CHAPTER 6

SATELLITE-RECEIVER GEOMETRY CONFIGURATION ANALYSIS OVER THE INDIAN SUBCONTINENT

6.1 INTRODUCTION

GPS system performance is judged by the users in terms of accuracy. The accuracy is the degree of conformance between measured and true positioning and timing information. This accuracy depends on several factors which are interdependent. The key important factors are Quality of the pseudorange measurements, satellite ephemeris data, accuracy of satellite clock offset relative to GPS time and satellite downlink propagation error estimation. The predominant error sources are in the space, control and user segment of system. For a given satellite, the user equivalent range error is computed as the statistical sum of the contributions from each error sources associated with the satellite. The error in the GPS navigation solution can be estimated using the satellite-receiver geometry factor and the pseudorange error factor under proper assumption. The satellite-receiver geometry factor is a measure of the spread of the satellite transmitters in the space with reference to the receiver/user location and is called Dilution of Precision (DOP). The DOP is a measure that can be calculated to determine how uncertain the navigation solution will be. Usually, the smaller the DOP number, the smaller is the uncertainty area, hence, a more accurate location. Since the visibility of GPS satellites is a function of geographic
location, the DOP values obtained in the mid latitude regions like USA, Europe etc. are different from the low latitude regions (where Indian subcontinent is located).

Therefore, for making use of GPS in India, particularly in the critical application area such as en-route and Precision Approach (PA) aircraft landings, the aspect of best Geometrical Dilution of Precision (GDOP) value to be used in the user position computation is investigated due to All-in-view satellite-receiver configuration and Best-4 satellite-receiver configuration. A new algorithm is proposed in this chapter to compute various DOPs and to carry out the analysis for different satellite-receiver configurations to obtain the best GDOP. Various DOPs are computed using 3 navigation solutions i.e., iterative Recursive Least Squares (RLS) and non iterative Jacobian determinant based multipolynomial resultant technique (JMR) and the Minkowski function based absolute position (MAP) algorithms. Several days of dual frequency GPS receiver’s data collected from various Indian stations (Bangalore, Hyderabad and Visakhapatnam) are used in finding out the best GDOP configuration to be used over the Indian subcontinent.

6.2 SATELLITE-RECEIVER GEOMETRY EFFECT ON THE NAVIGATION SOLUTION

The accuracy of GPS receiver positioning depends on the following

i) The precision with which the distance to each GPS satellite is known

ii) Geometry of the satellites, i.e. how closely or far apart they are spaced across the sky.
The positioning error ($\sigma_p$) can be expressed as

$$\sigma_p = GDOP \times \sigma_R$$

where, $\sigma_R$ is user equivalent range error.

GDOP = $1/V$

where, $V=$ Volume of tetrahedron between satellite positions in the space and their vectors to the receiver.

The error in the distance measurement can be compensated by various techniques such as post processing, averaging, where as the satellite-receiver geometry is a fundamental limiting factor. Accuracy of the navigation solution is limited by satellite-receiver geometry (Langley 1999).

As an example, Fig. 6.1 illustrates the satellite-receiver geometry representation in which a user (receiver) measures the ranges to two satellites (transmitters). The two arcs are drawn from each GPS satellite considering the satellite as the center. The inner arc is drawn considering the true range/geometric range as the radius and the outer arc is drawn with pseudorange as the radius. The receiver lies at the intersection of the circular lines of position that are centered on the transmitters. Because of the uncertainty in the receiver measurements, the location of the range circles is not exact and results an error in the computed position of the receiver. This error depends on the geometry relating the receiver and transmitters in the space.

In Fig. 6.1a, the satellites are far apart, giving a relatively small area in which the receiver must lie with some degree of uncertainty. In Fig. 6.1b, the
satellites are closer together resulting in a considerably larger uncertainty region. In the similar way, with many satellites in view, good satellite-receiver geometry is formed when the satellites are spread wider in space. The GPS satellite-receiver geometry factor is represented by a numerical measure known as ‘Dilution of Precision’ or DOP (Chafee and Abel 1994). The higher the DOP number, the greater the possible error in the accuracy of receiver position.

