Accuracy improvements of local GPS coordinates measured with LEA -6 GPS receiver modules by using software techniques

BAKI KOYUNCU[1], HAKAN KOYUNCU[2]

Computer Engineering department, Altınbas University, Istanbul, TURKEY

Abstract: In this study, a GPS receiver module LEA-6 was deployed to measure the longitude and latitude of a static point on the ground in the open air. These measurement values are stored in 1-dimensional arrays in computer memory. Additionally, a top-grade GPS position recorder called iP90Pro with a very high-level positioning accuracy was employed to be used as a reference for LEA-6 module measurements. Various software techniques such as regression analysis, moving averaging algorithms, (MA), offsetting, and polynomial curve fitting was deployed on the measured raw longitude and latitude values of the LEA-6 module. As a result, the accuracy levels of these values are improved to the levels of the iP90Pro device. A mathematical analysis was carried out and formulas were developed for longitude and latitude values to bring the accuracy levels of a commercial average-grade GPS module to the accuracy levels of a top-grade GPS module.

Keywords: GPS, Longitude, Latitude, Receiver module, Regression analysis, filtering, Moving Averaging (MA)

1. Introduction

GPS positioning is one of the most popular positioning systems outdoors.[1,2] GPS Receiver modules with the appropriate circuitry were developed and made available for public use. The global satellite network is used to estimate distances with remarkable precision, as shown in Figure 1. By using this technique, object positions may be calculated to within 1 to 5 meters with average GPS devices. This accuracy increases with the usage of more advanced GPS devices. When the GPS receivers are indoors, however, it usually does not work.

GPS receivers receive signals from multiple satellites and they use the triangulation method to establish physical positions. GPS is made up of three sections: Space, Control, and User. The Space part is composed of 32 satellites in the earth's orbit. The Control part is composed of a Master Control Station and many shared Ground Stations with Antennas and Monitors.[3] The User part is composed of hundreds of thousands of commercial, military, and scientific users.

Figure 1: Positioning Satellite in the orbit

GPS satellites broadcast signals from space to GPS receivers on earth to provide 3-D location information (latitude, longitude, and altitude) and precise time.

Each GPS satellite continually broadcasts a signal of a carrier wave with modulation. This signal has a binary code known to the receiver.[4]

A receiver-generated version and the receiver-measured version of the code are time-aligned, and the time of arrival of a defined point in the code sequence can be obtained in the receiver clock time scale.

A message includes the time of transmission (TOT) and the satellite position at that moment (in GPS time scale). Longitude is expressed as an angular measurement that ranges from 0 degrees at the Prime Meridian to +180 degrees Eastward and -180 degrees Westward.

Each degree of longitude is subdivided into 60 minutes, which are then subdivided further into 60 seconds. In sexagesimal notation, longitude is expressed as 23° 27′ 30″ E.

The north-south position of a point on the Earth's surface is specified by latitude, which is a geographic coordinate. The term Latitude refers to an angle that spans from 0° at the Equator to 90° (North or South) at the poles. Parallels, or lines of constant latitude, travel East-West as circles parallel to the equator. Latitude should normally refer to the geodetic latitude. Latitude is expressed as 48° 51′ 29″ N. Longitude and Latitude are used combined to indicate the precise position of locations on the earth's surface.

Decimal degrees (DD) are fractions of a degree used to represent geographic coordinates such as latitude and longitude. Many geographic information systems (GIS), web mapping apps, and GPS devices make use of DD. Sexagesimal degrees (degrees, minutes, and seconds > DMS) can be replaced with decimal degrees. The values are limited by ±90° and ±180°, for latitude and longitude. For example, Latitude (Degrees Minutes Seconds) 25^0 33' 45'' becomes 25,5625 in Decimal degrees and Longitude (Degrees Minutes Seconds) 28^0 45' 30'' becomes 28,758333 in Decimal degrees.

In this study, Decimal degrees are used for Longitude and Latitude values. All the recordings are converted to DD values. The study consists of 6 sections. In section 1; a general introduction is given. In section 2; a literature review about the previous research work is presented. In section 3: The methodology of the study is explained. In section 4: The implementation techniques used during accuracy improvements are given. In section 5: The results of accuracy calculations and discussions are given. In section 6; The conclusions and further recommendations are presented.

