ANALYSIS OF GPS VISIBILITY AND SATELLITE-RECEIVER GEOMETRY OVER DIFFERENT LATITUDINAL REGIONS

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Abstract

GPS is the only fully-operational GNSS currently available to all-inclusive users at no direct charge. Given that users obtain their positions by receiving radiowave signals transmitted from its continuously orbiting satellites, proper functioning of a GPS receiver requires uninterrupted signal reception from at least four orbiting satellites with good satellite-receiver geometry. This paper investigates the variation of satellite visibility and satellite-receiver geometry over three latitudinal regions. To signify the corresponding high latitude region, mid latitude region and equatorial region, three reference stations namely IRKT, XIAN and NTUS were selected. Based on series of satellite almanac data, it is suggested that local sky coverage varies as a function of the tracking station latitude. Throughout the observation period, it is noted that equatorial region provides the most number of satellites in comparison to the mid latitude and the high latitude region. As far as satellite-receiver geometry is concern, equatorial region tends to produce the best DOP hence more likely to produce better result in GPS positioning in comparison to the other regions. As the satellite-receiver geometry changes with time due to the relative motion of the orbiting satellites, it is suggested that DOP value is inversely proportional to the number of observed satellites. It is detected that DOP value also increases with increases in the elevation angle.

Keywords: satellite visibility, satellite-receiver geometry, three latitudinal regions

1.0 BACKGROUND

1.1 Global Positioning System

With rapid advance in space-based positioning technology, Global Navigation Satellite System (GNSS) receiver has become increasingly popular among surveyors and engineers worldwide. Global Positioning System (GPS) is the only fully-operational GNSS currently available to all-inclusive users at no direct charge. Triggered by value-added functionality and innovative field interoperability brought by the all-weather satellite system, this ingenious combination of applied science and technology has been responsible for many exciting and beneficial discoveries ranging from navigation, structural health monitoring and geoscientific studies (Nordin et al. 2008; Yahya & Kamarudin 2008a; Yahya & Kamarudin 2008b). Initially developed as part of a sophisticated military system, there are three core segments within the GPS system i.e. the space segment, control segment and user segment. GPS regains its full operational capability (FOC) on 17 July 1995 with 24 Block II/IIA satellites (Hofmann-Wellenhof, et al. 2001). By 2008, GPS constellation increases to 32 nominal satellites (Peetz 2008; Visser 2008). Similarly, each of these operational satellites transmits a unique code modulated on a carrier based on GPS atomic clocks. Users equipped with appropriate receivers can obtain the antenna position by interpreting the codes, determine its receiver-to-satellites distance (pseudo range), and pinpoint its position through triangulation method to within a few centimeters.

1.2 Satellite Visibility

GPS utilizes the time-of-arrival (TOA) ranging concept based on its orbiting satellites to determine user position (Kaplan 1996). Proper functioning of a GPS receiver requires uninterrupted signal reception from at least four GPS satellites. GPS radiowave signals however, cannot considerably penetrate sea surface, soil, trees or other manmade structure such as walls, dams, buildings and bridges. In many cases, this signal shading will be transitory and hence will not severely hamper the positioning. Nonetheless, in the inner city streets of urban areas line with skyscrapers (see Figure 1), the visibility of the GPS satellites is often limited for extended periods or simply unavailable throughout the observation campaign. This so called "signal outages situation" can also happen in forestry applications with dense canopy area. As in coastal and in land water navigation, transitory signal shading by large topography, wide-span bridges and vessel's own high-rise structures can also be found depending on the location of the GPS antenna. At high banking angles, signal shading through the aircraft fuselage and wings can also happen in airborne applications.

