevations were not considered in this work.

The GPS road mapping field has been explored by several interesting researchers. Cao [1] presented an algorithm for merging the clarified traces into a representation of the road network in terms of nodes and edges. Zhang, et al [2] explore the effect of the number of observed tracks, the width of the roads on the accuracy of GPS route maps.

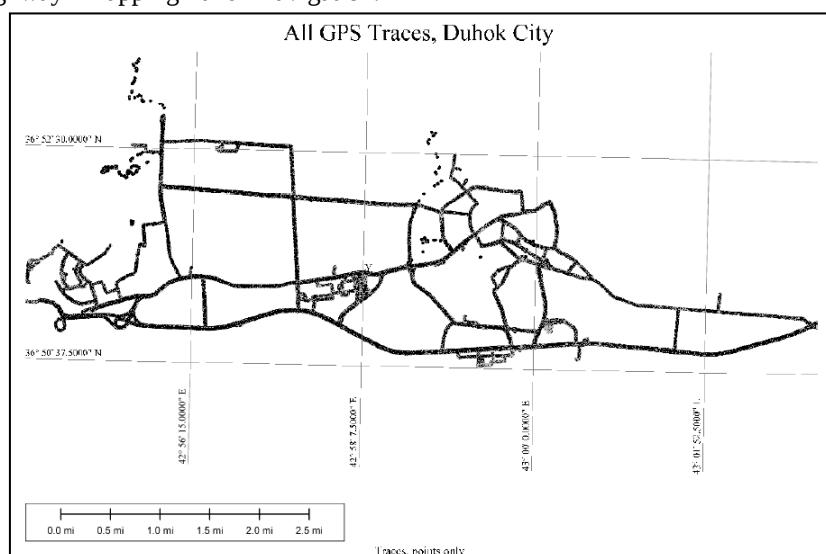


Figure (1): Observed raw data along the streets of Duhok city.

II. THE GPS SYSTEM

The Global Positioning System (GPS) is a space-based global navigation satellite system (GNSS) that provides location and time information in all weather at all times and anywhere on or near the Earth when and where there is an unobstructed line of sight to four or more GPS satellites.

In general, the positioning system consists of three major segments. These are the space segment (satellites), a control segment, and a user segment (the receiver). The satellites broadcast signals from space, and each GPS receiver uses these signals to calculate its three-dimensional location (geographic or UTM coordinate system) and the current time.

The major global positioning systems are the U.S (GPS) system and the Russian (GLONASS) system. In the U.S (GPS) system, the space signal consists of 24 operational satellites in six orbital planes. The control segments consists of five tracking stations evenly spaced on the earth. In GLONASS system, the designed space constellation consists of 24 satellites in three orbits. The ground control segment of GLONASS is entirely located within former Soviet Union territory [3, 4].

The user segment (the receivers) varies in sophistication and accuracy between the accurate and complex Leica Viva system with an accuracy of few millimeters (if the data is properly processed) to the simpler, compact, and cheap mobile GPS instruments with an error reaches several meters.

Some brands of the public mobile phones are equipped with a satellite positioning options. However there are special portable instruments designed mainly for real time navigation, GIS data collection, and map updating [5]. Among these are: BRUNTON, BUSHNELL, MAGELLAN, CONTOUR, GARMIN, KONUS, TRIMBLE, and NAVMAN. These instrument vary in specifications and design from simple devices capable of storing few locations, to a complex multi-option design capable of storing millions of locations, preloaded base maps of some countries (figure 2), route planning, text-to-speech and turn-by-turn voice guide. The antenna is integrated into the top of the unit. Some of the devices are even equipped with gyroscopes for tunnels and underpasses navigation. The Garmin eTrex Legend C instrument used in this project is located in the middle of this range. It is given in more details in section (III).



Figure (2): Preloaded base map on the mobile GPS instrument.

III. INSTRUMENTATION

a. The total station instrument

The Leica total station TCR1101 was used. The instrument can operate in two modes; the first is the reflector mode using the infrared radiation, and the second is the reflectorless mode. The instrument range (reflector mode) in an average atmospheric conditions is 3km. Its distance accuracy is $\pm 2\text{mm} \pm 2\text{ppm}$, with angle accuracy of $\pm 1.5''$. The instrument was used to produce a base map for accuracy checks.

b. The GPS instrument

A mobile GPS instrument, Garmin Terex Legend C, Figure (3) is used as a tracking instrument.



Figure (3): The mobile GPS instrument, Garmin eTrex Legend C.

The hand held instrument is capable of continuously tracks 12 satellites. Figure (3) shows the logged satellite configuration and signal strength display. The instrument has a 24MB internal memory, an equivalent to 10,000 track point. The memory can be extended to 2GB by a removable SD card. Track point coordinates can be saved in different systems among which are UTM, and Lat /Lon. systems. The tracks are updated every 1 second. A starting warm up period of 15-45 seconds is required. The instrument has a 256 color display screen. The manufacturer claims a conservative positional accuracy of ± 15 meters.

The instrument can display different main pages: the Map page, compass page, and mark waypoint page. The main menu can also guide to sub functions like: satellite, trip computer, mark, find, route, highway, setup, proximity, and track. The latter option allow for maintaining a record of vehicle movement (track log). Track log mode recording methods allows for either distance or time mode. A track is made of a series of points that define the path of travel. These points can be placed at a specified "distance" apart or placed at a selected "time" interval. For this project a time interval track is selected. A track can be saved under a given name. The saved track can be displayed at a given color on the track page.

