GPS ERRORS

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GPS ERRORS

GPS errors are a combination of noise, bias, blunders. PS measurements are potentially subject to numerous sources of error in addition to clock bias. Among these are uncertainties in the satellite orbits (known as satellite ephemeris errors), errors due to atmospheric conditions (signal velocity depends on time of day, season, and angular direction through the atmosphere), receiver errors (due to such influences as electrical noise and signal matching errors), and multipath errors (reflection of a portion of the transmitted signal from objects not in the straight-line path between the satellite and receiver (Lillesand and Keiffer, 2004).

1.1.1. Noise Errors:

Noise errors are the combined effect of PRN code noise (around 1 meter) and noise within the receiver noise (around 1 meter). Noise and bias errors combine, resulting in typical ranging errors of around fifteen meters for each satellite used in the position solution (Dana, 1997).

1.1.2. Bias Errors

Bias errors result from Selective Availability and other factors. Selective Availability (SA) is the intentional degradation of the SPS signals by a time varying bias. It is controlled by the DOD to limit accuracy for non-U. S. military and government users (Dana, 1997). Other Bias Error sources are discussed in the later part of the module.

1.1.3. Blunders

Blunders can result in errors of hundreds of kilometers. Control segment mistakes due to computer or human error can cause errors from one meter to hundreds of kilometers. User mistakes, including incorrect geodetic datum selection, can cause errors from 1 to hundreds of meters. Receiver errors from software or hardware failures can cause blunder errors of any size. (Dana, 1997)

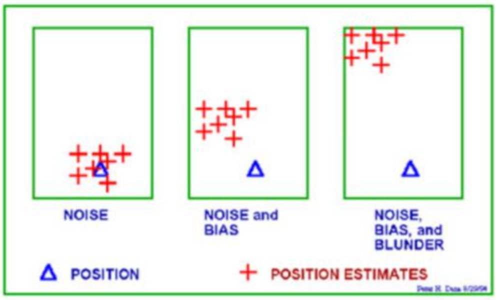

Fig. 1.1. Showing the three types of errors.

The analysis of errors computed using the Global Positioning System is important for understanding how GPS works, and for knowing what magnitude errors should be expected. The Global Positioning System makes corrections for receiver clock errors and other effects but there are still residual errors which are not corrected.

The term user equivalent range error (UERE) refers to the error of a component in the distance from receiver to a satellite. These UERE errors are given as ± errors thereby implying that they are unbiased or zero mean errors. These UERE errors are therefore used in computing standard deviations. The standard deviation of the error in receiver position, σrc, is computed by multiplying PDOP (Position Dilution of Precision) by σR, the standard deviation of the user equivalent range errors. σR is computed by taking the square root of the sum of the squares of the individual component standard deviations. PDOP is computed as a function of receiver and satellite positions.

User equivalent range errors (UERE) are shown in the Table 1.1. There is also a numerical error with an estimated value, σnum, of about 1 meter. The standard deviations, σR, for the course/acquisition and precise codes are also shown in the table. These standard deviations are computed by taking the square root of the sum of the squares of the individual components (i.e., RSS for root sum squares). To get the standard deviation of receiver position estimate, these range errors must be multiplied by the appropriate dilution of precision terms and then RSS'ed with the numerical error. Electronics errors are one of several accuracy-degrading effects outlined in the table above. When taken together, autonomous civilian GPS horizontal position fixes are typically accurate to about 15 meters (50 ft). These effects also reduce the more precise P(Y) code's accuracy. However, the advancement of technology means that today, civilian GPS fixes under a clear view of the sky are on average accurate to about 5 meters (16 ft) horizontally. σ_R for the C/A code is given by:

$$\sigma_R = \sqrt{(3^2 + 5^2 + 2.5^2 + 2^2 + 1^2 + 0.5^2)}m = 6.7m$$

The standard deviation of the error in estimated receiver position σ_{rc}, again for the C/A code is given by:

$$\sigma_R = \sqrt{(PDOP^2 + \sigma_R^{\ 2} + \sigma_{num}^{\ 2})}$$

$$\sigma_R = \sqrt{(PDOP^2 + 6.7^2 + 1^2)}m$$

The error diagram in the Fig. 1.2 shows the inter relationship of indicated receiver position, true receiver position, and the intersection of the four sphere surfaces.

