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A Study on Satellite Geometry Variation for Multi-GNSS from India

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Abstract: ***Satellite navigation (satnav) systems are now popular with different usable satnav systems. Accuracy of navigation solution depends on satellite geometry; an integrated mode of operation using more than one system is now possible that is supposed to provide better satellite geometry. This paper presents a study on obtainable satellite geometry involving GPS and GLONASS in stand-alone and mixed modes of operation based on collected data from different parts of India.***

Keywords:GNSS, GPS, GLONASS, DOP, PDOP

I. Introduction

Since early age of human civilisation, "navigation" is a basic need for survival and development. Satnav became a popular tool for modern society because of its manifold advantages, accuracy and cost effectiveness. In satnav, signals from 4 or more satellites are used simultaneously to solve for Position, velocity and Time (PVT) solutions. Along with fully operational US-operated Global Positioning System (GPS), the Russian counterpart GLObal NAvigation Satellite System (GLONASS) became fully operational since late 2011 [1] and many other systems like GALILEO, BEIDOU, QZSS and IRNSS are coming up fast. To recognize all these systems together, new terms like Global Navigation Satellite System (GNSS) or multi-GNSS have been coined. Currently, all the stakeholders are expecting to have options for using more than one systems in tandem with their full deployment for increased benefits.

In case of satnav, geometrical configuration, i.e., relative position of the used satellites in the sky plays a vital role in the accuracy of navigation solutions towards achieving high-quality results especially for point positioning and kinematic surveying [2]. A quantitative measure of the instantaneous satellite geometry is the dilution of precision (DOP) factor, more specifically the Geometrical Dilution of Precision (GDOP)– which quantitatively represents the overall satellite geometry. The effect of satellites geometry on various solution parameters are normally quantified by the terms PDOP, TDOP, HDOP and VDOP for 3-dimensional (3d) position, time, horizontal 2-dimensional (2d) position and vertical position errors respectively. In this paper, efforts have been concentrated with Position Dilution of Precision (PDOP) values only as it is concerned with 3d position solution accuracy. More scattered satellites in the sky presents a better satellite geometry resulting in lower PDOP (best possible value of PDOP is 1.0) than the cases where satellites used for navigation solution are concentrated over a part of the sky with PDOP> 1.0 More detailed discussions on satellite geometry and DOP values can be found in [3, 4, 5].

Geometric configuration of the used satellites is dependent on the location of the receiver w.r.t the used satellites and it changes with time due to the relative motion of the satellites and the receiver. It is well established that the amount of the ranging error combined with the geometry of the used satellites decides the magnitude of the user position error in GNSS fix. PDOP is related to position error as shown by Equation 1 [6].

$$\text{3d error in position } 1\sigma = (\text{PDOP}) \times \text{ user to satellite range error } 1\,\sigma \qquad (1)$$

Equation (1) clearly indicates that a low value of PDOP results in lower error in 3d position solution. Therefore, favourable value of PDOP, in other words, selection of satellites with good geometry for navigation solution is an important issue in mission planning using GNSS and efforts can be seen for calculation of PDOP values using different algorithms [7, 8]. Before the operational of multi-GNSS, navigation solution was performed on the basis of standalone GPS system. Currently, in a changed scenario of multi-GNSS, instead of using a stand-alone single system, users are keen to use all the existing satellite systems together. Another important aspect of multi-GNSS is the availability of more number of satellite signals for use from different directions of the sky in comparison to a single constellation operation. As an example, in GPS only operation from India, an user on the average can have around 8-9 usable satellites at a time while for GPS+GLONASS mode of operation, the number goes up to 13-14 enhancing the probability of better satellite geometry providing a lower PDOP value.

GPS and GLONASS is now fully operational. Therefore, it would be interesting to study GLONASS signals from India as an active alternative to GPS or as a supplementary system. Such a study was taken up during 2012 – 13 wherein availability, reliability and significance of the multi-GNSS environment from INDIA using GPS and GLONASS has been studied [9]. Observations related to satellite geometries based on a detailed analysis of the data is being presented in this paper. Obtained PDOP values for individual (GPS or GLONASS) and GPS+GLONASS (MIXED) modes of operation are discussed to study the satellite geometry in each case.