![Diagram of satellite-receiver geometry](image)

**Fig. 6.1** Satellite-receiver geometry representations for two satellites

As GPS requires a minimum of four satellites for receiver position determination, illustration of the satellite-receiver geometry for four satellites is shown in Fig. 6.2. The satellites are spread apart in Fig. 6.2a representing the good satellite-receiver geometry. In Fig. 6.2b, satellites are closer together representing the poor satellite-receiver geometry. When more number of satellites are in view, Best-4 satellites are taken in the position fix computation in order to reduce the redundancy. With four satellites, best
geometry is obtained when one of the satellites is at the zenith (90° elevation angle) and remaining 3 forms an equilateral triangle and all the four together forms a tetrahedron structure. The larger the volume of the tetrahedron, the better is the value of Geometric Dilution of Precision (GDOP). Similarly, greater the number of satellites, better the GDOP value. Practically, GDOP number ranges from 2 to 6. As the satellite constellation geometry continuously vary over a period of 24 hours, the number and satellites position for the user at any point on the earth will seldom be ideal. Therefore, most of the times the maximum achievable precision will be diluted in practice (Zhu 1992).

![Satellite-receiver geometry representations for four satellites](image)

**Fig. 6.2** Satellite-receiver geometry representations for four satellites

### 6.2.1 Various forms of Dilution of Precision

The GPS receivers could track only some of the satellites in view and a subset of satellites (four satellites) are used for navigation solution even though more satellites are in view, which is called as optimum four GPS satellite positioning. In such a case, DOP computation is based on the optimum four satellites in view. Most of the present GPS receivers can track
all the satellites in view and the navigation solution is based on the signals from all satellites in view. In such case, DOP is computed using all satellites in view. In this chapter, GDOP is computed by selecting the ‘Best-4’ satellites in view as well as ‘All-in-view’ satellites configuration. Selection of ‘Best-4’ satellite configuration is based on the azimuth and elevation angles of the satellites. In real time applications, quality of the navigation solution can be determined by examining the DOP numbers. To examine the specific components such as three dimensional (3D) receiver position coordinates, horizontal coordinate, vertical coordinate or the clock offset, the GDOP is resolved into various forms as

i) Horizontal Dilution of Precision (HDOP)
ii) Vertical Dilution of Precision (VDOP)
iii) Position Dilution of Precision (PDOP)
iv) Time Dilution of Precision (TDOP)

**Horizontal Dilution of Precision (HDOP):** HDOP is a measure of how well the positions of the satellites, used to generate the latitude and longitude solutions, are arranged (Eq. (6.10)). HDOP number less than 4 gives the best accuracy, between 4 and 8 gives acceptable accuracy and greater than 8 gives unacceptable poor accuracy. Higher HDOP numbers can be caused if the satellites are at high elevations. For the vehicles moving in terrestrial environment, information of horizontal position accuracy is adequate. For estimating the horizontal position accuracy, HDOP is needed. Therefore, HDOP plays a vital role in position fixing and navigation for terrestrial and marine navigation applications.
Fig. 6.3a represents a satellite geometry using four satellites from the 4 compass quadrants which provides a good horizontal solution i.e. low HDOP. Similarly poor satellite geometry is represented in Fig. 6.3b, in which satellites from 1 or 2 quadrants provide a poor horizontal solution i.e high HDOP.

Vertical Dilution of Precision (VDOP): VDOP is a measure of how well the positions of the satellites, used to generate the vertical component of a solution, are arranged (Eq. (6.11)). Higher VDOP number means less certainty in the solution and can be caused if the satellites are at low elevations. VDOP is needed, when the user altitude or height is an important factor for vertical movements. Especially in civil aviation, the information of user height is most essential during takeoff and landing phases of the aircraft. Fig. 6.4 represents the satellite geometry for VDOP. If the satellites are at high elevation angles and are well spread out in the sky will provide a good vertical solution i.e. low VDOP numbers.

Fig. 6.4a represents the satellite geometry required for good vertical solution. The satellites located low on horizon i.e. low elevation angles, will
provide a poor vertical solution (High VDOP). Fig. 6.4b illustrates the satellite-receiver geometry that gives high VDOP.

