[Request the full white paper at https://psionic.ai/request-form-white-paper-on-advanced-navigation/]

White Paper: Overcoming Issues in Precise Navigational Methods *(Excerpt)*

Dr. Donald R. Erbschloe

Errors and uncertainty in GPS navigation

It is instructive to conduct a deeper dive into a ubiquitous navigation approach: GPS. This system consists of a constellation of 24 or more satellites in Mid-Earth Orbit (MEO) at altitudes of approximately 12,500 miles.[i] Each satellite broadcasts a message (50 bits/second) containing a variety of navigation information (satellite position, time, status, ionospheric modeling, and satellite clock corrections). This message must travel through space, the atmosphere, and may be reflected from the ground as well as natural or man-made surfaces before reaching the GPS system receiver.

Complicating this picture is the need for simultaneous signals from a minimum of 4 satellites to obtain full 3-D position information and time. Each of these signals is subject to a variety of effects and issues listed in Table 2 (below). Satellites and receivers can fail or suffer from noise and timing instabilities; the satellite might deviate from predicted orbital path; relativistic effects need to be considered; space or terrestrial weather-caused variations in the atmosphere are unpredictable and can alter signal propagation; line of sight can be blocked or limited by obstacles; and intentional and unintentional denial or degradation of signal can occur.

Table 2: GPS Errors, Causes, Effects, and Remedies

ERRORS AND ISSUES	DESCRIPTION	EFFECT MAGNITUDE	REMEDIATION
Intentional issues (human-caused)			
GPS scheduled maintenance	Routine servicing or upgrades of satellite or ground systems.	0.5 years MTBF[ii]	
Jamming	Intentional overwhelming of and drop GPS signal strength.[iii]	Can be continuous or intermittent while in range of transmitter	Switch to other navigation system during jamming exposure.
Spoofing	Transmission of false or inaccurate GPS signals to deceive or divert.[iv]	Can be continuous or intermittent while in range of transmitter	Authentication of signal allows operator not to act on spurious signal.
Selective availability	Deliberate signal degradation to decrease precision for non-military use.	100 m	Discontinued in 2000.

ERRORS AND ISSUES	DESCRIPTION	EFFECT MAGNITUDE	REMEDIATION
Receiver issues			
Receiver clock error	The accuracy of receiver clocks (often quartz-based) is very low compared to atomic clocks in GPS satellites.	Highly dependent on quality of clock	Clock steering, error estimation, differencing[v]
Receiver noise	Noise due to various factors: temperature, shock, vibration, interference from receiver components (e.g., antenna).	3 cm[vi]	Adaptive filters
Satellite issues			
Satellite clock stability	GPS atomic clocks stable to within 2 ns / day	1.35 m[vii]	Correction from Navigation Broadcast Signal
Satellite clock bias	Difference between on-board clock time and GPS time. Includes clock and rate drift.	10 m[viii]	Correction from Navigation Broadcast Signal
Hard failure	**Two types:** Long-term (LT)-irreparable signal loss Short-term (ST)-temporary loss of signal	LT: 15 years mean time between failure (MTBF) ST: 0.5 years MTBF[ix]	LT: replace satellite ST: switch to redundant sub-system
Orbital Mechanics and Relativity			
Eccentricity	Deviation from pure circular orbit (affects velocity and position of satellite).	45 ns max for eccentricity of 0.02 = 1.35 m[x]	Can be predicted and compensated for
Sagnac effect	Variance in signal propagation time due to rotation of Earth.	30 m[xi]	Can be predicted and compensated for
Ephemerides	Deviation from calculated orbital trajectory.	2 m[xii]	Correction from Navigation Broadcast Signal
Relativistic effects	**Two types:** **Special relativity (SR):** because of its motion, satellite clock seems to run slower than receiver clock. **General relativity (GR):** gravity is weaker for satellite and its clock runs faster.	Combined effect: 38 μs / day = 11.4 m[xiii]	Can be predicted and compensated for
SIGNAL PROPAGATION			
Ionospheric effects	Occurs during transit of ionosphere (50-1000 km altitude). Interaction with ionized gases results in refraction, dispersion, and attenuation.	Delay can be as high as 300 ns (100 m) for long slant paths.	Partial compensated for from ionospheric information in Navigation Broadcast Signal