IV. FIELD MEASUREMENTS

For highway centerline tracking, the hand held eTrex instrument was mounted on the car dashboard near the wind screen, Figure (4) to ensure receiving a strong satellite signal. The instrument was taped vertically as the special mounting base is not available.



Figure (4): The Garmin eTrex Legend C mounted on the car dashboard.

At the beginning of each tracking session the instrument is powered on. From the main instrument menu the track option is selected. The track log setup page is displayed and time record method is selected. The recording interval is set to (1) second. At a speed of 30 km/hr the vehicle will travel about 8m during the (1) second time interval. The tracks can be saved under a given name.

The highways at the University of Duhok and the surrounded area were selected as a test site. The area covered about (1.4×1.4) km. On driving, the vehicle is

kept on or as close as possible to the centerline of the highway. Number of tracks on the highway varies between (10) and (30).

The tracking data was collected over 26 days on the period from the 1st of September to the 11th of November 2010. At the end of each working day the data was downloaded to the PC using a USB cable. The (Expert GPS) software was used for the data transfer. The data format used for saving is (GPX: GPS Exchange Format). The software allows for track editing. Visual inspection of the track can diagnose any track error or any missing tracks.

The GPX data format is then saved or exported as comma-separated track points (CSV) to be ready for other applications. The data can be transferred to a (DXF) format using the (export track) option on the (Expert GPS) program. The DXF format can be handled by the AutoCAD programs.

V. DATA PROCESSING AND PLOTTING

The tracks raw data after each observation day is transferred to the computer. The (Expert GPS) program can be used to display the track points. As different colors are assigned to different tracks, the different track points appear as a cloud of multi-color points along the observed path. Figure (5) shows different track points. The figure on the right is a zoom in view on a T intersection.

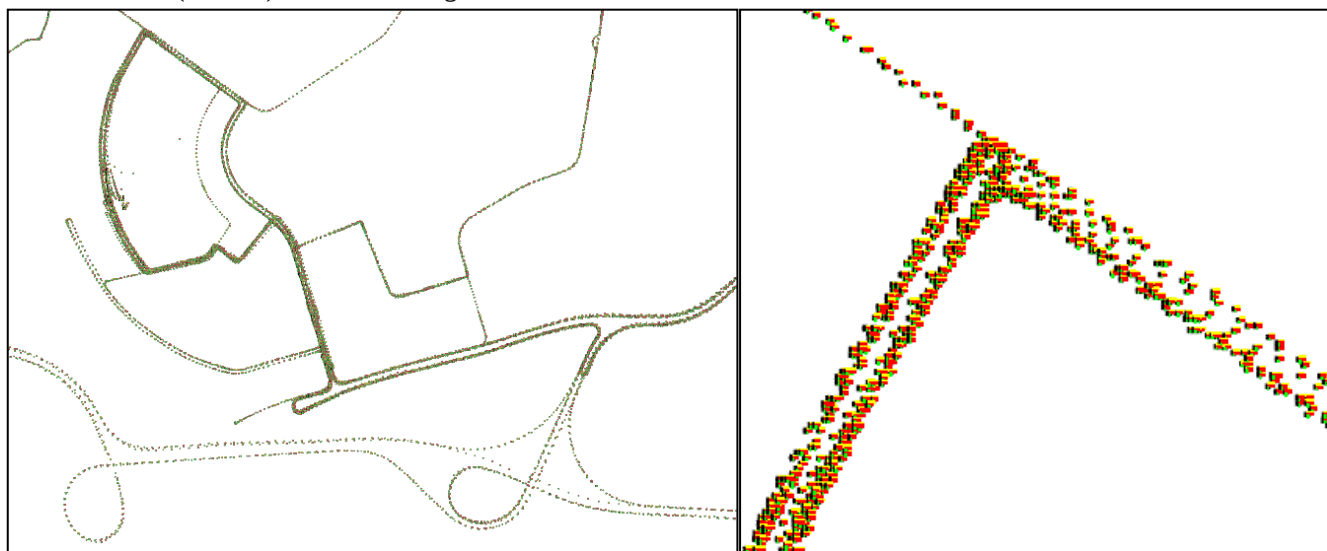


Figure (5): Measured track points along the vehicle path in the test area.

The displayed point cluster varies in thickness from one road to another as a result of different number of observed tracks from one road to another.

To visualize the observed track lines, the measured track points are connected by line segments using the program (Expert GPS). Figure (6) shows the working panel of the program. Obviously editing is required to remove highly erroneous tracks.