![Satellite geometry for VDOP](image)

**Position Dilution of Precision (PDOP):** PDOP is a measure of overall uncertainty in GPS position solution with TDOP not included in the estimated uncertainty (Eq. (6.9)). PDOP is the combination of both the horizontal and vertical components of position error caused by satellite geometry. Fig. 6.5 represents the satellite geometry for VDOP. The best PDOP (lowest number) would occur with one satellite directly overhead and three others evenly spaced about the horizon. Fig. 6.5a represents satellite geometry for best PDOP and Fig. 6.5b illustrates the satellite geometry that yields poor PDOP.

![Satellite geometry for PDOP](image)
**Time Dilution of Precision (TDOP):** TDOP is a measure of how the satellite geometry is affecting the ability of the GPS receiver to determine time (Eq. (6.12)). GPS positioning accuracy is the combined effect of the pseudorange measurement errors and satellite geometry. The measurement errors and biases can be represented by User Equivalent Range Error (UERE). The UERE is defined as the root sum square (rss) of all the components of the measurement errors (Dailey and Bell 1996). Various DOP ratings are listed in Table 6.1 (Langley 1991b).

<table>
<thead>
<tr>
<th>DOP number</th>
<th>Corresponding Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ideal</td>
</tr>
<tr>
<td>2-4</td>
<td>Excellent</td>
</tr>
<tr>
<td>4-6</td>
<td>Good</td>
</tr>
<tr>
<td>6-8</td>
<td>Moderate</td>
</tr>
<tr>
<td>8-20</td>
<td>Fair</td>
</tr>
<tr>
<td>20-50</td>
<td>Poor</td>
</tr>
</tbody>
</table>

### 6.2.2 Dilution of Precision estimation algorithm

The satellite-receiver geometry relates position errors to range measurement errors. The solution to the nonlinear GPS measurement equation is

\[
\delta \mathbf{U} = (\mathbf{A}^T \mathbf{A})^{-1} \mathbf{A}^T \delta \mathbf{P}
\]

where, matrix ‘A’ represents the line of sight vectors from receiver to satellites in the space, ‘δP’ represents pseudorange measurements matrix and ‘δU’ represents navigation error state vector. By considering \( \delta \mathbf{U} \) as a zero-mean vector containing the errors in the estimated user state, then our interest is in the statistics of \( \delta \mathbf{U} \) because that will characterize the expected
position errors. Using the generalized inverse of \( A \) (\( A^{-1} \)), covariance of \( \delta U \) can be written as (Langley 1991c)

\[
\text{cov}(\delta U) = E(\delta U \delta U^T) = E((A^T A)^{-1} A^T \delta P \delta P^T A(A^T A)^{-T})
\]

\[
= (A^T A)^{-1} A^T E(\delta P \delta P^T) A(A^T A)^{-T}
\]

\[
= (A^T A)^{-1} A^T \text{cov}(\delta P) A(A^T A)^{-T} \tag{6.2}
\]

The \( \text{cov}(\delta P) \) represents the pseudorange errors. These errors are assumed to be uncorrelated, Gaussian random variables and they are statistically independent which results in a diagonal covariance matrix. Further, the range measurement errors are assumed to have the same variance (\( \sigma_n \)) for each satellite. So, \( \text{cov}(\delta P) \) can be written as

\[
\text{cov}(\delta P) = \sigma_n^2 I \tag{6.3}
\]

By substituting Eq. (6.3) in Eq. (6.2), covariance of \( \delta U \) can be written as

\[
E(\delta U \delta U^T) = \sigma_n^2 (A^T A)^{-1} A^T A(A^T A)^{-T}
\]

\[
= \sigma_n^2 (A^T A)^{-T} \tag{6.4}
\]

As \( (A^T A) \) is symmetric, transpose is not required.

