Standard Positioning Service
Handheld GPS Receiver Accuracy

Christian Tiberius

Officially, the Global Positioning System has two levels of service: the Precise Positioning Service (PPS) which is afforded to the United States military, allied military forces and some other U.S. government agencies, and the Standard Positioning Service (SPS), available to all users worldwide. Currently, the SPS is provided by way of the Coarse/Acquisition (C/A) 1.023 megachip per second pseudorandom noise (PRN) code on the GPS L1 frequency at 1575.42 MHz. The vast majority of GPS receivers now in existence, including virtually all civil-use handheld receivers, are SPS receivers which determine their positions by tracking the L1 C/A-code.

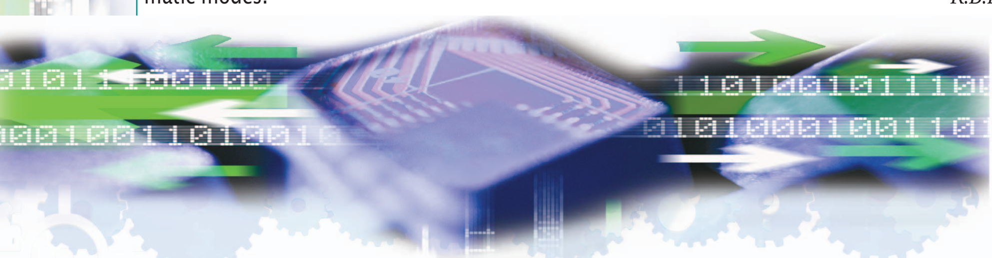
SPS policy initially dictated a predictable positioning accuracy of 100 meters, at the 95 percent confidence level, horizontally and 156 meters (95 percent) vertically. SPS positioning accuracy was purposely degraded to this level through the use of Selective Availability (SA). When SA was removed on May 2, 2000, SPS accuracy improved greatly, approaching that of the PPS.

The civil benefits of discontinuing SA. Previously, SA made it difficult to determine which highway a car was on, in areas where several highways run in parallel. Such inaccuracy caused problems for in-car navigation systems which could sometimes give erroneous turn information. Now, it may even be possible to determine in which lane of a multi-lane highway a car is traveling. Such distinction not only improves navigation but can also significantly benefit emergency vehicle response to E-911 calls which provide automated position information and roadside assistance vehicles responding to disabled cars.

SA removal has also benefited fleet management. Tracking the locations of taxis, buses, tractor trailers, and boxcars has become much more efficient especially in crowded parking lots and railway yards. In the field of aviation, SA removal enhanced the safety of GPS for non-precision runway approaches and generally improved pilot situational awareness. Recreational users of GPS have also benefited from SA removal as their waypoints now more precisely locate favorite fishing holes, boating obstacles, and game left for future retrieval. Fishermen can more accurately locate lobster pots and other fishing gear, and with SA removal, the orbits of satellites carrying GPS receivers can be more accurately determined and real-time onboard orbit determination is now possible.

So just how good is the SPS now? In this month's column, Dr. Christian Tiberius assesses current SPS performance in a case study using a handheld GPS receiver in both static and kinematic modes.

— R.B.L.



With a background in geodesy, I'm quite familiar with high precision applications of GPS. Working and researching in this area entails processing raw measurements of range in differential mode, resolving carrier-phase cycle ambiguities and using sophisticated models and calibrations for a wide range of error sources.

A few months ago my first personal handheld GPS receiver, five years old, was getting a little slow in acquiring satellites — or did I get impatient and more demanding in the meantime? I decided to replace it. I was surprised, to say the least, by the performance of the new one. Driven by personal curiosity, I decided to objectively assess this improved capability with regard to both position accuracy and signal tracking ability.

The results of my investigations show that the accuracy of single point or standalone GPS positioning lies at the few-meter to dekameter level, instead of – naturally – the millimeter to centimeter-level found in high-precision applications. Instead of using raw pseudorange measurements, this assessment is based on the positions as output by the receiver. The receiver was first installed at a known location (static test) and then I repeatedly drove a particular trajectory in a small van (kinematic test).

Static Analysis

A small external antenna attached to the handheld receiver was installed at a known location and measurements were taken over almost 14.5 hours in July 2002.

