Global Positioning System

(GPS) Lectures

References

1- L.F.Wiederholt, "GPS SYSTEM SEGMENTS " lecturer. 2012
2- E. Calais," The Global Positioning System" Purdue University - EAS Department, Civil 3273 – ecalais@purdue.edu
3- Elliott D. Kaplan," Understanding GPS Principles and Applications" © 2006 ARTECH HOUSE, INC. 685 Canton Street, Norwood, MA

Lecture (4) GPS

11. Basic GPS Positioning Concept

The position of a certain point in space can be found from distances measured from this point to some known positions in space. This is a one-dimensional case (1D). If the satellite position S_1 and the distance to the satellite x_1 are both known, the user position can be at two places, either to the left or right of S_1. In order to determine the user position, the distance to another satellite with known position must be measured. In the figure (13), the positions of S_2 and x_2 uniquely determine the user position U.

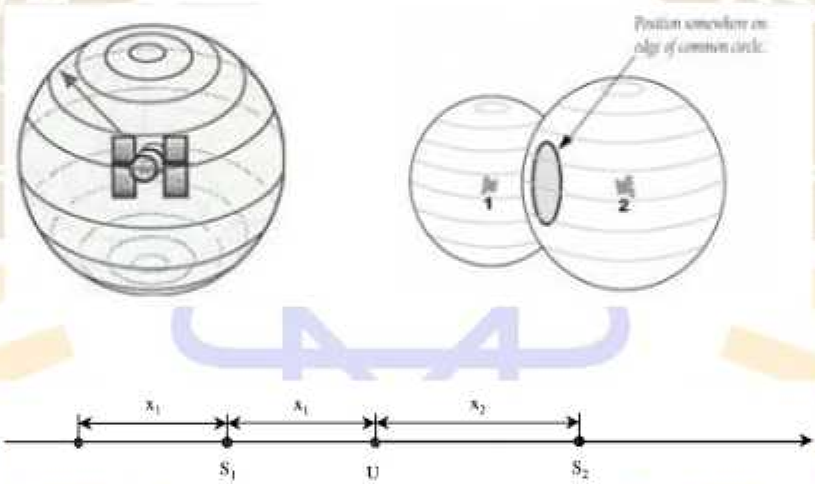
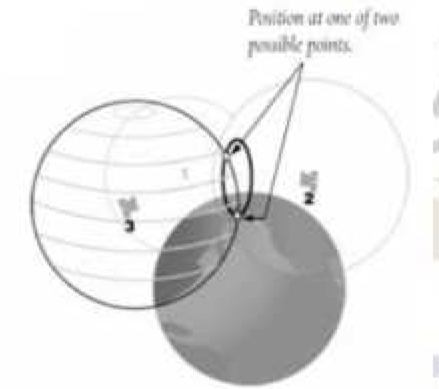


Figure (13): One-dimensional (1D) user position.

Figure (14) shows a two-dimensional case (2D). In order to determine the user position, three satellites and three distances are required. The trace of a point with constant distance to a fixed point is a circle in the two- dimensional case. Two satellites and two distances give two possible solutions because two circles intersect at two points, as shown in figure (13). A third circle is needed to uniquely determine the user position.



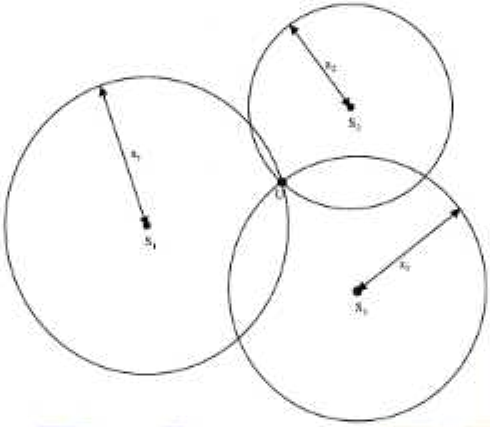


Figure (14): Two-dimensional (2D) user position.

For similar reasons one might decide that in a three-dimensional case (3D) **four** satellites and **four** distances are needed. The equal-distance trace to a fixed point is a sphere in a three-dimensional case, as shown in figure (15).