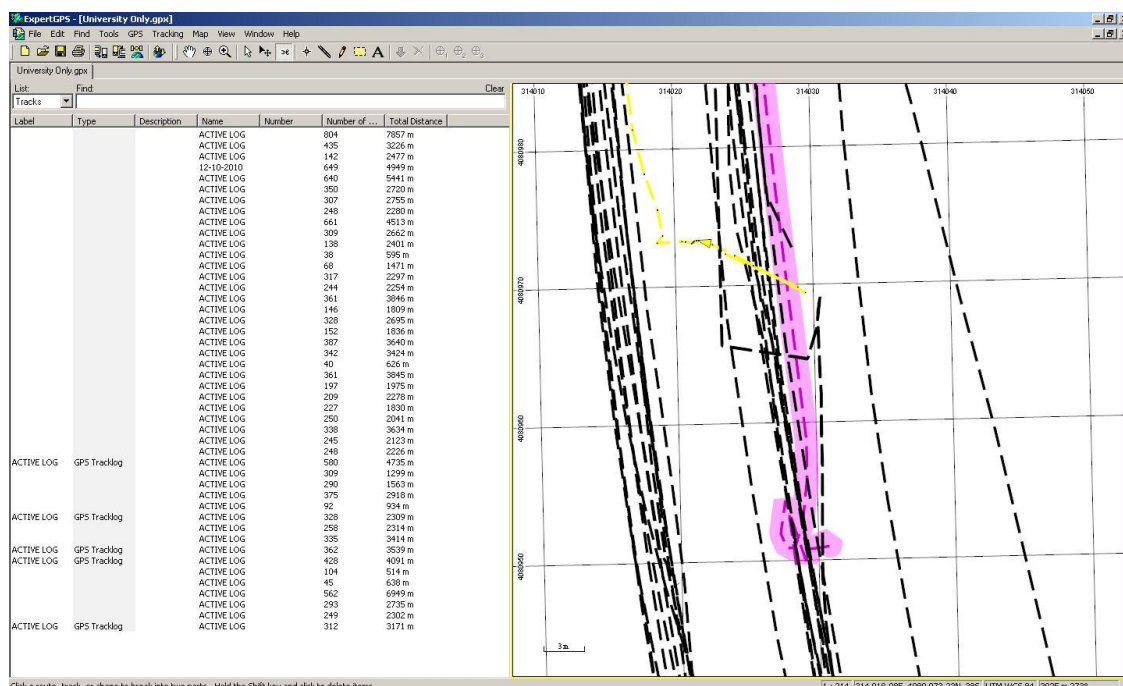


Figure (6): The working display panel of the Expert GPS program

Figure (7) shows the track lines in the test area after the editing process. Due to the small display scale, the different tracks appear as single lines. The varying thickness of these lines is again due to the different number of tracks along each road.

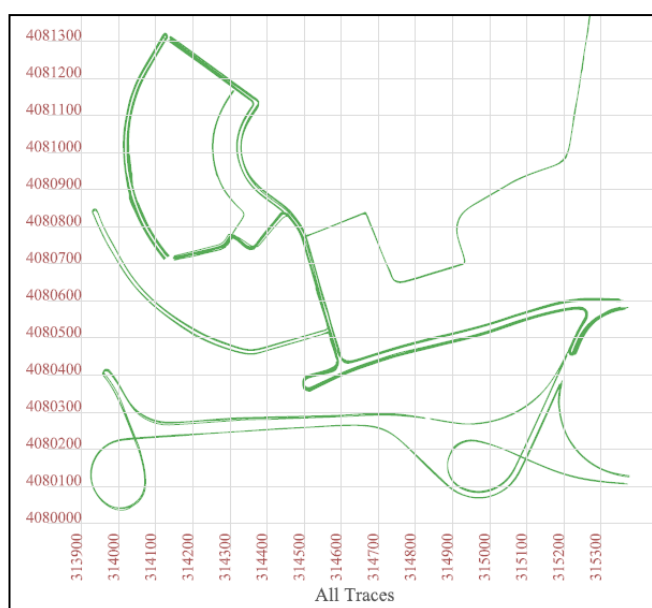


Figure (7): The observed track paths as line segments.

Due to the slow movement speed of the observation vehicle, and the short tracking interval that generates a short line segments, the tracks appear perfectly curved on the curved roads. Enlarging the view and carefully inspecting the tracks, straight line segments can be detected, Figure (10).

To assess the tracks spatial accuracy, the upper left loop appears in the test site is selected, Figure (8). The loop extends over an area of (500×600) m. The highways on this

area are four lane divided highway, except the southern side road which is undivided 30m road. The figure also shows a zoom in view on the upper corner of this area. Lines represents different tracks are obvious on this figure. One can distinguish that all the tracks run together in a single bunch, except an occasion offset of one of the tracks to the left or right side of the main bunch, figure (9). So two parallel bunches represent a divided four lane highway.

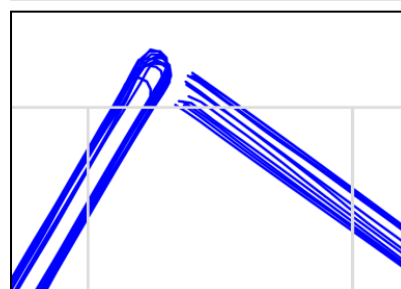
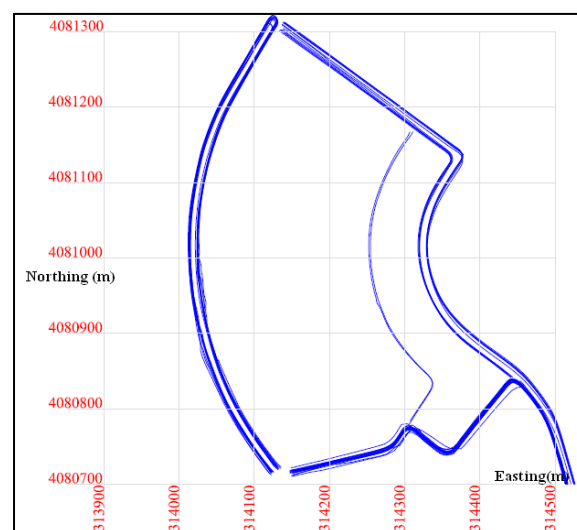


Figure (8): The tracks of the selected loop and a zoom in view on the upper corner.

