Improving the Accuracy of Handheld GPS Receivers Based on NMEA File Generating and Least Squares Adjustment

Zahraa Ezzulddin Hussein
Assistant Lecturer
College of Engineering - University of Baghdad
E-mail: **Zahraaazeldeen@yahoo.com**

ABSTRACT

This study aims to improve the quality of satellites signals in addition to increase accuracy level delivered from handheld GPS data by building up a program to read and decode data of handheld GPS. Where, the NMEA protocol file, which stands for the National Marine Electronics Association, was generated from handheld GPS receivers in real time using in-house design program. The NMEA protocol file provides ability to choose points positions with best status level of satellites such as number of visible satellite, satellite geometry, and GPS mode, which are defined as accuracy factors. In addition to fix signal quality, least squares technique was adopted in this study to minimize the residuals of GPS observations and enhance its accuracy. Moreover, one hundred reference control points were established using geodetic GPS receiver (GR5 receiver), and fixing them in a specified sites of the University of Baghdad, Al Jadriya campus, which selected as a study area, to evaluate positioning accuracy of handheld GPS before and after adjustment. The study findings showed significant decrease in root mean square error (RMSE) in both horizontal and vertical directions from 9.4 m to 3.2 m and 6.8 m to 2.4 m respectively.

Key words: handheld GPS, least square adjustment, accuracy, NMEA file.

تحسين دقة مواقع اجهزةالـ GPS المحمولة القائمة على توليد ملف NMEA وتقنية التصحيح بأقل المربعات

م.م زهراء عزالدين حسين
قسم هندسة المساحة
كلية الهندسة/جامعة بغداد

الخلاصة

تهدف هذه الدراسة إلى تحسين جودة إشارات الأقمار الصناعية بالإضافة إلى زيادة مستوى الدقة لاجهزة الـ GPS المحمولة من خلال تصميم برنامج لقراءة ومعالجة بيانات اجهزة الـ GPS المحمولة. حيث تم انشاء ملف بروتوكول NMEA، والتي تشير الى الجمعية الوطنية للإلكترونيات البحرية، من مستقبلات الـGPS المحمولة في الوقت الحقيقي باستخدام البرنامج المصمم. يوفر هذا الملف امكانية اختيار مواقع النقاط مع أفضل مستوى من وضع الأقمار الصناعية مثل عدد الاقمار المرئية والهندسة الفضائية (HDOP، GDOP) وحالة اقمار الـ GPS، التي تعرف بأنها عوامل الدقة. ولقد تم الاعتماد على تقنية اقل المربعات في هذه الدراسة أضافة إلى تثبيت جودة الإشارة لتقليل الخطأ المتبقي من رصدات الـ GPS الى اقل ما يمكن و تعزيز دقتها. وعلاوة على ذلك، تم إنشاء مائة نقطة مرجعية باستخدام المستقبلات الجيودسية (GR5 receiver) وتثبيتها في مواقع معينة من جامعة بغداد/ الجادرية / الحرم الجامعي التي اختيرت كمنطقة دراسة ،لتقييم دقة مواقع اجهزة الـ GPS المحمولة (قبل وبعد إجراءات التصحيح). نتائج هذه الدراسة أظهرت انخفاضا" ملحوظا" بجذر متوسط مربع الخطأ (RMSE) في كلا المواقع الراسية والافقية للـ GPS من حوالي 6.8 متر إلى 2.4 متر ومن 9.4 متر الى 3.2 متر على التعاقب .

الكلمات الرئيسية: نظام تحديد المواقع المحمول، التصحيح بأقل المربعات، معاملات الدقة، ملف NMEA.

1. INTRODUCTION

In general, usage of handheld GPS for several applications is very economic; however it is limited because of its low accuracy. This is due to the fact that the handheld GPS suffers from lacking in generating raw data in real time, **Syedul Amin, et al., 2013**. National Marine Electronics Association produced uniform protocol, which defined as NMEA protocol, to exchange data between different marine electronics devices. NMEA protocol has special format, which was defined for all marine devices such as GPS. In this paper, the program was designed to read this special format in real time, using a pc as a collector of logging observation. The NMEA standard provides conforming devices those speak the same language, **Parmar, 2011**. This language can be interpreted by a PC program like the one designed in this study. The accuracy of handheld GPS is not homogeneous and they are ranging between 5-10 meters. Where, the accuracy of GPS devices is based on several factors such as a number of visible satellites, signal strength, period of observation and the geometry of satellites , which are determined by dilution of precision (DOP) or geometric dilution of precision (GDOP), **Meduri, and Bramhanadam, 2012**. Additionally, the DOP is determined for each of horizontal (HDOP), vertical (VDOP), 3D position (PDOP), and time dilution of precision (TDOP). Accuracy level of GPS observations can be improved by minimizing its residual using least square adjustment method, which provides the best fitting for all GPS track points. Thus, increasing accuracy of handheld GPS is an important factor to give possibility of using it in specific applications consistent with the resulting accuracy. Improving accuracy of low cost GPS was considered by some of researchers in previous studies. This accuracy may be enhanced by decoding the specific format of handheld GPS and generating the RINEX file depending on a developed program in addition to commercial software, **Schweiger, 2003**. Other hand, the Web services offers the ability to improve the accuracy of low cost GPS receivers a few centimeters or more by exchanging Continuously Operating Reference Stations (CORS) network data using wireless mobile devices, **Fraser, et al., 2004**. The differential relative positioning technique, which based on using two or more than one receiver in a same time, was applied to get a sub-metric accuracy level less than 5 meters, **Acosta, and Toloza, 2012**. Thus, the results of this study show best accuracy and simplest approach comparing with previous studies.

