GPS: Location-Tracking Technology

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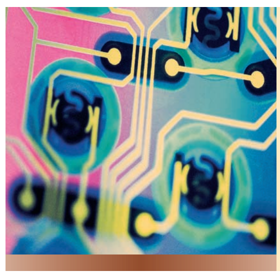

Increasing commercial use of the Global Positioning System will soon make it possible to locate anything, anywhere, anytime.

Radiolocation tracking systems are an area of growing significance in the field of wireless communications. In particular, the satellite-based Global Positioning System initiated by the US Department of Defense in 1978 promises to revolutionize location-tracking technology as commercial usage increases. Offered free of charge and accessible worldwide, GPS is rapidly becoming a universal utility as the cost of integrating the technology into vehicles, machinery, computers, and cellular phones decreases.

Location tracking has been of great importance since World War II, when military planners realized its usefulness for targeting, fleet management, positioning, and navigation. Today, GPS has a wide range of other applications including tracking package delivery, mobile commerce, emergency response, exploration, surveying, law enforcement, recreation, wildlife tracking, search and rescue, roadside assistance, stolen vehicle recovery, satellite data processing, and resource management.

Tracking methods are generally based on a moving object's distance, direction, or both. Dead reckoning is a primitive location estimation technique that involves computing an object's direction and distance from a known starting position. Beacon systems, also known as proximity or signpost systems, use an object's acceleration to calculate its location and are well suited for fixed-route operations in small areas. Radiolocation systems including GPS and more limited systems such as Loran—a long-range, accurate navigational system used by ships and aircraft—measure the radio signals exchanged between a mobile unit's transceivers and a set of fixed stations.

A GLOBAL TECHNOLOGY

GPS consists of a network of 24 satellites in six different 12-hour orbital paths spaced so that at least five are in view from every point on the globe. The satellites continuously transmit military and civilian navigation data on two L-band frequencies. Five monitor stations and four ground antennas located around the world passively gather range data on each satellite's exact position. The system relays this information to the master control station at Schriever Air Force Base in Colorado, which provides overall coordination of the network and transmits correction data to the satellites.

Each satellite emits radio signals that a receiver—a miniature device installed on a vehicle or carried by hand—uses to estimate the satellite's location as well as the distance between satellite and receiver. As Figure 1 shows, the receiver can roughly determine its position by locking on to the signals of at least three satellites, a technique commonly known as triangulation but more precisely called *trilateration*.

With four or more satellites in view, the receiver can determine the user's latitude, longitude, and altitude. Once it has calculated the user's 3D position, the receiver can calculate other useful information such as speed, bearing, track, trip distance, distance to destination, and sunrise and sunset time.

To obtain an accurate fix on a moving object or person, GPS determines how long it takes a satellite signal to reach a receiver, which generates its own signal. Assuming that the signals are synchronous, GPS compares the satellite signal's pseudorandom number code—a digital signature unique to each satellite—with the receiver's PNC to determine the signal's travel time. The system multiplies this value by the speed of light to compute the satellite's distance from the receiver.

Because the satellites are nearly 11,000 miles away, miscalculating signal travel time by even a few milliseconds can cause a location error measuring as much as 200 miles. Satellites therefore use extremely precise—and expensive—atomic clocks. A receiver's clock doesn't need to be as accurate because it measures the distance to a fourth satellite to synchronize its PNC with the satellites and correct for any timing offset.

Because the satellites serve as reference points, accurate location tracking requires knowing exactly where they are at all times. In addition to pseudorandom code, satellite signals include navigation data. The monitoring stations and ground antennas, which constantly check satellites' speed, position, and altitude, look for ephemeris (orbital) errors caused by gravitational pulls from the moon and sun as well as solar radiation pressure. The monitors relay this information back to the satellites, which incorporate it into the timing signals.

LIMITATIONS

Several factors limit GPS accuracy. A major source of error arises from the fact that radio signal speed is constant only in a vacuum. Water vapor and other particles in the atmosphere can slow signals down, resulting in *propagation delay*. Errors due to *multipath fading,* which occurs when a signal bounces off a building or terrain before reaching the receiver's antenna, also can reduce accuracy. In addition, distance measurements are less reliable when the satellites a receiver locks on to are closely oriented with respect to each other. Atomic clock discrepancies, receiver noise, and interruptions to ephemeris monitoring can result in minor errors.

The largest source of potential error is *selective availability,* an intentional degradation of L1, the civilian GPS signal. SA was originally intended to prevent a hostile force or terrorist group from exploiting the technology. However, the enormous benefits to the world community of increasing GPS accuracy led the US government to turn SA off in 2000. Although it has no intention of reactivating it, the government could do so in a crisis or war.

IMPROVING ACCURACY

The typical GPS receiver is accurate from 60 to 300 feet—suitable for most, but not all, applications. Sophisticated models that compare the relative speeds of two timing signals can provide location accuracy within half an inch, but they are too expensive for the average user. Two cost-effective alternatives, however, can eliminate most of the errors associated with GPS.