2. Literature review

The Global Positioning System (GPS), formerly known as Navstar GPS [1], is a satellite-based radio navigation system [2]. It is a global navigation satellite system (GNSS) that sends geolocation and time information to a GPS receiver anywhere on the Earth with an unobstructed line of sight to the satellite.

The GPS does not need the user to transmit any data, and it works independently of telephonic or internet reception, but both technologies can improve the accuracy of GPS location data. Military, municipal, and commercial users throughout the world rely on GPS for vital location information. The United States government developed, maintains, and regulates the system. Military units, surveyors, sailors, pilots, and others, etc.. all employ GPS satellite navigation, by using tiny handheld receivers. Many cars come equipped with such devices.

With the launch of the Navy Navigation Satellite System in the 1970s, the use of satellites in navigation became more prevalent (NAVSAT or TRANSIT). To establish lines of position and localities, this method employs the Doppler shift in radio frequencies.[9,11]

The system was designed to include 24 satellites, with 4 satellites in each of six orbits. The six orbits are uniformly spaced every 600 kilometers around the Earth, on planes inclined at 55^0 degrees from the Equator, according to the fundamental plan. Orbits are circular and take place at a relatively high altitude of 20,200 kilometers above the Earth's surface.

GPS receivers today are technological devices. They're portable, run on small batteries, weigh as little as nine ounces, and cost less than $100. The receiver can be turned on at any location on or above the Earth's surface. Its display unit shows latitude, longitude, and altitude in a matter of seconds. The stated surface position is typically correct to within 100 meters, and the altitude is usually accurate to within 100 meters.

Many flaws, such as satellite ephemeris inaccuracy, satellite clock bias, atmospheric effects, receiver noise, and multipath, formerly restricted the immediate accuracy of GPS Single Point Positioning (SPP).[5,6]

Finally, The GPSSPP solutions were created using the Precise Single Point Positioning (PSPP) software developed at the University of New South Wales (UNSW). The accurate International GPS Service (IGS) orbits and related satellite clock adjustments can be entered into this program. These are of greater quality than the data in the navigation message, which explains the influence of residual satellite euphemism.[12,13]

Satirapod et al (2001) examined the accuracy increase in the case of averaged static solutions and showed some results from various SPP processing techniques. Finally, the study speculated on the SPP precision achievable with single-frequency GPS receivers in the future when ionospheric activity is less strong.

Several research studies are carried out with GPS signals to increase localization accuracies in the literature.

Liu et al (2014) revealed that cooperative localization is a potential technique for precise vehicle location with communication technology. In this study, they first present a ranging approach termed weighted least squares double difference (WLS-DD), which is based on the sharing of GPS pseudo-range data and a weighted least squares method for detecting intervehicle distances.[3] They presented a distributed location estimation algorithm (DLEA) based on inter-vehicle distance detection to increase vehicle positioning accuracy.

Jie Lin et al (1996) showed the challenge of improving GPS location accuracy by using a novel use of fuzzy set theory. [4] They used fuzzy processing on the C/A code, stand-alone receiver, and DGPS receiver, Location dilution of precision (PDOP), signal to noise ratio (SNR), and the dependable factor of fixed position established the membership functions for the processing.

Cui et al (2003) tried the correct the positioning errors in urban environments.[6] GPS signals are frequently obstructed by highrise structures and there are insufficient satellite signals to estimate the location information of GPS-based positioning systems. A restricted technique is provided to address the problem by roughly simulating the vehicle's route. Using the constrained techniques, several methods are created. In addition, a state-augmentation approach is presented for simultaneously estimating the GPS receiver's position and the line's characteristics.

Lecce et al in 2008 defined many of the factors affecting the GPS accuracy, when evaluated in a specific geographic area, have a certain periodicity, according to the authors.[10] The location of the sky satellite relative to the receiver is a good illustration of this type of factor. To adjust the location calculated by the receiver, they suggested a technique that employed a neural network. The neural network is trained to understand how the cyclic phenomena introduce mistakes into the measurement system at different times of the day.

