Geomatics correction model for GPS data using RTK-DGPS survey

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Abstract

   Determination of the sites of geographical coordinates with high accuracy and in short time is very important in many applications, including: air and sea navigation, and in the uses geodetic surveys. Today, the Global Positioning System (GPS) plays an important role in performing this task. The datum used for GPS positioning is called World Geodetic System 1984 (WGS84). It consists of a three-dimensional Cartesian coordinate system and an associated ellipsoid so that WGS84 positions describe coordinates as latitude, longitude and ellipsoid height (h) coordinates, with respect to the center of mass of the Earth This study develops a mathematical model for geomantic measurement correction for ellipsoidal heights (h) between two different receivers of different accuracies (i.e. high and low). The results are examined using statistical analysis for the accuracy and reliability of the computed positions. The receivers used in this study were, the Topcon HiPer-II and the Garmin eTrex vista. The first receiver use Global Navigation Satellite Systems (GNSS) signals on the L1 and L2 frequencies of both the GPS and GLONASS satellite navigation systems, while the second receiver was the Garmin eTrex vista.

Keywords: Global Positioning System (GPS), Real Time Kinematic (RTK) surveying, local and global correction models

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نموذج تصحيح هندسي لبيانات نظام تحديد المواقع باستخدام جهاز التموضع التفاضلي

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الخلاصة

   تحديد للمواقع الاحداثيات الجغرافية بدقة عالية ووقت قصير جدا مهم في العديد من التطبيقات التي تتضمن الملاحة الجوية والبحرية وفي الاستخدامات المسوحات الجيودسية . يلعب نظام تحديد المواقع العالمي في الوقت الحاضر دوراً مهماً في انجاز هذه المهام . تتالف بوصف الاحداثيات باحداثيات خطوط الطول ودوائر العرض والمرتفعات الاهليلجية باعتبار مركز كتلة الارض .هذه الدراسة تطور نموذج رياضي لتصحيحات قياسات الجيومانتك لارتفاعات الاهليجية (h) بين اثنين من اجهزة الاستقبال المختلفة بدقة مختلفة (عالية وواطئة الدقة) . النتائج المفحصة استخدام التحليل الاحصائية للدقة والوثوقية للمواقع المحسوبة . المستقبلات المستخدمة في هذه الدراسة كانت ، Topcon HiPer−II و .Garmin eTrex vista . ألاول جهاز استقبال TOPCON HiPer−II الذي يستقبل ويعالج اشارات نظم سوائل الملاحة العالمية (GNSS)

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على الترددات L1 و L2 كل من نظام تحديد المواقع ونظم الملاحة الفضائية غلوناس. الملاحة والجهاز الثاني
Garmin eTrex vista .

Introduction

The Global Positioning System (GPS) is a satellite-based radio positioning system developed by the United States Department Of Defense (DOD), The Global Positioning System (GPS) is comprised of three segments: satellite constellation, ground control/monitoring network, and user receiving equipment [1] . The control segment consists of a system of tracking stations located around the world. The master control facility is located at Falcon Air Force Base in Colorado. The monitor stations measure signals from the Space Vehicles (SV) which were incorporated into orbital models for each satellite. The models compute orbital data and satellite clock corrections for each satellite. The master control station uploads ephemeris and clock data to the space vehicles. The satellites then send subsets of the orbital ephemeris data to GPS receivers through radio signals [2].

The user segment consists of all the users of the GPS signals, including both civilian and military users. With a GPS receiver connected to a GPS antenna, a user can receive the GPS signals, GPS receiver's measure and convert SV signal into position, velocity and time. The space segment consists of at least 24 nominal satellites which are distributed on six orbital planes which are equally spaced 60° apart in longitude and inclined to the equator at 55°. The nominal orbital period of a GPS satellite is one-half of a sidereal day or 11 hours, 58 minutes. The orbital radius (i.e., nominal distance from the center of mass of the Earth to the satellite) is approximately 26,600 km [1].