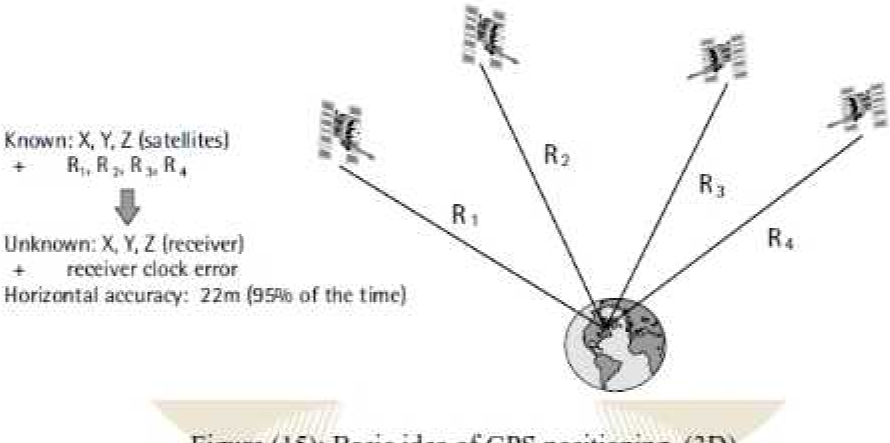


Figure (15): Basic idea of GPS positioning, (3D).

12. GPS Observables

The basic GPS observables are Code Pseudo-ranges and carrier phases.

12.1. Measurement of Pseudo-range

Calculating precise user position needs more than four satellites' positions which are known from the ephemeris data transmitted by the satellites, and pseudo range from user receiver to the satellites. With this information, user's position can be determined through following equations.

$$\rho_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} + b_u$$
$$\rho_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} + b_u \qquad (1)$$
$$\rho_3 = \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} + b_u$$
$$\rho_4 = \sqrt{(x_4 - x_u)^2 + (y_4 - y_u)^2 + (z_4 - z_u)^2} + b_u$$

Where x_u, y_u, z_u are user receiver position and b_u is the user clock bias error expressed in distance. Four equations are needed to solve four unknowns: x_u, y_u, z_u and b_u. Satellite positons x_n, y_n, z_n , (n=1, 2, 3 and 4) are acquired from ephemeris data.

Pseudo-ranges ρ_i , (n=1, 2, 3 and 4) are calculated through following sequences.

- Every satellite sends a frame sync preamble at a certain time t_{si} which is synchronized to zero second in GPS time.
- The receiver will receive the signal at a later time t_u.
- The distance between the user and the satellite i is

$$\rho_{iT} = c(t_u - t_{si}) \qquad (2)$$

Where:

$c = 299{,}792{,}458$ m/s is the speed of light.

ρ_{iT} is often referred to as the true value of pseudo-range from user to satellite i .

t_{si} is referred to as the truth time of transmission from satellite i.

t_u is the true time of reception.

Example:

Find the distance between the satellite and the receiver if the true time of transmission from satellite is (0.00 s) and the time of reception is (0.0673799).

Solution:

$\rho_{iT} = c(t_u - t_{si})$ = 299,792,458 x (0.0673799) = 20199985.840 m

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The receiver declares frame sync when it receives frame preambles which start satellites at certain time zero second, as shown in figure (16). The receiver has a receiver clock and a TIC which occurs at 100 ms interval. When the receiver gets frame data, precise counter starts to count code chips passing through from the first receiving time to the receiver TIC occurring time. The receiver stores this value as a code time then converts the receiver time to GPS time. Propagation delay can be calculated with information such as frame data start time, code time and GPS time at the TIC. Finally pseudo-range is calculated Eq.(2) by multiplying propagation delay time with the speed of light constant.

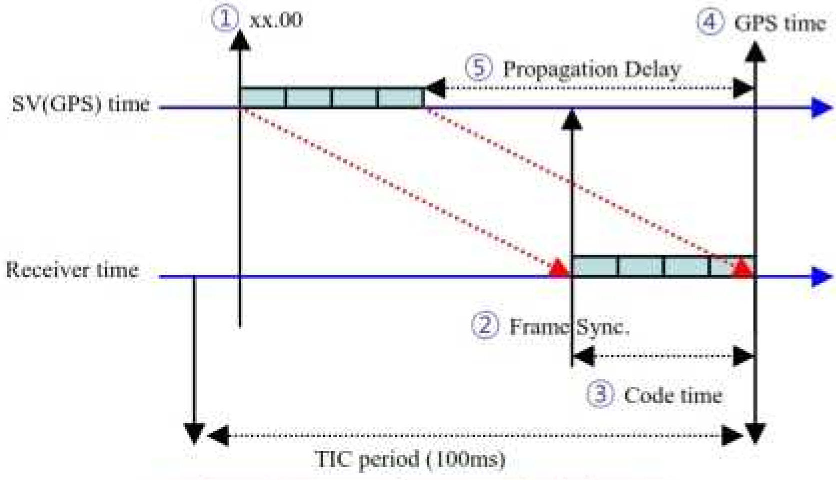


Figure (16): Pseudo-range calculation.

