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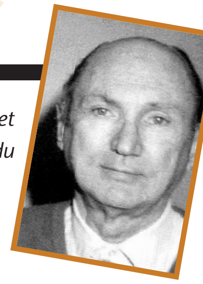

FINDING YOUR WAY WITH THE GARMIN GPS V

By Douglas Tougaw

GLOBAL POSITIONING SYSTEM (GPS) TECHNOLOGY BEGAN WITH THE LAUNCH OF THE FIRST NAVSTAR SATELLITE IN 1978. BY 1994, A FULL CONSTELLATION OF 24 satellites was orbiting Earth, providing military personnel with precise positioning data for such tasks as troop movements, artillery targeting, and missile guidance. Many of the most impressive military videos seen over the past 15 years have partially resulted from the Navstar satellite constellation's success.

Fortunately for us civilians, the government has also allowed nonmilitary users access to their multibillion-dollar investment. Thus, the technology originally designed to enable a missile to find a particular building hundreds of miles from its launch site can now help you find your way to an unknown destination hundreds of miles from your home.

Perhaps even more important for our community is the wide variety of scientific and engineering applications to which we can apply this technology. Any scientist or engineer whose job description includes fieldwork should consider a GPS unit as invaluable as a calculator or a laptop computer. Whether you are responsible for maintaining an array of power distribution equipment, collecting geological samples, or taking meteorological readings, the GPS system can be a powerful tool in your professional life.

The basics of GPS operation

GPS technology determines a user's position by calculating the distance from several satellites whose locations are precisely known. If you know, for example, that you are 10,500 miles from a particular satellite, then you can state with certainty that your location is somewhere on a sphere whose center is the satellite and whose radius is 10,500 miles. If you know that your location is also 11,000 miles from a second satellite, you can further restrict your location to a second sphere. The intersection between these two spheres is a circle. Knowing your distance from a third satellite would further limit your possible location to the surface of a third sphere; the intersection of three spheres is, at most, two points.

Typically, one of these two points will be on or near the Earth's surface, so if you know your approximate altitude, you can identify your location with just three satellites. However, GPS is designed to help control airborne systems as well as ground-based ones, so a fourth satellite can distinguish between these two remaining points, providing altitude in addition to latitude and longitude.

Thus, determining a user's location on or near the Earth's surface can be reduced to determining the distance to each of three or four satellites whose positions are precisely known. Each satellite used for GPS contains an atomic clock that keeps virtually perfect time. The satellites use these clocks to send pseudorandom sequences of numbers over their radio antennas. The satellite antennas operate at a frequency of 1575.42 MHz and at a power of approximately 50 watts. Each of the 21 active GPS satellites has its own well-known algorithm for calculating a particular pseudorandom number sequence, so at any particular time, we can determine the number that each active satellite is transmitting. The remaining three satellites are kept in reserve in case one of the primary satellites fails.

A typical handheld GPS unit also contains a precise clock, although most do not contain an atomic clock. The unit calculates the same pseudorandom sequence of numbers that the satellites calculate and transmit. By measuring the delay between when it calculates that a satellite transmits a particular number and when the GPS unit receives that number, and then dividing by the speed of light, the unit can calculate its distance from the satellite.

Two potential problems arise in this calculation. First, a satellite's orbit is not perfect. It occasionally needs to fire a small thruster to correct for small orbital imperfections. If a typical non-GPS satellite's location is imperfect by, say, 100 feet, this doesn't greatly affect its correct operation. However, if a GPS satellite's position is off by 100 feet, it will substantially degrade the receiver's precision. We can overcome this problem using *almanac* and *ephemeris* data. Each satellite constantly broadcasts almanac data, giving its ideal location. Ephemeris data corrects this ideal almanac data, accounting for small fluctuations in the satellite's path. The base station controlling the satellite determines ephemeris data and broad-

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Figure 1. The Garmin GPS V unit.

casts it up to the satellite, which transmits it along with its almanac data and pseudorandom sequence.

The second problem with the basic algorithm for determining the distance to a satellite is the imprecision of the local clock onboard the GPS unit. A quartz clock might have more than sufficient precision for most applications, but light travels approximately one foot per nanosecond, so the requirements for precisely measuring time in this application are incredibly strict. We can overcome this by using an additional satellite. Four satellites are sufficient for determining 3D location given a perfect local clock, so a fifth satellite can correct small errors to the local clock.

Imagine, for example, that you had precisely determined your location in space using four satellites, but that the location you determined was not on the sphere a fifth satellite defined. This error can only be due to fluctuations in the speed of light (more on this later) or the local clock's imprecision. An iterative adjustment of the local clock phase can minimize the error seen by all five satellites. Even more precise corrections can be made when we use more than five satellites. Currently, the best commercially available GPS units can monitor up to 12 satellites at once.

It is important to note that the government has not completely released GPS technology into the public domain. Of course, they still control all the satellites, so they can adjust the signals being transmitted to suit their needs. In fact, the civilian and military GPS signals are transmitted at different frequencies, so one could be disabled without affecting the other. Until May 2000, a strategy known as *selective availability* introduced random timing errors into the civilian GPS signals to prevent them from being precise enough for enemy troops to use against the United States. Since the government disabled SA, precision of civilian GPS has improved tremendously. The introduction of the Wide-Area Augmentation System has further improved GPS precision.