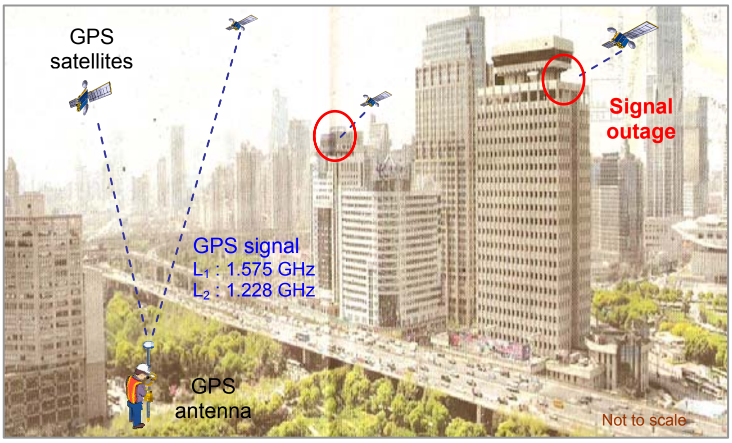


Figure 1: Satellite Visibility at Poor Visibility Condition

1.3 Satellite-Receiver Geometry

Satellite-receiver geometry is another important factor in achieving high quality results especially for point positioning and kinematic surveying (Januszewski, 1999). The satellite-receiver geometry changes with time due to the relative motion of the orbiting satellites. Different satellite-receiver geometries can magnify or lessen the errors in the GPS derived positions. Positioning accuracy can then be estimated as the ranging accuracy multiplied by a dilution factor that depends solely on the satellite-receiver geometry. Under the assumption of uniform, uncorrelated, zero-mean, ranging-error statistics, this can be expressed as follows (Parkinson, 1994(a,b)):

$$\text{RMS position error} = (\text{Geometric dilution}) \cdot (\text{RMS ranging error}) \quad (1)$$

As it is crucial that at least four satellites be in view to obtain one position, four satellites by themselves may not provide sufficient satellite-receiver at certain times. Good satellite-receiver geometry is primarily obtained when the simultaneously tracked satellites are considerably visible within all receiver observational quadrants. As the geometric dilution theoretically increases when the satellites are all clustered together in a single quadrant, the positioning accuracy will tend to be reduced. Figure 2(a,b) illustrates two different conditions of satellite-receiver geometry.

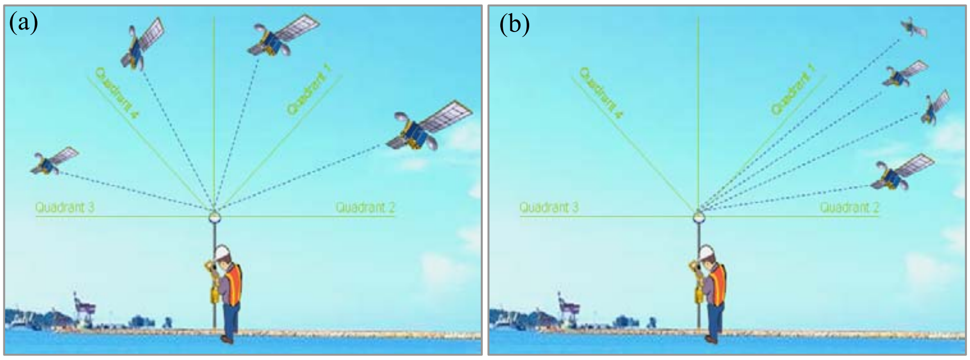


Figure 2: (a)Good Satellite-Receiver Geometry (b)Poor Satellite-Receiver Geometry

Satellite-receiver geometry is commonly measured using a single dimensionless number namely the dilution of precision (DOP). To characterize the accuracy of each GPS components, DOP is often divided into several terms. These include vertical DOP (VDOP), horizontal DOP (HDOP), position DOP (PDOP) and time DOP (TDOP). The most general parameter is termed geometric DOP (GDOP). It is commonly defined based on the user-equivalent range error (UERE). UERE is the standard deviation of the psuedoranges errors of the satellites at the user's position. Psuedoranges errors are generally grouped into six major causes namely satellite ephemeris, satellite clock, ionospheric group delay, tropospheric group delay, multipath and receiver measurement errors (Parkinson, 1994(b)). As defined by Kaplan (1996), the mathematical expression of GDOP is:

$$GDOP = \frac{\sqrt{\sigma_{x_u}^2 + \sigma_{y_u}^2 + \sigma_{z_u}^2 + \sigma_{ct_b}^2}}{\sigma_{UERE}} \tag{2}$$

where:

$$\sqrt{\sigma_{x_u}^2 + \sigma_{y_u}^2 + \sigma_{z_u}^2} = PDOP \cdot \sigma_{UERE} \tag{3}$$

$$\sqrt{\sigma_{x_u}^2 + \sigma_{y_u}^2} = HDOP \cdot \sigma_{UERE} \tag{4}$$

$$\sigma_{z_u} = VDOP \cdot \sigma_{UERE} \tag{5}$$

$$\sigma_{ct_b} = TDOP \cdot \sigma_{UERE} \tag{6}$$

In brief, the square root term in Equation (2) entails an overall characterization of the error in the GPS solution. Each error is then signified by a unique DOP component as shown in Equation (3) to (6). DOP denotes the amplification of the standard deviation of the measurement errors onto the solution. Using only satellites as ranging sources, well-distributed satellite above the user's antenna provides less number of DOP. It is often suggested that less number of DOP provides better result in the positioning accuracy. Ideally, DOP value of zero is the highest possible confidence level to be achieved for applications demanding the highest possible precision at all times. Nevertheless, DOP between 1 and 3 is sufficient to cater most of the GPS applications at high confidence level.

2.0 THE EXPERIMENT

GPS performance in certain environments and for particular applications can be quite limited. To study the variation of satellite visibility and satellite-receiver geometry over three latitudinal regions, series of satellite almanac data retrieved from three reference stations (i.e. IRKT, XIAN and NTUS) provided by International GNSS Service were selected. Details of these stations are as shown in Figure 3.

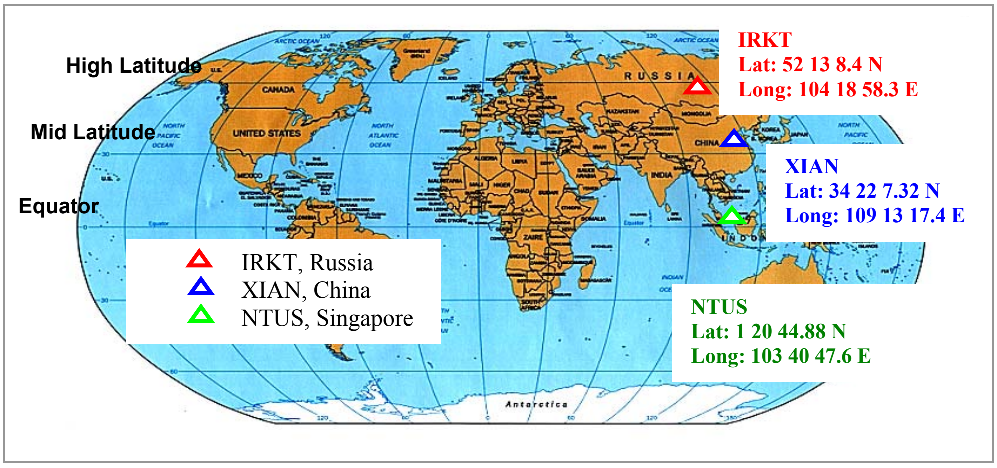


Figure 3: Distribution of Selected Reference Stations

IRKT, XIAN and NTUS represent the high latitude region, mid latitude region and equatorial region respectively. Being located within the longitude of about 103 degrees to 109 degrees only, assumption were made that in this particular case, longitudinal factor does not significantly influence the end result of the study. Throughout the observational period of July 2007, elevation mask were set at the most desirable angle of 15 degrees at 0 hour. Using Trimble™ Planning tools, discussion were made based on several analyses on the satellite condition conducted at different latitudinal regions.