12.2. Carrier-phase Measurements

Another way of measuring the ranges to the satellites can be obtained through the carrier phases. The *range* would simply be *the sum of the total number of full carrier cycles plus fractional cycles at the receiver and the satellite, multiplied by the carrier wavelength*.

The ranges determined with the carriers are far more accurate than those obtained with the codes (i.e., the Pseudo-range).

This is due to the fact that the wavelength (or resolution) of the carrier phase, 19 cm in the case of L1 frequency, is much smaller than those of the codes.

Signals from GPS satellites are continuously transmitted on two carrier frequencies, 1575.42 MHz and 1227.60 MHz, and are referred to as L1 and L2 respectively. Since radio waves propagate through space at the speed of light, the wavelengths of the GPS carrier signals are computed as:

$$\lambda = c/f$$

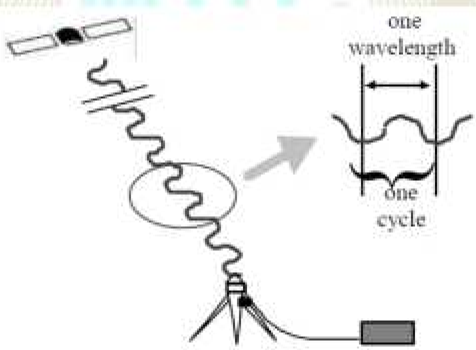
Where

$\lambda =$ is the wavelength in meters,

$c =$ is the speed of light, and

$f =$ is the center frequency in Hz.

A snapshot of one section of carrier transmission which illustrates the definition of wavelength and cycles is shown in figure (17).



The frequency and wavelength of the L1 and L2 carriers are presented in the following table:

Carrier	Frequency (f)	Wavelength (l)
L1	1575.42 MHz	19 cm
L2	1227.60 MHz	24 cm

GPS receivers which record carrier phase, measure the fraction of one wavelength (i.e., fraction of 19 cm for the L1 carrier) when the receiver first locks onto a satellite and continuously measure the carrier phase from that time. The number of cycles between the satellite and receiver at initial startup (referred to as the **Ambiguity**) and the measured carrier phase together represent the satellite-receiver range (i.e., the distance between a satellite and a receiver). In other words:

Measured carrier phase = difference in phase + (ambiguity × wavelength)

$$\phi = \Delta\phi + N\lambda$$

Where

ϕ = is the measured carrier phase in meters,

$\Delta\phi$ = is the difference in phase,

N = is the ambiguity (i.e., number of cycles) and

λ = is the carrier wavelength in meters.

13. GPS Positioning Modes

Positioning with GPS receiver as shown in the following figures, can be performed by either of two ways in order of precision:

- **Point Positioning (Autonomous)**: employs one GPS receiver that measures the code Pseudo-ranges to determine the user's position instantaneously, as long as four or more satellites are visible at the receiver, as shown in the figure (17).

- **Relative Positioning (Differential, Kinematic, and Static)**: relative positioning that is shown in the figures (18, 19, and 20) employs two GPS receivers simultaneously tracking the same satellites.

13.1. Autonomous Positioning

Autonomous positioning is a mode of operation of a GPS receiver where the receiver calculates position in real-time from *satellite data alone* without reference to data supplied from another receiver that is located at a fixed, known, location (i.e., base station). This is the least precise mode of operation. Point coordinate accuracy of ±100 m RMS (Root Mean Square) is obtainable when selective availability is in effect and ±10 m when it is not.

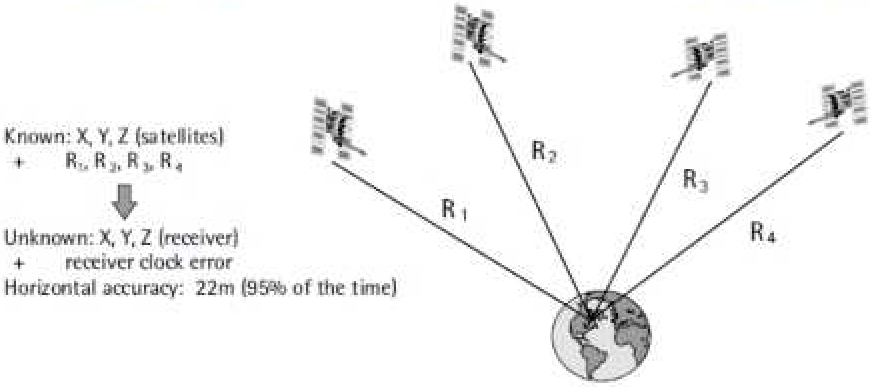


Figure (17): Principle of GPS point positioning.