II. Experimental Set-up and Data

For the study, data recording and analysis for GPS and GLONASS constellation was done over a long period of time during 2012 - 2013 from different parts of India as shown and described in Figure 1 and Table 1. Data monitoring locations were chosen in such a way so that they are widely scattered over India to have general results for the whole region.

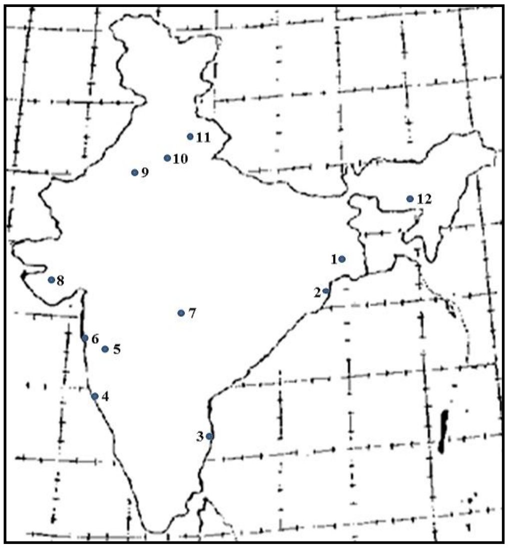

Fig 1: GNSS data monitoring locations in India

GNSS Data was recorded using a fixed single frequency GoeS-1M OEM receiver (Rx #1) from Burdwan University, India (Location #1), the permanent data monitoring station and using a similar model from all other locations of India. Data for Burdwan was also validated using a dual frequency Javad DELTA G3T GNSS receiver (Rx #2). The general hardware experimental set-up for Rx #1 is shown in Figure 2; software for receiver control and data recording through a PC as per experimental need was developed in-house that was capable of selection of mode of operation (GPS/ GLONASS/ GPS+GLONASS), time of data recording (start and stop) for automatic recording [10, 11] . Set-up for Rx #2 is similar to that shown in Figure 2 but in this case vendor supplied software is used for data recording. For both the cases, incoming data raw data at a rate of 1 Hz is recorded to a PC in National Marine Electronics Association (NMEA) 0183 format [12] as shown in Table 2. Useful data for each observation was extracted from the recorded raw data using in-house developed software that includes date, time of observation, navigation solution, DOP values (including PDOP) for each observation and information of all satellites used for the particular observation. Results discussed in the following sections are based on these recorded and subsequently post processed GNSS data.

Table 1: GNSS Data monitoring plan

Location #	Location	Comment
1	Burdwan	Permanent station Using Rx #1 and Rx #2
2	Balasore	Data recorded for 2-4 days at each data monitoring location using Rx #1 during August, 2012 – November, 2012.
3	Chennai	
4	Goa	
5	Pune	
6	Panvel	
7	Nagpur	
8	Rajkot	
9	Pilani	
10	Noida	
11	Dehradun	
12	Shillong	

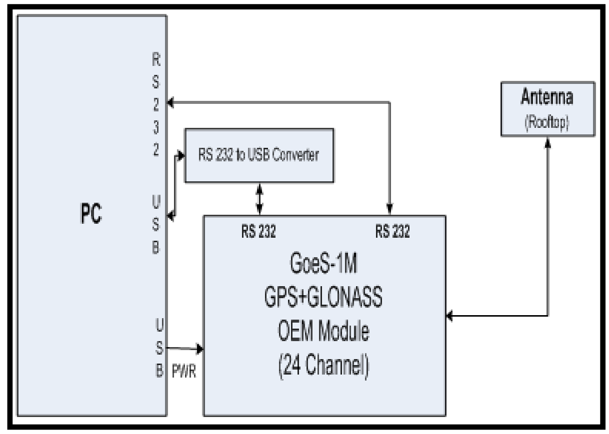

Fig 2: Experimental set-up for GNSS data monitoring (Rx #1)

