Global Positioning Systems

The Global Positioning System (GPS) is a U.S.-owned utility that provides users with positioning, navigation, and timing (PNT) services. This system consists of three segments: the space segment, the control segment, and the user segment. The U.S. Space Force develops, maintains, and operates the space and control segments.

The Global Positioning System (GPS), originally Navstar GPS, is a satellite-based radionavigation system owned by the United States government and operated by the United States Space Force.

It is a technology by which the location of an object, its velocity, direction, altitude and time can be known precisely at any time, irrespective of day/night, weather, or the configuration of the object.

History of GPS

GPS, originally named NAVSTAR - Navigation System with Time and Ranging was introduced by the United States Department of Defence in 1987. The full constellation of 24 satellites became operational in 1994 and was later launched for civilian use in the 1980s.

Today, GPS is a multi-use, space-based radionavigation system owned by the US Government and operated by the United States Air Force to meet national defense, homeland security, civil, commercial, and scientific needs.

GPS currently provides two levels of service: Standard Positioning Service (SPS) which uses the coarse acquisition (C/A) code on the L1 frequency, and Precise Positioning Service (PPS) which uses the P(Y) code on both the L1 and L2 frequencies. Access to the PPS is restricted to US Armed Forces, US Federal agencies, and selected allied armed forces and governments. The SPS is available to all users on a continuous, worldwide basis, free of any direct user charges.

Segments of GPS

GPS satellites fly in Medium Earth Orbit (MEO) at an altitude of approximately 20,200 km (12,550 miles). Each satellite circles the Earth twice a day. The **space segment** of GPS consists of 24 main satellites & 8 backup satellites placed in near circular orbits, arranged in 6 orbital planes, with 55 degree inclination to equator. The period of revolution is 12 hrs, thus there are at least 4 satellites available for observation every time worldwide.

The GPS **control segment** consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation. The current Operational Control Segment (OCS) includes a master control station, an alternate master control station, 11 command and control antennas, and 16 monitoring sites.

User Segment:

- GPS technology is now in everything from cell phones and wristwatches to bulldozers, shipping containers, and ATM's.
- Major communications networks, banking systems, financial markets, and power grids depend heavily on GPS for precise time synchronization.
- GPS boosts productivity across a wide swath of the economy, to include farming, construction, mining, surveying, package delivery, and logistical supply chain management.
- GPS saves lives by preventing transportation accidents, aiding search and rescue efforts, and speeding the delivery of emergency services and disaster relief.
- GPS also advances scientific aims such as weather forecasting, earthquake monitoring, and environmental protection.
- GPS remains critical to U.S. national security, and its applications are integrated into virtually every facet of U.S. military operations. Nearly all new military assets -- from vehicles to munitions -- come equipped with GPS.

Applications of GPS

Time Synchronization

In addition to longitude, latitude, and altitude, the Global Positioning System (GPS) provides a critical fourth dimension – time. Each GPS satellite contains multiple atomic clocks that contribute very precise time data to the GPS signals. GPS receivers decode these signals, effectively synchronizing each receiver to the atomic clocks. This enables users to determine the time to within 100 billionths of a second, without the cost of owning and operating atomic clocks.

- Widespread availability of atomic clock time, without the atomic clocks.
- Precise synchronization of communications systems, power grids, financial networks, and other critical infrastructure.
- More efficient use of limited radio spectrum by wireless networks.
- Improved network management and optimization, making traceable time tags possible for financial transactions and billing.

- Communication of high-precision time among national laboratories using "common view" techniques.

There is an unknown offset between the satellite clocks and the receiver clock that introduces a corresponding offset in the distance calculation. Because of this offset, the measured distance is called a **pseudorange**.

Public Safety & Disaster Relief

A critical component of any successful rescue operation is time. Knowing the precise location of landmarks, streets, buildings, emergency service resources, and disaster relief sites reduces that time -- and saves lives. This information is critical to disaster relief teams and public safety personnel in order to protect life and reduce property loss.