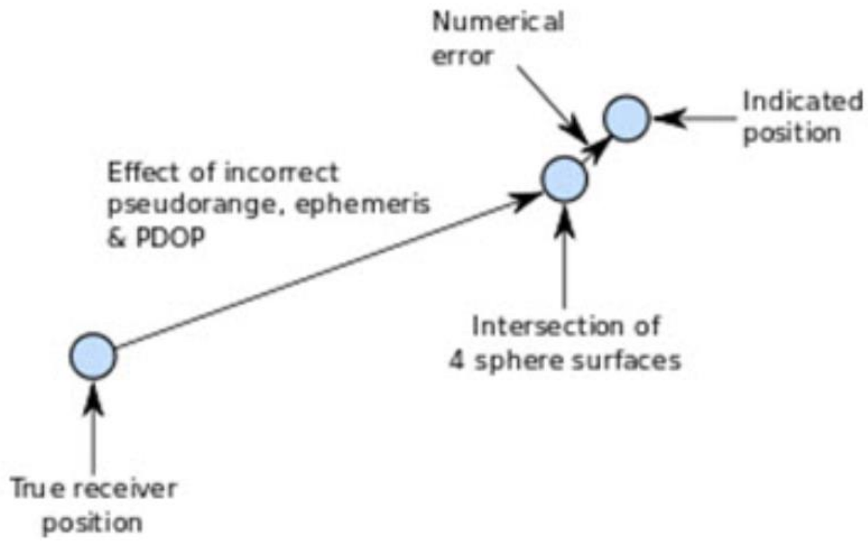

Fig. 1.2. Geometric Error Diagram Showing Typical Relation of Indicated Receiver Position, Intersection of Sphere Surfaces, and True Receiver Position in Terms of Pseudo range Errors, PDOP, and Numerical Errors.

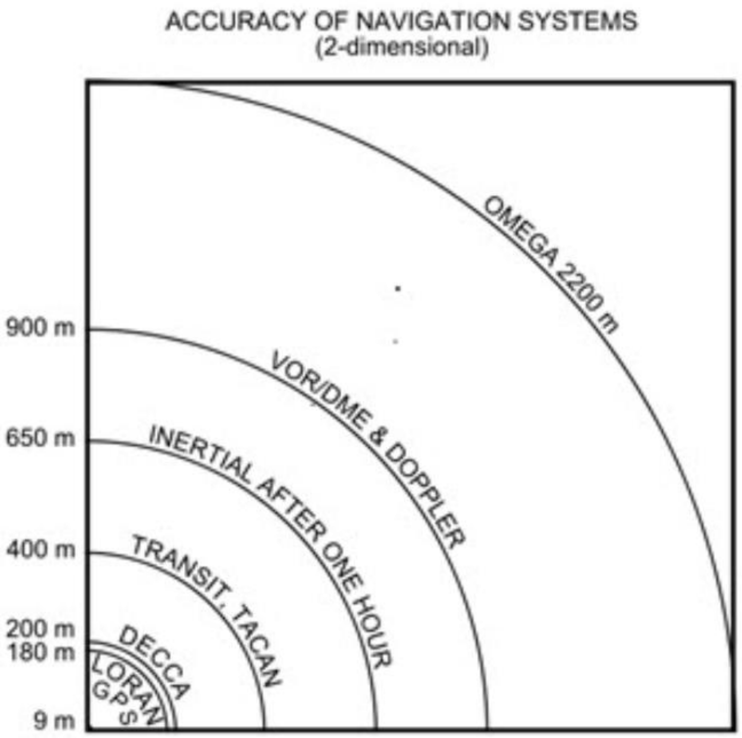

Fig. 1.3. Accuracy of navigation systems.

Table 1.1 Sources of user equivalent range errors (UERE)

Sl. no.	Source	Effect(m)
1.	Signal arrival C/A	±3
2.	Signal arrival P(Y)	±0.3
3.	Ionospheric effects	±5
4.	Ephemeris errors	±2.5
5.	Satellite clock errors	±2
6.	Multipath distortion	±1
7.	Tropospheric effects	±0.5
8.	σ_R C/A	±6.7
9.	σ_R P(Y)	±6

1.2 Sources of GPS Error

The GPS signals sent from the SVs are subject to a variety of error sources before they are processed into a position and time solution in the receiver. As with most systems these error sources take the form of zero-bias noise, bias errors, and blunders. A number of conditions can reduce the accuracy of a GPS receiver. From a top-down perspective (from orbit down to ground level), the possible sources of trouble look like this:

1.2.1 Selective Availability:

Selective availability is the single largest source of C/A-code error. Y-code capable GPS receivers can remove SA with knowledge of the SA algorithm. SA takes the form of a slowly varying range error for each SV. SA introduces the largest bias errors in the Standard Positioning System accounting for most of the 100-meter (95 percent) error in the SPS (Dana, 1997).

