GPS: FROM STONES TO SATELLITES

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ABSTRACT

Throughout time people have developed a variety of ways to figure out their position on earth and to navigate from one place to another. Early mariners relied on angular measurements to celestial bodies like sun and stars to calculate their location. The 1920s witnessed the introduction of more advanced technique-radio navigation-based at first on radios that allowed navigators to locate the direction of shore-based transmitters when in range. Later development of artificial satellites made possible the transmission of more precise, line of sight radio navigation signals and sparked a new era in navigation technology. Satellites are first used in position finding in a simple but reliable 2D Navy system called Transit. This laid the groundwork for a system that would later revolutionize navigation for ever-the Global Positioning System. In this paper we explain variety of ways to figure out their position on earth and also explain the GPS working.

Keywords: *GPS, points of reference, navigation systems.*

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1. INTRODUCTION

The Stone Age

Identifying and remembering objects and landmarks as ***points of reference*** were the techniques that the early man used to find his way through jungles and deserts. Leaving stones, marking trees, referencing mountains were the early navigational aids. Stones, trees and mountains were the early examples of "points of reference", a concept that has evolved through times with the advent of (and the need for) more sophisticated techniques, objects and instruments.

The Star Age

Identifying points of reference was easy on land; but it became a matter of life and survival when man started to explore the oceans, where the only visible objects were the Sun, the Moon and the stars. Naturally, they became the "points of reference" and the era of celestial navigation began.

Celestial navigation was the first serious solution to the problem of finding one's position in unknown territories, where the Sun, the Moon and stars were used as points of reference. The relative position of stars and their geometrical arrangement look different from different locations on Earth. Therefore, by observing the configuration of stars one could estimate his position on Earth and the direction that he should take for his destination. The Great Bear and Small Bear constellations are two examples. The geometrical configurations of stars from the observer's point of view were more accurately determined later by measuring the relative angles between them. For better accuracy, special optical instruments were invented to measure the angles of view between stars. These measured angles were then used to determine the position of the observer with the aid of published pre-calculated charts that eased the tedious computation t

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The process of measuring the angles of the stars with optical instruments was time-consuming and inaccurate. It could not be used during the day or on cloudy nights. The measured angles had to be transferred to special charts and after tedious calculations, the derived position was good only to about several miles. The calculation process was the basic triangulation geometry, where the stars became the known points of reference and the measured angles between them and the

navigator would solve for the triangles' components and determine the navigator's position.

In frustrated moments of trying to determine a position, many navigators must have dreamed, conceivably, of gadgets that would do such a task automatically and more accurately. There were probably people that pictured a device, or even worked on building one, that aligned itself with stars quickly, measured angles to these points of reference and computed its position automatically. The idea of automatic computation of position through measurement of distances to points of reference became a reality only recently when radio signals were employed and the age of radio navigation began.

The Radio Age

About the middle of last century, scientists discovered a way to measure distances using radio signals. The concept was to measure the time it took for special radio signals to travel from a transmitting station to a special device designed to receive them. Multiplying the signal travel time by the speed of the signal gives the distance between the transmitter and the receiver. The speed of radio signals is the same as the speed of light — about 300,000,000 meters per second (about 186,500 miles per second). Accurate measurement of signal travel time is important since one microsecond (one millionth of a second) of error in measuring the travel time is equal to 300 meters of error in distance.

How could such a radio signal transmitter-receiver system be used to determine a person's location?

Assume that a transmitting tower is installed at a known point, A, on the earth and we have a special radio that can receive signals from transmitter A and measure the distance to the transmitter. Next, assume that a second transmitter tower is installed at another known point, B, on the earth. The same special receiver measures our distance to transmitter B.

So we are on circle A and circle B at the same time. We must be at the intersection of the two circles, one of the two points P or Q shown in Figure 1.

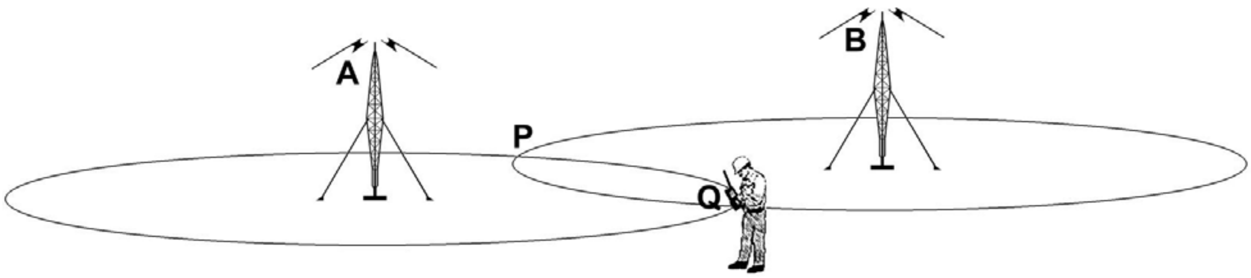


Figure 1

Measuring our distance to a third transmitter C would identify exactly where we are. Transmitters A, B, and C together are called a transmitter "chain". A chain may have four or more transmitters in order to have better coverage. Navigational systems that use such radio signals to measure distances to several transmitting towers located at known points are called *radio navigation systems.*

The LORAN Age

LORAN (LOng RAnge Navigation) is one such radio navigation system that became operational around 1950. Each LORAN chain consists of at least four transmitters and typically covers areas of about 500 miles. To provide LORAN coverage for larger areas, several LORAN chains are used.