Table 2: Recorded NMEA raw output data sample

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$GPGGA,074001.00,2315.2731,N,08750.8080,E,1,09,1.2,00042.9,M,-056.9,M,,*74
$GPGSA,A,3,28,10,04,12,06,17,02,20,24,,,,1.9,1.2,1.5*37
$GPGSV,3,1,10,02,55,254,44,04,13,042,37,05,12,190,28,06,70,347,40*7E
$GPGSV,3,2,10,10,43,146,40,12,15,322,38,17,37,047,44,20,06,042,32*75
$GPGSV,3,3,10,24,25,286,40,28,35,129,38*7C
$GLGSV,3,1,09,65,20,149,38,71,10,042,39,72,30,091,44,76,25,184,36*63
$GLGSV,3,2,09,77,56,252,40,78,27,319,29,86,06,056,33,87,35,009,40*6A
$GLGSV,3,3,09,88,30,307,42*5D
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$GPVTG,353.7,T,,,0000.0,N,0000.0,K,A*42
$GPZDA,074001.00,26,08,2014,+03,00*47
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III. Results

A. PDOP in different modes of operation from Burdwan

For the study, GNSS data is recorded at Burdwan University [Location #1] to a PC for most of the working days in GPS-only, GLONASS-only and MIXED modes of operation using the described set up and also at the other locations [Locations #2 to #12] for 2-4 days each. Data recording schedules for a particular day were selected in such a way that any individual mode of operation is scattered over all parts of the day. It was necessary for obtaining the data for any particular mode of operation for any hour of a day within a couple of days' data-set for the sake of generalness of the results.

To study the PDOP values and their variations in each mode of GNSS operation, PDOP values for a complete month's observations were collected together from each days' data set for the concerned month and was analysed. Maximum, minimum and average values of PDOP for several month's data thus obtained using Rx #1 during late 2011 to late 2012 were found out and is shown in Table 3. The average values of PDOP for each month of observation is shown graphically in Figure 3. Similarly, average PDOP values for different months of 2013 using Rx #2 is shown in Figure 4.

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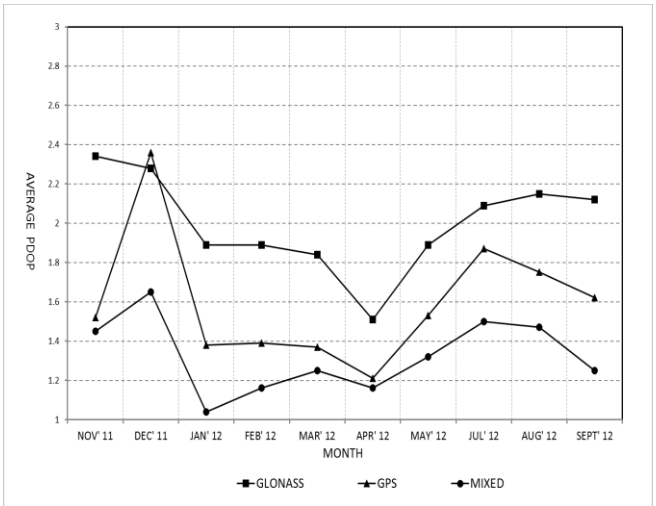

Fig 3:Average PDOP variation for different GNSS modes (Rx #1)

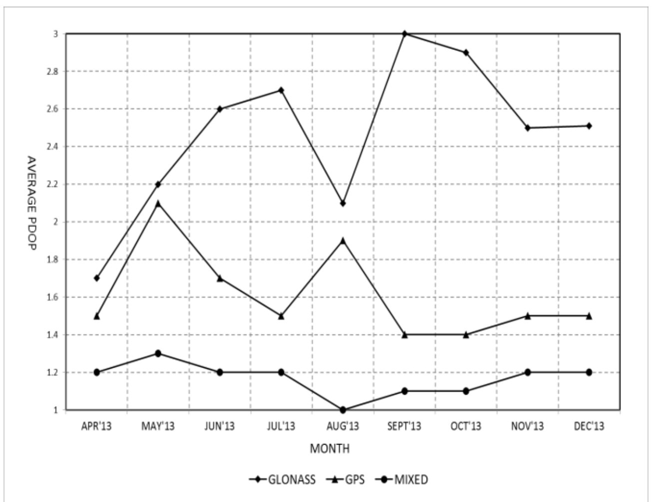

Fig 4:Average PDOP variation for different GNSS modes (Rx #2)