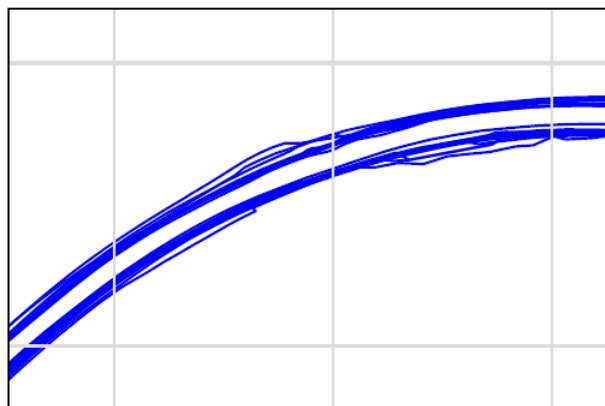


Figure (9): A bunch of tracks on a 4-lane divided highway.

The task now is to represent the tracks group by a single track that can be used for map plotting and accuracy checks. The mean of the tracks group can be used as a representative for these tracks.

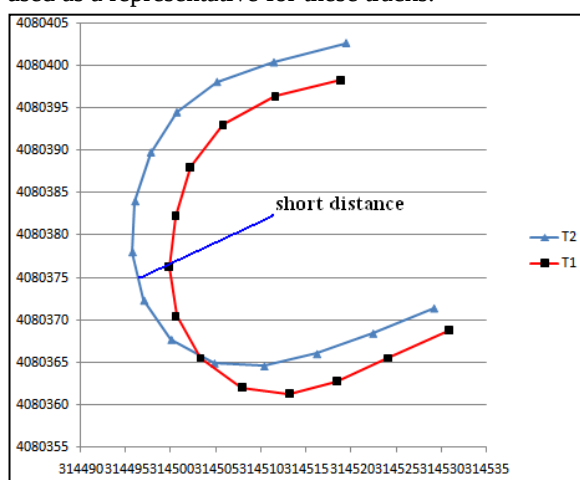


Figure (10): A zoom in view on two curved track segments

Figure (10) shows a zoom in view on a curved segment of the test area. The figure shows only two tracks among several observed. If an algorithm is used to locate the position of the mean of the two tracks depending on the original recorded points, then a selected point on track (1) will search for the closest recorded point on track (2). The mean point will be located at mid-distance between the two.

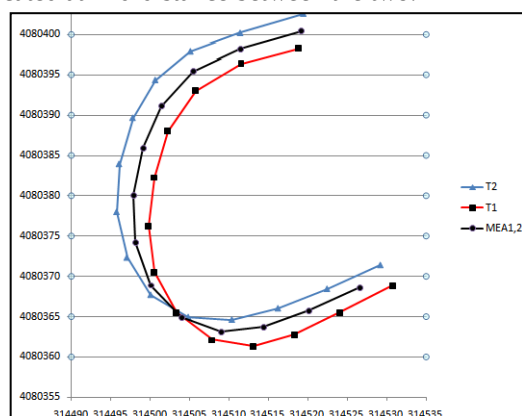


Figure (11): The original track points and the mean track.

To achieve this, the basic principle of least squares is utilized. If track(1) is assumed to be the reference track then the distance from point (i) on this track: (p_{1-i}) is calculated to all the points on the track (2). These distances are sorted out to find the minimum distance. Once this minimum distance is found then the reference point will be twined to its closest point on the other track and both will be transferred to the Excel program where the mean of the Easting and Northing coordinates will be computed and plotted, Figure (11).

To achieve an accurate mean, the shortest distance between a point and a line must be determined. This shortest distance is the perpendicular from that point to the line. Figure (10) shows this shortest line. On searching between the original observed points, the shortest distances are not readily available. For this reason, additional points among the original points have to be generated. The aim is to increase the density of points between the original points. The steps of doing this with reference to Figure (12) are as follows:

- 1- Calculate the distances between the consecutive original points on the same track :($dist_{AB}$)
- 2- Calculate the azimuth of the line connecting the consecutive points: (Az_{AB})
- 3- Calculate the coordinates of the interpolated point (i) on the track using the base original track point, the azimuth, and the distance segment (one meter segments are used)

$$E_i = E_A + d_{A-i} \times \sin(AZ_{AB})$$

$$N_i = N_A + d_{A-i} \times \cos(AZ_{AB})$$
($Dist_{A-i}$ is taken as 1,2,3,4m,.. till the total distance A-B is reached).
- 4- Repeat for all the interpolated points on the line till the total distance is reached.