2. NMEA STRUCTURE

The National Marine Electronics Association (NMEA) has applied to define the interface between various marine electronic. Information of marine electronics can be sent to computers and to other marine equipment for post-processing. Communication for most GPS receiver is defined within standard of NMEA, **Sinivee, 2010**. The notion of NMEA is to transmit a line of data named a sentence that is fully autonomous. There are regular signal sentences for each device kind and there is also the capability to define proprietary sentences for usage by the specific company. All devices that use the standard sentences are defined by a two letter prefix in this sentence form, **Amin, et al., 2014**. Moreover, the NMEA standard relies on ASCII (American standard code for information interchange) format. Each sentence starts with the character of dollar, $, and ends with a carriage return and a line feed. Identifier and data fields are between the beginning and the end, separated by commas. The first two characters following the $ include the "talker" identifier, describing the type of instrument sending the data. For example $ZA for atomic clock or $GP for GPS receiver. A three letter code, which identifying the type of signal sentence, is followed the talker ID such as GSA referring to GNSS Satellites active, **Bosy, et al.,2007; Rajendran, 2010**. Additionally, message of NMEA contains information about position, time and velocity which identified as follow, **Adrdalan, and Awange, 2000 and Park, et al., 2013.**

A. GNSS Fix Data (GGA) refers to position, time, and fix regarding data for a GPS receiver. The format of GGA sentences is illustrated in **Table 1.**

B. Geographic Position – Latitude/Longitude (GLL) stands for longitude of vessel position, latitude, and time of position. The format of these elements is explained in **Table 2**.

C. GNSS Satellites Active (GSA) refers to DOP values, satellites used in the navigation solution which mentioned by the GGA or GNS sentence and GPS receiver operating mode. This sentence is listed in **Table 3.**

D. GNSS Satellites in View (GSV) represents each of satellite ID numbers, number of satellites (SV) in view, elevation, azimuth, and SNR value. Format of this sentence is explained in **Table 4.**

E. Recommended Minimum Specific GNSS Data (RMC) stands for position, time, date, path and speed data determined by a GNSS navigation receiver. Format of RMC is decoded in **Table 5**.

F. Course over Ground and Ground Speed (VTG) represent the elements of actual course and speed relative to the ground. The solution of this format is explained in **Table 6**.

3. METHODOLOGY

The positioning accuracy of handheld GPS is inhomogeneous along period of observation, because of the constant changing in both of number and geometry of satellites. Thus, the methodology of this study was considered to fix the quality of received GPS signal in addition to increase the level of accuracy. The main stages of this methodology are explained as following:

A. The designed program

Graphical user interface (GUI), using MATLAB Language, was employed and designed to read the NMEA file in addition to adjust the coordinates of GPS track points observed by handheld GPS, (illustrated in **Fig.1**). The program code includes two steps as follow:

1. In the first step, the designed program downloads NMEA data in real time for any period of observation time. Then, this data were processed depending on the quality of satellites signals to determine the positions for all GPS track points. For example, this program downloads the initial GGA sentence of NMEA file as following, **Ince, and Sahin, 2000 and Amin, et al., 2013:**

$GPGGA,090726,3316.4104,N,04422.6311,E,1,04,3.6,49.5,M,3.4,M,,*45

where:

$GPGGA : Protocol header

090726 : UTC position which equals to 09h 07m 26s

3316.4104 : Latitude which equals to 33° 16.4104'

N : North

04422.6311: Longitude which equals to 044° 22.6311'

E : East

1 : Position Fix Indicator, where number 1 refers to GPS SPS Mode, fix valid
04 : Satellites used which range 0 to 12
3.6 : Horizontal Dilution of Precision (HDOP)
49.5 : Mean sea level
M : Units in meters
3.4 : Geoid separation
M : Units in meters
*45 : Checksum (detect errors in the data)

While, the next GGA sentence for specific period of observations is shown as follow:

$GPGGA,093112,3316.4079,N,04422.6435,E,1,07,1.9,32.1,M,3.4,M,,*4B

By comparing between the initial GGA sentence and the next sentence, we can find the following:

- Period of observation equals to $23^m\ 46.33^s$ which is computed by subtracting the UTC values between the next sentence of GGA and the initial sentence.
- Increasing number of observed satellite from 4 to 7 refers to improve the accuracy of positioning, **Meduri, and Bramhanadam, 2012**.
- Decreasing HDOP factor from 3.6 to 1.9 refers to increase the level of accuracy, see **Table 7**.
- Logging rate of this period of observation equals to 2^s, which is computed by subtracting the UTC values between two sequential sentences, see Appendix A.