Table 3: PDOP variation observed from Burdwan using Rx #1

Month	Max PDOP			Min PDOP			Mean PDOP		
	GLO	GPS	MIX	GLO	GPS	MIX	GLO	GPS	MIX
Nov '11	2.8	1.6	1.6	1.5	1.1	1.2	2.34	1.52	1.45
Dec '11	2.3	2.4	2.3	2.2	1.1	1.1	2.28	2.36	1.65
Jan '12	2.0	1.4	1.2	1.6	1.0	1.0	1.89	1.38	1.04
Feb '12	2.4	1.4	1.4	1.6	1.1	1.0	1.89	1.37	1.25
Mar '12	3.0	1.5	3.2	1.5	1.7	1.0	1.84	1.37	1.25
Apr '12	1.4	1.3	1.3	1.0	1.0	1.0	1.51	1.21	1.16
May '12	1.8	1.3	1.3	1.6	1.0	1.0	1.89	1.53	1.32
July '12	3.0	1.3	1.3	1.6	1.0	1.0	2.09	1.87	1.50
Aug '12	3.5	1.3	1.3	1.6	1.0	1.0	2.15	1.75	1.47
Sep '12	2.4	1.7	1.6	1.6	1.3	1.0	2.12	1.62	1.25

It may be clearly observed from the table and graphs that, MIXED, i.e., multi-GNSS mode using GPS and GLONASS together provides best PDOP values out of the three modes of operations. GLONASS mode provides worse PDOP values than GPS mode of operation. A closer look reveals that (i) although providing worse satellite geometry, PDOP values using GLONASS mostly remains within the desired value of 3.0. Few higher values are obtained only for brief periods of time as evident from the corresponding average values those remains well within a maximum value of 3.0 or lower. Maximum values for GPS and MIXED mode of operation are occurring below 2.0 in most of the cases, (ii) Desired minimum possible PDOP value of 1.0 is obtained more frequently in case of MIXED operation than GPS only operation (iii) Average PDOP values in case of MIXED operation is always remaining near 1.5 and that for GPS-only operation remains mostly within 2.0 and (iv) Average PDOP value for MIXED mode is always lower than that for GPS only operations. The result agrees well for both types of receivers operating over different time periods of observation.

The study results shows the importance and advantages of use of more than one available constellations together for navigation for stand-alone solutions. It may be inferred w.r.t Equation 1 that, a MIXED GNSS mode operation is favourable as it is expected to introduce less error in solution from the satellite geometry point of view. But for integration of more than one system, the important issue of efficient coordinate transformation relevant to the region of operation must be addressed properly for obtaining the best accuracy levels.

B. PDOP values and variation as observed from different locations of India

Similar study was made to observe the values and variation of PDOP from other data recording places [Location # 2 to #12 shown in Figure 1 except for Pune and Goa] during August to November, 2012 using Rx #1 for 2-4 days observation at each location. PDOP values obtained from each location for a particular mode of operation was collected together to form a group and was analysed.

The results for minimum, maximum and average values of PDOP values obtained is shown in Table 3 while Figure 5 pictorially shows the average PDOP variation for different places of observations.

Table 4: PDOP variation observed other locations using Rx #1

Place	Max PDOP			Min PDOP			Mean PDOP		
	GLO	GPS	MIX	GLO	GPS	MIX	GLO	GPS	MIX
Balasore	3.6	2.4	1.3	1.6	1.6	1.1	2.52	1.62	1.21
Chennai	2.6	1.5	1.2	1.6	1.4	1.2	2.29	1.45	1.20
Panvel	3.5	3.2	2.2	1.8	1.6	1.2	2.61	1.82	1.32
Nagpur	3.2	2.4	1.6	1.6	1.2	1.0	2.16	1.61	1.16
Rajkot	3.2	2.7	1.5	1.4	1.2	1.0	2.20	1.69	1.18
Pilani	9.9	2.2	1.9	1.5	1.2	1.1	2.12	1.60	1.23
Noida	3.6	2.2	1.6	1.6	1.2	1.0	2.09	1.61	1.14
Dehradun	3.8	2.4	1.5	1.5	1.4	1.0	2.15	1.42	1.21
Shillong	9.9	2.4	3.0	1.5	1.2	1.0	2.34	1.66	1.31

