"Knowing where you are is so basic to life."
Jeff Hurn, Trimble Navigation

Chapter 6 Global Positioning System

Where do I stand?

Knowing where you are and where you are going was the most crucial and challenging task faced by explorers in ancient times. Positioning and navigation are extremely important to many activities, and many tools and techniques have been adopted for this purpose. People have used a magnetic compass, sextant or theodolite and measured the positions of the sun, moon and stars to find their own position. More recently, a global positioning system (GPS) has been developed by the US Department of Defence (DoD) for world-wide positioning at a cost of 12 billion US dollars.

GPS is a world-wide radio-navigation system formed from a constellation of 24 satellites and their ground stations. It uses these 'man-made stars' as reference points to calculate positions accurate to a matter of metres. GPS receivers are remarkably economical and have made the technology accessible to virtually everyone. The GPS provides continuous three-dimensional positioning 24 hours a day to military and civilian users throughout the world. These days, GPS is finding its way into cars, boats, planes, construction equipment, farm machinery and even laptop computers. It has tremendous scope for use in GIS data collection, surveying and mapping. GPS is increasingly used for precise positioning of geospatial data and collection of data in the field.

Components of the GPS

The global positioning system is divided into three major components: the control segment, the space segment and the user segment. All three segments are required to perform positional determination.

Control segment

The Control Segment consists of five monitoring stations—Colorado Springs, Ascension Island, Diego Garcia, Hawaii and Kwajalein Island (Figure 6.1). Colorado Springs serves as the master control station. The control segment is the sole responsibility of the DoD who undertakes its construction, launching, maintenance and constant monitoring of all GPS satellites. The monitoring stations track all GPS signals for use in controlling the satellites and predicting their orbits.

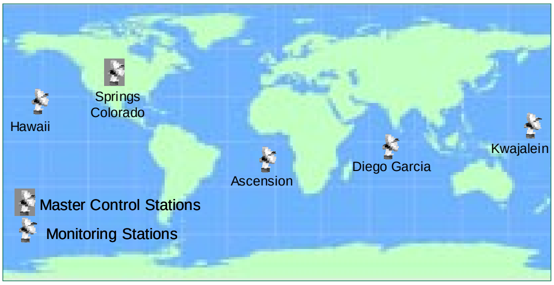


Figure 6.1
Control segment

Space segment

The space segment consists of the constellation of Earth-orbiting satellites. The satellites are arrayed in six orbital planes inclined 55 degrees to the equator (Figure 6.2). They orbit at an altitude of about 12,000 miles. Each satellite contains four precise atomic clocks (Rubidium and Cesium standards) and has a microprocessor on board for limited self-monitoring and data processing. The satellites are equipped with thrusters that can be used to maintain or modify their orbits.

User segment

The user segment consists of all Earth-based GPS receivers (Figure 6.3). Receivers vary greatly in size and complexity although the basic design is rather simple. The typical receiver is composed of an antenna and preamplifier, radio-signal microprocessor, control and display device, data recording unit and power supply. The GPS receiver decodes the timing signals from the 'visible' satellites (four or more) and, having calculated their distances, computes its own latitude, longitude, elevation and time. This is a continuous process and generally the position is updated on a second-by-second basis. It is output to the receiver display device and, if the receiver provides data capture capabilities, stored by the receiver logging unit.

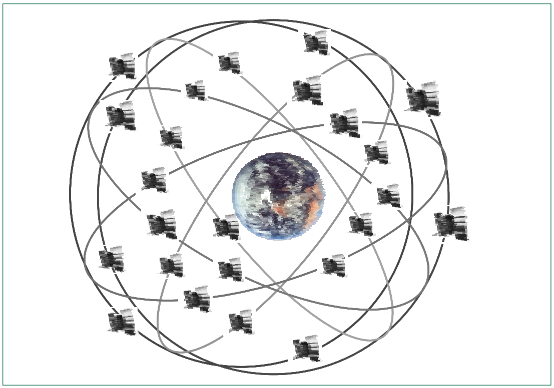
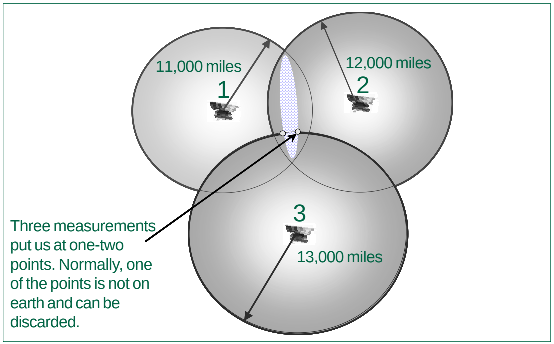


Figure 6.2
Space segment

Figure 6.3
GPS receiver



Three measurements put us at one-two points. Normally, one of the points is not on earth and can be discarded.