2. Least square adjustment was applied in the second step to find the best fitting of GPS track points based on existence of two control points, which are often available from previous surveys with accuracy less than 1 cm derived from practical experiments of this study. In this program, baseline vectors were created between the reference points and the GPS track points to adjust their positions as shown in **Fig. 2**. Where, the least squares adjustment method is considered to minimize the residual of observations (coordinates of GPS track points) based on the following observational equations, **Witchayangkoon, 2000; Amiri-Simkooei, and Sharifi, 2004** :

$$(x_p + v_{xp}) - x_R = dx_{Rp} + \Delta_x \tag{1}$$

$$(y_p + v_{yp}) - y_R = dy_{Rp} + \Delta_y \tag{2}$$

$$(z_p + v_{zp}) - z_R = dz_{Rp} + \Delta_z \tag{3}$$

where, (x_p, y_p, and z_p) are the coordinates of GPS track points, (x_R, y_R, and z_R) are the coordinates of reference control points, (dx_{Rp}, dy_{Rp}, and dz_{Rp}) are the baseline vectors, (v_{xp},

v_{yp}, and v_{zp}) are the residual of observations, and (Δ_x, Δ_y, and Δ_z) are the correction of unknowns (baseline vectors).

B. The fieldwork

For accuracy assessment purpose of handheld GPS positions after adjustment, one hundred reference points (as shown in **Fig. 3**.), were established in Baghdad University campus using differential technique (DGPS), with period of observation equals to 25 minutes (static method). These reference points were observed by handheld GPS receiver (Garmin eTrex) to collect GPS track points using two methods of observation, which are observation with adjustment procedure (generating and processing NMEA file) and observation without adjustment. Firstly, GPS track points were collected without the adjustment procedures of this study. While, in the second method of observation, handheld GPS was connected with a PC using the serial port (RS232) to gather NMEA files of track points (for 10 minute period of observation) by the designed program as shown in **Fig. 4**. In later method, GPS track points were adjusted based on the best fitting tools, which is used in this study (processing of NMEA files and least squares technique). Consequently, the handheld positioning, which resulted from both methods, were evaluated by compare them with the reference points.

C. Accuracy assessment

Accuracy assessment of GPS track points can be applied based on computation of root mean square error (RMSE) for the delivered observations. For specific number of GPS track points (n) defined by geocentric coordinates $(X, Y, and\ Z)$, the vertical and horizontal RMSE, in addition to the total 3D RMSE are explained as following, **Misra and Enge, 2001 and Diggelen, 2007**:

$$RMSE\ vertical\ error = \sqrt{\frac{\sum \Delta Z^2}{n}} \quad (4)$$

$$RMSE\ horizontal\ error\ (2D\ RMSE) = \sqrt{\frac{\sum \Delta X^2 + \Delta Y^2}{n}} \quad (5)$$

$$RMSE\ of\ three\ dimensional\ error\ (3D\ RMSE) = \sqrt{\frac{\sum \Delta X^2 + \Delta Y^2 + \Delta Z^2}{n}} \quad (6)$$

where $\Delta X, \Delta Y, \Delta Z$ refers to the coordinates difference between GPS track points observed by handheld GPS and reference points measured by DGPS. Additionally, the distance error (D-error) between track and reference points can be calculated as following, **Boal, 1992**:

$$D - error = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} \quad (7)$$

4. RESULTS

The results delivered from this study refer to significant improvement of positioning accuracy for all GPS track points, which were adjusted based on the methodology suggested in this study. The results showed that the vertical accuracy of GPS track points, which was computed based on the RMSE values, decreased from 6.8 m to 2.4 m by applying the adjusted procedures. Additionally, both of horizontal accuracy and three dimensional accuracy values were reduced with a percentage reaches to 66% and 65% respectively as shown in **Table 8**. Thus, distance error were computed for all GPS track points (before and after adjustment technique), and summarized in **Fig. 5**. It is remarkable that a considerable improvement in the homogeneity of the resulting coordinates, which was delivered by decreasing the standard deviation value from 4.3713 m to 1.0909 m. Thus, differences of coordinates values, which computed relative to the reference points, were summarized in **Table 9**, for some of GPS track points.

5. CONCLUSIONS

This study showed the ability to enhance the quality of handheld GPS signals using a designed program for receiving and processing NMEA files. Additionally, the accuracy of handheld GPS positioning were increased to about 3m based on least squares adjustment technique with existing two control points. Moreover, decreasing of standard deviation to around 75% refers to the homogeneity improvement regarding distribution of errors on all GPS track points. Therefore, this study give the facility to use the low cost GPS in certain applications compatible with accuracy of 3 meters such as for GIS applications.