GPS Signals

The GPS signals are transmitted on two radio frequencies in the ultra-high frequency (UHF) band. The UHF band covers the frequency from 500 MHz to 3 GHz, frequencies are referred to as L1 and L2 and are derived by a common frequency of (f_0 =10.23 MHz) [3]. The GPS signals are a combination of three main parts namely the carrier frequency, navigation data and the spreading sequence namely the C/A code and P code. The navigation data is the main component that has to be actually transmitted because it contains information about the satellite orbits. Each satellite has two unique spreading sequences or codes. The first one is the coarse acquisition code (C/A). The C/A code that modulates the L1 carrier is the basis for the civil SPS (standard positioning service) code signals .The code is repeated each millisecond (ms) giving a chipping rate of 1.023 MHz . The second is the Precise code (P-code) modulates L1 and L2 carriers in phases. In normal operation, the so-called "anti-spoofing mode", the P-code is first encrypted into the Y-code, or P(Y). It is broadcasted at 10.23 MHz and it repeats only once a week .The P(Y) code is only available for GPS users. The components of the signal are given in Table-1.

Table 1- GPS Signal Components [4]

Component	Frequency (MHz)
Fundamental Frequency	f_0 =10.23
Carrier L1	154 f_0 = 1575.42
Carrier L2	120 f_0 =1227.60
p-code	f_0 =1.023
C/A-code	f_0/10 =1.023
Navigation message	f_0/205600 =50.10^{-5}

Types of Receivers

Commercial GPS receivers can be divided into four types, according to their receiving capabilities, these are: single-frequency code receivers, single-frequency carrier-smoothed code receivers, single-frequency code and carrier receivers, and dual-frequency receivers. Single-frequency receivers access the L_1 frequency only, while dual-frequency receivers access both the L_1 and the L_2 frequencies [5].

Another distinction is related to the technical of the channels multichannel receiver, sequential receiver and multiplexing receiver .Finally a classification is possible with respect to the user community, (e.g. military receiver, civilian receiver, geodetic/ survey receiver and navigation

receiver). The navigation receivers are the typical low-cost and the accuracy range of up to 10 m, while geodetic / survey receivers are high-cost and the accuracy less than 1cm [6].

GPS Error Sources

Major sources of error that affect the accuracy of stand-alone GPS receiver include ephemeris errors, atmospheric errors (including Ionosphere and Tropospheric propagation delays), satellite and receiver clock errors, Dilution of Precision (DOP), receiver noise and multipath errors. Ephemeris errors are largely diminished by differential corrections. Ionospheres' errors can be remedied with dual frequency (L1/L2). Double difference information is provided for these errors. Troposphere affected the two frequencies equally. When base station and rover are close enough, satellite signals pass through almost same atmospheric conditions, so ionosphere and troposphere errors are almost identical and can be effectively cancelled with DGPS technique. Satellite clock errors are due to synchronization between satellite clock and receiver clock. These include Satellite Vehicle (SV) clock offset, clock drift and clock drift rate [7].

Differential GPS

DGPS is a technique that improves the solution accuracy while removing these errors. It was developed to meet the needs of positioning and distance measuring applications that required higher accuracies than stand-alone Standard Positioning Service (SPS). Major sources of error that affect the accuracy of stand-alone GPS receiver include ephemeris errors, atmospheric errors (including Ionospheric and Tropospheric propagation delays), satellite and receiver clock errors, receiver noise and multipath errors [7] . DGPS receiver utilizes information from one or more stationary base-station GPS receivers at accurately known locations, figure-1. The base-station GPS receiver calculates a position from the satellite signals [8].
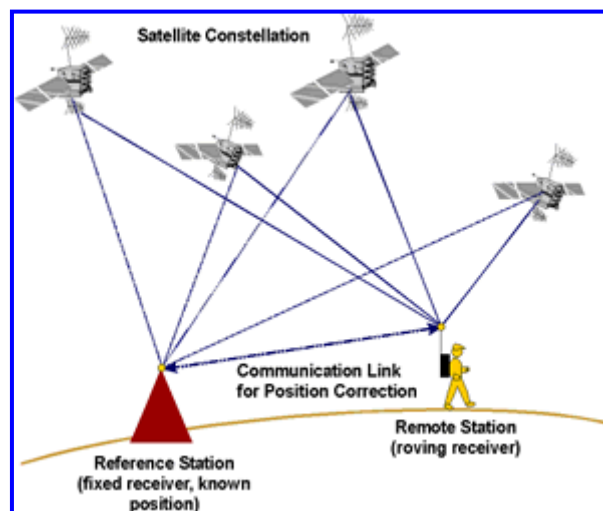