ERRORS AND ISSUES	DESCRIPTION	EFFECT MAGNITUDE	REMEDIATION
Tropospheric effects	Occurs during transit of troposphere (surface – 20 km altitude). Interaction with non-ionized gases results in refraction and attenuation. Two components: wet (accounts for 10% of total effect, difficult to model) and dry (accounts for remainder, straightforward to model).	2.5 – 25 m[xiv]	Can be partially predicted and compensated for
Multipath	Increased path length and interference, caused by signals reflected from surfaces prior to reception.	Up to 100 m[xv]	Clutter free receiver environment, choke ring antenna
Positional Dilution of Precision	Baseline vectors from 3 or more satellites fix the position of the receiver. Uncertainties in the length of these vectors generates an error “volume” around the true position.	Dependent upon vector uncertainty and desired confidence level [xvi]	Can be calculated
UNINTENTIONAL ISSUES			
Space weather	Sun-produced radio bursts degrade signal to noise ratio of GPS broadcasts. Geomagnetic storms can distort upper atmospheric layers and double the total electron content of ionosphere, impacting signal transmission.[xvii]	Variable	Modeling and monitoring of space weather.
Spectrum interference	Transmission in spectrum bands adjacent to GPS can interfere with or degrade GPS signals.	Variable	Regulation of spectrum and power limit criteria.[xviii]

[Request the full white paper at https://psionic.ai/request-form-white-paper-on-advanced-navigation/]

---

[i] https://www.gps.gov/systems/gps/space/

[ii] Global Positioning System, op. cit., pg A-35.

[iii] https:// www.gps.gov/spectrum/jamming/

[iv] Karaim, op. cit., pgs 80-81.

[v] Karaim, op. cit., pg 73.

[vi] https:// www.e-education.psu.edu/geog862/node/1722

[vii] Karaim, M., Elsheikh, M., and Noureldin, A., “GNSS Error Sources”, Multifunctional Operation and Application of GPS, Chapter 4, pg 72. https:// www.intechopen.com/books/multifunctional-operation-and-application-of-gps/gnss-error-sources

[viii] https:// web.archive.org/web/20090429034807/http:// seismo.berkeley.edu/~battag/GAMITwrkshp/lecturenotes/unit1/unit1.html

[ix] Global Positioning System Standard Positioning Service Performance Standard, Appendix A, SPS Signal-in-Space (SIS) Background Information, 4th ed., September 2008, pgs A32-35.

[x] https:// www.e-education.psu.edu/geog862/node/1714

[xi] Karaim, op. cit., pg 74.

[xii] https:// web.archive.org/web/20090429034807/http:// seismo.berkeley.edu/~battag/GAMITwrkshp/lecturenotes/unit1/unit1.html

[xiii] https:// en.wikipedia.org/wiki/Error_analysis_for_the_Global_Positioning_System#cite_note-Rizos-16

[xiv] Karaim, op. cit., pgs 76-77.

[xv] ibid., pg 77.

[xvi] Langley, R.B., “Dilution of Precision”, GPS World, May 1999, pgs. 52-57, http:// www2.unb.ca/gge/Resources/gpsworld.may99.pdf

[xvii] Comberiate, J., Kelly, M., Dyrud, L., and Weaver, G., “Space Weather Effects on GPS Systems”, 52nd Meeting of the Civil GPS Service Interface Committee, Nashville, TN, September 2012. https:// www.gps.gov/cgsic/meetings/2012/comberiate.pdf

[xviii] https:// www.gps.gov/spectrum/ABC/