Precise GPS Point Positioning: the Future Alternative to Differential GPS Surveying

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Positioning with GPS can be performed by either of two ways: point positioning or differential (relative) positioning. GPS point positioning employs one GPS receiver, while differential positioning employs two (or more) GPS receivers simultaneously tracking the same satellites. Surveying works with GPS have conventionally been carried out in the differential positioning mode. This is mainly due to the higher positioning accuracy obtained with the differential positioning mode compared to that of the GPS point positioning. A major disadvantage of GPS differential positioning, however, is its dependency on the measurements or corrections from a reference receiver; i.e. two or more GPS receivers are required to be available. New developments in GPS positioning show that a user with a single GPS receiver can obtain positioning accuracy comparable to that of differential positioning (i.e., centimetre to decimetre accuracy). This article discusses these new GPS developments and shows how this high accuracy level could be achieved.

Classical GPS Point Positioning:

GPS point positioning, also known as the standalone or autonomous positioning, involves one GPS receiver only. That is, one GPS receiver simultaneously tracks four or more GPS satellites to determine its own coordinates with respect to the center of the earth (Figure 1). To determine the receiver's point position at any time, the satellite coordinates as well as a minimum of four ranges to four satellites are required (El-Rabbany, 2002). The receiver gets the satellite coordinates through the broadcast navigation message, while the ranges are obtained from either the C/A-code or the P-code depending on the receiver type. As is well known, the measured pseudoranges are contaminated by both the satellite and receiver clock synchronization errors. Correcting the satellite clock errors may be done by applying the satellite clock correction in the navigation message, while the receiver clock error is treated as an additional unknown parameter in the estimation process (El-Rabbany, 2002). This brings the total number of unknown parameters to four: three for the receiver coordinates and one for the receiver clock error. This is the reason why at least four satellites are needed. If more than four satellites are tracked, either of the least-squares estimation or Kalman filtering technique is applied. As the satellite coordinates are given in the WGS 84 system, the obtained receiver coordinates will be in the WGS 84 system as well.

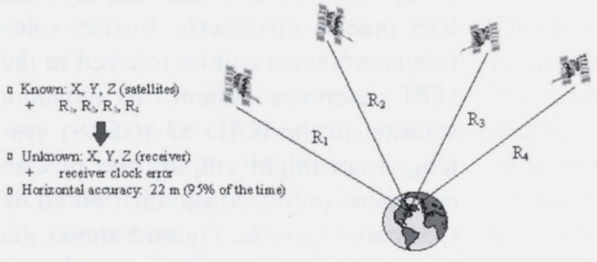

Figure 1
The Principle of GPS point positioning.

The expected horizontal positioning accuracy of the classical approach has improved from about 100m (2 drms) when Selective Availability (SA) was on, to about 22m (2 drms) or better in the absence of SA (Shaw et al., 2000). To demonstrate the performance of the classical approach, GPS data collected at Algonquin, a continuously tracking site of the Canadian Active Control System (CACS) network, was processed in the point positioning mode. The data was collected on November 1, 2002, spanning 24 hours, and was processed using the GPSPace software, which was developed by the Geodetic Survey Division (GSD) of Geomatics Canada. It is worth mentioning that this and several other software packages can be obtained at no cost from Geomatics Canada's website (http://www.geod.emr.ca/index_e/products_e/software_e/software_e.html). Figure 2 shows the true error in the latitude, longitude and height components, when the L1 code pseudorange and broadcast ephemeris were used. It can be seen that the error in either of the horizontal components reaches a maximum of 10m, while the error in the height component is about 19m. Obviously, this level of accuracy is not suitable for almost all of the surveying works.

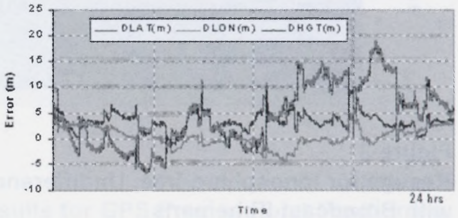

Figure 2
Epoch-by-epoch Results (L1 code pseudorange and broadcast Ephemeris)

Improving Point Positioning Accuracy:

The accuracy of classical GPS point positioning is limited as a result of the presence of unmodelled errors and biases. These include ephemeris errors, residual satellite clock errors, multipath error, ionospheric and tropospheric delays, satellite attitude error, and site displacement effect (see El-Rabbany, 2002 for details). With the termination of SA, ionospheric delay becomes the largest contributor to the GPS error budget (Shaw et al., 2000).

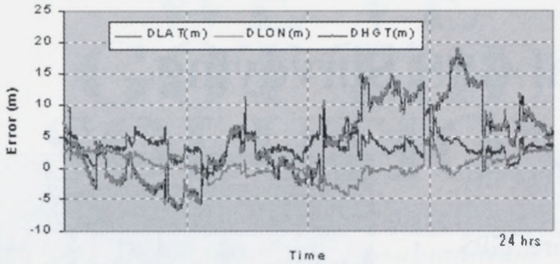

Figure 3
Results for Ionosphere-free, Undifferenced Pseudorange with Broadcast Ephemeris

Figure 4 - IGS Tracking Network (from http://igscb.jpl.nasa.gov/network/netindex.html)

As the ionosphere is a dispersive medium, it causes a delay to the GPS signal that is frequency dependent. Therefore, using a dual frequency receiver, we can combine the L1 and L2 measurements to generate the so-called ionosphere-free linear combination, which removes the ionospheric error. Figure 3 shows the true error in the latitude, longitude and height components for the same data set described above, when the ionosphere-free, undifferenced pseudorange and broadcast ephemeris were used. Comparing the obtained results with the classical point positioning results, it can be seen that the solution has improved in all three components.