Figure-1 The basic principle of Differential GPS [8]

Real Time Kinematic (RTK) Surveying

RTK surveying is a carrier phase based relative positioning technique that, like the previous methods [5]. In RTK-DGPS mode, one GPS receiver placed on a station is kept static (reference station) during the whole observation session, while the other receiver moves among points (rover stations) whose spatial positions are to be determined. Both reference and rover stations are equipped with dual frequency receivers. Reference receiver has a radio transmitter aimed to send phase observation corrections to rover receiver which is also equipped with radio modem to establish a link with the reference station [9].

Polynomials

A polynomial is a mathematical expression consisting of variables and coefficients. A coefficient is constant, which is multiplied by a variable in the expression. The variables in polynomial expressions can be raised to exponents. The highest exponent in a polynomial is given by [10].
The general equation of polynomial:

$$Z(x, y) = \sum_{i=0}^{n} \sum_{j=0}^{m} a_{ij} x^i y^j \tag{1}$$

Where:

    x, y   represent the position coordinates,

    a_{ij} symbolize the polynomial coefficients,

    n, m   represent the degree of the polynomial.

For the polynomial method it is necessary to determine a polynomial that has the property to go through some data points by using different methods. This method is used to determine the general trend of the values of a polynomial function, as follows:

- **First Order Polynomial;**

$$Z(x, y) = a_0 + a_1 x + a_2 y \tag{2}$$

- **Second Order Polynomial;**

$$Z(x, y) = a_0 + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2 \tag{3}$$

- **Third Order Polynomial;**

$$Z(x, y) = a_0 + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2 + a_6 x^2 y + a_7 xy^2 + a_8 x^3 + a_9 y^3 \tag{4}$$

In cases of unknown coefficients ($a_0, a_1, a2...., a_n$), they can be determined by utilizing the least square adjustment method.

The Study Area

As illustrated in Figure-2, Baghdad University Campus, which covers about (3.4 km^2), was the study area. The work was accomplished by using Real Time Kinematic-Differential Global Position System RTK-DGPS, type Topcon Hiper-II, and GPS handheld Garmin eTrex vista receiver. The study region is located at Latitude (33º 16' 32.1") to (33º 16' 2.9") N, and Longitude (44º 22' 10.1") to (44º 23' 18.5") E.

Data Acquisition

The Easting and Northing of 364 points were selected to perform the tests, illustrated in Figure-2. The study area have been navigated using GPS survey; i.e. Universal Transverse Mercator (UTM) projection and WGS-84 systems. Figure- 2 shows the distribution of DGPS and GPS test points.
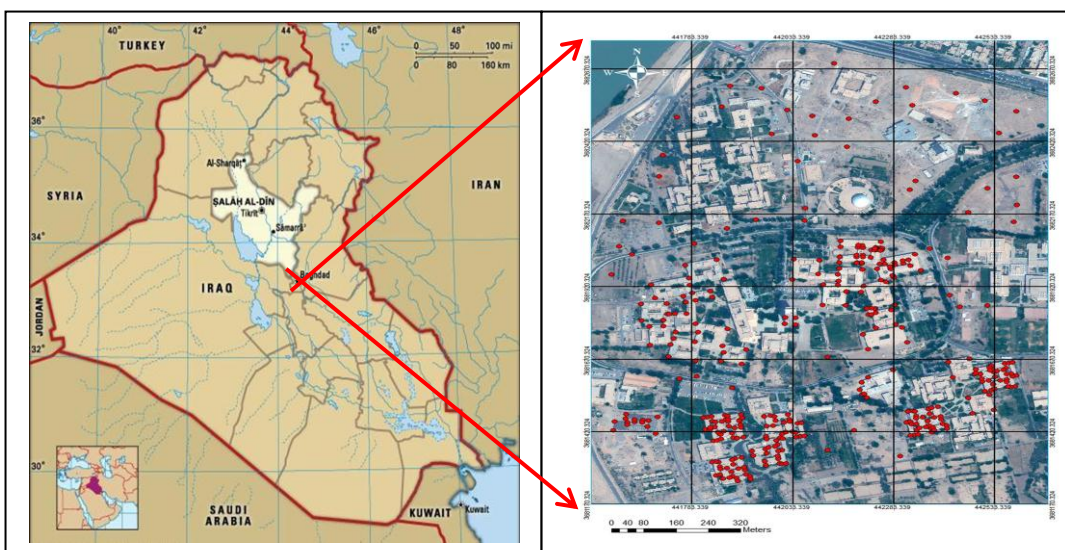