13.2. Differential Positioning.

Differential positioning that is a mode of GPS surveying that uses two or more receivers with one receiver acting as a base station that is located at a known, fixed location and the other receiver roving to unknown points. The base station computes corrections based on the differences between its known location and its location as computed from the satellite C/A code. These corrections are applied to positions collected by the roving unit. This correction can be done in real-time via a radio link or during post processing back in the office. Point coordinate accuracy of ±30 m RMS is obtainable when selective availability is in effect and ±1 m when it is not.

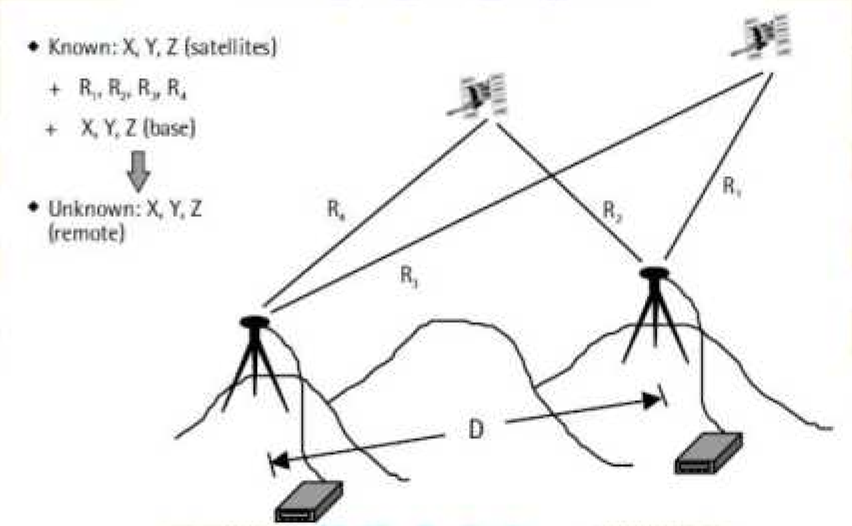


Figure (18): Principle of GPS relative positioning.

13.3. Kinematic Positioning:

Kinematic positioning is a mode of GPS surveying that uses two or more receivers with one receiver acting as a base station that is located at a known, fixed location and the other receiver roving to unknown points, as shown in figure (19). The receivers use the L1/L2 carrier-phase observation (including both the C/A code and P-code) and requires short (1 second to 10 minute) occupation times at the locations being visited by the roving GPS receiver. This method uses baselines to calculate position and has the potential to obtain greater accuracy than is possible with differential positioning methods. Point coordinate accuracy of ±1 m RMS is obtainable when selective availability is in effect and ±0.02 m when it is not.

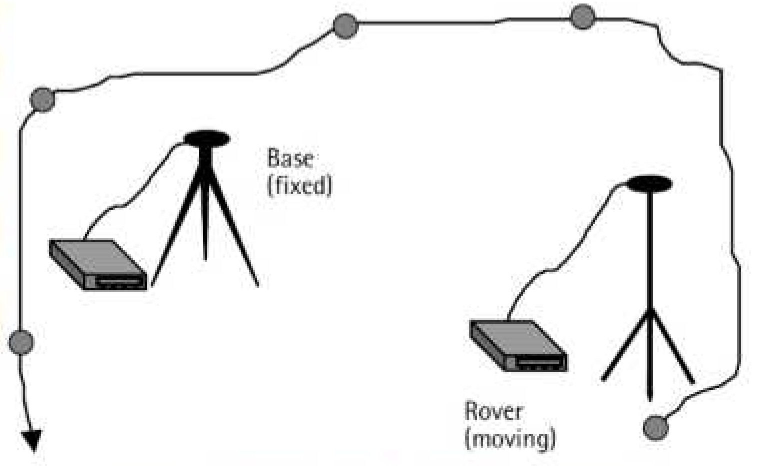


Figure (19). Kinematic Positioning surveying.

13.4.Static Positioning.

Static positioning (geodetic survey) is a mode of GPS surveying that uses two or more receivers. The receivers monitor the L1/L2 carrier-phase observations (including both the C/A code and P-code) and use long occupation times (> 20 minutes). This method uses baselines to calculate position and has the potential to obtain greater accuracy than is possible with differential and kinematic positioning methods. Location is determination when the receiver's antenna is stationary on the earth. Point coordinate accuracy of ±0.05 m RMS is obtainable when selective availability is in effect and better than ±0.01 m when it is not. At least three of the points visited during the survey should have known horizontal and vertical position. These known points are held fixed when calculating the baselines and ensure that the newly surveyed points are tied into the local geodetic control network.