Ground Truth. For measuring position performance, one should use a location with position coordinates known to an accuracy at least one order better than the accuracy of the standalone GPS positioning under assessment. TU Delft maintains several reference points. One of the sites, part of the European Reference Frame (EUREF), sits atop the roof of the building housing the TU Delft Department of Geodesy. EUREF is the European densification of the International GPS Service (IGS) global tracking network, which provides a worldwide fundamental geodetic reference. The IGS employs, maintains, and contributes to the International Terrestrial Reference Frame (ITRF). At present, similar to the IGS tracking network, EUREF is realized by more than 100 permanent stations across Europe: the EUREF Permanent GPS Network.

The geodetic (ellipsoidal) coordinates of the point (see photo) are available in ITRF2000 (evaluated at a specific epoch (2002.0), as all points on the Earth's crust slowly move with respect to each other due to plate tectonics), and the local identification of the point is "Marker #18".

GPS uses a reference system known as the World Geodetic System 1984

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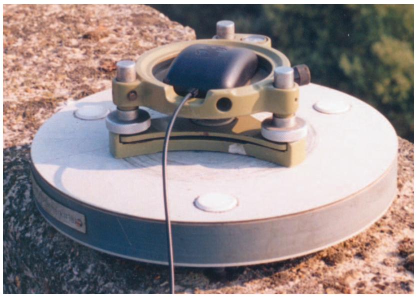


The external antenna atop marker #18, on the roof of TU Delft's Geodesy building. The site, 30 meters above ground level, has unobstructed visibility of the sky virtually down to the horizon, 360 degrees around.

The Continuing Need for DGPS

The removal of SA has not obviated the need for differential GPS (DGPS). Although in some places accuracies of stand-alone SPS might be as good as 5 to 7 meters in the horizontal, and 8 to 9 meters in the vertical, 95 percent of the time, such accuracies are by no means guaranteed. Furthermore, what about the remaining five percent of the time? To obtain horizontal and vertical position accuracies better than 5 meters with any kind of consistency, differential corrections are required. These may come from a regional source such as a coast guard radiobeacon or a wide-area system such as a space-based augmentation system. These differential systems also provide higher integrity than that afforded by basic GPS. Users requiring higher accuracy and integrity include aircraft, vessels navigating in congested harbors, railroads using precise train control, precision farmers and miners, and those entering data into geographic information systems.

Removal of SA has meant that DGPS systems do not have to transmit corrections as frequently. Satellite orbit and clock errors and ionospheric propagation delay errors, to a certain extent, do not change as quickly as SA errors did. So DGPS corrections now remain valid for longer periods than they did under the SA regime. — *R.B.L*

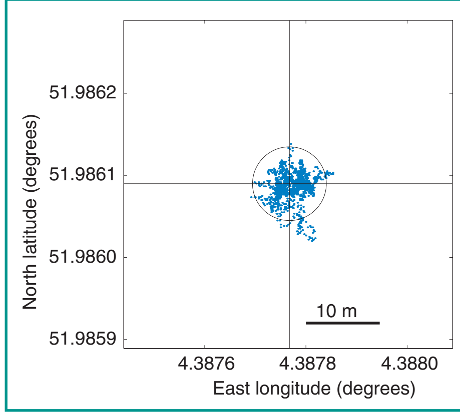


FIGURE 1 Horizontal position scatter (in WGS84) of over 1,700 samples at a 30-second interval. Grid represents the ground truth; circle has 5-meter radius.

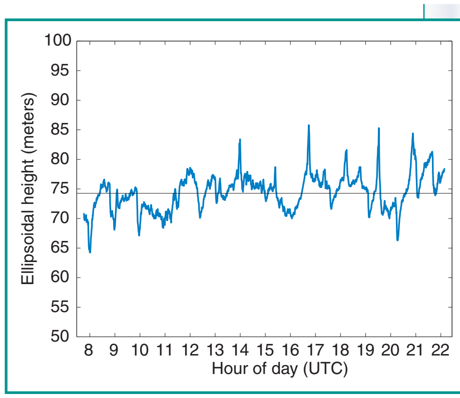


FIGURE 2 Height (in WGS84) as function of time; the horizontal line represents the ground-truth.