Industrial Economy

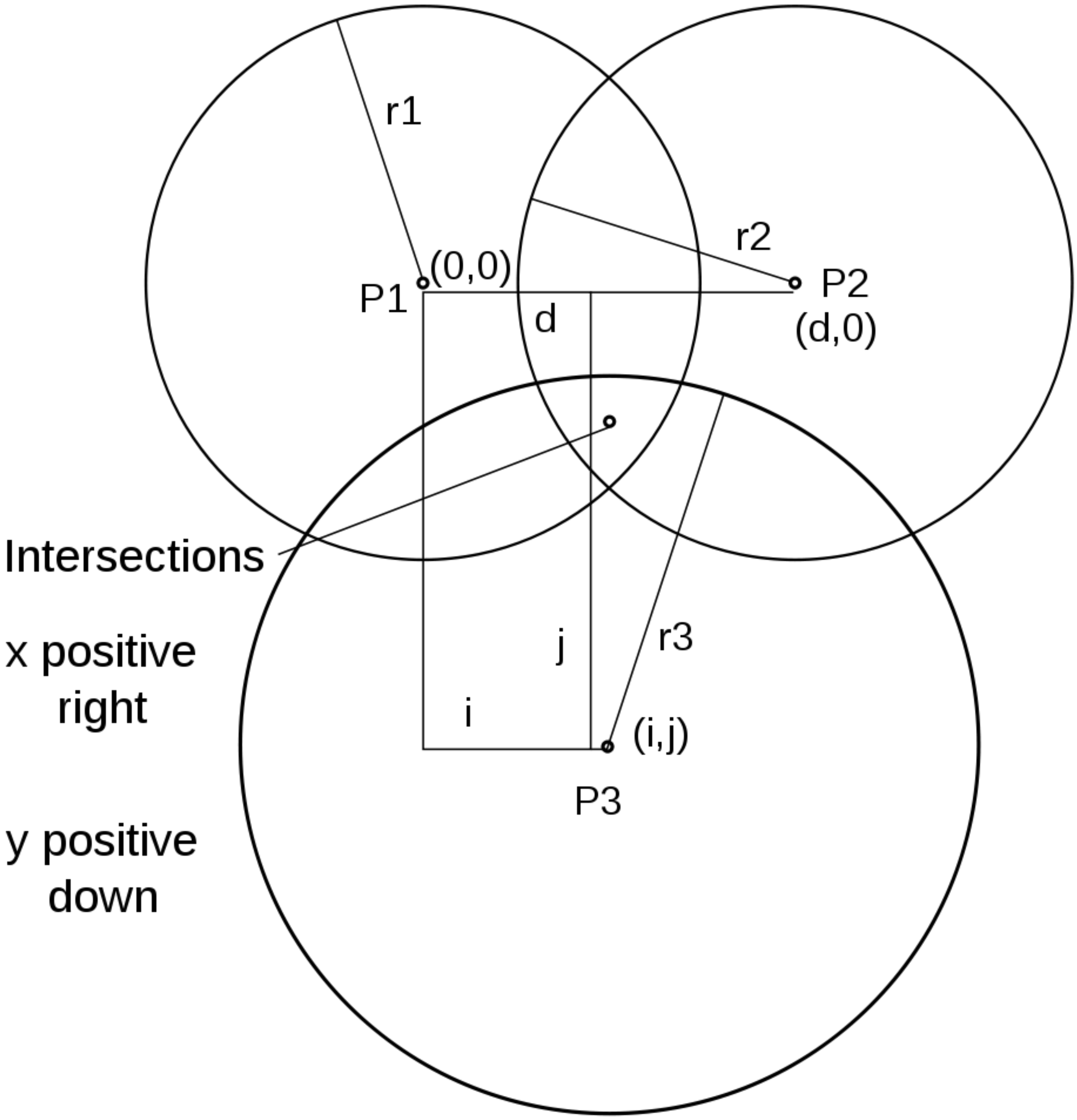
GPS boosts productivity across a wide swath of the economy, to include farming, construction, mining, surveying, package delivery, and logistical supply chain management. Major communications networks, banking systems, financial markets, and power grids depend heavily on GPS for precise time synchronization. Some wireless services cannot operate without it.