Figure (16) shows the flow chart of computing the coordinates of the interpolated points

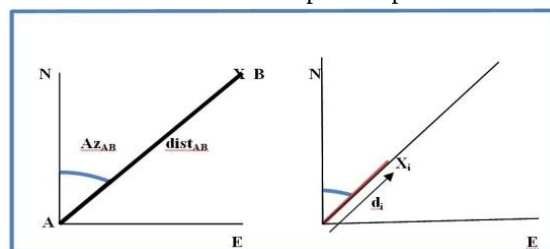


Figure (12): Calculating the coordinates of the interpolated points

Finishing this step, the original track lines will be divided into points at a distance of one meter. The principal of least squares can now be applied to find the matching points between the different tracks utilizing the derived points.

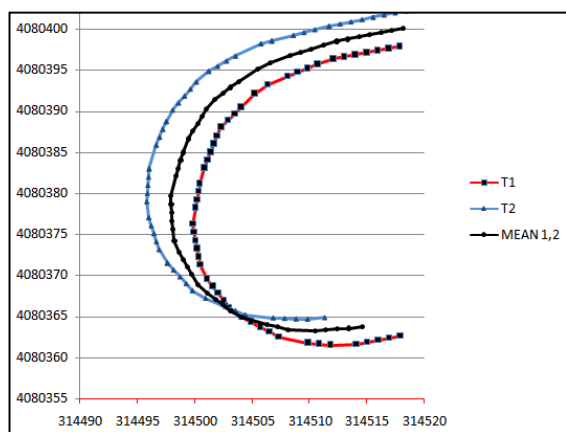


Figure (13): The densification points on the original tracks and the mean track.

Figure (13) shows track (1) and (2) consisting of the interpolated points plus the tracks mean. For this purpose track (1) is selected as a reference and a search from the points on this track and the second track is made. The search for minimum distance is made between the derived points. This will ensure that the closely located points are selected.

Figure (17) shows the flow chart of the program developed in Visual Basic software. It selects the closest points on the tracks and calculates the coordinates of the mean position.

The program starts by assigning a limit for road width (e.g. 6m). This limit will enable to discard erroneous points located at distances greater than road width.

A reference track is selected among the observed tracks. The distances between the first point on the reference track and the next track is calculated. The minimum distance point is selected. The easting and northing coordinates of this point is added to the easting and northing coordinates of the point on the reference track. The process is repeated to select a matching between the next point on the reference track and the selected nearby track. This will be repeated for all the reference track points (nRT). The process is repeated for all other tracks. The tracks mean coordinates is then calculated as follows:

$$E_{mean-i} = (E_{ref,i} + E_{track1-i} + E_{track2-i} + E_{track3-i} + \dots) / n$$

$$N_{mean-i} = (N_{ref,i} + N_{track1-i} + N_{track2-i} + N_{track3-i} + \dots) / n$$

The selected coordinates of the reference track point and the matched points coordinate are cumulated and the mean coordinates are obtained by dividing this sum over the number of the chosen matched points. A list of the coordinates of the tracks mean is prepared

Figure (14) shows the original tracks with the tracks mean as a single line. Figure (15) shows the tracks mean line only.

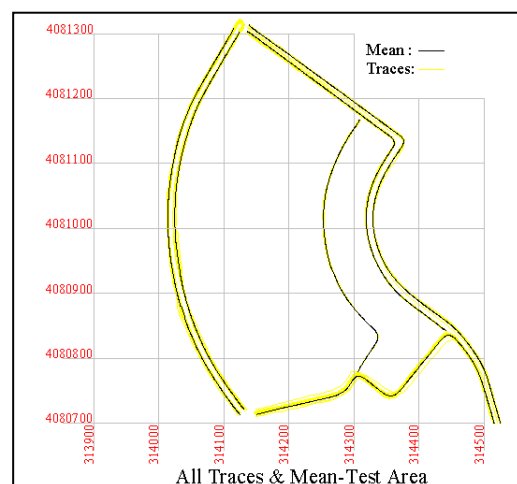


Figure (14): The original tracks in the test loop plus the tracks mean.

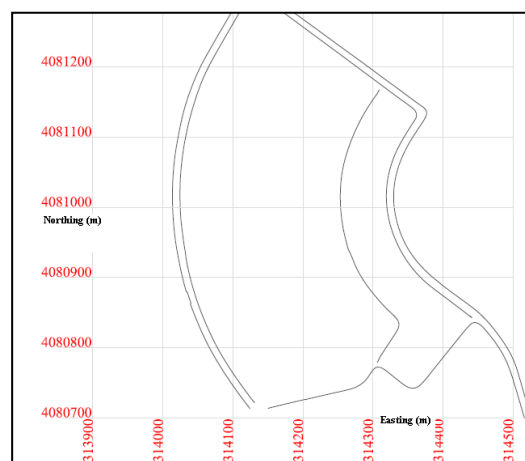


Figure (15): The plot of the tracks mean.