Figure 2- QuickBird satellite image (0.6 m) for the study area (Baghdad University Campus)

Correction Models for Navigation GPS Data

The correction models were evaluated using the polynomials transformation methods, using the MATLAB environment facilities usage. The following summarizes these models and the results.

Results for Local and Global Correction Models

The local z-coordinate represent the highest of ellipsoid for cretin region of interest, using least square method (utilizing MATLAB program) are given by the following;

- **Using 1st Order Polynomial:**

$$Z_1=34.6017225+0.00045934129x+ 0.000508075y \tag{5}$$

- **Using 2nd Order Polynomial:**

$$Z_2=34.8588+0.0003966x+ 0.00083576y -1.53\times10^{-6}\ xy-1.24\times10^{-6}x^2 -1.33\times10^{-6}\ y^2 \tag{6}$$

- **Using 3rd Order Polynomial:**

$$Z_3=34.7305+0.00049x+0.001167y-3.25\times10^{-6}xy-8.96\times10^{-7}y^2 + 4.82\times10^{-7}y^2 +.89\times10^{-9}xy^2 -4.34\times10^{-8}x^2y-$$
$$2.85\times10^{-9}x^3-2.26\times10^{-9}y^3 \tag{7}$$

Therefore, the global Z-coordinate is given by;

$$Z=h_{GPS} \pm error \tag{8}$$

In global correction model (Z) for Ellipsoid finding can be given as according to above calculations where error in equation-8 equal (6.426 m); The results of local and global corrections have been found using polynomial equations in order to correct the data.

1- The results in Figures-3and5 represent, 1st,2nd and 3rd orders methods respectively for local correction models (Z_1,Z_2,Z_3) , figure-6 represent global correction model (Z), elevation points measured DGPS receiver (h_{DGPS}) and elevation points measured GPS navigation receiver (h_{GPS}) of Baghdad University Compass .

2- Figures-7and10 illustrate, respectively, residual between global correction model (Z), local correction models (Z_1,Z_2,Z_3) and DGPS ,GPS heights data of Baghdad University Compass .
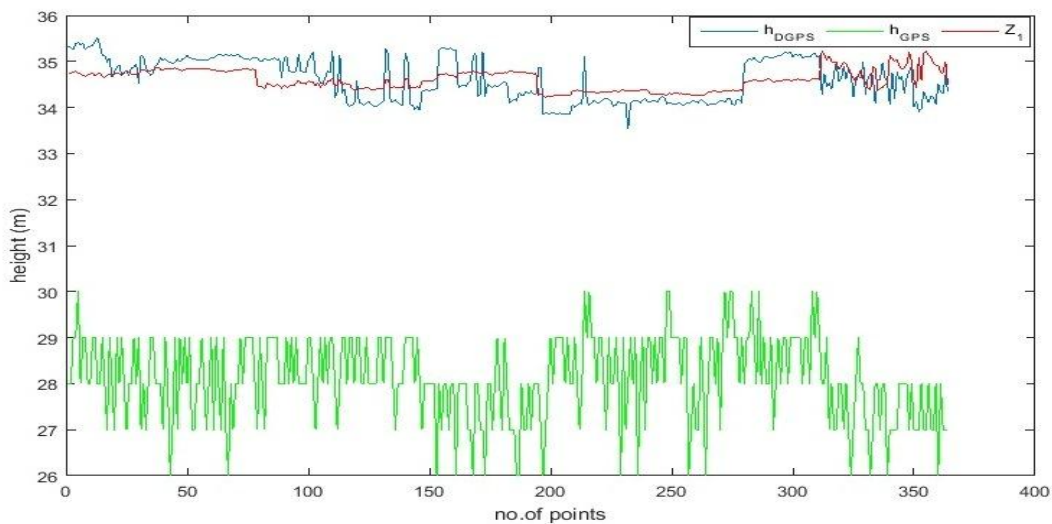