Using coordinate data (latitude, longitude, time, and velocity) from the GPS receiver, Islam et al. (2014) presented a technique for precisely predicting location by integrating vehicle movement direction, velocity averaging, and distance between waypoints.[7] Additionally, the previously estimated valuable reference point, coordinate translation, and invalid data check increase accuracy. They ran an experiment utilizing a GARMIN GPS 19xHVS receiver mounted to a vehicle and Google Maps to plot the processed data to evaluate the suggested method's performance. In numerous trials, the proposed technique improved by 4–10 meters.

By utilizing IR pictures, Meguro et al. (2008) suggested a strategy for mitigating GPS multipath using an omnidirectional infrared (IR) camera, which can eliminate the requirement for unseen satellites (a satellite recognized by the receiver but not in LOS (Line Of Sight).

Isa et al. (2017) suggested an architectural solution that included two GPS devices that communicated with the ESPresso Lite V2.0 controller. At both the Reference Station (RF) and the Rover, the GPS module was installed. The RF position error is provided to the Rover to enhance the Rover's placement. The location's position is enhanced by 1–3 meters. [8]

3. Methodology

In this study, GPS coordinates of a location in longitude and latitude are recorded at static locations. Initially, the recordings are carried out in sexagesimal notation of degrees + minutes and seconds. These recordings are carried out with a GPS receiver module called LEA -6 which was purchased cheaply from the market. See Figure

2. The device had a positioning accuracy of 3.5 m.

Figure 2: an LEA-6 Receiver module

These coordinates were later compared with the longitude and latitude coordinate recordings of an upmarket receiver i90Pro with a positioning accuracy of 8mm-15mm. See Figure 3. This i90Pro receiver was used as a reference receiver due to its higher accuracies.

Figure 3: i90Pro GNNS Receiver from GNSS Teknik

The recordings of the LEA-6 module are taken as the source data and their positioning accuracies are improved by using software techniques to the accuracy levels of the i90Pro device. LEA-6 receiver module recordings are converted into decimal degrees. Decimal degrees (DD) are fractions of a degree used to represent geographic coordinates such as latitude and longitude. Many geographic information systems,(GIS), employ DD and they are an alternative to using sexagesimal degrees (degrees, minutes, and seconds -> DMS).

A DMS value can be converted to decimal degrees using the equation (1):

$$D_{dec} = D + \frac{M}{60} + \frac{S}{3600} \qquad (1)$$

For instance, the decimal degree representation for Latitude and Longitude 32° 43′ 21″ N, and 67° 12′ 31″ W becomes 32.7224999^0 and 67.2086111^0

A sample of raw Longitude and Latitude recordings for LEA-6 and i90Pro at the same earth point are displayed in Figures 4a and 4b.

LEA-6 Receiver	
Latitude	**Longitude**
40.97626800	28.74822550
40.97626783	28.74822600
40.97626783	28.74822617
40.97626767	28.74822650
40.97626783	28.74822667
40.97626817	28.74822683
40.97626850	28.74822717
40.97626867	28.74822750
40.97626883	28.74822783
40.97626900	28.74822817
40.97626900	28.74822833

Figure 4a: LEA-6 Receiver raw recordings in Decimal degrees

i90Pro Receiver	
Latitude	**Longitude**
40.97625614	28.74821689
40.97625618	28.74821690
40.97625611	28.74821688
40.97625613	28.74821694
40.97625610	28.74821689
40.97625611	28.74821689
40.97625612	28.74821691
40.97625612	28.74821691
40.97625610	28.74821688
40.97625612	28.74821692
40.97625616	28.74821690

Figure 4b: i90Pro Receiver raw recordings in Decimal degrees.