1.2.2. Clock and Ephemeris Errors:

Ephemeris errors occur when the satellite doesn't correctly transmit its exact position in orbit. Clock and ephemeris data sets represent the difference between the SV clock and GPS time and permit the estimation of SV position at the time of transmission of the tracked codes. A GPS parameter, the User Range Accuracy (URA), is a range error estimate indicative of the "maximum value anticipated during each sub frame fit interval with uniform SA levels invoked" (Anon 1995, 35). The URA is transmitted as an integer power of two. Although the URA is not specified as a definite indicator of SA error magnitude, for a Block II SV affected by SA, a URA of 32 meters is common (Dana, 1997).

1.2.3. Ionospheric Delays:

The ionosphere starts at about 43–50 miles above the Earth and continues for hundreds of miles. Satellite signals traveling through the ionosphere are slowed down because of plasma (a low-density gas). Although GPS receivers attempt account for this delay, unexpected plasma activity can cause calculation errors. (Dana, 1997)

A major source of bias error is the delay of the GPS carrier signals as they pass through the layer of charged ions and free electrons known as the ionosphere. (Dana, 1997). Varying in density and thickness as it rises and falls (50 to 500 kilometre's) due to solar pressure and geomagnetic effects, the ionosphere can delay the GPS signals by as much as 300 nanoseconds (100 meters) (Klobuchar 1982). The diurnal (24-hour) changes in the ionosphere cause the largest variations in delay. At night the delay is at a minimum and the thinner and higher night-time ionosphere is more easily modelled than the less dense and thicker layer during the day. The signals from SVs at low elevation angles with respect to the local horizon experience the largest delays as the signal passes through more ionosphere than if the SV were directly overhead. Using the P-code, or special codeless (signal-squaring) techniques, the delay through the ionosphere can be computed by a receiver capable of measuring the phase delay difference between the code carried on the L1 and L2 signals (Dana, 1997). These dual frequency methods result in a substantial reduction of the ionospheric bias, making it possible to transfer sub-nanosecond clock offset measurements over thousands of kilometres (Dunn and others 1993, 174). For a single frequency (L1) C/A-code receiver the ionospheric delay can be estimated from the ionospheric delay model broadcast by the SVs. The Master Control station calculates the parameters for delay using a cosine model that computes delay for a given local time-of-day and the elevation angle for the path from the receiver to an SV. Some users compute an ionospheric delay estimate from their own models. Using the broadcast model under normal conditions removes about half of the error (Fees and Stephens 1987) leaving a residual error of around 60-90 nanoseconds during the day and 10 to 20 nanoseconds at night (Knight and Rhoades 1987). Signals from SVs at high elevation angles experience smaller delays, but use of the broadcast model under abnormal conditions can occasionally introduce more error than that caused by the actual delay (Dana, 1997).

1.2.4. Tropospheric Delays:

The troposphere is the lowest region in the Earth's atmosphere and goes from ground level up to about 11 miles. Variations in temperature, pressure, and humidity all can cause variations in how fast radio waves travel, resulting in relatively small accuracy errors. GPS signal delays through the troposphere, the layer of atmosphere usually associated with changes in weather (from ground level up to 8 to 13 kilometre's), are subject to local conditions and are difficult to model. GPS does not broadcast a tropospheric correction model but several such models have been developed. Some receivers make a limited model available that computes tropospheric delay from receiver height and SV elevation angle using nominal atmospheric parameters. (Dana, 1997). Because accurate tropospheric delay models (Turner and others 1986) require local pressure, temperature and humidity (PTH) data as well as receiver height and elevation angle to the SV, these models are difficult to apply in real-time situations. The errors introduced by an unmodeled troposphere may be as much as 100 nanoseconds at low elevation angles (less than 5 degrees), but are more typically in the 30-nanosecond range (Knight and Rhoades 1987). Residuals after application of a simple, no-PTH, model (Gupta 1980) are in the 10-nanosecond range.

