

Part 2: GPS Position and Time

Practical Satellite Navigation

In the GPS article in Geoinformatics 1-2006 the various elements of a Global Navigation Satellite System (GNSS) were discussed as well as the method by which signals are sent from the GPS satellites to a receiver. This article will expand on this and discuss the methods used by the GPS receiver to establish a position from these signals.

By Huibert-Jan Lekkerkerk

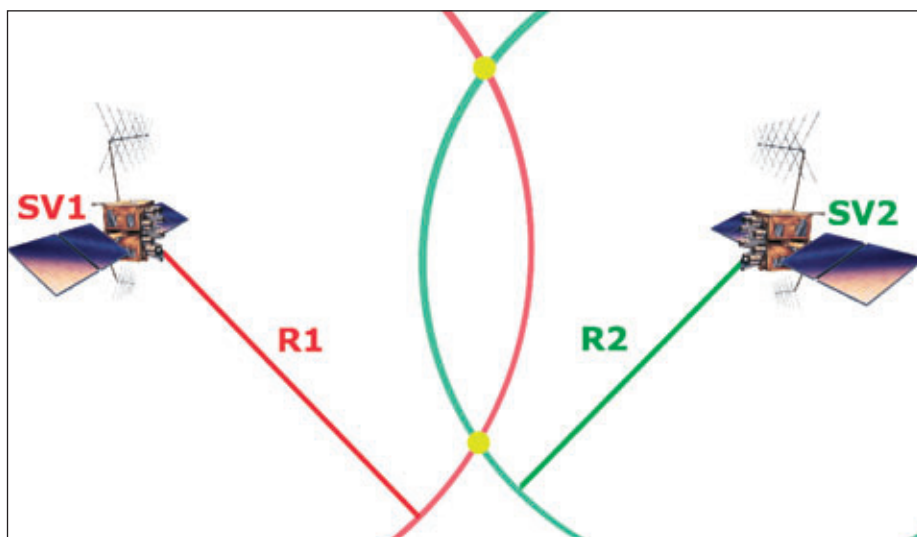


Figure 1: Two-dimensional positioning using two transmitters.

As discussed in the previous article, a GPS satellite is transmitting C/A code that is used for civilian purposes on L1 frequency.

Furthermore a navigation message is sent containing the almanac and ephemeris. But how does our receiver determine a position from these signals?

Let's first make the problem a little simpler and consider a two-dimensional system. Say we have a transmitter (GPS satellite) in a fixed location. From this transmitter we send a signal to a receiver whose position is unknown. If we can determine the exact time of transmission and reception, we can also determine the travel time of the signal.

When the propagation velocity of the signal is known as well, we can multiply the travel time by the propagation velocity and thus determine the range between the transmitter and the receiver. The velocity used is equal to the speed of light and is roughly equal to 300,000 kilometers per second. The range

we have determined in this manner is called a Pseudo Range in GPS.

Positioning

From a single range measurement a circle with a radius equal to the pseudo range and with the transmitter in the centre is obtained. Our receiver is somewhere on this circle. If we now measure the pseudo range from a second transmitter at the same moment, we will obtain two points where the circles intersect, see Figure 1.

But which of the two positions is correct?

This does not pose a problem since we have a rough idea of where our receiver is located because we can now exclude one of the two positions. The consequence is that if only few satellites are in sight, we need to tell the receiver the estimated position. The accuracy with which this estimated position should be determined is in the order of 300 kilometers from our true position.

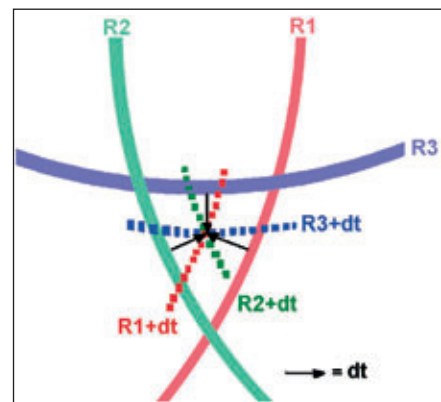


Figure 2: Clock correction with two-dimensional positioning.

When considering a two-dimensional system, only two transmitters and an estimated position will suffice for a position determination. However, GPS operates as a three-dimensional system and thus needs an additional transmitter (satellite) to determine its position. Furthermore, until now we assumed that the transmitters were fixed, but in the previous article it was shown that the satellites are revolving around the earth. The receiver thus needs the information in the almanac or ephemeris to determine the position of the satellite at the moment of transmission.

Travel Time Measurement

The accuracy at which the travel time from satellite to receiver has to be determined is high: for a range resolution of 15 meters a travel time accuracy of 2 nanoseconds is needed. And this on a total travel time between satellite and receiver of less than tenth of a second!

Hitherto we assumed that we could exactly determine the travel time, however while the satellites are equipped with atomic clocks our receiver must do with a simple quartz clock. In order to perform an accurate position determination, the receiver uses a special correction method with which the clock error of our quartz clock is determined.