3.1 Regression Analysis

Regression analysis is a collection of statistical procedures for evaluating the connections between a dependent variable and one or more independent variables or features.[14] Linear regression is the most frequent type of regression analysis, in which one finds the line that best fits the data according to a set of mathematical formulations. The simple Linear regression model can be represented by equation (2).

$$Y_t = \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \beta_3 Y_{t-3} + .. + \beta_p Y_{t-p}$$

Equation (2)

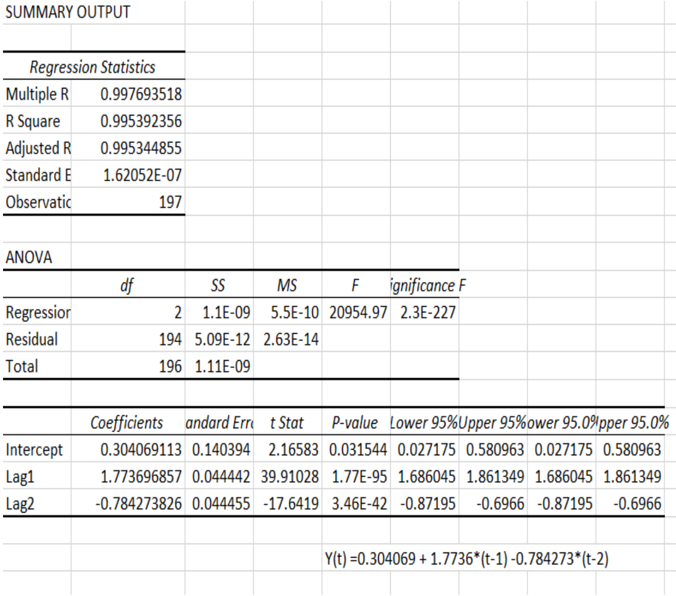
A linear regression model can be set up between the present value Y_t and the previous values Y_{t-1}, Y_{t-2}, Y_{t-3}, and so on.

200 Longitude Decimal degree values are listed as a one-dimensional array t between t=1 and t=200 For multiple regression analysis, the listing of t-1, t-2, and t-3 arrays are arranged and 3 top and bottom values are cut off. A sample of resultant t, t-1, t-2, and t-3 arrays is shown in Figure 5.

t	**t-1**	**t-2**	**t-3**
28.7482265	28.7482262	28.7482260	28.7482255
28.7482267	28.7482265	28.7482262	28.7482260
28.7482268	28.7482267	28.7482265	28.7482262
28.7482272	28.7482268	28.7482267	28.7482265
28.7482275	28.7482272	28.7482268	28.7482267
28.7482278	28.7482275	28.7482272	28.7482268
28.7482282	28.7482278	28.7482275	28.7482272
28.7482283	28.7482282	28.7482278	28.7482275
28.7482285	28.7482283	28.7482282	28.7482278
28.7482285	28.7482285	28.7482283	28.7482282
28.7482287	28.7482285	28.7482285	28.748228

Figure 5: Sample table of longitudes at different t values.

The regression analysis function in excel was deployed and the summary output is given in Figure 6.



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997693518
R Square	0.995392356
Adjusted R	0.995344855
Standard E	1.62052E-07
Observatic	197

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regressior	2	1.1E-09	5.5E-10	20954.97	2.3E-227
Residual	194	5.09E-12	2.63E-14		
Total	196	1.11E-09			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.304069113	0.140394	2.16583	0.031544	0.027175	0.580963	0.027175	0.580963
Lag1	1.773696857	0.044442	39.91028	1.77E-95	1.686045	1.861349	1.686045	1.861349
Lag2	-0.784273826	0.044455	-17.6419	3.46E-42	-0.87195	-0.6966	-0.87195	-0.6966

Y(t) =0.304069 + 1.7736*(t-1) -0.784273*(t-2)

Figure 6: Summary output of regression analysis

The result of 2nd order regression analysis is concluded and the regression output equation is obtained as shown in equation (3).

$$Y(t) = 0.304069 + 1.7736*(t-1) - 0.784273*(t-2)$$

equation (3)

Equation (3) is deployed to generate a resultant new 1 Dimensional data array by using t-1 and t-2 arrays in Figure 5. This new array is called 2nd order regression array.

3.2 Moving Averaged analysis

This is an algorithm that is used to smooth the sequential data variations in a 1-dimensional array. These 1 Dimensional arrays are obtained after applying 2nd order regressing analysis to recorded Longitude and Latitude values. Moving Average (MA) algorithm was applied to introduce a further smoothing on the raw Longitude and Latitude data. A simple moving average is a statistical technique that calculates the unweighted mean of the most recent “n “ samples. Because the technique can be thought of as a window that glides across the data points, the number “n” is sometimes referred to as the window size.