Wide-Area Augmentation System

WAAS is a GPS enhancement that accounts for local variations in the composition of the Earth's ionosphere and troposphere. Because light travels at different speeds through materials of differing composition, there will always be some error in the distance measured to a particular satellite. Using an array of 25 ground reference stations that are at precisely surveyed locations throughout the US, we can determine the effect of these local atmospheric variations. We can then calculate and broadcast (via satellite) the corrections to all WAAS-enabled GPS units in the country.

For example, suppose I calculate my location in the traditional way using five or more satellites, but I am very near a WAAS correction station that has identified a known 10-foot error in the location it is calculating from the same satellites. I can subtract that 10-foot error from my calculated position to make my measurement more precise, canceling the effect of atmospheric variations.

With SA disabled, WAAS-enabled GPS units can typically measure position with an accuracy of approximately 10 to 16 feet. This is the best precision currently available using commercially available handheld GPS units.

The Garmin GPS V unit

The GPS V unit is Garmin's (www.garmin.com) most recent model. It is 5.0 × 2.3 × 1.6 inches, weighs just nine ounces, and has a built-in high-resolution LCD screen with backlighting (see Figure 1). It contains 19 Mbytes of nonvolatile user memory in addition to an unspecified (but substantial) amount of system memory that comes preprogrammed with the locations of every major US road, highway, interstate, town, and city.

We can power it for up to 25 hours on four AA batteries, although using backlighting substantially decreases this time. It also comes with a serial cable for connection to a laptop or desktop PC and a 12-volt power cable for powering by an automobile accessory outlet.

The GPS V takes approximately five minutes to acquire a satellite lock in a "cold start" (one in which it has been turned off for more than a few days). If it has only been turned off for a short time period, it still has information about the satellite almanac and can quickly determine the satellites it expects to be currently visible. In such a "warm start," the GPS V can reacquire its satellites in a matter of seconds.

The GPS V has 12 parallel channels designed to independently track up to 12 satellites at once. One of the user interface's main pages shows which satellites should be visible and which ones are actually being used to calculate the unit's position. In my experience, you can usually expect the device to lock on to approximately eight satellites. Fortunately, because these transmissions are satellite-based, there are few "dead zones" such as those encountered with cellular phone networks. However, these are line-of-sight signals, meaning that GPS cannot typically be used indoors, underground, or underwater. I have had some luck with indoor reception using this unit, but it is definitely less reliable.

Used correctly, precision is typically excellent, and the GPS V helpfully calculates an approximate error range on the position it delivers. This error range varies as the atmospheric conditions change but is usually in the range of 15 to 20 feet. Another nice GPS V feature is that it can collect many samples from the same location and integrate them together to provide higher precision on that one point's location. When my GPS collected and integrated data at a particular point for 10 minutes, it collected 600 samples. The predicted error of each individual measurement was 19 feet, but the predicted error of the integrated data was just 7.6 feet. For most nonsurveying applications, this precision is more than sufficient.

I found the screen very easy to read, although those who have trouble reading fine print might want to consider a unit with a larger screen. The resolution was excellent (256×160 pixels), and variable backlighting and contrast provide a great deal of control, letting the user adjust to many different environments. A color screen would, of course, be welcome, but it would come at a higher cost in terms of both power consumption and list price. For the purposes of this device, a four-level grayscale screen is sufficient.

The interface to the PC is convenient and quite intuitive. The unit's purchase price includes the opportunity to "unlock" detailed map information for one of seven regions of North America. Additional regions can be unlocked at an additional expense. This "feature" frustrated me, because I live quite near the boundary between two regions. I'm sure that for most users this will not be a great problem, but it would be more convenient if two regions could be unlocked with the purchase of the GPS unit.

The MapSource software lets the user upload information from the GPS unit to the PC, including the location of marked points and precise tracks that the user followed. This is probably one of the most useful features for scientific users, because it can precisely mark the location of a particular specimen, measurement, or job site.

In addition, the MapSource software can download detailed maps (within your chosen region), selected routes, and waypoints directly to the GPS unit. Just as with devices such as Palm Pilots, I found it much more efficient to do most of my work on the PC and download the results to the GPS unit.

The user interface consists of the LCD screen, eight buttons, and a single eight-direction rockerpad. Unlike many engineers, I tend to read a new piece of equipment's instruction manual cover-to-cover before I turn it on, but I didn't find that helpful here. The manual appears to be well written, but I learned more about the correct operation of this device in a 10-minute test than I did in an hour of reading about it. The layout of the buttons is not intuitive but is easily learned. At least two of the buttons seem redundant and could be removed in future models.

The most frustrating thing I encountered in approximately 15 hours of testing is the wrist strap connection's poor design. This might seem trivial, but the wrist strap connects directly to the battery cover. If you lift the metal tab on this cover and rotate it 90 degrees (which can happen quite easily if you carry the device by the wrist strap), the batteries automatically eject themselves quite forcefully. This happened twice during my testing, and one of these times I was unable to locate all the batteries after they fell out. Of course, removing power from the system requires a reacquisition of the satellites and a confirmation of the new location. This is more of a nuisance than anything else, but I would recommend throwing away the wrist strap and carrying the unit in your pocket when it is not in use.

The Garmin GPS provides excellent precision, a flexible user interface, and detailed built-in mapping capabilities for a reasonable price. (The list price is US$499, and several authorized resellers offer discounts over the Internet.) It is unlikely that GPS technology will improve substantially on the currently available precision without the use of much more advanced (and expensive) add-on units, so if your work could benefit from precise knowledge of your current location, I highly recommend the Garmin GPS V.

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