(WGS84), consistent with the International Terrestrial Reference System (ITRS). The current implementation of WGS84 is WGS84 (G1150) of January 2002, and coordinates in this frame agree at the few-centimeter level with those in ITRF2000. In summary, the coordinates of the point used are known with centimeter accuracy and were used here as absolute ground truth, to assess the position accuracy of standalone GPS.

The antenna was centered on the marker plate. The offset in height between the antenna's phase center (to which the receiver's positions refer) and the plate is just a few centimeters and has been neglected.

Positioning. Latitude and longitude, shown in **Figure 1**, can be interpreted as north and east coordinates in the local horizontal plane. Most of the positions, over the whole 14.5-hour time span, are within 5 meters of the ground truth. No outlying position samples were encountered. The horizontal dilution of precision (HDOP) was generally between 1 and 2.

Figure 2 shows the ellipsoidal height as a function of time. Note that local time is two hours ahead of UTC in The Netherlands during the summer.

The measurement time span comprised morning, afternoon, and evening, but no apparent atmospheric effects (in particular ionospheric) can be observed in Figure 2.

The height varies in a band of 10 meters on either side of ground truth.

For numerical analysis, the difference of latitude, longitude and height from the ground truth has been computed, and **Table 1** gives the mean and standard deviation over the full time span. As already indicated by Figures 1 and 2, there is no reason to suspect any systematic offset or bias in the obtained position solutions. The mean position over all 1,712 samples is in good agreement with the ground truth; the deviation is only a few decimeters.

The spread in the position solutions is remarkably small. The precision of the individual position solution (given by the standard deviation) is less than 2 meters for the horizontal components and slightly over 3 meters for the vertical. These values are close to those that can be obtained with conventional code-differential GPS.

The last row of Table 1 contains the 95th sample percentiles of horizontal and vertical position error; 95 percent of the position errors, over the full time span, are within the limits given.

Other Analyses. Of course, I cannot claim that the results from a single 14.5-hour session are necessarily typical. In fact, they appear to be representative of the best SPS results currently achievable without differential corrections.

Colleagues at the University of New Brunswick in Fredericton, Canada have also performed some SPS accuracy tests. Using an OEM receiver and a rooftop-mounted antenna, they collected position results continuously for two days in December 2002 at a nominal 3-second sampling interval. On December 18, the 95 percent horizontal and vertical accuracies obtained were 5.3 and 6.9 meters respectively. However, on December 19, the corresponding horizontal and vertical accuracies were 9.6 and 9.8 meters.

Dennis Milbert, a geodesist with the U.S. National Geodetic Survey, using a receiver similar to that used in my own

TABLE 1 Mean and standard deviation of GPS single point positions with respect to known reference, over almost 14.5 hours of data at a 30-second sampling interval. The 95th sample percentile values refer to the (2-D) horizontal position error and the absolute vertical position error.

	latitude	longitude	height
mean [meters]	−0.40	0.50	0.17
standard deviation [meters]	1.79	1.82	3.11
95th percentile [meters]	4.83		6.34

tests, collected 2-second position results (subsequently decimated to 30 seconds), more or less continuously for the month of June 2001. The antenna was located in the attic of a Washington, D.C.-area town house, and an accurate reference position was determined for it using differential carrier-phase observations. He obtained an overall 95 percent horizontal accuracy of 7.7 meters and a 95 percent vertical accuracy of 14.3 meters.

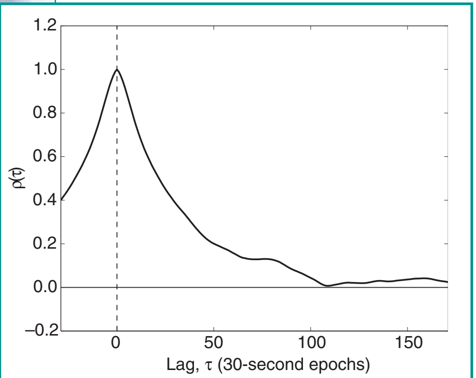


FIGURE 3 Auto-correlation function of height from 1,700 samples at 30-second intervals

Comprehensive Testing. The U.S. Federal Aviation Administration assesses SPS performance through observations made continuously at more than a dozen sites around the country. It reports 95 percent horizontal and vertical accuracies in its quarterly performance reports; these values are usually between 5 and 7 meters and around 8 to 10 meters, respectively.