Each LORAN transmitter chain broadcasts radio signals on its own designated frequency. A LORAN receiver tunes in to the radio signals of the transmitters of the chain, measures distances to them automatically, and computes the position of the receiver. A LORAN receiver has the exact locations of all LORAN transmitter chains in its database. In a journey, one may pass through several LORAN chains. So, the navigator needs to know and tune in to the frequency of each LORAN chain he is passing through. The entire operational LORAN chains worldwide cover only a small portion of the earth. They are operated by local governments and are generally situated near coastal areas that have high traffic volume.

Although LORAN was a major breakthrough for navigation, it has the following shortcomings:

· LORAN coverage is limited to about 5% of the surface of the earth where the chains are established. It is not a global system.

· LORAN transmitters send out signals along the surface of the earth and can therefore provide only two dimensional position information (latitude and longitude). It cannot provide information about height and, for example, cannot be used in aviation to provide altitude.

In general, the accuracy of LORAN is good to only 250 meters.

The Satellite Age

To overcome these limitations, satellite-based radio navigation systems were conceived in which improved radio transmitters were put aboard satellites orbiting the earth at high altitudes to give wider coverage.

Signals from navigation satellites can cover large areas of the earth, and several satellites can cover the whole planet. The theory behind the operation of the satellite navigation systems is similar to that of the land-based systems. In land-based navigation systems, the transmitting towers are the reference points located on the earth and the distance to them is measured by the receivers to compute the two-dimensional position (Latitude and Longitude or X and Y) by finding the intersection of several circles. In satellite-based systems, the satellites act as the reference points and the distance to them is measured to determine the three dimensional position (Latitude, Longitude, and Altitude or X, Y, and Z) by finding the intersection of several spheres.

In land-based systems, the location of the transmitting towers are fixed, accurately known, and stored in the data base of the receivers. In satellite-based systems, the locations of the satellites are not fixed. They orbit the earth at high speeds. However, satellites have a mechanism of giving information about their location at any instant in time. The accuracy of the calculated location of the satellites, at the time at which distances to them are measured, affects the accuracy of calculated position of the receiver.

With satellite systems, we are once again "looking" up to the sky. This time, however, we are "looking" at man-made objects instead of stars. And unlike celestial navigation utilizing stars, man has now devised a scheme (using radio signals and receivers) to measure distances to reference points. One of the first satellite navigation systems was Transit. The experience gained from Transit and several other experimental systems led to the development of the current Global Positioning System (***GPS***) by the United States of America and GLObal Navigation Satellite Systems (***GLONASS***) by the Russian Federation.

1. GPS—The Most Precise

The Global Positioning System (GPS) is a satellite based navigation system. The concept of GPS was introduced by the United States Department of Defense (DoD). It is in the year 1994 that the GPS was completely developed. The GPS is developed to provide continuous, highly precise positions, velocity and time information to the land, sea, air and space based users. The intent of system is to use a combination of ground stations, orbiting satellites and special receivers to provide navigation capabilities to virtually everyone, at anytime, anywhere in the world, regardless of weather conditions.

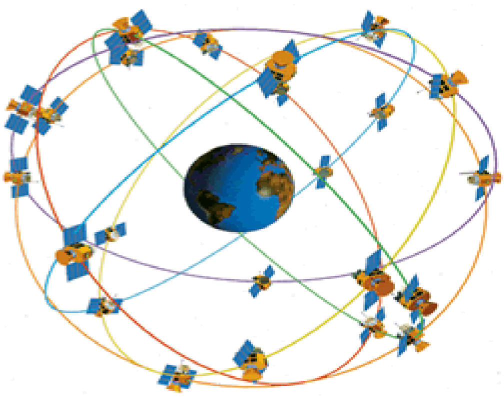
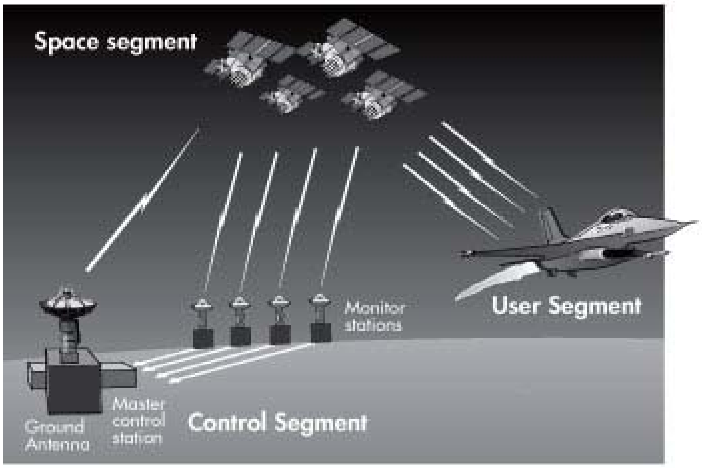


