Part 3: Error Sources

Practical Satellite Navigation

In the previous articles the position determination of GPS was discussed. The GPS position, based on the C/A code, nowadays has a precision of approximately 5 – 20 meters. With the P code, more precise results can be achieved (1 - 5 meters). The difference in precision between the C/A and P code is largely due to the length of the code and the broadcasting of the P-code on two frequencies. There are however a number of error sources that influence the precision of the GPS position and which can degrade the position with meters. This article will give a brief overview of a number of large error sources that can influence the position determination.

By Huibert-Jan Lekkerkerk

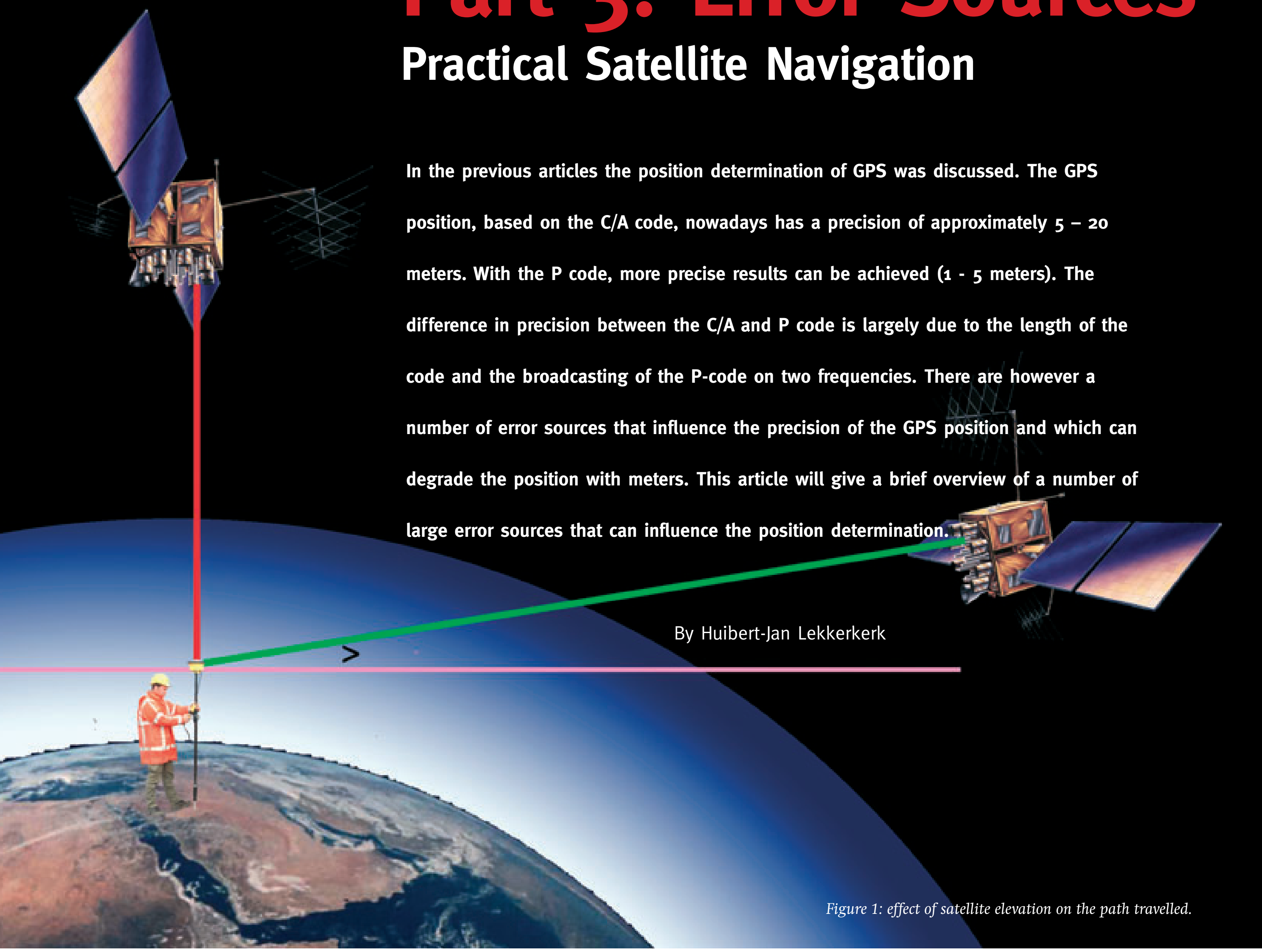

Figure 1: effect of satellite elevation on the path travelled.

