Global Positioning System (GPS) Cart & Display Board

Brief Summary

GPS technology allows a person with a hand held receiver, cell phone, or other electronic device to determine his or her exact location on the globe. GPS works by measuring distances from orbiting satellites and using that information to pinpoint your location by a process known as trilateration. Originally developed for military purposes, GPS technology has expanded rapidly. GPS navigation systems have now become standard in emergency response vehicles, on planes and ships. Combined with digital maps, GPS receiver units are now available in phones, cars, boats and as hand held units for skiers and hikers to determine where they are.

Equipment Required

The GPS Cart. The knobs on stalks represent some of the GPS satellites. Note that each satellite is coded with colored tape (red, blue, yellow and green) to distinguish the four satellites from each other. Front side of free-standing GPS Display Board
Main Teaching Points

- GPS is a technology that allows locating a place on Earth (giving its longitude and latitude) to a very accurate degree. GPS signals also determine altitude, but not all receivers have that capability.
- GPS works by determining your distance from orbiting satellites. Your GPS receiver unit knows for example, it is 87 milliseconds from satellite #1, nothing more. This basic information can be combined with other data to map your location.
- This technology requires knowing the distance from at least three satellites (in practice four satellites) in order to pinpoint your location. This process is called trilateralization.
- GPS requires 24 orbiting satellites to cover the entire globe (of which four must be in range at a time) and receiving unit.
- As of now (2015) the best GPS units can give the location of a place on Earth down to within eight inches (using specialized corrective software). That is, the GPS readings are different for two locations eight inches apart. However, most commercially available and smartphone GPS units have a margin of error of about three to ten feet.
- GPS units are useful for sailors, pilots, hikers and skiers, the military, remote sensing devices, and map making.

Enriching teaching points

- Distance from the satellite to the receiver is found by the equation Distance = speed × travel time, the same equation used to find out that you travel 120 miles when going 60 mph for 2 hours. For GPS, “speed” is the speed for light (670 million miles per hour or 186,000 miles per second) and the time for the signal to reach your GPS receiver, typically 50 to 110 milliseconds. (A millisecond is a thousandth of a second.) To get this level of accuracy, each satellite carries its own atomic clock.
- When the first GPS satellites were sent into orbit, they did not account for the effects of Einstein’s General Relativity, but later these corrections had to be added to make the system work to the desired accuracy.

Set Up

There are three components to the GPS exhibit:

1) the GPS cart with map, tape measures and four laminated pictures in a storage bin
2) a laptop on a computer cart.
3) the free-standing GPS Display Board on wheels with two unique sides:
   a. Front (see above)
   b. Back is titled, “What’s on the Horizon?”

Set up Procedure:

- Get out the GPS cart and laptop from storage. The wheeled GPS display board lives just outside of the 2003 room, where people often facilitate the GPS cart.
- Arrange the three components in a way that makes it convenient for you to refer to all three.
Pictures used with GPS CART and GPS Display Board

24 GPS satellites orbit Earth in a shell at 12,500 miles from Earth. This location in space means that they appear to move slowly across the sky. (This picture is also on Display Board.)

One of the 24 identical GPS satellites that orbits the Earth at 12,500 miles out in space.

Hand held GPS units such as these are now available for under $300. Note that one unit has a compass, one has a map and the other an altimeter. (Also on Display Board)

The signals from at least three GPS satellites are needed to locate a position on Earth uniquely. (Also on Display Board)
Suggested ways of Presenting the Demo

Try This

- Ask visitor if they have ever used GPS, and if so, how.
- Remind visitors that the brass knobs attached to the map represent GPS satellites that are far out in space, not close to Earth.
- Illustrate the way the tape measures work, and assign a different person to take charge of each. The tape measure corresponds to the time a GPS satellite signal takes to get to a given location. You may have to have someone put his or her finger on the tape measure to keep it from slipping.