The atomic clocks in the GPS satellites have an accuracy of only a few nanoseconds per day. The time difference and rate of change in the clocks is determined at each passage of the satellite over a ground station. This information is transmitted to the satellites once a week and is re-transmitted from the satellite to the receiver in the navigation message. The time of transmission of the

Determination

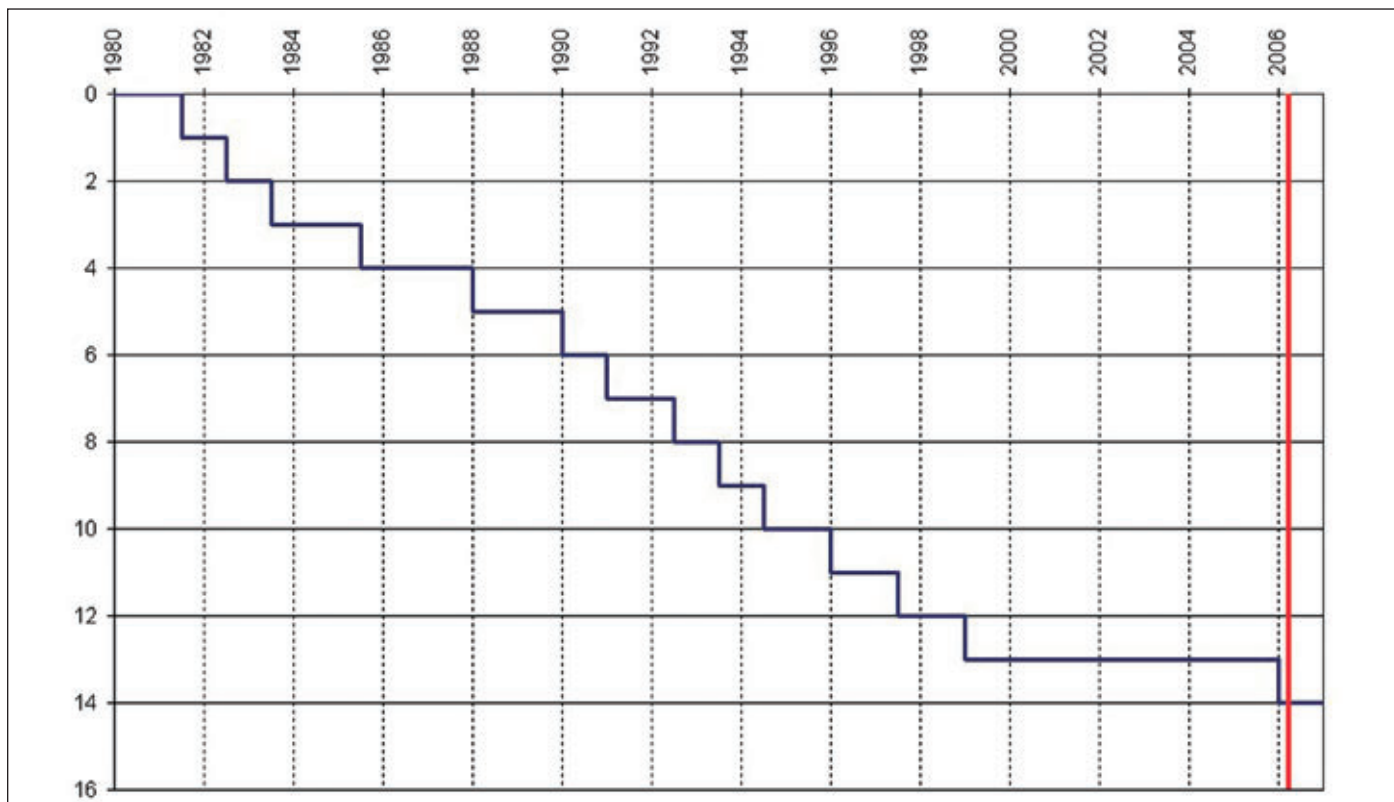


Figure 3: The atomic clocks in the GPS satellites were set to UTC in 1980. On the first of January the difference between UTC and TAI was 19 seconds. The atomic clocks in the satellites have since then not been adjusted to UTC and run 14 seconds late when compared to UTC as a consequence. On the first of January this year another leap second was introduced for the first time in several years.

GPS signals can thus be determined exactly. In order to obtain an accurate time measurement the receiver clock is set equal to the satellite clock every second by using an additional pseudo range measurement. In order to explain this correction method, a two-dimensional situation is considered, see Figure 2. If ranges from three transmitters are measured, these three ranges will not intersect exactly in one point due to the fact that our receiver clock contains an error. The three ranges (or Lines of Position – LOP) will form a so-called position triangle containing our true position. If the only error in our measurement is the clock error, then we can easily adjust since all the measured ranges will contain the same clock error. By correcting all pseudo ranges with the same clock offset (Δt) in such a manner that they intersect in one point, we will find our position and the clock error.

In the case of GPS however, we are not on a two-dimensional plane but in three-dimensional space. This means we need to have four satellites instead of the three from

our example in order to determine a single position.