DGPS

Differential GPS can improve accuracy to three feet or better. DGPS employs both roving receivers that make satellite position measurements and stationary receivers that use their position to compute signal timing.

The receivers are relatively close to each other compared with the distances that signals from space travel. Because the signals that reach both receivers have virtually identical errors, the reference receiver can compute the difference between projected and actual signal travel time. The reference receiver doesn't know which satellite the roving receiver is using to calculate its position, so it calculates error corrections for *all* visible satellites. The receiver broadcasts this information to the roving satellites, which then apply corrections for the particular signals they are using.

Numerous public agencies, including the US Coast Guard and Army Corps of Engineers, transmit corrections to GPS measurements from existing radio beacons placed around harbors, waterways, and other locations to facilitate navigation. Subscription transmission services are also available on FM radio station frequencies or via satellite. In the absence of either a radio receiver or a nearby reference receiver, GPS corrections can be distributed via the Internet.

AGPS

GPS was not designed for use indoors or in urban areas. However, linking mobile receivers to a cellular, Bluetooth-based, or wireless local-area network infrastructure that has a reference receiver with a clear view of the sky—for example, on top of a high-rise building—can substantially improve GPS performance in such environments.

With assisted GPS, a reference receiver provides navigation and signal timing data to a location server, which relays this information to a GPS-enabled cell phone or personal digital assistant. The client device preprocesses and returns basic GPS measurements along with statistical measures that characterize the signal environment to the server, which performs a series of complex calculations on data received from the client to determine the user's position.

By distributing data and processing, AGPS optimizes air-interface traffic. Because the network assumes the burden of measurement calculations, developers can scale down the mobile receiver to allow easier, more cost-effective implementation on a wide scale. AGPS also provides better accuracy than standard GPS—within less than 50 feet when users are outdoors and within 160 feet when they're inside a building. Another advantage of AGPS is that clients can withhold data for privacy reasons, and the network operator can restrict assistance to service subscribers.

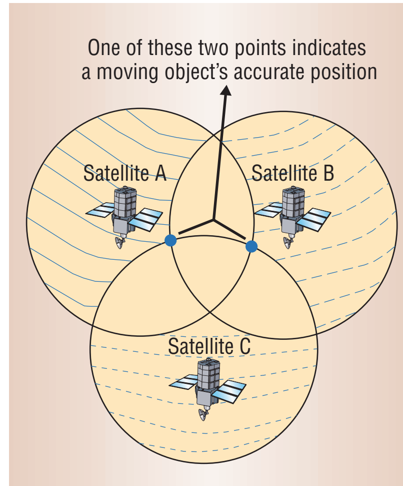

Figure 1. GPS trilateration. Satellites A and B are each at the center of an imaginary sphere, the radius of which is equal to the distance to the receiver. Knowing the distance from satellite C lets the receiver narrow its position to one of two points on the circle that the intersection of these two spheres forms.

Resources

The following resources provide additional information on GPS technology and its applications.

Publications

- N. Davies et al., "Using and Determining Location in a Context-Sensitive Tour Guide," *Computer,* Aug. 2001, pp. 35-41.
- C. Drane, M. Macnaughtan, and C. Scott, "Positioning GSM Telephones," *IEEE Comm. Magazine,* Apr. 1998, pp. 46-59.
- G.M. Djuknic and R.E. Richton, "Geolocation and Assisted GPS," *Computer,* Feb. 2001, pp. 123-125.
- R. Klukas, G. Lachapelle, and M. Fattouche, "Cellular Telephone Positioning Using GPS Time Synchronization," *GPS World,* Apr. 1998, pp. 49-54.
- H. Koshima and J. Hoshen, "Personal Locater Services Emerge," *IEEE Spectrum,* Feb. 2000, pp. 41-48.
- J. Samaha et al., "G3 Integrates Three System Technologies," *Computer,* Oct. 2000, pp. 107-110.

Online resources

- Aerospace Corp., "Military Uses for GPS," http://www.aero.org/publications/GPSPRIMER/MltryUse.html.
- P.H. Dana, "Global Positioning System Overview," http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html.
- H. Sandstrom, "GPS RAIM and Measurement Signal Analysis in Personal Positioning," http://www.cs.tut.fi/~sandstro/di.pdf.
- Federal Communications Commission, "Enhanced 911," http://www.fcc.gov/911/enhanced/.
- Trimble, "All About GPS," http://www.trimble.com/gps.

The Global Positioning System can provide extremely accurate location information for mobile objects and people—far superior to earlier tracking techniques. The challenge today is integrating the necessary components into older systems and improving GPS accuracy in areas with numerous obstructions. As more devices become GPS enabled, accuracy will increase and the system's scale and global reach will benefit everyone. Wireless technology promises to be a key element in any long-term solution. ■

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