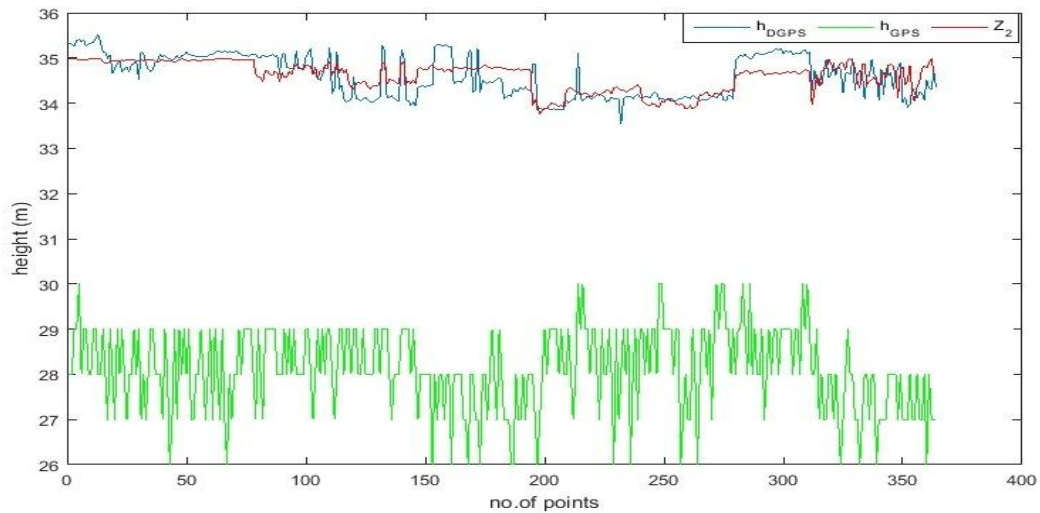**Figure 3**- Comparison among DGPS, GPS and correction model heights data using 1st order

Figure 4- Comparison among DGPS, GPS and local correction model heights data using 2nd order
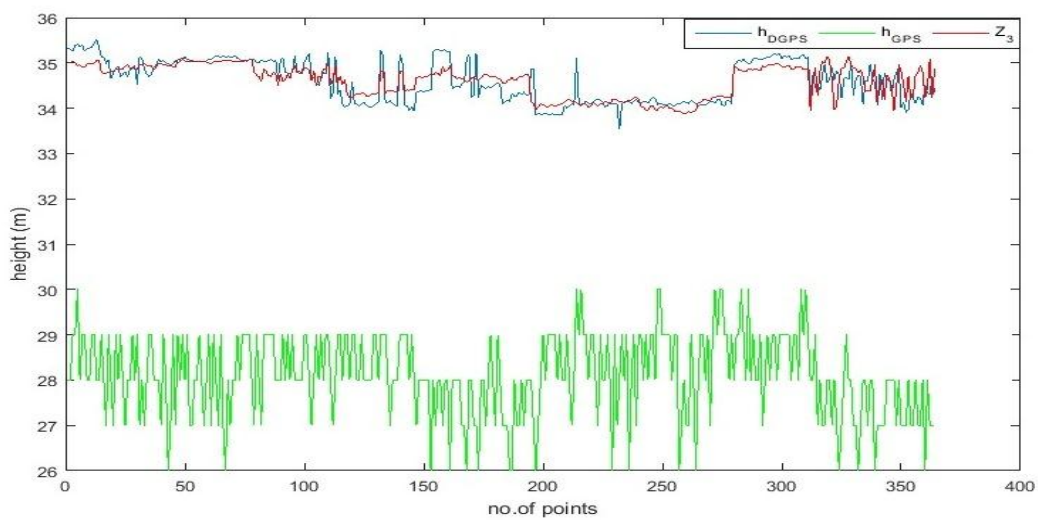

