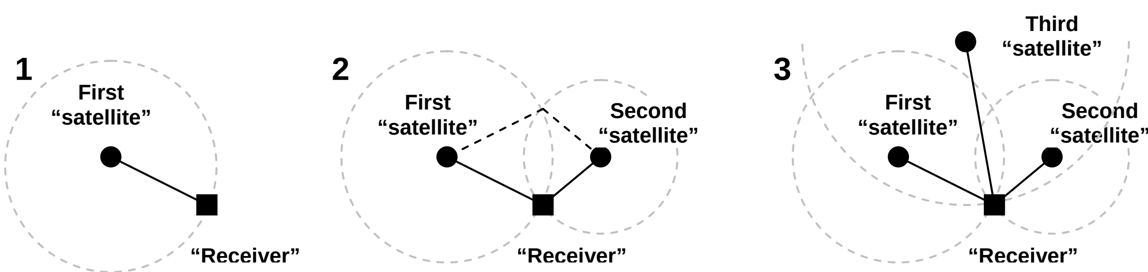
Triangulation and Space

While simultaneously tracking distance to several satellites, a Global Positioning System (GPS) receiver uses the method of triangulation to determine its location in real time. This is the basics of how GPS and other positioning systems work.

Explorer's Guide

Before You Start

To understand the way GPS receiver interprets satellite signal, let's assume that one explorer volunteers to be a "receiver" while three other explorers agree to be "satellites". Each "satellite" should take a fixed position in the room away from each other. Then, the "receiver" and first "satellite" take a string of a fixed length and pull it tight. While maintaining the fixed distance to the first "satellite" (holding string tight), "receiver" can freely move around it. Now, let the second "satellite" also hold a tight string together with the "receiver". In most cases, the "receiver" can be in one of two locations in the room to have both strings tight. Finally, when the third "satellite" connects to the "receiver", the receiver can't move. In GPS terms, we have "position fix" (se figures below):



What would happen if a fourth "satellite" will get involved? Compare two situations: 1) all "satellites" stay in the same direction from "receiver" and 2) all "satellites" are far from each other and "receiver" is in the middle. In which case is it easier for the "receiver" to move with all the strings tight?

Learning by Doing

1. Detective James is set to find the missing treasure. He knows it is hidden in the United States in state capital city. The city is located: a) 309 miles from the capital city of SD (South Dakota), b) 400 miles from the capital city of WI (Wisconsin) and c) 745 miles from the capital city of TX (Texas). Can you help him find the capital city with the hidden treasure?

   To apply the method of triangulation, you can use the appended map of the USA assuming that 1 in. equals to 364 miles.

   The hidden treasure is located in the capital city of _____________________

2. GPS signal travels with a speed of light (300,000 km/s). GPS satellites orbit the Earth 20,200 km above ground. What is the smallest time it takes for the signal from a given satellite to reach receiver located on the surface?

   Time = ________________ / __________________ = ___________ s

   If the clock in your receiver underestimates GPS signal travel time by 1 ms (millisecond = 1/1,000,000 s), what will be the resultant distance estimation error.

   Distance _______________ * __________________ = ___________ km = ________ m

3. Walk to an open space outside and turn on the GPS receiver[1]. Wait a couple of minutes for "warming up" and take a look at the **Satellite Page**. Both the circular symbols and bar graph provide information about visible GPS satellites and the strength of signal received from these satellites. How many satellites are visible (total number of circular symbols)? How many of them are used to calculate position (black symbols only)? What is the estimated accuracy? How well are the satellites spread around in the sky? What will happen if you come close to a tree or a tall building? What does it do to the accuracy? Why?

How Does It Work

Global Positioning System (GPS) is one of three global satellite navigation systems (GNSS) in operation that allow determining geographic location anywhere around the Earth anytime. GPS includes a constellation of 24 NAVSTAR (NAVigation System with Timing And Ranging) satellites orbiting our planet 20,200 km above ground. These satellites have been placed in 6 different orbital planes at an inclination of 55°. They circle the Earth every 12 hours and use two L band (L1and L2) frequencies to broadcast pseudo-random radio signal.
As any other radio signal, messages broadcast by GPS satellites travel at the speed of light (300,000 km/s = 186,000 miles/s). These messages contain names of the satellites that sent them, time when the messages were sent and other technical information. The exact location in the space of every satellite at every moment of time is known. A GPS receiver listens to several satellites simultaneously and measures the time it takes for the signal to reach the receiver. Then, distance from the receiver to each satellite can be found as follows:

Distance = Speed of light * Signal travel time

Like in the exercise with the strings, the receiver used the method of triangulation to determine its location. Therefore, it needs to calculate distances to a minimum of three visible satellites if the receiver is located on the surface of the Earth. The fourth satellite is needed to calculate the height of the receiver (position in 3D). Although clocks installed on the satellites are very accurate, the clock inside a GPS receiver may provide significant errors. To adjust time measurements, additional satellites are desirable. Therefore, more visible satellites usually result in more accurate distance measurements.