REFERENCES

- Acosta, N., and Toloza, J., 2012, *Techniques to Improve the GPS Precision*, International Journal of Advanced Computer Science and Applications, Vol.3, No.8, PP.125-130.

- Adrdalan, A., and Awange, J.L., 2000, *Compatibility of NMEA GGA with GPS Receivers Implementation*, GPS Solutions journal, Vol.3, No.3, PP.1-3.

- Amin, M. S., Reaz, M. B. I., Bhuiyan, M. A. S., and Nasir, S. S., 2014, *Kalman Filtered GPS Accelerometer Based Accident Detection and Location System: A Low-Cost Approach*, Current Science, Vol.106, No.11, PP.1548-1554

- Amiri-Simkooei, A., and Sharifi, M., 2004, *Approach for Equivalent Accuracy Design of Different Types of Observations,* Journal of Surveying Engineering, Vol.130, No.1, PP.1-5.

- Boal, J. D., 1992, *Guidlines and Specifications for GPS Surveys*, Geodetic Survey Division, Canada.

- Bosy, J., Graszka, W., and Leończyk, M., 2007, *ASG-EUPOS. A Multifunctional Precise Satellite Positioning System in Poland*, European Journal of Navigation Vol.5, No.4, PP.2-6.

- Diggelen, F. v., 2007, *GNSS Accuracy: Lies, Damn Lies, and Statistics*, GPS World, Vol.18, No.1, PP.26-32.

- Fraser, R., Mowlam, A., and Collier, P., 2004, *Augmentation of Low–Cost GPS Receivers via Web Services and Wireless Mobile Devices*, Positioning,Vol.1, No.08, PP.85-94.

- Ince, C. D., and Sahin, M., 2000, *Real-time Deformation Monitoring with GPS and Kalman Filter*, Earth, planets and space, Vol.52, No.10, PP.837-840.

- Meduri, S.R, and Bramhanadam, P.S, 2012, *Comparison of Dilution of Precision (DOP) in Multipath and Error free Environment Using Single Frequency Global Positioning*

System, International Journal of Engineering and Advanced Technology (IJEAT), Vol.1, No.5, PP.445-448.

- Misra, P. and Enge, P., 2001, *Global Positioning System. Signals, Measurements and Performance*. Ganga-Jamuna Press, Massachusetts, U.S.

- Park, B., Lee, J., Kim, Y., Yun, H., and Kee, C., 2013, *DGPS Enhancement to GPS NMEA Output Data: DGPS by Correction Projection to Position-Domain*. Journal of Navigation, Vol.66, PP.249-264.

- Parmar, S. N., 2011, *Design and Implementation of GPS based Navigation System for Location based Services*, in International Conference on Technology Systems and Management (ICTSM) proceedings published by International Journal of Computer Applications (IJCA), PP.24-27.

- Rajendran, G., Arthanari, M., and Sivakumar, M., 2010, *A Simplified NMEA Sentence Generator for the Simulation of GPS Tracking*, Global Journal of Computer Science and Technology Vol.10, No.14, PP.19-26.

- Schwieger, V., 2003, *Using Handheld GPS Receivers for Precise Positioning*, 2nd FIG Regional Conference, Marrakech, Morocco, December 2-5, 2003.

- Sinivee, V., 2010, *Simple Yet Efficient NMEA Sentence Generator for testing GPS Reception Firmware and Hardware*, Novel Algorithms and Techniques in Telecommunications and Networking, Springer Netherlands, PP.207-210.

- Syedul Amin, Md., Bhuiyan, M.A.S., Reaz, M.B.I. and Nasir, S.S., 2013, *GPS and Map Matching Based Vehicle Accident Detection System*, IEEE Student Conference on Research and Development (SCOReD), Putrajaya, 16-17 December 2013.

- Witchayangkoon, B., 2000, *Elements of GPS Precise Point Positioning*, Maine: University of Maine.

Table 1. Format of signal sentences regarding to GGA – GNSS Fix Data, **Adrdalan, and Awange, 2000 and Park, et al., 2013**.

Field	**Name**	**Explanation**
hhmmss.ss	UTC Time	UTC of position in hhmmss.sss format
llll.lll	Latitude	Latitude in ddmm.mmmm format
A	N/S Indicator	‘N’ = North, ‘S’ = South
yyyyy.yyy	Longitude	Longitude in dddmm.mmmm format
A	E/W Indicator	‘E’ = East, ‘W’ = West
X	GPS quality indicator	GPS quality indicator
Uu	Satellites Used	Number of satellites in use, (00 ~ 24)
v.v	HDOP	Horizontal dilution of precision, (00.0 ~ 99.9)
w.w	Altitude	Mean sea level altitude in meter
x.x	Geoid separation	In meter

Zzzz	DGPS Station ID	Differential reference station ID, NULL when DGPS not used
Hh	Detect errors in the data	

Table 2. Format of GLL – Geographic Position – Latitude/Longitude, **Adrdalan, and Awange, 2000; Park, et al., 2013 and Amin, et al., 2014**.

