ERROR PATTERN RECOGNITION OF STATIC GPS OBSERVATION WITH CHANGE OF PDOP, BASELINE AND OBSERVATION DURATION.

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Abstract: One of the problems that is faced by a surveyor who is not well acquainted with GPS measuring is to determine the sufficient observation duration for particular baseline under certain PDOP value in order to achieve the required precision. The objective of this research project is to determine the variation of accuracy in static GPS measurements with above variables so as to ensure desired accuracy.

Baselines between lengths of 1 Km to 18 Km were used and their most probable values have been taken by making the observation duration beyond the limit specified under best PDOP values. Standards deviation of different baseline lengths observed for different time durations and under different PDOP values were obtained by compared with their corresponding most probable values. Then the obtained standards deviations were plotted against the time duration for various ranges of PDOP values. These graphs allow to determine achievable accuracy under given values of above variables.

1 INTRODUCTION

The concept of Global Positioning Systems (GPS) was conceived by the Department of Defence (DOD), USA, towards the end of seventies, for use of their military activities. But, in the early nineties, GPS technology deviated from its original intention to support day to day activities of civilians. From there on it has been intensively practiced in all spatial information related streams such as Land Surveying, Navigation, GIS etc. around the world. Currently there are 32 satellites in the GPS satellite constellation and this was given the name NAVSTAR system

Although the capability of this technology is well ahead of the other conventional surveying techniques, there are some constrains which prevent surveyors from using this technology. One of the problems that faced by most surveyors who are not well acquainted with GPS instrument handling is to determine the length of time to operate an instrument at a particular station in order to get the required accuracy. The accuracy of static GPS observations, according to Seeber (2003, p. 300) mainly depends on two factors, namely; The accuracy of pseudorange measurement and the geometric configuration of the satellites used

The errors in pseudorange measurements are mostly eliminating through the DGPS (differential GPS) observation method and are out of the interest of this article. The main focus of this is geometric configuration of the satellites. According to Misra & Enge (2004 p. 182) measurement from maximum number of satellites (i.e. 4 to 8 satellites) does not grantee the maximum accuracy. It is basically the geometric configuration of satellites that determine the accuracy of GPS positioning. The satellite geometry is denoted by DOP (Dilution of Precision). There are several kinds of DOP can be found in GPS literature. However, in the case slant range measurement most relevant is Positional DOP (PDOP).

When considering the PDOP and the required positional accuracy it is depending on the baseline length and observation period. However, there is no proper means to determine the exact period of time for a given ***Baseline*** and ***PDOP (Satellite Geometry)*** value to achieve required precision. Lack of this knowledge result in unnecessary observation times, which is a waste of money. On the other hand, surveyors with some experience with GPS, use their knowledge to determine the optimal period of observation for a particular baseline. However, this would be a most difficult part for a new comer to this technology and would create a doubt in his mind.

2 OBJECTIVE

The objective of the paper is to identifying the behaviour of errors in static GPS observation with the change of PDOP, baseline length and duration of observation so as to make easier to achieve the required accuracy of a certain baseline under given conditions by a surveyor

3 THEORETICAL FRAMEWORK

There are several GPS observation methods existing to ascertain a position. They can be broadly categorized as ***Static*** and ***Kinematics*** GPS. In Static observation, as the name implies, both receivers remain stationary, whereas in Kinematics observation one receiver moves during the time of observation.

Receiver position (*Latitude, Longitude and Ellipsoidal Height)* can be obtained by logging into three or more satellites, as the satellites in NAVESTAR system moves in their predetermined path at known speeds. This is called Point Positioning.

The range (between satellite and GPS receiver) measurement techniques in GPS can be categorized into two types, namely, *Pseudo Ranging* and *Carrier Phase*. In Pseudo Ranging observable is the time difference between transmission and receiving while Carrier Phase observable is the phase difference between the original wave and received wave. Equation 1.1.1 and 1.1.2 (Leick, 2003) is showing the range determine by these techniques.