Figure 6.4
GPS triangulation

How GPS works?

The GPS uses satellites and computers to calculate positions anywhere on earth based on satellite ranging. This means that a position on Earth is determined by measuring its distance from a group of satellites in space. The GPS measures the time it takes for a radio message to travel from each satellite to the position on Earth. For this, it needs an extremely accurate clock. It then converts this time into a distance and, using triangulation, calculates each satellite's distance from Earth. It then needs to know where each satellite is in space. To compute a satellite's position in three dimensions, the GPS needs to have four satellite measurements. It uses a trigonometric approach to calculate these positions (Figure 6.4). The satellites are so high that their orbits are very predictable.

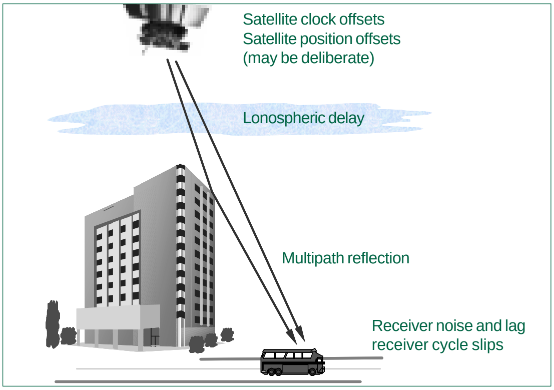


Figure 6.5
GPS Errors

GPS errors

Although the GPS looks like a perfect system, there are a number of sources of errors that are difficult to eliminate (Figure 6.5). The ultimate accuracy of GPS is determined by some of these several sources of error.

Satellite errors

Slight inaccuracies in time-keeping by satellites can cause errors in calculating positions on Earth. Also, the satellite's position in space is important because it is used for the starting point of the calculations. Although GPS satellites are at extremely high orbits and are relatively free from the perturbing effects of atmosphere, they still drift slightly from their predicted orbits. This contributes to errors.

The atmosphere

The GPS signals have to travel through charged particles and water vapour in the atmosphere. This slows their transmission. Since the atmosphere varies in different places and times, it is not possible to compensate accurately for the delays that occur.

Multipath error

As the GPS signal arrives on the Earth's surface, it may be reflected by local obstructions before it reaches the receiver's antenna. This is called multipath error because the signal reaches the antenna along multiple paths.

Receiver error

Receivers are also not perfect. They introduce errors that usually occur from their clocks or internal noise.

Selective availability

Selective availability (SA) was the intentional error introduced by the DoD to make sure that hostile forces could not use the accuracy of the GPS against the US or its allies. Some noise was introduced into the GPS satellite clocks that reduced their accuracy. The satellites were also given erroneous orbital data that were transmitted as part of each satellite's status message. These two factors significantly reduced the accuracy of GPS for civilian uses. On 1 May 2000, the US Government announced a decision to discontinue the intentional degradation of the GPS signals to the public. Civilian users of GPS are now able to pinpoint locations up to ten times more accurately. The decision to discontinue SA is the latest measure in an on-going effort to make GPS more responsive to civil and commercial uses world-wide.

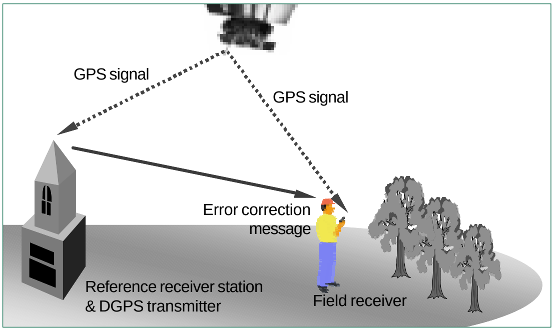


Figure 6.6
Differential positioning

Differential positioning

To eliminate most of the errors discussed above, the technique of differential positioning is applied. Differential GPS carries the triangulation principle one step further, with a second receiver at a known reference point. The reference station is placed on the control point—a triangulated position or the control point coordinate. This allows for a correction factor to be calculated and applied to other roving GPS units used in the same area and in the same time series. This error correction allows for a considerable amount of error to be negated—potentially as much as 90 per cent. The error correction can either be post-processed or in real time (Figure 6.6).

Integration of GPS and GIS

It is possible to integrate GPS positioning in GIS for field data collection. GPS is also used in remote-sensing methods such as photogrammetry, aerial scanning and video technology. GPS is an effective tool for GIS data capture. The GIS user community benefits from the use of GPS for locational data capture in various GIS applications. The GPS can easily be linked to a laptop computer in the field and, with appropriate software, users can place all their data on a common base with little distortion. Thus, GPS can help in several aspects of the construction of accurate and timely GIS databases.