1.2.5. Multipath:

When a satellite signal bounces off a hard surface (such as a building or canyon wall) before it reaches the receiver, a delay in the travel time occurs, which causes an inaccurate distance calculation. Multipath interference, caused by local reflections of the GPS signal that mix with the desired signal, slowly introduces varying bias errors of one to two nanoseconds for navigation receivers aboard aircraft in flight. For land-based systems, local conditions and exact antenna placement can result in errors of up to 150 nanoseconds. (Dana, 1997). Nominal errors for land-based receivers are in the 30-nanosecond range (Braasch, 1995). Careful attention to antenna placement, antenna design, the use of choke rings, and the use of materials that absorb GPS radio-frequency signals can mitigate much of the potential multipath interference, but these measures must be carefully designed to allow for the different multipath reflections from the constantly changing SV elevations and azimuths. In many applications it is difficult or impossible to completely eliminate multipath errors. (Dana, 1997)

1.2.6. GPS Signal Noise

Propagation of the GPS signals from the SV to the receiver introduces noise from galactic sources, ionospheric scintillations, and cross correlation from other GPS SV signals that results in small noise (zero bias) errors in the three-nanosecond range. (Dana, 1997)

1.2.7. Receiver Noise and Delays

Receiver noise can introduce two to three nanoseconds of zero bias noise in the timing measurements of a GPS receiver. Delays within a receiver can be calibrated by the manufacturer, but if receiver delays change with temperature or change differently between channels of a multi-channel receiver, timing bias errors can result. Antenna cable delays must be recomputed or calibrated if cable lengths change or cables of different materials are used. (Dana, 1997). There have been reports of cable delays being both temperature and signal strength dependent (Lewandowski, Petit and Thomas 1991, 5). Manufacturers can provide cable delays for the equipment they supply (Dana, 1997).

1.2.8. Receiver Oscillator Errors

While precise time standards at the Control and Space Segments of GPS are designed to keep user clock requirements to a minimum, receiver oscillators must provide enough stability to ensure that they can be rated properly by GPS receiver software and that they provide a low noise timing reference. This is sometimes difficult to accomplish in high dynamic environments or when the receiver internal temperatures cannot be controlled or compensated for (Dana, 1997).

1.2.9. SV clock errors

The uncorrected by Control Segment can result in one-meter errors in position. (Dana, 1997)

1.2.10. Geometric Dilution of Precision

Geometric Dilution of Precision (GDOP) is a measurement of the sensitivity of a receiver position or time estimate to changes in the geometric relationship between the receiver position and the positions of all of the SVs used to form the position or time estimate. If the

SVs used for a navigation solution were all in about the same place in the sky, directly above a receiver position, for instance, the position solution for height would be less sensitive to pseudo-range changes than would the poorly defined (diluted) solution for horizontal position. If the SVs were distributed around the field of view of the receiver, horizontal and vertical positioning would be more equally sensitive to pseudo-range changes. GDOP is a dimensionless multiplier that can be used to estimate the effect of pseudo-range errors on a complete position and time solution. The single GDOP parameter is the square root of the sum of the diagonal terms of the covariance matrix that is formed from the inverse of the matrix of directional derivatives for each of the SV positions and pseudo-ranges used in the position solution. For a specified receiver position and a set of SVs, GDOP can be separated into three-dimensional position (PDOP) or spherical (SDOP) dilution, two-dimensional horizontal (HDOP), or one dimensional vertical (VDOP) or time (TDOP) estimates. These separate components of GDOP are formed from covariance terms and so are not independent of each other. A high TDOP (time dilution of precision) in a navigation receiver will eventually influence position errors as erroneous receiver clock bias estimates are used to correct pseudo-range measurements.

The computation of geometric dilution of precision involves many numerical equations. Computations were provided to show how PDOP was used and how it affected the receiver position error standard deviation. When visible GPS satellites are close together in the sky (i.e., small angular separation), the DOP values are high; when far apart, the DOP values are low. Conceptually, satellites that are close together cannot provide as much information as satellites that are widely separated. Low DOP values represent a better GPS positional accuracy due to the wider angular separation between the satellites used to calculate GPS receiver position. HDOP, VDOP, PDOP and TDOP are respectively Horizontal, Vertical, Position (3-D) and Time Dilution of Precision. (Dana, 1997)

1.2.11. Poor satellite coverage

When a significant part of the sky is blocked, your GPS unit has difficulty receiving satellite data. Unfortunately, you can’t say that if 50 percent (or some other percentage) of the sky is blocked, you’ll have poor satellite reception; this is because the GPS satellites are constantly moving in orbit. A satellite that provides a good signal one day may provide a poor signal at the exact same location on another day because its position has changed and is now being blocked by a tree. The more open sky you have, the better the chances of not having satellite signals blocked. Building interiors, streets surrounded by tall buildings, dense tree canopies, canyons, and mountainous areas are typical problem areas (McNamara, 2004).

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