Correlations. The auto-correlation function of the height determinations appears in **Figure 3**. The lag along the horizontal axis is given in terms of 30-second intervals. At lag zero, the correlation coefficient is 1 by definition. The correlation in the position coordinates extends over several tens of minutes. The correlation is 0.5 at about lag 20, corresponding to 10 minutes. Only after more than half an hour does the correlation drop off to about zero.

Why are the sequentially determined heights so correlated? Causes for the observed time correlation can lie in effects of error sources not (or not sufficiently) accounted for by models employed and which change (at the decimeter-meter level) relatively slowly, as for instance atmospheric delays. Secondly, filtering by the receiver itself introduces correlation in its output. The latter effect is not believed to be severe, as the receiver seems to respond adequately to changes in motion (accelerations), both slow and very sudden.

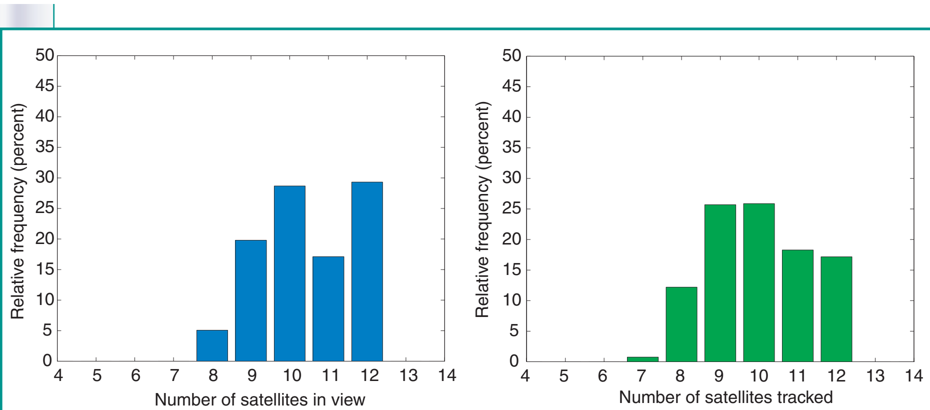


FIGURE 4 Histograms of number of satellites in view (left) and tracked (right) in static test over almost 14.5 hours; no elevation cut-off angle was imposed, and there was unobstructed visibility of the sky down to the horizon

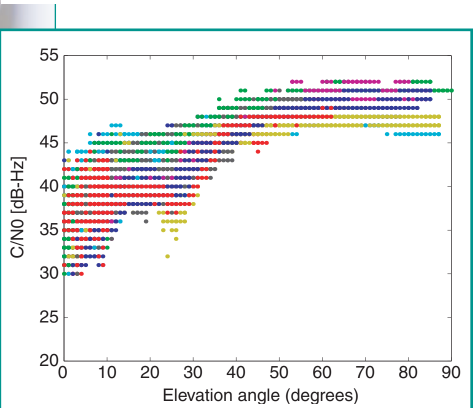


FIGURE 5 Carrier-to-noise density ratio versus satellite elevation angle of observation in static test. Colors designate different satellites.

Although the receiver provides new positions at a high rate (up to once per second), the successive positions definitely do not represent independent samples. On the other hand, the correlation implies that coordinate differences can possess sub-meter precision (standard deviation), provided that the positions are observed at closely spaced epochs in time, for example, just a few minutes apart.

Signal tracking. Comparison of the two histograms of **Figure 4** shows that the receiver rarely misses any visible satellite; overall the receiver tracked 95.6 percent of the satellites available above the horizon. Detailed analysis showed that all satellites above an elevation angle of 10 degrees are tracked. Usually a satellite is tracked from a few degrees above the horizon when it rises, down to a few degrees when it sets again, and some satellites are tracked from horizon to horizon. Over nearly 14.5 hours, the minimum number of satellites tracked was seven, but tracking of seven satellites occurred for less than 1 percent of the time. On average, 10 satellites were tracked simultaneously. The histograms, both the number of satellites in view (in blue) and the number of satellites tracked (in green), are bounded to 12 satellites, the maximum number of satellites which the receiver can track.