Gravity Field

Satellites are equipped with very accurate atomic clocks, as was discussed in the previous article. Nonetheless there are still small errors at work mainly due to variations in the gravity field of the earth. As a result of relativity related errors, the satellite clock can show small discrepancies when compared to the mother clocks on earth. Furthermore small changes in the gravitational field of the earth will cause small changes in the satellite orbits. It was already shown that ground stations are constantly tracking the satellites. These control stations determine the corrections for both orbit and clock and transmit these to the satellites once a week. This implies that it is possible to calculate satellite positions based on an almanac which is almost a week old and possibly incorrect. For GPS applications where accuracy is of utmost importance, the correct almanac is therefore applied afterwards to the raw satellite measurements (post-processing).

Selective Availability

Shortly after the GPS system was completed tests showed that the system functioned better than expected. Instead of the predicted precision of 50 –100 meters for the civil signal (C/A code – Standard Positioning Service) the results were in the order of 10 – 20 meters. Although these results were very positive in a scientific sense, the American government felt these results were a threat. The main reason for this was that all users could calculate positions with a precision that was almost equal to that of the military signal (P-code – Precise Positioning Service). It was thus decided in 1989 to introduce errors in the C/A coded signals, bringing the precision artificially back to 50 – 100 meters. This signal degradation was called Selective Availability (SA) and has been in use for over a decade, with the exception of the first Gulf war in 1991 when the American army did not have enough military GPS receivers for their own troops. On the first of May 2000, president Clinton declared that, as a result of the broad use of GPS and DGPS, there was no further need to continue SA and it was switched off. This switch-off was however conditional with the reservation that it could be put back on in times of emergency. Until today SA has been switched off, even after the events of September 11.

Troposphere

The earth atmosphere consists of a number of layers, the troposphere being the first layer (up to a height of approximately 13 kilometres) where the weather is formed. Since the GPS satellites are orbiting high above the earth, their signals need to cross the atmosphere before reaching our receiver. Factors like humidity influence the speed of light, and as such delay the GPS signals resulting in travel time errors in the order of tens of meters.

GPS receivers do employ an atmospheric model to correct for these delays. Local weather variations cannot be modelled however and will result in errors of meters in the pseudorange measurement. The amount of delay depends on the time it takes the signal to travel through the atmosphere, which in turn depends on the satellite elevation above the horizon, see Figure 1. Satellites directly above the horizon will cause the smallest error, and as a rule of thumb, keep the elevation of the satellites used above 10° to 15° in order to reduce the potential error as much as possible.

Another method by which tropospheric error can be reduced is the use of a multi-frequency receiver. It has been demonstrated that the amount of delay depends on the frequency of the radio signal. If we measure the travel time for both the L1 and the L2 frequency, we can estimate the tropospheric error to some degree. Most dual frequency receivers use the P-code for correcting the atmospheric error. Since this code is transmitted on both frequencies (L1 / L2) but has an unknown starting point, it cannot be used for determination of the absolute travel time. We can however take differential measurements since the code starts at the same point in time for both frequencies.

Ionosphere

The ionosphere is the layer in the atmosphere reaching from 50 to 500 kilometres. The sun ionises the air in this layer, creating a charged particle layer. A striking example of this ionisation is the polar light. The ionised particles delay the GPS signal, creating errors of up to 30 meters in the daylight or 6 meters at night. Large sources of ionisation are the so-called sunspots and related magnetic storms. These sunspots have an 11-year cycle with the next peak occurring in 2011 – 2012, see Figure 2.