Figure 5- Comparison among DGPS, GPS and local correction model heights data using 3rd order
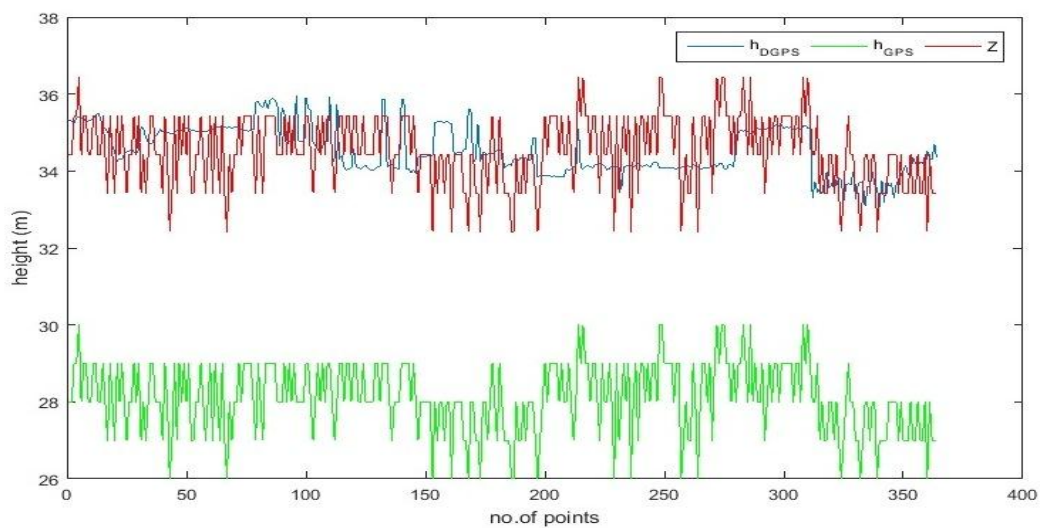

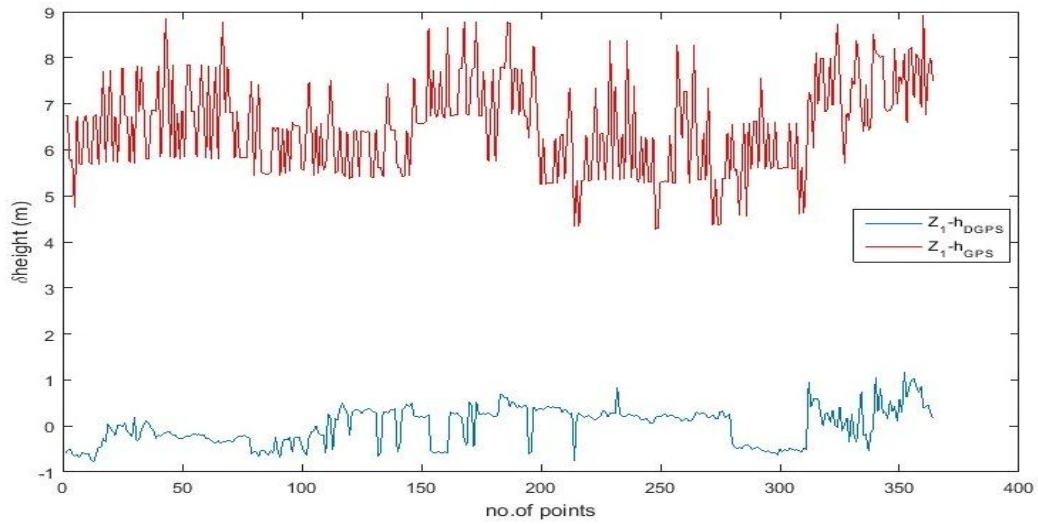**Figure 6**- Comparison among DGPS, GPS and global correction model heights data

