

GPS height aiding computation using multi-resolution Digital Terrain Models

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Abstract

This paper aims to investigate how the accuracy of a standalone GPS receiver changes when the height derived from DTMs is used as an extra equation in the single-point least squares solution. The results show that height aiding can improve the accuracy of a GPS receiver when the number of satellites is low and PDOP (Position Dilution of Precision) is high.

1. Introduction

GPS requires a minimum of four satellites to provide a 3D position fix. However, in dense urban areas, the number of satellites can drop down to three or less, and hence a 3D position fix is not available. In order to augment GPS with additional measurements, a variety of aiding techniques such as inertial sensor and barometer have been widely used to improve GPS availability and accuracy. In this paper, we investigate the effect of using digital terrain models on the accuracy of GPS single point positioning.

2. Methodology

In GPS positioning, height aiding is often used to reduce the number of satellite required to obtain a position fix in that the distance from the centre of the Earth is used as an extra equation within the least squares positioning solution. From Figure 1, the height above mean seal level along with plane coordinates of the receiver (i.e. Easting and Northing) may be converted to WGS84 Cartesian coordinates (i.e. X Y and Z) whose origin is considered as the centre of the Earth. As such, the centre of the Earth may be treated as an additional satellite in order to adds further redundancy into the solution especially when the satellite geometry is poor (i.e. DOP values are high). Furthermore, height aiding is particularly useful in cities where satellite availability is poor due to signal

obstructions, as only three satellite satellites are required for a 3D position fix instead of four (i.e. minimum of four satellites are required for a 3D fix without height aiding) [1].

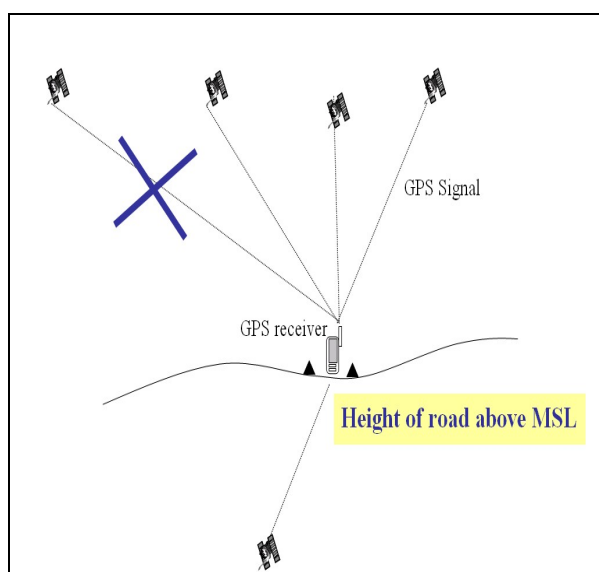


Figure 1. Height aiding

In this work, we used two types of Digital Terrain Models (DTM) to provide height information. That is, the height of previous GPS point is interpolated from the DTMs and then used in the least squares computation for the current point. The DTMs are sampled at two different resolutions (i.e. 5m and 10m). The 5m bare-earth DTM was acquired by Interferometric Synthetic Aperture Radar (IFSAR) technology which is typically accurate to half a meter vertically. The Ordnance Survey 10m DTM is also used for comparison.

3. Results

In this experiment, RTK (Real-Time Kinematic) data was collected using a pair of Leica dual frequency receivers which is typically accurate to around 5 centimeters. RTK data was used as a benchmark. The 2D position error is the difference between the RTK coordinates and the coordinates collected by a single GPS receiver. As shown in Figure 2, height aiding provides an improvement of around 10 meters between epoch 126750 and 126782. After epoch 126782, height aiding does not help improve the accuracy. There is a sharp drop in PDOP as shown in Figure 4 at epoch 127782 which is caused by one satellite that has just become visible to the receiver. It can be seen in Figure 3 that the number of satellites visible has increased to five at epoch 127683 as opposed to only four visible satellites before epoch 126783. Note that the smaller the PDOP, the better the accuracy would be [2] [3]. A PDOP value of more than 9 in Figure 4 is usually considered very poor in practice. More satellites in general produce a smaller PDOP and add redundancy to the least squares solution. Furthermore, the use of the finer resolution 5m IFSAR DTM does not make much difference to the position calculation compared with 10m Ordnance Survey DTM although the 5m DTM is supposed to be more accurate vertically than the 10m DTM.