In a 3 point MA Algorithm, the first 3 data points are averaged out and the average value becomes the first data point of a new 1 D array. 3 point window advances one data point in the first array and takes the next 3 points, averages them out, and places them as the second point in the new array. Hence 1 data point disappears at the head of the original data array. This sequential operation continues for the data points in the first array. Finally, 2 data points at the end of the first array are discarded due to the missing third point for the averaging.

A 1 Dimensional array of **n** data can be shown as $\mathbf{a_i}$ where i= 1 to n.

The new generated 1D array after applying the MA algorithm is called **bj** where j=1 to m.

Hence $b_1 = (a_1 + a_2 + a_3)/3$, $b_2 = (a_2 + a_3 + a_4)/3$.. $b_m = (a_{n-2} + a_{n-1} + a_n)/3$

The new 1D array introduced a further reduction on the random variations of Longitude and Latitude values.

3.3 Polynomial curve fitting

Curve fitting is the act of creating a curve, or mathematical function, that best fits a set of data points, sometimes under limitations. Curve fitting can produce smoothing in which a polynomial smooth function is constructed that approximately fits the data.[15].

In this study, The first level of smoothing on variations of Longitude and Latitude values was carried out by a 2nd order regression analysis. Second level smoothing of variations was carried out by using a moving average analysis. The third level of smoothing was further introduced by using polynomial curve-fitting on the 3-point MA output data with an offset value.

The polynomial equation of first degree is

$y=ax+b$

is a line that has a slope of a. Because any two locations may be connected by a line, a first-degree polynomial equation is a perfect fit through any two points with different x coordinates.

The following findings are obtained when the order of the equation is increased to a second-degree polynomial of

$y= ax^2 + bx + c$

This will fit a basic curve to three points.

The following is produced when the order of the equation is raised to a third-degree polynomial of

$y= ax^3 + bx^2 + cx + d$

This will fit a basic curve to four points.

The polynomial curve can still be run through those restrictions if there are more than $n + 1$ constraint (n being the degree of the polynomial).

Matlab can be used to apply polynomial curve-fitting on the data values in the form of 1D arrays to generate algebraic equations of the data distribution. This curve fitting was introduced to quantize the amplitude variations of Longitude and Latitude data values during the processes.

3.4 Linear Offset

Equal numerical offset values are introduced to the values in a 1D array. All the values are shifted by a positive amount.

This offset is considered as the numerical constant between the measured Longitude and Latitude data by i90Pro against time and the output data of the MA algorithm. This constant difference between the MA algorithm data values and the i90pro output data values was taken as the mean value of the MA algorithm data values. This mean value is added to the MA algorithm data values as a linear offset. The distance between the new MA algorithm data values with offset and the i90Pro data values is reduced to minimum values.

4. Implementation

In this study, the purpose of introducing several algorithms and analysis techniques on the measured data with an average GPS position device is to reduce the values of error readings.

In practice, there is an error margin between the readings of an upmarket accurate GPS position device and the average GPS device.

Generally, it is difficult to buy an accurate but expensive GPS device due to its cost. Most people usually buy a cheap GPS device that has a handicap of high error readings. Hence software techniques can be introduced to compensate for this error margin and simulate the average device as if it is an expensive accurate device.

The first operation carried out on the raw Longitude and Latitude decimal degree data is the regression analysis. Excel regression analysis facility was employed. A small amount of smoothing effect is introduced on the raw data. A graph of Longitude raw data and the output data after regression analysis applied versus time is plotted in Figure 7.