Determined the range by Pseudo ranging

$$P_k^P(t_k) \equiv (t_k - t^P)c = \rho_k^P(t^P) - cdt_k + cdt^P + I_{k,1,P}^P(t_k) + T_k^P(t_k) + \delta_{k,1,P}^P + \varepsilon_{1,P} \quad \ldots\ldots (1.1.1)$$

Where; $P_k^P(t_k)$ *-Pseudo range,* t_k *-Receiver clock reading,* t^P *-Satellite clock reading,* c *-Velocity of light,* $\rho_k^P(\hat{t}^P)$ *-Geometric distance between satellite & receiver,* cdt_k *-Receiver clock offset,* cdt^P *,-Satellite clock offset,* $I_{K,1,P}^P$ *-Ionospheric P(Y) – code delay,* T_k^P *-Tropospheric delay,* $\delta_{k,1,P}^P$ *-Hardware delay & Multipath effect,* $\varepsilon_{1,P}$ *-Pseudorange measurement delay*

Determined the range by Carrier Phase

$$\varphi_k^P(t_k) = \frac{f_1}{c}\rho_k^P(\hat{t}^P) + N_k^P(1) - f_1 dt_k + f_1 dt^P + I_{k,1,\varphi}^P(t_k) + \frac{f_1}{c}T_k^P(t_k) + \delta_{k,1,\varphi}^P + \varepsilon_{1,\varphi} \quad \ldots\ldots (1.1.2)$$

Where, $N_k^P(1)$ *-Integer ambiguity,* $I_{k,1,\varphi}^P$ *-Ionospheric carrier phase advance,* $\delta_{k,1,\varphi}^P$ *- Hardware delay & Multipath effect,* $\varepsilon_{1,\varphi}$ *- Phase measurement noise*

Since the method in subject to errors (equation 1.1.1 and 1.1.2) these methods are not suitable for most land surveying practices. To overcome this problem, DGPS (Differential GPS) method was introduced, where two receivers along a baseline log to four or more satellites simultaneously. By doing so it can eliminate or minimize errors caused by cdt_k, cdt^P, $I_{K,1,P}^P$, T_k^P, $N_k^P(1)$, provided the two receivers are not too far apart. Hence, the both methods i.e. Static and Kinematics use DGPS in order to achieve sub centimetre positional accuracy

There is a relationship between *DOP* values and standard deviation of the receiver location (Leick, 2003). If we ignored other errors (as they are being eliminated by DGPS method) except receiver clock offset i.e. cdt_k in equation 1.1.1 then it can be written as;

$$P_k^P = \begin{bmatrix} \frac{x^P - x_k}{\rho_k^P} & \frac{y^P - y_k}{\rho_k^P} & \frac{z^P - z_k}{\rho_k^P} \end{bmatrix} \begin{bmatrix} dx_k \\ dx_y \\ dx_z \end{bmatrix} - cdt_k \quad \ldots\ldots (1.1.3)$$

$$\Rightarrow P_k^P = e_k^i \cdot dX_k - cdt_k \quad \ldots\ldots (1.1.4)$$

Hence, the design matrix A for all the observations from can be written as

$$A=\begin{bmatrix} e_k^1 & c \\ e_k^2 & c \\ e_k^3 & c \\ . & . \\ . & . \\ . & . \end{bmatrix} \quad (1.1.5)$$

$$Q_x=\left(A^T A\right)^{-1}=\begin{bmatrix} q_{xx} & q_{xy} & q_{xz} & q_{xt} \\ & q_{yy} & q_{yz} & q_{yt} \\ & & q_{zz} & q_{zt} \\ sym & & & q_{tt} \end{bmatrix} \quad (1.1.6)$$

Where, Q_x matrix is called the ***Variance Co-variance matrix.*** Hence the DOP expressions can be written as follows.