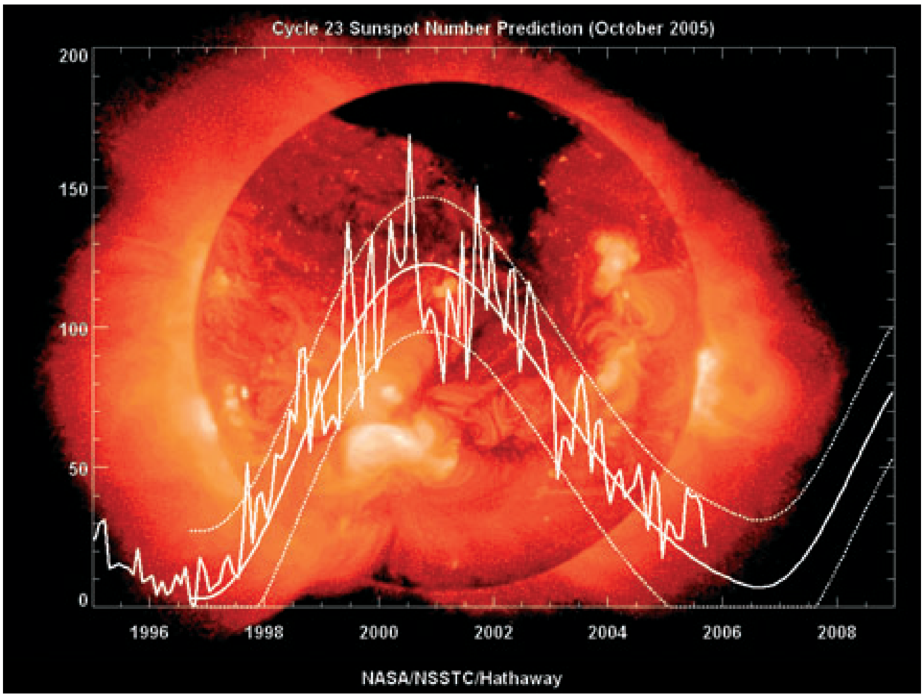

Figure 2: number of (predicted) sun spots for the current solar cycle. (source: www.taborsoft.com)

At the moment we are approximately at the minimum of the solar cycle.

This effect will also occur around the year in locations with a large amount of exposition to the sun (equator, around noon).

With a small amount of ionisation the problem will be measurement errors. When there is a lot of activity, the GPS signal can be influenced in such a way that reception is impossible, see Figure 3. When using DPGS systems the effective range can, as a result of the solar activity, be reduced with a factor 2 to 4. Ionospheric errors as a result of sunspots cannot be predicted, but the regular ionisation of the atmosphere can be predicted using an ionospheric model. A multi-frequency receiver can resolve these errors in the same manner as with the tropospheric error.

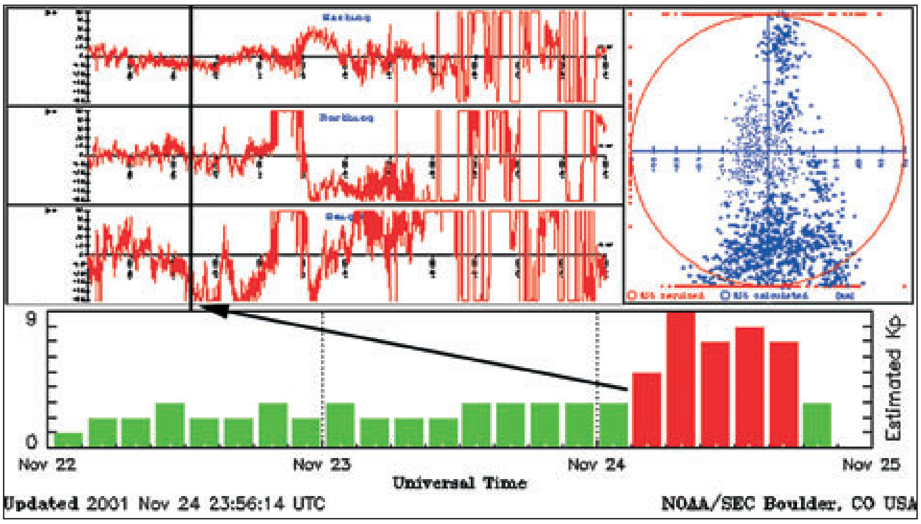

Figure 3: RTK GPS measurements in november 2001. The scale for both X,Y and Z is 0.25 meters. The Kp index is an indication of the radio environment in the ionosphere (red = bad). (source Kp index: http://www.sec.noaa.gov)

Multipath

Just as light is reflected by a shiny surface, radio signals can be reflected by things like the water surface, tanks filled with oil and water, but also by cars and ships or bridges. The reflected signals will interfere with the signals that are received via a direct path, see Figure 4. The receiver may start using the reflected signal, which has a longer travel time, instead of the direct signal. As a result the position will be calculated incorrectly, with the position shifting in the direction of the multipath source.

Since multipath is hard to correct for, it is better to prevent it altogether. As the first rule in preventing multipath is to keep the antenna as far away as possible from reflectors. Enlarging the elevation mask of the receiver can be of some help as can changing the height of the antenna. A multipath error will last a couple of minutes and will disappear as soon as the signal is no longer reflected towards the antenna.