Field	**Name**	**Explanation**
llll.lll	Latitude	Latitude in ddmm.mmmm arrangement
A	N/S Indicator	'N' = North, 'S' = South
yyyyy.yyy	Longitude	Longitude in dddmm.mmmm arrangement
B	E/W Indicator	'E' = East, 'W' = West
hhmmss.sss	UTC Time	UTC of position in hhmmss.sss arrangement
A	Status	A= data adequate, V= data not adequate
Hh	Detect errors in the data	

Table 3. Format of GSA – GNSS Satellites Active and DOP, **Adrdalan, and Awange, 2000 and Park, et al., 2013**.

Field	**Name**	**Explanation**
A	Mode	Mode 'M' = Manual, required to run in 2D or 3D style 'A' = Automatic, acceptable to mechanically shift
X	Mode	Fix form 1= Fix not accessible, 2= 2dimention, 3= 3dimention
xx's	Satellite ID	In the best way 12 satellites are involved in each GSA sentence.
u.u	PDOP	Position dilution of precision (00.0 to 99.9)
v.v	HDOP	Horizontal dilution of precision (00.0 to 99.9)
z.z	VDOP	Vertical dilution of precision (00.0 to 99.9)
Hh	Detect errors in the data	

Table 4. Format of GSV – GNSS Satellites in View, **Adrdalan, and Awange, 2000 and Park, et al., 2013** .

Field	**Name**	**Explanation**
X	Number of message	Whole number of GSV messages to be transferred (1-3)
U	Order number	Order number of current GSV message
Xx	Satellites in view	Total number of satellites in view (00 ~ 12)
Uu	Satellite ID	Greatly 4 satellites are included in each GSV sentence.
Vv	Elevation	Elevation of satellite in degrees, (00 ~ 90)
Zzz	Azimuth	Satellite azimuth angle in degrees, (000 ~ 359)
Ss	SNR	C/No in dB (00 ~ 99) Useless when not tracking
Hh	Detect errors in the data	

Table 5. Format of RMC – Recommended Minimum Specific GNSS Data, **Adrdalan, and Awange, 2000; Park, et al., 2013 and Amin, et al., 2014**.

Field	Name	Explanation
hhmmss.ss	UTC Time	UTC time in hhmmss.sss format
X	Situation	Situation ‘A’ = Data Suitable ‘V’ = Navigation receiver caution
llll.lll	Latitude	Latitude in dddmm.mmmm format.
A	N/S Indicator	North=’N’, South=’S’
yyyyy.yyy	Longitude	Longitude in dddmm.mmmm arrangement
A	E/W Indicator	East=‘E’, West=‘W’
x.x	Speed above ground	Speed above ground in knots (000.0 ~ 999.9)
u.u	Track above ground	Track above ground in degrees (000.0 ~ 359.9)
Xxxxxx	UTC Epoch	UTC epoch of position solution, ddmmyy
V	Style index	Style index ‘N’ = Files not adequate, ‘A’ = at large style ‘D’ = differed style, ‘E’ = Expected style
Hh	Detect errors in the data	

Table 6. Format of VTG – Course over Ground and Ground Speed, **Awange, 2000 and Amin, et al., 2014**.

Field	Name	Explanation
x.x	Course	Track above ground, degrees Right (000.0 ~ 359.9)
y.y	Course	Track above ground, degrees Magnetic (000.0 ~ 359.9)
u.u	Quickness	Quickness above ground in knots (000.0 ~ 999.9)
v.v	Quickness	Quickness above ground in kilometers per hour (0000.0 ~ 1800.0)
M	Style index	Style index ‘N’ = not adequate, ‘A’ = at large style, ‘D’ = = differed style, ’s’ = Expected style
Hh	Detect errors in the data	

Table 7. Values of dilution of precision, **Awange, 2000 and Amin, et al., 2014.**

DOP Value	Ranking	Explanation
< 20	Poor	Observations are inaccurate
10-20	Fair	Denotes a low confidence level. Positional observations should be used only to show a very irregular estimate of the current location.
5-10	Mild	Positional observations could be used for designs, however the fix quality could still be improved
2-5	Good	Positional observations could be used to make reliable in-route navigation plans to the user.
1-2	Excellent	For precise positional observations
< 1	Ideal	For peak possible confidence level

Table 8. Resulting errors of GPS track points.

GPS points	RMSE (vertical error)	RMSE (horizontal error)	RMSE (three dimensional error)	standard deviation
Before adjustment	6.8131	9.3847	11.5970	4.3713
After adjustment	2.4012	3.1667	3.9741	1.0909

Table 9. Difference of coordinates between reference points and GPS track points for arbitrary sample of points.