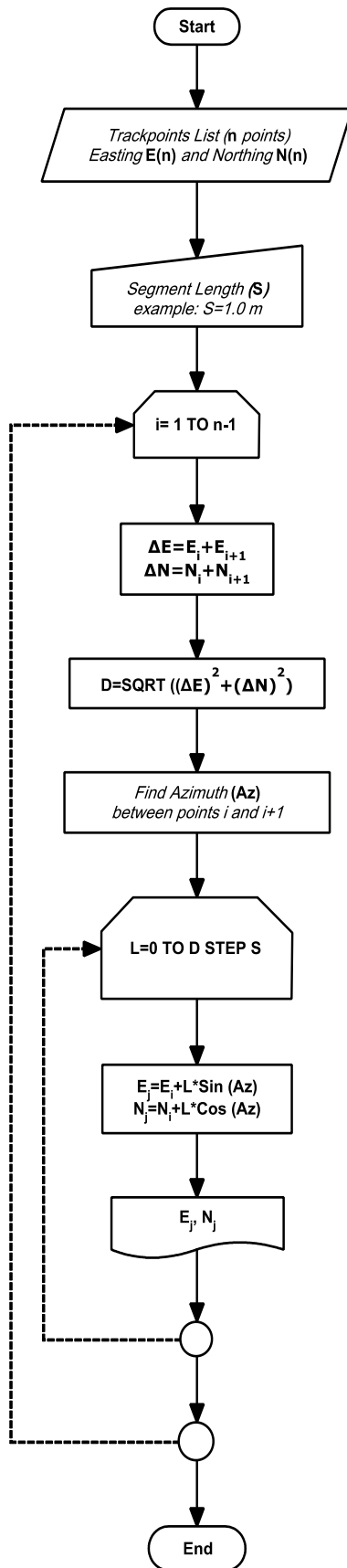


Figure (16):Flow chart of computing the coordinates of the interpolated points

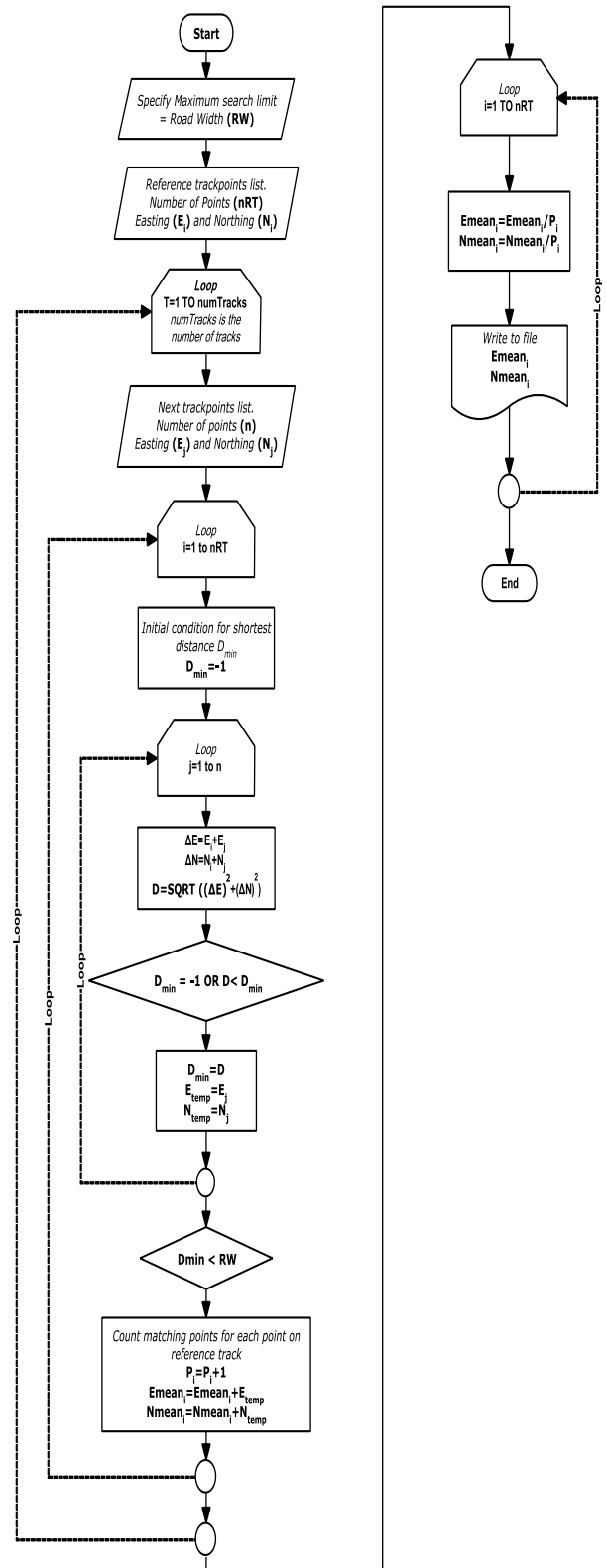


Figure (17) Flow chart of selecting the tracks matched points and the mean

VI. ACCURACY CHECK AND PRESENTATION

To check the spatial accuracy of the tracks mean, a more accurate measurement has to be taken. A base map has to be prepared and use as a base for accuracy check. The Leica TCR1101 total station instrument (the reflector mode) was used for this purpose. The instrument was set up on the rooftop of a three story building to view all the selected test area. A radial surveying was carried out for the detail measurements of the roads curbstone lines.