- Have visitors find the many locations on the map that are exactly 25 units from the yellow satellite. Actually, these points form a circle, so the number of possible points that lie 25 units away is infinite.
- Ask: If you know you are 25 units from the yellow satellite, does this tell you EXACTLY where you are?
- Next, have visitors find all the points that are BOTH 25 units from the yellow satellite AND 32 units from the blue satellite. (This reduces the number from infinity to just two points.)
- Ask: Now can you tell EXACTLY where you are?

For example, where are you if you are 25 units from the yellow satellite and 30 from the green? Is that enough information to determine uniquely where you are?
Finally, find all the points that are 25 from yellow, 30 from green AND 68 units from the blue satellite. (Now there is only one location possible.) These three numbers from the specific satellites are the unique location signature for Scrapiron Peak.

Only when you have information from three satellites can you determine exactly where on Earth you are.

Note: even if you know the distance to three satellites, there is another place you could be. Have visitors hold their fingers on the satellites to keep tapes from slipping. Lift all three rings up into the air until tapes are taut to show the place in space that you could theoretically be. This position is typically far from earth’s surface is disregarded.

In practice, however, a forth measurement is needed to correct for clock error and provide a more accurate location.

Alternative Facilitation strategies:
Try this
- Take a moment to have visitors orient to the map.
  - Where is the Sun?
  - Find Elephant Peak. Look closely at it and you’ll see why it has this name.
  - There are five airborne jets, one helicopter and one propeller plane. Each of these has a shadow. Using the distance between the aircraft and its shadow, determine which is highest. Which is lowest?
- Illustrate the way the tape measures work, and assign a different person to take charge of each. The tape measure corresponds to the time a GPS satellite signal takes to get to a given location. You may have to have someone put his or her finger on the tape measure to keep it from slipping.
  - Extend the rings from three satellites to a point of the road in the center of the map. Holding all three rings together, move along the road and note how the length of each tape measure changes.

Or try this:
A. Draw out from visitors (or just tell them) that GPS is a way of determining the location of a place on Earth down to within eight inches. That is, the GPS readings are different for two locations eight inches apart. Show pictures of GPS satellite, the network of GPS satellites in orbit and the hand held receiver.
  a. Note: Eight inches is the highest accuracy achievable with today’s GPS satellites and specialized systems here on earth. Typically, accuracy with commercially available devices is within a few meters.
B. Illustrate the way the tape measures work, and assign a different person to take charge of each.

C. Ask: At $75 to $100 million per satellite, (See Q&A section below) the fewer satellites the better. What is the minimum number of satellites to do the job of finding your exact location on Earth?

D. Illustrate or facilitate visitor’s discovery that using only one satellite determines the infinitely numerous locations on a circle--this is not very helpful--so we need more than one satellite.

E. Illustrate or facilitate visitor’s discovery that two circles on a flat surface intersect at a pair of points. Helpful but not unique. You might be at either one of two points thousands of miles apart.

F. Illustrate or facilitate visitor’s discovery that three satellites determine the point uniquely on a flat surface, (but not the elevation.)

G. For technical reasons, at least four satellites must be used to get your exact location. The fourth satellite is used for location and time corrections See Q and A for more information.

H. Using the tape measures, have visitors find the numbers of the four GPS readings of several locations. (See pictures above.) For example, the center of Lake Eddie is

- 16 units from the red satellite
- 29 units from the yellow satellite
- 47 units from the green satellite
- 33 units from the blue satellite.

These four numbers are the location signature of Lake Eddie.

**Tips and Potential Problems Using GPS Cart and Display Board**

- The tape measures in the satellites are retracted by weights at the end. Please handle them gently and watch that visitors do not try to force them.
- Sometimes the tape measures turn over, number side down and black side up. To get the twist out, let the tape retract all the way into its holder, then straighten it before you pull it out again.
Questions and Answers

When did GPS first become operational?

Does using GPS cost anything to use?
No. It was a U.S. Department of Defense Project, and is now free of charge to use, though receivers can cost from $100 to many thousands. However, most cell phones now include GPS as a standard feature and can be used with navigation and map applications, such as Google Maps.