$$VDOP = \sqrt{q_{zz}}$$

$$HDOP=\sqrt{q_{xx}+q_{yy}}$$

$$PDOP=\sqrt{\left(q_{xx}+q_{yy}+q_{zz}\right)}$$

$$GDOP = \sqrt{\left(q_{xx}+q_{yy}+q_{zz}+q_{tt}c^2\right)}$$

Where; (x_k, y_k, z_k) *-Position of the receiver,* $\left(x^P, y^P, z^P\right)$ *-Position of the satellite,* $e_k^i dX_k$ *-Range calculated from the* i^{th} *satellite*

Where: **VDOP, HDOP, PDOP, GDOP**, refers to the **V**ertical, **H**orizontal, **P**osition, and **G**eometric **D**ilution **O**f **P**recision respectively.

4 THE METHODOLOGY

4.1 Project Area Selection

Balangoda division was initially selected for field observations. But, the hilly condition of the terrain was a problem. This was on account of the Long time it took to access the points. The other problem is signal disruption due to the high terrain. Hence, the region from Habarana to Kantale where the terrain is characterized by less undulation and less features, was selected for observations.

4.2 Error Minimizing

At the stage of selecting the instrument station locations, extreme care was taken to ensure that there were no obstructions above 15^o from horizon in order to eliminate signals reflect from surrounding surfaces (Multipath). However if such a obstruction was present, it was marked on the *Station Visibility Diagrams* so as to be able to obtain realistic PDOP values at the preprocessing stage.

Further, when those stations lie close to tarred road ways, care was taken to place the monument away from the road margins to minimize the error factor caused by the Multipath. Observation schedules were prepared prior to the day of observations. At this stage possibilities were sort to shift the period to nighttimes in order to minimize the ionospheric effect. Method adopted for data collection was DGPS. Two geodetic accuracy dual frequency Leica GPS receivers were used. Data were sampled for every 15 second and stored with date and point identification tag to ensure easy retrieval of same data set at the time of post processing.

4.3 Determination of Baseline Lengths and Observation Periods

It was originally our intention to determine base lines going up to about 50 km. But the basic concept of DGPS is to eliminate errors due to variation in the Ionosphere. Within process it is presumed that the signals received by the two GPS units travel through a section of the Ionosphere where any variations will simultaneously afford both signals. This condition is satisfied for base lines up to about 20 km (Leick, 2003). For Longer Baselines, Ionosphere effects have to be taken into account.

Hence, we had to restrict our range up to 20 km as we were not investigating the errors caused by the ionosphere and troposphere. These lines, initially, were selected as a Network of baselines to be adjusted by the least squares. But, this will add extra corrections to the final solution by distributing errors. Hence, independent baseline observations were considered as the most favourable method.

Accordingly, baselines are selected within the range of 1 km to 20 km. At this stage, there was a problem as we did not have sufficient GPS calibration baselines inside the selected range. Hence, we had to depend on the most probable value, obtained by long periods of observation under best PDOP, for the selected baseline lengths. The two GPS units used for this project were Leica 500 instruments. The software used for the computations is Leica-Ski-Pro processing software. This software was sufficient to determine the periods of best PDOP values for a given future date. Accordingly, it was decided to observe the 5.5 km, 14 km, and 18 km lines during the best PDOP periods and observe these lines for periods well in excess of the times specified by FIG (International Federation of Surveyors) in order to identified the maximum observation period for each selected baselines (see graph 1, 2 and 3).

The accurcy change of baseline length is only checked with the change of PDOP value as this value is the mostly relevant for surveying purposes. PDOP value is changed by excluding or including satellite signals from observed data by using Satellite Availability tool in the Ski Pro Software. Then calculate the baseline vector for each selected baseline lengths. In some cases, when excluding a particular satellite there was a significant increase in the positioning accuracy. Such satellites were excluded from calculation. Then the length of the selected baseline was calculate for time duration of 0 h 30 m, 1 h 00 m, 1 h 30 m, 2 h 00 m, 2 h 30 m and 3 h 00 m for different range of PDOP values . PDOP values were selected with in the range of 0.0 – 1.5, 1.6 – 2.5, 2.6 – 3.5, 3.6 – 4.0, above 4.0. The results of Length of the Slope Distance and Standard Deviation for the each periods of observation were stored in a *Microsoft Excel* file. Other baseline vectors were processed in a same manner and stored in the *Microsoft Excel* file.