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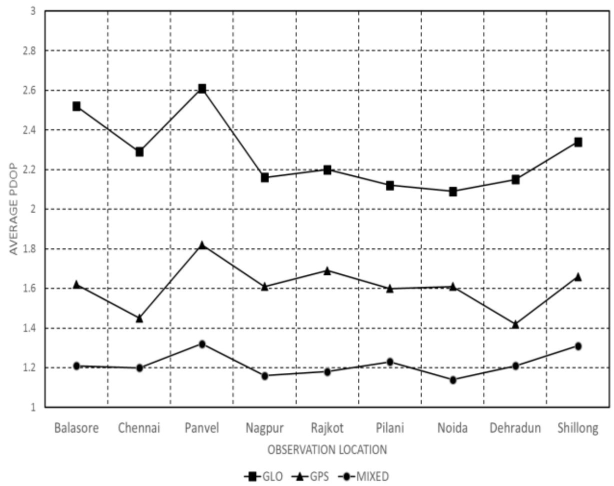

Fig 5: PDOP variation observed from other locations of India during August 2012 – September, 2012

It may be observed from the Table and the graph that, the PDOP values improve in order of GLONASS, GPS and MIXED modes of operation as have been observed earlier for Location #1. For GLONASS mode of operation, for small instances of time high values of PDOP was observed but considering the average values for the data set the cases may be attributed to hardware limitations rather than to the problems of the satellite system. Obtained average PDOP values are below 3.0, 2.0 and 1.5 respectively for GLONASS, GPS and MIXED modes of operations. The result may be considered to be valid for the whole of the India and the adjacent regions due to the varying temporal and spatial conditions.

C. Study on PDOP value distribution

Another study using the same data set has been made to observe the distribution pattern of PDOP values in different modes of GNSS operation. For the requirements of the study, data in each operational GNSS mode (GPS, GLONASS, MIXED) for each month of observation using Rx #1 operating from Burdwan University is collected together as described earlier. Then they are grouped in small sets based on PDOP range bins. Class width of 0.2 are taken for low PDOP values up to 3.0 while above that, class widths are taken to be 1.0 up to 10.0. As an example, observations for GPS only modes for March 2012 are collected together and then the data are subdivided into classes of PDOP values with 1.0, above 1.0 to 1.2, above 1.2 to 1.4 etc. Similar classes for GLONASS and MIXED operation for the same month of March 2012 are created. Then the analysis has been done in two ways:

(i) Firstly, for any GNSS operation mode, the percentage of occurrence of PDOP values falling within a particular range bin has been calculated. To do so, the number of occurrence of PDOP value lying within a particular range bin has been counted against the total number of samples for the month. The process is repeated for other two GNSS modes of operation too. Result thus obtained for the month of September, 2012 has been shown pictorially as an example in Figure 6 where the values of percentage of occurrence has been plotted against the higher boundary of the PDOP range bin, i.e., values between 1.2 and 1.4 has been plotted against PDOP value of 1.4.

Here it may be seen that in MIXED operation mode, about 68% of PDOP values lies between 1.0 and 1.2, while in GPS mode about 58% of PDOP values lie between 1.4 and 1.6; in GLONASS only mode, providing worst PDOP values out of the three, about 20% PDOP values lie in between 1.6 to 1.8 while nearly 28% values lie between 2.4 and 2.6. Therefore, occurrence of lower PDOP values with much higher probability is observed for MIXED mode as compared to other two standalone GNSS modes. Similar results has been found for other months also.