Can you determine your elevation with GPS?
Yes, if you have a receiver with that option, but not all GPS receiver units automatically have that capability. (See laminated pictures and Display Board. One sample unit has a map, another one a compass, and one an elevation indicator.) The four satellite readings determine your position in 3-D space. They then use a simplified model of the earth to determine sea level, and your height above that know distance. For more information on how altitude is collected, check out: http://edu-observatory.org/gps/height.html.

How far out in space are the GPS satellites? Can astronauts go out there to fix them?
12,500 miles. This is far too far from Earth for servicing by astronauts. The Hubble Space Telescope orbits at only about 320 miles above the surface of the Earth.

How fast do the GPS satellites go?
Approximately 8,700 mph. with respect to Earth.

How long does it take for the signal to go from a satellite to your handheld unit?
60 to 110 milliseconds. (This equals 0.06 to 0.110 seconds.)

Why didn’t they put the GPS satellite network into geosynchronous orbit so the satellites wouldn’t move?
A: Because to be geosynchronous requires a satellite to orbit the equator, and the GPS satellite network encircles the globe with satellites above many more places than just the equator. The 24 satellites operate at semi-synchronous altitude in six orbital planes.

Why are four satellites needed instead of three?
Three satellites can determine your location, but less accurately than with four satellites. The image below shows the signal from three different satellites and where the spheres of possible locations intersect. As you can see, there are two positions where all three spheres intersect. One of these measurements can typically be disregarded because it will be far from the Earth’s surface. However, GPS receivers use simplified models of the Earth with an assumption of where sea level is to be able to determine altitude. So, if you are at sea level, this measurement will be fairly accurate. However, if you are in the mountains, this could be hundreds of meters off.
Time is a complication when determining location with GPS signals. Each GPS satellite gets a sphere of possible locations by measuring the difference in the time from when the signal was sent, to when it arrives back at the satellite. These measurements need to be highly precise which is why each GPS satellite is equipped with multiple atomic clocks. A GPS receiver can use a signal from a fourth satellite to solve an equation that lets it determine the exact time, without needing an atomic clock. By determining the exact time, the receiver can find a much more accurate location. This also allows the receiver to determine your altitude. That way you are able to find your location more precisely.

What are potential sources of error in a GPS position reading?
As the GPS signal passes through the atmosphere, it can be refracted, causing the speed of the signal to be different than the speed of light. This is especially true of satellites near the horizon, where signals must pass through more of the atmosphere. Most GPS receivers can account for this to some degree by using software to correct for these errors. Sunspot activity, measurement noise, signal distortion, and errors in information of the satellite’s orbit are all possible sources of error in a GPS reading. Signals may also be blocked by obstructions such as buildings and mountains. To compensate for this, extra satellites were
placed into the satellite network. At any one instant 11 satellites signals may be available, so the GPS receiver can pick the best four and ignore the rest.

**Does GPS tell me how to get to a place?**
Not by itself. You also have to have a digital map and software to integrate the GPS signal and the digital map. However, this combination, in the form of apps on phones or tablets, is how most people are familiar with GPS,

**What does each GPS satellite cost and how long does satellite each last?**
GPS satellites are designed to last at least 6 years. Each GPS satellite costs $30-$40 million and boosters will set you back $30-$40 million each. In addition each launch costs $15-$20 million. Total cost $75-100 million dollars each. The cost of GPS ground services for the entire network is approximately $400 million per year.

**Background materials (websites, videos, articles, digital collections links)**

University of Colorado website:  
http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html

University of Montana website:  
http://www.montana.edu/gps/understd.html  
http://www.montana.edu/gps/understd.html#How_does_GPS_work

GPS receivers  
http://www.garmin.com/aboutGPS/

General Article on GPS  

U.S. Government GPS website  
http://www.gps.gov/

List of Websites at DMOZ  
http://www.dmoz.org/Science/Earth_Sciences/Geomatics/Global_Positioning_System