To accurately orient the survey, two points widely spaced on the base map were selected and accurately positioned using the Leica CS15 GPS measuring system. The positional accuracy of these two points is $\pm 6\text{mm}$. A rotation matrix and a scale factor can now be derived and used to orient and scale the coordinates of the base map. The total station survey map of the test site is shown in Figure (18). The map also shows the centre line of the roads. The road centre line is derived from the survey by offsetting the road edge. This offset is made to allow for the comparison with the tracks mean as the test vehicle was driven approximately over the road centerline.

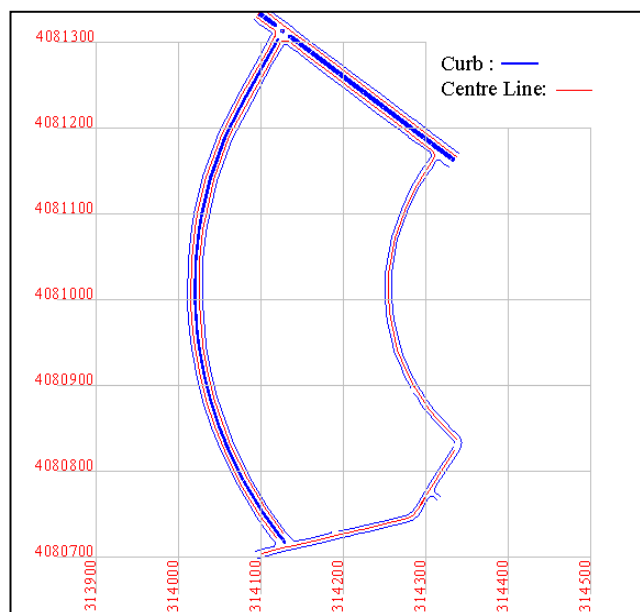


Figure (18): The total station base map

Figure (19) shows the GPS tracks mean map superimposed over the base map prepared by the total station instrument. On smaller scales it is hard to distinguish between the two lines. A zoom in view of three locations are shown to the right of the figure. In most positions the tracks mean is located to one side of the total station mean (left side). An indication of a systematic error. The discrepancy between the two lines is assessed every 50 meters.

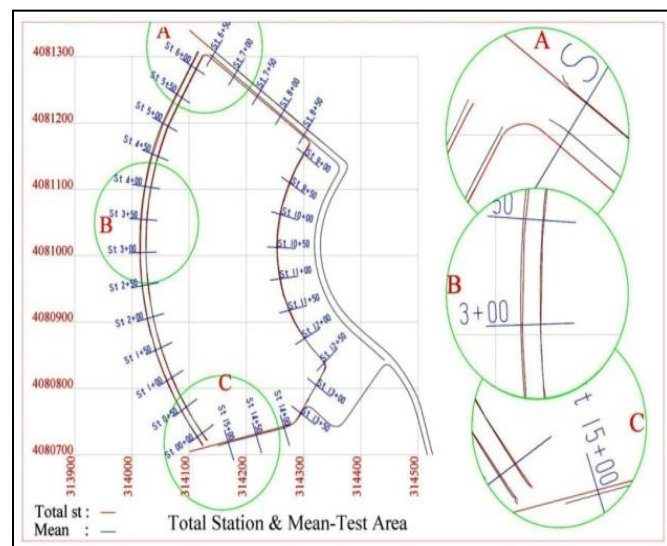


Figure (19): The total station base map and the GPS mean track.

Table (1) lists the discrepancy over the selected points. The standard deviation of these discrepancies is ($\pm 0.92\text{m}$). For the small scale maps and navigation maps this difference can hardly be noticed.

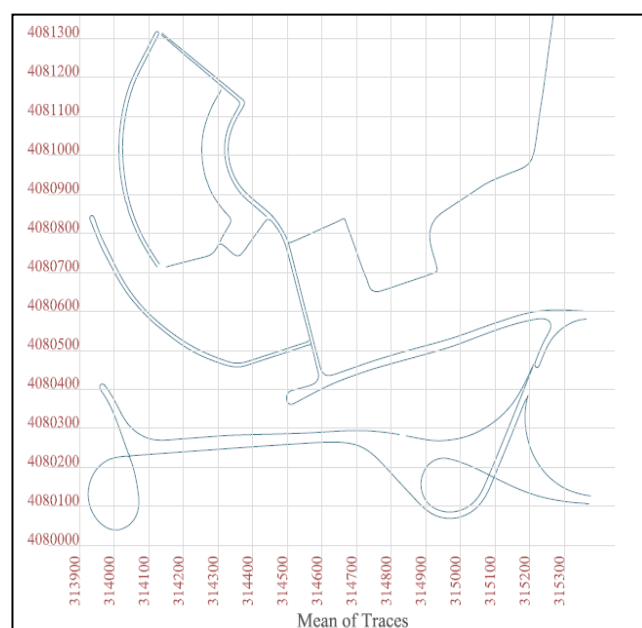


Figure (20): A line map of the mean of all tracks.