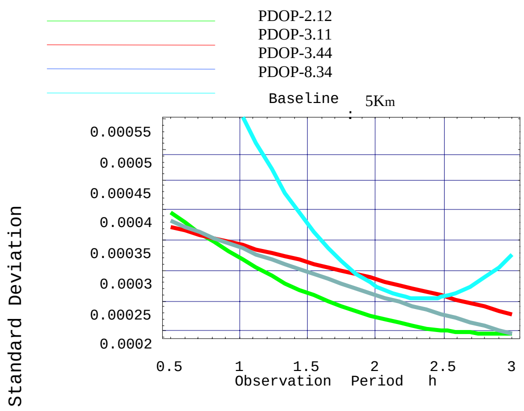
The most probable values of the selected baseline lengths have been obtained by making the observation period beyond the limit acquired from initial study (see grah 1-3) and under the best possible PDOP values. These values were then used to calculate standards deviations of different baseline lengths, observed at different time durations and under different PDOP values. The obtained standards deviations were then plotted against the PDOP values at different time durations for all baselines (figure 1).

5 RESULT ANALYSIS

5.1 Determination of Maximum Duration of Observation for Various Baseline Lengths

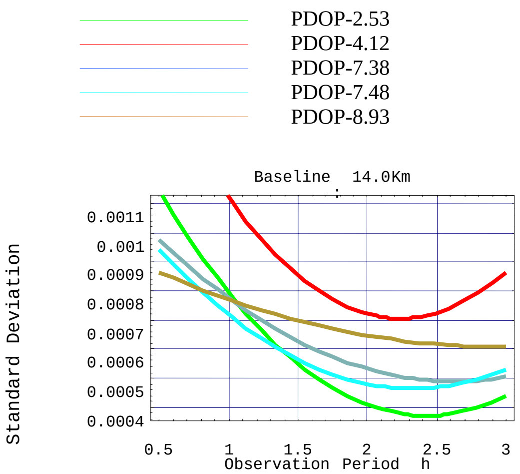
The observations for 5.5Km, 14Km and 18Km were plotted using Mathematica V 4.2 software to determine behaviour of the standard deviation with observation period. The results are showing in below.

According to the graphs standard deviation of the observations become almost stable as the observation period increasing although there are a few out lies for higher PDOP values. By studying the Graph 1, it is obvious that observations beyond 02 hours will not considerably affect the accuracy of the baseline. Hence, for baselines below 5.5 km, it is sufficient to observe for 02 hours to get precise observation for a PDOP range up to 8. Similar conclusions can be arrived for baselines below 14 km and 18 km by studying the Graphs 2 and 3 respectively. Accordingly 02 hours and 30 minutes of observations are sufficient for baselines between 5.5 km to 18.0 km.



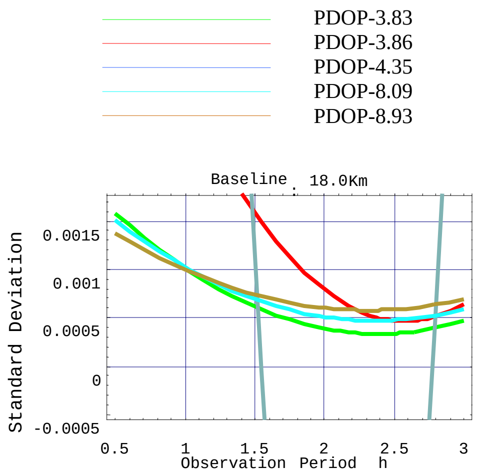
Graph 1

Standard Deviation against Observation Period – For 5.5 km Baselines



Graph 2

Standard Deviation against Observation Period – For 14.0 km Baselines



Graph 2

Standard Deviation against Observation Period – For 18.0 km Baselines

5.2 Empirical results analysis

Standard deviation obtained against the relevant most probable values for different PDOP values were plotted against time duration for each selected baselines. The figure 1 below shows the pattern of the variation of the Errors with increase of the PDOP vales for each observation period.