Further improvement to the point positioning solution could be attained through the use of precise satellite ephemeris and clock data produced by, e.g., the International GPS Service (IGS). The IGS is a service with international multi-agency membership to support global geodetic and geophysical activities. Such a service is accomplished through a global network of tracking stations equipped with continuously operating dual frequency receivers (Figure 4). The IGS precise satellite ephemeris and clock products are currently made available at no cost in three different forms: (1) Final product, which is made available at 12 days latency; (2) Rapid product, which is made available at approximately 17 hours latency; and (3) Ultra-Rapid product, which is created twice daily (at 3:00 AM and 3:00 PM UTC) and contains 48 hours of orbital information (IGS, 2002). The three types of IGS products differ by their varying accuracy, depending on the time of availability, with the final orbit being the most accurate. The Root-Mean-Square (RMS) error of the final IGS orbit is in the order of 3-5 cm, compared to about 260 cm for the broadcast orbit (IGS, 2002). Similarly, the RMS error of the final IGS satellite clock correction is in the order of 0.1 of a nanosecond (equivalent to a range error of 3 cm), compared to about 7 nanoseconds (equivalent to a range error of 210 cm) for the broadcast satellite clock correction.

It should be pointed out that the IGS precise ephemeris is referred to the ITRF reference system (El-Rabbany, 2002). That is, if a user employs the IGS precise ephemeris, his/her solution coordinates will be referred to the ITRF reference system. To obtain a solution in the NAD 83 (CSRS) system, users might employ the precise ephemeris produced and distributed by Geomatics Canada. Figure 5 shows the true error in the latitude, longitude and height components for the same data set described above, when the iono-

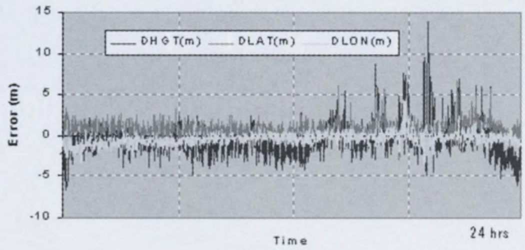

Figure 5
Results for Ionosphere-free, Undifferenced Pseudorange with Precise Ephemeris and Clocks

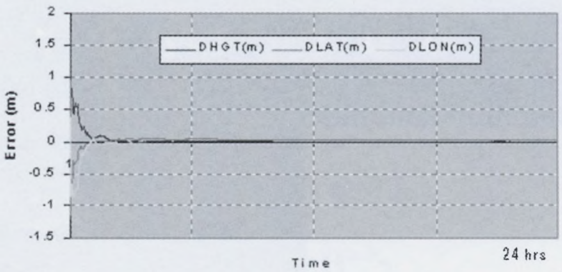

Figure 6
Results for GPS Precise Point Positioning.

sphere-free, undifferenced pseudorange and IGS precise ephemeris and clock data were used. It can be seen that the solution has improved in all three components, compared to the above cases. In fact, the solution is comparable to that of the code-based Differential GPS.

GPS Precise Point Positioning (PPP):

It has been shown that the code-based point positioning solution could be improved to match the DGPS solution through the use of ionosphere-free, undifferenced pseudorange with precise ephemeris and clock data. To achieve the highest possible point positioning accuracy, both carrier-phase and pseudorange measurements should be used. In addition, the remaining unmodelled errors, namely tropospheric delay, satellite attitude error, and site displacement effect, must be dealt with. This approach is commonly known as the Precise Point Positioning, or PPP (Heroux et al., 2001).

Tropospheric delay is commonly broken into two components, dry and wet (El-Rabbany, 2002). Dry component represents about 90% of the delay and can be predicted to a high degree of accuracy using a mathematical model, e.g., the Hopfield model. The wet component of the tropospheric delay depends on the water vapour along the GPS signal path. Unlike the dry component, the wet component is not easy to predict, and is commonly treated as an additional unknown parameter in the estimation process. Satellite attitude error includes offset between the satellite centre of mass and its antenna phase centre, phase wind-up due to relative rotation of the satellite and receiver antennas, and rapid rotation during eclipsing season. Site displacement effect, on the other hand, includes solid earth tides, effect of polar motion, and ocean loading (Heroux et al., 2001). The same data set described above was processed again using the GPS Precise Point Positioning approach. However, unlike the above cases, a sequential filter was used in this case. Figure 6 shows the true error in the latitude, longitude and height components. It can be seen that the PPP solution converges after a small number of epochs to approach, within several centimetres, the true station coordinates. It should be emphasized, however, that the PPP solution was based on a sequential processing and that the receiver was known to be stationary (i.e., static). As shown by Abdel-Salam et al. (2002), ignoring the receiver dynamics would certainly degrade the accuracy.

Conclusions and Future Outlook:

This article presented a number of GPS point positioning approaches. It has been shown that a centimetre to decimetre positioning accuracy is possible with the Precise Point Positioning approach. To achieve this high level of accuracy, precise ephemeris and satellite clock data must be used, which unfortunately is available at some latency at present. However, a number of researchers and institutions are developing models for predicting ephemeris and satellite clock correction, which would make the real-time PPP possible.

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