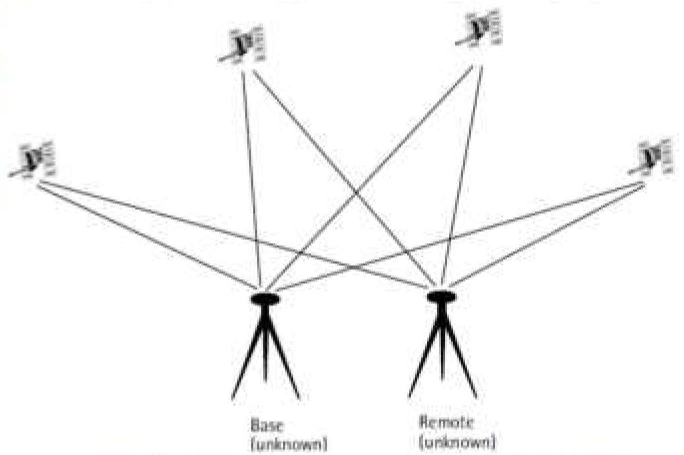


Figure (20): Static GPS surveying.

14. GPS Methods

The three methods used by GPS receivers to obtain position information are: **Autonomous, Post processed and Real-Time.**

1. The Autonomous Method

It occurs when the GPS receiver is used as a stand-alone data collector and no further processing of the data will be done on return to the office. The location information collected is transcribed onto paper in the field or stored in the GPS unit for later transfer in the office to a database for mapping purposes. This method is the simplest and the least accurate of the three methods.

2. The Real-Time Method

It occurs when the GPS receiver is used as a data collector and the positions obtained are corrected on-the-fly based on information received via radio signal received from a base station (located at a known, fixed, position). Based on the types of receivers and antennas used during the survey either the differential or kinematic mode may be used.

3. The Post Processing Method

It is used when the GPS receiver is used as a data collector and further processing of the position data will be completed after downloading the data at the office. This method assumes that a base station receiver (located at a known, fixed, position) was collecting data simultaneously with the roving unit. Based on the types of receivers and antennas used during the survey and the positioning data collected either the differential, kinematic, or static processing mode may be used. There are, however, some **advantages in the post processing mode** as well.

1. More accurate results are generally obtained with the post processing mode.
2. More flexibility in editing and cleaning of the collected GPS data.
3. There is no accuracy degradation due to data latency.

4. The communication link problems, such as the relatively unobstructed line-of-sight requirement, are avoided.
5. In some cases, the input parameters, such as the base station coordinates or the antenna height, may contain some errors, which lead to errors in the computed rover coordinates. These errors can be corrected in the post processing mode, while they cannot be completely corrected in the real-time mode.

15. GPS Applications

GPS has been available for civil and military use for more than two decades. That period of time has witnessed the creation of numerous new GPS applications. Because it provides high-accuracy positioning in a cost-effective manner

1. GPS for the utilities industry

Accurate and up-to-date maps of utilities are essential for utility companies. The availability of such maps helps electric, gas, and water utility companies to plan, build, and maintain their assets.

2. GPS for forestry and natural resources

GPS has been applied successfully in many areas of the forest industry. Typical applications include fire prevention and control, harvesting operations, insect infestation, boundary determination, and aerial spraying.

3. GPS for precision farming

The ability of DGPS to provide real-time sub-meter or even decimeter level accuracy has revolutionized the agricultural industry GPS applications in precision farming include soil sample collection, chemical applications control, and harvest yield monitors.

4. GPS for monitoring structural deformations

Since its early development, GPS has been used successfully in monitoring the stability of structures, an application that requires the highest possible accuracy.

5. GPS for civil engineering application

In road construction and Earth moving, GPS, combined with wireless communication and computer systems, is installed onboard the Earthmoving machine.

6. GPS for open-pit mining

Until recently, conventional surveying was the only method available for staking drill patterns and other mining surveying. As a result of the harsh mining environment, however, stakes were often buried or displaced. In addition, drill operators had no precise way of determining the actual bit depth.

7. GPS for airborne mapping

GPS alone has been successfully used for topographic mapping of small size areas. Using either conventional GPS kinematic surveying or GPS RTK, a user takes positions of the points on the ground where the topography changes, which can be used at a later, time to produce the topographic map of that area. Even in rough areas, GPS can be mounted on all-terrain vehicles (ATVs) to precisely map those areas.

8. GPS for vehicle navigation

When traveling through unfamiliar areas, vehicle drivers often use paper road maps for route guidance. However, besides being inefficient, searching for a destination using a paper map is unsafe, especially in busy areas.