Nowadays most professional GPS antennas have a built-in ground plate or choke ring, see Figure 6, which prevents the reception of reflected signals from under the antenna horizon.

User Errors

The main sources of error in GPS measurements are user errors or as they are usually called, blunders. As a rule, blunders can be prevented by a consequent measurement strategy using as many control options as practically possible. Common blunders are:

- Measuring too close to objects with either multipath or shielding from the horizon as a result. This results in a degraded

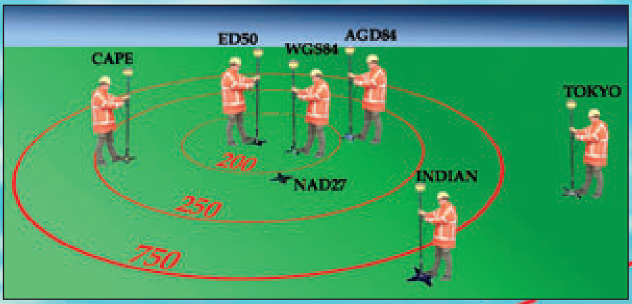

Figure 6: Position error through an incorrect choice of geodetic datum. In the example we read ED50 positions (centre). The WGS84 positions from the GPS receiver are 180 meters further in coordinates.

Figure 4: Through reflection of GPS signals a longer travel time is registered, resulting in position errors.

position and a difficulty to detect. Large steel structures such as cranes or masts will shield the horizon just as a bridge or a tree, a fact that is not always appreciated in the field;

- The use of height aiding without entering the correct antenna height above sea level. As was discussed in the previous article, the use of height aiding should be questioned these days since sufficient satellites are available for a good positioning fix under normal conditions;
- Incorrect initialisation position after a cold start of the receiver. This will not result in an incorrect position, but in no position reading altogether;
- Incorrect geodetic settings. GPS calculates all positions in WGS84 coordinates, but most receivers have the option to transform these to any other coordinate system for presentation on the screen. With most receivers the output message will however contain WGS84 coordinates. Errors as a result of the selection of an incorrect geodetic datum can be as high as hundreds of meters, see Figure 5.

Quality Control

To gain insight into the quality of a calculated position there are a number of quality control parameters available in most GPS receivers. The most important one probably is the Dilution of Precision (DOP). The DOP describes the geometric strength of the satellite configuration, or in other words the spreading of the satellites around the horizon. When all satellites are on one side of the horizon, see Figure 7a, the receiver will calculate a high DOP value. There are a number of DOPs available, but with ordinary GPS positioning the Horizontal DOP (HDOP) and geometric DOP (GDOP) are possibly the most important ones.

Next to the DOP, some receivers have the ability to calculate the so-called Line of Position Mean Error (LPME). This is an indication of the precision of the position itself and will factor in other parameters like the travel time measurement.

Some manufacturers present the user with a so-called quality figure that is said to indicate the precision of the position determination. This quality figure is usually calculated from parameters like the HDOP and LPME. As a rule one should treat these figures with due caution since the formula used to calculate this is generally unknown to the user.

Figure 5: antenna with choke ring to prevent multipath (source: www.ipgp.jussieu.fr).

Summary

From this article it can be seen that there are a large number of error sources influencing the GPS position determination. We should take these error sources rather serious when performing high quality GPS measurements. A number of the errors described in this article can be corrected using DGPS, which will be described in the next article.

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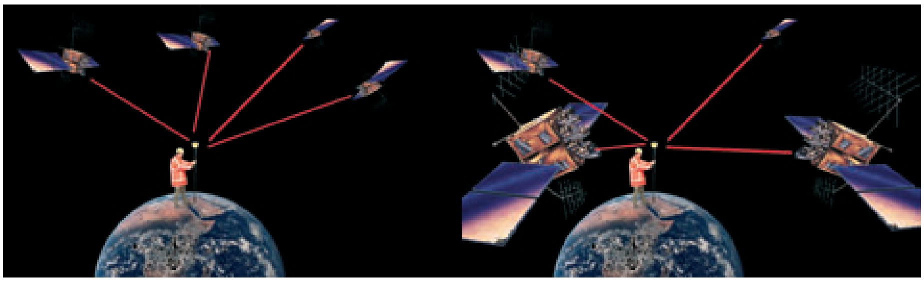

Figure 7: the Dilution of Precision is high (a) when all satellites are on one side of the antenna and low (b) when there is an even geometric spreading of the satellites.