Figure 5 shows the signal-to-noise ratio (actually the carrier-to-noise density ratio C/N_0, as output by the receiver and likely expressed in dB-Hz) as a function of satellite elevation angle. The trend in keeping with the rule-of-thumb, "the higher the satellite elevation angle, the stronger the received satellite signal," can be observed clearly. When a satellite appears at the horizon, the signal-to-noise ratio is in the range of 30-40 dB-Hz, and it increases up to a maximum of slightly over 50 dB-Hz once the satellite is at 50–60 degrees elevation angle or higher.

The trend in Figure 5 is in large measure due to the antenna gain pattern: the antenna is less sensitive to signals arriving at low elevation angles. Low elevation angle signals can be affected by undesired reflections (multipath), and their effect (as they arrive delayed, by the detour, as compared to the direct path signal) on the receiver's tracking loops and eventual pseudorange measurements should be minimized. Even signals at negative elevation angles are possible. The antenna gain is therefore typically reduced at low elevation angles.

During the full measurement time span of almost 14.5 hours in Figure 5, all of the 28 available GPS satellites were tracked (each for at least 250 epochs, at the 30-second interval).

Kinematic Analysis

The antenna was mounted on the back of a small van (see **photo**), and the same trajectory was driven, both ways, five times. The drive starts just outside the town of Delft, in The Netherlands' metropolitan area, taking highways past built-up areas of Rotterdam and Dordrecht. It ends in the provincial town of Roosendaal, 50 kilometers south of Delft, right in the town-center, after a few kilometers track over local streets through a built-up area.

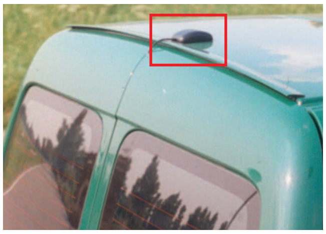
Positions were recorded at 2-second intervals, at highway driving speeds of 80 to 100 kilometers per hour, over a one-hour run. For the purpose of repeatability, I always drove in the same right-hand lane. The measurements were carried out on different days from July through September 2002.

Positioning. For the kinematic test, I considered position repeatability instead of establishing precise ground truth. **Figure 6** shows five runs in each direction, outbound in red and return in blue. Street width is indicated at two spots on the graph. The area in the middle of the single lane roundabout in the right lower corner has an 18-meter diameter.

On a straight section of highway, about halfway through the trip, the desired track could be followed to within a few decimeters. There is generally an unobstructed view of the sky at this site, and the driving speed was usually about 90 kilometers per hour.

Though a precise reference trajectory is absent, the good physical repeatability allows us to partly assess positioning accuracy numerically under kinematic circumstances. I have examined the across track (horizontal) error and the height error over ten one-way runs in the forward direction (using five additional runs in this direction, September–December). **Table 2** gives the empirical standard deviations and the

The kinematic test included travel on the A16 multilane highway.



The external antenna mounted on the back of the van. The roof is about 1.8 meters above the road surface.

The Standard Positioning Service

Each GPS satellite currently in orbit transmits two positioning signals: L1 centred on a carrier frequency of 1575.42 MHz and L2 centred on 1227.60 MHz. Modulated onto the L1 carrier are two pseudorandom noise (PRN) codes: the 1 millisecond-long Coarse/Acquisition (C/A)-code with a chipping rate of 1.023 megachips per second and a week-long segment of the encrypted precision (P)-code with a chipping rate of 10.23 megachips per second. The C/A-code and the one-week segment of the P-code are unique to each satellite. Also superimposed on the carrier is the navigation message, which, among other items, includes the ephemeris data describing the satellite's position and clock correction terms. The encrypted P-code and the navigation message modulate the L2 carrier – the C/A-code is not present. Provision of the C/A-code to all GPS users is known as the Standard Positioning Service (SPS).

The encrypted P-code (called the Y-code) is available only to users authorized by the U.S. Department of Defense (DoD) through the Precise Positioning Service (PPS). A receiver with a cryptographic key is required for PPS access. The encryption procedure is known as anti-spoofing and was formally activated on all Block II satellites on January 31, 1994.

