Precise Point Positioning: Breaking the Monopoly of Relative GPS Processing

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GPS has provided us with a marvellous survey tool but to get the best results you need to understand which processing method is appropriate for your task. The authors demystify the jargon, explain what the errors sources are and provide some answers. But is there really any suitable software yet?

JUST FOR A MOMENT, imagine the world of GPS processing as one cardboard box. For some, a 'black box' will spring to mind. Others may not have yet delved into the wonders of GPS processing. Regardless of your own experience, this article is aimed at opening up this box and letting some light into its dark recesses.

Now, imagine opening your GPS processing box. Inside is a series of different commercial and scientific software. Any one piece of software may be pulled out of the box and applied to some GPS data. The different software have different strengths and weaknesses; some are good for processing data over long distances, others specialise in kinematic processing. However, despite their differences these software are largely built on the same technology - relative GPS processing.

Since the inception of the Global Positioning System during the late 1970s, relative processing has dominated the field of GPS data processing. In fact, until quite recently, it would be true to say that relative processing had a monopoly on precision GPS processing. This all changed during the late 1990s when some competition entered the market place in the form of Precise Point Positioning (PPP). All of a sudden a new box had appeared! Furthermore this new box promises precisions comparable to those achievable from relative processing. The question you might be asking at this point is: "How is this possible?" Read on and all will be explained. But first a quick refresher on relative processing is in order.

Relative processing

The 'relative' part of relative processing suggests that more than one receiver is required and indeed this is the case. The minimum configuration for the determination of precise coordinates for one new point is of course two receivers. However, in order to obtain precise coordinates for a point from GPS data, a number of nuisance parameters first need to be removed from the data. These may be classified as satellite 'errors', atmospheric 'errors' and receiver 'errors'. Satellite errors include errors in the reported satellite coordinates and satellite clocks, atmospheric errors include signal delays due to the troposphere and ionosphere while receiver errors include receiver clock errors. Let us consider for a moment how each of these errors might be removed or mitigated.

Tropospheric errors are largely removed by either applying a model which attempts to mathematically simulate the signal delay (as in most commercial software), or by estimating the signal tropospheric delay along with the receiver coordinates (as in most research software). Ionospheric errors are removed by observing both GPS frequencies (L1 and L2) and combining the two observations to derive an ionosphere-free observation. Errors in satellite positions can be reduced by using precise satellite orbits available from the International GPS Service (IGS; http://igscb.jpl.nasa.gov) and any remaining error (except multipath) largely cancels over short distances. That leaves satellite and receiver clock errors as the dominant errors to be dealt with and this is where relative positioning comes to the fore.

Recall the basic receiver configuration for relative positioning (Figure 1). Suppose we have one receiver at a known location and at the same time another receiver is at an unknown location. By observing the GPS signals from two satellites at the known location and differencing, the errors in the receiver clock are removed from the observations at this site. If this process is repeated at the unknown location, the receiver clock errors are removed from this receiver's observations also. Hence, the receiver clock errors are removed. This leaves just the satellite clock errors. By observing signals from the same satellite at two receivers at different locations and differencing, the errors in the satellite clock are largely removed. As each satellite signal is observed by the two receivers a difference may be taken and hence all of the satellite and receiver clock errors may be differenced out! This process is known as double differencing.

At the end of the double difference process we are left with observations that are only contaminated by what are typically small errors. By observing signals from at least four satellites common to both receivers (i.e. known and unknown locations), a precise three dimensional baseline may be obtained. A baseline is obtained rather than an absolute position due to the double differencing process described above. The coordinates of the unknown location are determined relative to those of the known location and hence the name relative positioning.

Precise Point Positioning explained

The vast majority of commercially available software utilises the principles of relative positioning. However, in the late 1990s, the Jet Propulsion Laboratory (NASA) pioneered a new technique that did not require differencing to obtain precise positions. They labelled it Precise Point Positioning (PPP) and implemented it in their GIPSY/OASIS II GPS processing software.

The largest difference between relative processing and PPP is the way that the satellite and receiver clock errors are handled. Instead of between-receiver differencing to remove the satellite clock errors, PPP uses highly precise satellite clock estimates. These satellite clock estimates are derived from a solution using data from a

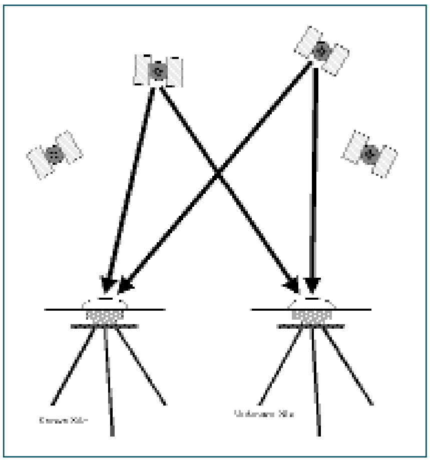

Figure 1: The basic receiver configuration for relative positioning.

globally distributed network of GPS receivers. Instead of between-satellite differencing to remove receiver clock errors, PPP estimates these as part of the least squares solution for the coordinates. Consequently, precise absolute coordinates for a single receiver at an unknown location may be obtained without the need of a second receiver at a known location (see Figure 2).