Therefore,

\[
\text{cov}(\delta U) = \sigma_n^2 (A^T A)^{-1} \tag{6.5}
\]

Let \( G = (A^T A)^{-1} \) so that \( \text{cov}(\delta U) = \sigma_n^2 G \)

By expanding (6.5), we have

\[
\begin{bmatrix}
\sigma_x^2 & \text{cov}(x, y) & \text{cov}(x, z) & \text{cov}(x, b) \\
\text{cov}(y, x) & \sigma_y^2 & \text{cov}(y, z) & \text{cov}(y, b) \\
\text{cov}(z, x) & \text{cov}(z, y) & \sigma_z^2 & \text{cov}(z, b) \\
\text{cov}(b, x) & \text{cov}(b, y) & \text{cov}(b, z) & \sigma_b^2
\end{bmatrix}
= \sigma_n^2
\begin{bmatrix}
G_{xx} & G_{xy} & G_{xz} & G_{xb} \\
G_{yx} & G_{yy} & G_{yz} & G_{yb} \\
G_{zx} & G_{zy} & G_{zz} & G_{zb} \\
G_{bx} & G_{by} & G_{bz} & G_{bb}
\end{bmatrix} \tag{6.6}
\]
The elements of $G$ give a measure of the satellite-receiver geometry i.e. Dilution of Precision (DOP) and various DOPs values can be calculated from the diagonal elements of $G$

$$
\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_b^2 = (G_{xx} + G_{yy} + G_{zz} + G_{bb})\sigma_n^2
$$

$$
\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_b^2} = \sigma_n \text{GDOP} \quad (6.7)
$$

Therefore,

$$
\text{GDOP} = \frac{\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_b^2}}{\sigma_n} = \sqrt{G_{xx} + G_{yy} + G_{zz} + G_{bb}} \quad (6.8)
$$

$$
\text{PDOP} = \frac{\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2}}{\sigma_n} = \sqrt{G_{xx} + G_{yy}} \quad (6.9)
$$

$$
\text{HDOP} = \frac{\sqrt{\sigma_x^2 + \sigma_y^2}}{\sigma_n} = \sqrt{G_{xx} + G_{yy}} \quad (6.10)
$$

$$
\text{VDOP} = \frac{\sigma_z}{\sigma_n} = \sqrt{G_{zz}} \quad (6.11)
$$

$$
\text{TDOP} = \frac{\sigma_b}{\sigma_n} = \sqrt{G_{bb}} \quad (6.12)
$$

These DOP terms can be related as

$$
\text{PDOP}^2 = \text{HDOP}^2 + \text{VDOP}^2 \quad (6.13)
$$

$$
\text{GDOP}^2 = \text{PDOP}^2 + \text{TDOP}^2 \quad (6.14)
$$

The GDOP is computed by using Eq. (6.8). All the DOP terms can be computed individually, and they are independent of each other. A high VDOP number, for example, signifies a large error in altitude of receiver position.
6.3 BEST SATELLITE RECEIVER GEOMETRY CONFIGURATION ANALYSIS

6.3.1 DOPs due to ‘Best -4’ satellite-receiver geometry configuration

For GPS position fix, ranging signals from minimum of four satellites is sufficient. These four satellites can be selected from a group of satellites in view at an epoch based on their azimuth angles to yield the minimum number of DOP. When more number of satellites in view, the number of possible combinations becomes more and hence the selection of best four satellites is difficult. Over the entire day, the number of satellites in view changes and hence, selecting the Best-4 satellites for every epoch of the day is a complicated and time consuming process.

For example, if there are 14 satellites in view at an epoch over the horizon, selecting Best-4 satellites is possible in 1001 ways (Steven and Raymond 1989). Selecting one best combination to get the best DOP out of these several combinations is highly unproductive. For this reason, all GPS receivers adopt ‘All-in-view’ satellite-receiver geometry configuration.

![Diagram of Trilateration](image_url)

Fig. 6.6 Volume of the tetrahedron
Fig. 6.6 illustrates the volume of the tetrahedron formed from the unit vectors of the four satellites. When only four satellites are used for navigation solution, the GDOP analysis is based on the volume of the tetrahedron, which is formed closing off the unit vectors from the satellites to the receiver. The larger the volume of the tetrahedron, the smaller is the GDOP number. The largest possible tetrahedron is one for which one satellite is at the zenith (90° elevation angle) and the remaining satellites are below the earth’s horizon at an elevation angle of -19.47° and equally spaced in azimuth. The GDOP in this case is 1.581. But this is not practical as a GPS receiver located on or near earth’s surface cannot see three satellites below horizon. Practically, lowest GDOP (1.732) number can be obtained with one satellite at zenith and the three satellites equally spaced on the horizon (Enge and Van Dierendonck 1996).