Height Aiding

Before GPS was fully operational there were insufficient satellites and a special method was used to determine a GPS position using only three satellites instead of the four mentioned in the previous paragraph. With this method the height of the GPS antenna above sea level was inserted into the receiver. Because one of the four variables to be determined (Z) was now known, the reception of only three satellites sufficed to determine a position.

The great disadvantage of this so-called height aiding is that we need to determine the antenna height relatively accurate. This is hard if the antenna height is varying, as is the case in a vessel or aircraft, and results in a degraded position determination. The accuracy with which the antenna height needs to be determined is in the order of 1-2 meters. With the current GPS constellation of around 30 satellites the use of height aiding is only

needed under specific circumstances where one should question the use of GPS for position determination in the first place.

Receiver Clock

In the previous paragraphs it was shown that the clock time of the GPS receiver is closely linked to the clock of the GPS satellite. This results in the receiver clock having almost the same time accuracy as that of an atomic clock. Special GPS receivers are manufactured that are specifically meant for timing purposes. These receivers are for example used as input for the switching of power grids and telecommunications. Most people do not realize the effect of switching off the GPS signals in the Western world. They are not worried since they do not own a navigation system but will still be confronted with problems as telephone and electricity cease to function properly. From this point of view the development of both Glonass and Galileo can be easily explained. It is risky to depend on the goodwill of a single nation for a system that is such an integral part of the current, western, society.



Figure 4: GPS is not only used for positioning, but also for switching power and telecommunications. (source: www.convvoj.ch)

Time Systems

The method of time measurement in GPS is a mystery to most users. If, for example, we read the time of a simple GPS receiver and compare this time to that of an atomically controlled clock, we will find a difference of roughly 14 seconds.

In order to explain this phenomenon it is necessary to gain some insight into the various time systems in use today. The following time systems are generally used:

- Greenwich Mean Time (GMT). Also called solar time it is determined by taking the average time needed by the earth to make a complete revolution around the sun;
- Atomic Time (TAI). The time as displayed by atomic clocks. Since an atomic clock is accurate to roughly one second per million years this time is extremely accurate;
- Universal Time Coordinated (UTC). This is similar to atomic time but adjusted to GMT. The revolution of the earth around the sun is not constant causing the time needed for a complete revolution to change from day to day. Twice a year the difference between UTC and GMT is determined. If this difference is larger than 0.9 seconds UTC time is corrected with a single leap second. The current difference between TAI and UTC is 33 seconds.

The atomic clocks in the GPS satellites were set to UTC in 1980. On the first of January the difference between UTC and TAI was 19 seconds. The atomic clocks in the satellites have since then not been adjusted to UTC and run 14 seconds late when compared to UTC as a consequence, see Figure 3.

However, even though these leap seconds are not corrected in the satellite clocks, they are displayed in the navigation message of the GPS receiver.

Pulse per Second

Most professional GPS receivers offer the option for a co-called Pulse per Second (PPS) output. This is a signal that is exactly

half a second 'high' and half a second 'low'. Together with the PPS signal a message is sent (on a different port) stating the GPS time at which the PPS signal was transmitted. This message is sent within a second after the transmission of the PPS signal. The combination of both PPS signal and GPS time message is used in a number of systems and networks for time synchronization. The position messages from a GPS receiver contain both the calculated position as well as the time in UTC for which this position is valid. In the situation where we are using a PPS synchronized system a discrepancy will exist between the UTC time of the GPS position and the measuring time of the other sensors. This discrepancy, which is usually called the UTC-GPS time correction, will be highly significant when performing measurements from dynamic platforms. At a speed of 30 meters per second an error of a single second will result in a position error of 30 meters. In order to correct for this systems using PPS for synchronizing need to know the UTC-GPS time correction.

On the first of January this year another leap second was introduced for the first time in several years. Users with a PPS synchronized system who were not aware of this leap second were confronted with large errors in their survey systems as a result of an incorrect UTC-GPS time correction. Especially on slowly moving platforms such as vessels the detection of such an error can be particularly hard since the error is in the same order as the accuracy of the GPS position.

Notation of Time

GPS does not use a regular calendar with date and time but instead uses a week numbering system. Week 0 started 5/6 January 1980 at midnight UTC. The week numbers range from 0 to 1023. In 1999 GPS had its own "millennium" problem as the week number 1023 was reached in August. Contrary to the general expectation at the time, most receivers experienced no problems with this week number rollover and continued to work. Within the week numbering system, GPS does not work with days and hours but simply counts the number of seconds since the start of the GPS week. Because there is no correction for leap seconds in the GPS system, the current GPS week starts at 14 seconds before midnight in the night between Saturday and Sunday. A GPS week has a length of 604,800 seconds. When this is reached the week number is raised with one and the seconds are reset to zero.

This was the second article in a series considering the practical use of GPS. The next article will discuss the possible errors with satellite navigation and their impact on positioning.

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Figure 5: When measuring from dynamic platforms such as survey vessels, accurate timing is of utmost importance. (source: D.O.O.R. International)