Tests conducted in the late 1980s showed that use of single-frequency C/A-code measurements provided position accuracies approaching those of dual-frequency P-code measurements, especially during benign ionospheric conditions. In response, the DoD decided to limit the accuracy afforded by the SPS by purposefully degrading the SPS signal through a procedure called Selective Availability (SA). SA was effected through satellite clock dithering – manipulating the frequency of the satellite clock which affects all code and phase measurements. SA was imposed at a level which would yield a stated SPS horizontal position accuracy of 100 metres or better 95 percent of the time for any point in the world during a measurement interval of one day. The corresponding vertical positioning accuracy was 156 meters or better. On May 2, 2000, the SA level was set to zero. SPS users immediately saw a quantum jump in positioning accuracy. Some users reported twice distance-root-mean-square errors of 10 meters or less.

With the removal of SA, uncorrected ionospheric delay and multipath are the largest SPS error sources. Whereas dual-frequency PPS receivers can remove almost all of the ionospheric delay on their measurements, single-frequency SPS receivers must rely on an empirical model to reduce the effect of the ionosphere. The GPS navigation message includes parameter values for such a prediction model. However, this model typically accounts for only about 50 percent of the actual delay on average. Residual range errors can vary from a meter or so to 7 meters or more. The effect of multipath can be reduced through the use of special antennas and sophisticated receiver designs. However, most SPS receivers have no special provisions for attenuating multipath effects. Investigators have reported measured multipath on pseudoranges of about half a meter or less in benign environments and up to 4 to 5 meters or so in some highly reflective areas.

According to the U.S. government's 2001 Federal Radionavigation Systems report, "SPS [now] provides a global average predictable positioning accuracy of 13 meters (95 percent) horizontally and 22 meters (95 percent) vertically." These values should be considered as rather pessimistic even though they only account for signal-in-space errors (satellite orbit and clock errors) and do not account for the single-frequency ionospheric model errors, tropospheric delay model errors, multipath, or receiver noise. As the accompanying article helps illustrate, currently achieved horizontal SPS accuracies at a 95 percent probability level at sites with minimal multipath are often better than 7 meters – sometimes even better than 5 meters. SPS users can achieve even higher positioning accuracies through the use of differential GPS (DGPS) corrections from public or commercial DGPS service providers.

Under the GPS modernization program, a civil PRN code will be added to the L2 signal to be transmitted by the Block IIR-M satellites which will be launched starting in 2003 or 2004. The use of L2 code measurements along with those on L1 will virtually eliminate the ionospheric delay error and further improve SPS positioning accuracy. A third civil signal will be added on the L5 frequency (1176.45 MHz) for use in safety-of-life applications. L5 can also serve as a redundant signal to the GPS L1 signal. The L5 signal will be transmitted by Block IIF satellites with the first launch scheduled for 2005.

— R.B.L.

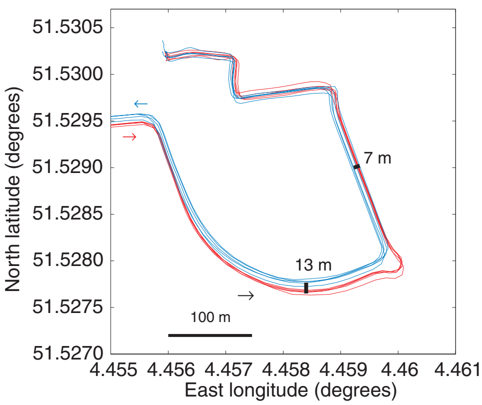


FIGURE 6 Position repeatability over the last part of the trajectory through a built-up area, with driving speeds up to 50 kilometers per hour. The photo at right is taken at the arrow; the street consists here of two single lanes, 4 meters wide, with a 5-meter green section in the middle.

TABLE 2 Kinematic positioning repeatability; standard deviation and maximum range of (horizontal) across-track and height error, in meters.

	across-track	height
standard deviation [m]	1.03	3.67
max-min [m]	2.95	10.13

total spread (maximum difference between two runs).

The standard deviation of the height component is slightly larger than that obtained in the static test, but for the across-track error it is clearly smaller than those for latitude and longitude as given in Table 1.