6.3.2 DOPs due to ‘All-in-view’ satellite-receiver geometry configuration

When ‘All-in-view’ or more than four satellite configuration are considered for estimation of DOPs the solution is said to be over determined. In this configuration, all the satellites are given equal importance and no satellite is given special significance. As all satellites are used for DOP computation as well as for position estimation, the time consumption for this configuration is very less compared to ‘Best-4’ satellite configuration (Langley 1993). The more the satellites used in the solution, smaller the DOP number and hence smaller the solution error. The GDOP computed with all satellites
in view configuration is better than the one computed using ‘Best-4’ satellite-receiver geometry configurations.

6.4 RESULTS OF GDOP ANALYSIS DUE TO THREE NAVIGATION SOLUTIONS

The dual frequency GPS receiver data is collected from three Indian stations (Andhra University College of Engineering, Visakhapatnam (17.73°N/83.319°E), NGRI, Hyderabad (17.417°N / 78.558°E) and IISc, Bangalore (13.021°N/77.5°E)) and the data is processed as shown in Fig. 7.3 (Chapter 7).

The various dilution of precision (GDOP, PDOP, HDOP, VDOP and TDOP) values estimated with the user positions obtained from the recursive least squares (RLS) approximation and the proposed Jacobian determinant based multipolynomial resultant technique (JMR) and Minkowski function based absolute position (MAP) algorithms corresponding to 19th February, 2010 with all in view satellites are given in Table 6.2. From this table, it is clear that, the mean values of various DOPs obtained by the MAP method are less compared to the JMR and the RLS methods, which indicates that the DOP values are also navigation solution dependent. The various dilution of precision values estimated with the user positions obtained from the RLS, JMR and MAP methods corresponding to 20th and 21st February, 2010 are given in Table 6.3 and Table 6.4 respectively.
Table 6.2 Various DOP values estimated due to all the three methods with all in view satellites corresponding to 19th February, 2010

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>RLS method</th>
<th>JMR method</th>
<th>MAP method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (σ)</td>
<td>Standard deviation (σ)</td>
<td>Variance (σ²)</td>
</tr>
<tr>
<td>1</td>
<td>GDOP</td>
<td>2.754</td>
<td>1.336</td>
<td>1.785</td>
</tr>
<tr>
<td>2</td>
<td>PDOP</td>
<td>2.374</td>
<td>1.026</td>
<td>1.053</td>
</tr>
<tr>
<td>3</td>
<td>HDOP</td>
<td>2.111</td>
<td>0.818</td>
<td>0.669</td>
</tr>
<tr>
<td>4</td>
<td>VDOP</td>
<td>1.029</td>
<td>0.711</td>
<td>0.505</td>
</tr>
<tr>
<td>5</td>
<td>TDOP</td>
<td>1.378</td>
<td>0.882</td>
<td>0.778</td>
</tr>
</tbody>
</table>

Table 6.3 Various DOP values estimated due to all the three methods with all in view satellites corresponding to 20th February, 2010

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>RLS method</th>
<th>JMR method</th>
<th>MAP method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (σ)</td>
<td>Standard deviation (σ)</td>
<td>Variance (σ²)</td>
</tr>
<tr>
<td>1</td>
<td>GDOP</td>
<td>2.560</td>
<td>1.260</td>
<td>1.588</td>
</tr>
<tr>
<td>2</td>
<td>PDOP</td>
<td>2.227</td>
<td>0.998</td>
<td>0.996</td>
</tr>
<tr>
<td>3</td>
<td>HDOP</td>
<td>2.025</td>
<td>0.906</td>
<td>0.820</td>
</tr>
<tr>
<td>4</td>
<td>VDOP</td>
<td>0.906</td>
<td>0.463</td>
<td>0.215</td>
</tr>
<tr>
<td>5</td>
<td>TDOP</td>
<td>1.251</td>
<td>0.787</td>
<td>0.620</td>
</tr>
</tbody>
</table>

Table 6.4 Various DOP values estimated due to all the three methods with all in view satellites corresponding to 21st February, 2010