A note of caution at this point is necessary. It may be possible to get PPP confused with another form of point positioning that many GPS users will be familiar with, i.e., Single Point Positioning (SPP). SPP is different to PPP in two ways. Firstly, SPP does not use precise satellite clock values and secondly, only the pseudo range observations are used. PPP uses both the pseudo range and more precise carrier phase observations. The difference between these methods in terms of coordinate accuracy is large: SPP produces coordinates accurate at the 1-10 m level while PPP can produce coordinates accurate at the 0.01 m level with 24 hours of observations. Consequently, PPP allows coordinate determination with a precision that is comparable to relative processing.

Since no base station is required in PPP, a further question is: "what datum are the coordinates in?" For PPP, the datum is hidden in the satellites' coordinates - the satellite reference frame (datum) will be the unknown ground site reference frame. This means that to obtain coordinates in a different reference frame the user needs to perform a usually straightforward coordinate transformation.

Comparison (Relative positioning vs PPP)

So what are the pros and cons of PPP compared to traditional relative processing? The main benefit of PPP is that its strengths are exactly in the areas of the weaknesses of relative processing and vice versa. Rather than being competitors, they complement each other perfectly. Let us consider two examples.

Firstly, consider the task of cm-level monitoring of an offshore oil platform. The most obvious logistical and cost benefit of PPP is that it does not require the operation of a base station - as long as data is available from the GPS receiver on the platform a position may be generated. By forming a time-series of PPP solutions movement of the platform can be monitored. Furthermore, any detected movement should be directly related to the platform, although it is important to note that it is the 'absolute' motion that is measured and hence the effects of ocean, atmospheric and ground water loading of the earth's crust are more apparent than in relative processing. With relative positioning, the user cannot be certain if detected movement is at the base station, the platform, or both, if the three-dimensional baseline changes. Put simply, PPP allows the unambiguous determination of the platform position. Furthermore, the accuracies of relative positioning degrade with distance from the base station. Of course, this is not the case with PPP since it does not rely on a base station. geomatics@newcastle has been successfully using PPP in a platform monitoring project for Shell Petroleum and Exploration (UK) since 1996.

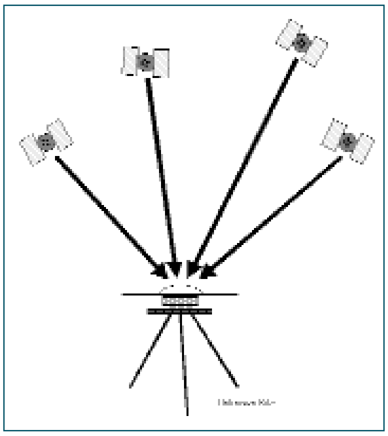

Figure 2: Precise absolute coordinates can be obtained for a single receiver without the need for a second receiver.

The main drawback with PPP is that there is a delay of approximately two weeks from the time of data collection to the availability of the precise satellite coordinates and clocks. Consequently, the most precise positions are not available until two weeks after the data were collected. A less precise (~0.1 m accuracy) solution is possible however, using the 'rapid' satellite position and clock solutions. Due to double-differencing, the degradation of the coordinate accuracy is less when using the rapid products in relative positioning.

For our second example, let us consider a small (10-50 km) survey control network observed using GPS. Relative positioning is a more logical choice for this task since it takes advantage of the cancellation effect when double differencing. That is, any errors common to the network partially or totally cancel - tropospheric, ionospheric, tidal and non-tidal loading each fall into this category. This may not be the case with PPP since each point is processed independently of the others. Ambiguity resolution is also simpler in relative processing. Great care must be taken, however, to ensure that correct antenna phase centre models are employed when mixing antenna types in relative processing, while PPP relies only on a single antenna. Within the UK, base station reliability should not be an issue by using the Ordnance Survey Active Network of continuously operating base stations (see the previous Engineering Showcase for our article on the applications of Active Network data). Using the Active or Passive Network also allows easy integration into the UK's ETRF89 reference frame. PPP coordinates, on the other hand, are produced in the ITRF and hence need to be transformed to ETRF89.

Conclusions

The choice of which box to reach into is ultimately yours! In the past the choice has been dictated to you - it must be relative processing. Now that choice has opened up and is governed by appropriate survey-related factors, i.e., the processing methodology and software that is best suited to a particular application. Unfortunately, we know of no 'nice' commercial product that presently allows you to process and analyse data using PPP. GIPSY/OASIS II, and other PPP-capable processing software such as Bernese, is a research package with a high level of expected knowledge of GPS theory. We would expect that given the flexibility of the PPP method, a commercial solution will be available in the future.

References

An excellent general GPS reference, including for relative positioning is:
Leick, A., GPS Satellite Surveying, 560 pp., John Wiley & Sons, New York, 1995.
For the intricate details of PPP, see: *Zumberge, J.F., M.B. Heflin, D.C. Jefferson, M.M. Watkins, and F.H. Webb, Precise point positioning for the efficient and robust analysis of GPS data from large networks, Journal of Geophysical Research, 102 (B3), 5005-5017, 1997.*

For information on GIPSY/OASIS II, see: *http://gipsy.jpl.nasa.gov/*

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