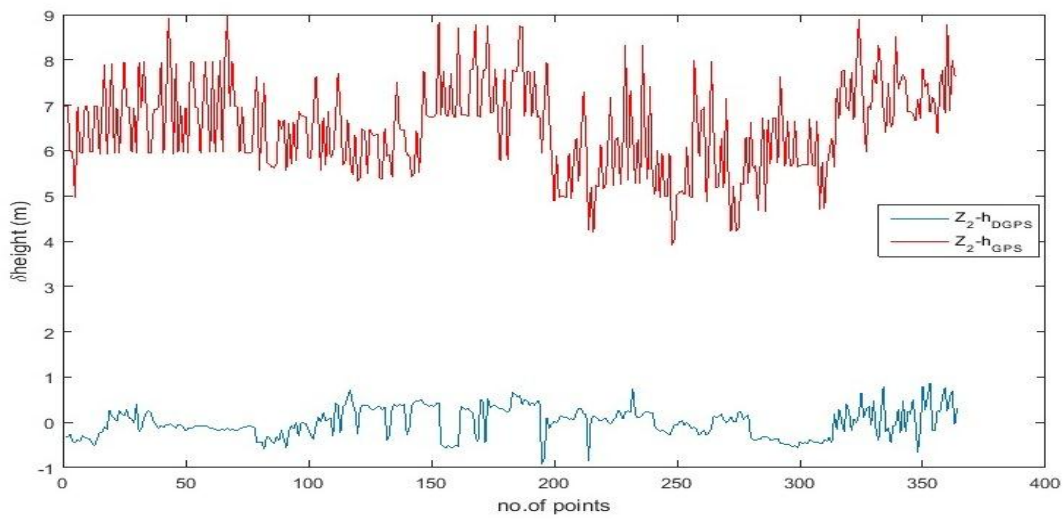**Figure 7**- Residual between local correction model and DGPS, GPS heights data using 1st order

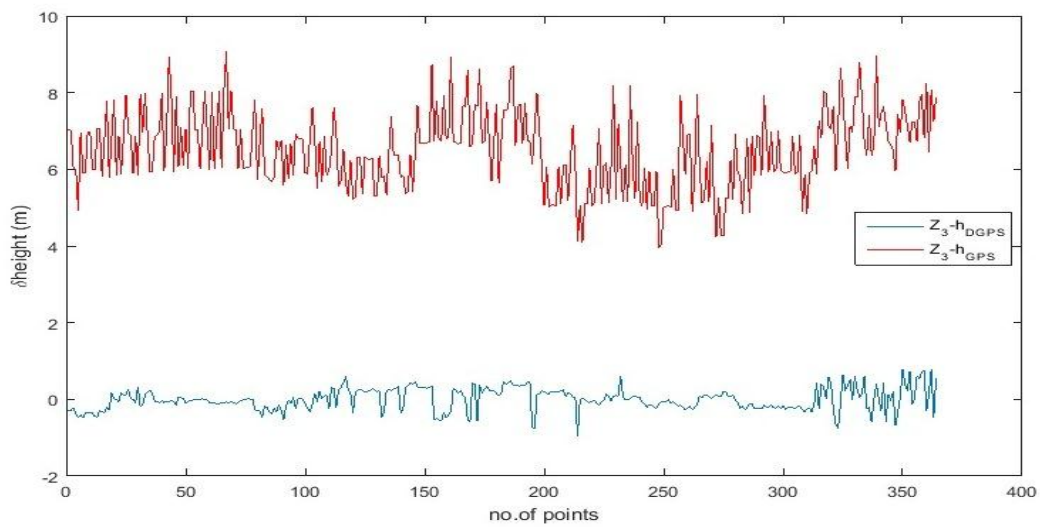**Figure 8**- Residual between local correction model and DGPS ,GPS heights data using 2nd order