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>RLS method</th>
<th>JMR method</th>
<th>MAP method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (σ)</td>
<td>Standard deviation (σ)</td>
<td>Variance (σ²)</td>
</tr>
<tr>
<td>1</td>
<td>GDOP</td>
<td>2.591</td>
<td>1.291</td>
<td>1.667</td>
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<tr>
<td>2</td>
<td>PDOP</td>
<td>2.252</td>
<td>1.023</td>
<td>1.047</td>
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<tr>
<td>3</td>
<td>HDOP</td>
<td>2.047</td>
<td>0.928</td>
<td>0.862</td>
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<tr>
<td>4</td>
<td>VDOP</td>
<td>0.919</td>
<td>0.472</td>
<td>0.223</td>
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<tr>
<td>5</td>
<td>TDOP</td>
<td>1.268</td>
<td>0.806</td>
<td>0.650</td>
</tr>
</tbody>
</table>
The various dilution of precision values estimated with the user positions obtained from the RLS, JMR and MAP methods corresponding to 19th, 20th and 21st February, 2010 with Best – 4 satellites are given in Table 6.5, Table 6.6 and Table 6.7 respectively. From Table 6.2 and Table 6.7 we can observe that the DOP values obtained considering all in view satellites are less compared to Best-4 satellites.

Table 6.5 Various DOP values estimated due to all the three methods with Best – 4 satellites corresponding to 19th February, 2010

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>RLS method</th>
<th>JMR method</th>
<th>MAP method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Standard deviation (σ)</td>
<td>Variance (σ^2)</td>
</tr>
<tr>
<td>1</td>
<td>GDOP</td>
<td>3.334</td>
<td>1.310</td>
<td>1.717</td>
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<tr>
<td>2</td>
<td>PDOP</td>
<td>2.931</td>
<td>0.982</td>
<td>0.965</td>
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<tr>
<td>3</td>
<td>HDOP</td>
<td>2.580</td>
<td>0.785</td>
<td>0.617</td>
</tr>
<tr>
<td>4</td>
<td>VDOP</td>
<td>1.330</td>
<td>0.714</td>
<td>0.510</td>
</tr>
<tr>
<td>5</td>
<td>TDOP</td>
<td>1.561</td>
<td>0.915</td>
<td>0.838</td>
</tr>
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</table>

Table 6.6 Various DOP values estimated due to all the three methods with Best – 4 satellites corresponding to 20th February, 2010

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>RLS method</th>
<th>JMR method</th>
<th>MAP method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Standard deviation (σ)</td>
<td>Variance (σ^2)</td>
</tr>
<tr>
<td>1</td>
<td>GDOP</td>
<td>3.131</td>
<td>1.168</td>
<td>1.365</td>
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<tr>
<td>2</td>
<td>PDOP</td>
<td>2.782</td>
<td>0.907</td>
<td>0.823</td>
</tr>
<tr>
<td>3</td>
<td>HDOP</td>
<td>2.482</td>
<td>0.843</td>
<td>0.710</td>
</tr>
<tr>
<td>4</td>
<td>VDOP</td>
<td>1.222</td>
<td>0.445</td>
<td>0.198</td>
</tr>
<tr>
<td>5</td>
<td>TDOP</td>
<td>1.418</td>
<td>0.772</td>
<td>0.597</td>
</tr>
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</table>

Table 6.7 Various DOP values estimated due to all the three methods with Best – 4 satellites corresponding to 21st February, 2010

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>RLS method</th>
<th>JMR method</th>
<th>MAP method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Standard deviation (σ)</td>
<td>Variance (σ^2)</td>
</tr>
<tr>
<td>1</td>
<td>GDOP</td>
<td>3.171</td>
<td>1.200</td>
<td>1.440</td>
</tr>
<tr>
<td>2</td>
<td>PDOP</td>
<td>2.812</td>
<td>0.931</td>
<td>0.867</td>
</tr>
<tr>
<td>3</td>
<td>HDOP</td>
<td>2.511</td>
<td>0.867</td>
<td>0.751</td>
</tr>
<tr>
<td>4</td>
<td>VDOP</td>
<td>1.231</td>
<td>0.451</td>
<td>0.204</td>
</tr>
<tr>
<td>5</td>
<td>TDOP</td>
<td>1.445</td>
<td>0.794</td>
<td>0.630</td>
</tr>
</tbody>
</table>
The GDOP, PDOP, HDOP, VDOP and TDOP values estimated due to recursive least squares approximation, multipolynomial resultant approach and point solution methods corresponding to 19th February, 2010 are plotted with respect to GPS time in hours and are shown in Fig. 6.7 to Fig. 6.11.