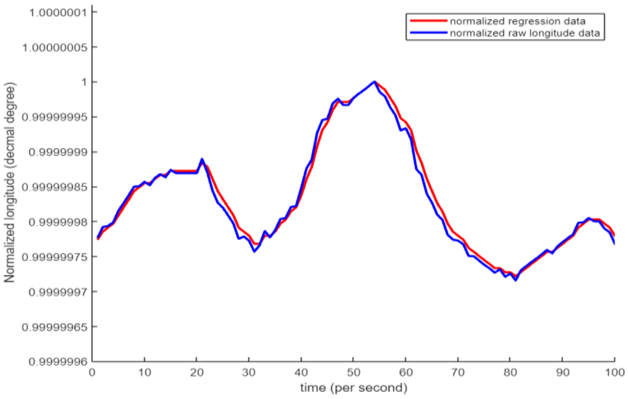


Figure 7: Plot of normalized raw longitude data and normalized regression data vs time

Secondly, a 3-point MA algorithm was applied to the regression introduced data. This algorithm was repeated in a loop of 1000 times. This loop is introduced to increase the smoothness of the output data. The output data is plotted against time in Figure 8.

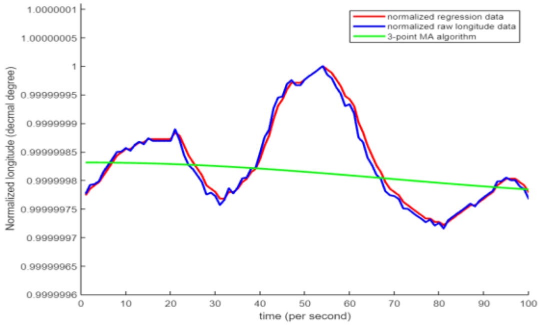


Figure 8: Plot of normalized raw longitude data, regression data, and 3-point MA data vs time

Thirdly, the resultant 3-point MA data is plotted against the normalized iP90Pro data in Figure 9. One can observe from Figure 9 that there is approximately a constant offset between these two results.

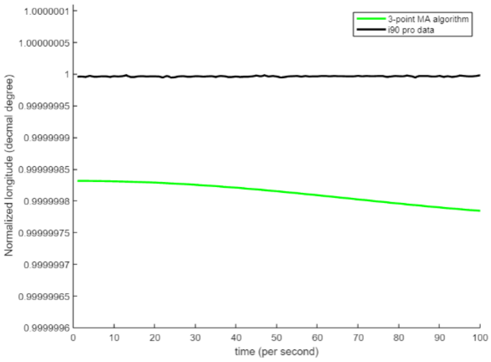


Figure 9: A plot of i90Pro data vs 3-point MA data

Hence this constant offset value is added to the MA output data. The offset value is taken as a constant of 0.012220638 which was equal to the mean value of MA data.

As it can be seen that the offset added values became very close to the iP90Pro recordings in the time domain. The final graphs of the 3-point MA data with offset and iP90Pro raw data are plotted as shown in Figure 10.

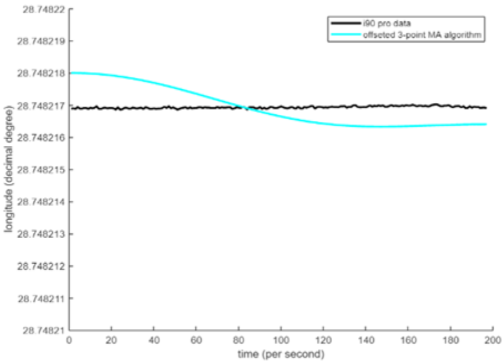


Figure 10: Plot of 3-point MA data with offset and iP90Pro data

Finally, polynomial curve fitting of the 3rd order was deployed on 3-point MA output data with offset and i90Pro output data. Linear model Poly3 function for 3point-MA data with offset is shown in equation 4.

$f_1(x)$ = p1*x^3 + p2*x^2 + p3*x + p4 equation 4.

Coefficients (with 95% confidence bounds):

p1 = 6.01e-13 (5.467e-13, 6.552e-13)
p2 = -1.148e-10 (-1.311e-10, -9.844e-11)
p3 = -8.6e-09 (-9.994e-09, -7.206e-09)
p4 = 28.75 (28.75, 28.75)

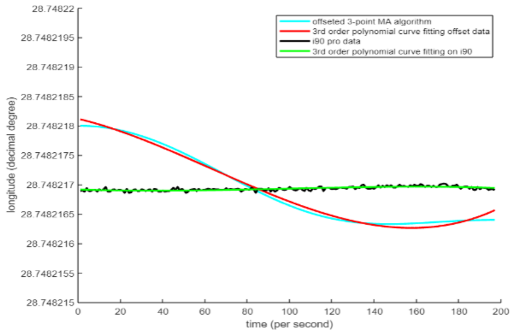
This function shows the algebraic equation of 3rd order polynomial for the MA data with offset. Similarly, another algebraic equation of 3rd order polynomial for the i90Pro data is also generated and shown in Equation 5.