Table (1): The discrepancy between the tracks mean and the total station base

Station	Left Side Road Discrepancy (m)	Two way, Two lane Discrepancy (m)	Right Side Road Discrepancy (m)
St 0+00	0.73 L		0.63 L
St 0+50	0.51 L		0.56 L
St 1+00	0.96 L		0.84 L
St 1+50	0.78 L		0.41 L
St 2+00	0.59 L		0.05 L
St 2+50	0.6 L		0.74 L
St 3+00	0.88 L		0.10 L
St 3+50	1.27 L		0.62 L
St 4+00	1.06 L		0.46 L
St 4+50	2.14 L		1.07 L
St 5+00	1.55 L		1.20 L
St 5+50	1.22 L		1.07 L
St 6+00	1.18 L		1.09 L
St 6+50	0.16 L		4.78 L
St 7+00	0.31 L		3.48 L
St 7+50	0.40 L		3.19 L
St 8+00	0.37 L		2.74 L
St 8+50	0.32 L		2.27 L
St 9+00		1.14 L	
St 9+50		1.21 L	
St 10+00		1.61 L	
St 10+05		1.06 L	
St 11+00		1.47 L	
St 11+50		1.55 L	
St 12+00		0.45 L	
St 12+50		1.0 L	
St 13+00		0.20 L	
St 13+50		1.32 L	
St 14+00		1.98 L	
St 14+50		1.98 L	
St 15+00		2.0 L	

The above technique is used to produce a line map of the mean of all tracks over all the test area, figure (20). The tracks line map is superimposed over the area's Google Earth image (2010) [6], figure (21). The figure shows a reasonable matching between the highways network and the tracks map. This merging technique is quite essential as many mapping, GIS, and navigation applications require a hybrid of raster images and a vector line map.

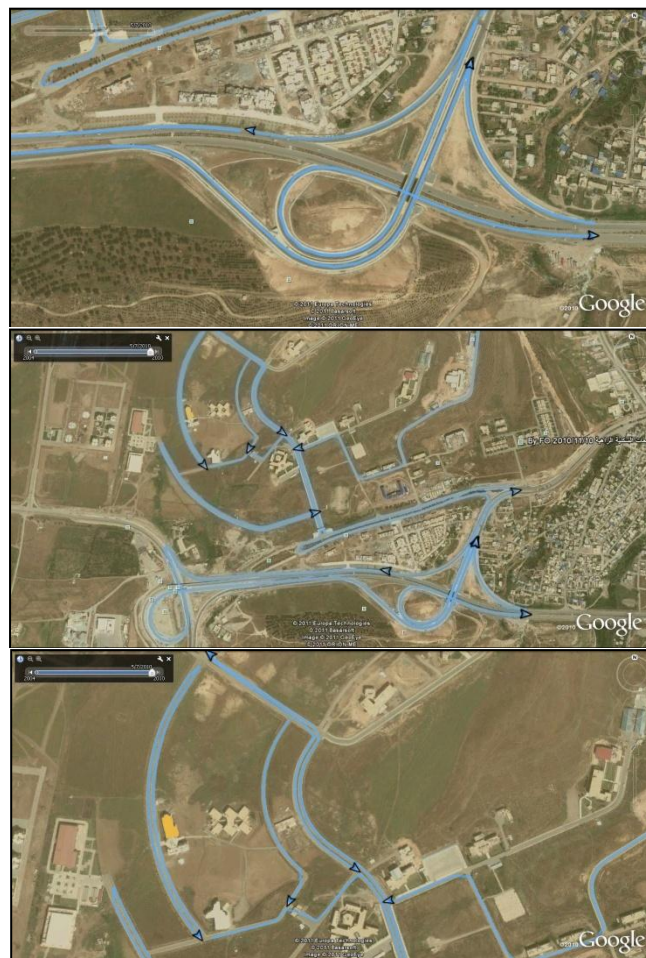


Figure (21): Superimposing the observed tracks mean over a satellite raster image.

VII. CONCLUSIONS

- 1- Using the mean of several track lines prove to have much better accuracy than if a single track is used. Test shows that a single track can deviate by as much as (9.0) meter, however if a mean of single track is used the error could be reduced to (1.5) meter.
- 2- The maximum discrepancy between the GPS mean and the base map on the test site was (4.8) meter. This value can hardly be distinguished if these tracks are displayed on the navigation screen.
- 3- If the aim is a detail street mapping, then an error is expected due to the fact that the surveying vehicle is moving along the centerline of the street. Maps obviously show the street edges and not the centerlines.
- 4- A considerable amount of editing is required to filter the raw data. By visual inspection, raw data may contain large amount of errors. Largely deviated points can be deleted manually. Driving off road centerline could produce such errors. At traffic signals or when the vehicle stops for some reason, the GPS instrument continues to record on the same point. Due to many

reasons, among which is the strength of satellite configuration, the instrument will record a stream of different coordinates to the same point. Therefore editing of the data is quite essential. An algorithm for automatic editing might be an open field of research.

- 5- The prepared tracks map can be fed to the navigation instrument. By adding street directions, speed limits, colors, of places of interest a complete city navigation map could be produced.
- 6- Highways (urban and rural) if properly surveyed can be fed to the World Wide Web such as Google Earth. Neighboring countries like Turkey and Iran are well mapped on such sites. Figure (22) shows the large difference between the present highway web mapping in Iraq (top image shows part of Duhok city) and a part of Istanbul city/ Turkey (bottom image).



Figure (22): A comparison of the web mapping of Iraq(top) and Turkey(bottom)

- 7- Further processing of data is needed at intersections as the utilized algorithm may confuse between the selected tracks used to obtain the minimum distance.

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