The GDOP, PDOP, HDOP, VDOP and TDOP values estimated due to recursive least squares approximation, multipolynomial resultant approach and point solution methods corresponding to 20th February, 2010 are plotted with respect to GPS time in hours and are shown in Fig. 6.12 to Fig. 6.16.

The GDOP, PDOP, HDOP, VDOP and TDOP values estimated due to recursive least squares approximation, multipolynomial resultant approach and point solution methods corresponding to 21st February, 2010 are plotted with respect to GPS time in hours and are shown in Fig. 6.17 to Fig. 6.21.
Fig. 6.7 GPS time versus GDOP plots estimated due to all the three methods corresponding to 19th February, 2010

Fig. 6.8 GPS time versus PDOP plots estimated due to all the three methods corresponding to 19th February, 2010
Fig. 6.9 GPS time versus HDOP plots estimated due to all the three methods corresponding to 19th February, 2010

Fig. 6.10 GPS time versus VDOP plots estimated due to all the three methods corresponding to 19th February, 2010
Fig. 6.11 GPS time versus TDOP plots estimated due to all the three methods corresponding to 19th February, 2010

Fig. 6.12 GPS time versus GDOP plots estimated due to all the three methods corresponding to 20th February, 2010
Fig. 6.13 GPS time versus PDOP plots estimated due to all the three methods corresponding to 20th February, 2010

Fig. 6.14 GPS time versus HDOP plots estimated due to all the three methods corresponding to 20th February, 2010
Fig. 6.15 GPS time versus VDOP plots estimated due to all the three methods corresponding to 20\textsuperscript{th} February, 2010

Fig. 6.16 GPS time versus TDOP plots estimated due to all the three methods corresponding to 20\textsuperscript{th} February, 2010
Fig. 6.17 GPS time versus GDOP plots estimated due to all the three methods corresponding to 21\textsuperscript{st} February, 2010

Fig. 6.18 GPS time versus PDOP plots estimated due to all the three methods corresponding to 21\textsuperscript{st} February, 2010
Fig. 6.19 GPS time versus HDOP plots estimated due to all the three methods corresponding to 21st February, 2010

Fig. 6.20 GPS time versus VDOP plots estimated due to all the three methods corresponding to 21st February, 2010
Fig. 6.21 GPS time versus TDOP plots estimated due to all the three methods corresponding to 21st February, 2010

6.5 CONCLUSIONS

Monitoring of satellite-receiver geometry is an important aspect for high-precision applications such as surveying and integrity monitoring in the GPS receivers. The satellite geometry seen by the user from the Indian subcontinent is different from the higher latitude regions such as U.S, Europe etc. The position accuracy of GPS system is affected by satellite geometry, which represents the geometric locations of the satellites as seen by GPS receiver. GPS requires minimum of four satellites to compute user position. Usually, when more number of satellites is in view, best four satellites are taken in user position computation in order to reduce the redundancy of measurements. In this chapter, the number of satellites to be
used for the best position computation is investigated by comparing the best GDOP value obtained with 2 different configurations i.e. Best-4 and All-in-view satellites configurations. With All-in-view satellite configuration, the GDOP value obtained with the proposed JMR and MAP methods are 2.754 and 2.623 respectively. Whereas, with Best-4 satellite configuration, the GDOP value obtained with the proposed JMR and MAP methods are 3.33 and 3.206 respectively. From the three days (19th Feb 2010–21st Feb 2010) of GDOP analysis results, it is found that the GDOP number obtained due to all satellites in view configuration is low. Therefore it is proposed that all the satellites in view can be used with the proposed navigation solutions, which avoids the troublesome computation of selecting four satellites.