2.1 Satellite Visibility at Different Latitude

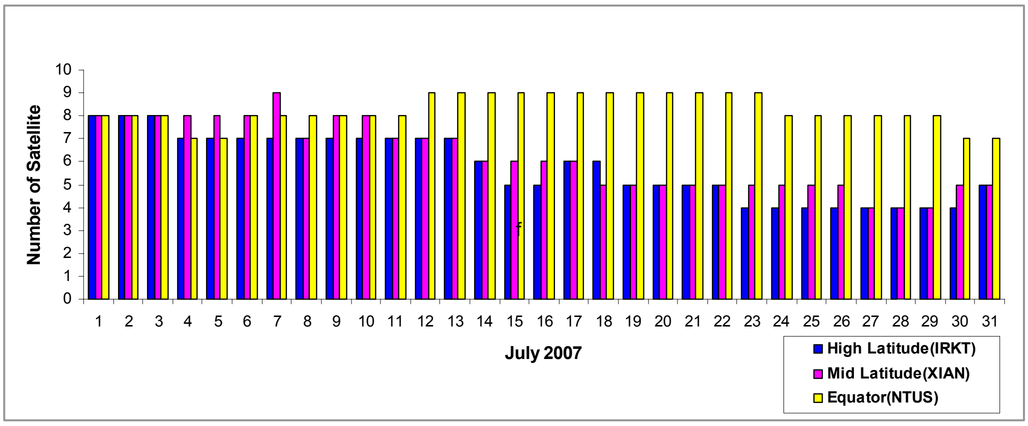


Figure 4: Satellite Visibility at Different Latitude

As depicted in Figure 4, it is noted that there are variations on the visibility of GPS satellites at different latitude. Although the variation is not obvious for some part of the first half of July 2007, towards the latter stage of the observational campaign, there are significant differences on the satellite visibility especially between the equatorial region (NTUS) and both high latitude (IRKT) and mid latitude (XIAN) regions. NTUS tends to observed three to five satellites more in comparison to the other respective stations. Providing the best coverage for GPS observation, the average number of observed satellites throughout the whole month at NTUS is about eight. For IRKT and XIAN however, the average observed satellites is only around five to six satellites each. Similarly, Figure 5 illustrates the sky plot of all reference stations during similar observation period.

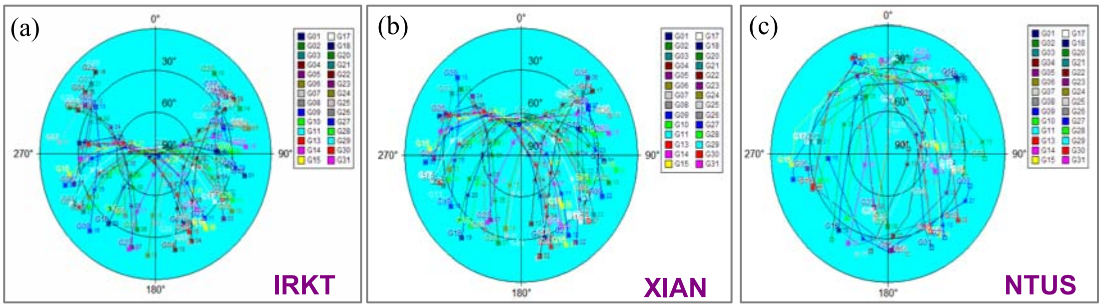


Figure 5: GPS Skyplot at Different Latitude

As shown in Figure 5, local sky coverage varies as a function of the tracking station latitude. It is noted that problem in satellite visibility is most likely to be detected at IRKT in comparison to the other reference stations. Apparently, towards the northern part of IRKT, there is almost no satellite coverage ranging from the horizon (the outer circle) to the zenith (elevation angle of 90 degree). For XIAN however, no satellite coverage is detected to within 60 degree above the northern horizon. Representing the most desirable configuration for GPS positioning, local GPS coverage at NTUS on the other hand is well distributed at all quadrants.