With the equipment used, multipath does not seem to be a concern. The metal surface of a car is not a benign environment for a sensitive GPS antenna, let alone other vehicles (such as large trucks) in the direct vicinity and tall structures along the road. With different satellite geometries over many days, the position repeatability is surprisingly good (see the example of Figure 6), and is also in line with the results of the static test.

Signal Tracking. Small obstacles (for example portals and overpasses) are bridged "unnoticed" by the receiver; it keeps on providing full position solutions at the required 2-second interval, and it keeps tracking the satellites (at least the higher-elevation angle ones). The only significant problem with signal reception was encountered in the Drecht Tunnel (see **Figure 7**). At a nominal speed of 90 kilometers per hour (25 meters per second), the interruption while traveling in the tunnel lasts for slightly more than 20 seconds (10 samples). Though the receiver indicates that no satellite signals are being received at all, it still outputs positions (apparently it extrapolates on previous positions, as can be seen in the graph on the right of Figure 7). Only when the tunnel is driven through slowly (with the satellite blockage lasting for more than 20 seconds) does the receiver eventually stop providing position solutions.

Concerning the number of satellites, a slight discrepancy has been observed between the signal-to-noise ratios (deter-

Further Reading

For the official government policy on the Standard Positioning Service levels of performance, see

- *Global Positioning System Standard Positioning Service Performance Standard*, by the U.S. Department of Defense, Washington, D.C., October 2001. Online version available at <http://www.navcen.uscg.gov/gps/geninfo/>

For the Federal Aviation Administration's quarterly SPS performance analyses, see

- *Global Positioning System (GPS) Standard Positioning Service (SPS) Performance Analysis Reports*, prepared by the William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The reports are available on line at <http://www.nstb.tc.faa.gov/>

For daily statistical analyses of GPS signal-in-space errors and daily PPS performance reports, see

- U.S. Space Command GPS Support Center <https://www.peterson.af.mil/GPS_Support/>

For further details on the SPS accuracy analyses carried out by Dennis Milbert, see

- GPS Accuracy Monitor <http://mywebpages.comcast.net/dmilbert/handacc/accur2.htm>.

For a discussion of the effect of ionospheric delay on SPS, see

- "Variations in Point Positioning Accuracies for Single Frequency GPS Users During Solar Maximum" by S. Skone, V. Hoyle, S. Lee and S. Poon in *Geomatica*, Vol. 56, No. 2, 2002, pp. 131-140.

For a discussion of the temporal correlation on standalone GPS positioning, see

- "Temporal Impact of Selected GPS Errors on Point Positioning" by M. Olynik, M.G. Petovello, M.E. Cannon and G. Lachapelle in *GPS Solutions*, Vol. 6, No. 1-2, 2002, pp. 47-57.

mining the number of satellites tracked) and the number of satellites in use for the position solution, as indicated by the receiver. When a satel- lite signal is lost, for instance by passing some overhead obstruction, the signal-to-noise ratio drops to zero immediately, but the number of satellites used in the position solution is adapted, apparently with a delay of a few seconds. Consequently, values for the number of satellites in use, as output by the receiver itself, may yield a statistic that is too optimistic. The number of satellites tracked, as presented in this article, is therefore based on the number of satellites with non-zero signal-to-noise ratios.

Figure 8 presents the number of satellites, accumulated over all runs. On average, eight satellites were tracked during the kinematic test. Compare these performances with the histogram of Figure 4 for the static test with unobstructed view of the sky.

Figure 9 shows the last part of the trajectory in the built-up area, where the individual position solutions are color-coded to indicate the number of satellites tracked; positions from fewer than the minimum number of four satellites are colored red, those from more than seven satellites blue, and those from 4, 5, 6, and 7 satellites are colored magenta, yellow, green, and cyan respectively. Again, five runs are shown, both ways.