$f_2(x)$ = p1*x^3 + p2*x^2 + p3*x + p4 equation 5.

Coefficients (with 95% confidence bounds):

p1 = -6.94e-14 (-9.249e-14, -4.631e-14)
p2 = 2.048e-11 (1.352e-11, 2.743e-11)
p3 = -1.205e-09 (-1.799e-09, -6.119e-10)
p4 = 28.75 (28.75, 28.75)

Both functions are plotted in Figure 11 together with i90Pro data and 3-point MA output data with offset.



.

Figure 11: polynomial curve fitting functions with their original plots in Figure 10.

The plot of the 3rd order curve fitted MA data + offset can be expressed by a mathematical function in equation 6.

y=28.748217 + 8*10-7*Cos(0.01876t) equation 6

This math function was plotted in Figure 12 with its average plot of y= 28.74821688. Similarly, the average value of iP90Pro data is calculated and expressed as y= 28.74821693.

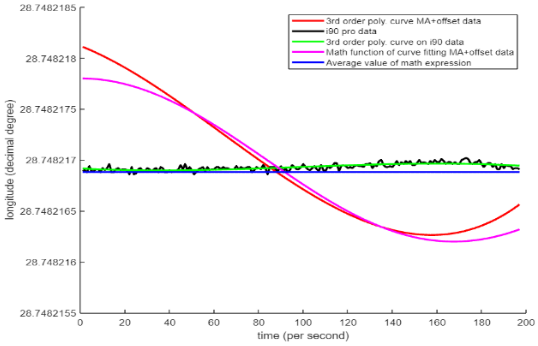


Figure 12: Plot of Math function for MA data with offset, its average, iP90Pro data, and 3rd order poly curve of iP90Pro data.

It can be observed that both average values are very close to each other with an error difference of $5*10^{-8}$ decimal degrees. This error difference was found to be for longitude values. Similarly, the same calculations are carried out for latitude values. The error difference of $6.5*10^{-8}$ decimal degrees was found to be for latitude values.

Finally, due to the smallness of these error differences, it was concluded that the average values for processed Longitude and Latitude values of LEA-6 are matched with the average value of iP90Pro Longitude and Latitude values.

5. Results and discussions

In this study, Software techniques were introduced to convert the Longitude and Latitude GPS data from an average LEA-6 device into a high accuracy GPS device iP90Pro. GPS data outputs of both devices are recorded in Decimal degree format. The conversion consists of several software stages.

iP90Pro longitude and Latitude data were accepted as the reference data and the LEA-6 data values are attempted to be converted into iP90Pro data.

Initially, LEA-6 Longitude and latitude data were subjected to 2nd order regression analysis. This caused a small amount of smoothing. The outputs of regression analysis on Longitude and latitude data are subjected to a recursive 3-point Moving Averaging algorithm. This algorithm smoothed the regression analyzed Longitude and Latitude data further.

Offset values corresponding to the mean values of recursive 3-point Moving algorithm results for Longitude and latitude data are applied to these results. Hence the resultant Longitude and latitude values approached to iP90Pro Longitude and Latitude data values.

Figure 10 shows the resultant Longitude data values together with iP90Pro longitude data values. 3rd-degree polynomial curve fittings were applied on the resultant Longitude and latitude data and the iP90Pro Longitude and Latitudes data. Figure 11 shows the curve fitted resultant Longitude data values together with iP90Pro longitude data values as an example.

Finally, the average value of the mathematical function generated in equation (6) from 3rd-degree polynomial curve fittings to the resultant Longitude and latitude data was calculated as y= 28.74821688. The average value of iP90Pro data is calculated and defined as y= 28.74821693.

The error difference between these two average values for both Longitude and latitude values was very small. Hence the average value of the GPS device, LEA-6, measurements are corrected and made close to the measurements of the high-level GPS device iP90Pro.