2.2 DOP Value at Different Latitude

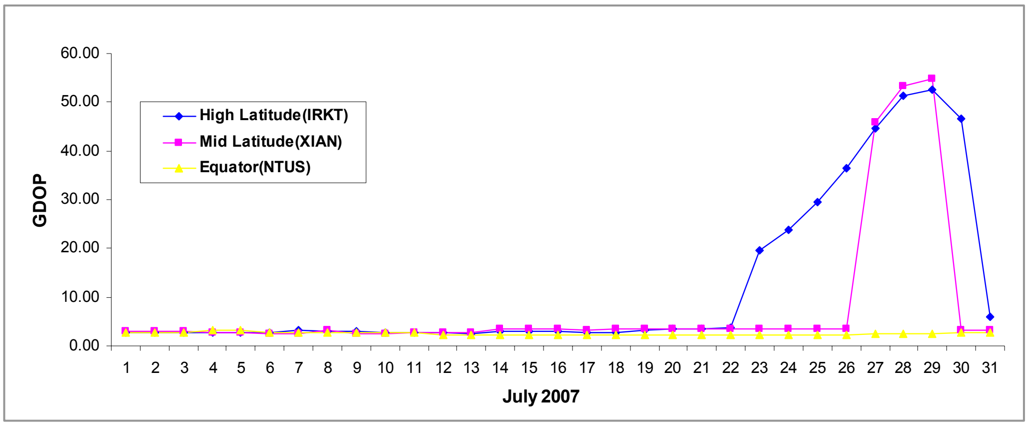


Figure 6: GDOP Value at Different Latitude

Figure 6 reveals the GPS GDOP value at different latitudinal regions. Observed throughout July 2007, it is noted that NTUS tends to produce better result in comparison to the other reference stations. The average GDOP value computed at NTUS is 2.50. Although both IRKT and XIAN manage to produce average GDOP value at an approximate of 2.90 to 3.00, towards the latter stage of observational period, there are sharp increases of GDOP value at both stations. For both IRKT and XIAN, the worst satellite-receiver geometry of 52.60 and 54.84 are detected on the 29 July 2007. With a factor of 52.60 and 54.84 correspondingly, erroneous positioning are very much expected and hence should be discarded. Given that during this observational period there are happen to have minimum number of satellites (four) above their respective region (refer Figure 4), it is suggested that DOP is largely a function of the number of available satellites. Similarly, it is also suggested that DOP value increases with decreases number of observed satellites. The geometry indicator at all latitudinal regions are as shown in Figure 7 (a,b,c).