By its nature, GPS signal is very weak and it cannot travel through a wall of a building or even through a canopy of a tree. Most modern receivers can "listen" to up to 12 satellites at the same time. However, only 8-9 satellites are normally visible in an open field. Therefore, when you come close to a building or a tall tree, your receiver may not be able to receive signal from more than four satellites. Clear sky is a "must have" condition for proper operation of a GPS receiver. It does not work inside.

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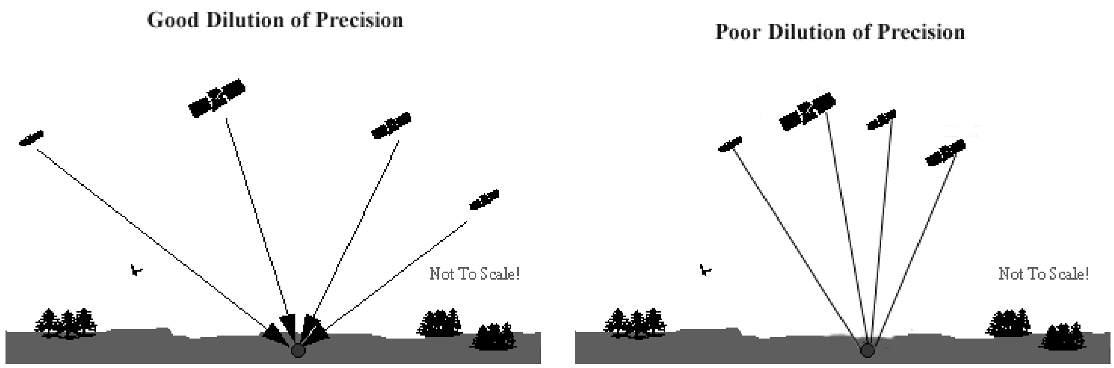
[1] Although many GPS receivers can be used for this exercise, our directions are relevant to Garmin Rino receivers. The University of Nebraska-Lincoln does not endorse usage of a particular product or exclude use of similar suitable equipment.

In addition to the number of satellites, it is important that all of them are spread around the sky instead of clustering on one side. Think what happened when those explorers who represented “satellites” moved to the same side of the room. The “receiver” could easily move around without getting any of the strings loose. In GPS terms, Dilution of Precision (DOP) is used to describe how well the visible satellites are spread around the sky. It is typically represented by a value from 1 to 6. A good DOP suggests a sufficient number of satellites evenly spread around the sky and is typically low. A poor DOP (greater than 3) means that the quality of position estimate is low (see figure below).

DOP < 3 **DOP > 3**



DOP can be separated into components that represent quality of position measurements (both horizontal and vertical) and time. Horizontal DOP (HDOP) is a good indicator of how well the geographic coordinates can be calculated. Some receivers indicate accuracy expressed in meters of feet that is derived from corresponding HDOP.

In addition to the clock inaccuracy, GPS signal is subject to many distortions caused by atmosphere, nearby object, or even artificial signal distortion. To account for some of these error common to every receiver used in a given area, various signal correction procedures have been implemented. In most cases that means placing a GPS receiver in a fixed location and comparing calculated and actual position. Existing differences are broadcast to the other receivers so that they could adjust their measurements accordingly. Wide Area Augmentation System (WAAS) is one such services when differential correction signal is transmitted through communication satellites (those are not GPS satellites). Therefore, GPS receiver with WAAS of another differential correction service enabled are more accurate. For example, in an open field, GPS receiver without differential correction may produce an error exceeding 10 ft, and depending on the type of differential correction service this error can be reduced to less than 1 in.

Additional Challenge

In general, the method of triangulation can be used for surveying, navigation, metrology, astrometry, seismology, binocular vision, rocketry, and other areas. Research some examples of such applications? What are the main laws of triangular involved?

Vocabulary

- ***Global Navigation Satellite System (GNSS)*** *is a generic term for a space-based radio-navigation system that provides the capability to determine geographic location anywhere on Earth.*
- ***Global Positioning System (GPS)*** *is a GNSS operated by US Department of Defense.*
- ***Triangulation*** *is the process of finding coordinates and distances using the laws of triangle.*

- ***GPS receiver*** *(sometimes called rover) is an actual devise used to determine geographic coordinate in real time.*
- ***Dilution Of Precision (DOP)*** *is a term used to describe the accuracy of receiver based on the number and location of visible satellites in the sky.*
- ***Horizontal Dilution of Precision (HDOP)*** *is the horizontal component of DOP.*
- ***GPS receiver accuracy*** *is an approximate estimate of expected positioning errors that is based on HDOP.*
- ***Differential correction for GPS (DGPS)*** *is a type of signal service used to increase GPS receiver accuracy by compensating for known errors caused by atmospheric distortion and other predictable anomalies for a given area.*
- ***Wide Area Augmentation System (WAAS)*** *is a type of differential correction service available through the US and implemented for the Federal Aviation Administration (FAA).*

Interesting to Know

The other two global satellite navigation systems are GLONASS of Russian Federation and GALILEO of European Union.

Viacheslav Adamchuk and Shana Thomas
Phone: 402-472-8431
E-mail: vadamchuk2@unl.edu
Last updated: May 12, 2008