6. Conclusions

There is a significant difference between the GPS measurements of expensive and not-so-expensive GPS devices. Expensive devices have an accuracy of a few cms while not so expensive devices have a few meters. At the end of the day cost of these devices affect the users.

Hence An idea was introduced to get the measurements of not-so-accurate devices and convert them into the measurements of accurate devices. Software techniques were introduced and this conversion was provided. Average values of the resultant Longitude and Latitude values after going through several smoothing algorithms approached to the accuracy levels of an expensive GPS device.

Consequently, any not-so-expensive GPS device can achieve similar accuracy levels by going through the software procedures mentioned in this study.

Acknowledgments

The authors appreciated and thanked for the assistance given and the iP90Pro data provided by the GNSS consultancy, Ankara, Turkey

References

[1]. R.Thomson, Global Positioning System: The
Mathematics of GPS Receivers, vol 71, No 4,

pp 260-269 , 1998

[2]. C. Satirapod, C. Rizos, J Wang, Survey Review, Gps single point positioning with sa off: how accurate can we get?, pp 255-262, 2013

[3]. K.Liu, H. Beng Lim, E.Frazzoli, H.Ji, and V.S. Lee, IEEE transactions on vehicular technology, Improving Positioning Accuracy Using GPS Pseudorange Measurements for Cooperative Vehicular Localization,Vol. 63, No. 6, 2014, pp 2544-2556

[4]. C.Jie Lin,Y.Yaw Chen,F. Ren Hang, Soft Computing in Intelligent Systems and Information Processing Proceedings, Fuzzy processing on GPS data to improve the position accuracy, pp 557 – 562, 1996

[5]. D.Brzezinska, C.Toth, and Y. Yi, On Improving Navigation Accuracy of GPS/INS Systems, Photogrammetric Engineering & Remote Sensing, Vol. 71, No. 4, pp. 377–389, 2005

[6]. Y. Cui and S. Sam Ge, Autonomous Vehicle Positioning With GPS in Urban Canyon Environments, IEEE transactions on robotics and automation, Vol. 19, No 1, pp 15-25, 2003

[7]. R. Islam and J.Myon Kim, An Effective Approach to Improving Low-Cost GPS Positioning Accuracy in Real-Time Navigation, The Scientific World Journal, Vol 4, pp 1-8, 2014

[8]. H. L. Isa, S. A.Saad, A..B. Hisham, and M.Hafis Ishak, Improvement of GPS Accuracy in Positioning by Using DGPS Technique, Springer Nature, AsiaSim 2017, Part II, CCIS 752, pp. 3–11, 2017.

[9]. M. Allisona, M. McEwen, A post-Path®nder evaluation of areocentric solar coordinates with improved timing recipes for Mars seasonal /diurnal climate studies, Planetary and Space Science 48, pp 215-235 ,2000

[10]. V. Di Lecce, A. Amato, V. Piuri, Neural Technologies For Increasing The GPS Position Accuracy, IEEE International Conference on Computational Intelligence for Measurement Systems And Applications, DOI: 10.1109/CIMSA.2008.4595822

[11]. K. Kawamura, T. Tanaka, Study on the improvement of measurement accuracy in GPS, SICE-ICASE, 2006. International Joint Conference ,pp 1372 – 1375, 2006

[12]. Yong He, Haihong Yu, Hui Fang, Study on Improving GPS Measurement Accuracy, IMTC 2005 - Instrumentation and Measurement Technology Conference Pp 1476-1479 ,2005

[13]. W. Lee1, W. Chung, Position Estimation Using Multiple Low-Cost GPS Receivers For Outdoor Mobile Robots, The 12th International Conference on Ubiquitous Robots and Ambient Intelligence, pp 460-461, 2015

[14]. C. Adradosa, I. Girardb, J.-P. Gendnerc, and G.Janeaua, Global Positioning System (GPS) Location accuracy improvement due to selective availability,removal, Elsevier vol. 325, issue 2, pp. 165–170, 2002

[15]. N.G.Yuting, Improving the robustness of gps direct position estimation, Msc Thesis, University of Illinois at Urbana-Champaign USA, 2016