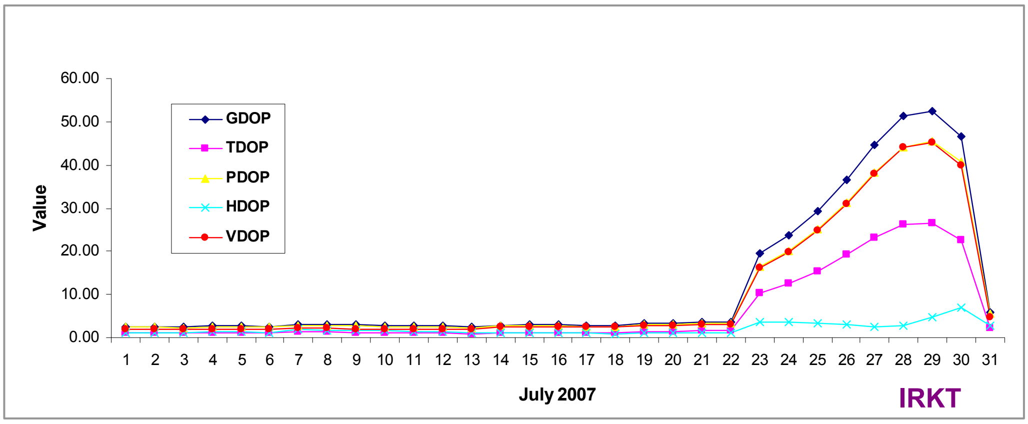


Figure 7(a): GPS Geometry Indicator at High Latitude

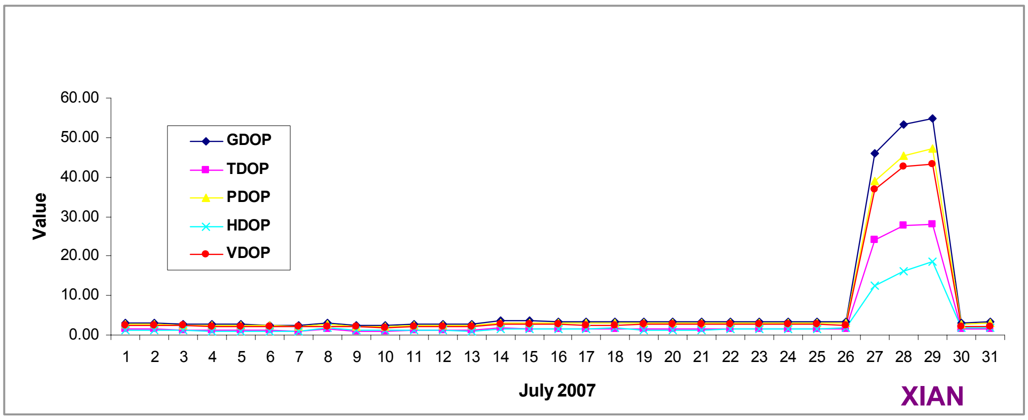


Figure 7(b): GPS Geometry Indicator at Mid Latitude

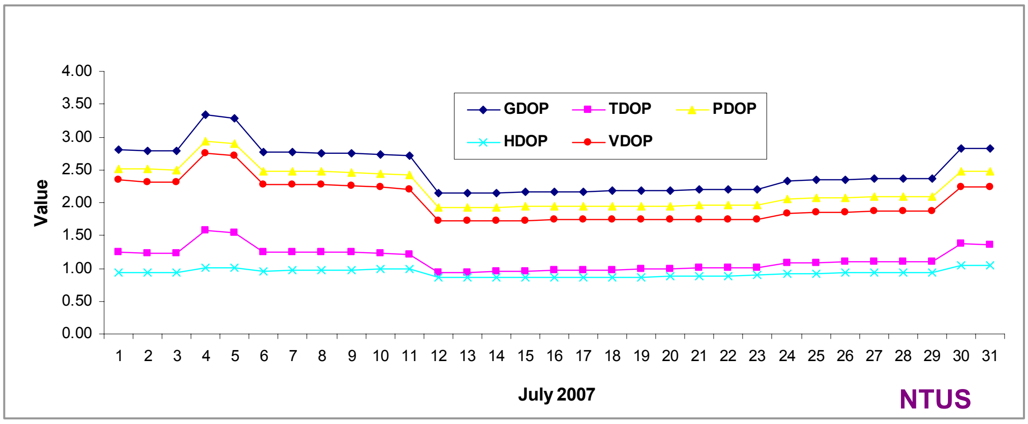
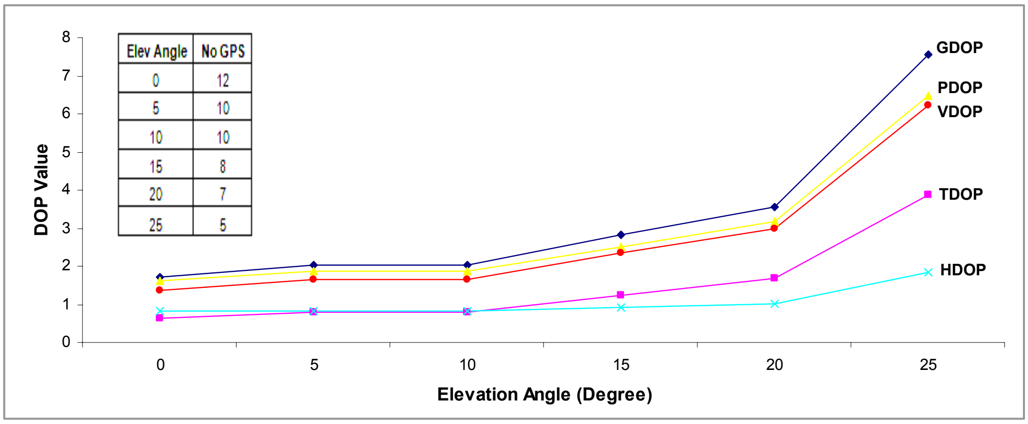