Figure 2

2. ELEMENTS OF GPS



GPS has three parts: the space segment, the user segment, and the control segment. The space segment consists of a constellation of 24 satellites (and about six "spares"), each in its own orbit 11,000 nautical miles above Earth. The user segment consists of receivers, which you can hold in your hand or mount in a vehicle, like your car. The control segment consists of ground stations (six of them, located around the world) that make sure the satellites are working properly. The master control station at Schriever Air Force Base, near Colorado Figure 3 springs, Colorado, runs the system.

3. HOW GPS WORKS

The principle behind GPS is the measurement of distance (or "range") between the satellites and the receiver. The satellites tell us exactly where they are in their orbits by broadcasting data the receiver uses to compute their positions. It works something like this: If we know our exact distance from a satellite in space, we know we are somewhere on the surface of an imaginary sphere with a radius equal to the distance to the satellite radius. If we know our exact distance from two satellites, we know that we are located somewhere on the line where the two spheres intersect. And, if we take a third and a fourth measurement from two more satellites, we can find our location. The GPS receiver processes the satellite range measurements and produces its position.

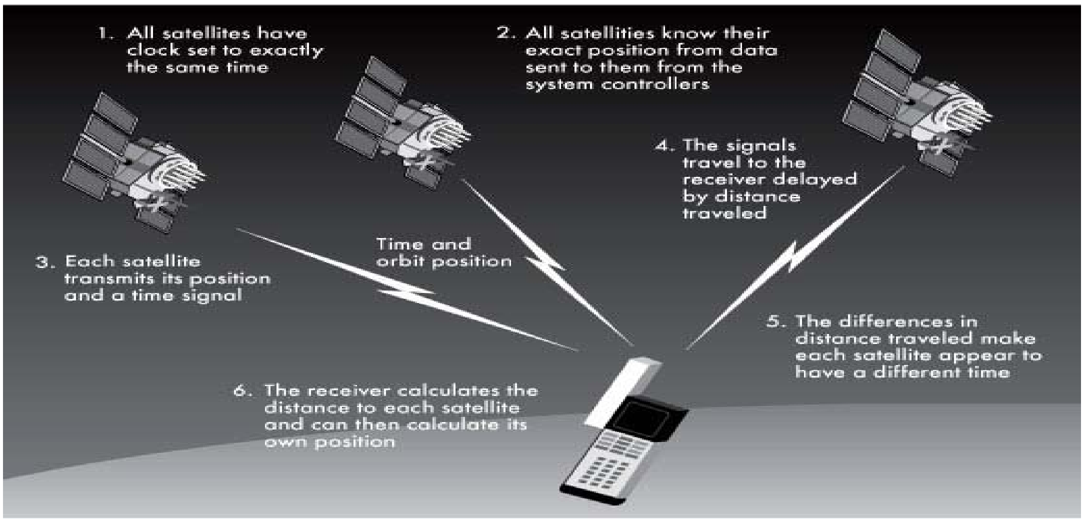


Figure 4

GPS uses a system of coordinates called WGS 84, which stands for World Geodetic System 1984. It allows surveyors all around the world to produce maps like the ones you see in school, all with a common reference frame for the lines of latitude and longitude that locate places and things. Likewise, GPS uses time from the United States Naval Observatory in Washington, D.C., to synchronize all the timing elements of the GPS system, much like Harrison's chronometer was synchronized to the time at Greenwich.

4. CONCLUSION

Although the GPS system was completed only in 1994, it has already proved to be a valuable aid to military forces. Navy ships used them for rendezvous, minesweeping, and aircraft operations. It is also used on satellites to obtain highly accurate orbit data and to control spacecraft orientation. GPS is helping to save lives and property across the nation. Many police, fire, and emergency medical-service units use GPS receivers to determine the police car, fire truck, or ambulance nearest to an emergency, enabling the quickest possible response in life-or-death situations. Mapping, construction, and surveying companies use GPS extensively. GPS-equipped fleet vehicles, public transportation systems, delivery trucks, and courier services use receivers to monitor their locations at all times for both efficiency and driver safety. Automobile manufacturers are offering moving-map displays guided by GPS receivers as an option on new vehicles. The future of GPS is as unlimited as our imagination.

New applications will continue to be created as technology evolves. GPS satellites, like stars in the sky, will be guiding us well into the 21st century.

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