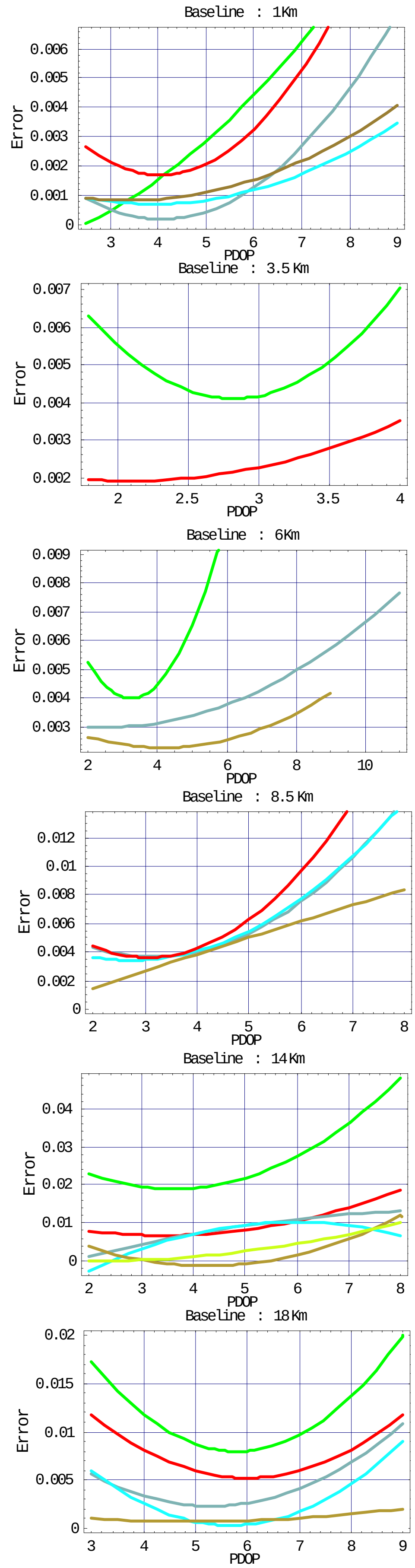


Figure 01
Standard Deviation against PDOP for different time ranges for all selected baselines.

6 CONCLUSION AND RECOMMENDATION

There is a significant change in accuracy with the increase of observation period to a certain limit, under selected PDOP values. This change is conspicuous as the baseline length increases. From the observed data, for baselines up to 8 km, 1 hour observation period under 4 PDOP value would enough to get maximum accuracy. For baselines beyond 8 km it secured to have 2 hour and 30 min observation under maximum of 5 PDOP. In general, when PDOP is within the range of 1-4 it will not affect significantly to the accuracy of measurement. However, beyond the values 4 PDOP, as the PDOP increases the positional accuracy is decreases for baselines within 1 km to 14 km. For 16 km and 18 km baselines this limit is 5.

The reason for the closeness of the error pattern when observation period increasing is due to the reduction of the sporadic effects such as signal diffraction, satellite geometry etc from the result. This further confirms the observations made by Hartinger and Brunner, 1998.

It is also important to highlight that all of above conclusions are made for PDOPs between 1 and 8, as they are the most likely values that can occur. To have a more realistic result for a baseline, it is necessary make observations under number of real PDOP values that occur actually on the site rather than depending on the values taken by adding or removing satellites using computer software as it some times tend to give unrealistic results.

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