(ii) Next, the cumulative probability of occurrence of PDOP values in different GNSS modes of operation is also calculated that presents a different view point about the PDOP distribution patterns. In this case, for a particular month of observation in a particular mode of operation, all PDOP values lying above the higher boundary of a particular range bin are collected together and the percentage of occurrence above the higher value of the range bin is calculated. As an example, all PDOP values higher than 1.0, 1.2, 1.4, 1.6 etc. in GPS-mode operation for February 2012 are collected and counted against total GPS observations for the month; similar calculations are done for GLONASS and MIXED operations. A sample result for the month of February 2012 using Rx #1 from Burdwan is shown in Figure 7 where the percentage values are plotted against the higher boundary of the range bin. It may be observed that, for that month for nearly 100% of cases, PDOP values in MIXED mode of operation lie below 1.6, for GPS and GLONASS similar values are 2.4 and 3.4 respectively. The Figure, and similar results for other months, once again points towards the possibility of obtaining lower PDOP values in case of MIXED mode of operation in comparison to other two stand-alone modes. It also shows that, GPS as a standalone solution provides better satellite geometry than GLONASS for the Indian region.

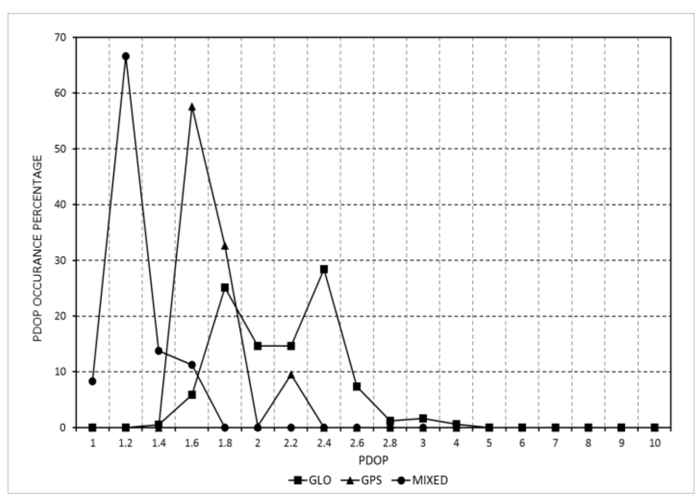

Fig 6: PDOP value distribution pattern
(March, 2012, Rx #1, Burdwan Univesity)

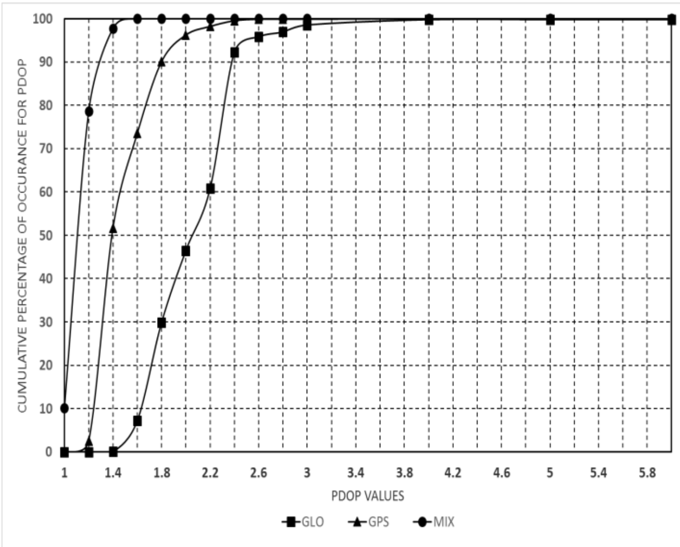

Fig 7: Cumulative probability of PDOP occurrence
(February 2012, Rx #1, Burdwan University)

IV. CONCLUSION

This paper discusses about satellite geometry in terms of PDOP values for different GNSS modes over India. It is observed that, for collected long-term data obtained from different parts of India, GPS+GLONASS combined mode of operation provides the best possible satellite geometry than GPS only operation. GLONASS only operation presents lowest favourable satellite geometry conditions out of the three cases – though even in this case mostly PDOP values remain within the desired value of 3.0. The findings here points towards the importance of use of multi-GNSS for stand-alone, low cost navigation applications. But in this context, efficient coordinate transformation and other issues impairing interoperability of the systems needs to be addressed properly for the best achievable solution accuracy. In future, with fully operational GALILEO, BEIDOU and/ or QZSS similar studies may be made from India to explore the improvement of satellite geometry towards an accurate and seamless navigation environment for the benefit of all users.

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