No.	Reference Control Points			GPS Track Points (before adjustment)			GPS Track Points (after adjustment)		
	X(m)	Y(m)	Z(m)	DX(m)	DY(m)	DZ(m)	DX(m)	DY(m)	DZ(m)
1	3681756.653	442080.126	37.055	11.801	10.756	10.388	1.5184	1.2763	3.9442
2	3681814.996	442074.611	37.173	9.6115	6.6597	5.0265	2.8727	1.6527	0.3945
3	3681817.526	442012.727	37.141	1.5255	7.8554	10.368	2.9382	2.5492	0.2954
4	3681819.211	441960.039	37.186	3.2952	10.082	0.84906	0.4820	3.9264	1.9872
5	3681881.184	441960.216	37.516	4.5455	3.218	1.8351	0.0897	0.2153	0.5635
6	3681930.842	441955.21	37.563	7.572	3.7965	11.509	3.5739	1.8633	2.2434
7	3681930.848	441955.224	37.552	5.9841	8.8633	0.15307	1.9778	0.2711	3.5906
8	3681987.892	441960.177	37.495	7.2642	6.9174	9.6885	1.1543	1.0762	2.3768
9	3682054.395	441961.244	37.476	7.8596	10.539	10.828	1.9035	1.4732	2.6224
10	3682052.282	442019.832	37.492	1.8268	2.311	9.4917	3.7528	2.4817	1.1314
11	3682010.698	442017.069	37.811	0.72846	4.6779	3.5996	0.8207	1.7565	0.1090
12	3681954.797	442014.695	38.057	8.8102	1.2505	9.5109	3.5047	2.4404	0.8144
13	3681882.434	442007.819	37.835	9.3927	6.3888	3.0402	2.0797	0.2153	3.4487
14	3681871.347	441911.405	38.302	0.85146	7.5096	0.29618	1.7717	2.1920	2.2674
15	3681857.675	441846.845	38.312	0.74451	1.5553	5.4074	2.7216	1.4855	0.3129
16	3681848.25	441795.361	38.224	8.068	10.273	5.9813	1.8254	0.1914	2.9530
17	3681858.177	441742.009	38.025	0.58541	3.766	7.6996	0.1520	3.8170	2.9695
18	3681867.205	441687.375	38.277	9.4366	3.4698	5.9744	3.7498	2.0535	0.9636
19	3681866.141	441626.473	37.76	9.8212	7.1415	6.4371	1.0399	3.0359	3.9734
20	3681932.233	441634.247	37.025	3.9705	4.9403	9.5281	1.4268	3.0114	0.4402
21	3681944.419	441677.567	37.735	4.1185	5.5513	4.4139	2.3882	1.7224	2.9229
22	3682021.664	441668.044	37.394	8.1548	6.8133	7.8213	1.0447	0.3792	1.8039
23	3682012.264	441608.496	37.133	5.8934	4.7815	5.7298	2.5603	0.5282	1.8113
24	3682036.929	441743.654	37.454	0.79905	4.9323	11.629	2.6088	3.3080	1.2323
25	3681988.463	441755.84	37.518	9.3687	8.7482	9.1878	1.6095	3.5369	2.8023
26	3682012.79	441805.479	37.993	9.079	10.119	9.2419	0.9675	3.0393	1.1637
27	3682055.342	441793.475	37.249	11.744	1.3363	4.7529	1.1098	0.0244	1.4988
28	3682055.827	441839.834	37.307	5.9047	3.0971	0.44359	1.7477	1.2172	1.1634
29	3682013.483	441859.114	37.814	11.693	8.7171	1.7756	0.9701	3.7467	3.4408

30	3681949.014	441882.158	38.02	1.7747	8.4579	4.5719	1.5889	1.9177	2.2600
31	3681936.117	441836.105	38.215	0.91694	4.9301	1.7159	1.9585	1.0792	3.9590
32	3681909.788	441784.371	38.321	9.587	11.163	0.056634	0.7347	3.4466	0.1305
33	3681791.576	441619.32	37.623	7.8005	8.1424	3.0435	1.3278	2.9950	2.1731
34	3681718.139	441620.216	37.704	10.118	3.5275	0.32232	0.6770	3.8088	3.6619
35	3681745.826	441734.395	37.71	1.1197	9.5746	8.5368	1.0057	2.3143	1.7710
36	3681798.809	441731.341	36.987	9.4009	7.4871	9.905	3.5824	1.9300	
37	3681737.609	441778.682	38.166	0.42027	4.8657	2.996	1.2470	0.2213	3.0152
38	3681728.833	441826.792	38.28	5.7708	10.57	3.3682	0.5278	1.4237	1.5835

