How GPS Works

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GPS – Global Positioning System – affects our lives every day.

Every time we make a mobile phone call, navigate around town or buy a house, GPS is involved.

But what is GPS, what is in a name and how does it work?

What's in a Name

GPS is not really Global as its function becomes more marginal at the poles

GPS is more than Positioning as you get really accurate timing as well, and

GPS is not a System but two Systems, one civilian and a second, a protected military system.

What does GPS do

I bought a receiver recently over e-bay for $19. Although GPS is a complex system, capable of being understood on many levels, even a small, inexpensive receiver like this can measure its position (latitude, longitude and elevation) and speed.

How does it work

There are 24 high altitude satellites orbiting the earth, each transmitting radio signals (1.5 GHz). Our little GPS receiver receives those signals and measures the time that each signal takes to propagate from the satellite to our receiver. Multiply the propagation time by the speed of propagation of the radio signal (the speed of light) to give the distance from the satellite to our receiver. How does that give our position?

The maths isn't that difficult if we work in Cartesian coordinates.

Receiver position = (x_r, y_r, z_r)

Position of Satellite no.1 = (x_{s1}, y_{s1}, z_{s1})

Using Pythagoras Equation (hypotenuse^2 = side a^2 + side b^2 of a right angle)

Then the distance from Satellite no.1 to Receiver extended to three dimensions is:

$$d_{s1 \rightarrow r} = c \, . \, \Delta t_{s1 \rightarrow r} = \sqrt{(x_{s1} - x_r)^2 + (y_{s1} - y_r)^2 + (z_{s1} - z_r)^2}$$

where c = speed of light = 2.99792458×10^8 m/s, and
$\Delta t_{r \rightarrow s1}$ = measured propagation time of the signal from satellite 1 to receiver

There are three unknowns (x_r, y_r and z_r) so we need three equations with three satellites Done, easy.

Not quite.

First of all, the satellites move at great speed. Fortunately, the satellites themselves transmit orbital parameters to our receiver and so we can calculate the positions of the satellites (x_{s1}, y_{s1} z_{s1}) with sufficient accuracy.

However, the clock in our GPS receiver is nothing like accurate enough to measure the propagation time. After all, light travels about 1 metre in 3 billionths of a second and so the measurement accuracy has to be within something like 15 billionths of a second (for a 5 metre error).

Allowing our GPS receiver to have a Clock Error which we have to include in each estimate of propagation time:

$$d_{s1 \to r} = c.(\Delta t_{s1 \to r} - \text{Clock Error}) = \sqrt{(x_{s1} - x_r)^2 + (y_{s1} - y_r)^2 + (z_{s1} - z_r)^2}$$

We now have four unknowns (receiver x_r, y_r and z_r positions and receiver Clock Error), so now we need four equations and four satellites:

$$d_{s1 \to r} = c.(\Delta t_{s1 \to r} - \text{Clock Error}) = \sqrt{(x_{s1} - x_r)^2 + (y_{s1} - y_r)^2 + (z_{s1} - z_r)^2}$$
$$d_{s2 \to r} = c.(\Delta t_{s2 \to r} - \text{Clock Error}) = \sqrt{(x_{s2} - x_r)^2 + (y_{s2} - y_r)^2 + (z_{s2} - z_r)^2}$$
$$d_{s3 \to r} = c.(\Delta t_{s3 \to r} - \text{Clock Error}) = \sqrt{(x_{s3} - x_r)^2 + (y_{s3} - y_r)^2 + (z_{s3} - z_r)^2}$$
$$d_{s4 \to r} = c.(\Delta t_{s4 \to r} - \text{Clock Error}) = \sqrt{(x_{s4} - x_r)^2 + (y_{s4} - y_r)^2 + (z_{s4} - z_r)^2}$$

There you go, solve these four simultaneous equations with four unknowns – easy.

Not quite. There is no known analytical solution for these four simultaneous equations (or even the previous three simultaneous equations) and so we have to resort to a technique of successive approximation. Have a guess at the unknowns, calculate the error and then have another guess to reduce the error. So, it is possible to approach the real receiver position sufficiently accurately.

But what is the accuracy of our receiver? Well, the answer is not that easy. Normally, the largest error is small changes in the speed of signal propagation due to electrons in the ionosphere. As we are in a solar minimum at the present, you should expect position accuracy of about 5 to 10 metres. In a few years as the sun becomes more active (that is, more sun spots), expect errors to rise towards 15 metres and more.

Clever schemes to correct for the change in the propagation through the ionosphere can improve accuracy to one metre and even a few millimetres. There are such systems to improve accuracy and resiliency in the presence of failures.

How might GPS be used

My yacht has six GPS receivers, yes, six.

1. The autopilot is able to steer the boat to a point using a GPS receiver position the boat.
2. The radar shows the boat's position to give me what we would call situational awareness even at night and in thick fog.
3. The radio transmits the boat's GPS position if I send an emergency mayday signal.
4. In an emergency, I start my Electronic Position Indicating Radio Beacon (EPIRB) which alerts the Australian Marine Safety Authority (AMSA) via satellite. It has a GPS receiver in it.
5. I have an electronic chart plotter that shows the boat on a chart. Obviously the boat's position is provided by a GPS receiver.
6. Just in case, I have another receiver which I use to plot the boat's position on a paper chart.

Beyond my boat, GPS receivers are used in many, many ways. Because receivers calculate the error of their clocks with great accuracy, accurate timing signals can be used for timing mobile phone networks, for example, critical for their operation. Positioning of land, sea and air vehicles and navigation, like the navigator in your car – marvelous aren't they? The valuation of your home depends on accurately knowing where it is – GPS positioning. Councils locate street furniture using GPS. Golf carts with GPS tell you how far to the pin and even suggest the club to use. The movement of bridges and continents. Guiding aerial spraying aircraft – a skilled pilot can lay down spray within a metre of the desired spot. Did you know that the first autonomous aircraft to fly the Atlantic was an Australian aircraft (Aerosonde)? It used GPS to guide it.

So, what about military applications? As you might imagine, there are parallels with civilian applications, such as navigating planes, ships, trucks, missiles, satellites, supply pallets, soldiers and so on; manned and unmanned vehicles, of course. How about guiding a parachute to its destination after flying to predefined way points to confuse the enemy? How about guiding an artillery shell to its target? All these are today's applications of GPS.

Not bad for a system run by a military (the US Navy) for anyone in the world to use at no cost. I bet that the rationale is that the cost to the US government is nil after you account for the taxes paid by US GPS manufacturers.

Think about this also; GPS relies on extremely accurate clocks flying in the satellites. Those clocks are the result of research conducted in the 1950s and 1960s to improve the accuracy of clocks. Who could ever use a clock accurate to a thousandth of a second per year? At that stage, there was no understanding where the research would lead – to GPS.

Oh, by the way, there are other positioning systems. The Russians have one (Glonass), the Europeans are working towards one (Galileo) as are China (Compass) and India (Indian Regional Radio Navigation System, IRNSS).

So, GPS and similar systems are here to stay.

They are available to anyone at no cost (though it won't always be so for all services). Consequently, there are many, many civilian and military applications.

Important Note:

- This information is provided for your interest only. It is intended to be a starting point only for your own research. It is not to be relied upon for any decisions.
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