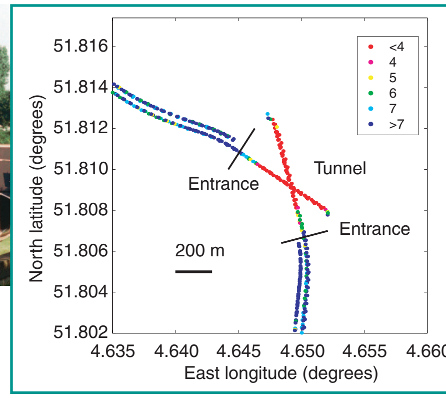


FIGURE 7 The Drecht Tunnel under the Oude Maas River in Dordrecht blocks satellite signal reception over a distance of more than 550 meters. During a short period without signal reception, the receiver provides positions by extrapolation; between entrance and exit however, the tunnel changes heading by about 60 degrees, and a significant correction (jump) in position is experienced upon exiting the tunnel, when the satellite signals are re-acquired; five runs are shown both ways. The individual position solutions are represented by dots, color-coded to indicate the number of satellites tracked. the receiver quickly re-acquires satellite signals upon leaving the tunnel.

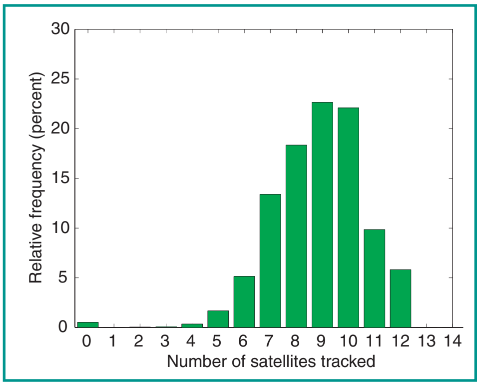


FIGURE 8 Histogram of number of satellites tracked, accumulated over all runs in the kinematic test, representing in total more than 700 km of measurements

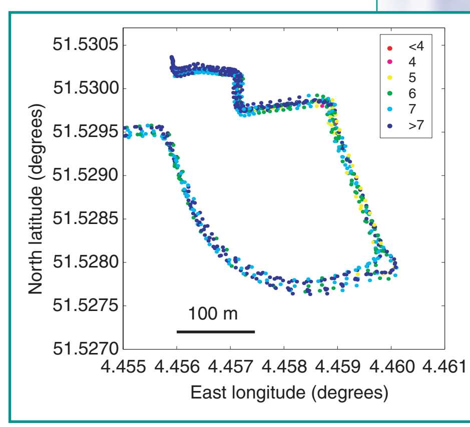


FIGURE 9 Number of satellites tracked along the trajectory. Foliage (see Figure 6) does not seem to affect signal reception. A narrow street north of the roundabout, with houses of up to three-storeys, reduces the number of satellites tracked incidentally to the minimum of four.

Data Logging

Data for all tests were output in NMEA 0183 format at a 2-second interval (the receiver sends the NMEA messages at 4800 bits per second). The NMEA sentences were logged, over the serial RS232 connection, to files on a simple laptop computer, by means of a rudimentary program running under MS-DOS.

Concluding Remarks

Static and kinematic tests carried out with a simple, current commercial handheld GPS receiver showed good overall performance. Standalone position accuracy was shown to be at the few-meter level (standard deviation). Tracking capabilities and position availability were found to be excellent. Accumulated over all kinematic runs, seven satellites or more (with four being the absolute minimum for a full three-dimensional position solution) were available for 92 percent of the time.

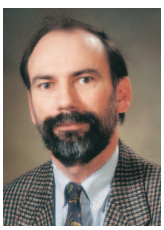
Note that the trials underlying these results are of a "snapshot" character; they refer to one particular receiver at one specific place on Earth, and to a limited interval of time — although the kinematic trials represent more than 15 hours of measurements over six months. Furthermore, these results are based on a redundant GPS constellation with up to 28 healthy — though for the majority ageing — satellites, whereas the nominal constellation features only 24 satellites. ⊕

Handheld GPS receiver used for the experiments.

Manufacturers

A **Garmin Ltd.** (Olathe, Kansas) *GPS 76* handheld receiver fed by a Garmin *GA-27C* external antenna provided the data for the Dutch tests.

The UNB tests used a **Mobile Knowledge Inc.** (Kanata, Ontario, Canada) *MKN5610* evaluation kit. The Washington, D.C.-area tests used a Garmin *GPS Map 76*.



"Innovation" is a regular column featuring discussions about recent advances in GPS technology and its applications as well as the fundamentals of GPS positioning. The column is coordinated by Richard Langley of the Department of Geodesy and Geomatics Engineering at the University of New Brunswick. To contact him, see the "Columnists" section on page 2 of this issue.