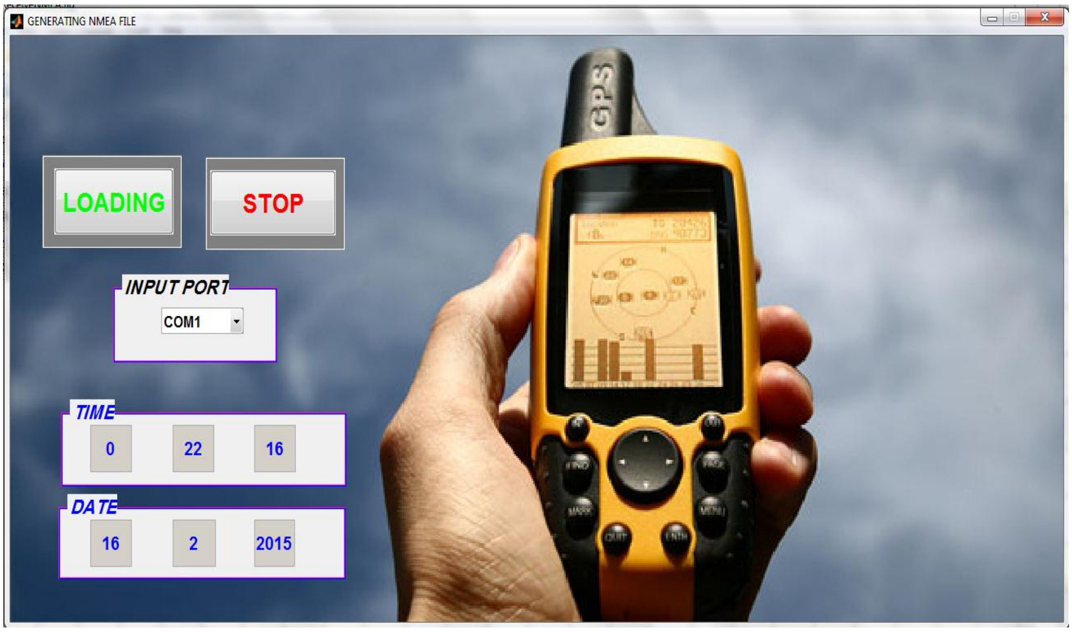

Figure 1. Designed program for loading and processing NMEA file.

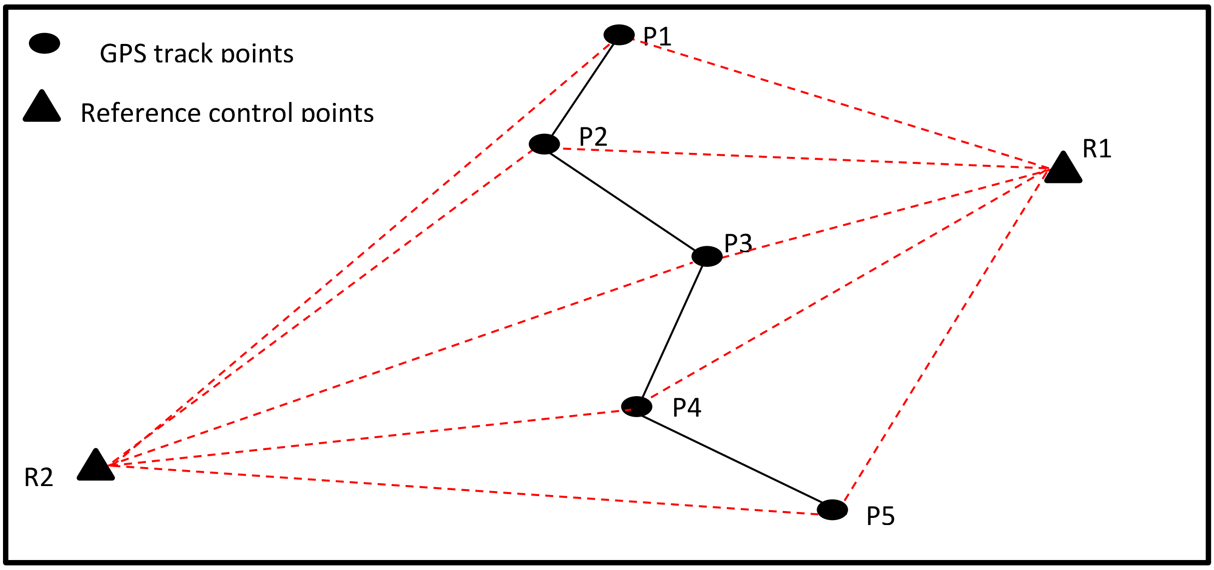

Figure 2. Illustrative sketch for the GPS baselines, which created between the GPS track points and the control points using the designed program.

Figure 3. Distribution of reference control points in the campus of the University of Baghdad.