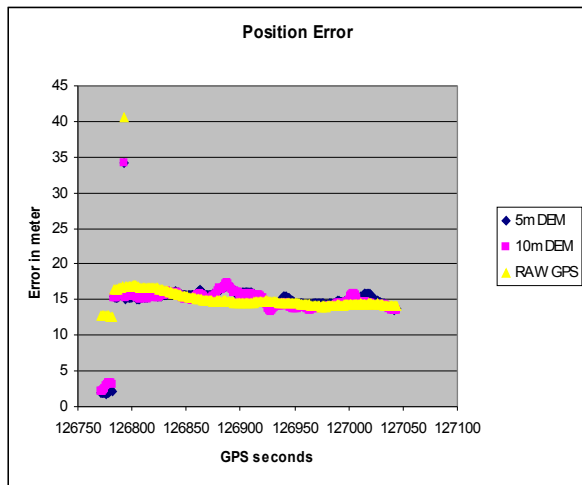


Figure 2. An improvement in position accuracy between epoch 126750 and 126782

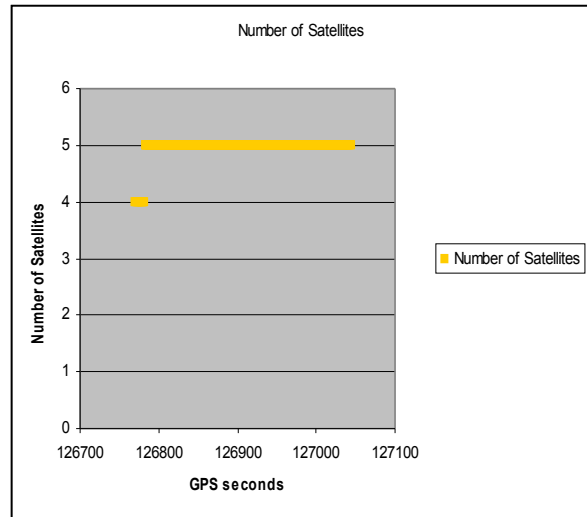


Figure 3. The number of satellites used in the solution

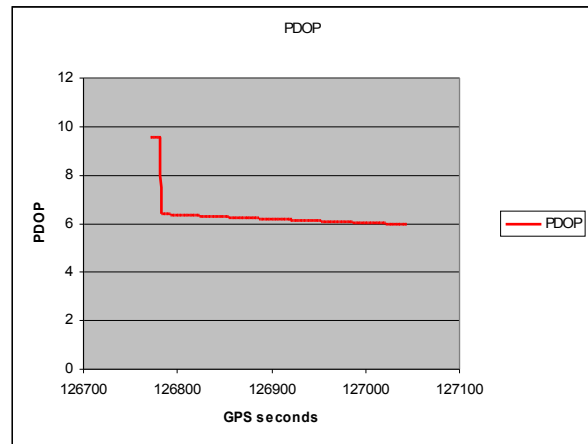


Figure 4. A sharp drop in PDOP at epoch 126783

4. Discussion

It should be noted that the position error shown in Figure 2 increases to around 15m metres after epoch 126782 even though the PDOP is lower than that of the previous epochs (i.e. 6 instead of 10). This is because the newly visible satellite SV7 has a very low elevation angle of just above 15 degrees which introduced exceptionally large pseudorange errors into positioning. In which case, the overall positioning accuracy deteriorated to around 15m from 10m despite the fact that the PDOP is smaller. As shown in Figure 5, having removed SV7 from the computation, both raw and

height aided GPS coordinates have become more accurate than those shown in Figure2.

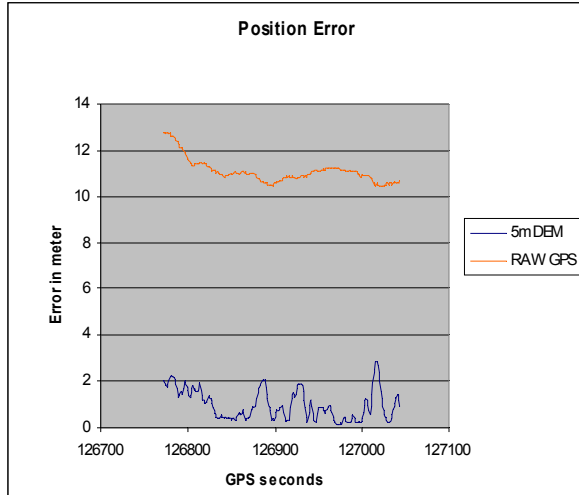


Figure 5 GPS accuracy calculated without SV7

Figure 6 displays the height error produced by raw GPS and interpolated height from 5m DEM.

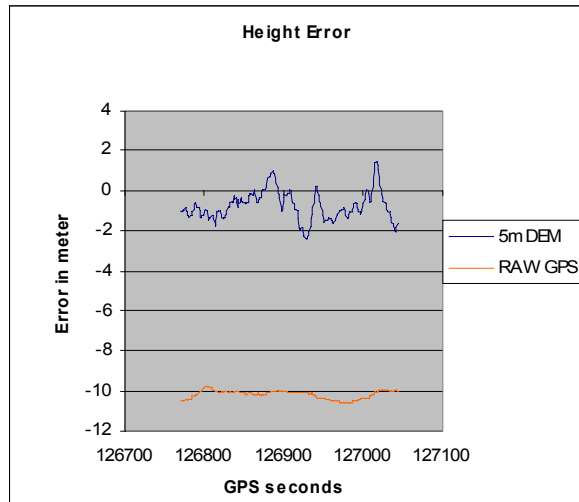


Figure 6 Height error computed without SV7

It can be seen in Figure 6 that the height error produced by 5m DEM is fairly small and close to the ground truth data.

5. Conclusion and Future work

Based on the experimental results in this research, height aiding can improve the accuracy of a single GPS receiver when PDOP is high and the number of visible satellites is low. This is due to the fact that height aiding provides an additional measurement to the centre of the earth in the least squares solution. In addition, higher resolution DTM does not help improve the positioning accuracy which indicates that 10m Ordnance Survey DTM is adequate for the purpose of height aiding compared with the more expensive 5m DTM.

In the results reported here, we have focused on the improvements gained by our height aiding approach through a temporal sequence. Future work will focus on collecting more data in various urban and rural areas to highlight the potential role of height aiding in highly spatially variant scenarios, in addition to the improvement of locational accuracy by means of integrating with other sensors (e.g. inertial measurement units).

6. References

- [1] Li, J., Taylor, G. and Kidner, D. (2005), Accuracy and reliability of map matched GPS coordinates: dependence on terrain model resolution and interpolation algorithm, *Computers and Geosciences*, 31, 241-251.
- [2] Langley, R.B. (1991) The mathematics of GPS. *GPS World*, Vol. 2: 45-50, 1991
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