Figure 7(c): GPS Geometry Indicator at Equator

As mentioned earlier, DOP signifies the amplification of the standard deviation of the measurement errors. As illustrated in Figure 7 (a,b,c), it is noted that major attention need to be given on the level of accuracy derived from GPS measurements towards the latter part of the month for both IRKT and XIAN due to sudden fluctuation on the geometry indicator. As in the case of NTUS, the satellite-receiver geometry tends to be stable with no sudden changes throughout the whole observation period. Even so, based on the geometry "pattern" of all cases, it is worth to mention that HDOP tends to produce the lowest value followed by TDOP, VDOP, PDOP and GDOP. Providing the best result in comparison to other stations, the average value of HDOP, TDOP, VDOP, and PDOP at NTUS is 0.93, 1.14, 2.02 and 2.22 respectively.

2.3 Influence of Elevation Angle on DOP

To analyze the impact of different elevation angle towards the amount of DOP computed at GPS reference station, satellite almanac data retrieved on 1 July 2007 at NTUS were used. For the purpose of study, elevation angle were set ranging from 0 degree to 25 degree since not enough satellites (less than four) can be observed at higher degrees. Figure 8 entails the result of the experiment.



Elev Angle	No GPS
0	12
5	10
10	10
15	8
20	7
25	5

Figure 8: Elevation Angle vs. DOP

As shown in Figure 8, it is obvious that with increases in elevation angle, significant increases can be expected on the DOP value. Under the assumption of free from signal perturbations due to obstructions and reflective surroundings, it is therefore recommended that minimum number of elevation angle need to be set prior any observation campaign to mitigate poor GPS satellite-receiver geometry. Based on the result, it is also noted that DOP value increases with decreases number of observed satellites (Again, this finding supports the suggestion that DOP is largely a function of the number of available satellites). With coverage of at least 7 satellites, gradual increase on the DOP value can be detected for the elevation angle less than 20 degree.

3.0 CONCLUSION

In order to understand the variation of satellite visibility and satellite-receiver geometry over high latitude region, mid latitude region and equatorial region, three reference stations namely IRKT, XIAN and NTUS were selected to characterize the corresponding regions. Based on series of satellite almanac data, it is suggested that local sky coverage varies as a function of the tracking station latitude. Throughout the observation period, it is noted that equatorial region provides the most number of satellites in comparison to the mid latitude and the high latitude region. As far as satellite-receiver geometry is concern, equatorial region tends to produce the best GDOP hence more likely to produce better result in GPS positioning in comparison to the other regions. Furthermore, unlike the mid latitude and the high latitude region, equatorial DOP components i.e. HDOP, TDOP, VDOP, and PDOP tend to be stable with no sudden fluctuations. As the satellite-receiver geometry changes with time due to the relative motion of the orbiting satellites, it is suggested that DOP value increases with decreases number of observed satellites. Being a function of the number of available satellites, it is detected that DOP value also increases with increases in the elevation angle. To improve GPS satellite-receiver geometry, it is recommended that minimum number of elevation angle need to be set (to attain more satellite) prior any observation campaign under the assumption of free from GPS signal perturbations.

4.0 ACKNOWLEDGMENT

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