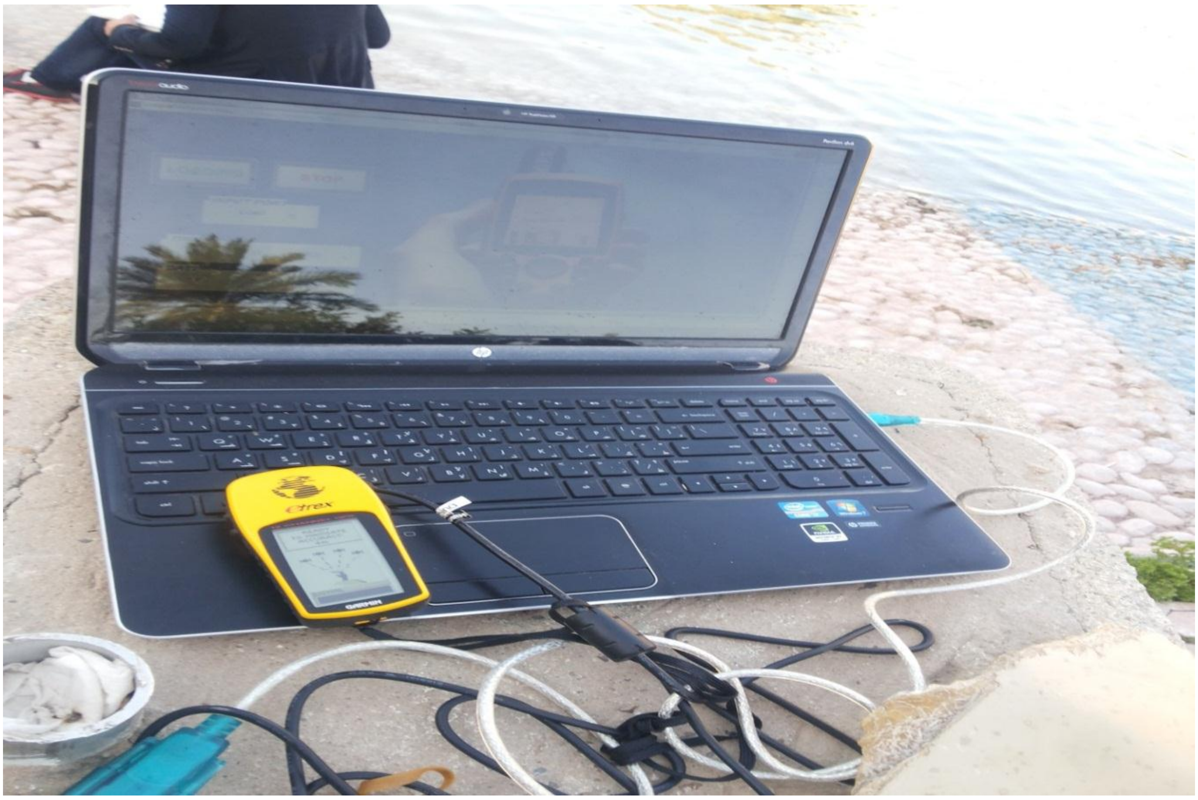

Figure 4. The connection between a Pc and Garmin GPS for data post - processing.

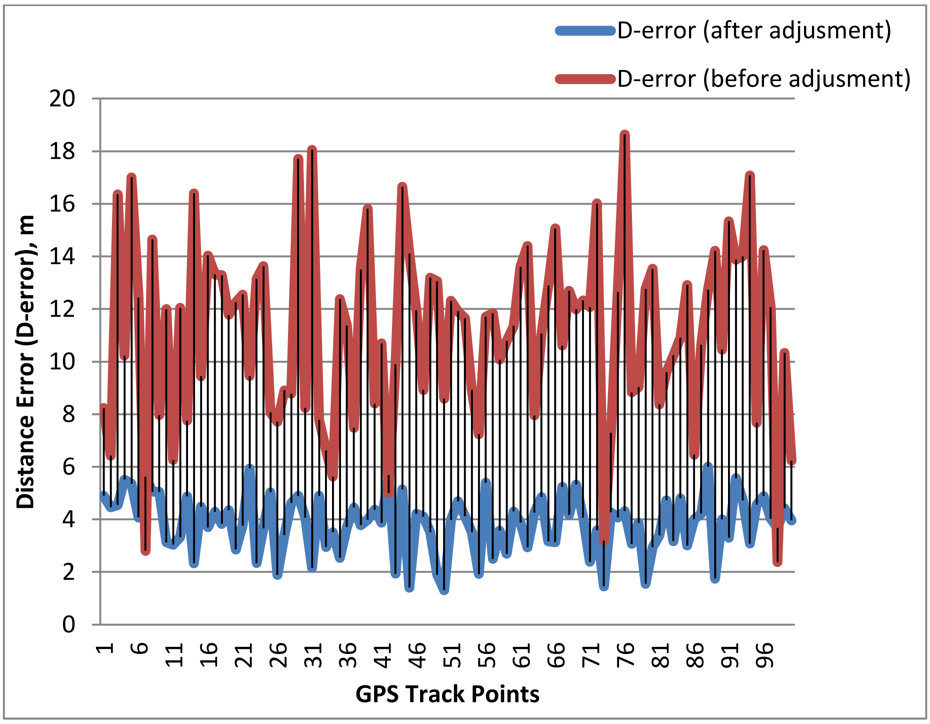

Figure 5. The histogram of distance error for all GPS track points before and after adjustment.