Figure 9- Residual between local correction model and DGPS, GPS heights data using 3rd order
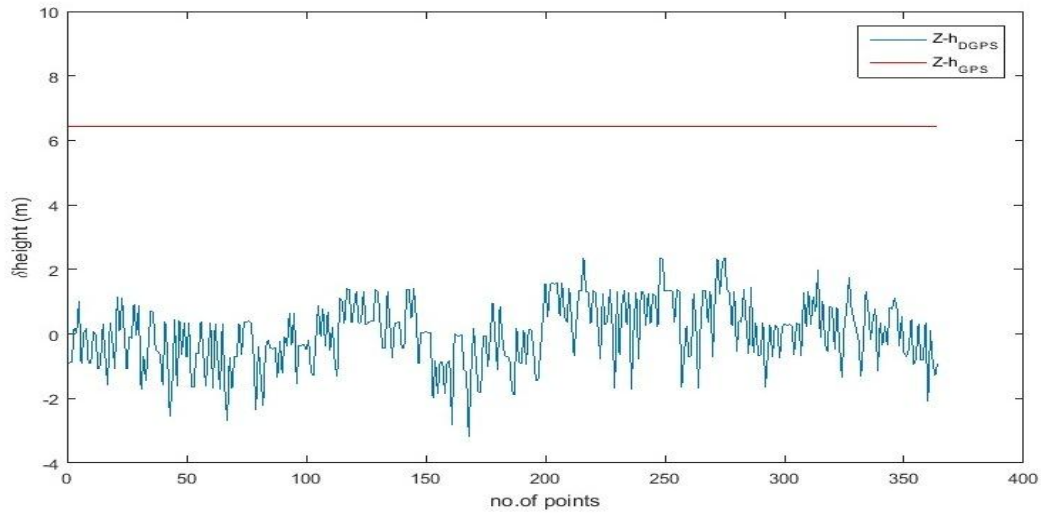
Figure 10- Residual between general correction model and DGPS, GPS heights data

Accuracy Assessment

To evaluate the accuracy of the utilized polynomial methods, the comparison between three polynomial methods with the recorded DGPS values to deviation of each, Table-2 and Figure-11 represents the statistics of the height residuals between h_{DGPS} and correction models(local and global).

Table 2- Statistics of the residuals between h_{DGPS} and correction methods (local and global) (in m)

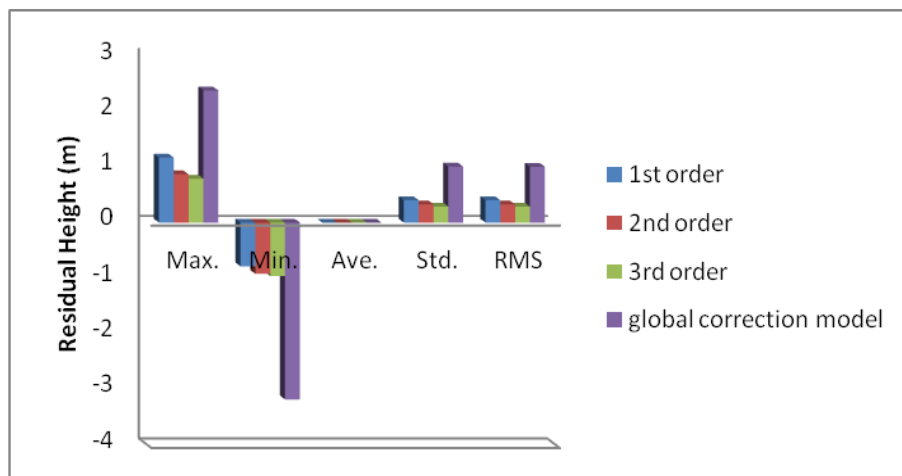| Statistics	Local correction models			Global correction model
	1st order	2nd order	3rd order	
Maximum	1.1675	0.8666	0.7898	2.375
Minimum	-0.7839	-0.9218	-0.9589	-3.178
Mean	-2.4×10^{-15}	-2.13×10^{-15}	2.24×10^{-13}	-3.57×10^{-5}
Standard deviation	0.4028	0.3267	0.2885	1.0052
Root mean Square	0.4022	0.3256	0.2881	1.0038

Figure11- Residual between local/global correction model and DGPS heights data

Conclusions

This study introduced a developed model to count the noticeable differences in height accuracy for two different receivers. The purpose of the study was to reduce the errors of low cost receivers by

introducing mathematical and statistical model. The local Z-coordinate correction models gave us best results using higher order for the regions of the area study. The results showed that 3rd order mode was better than the 1st and 2nd order models. The observed root mean Square (0.2881) for the 3rd order was less than that of the 1st and 2nd orders (0.4022 & 0.3256). The results obtained in this work can be used to correct the data of GPS navigation receiver for limited size areas which are almost flat or semi-level; this means it can be used in a wide area of Iraq country.

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