Working of GPS

Position fix is obtained in passive receivers by the triangulation method. Estimated ranges from four satellites are used to derive the position and altitude of a point. Ranges from three satellites can provide the latitude and longitude of a point on the Earth. The addition of a fourth satellite can provide a user’s altitude and correct receiver clock error.

Trilateration a.k.a True-range multilateration is a method to determine the location of a movable vehicle or stationary point in space using multiple ranges (distances) between the vehicle/point and multiple spatially-separated known locations (often termed 'stations'). Energy waves may be involved in determining range, but are not required.

For Example, on a plane, if we know our distance from three points, we know exactly where we are. Let us say that we are 10 miles away from point A, 12 miles away from point B, and 15 miles away from point C. If we draw three circles with the centers at A, B, and C, we must be somewhere on circle A, somewhere on circle B, and somewhere on circle C. These three circles meet at one single point (if our distances are correct), our position.



In three-dimensional space, we need at least four spheres to find our exact position in space, i.e., longitude, latitude, and altitude. However, if we have additional facts about our location (for example, we know that we are not inside the ocean or somewhere in space), three spheres are enough, because one of the two points, where the spheres meet, is so improbable that the other can be selected without a doubt.

Distance Measurement with GPS

Measuring the distance is done using a principle called one-way ranging. Each of 24 satellites synchronously transmits a complex signal each having a unique pattern. The computer on the receiver measures the delay between the signals from the satellites and its copy of signals to determine the distances to the satellites.

Synchronization with GPS

The satellites' clocks are synchronized with each other and with the receiver's clock. Satellites use atomic clocks that are precise and can function synchronously with each other. The receiver's clock however, is a normal quartz clock (an atomic clock costs more that $50,000), and there is no way to synchronize it with the satellite clocks.

There is an unknown offset (same for all satellites being used) between the satellite clocks and the receiver clock that introduces a corresponding offset in the distance calculation. Because of this offset, the measured distance is called a pseudorange. The calculation of position becomes finding four unknowns: the Xp, Yp, Zp coordinates of the receiver, and common clock offset dt. For finding these four unknown values, we need at least four equations, from the four connected satellites.

$$PR_1 = \frac{1}{2}[(x_1 - x_r)^2 + (y_1 - y_r)^2 + (z_1 - z_r)^2] + c.\,dt$$

$$PR_2 = \frac{1}{2}[(x_2 - x_r)^2 + (y_2 - y_r)^2 + (z_2 - z_r)^2] + c.\,dt$$

$$PR_3 = \frac{1}{2}[(x_3 - x_r)^2 + (y_3 - y_r)^2 + (z_3 - z_r)^2] + c.\,dt$$

$$PR_4 = \frac{1}{2}[(x_4 - x_r)^2 + (y_4 - y_r)^2 + (z_4 - z_r)^2] + c.\,dt$$

The coordinates used in the above formulas are in an Earth-Centered Earth-Fixed (ECEF) reference frame, which means that the origin of the coordinate space is at the center of the Earth and the coordinate space rotates with the Earth. This implies that the ECEF coordinates of a fixed point on the surface of the earth do not change.

Global navigation satellite system

GNSS is a general term describing any satellite constellation that provides positioning, navigation, and timing (PNT) services on a global or regional basis. While GPS is the most prevalent GNSS, other nations are fielding, or have fielded, their own systems to provide complementary, independent PNT capability.

- **BeiDou Navigation Satellite System (BDS)**
- **Galileo**
- **GLONASS**
- **IRNSS / NavIC**
- **Quasi-Zenith Satellite System (QZSS)**