



ERTH 455 / GEOP 555 Geodetic Methods

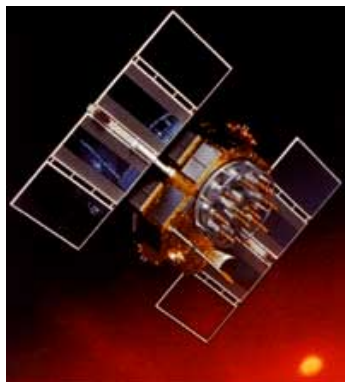
– Lecture 04: GPS Overview, Coordinate Systems–

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GPS Overview

- 1973: Architecture approved
- 1978: First Block-I satellite launched
- 1983: Korean Air 007 shot down after straying into USSR air space
- 1983: Pres. Reagan mandated civilian use of GPS
- 1985: 10 Block-I satellites in orbit for concept test
- 1995: Full Operational Capability (FOC)
- 2000: Selective availability turned off



GPS Block-I, NASA

GPS Overview

- 2005: Begin modernization, First Block IIR-M broadcasts L2C signal
- 2010-2015: 10/12 Block IIF satellites launched, broadcast L5 signal
- 2018 (?) Block III launches: new signals – Military (M-code), L1C, increased signal power, laser retro-reflectors for orbit tracking,
- total satellite launches: 72, only 2 failures! https://en.wikipedia.org/wiki/List_of_GPS_satellites



GPS Block-III, NASA

GPS Primary Uses

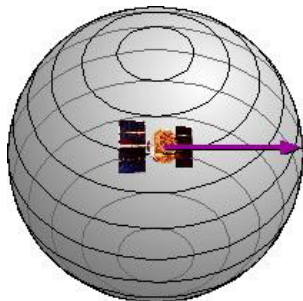
Navigation

real-time, meter accuracy (sub-meter in differential mode)

Surveying

post-processing, multi-receiver, millimeter accuracy

GPS Positioning (in a Nutshell) – Ranging



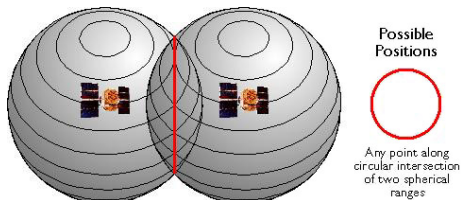
Possible
Positions



Any point on
range sphere

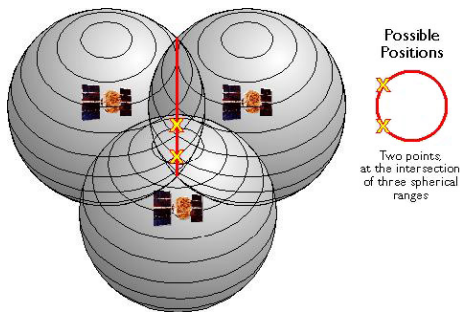
https://www.e-education.psu.edu/geog482spring2/c5_p18.html

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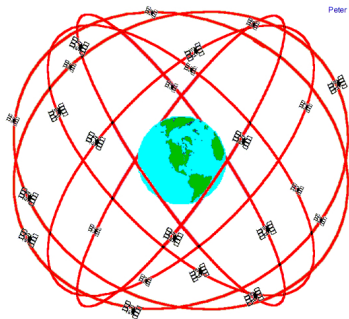


https://www.e-education.psu.edu/geog482spring2/c5_p18.html

- Space Segment – satellites
- Control Segment – management of satellites
- User Segment – Civil and military receiver development

System Architecture: Space Segment

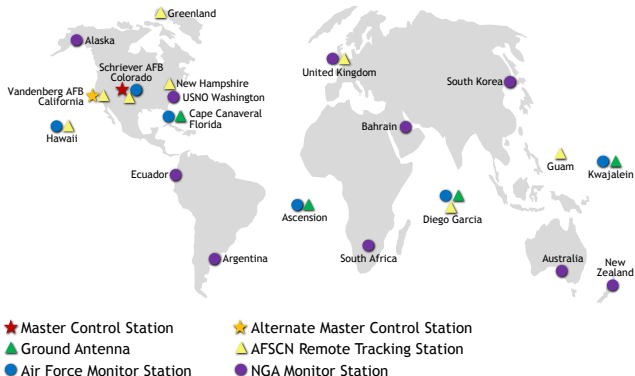
- Baseline constellation 24 satellites, 6 orbital planes, 55° inclined
- Period \approx 12 hours, stationary ground tracks
- Currently 32 satellites operational
- Constellation Status / Outages: <http://www.navcen.uscg.gov/>
- E.g. <http://navcen.uscg.gov/?Do=constellationStatus>



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

System Architecture: Control Segment

GPS Control Segment



Updated April 2014

gps.gov

Master control station (Colorado) operates system, sends commands

System Architecture: Control Segment

- monitor orbits, satellite health
- maintain GPS time (currently 18 s ahead of UTC)
- predict ephemerides, clock parameters
- update satellite navigation messages
- maneuver satellite: maintain orbit

local	2015-08-23 21:06:20	Sunday	day 235	timezone UTC-6
UTC	2015-08-24 03:06:20	Monday	day 236	MJD 57258.12939
GPS	2015-08-24 03:06:37	week 1859	97597 s	cycle 1 week 0835 day 1
Loran	2015-08-24 03:06:46	GRI 9940	349 s until	next TOC 03:12:09 UTC
TAI	2015-08-24 03:06:56	Monday	day 236	36 leap seconds

<http://www.leapsecond.com/java/gpsclock.htm>

System Architecture: Control Segment

- each satellite visible at min 2 monitor stations
- monitor stations operated remotely from MCS
- equipment: GPS receivers w/ cesium clocks, met instruments, comms to satellites
- GPS time based on atomic clocks on satellites and monitor stations
- satellite clock time offset, drift, drift rate part of navigation message, allows clock sync

System Architecture: User Segment



What's your coordinate system?

- need 2 coordinate systems
- one in which user position is fixed – rotates with Earth
- another spaced-fixed/inertial to express satellite motion – Earth rotates
- transformations (rotations) link the coordinate systems

Coordinate Systems 3/11 – CTRS

Coordinate system in which user position is fixed:

- rotates with the Earth:
conventional terrestrial reference system (CTRS)
- use cartesian coordinate system
- define origin at center of mass
- z-axis is axis of rotation
- x-axis goes through intersection of equatorial plane and reference median
- y-axis makes it right-handed

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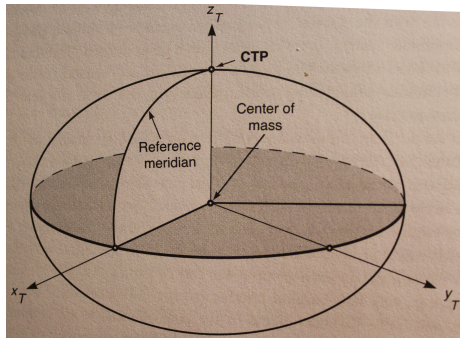
Easy, right?

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Easy, right?



Misra and Enge, 2011, GPS-Signals, Measurements, and Performance

Coordinate Systems 4/11 – CTRS

What are potential issues?

What are potential issues?

- *polar motion*: pole of rotation moves, roughly circular, several meters/year
- use conventional terrestrial pole (CTP) – average of polar motion between 1900-1905
- *center of mass*: where is it?

Coordinate Systems 4/11 – CTRS

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Actually,

- CTRS is *realized* through a set of points
- need consistent coordinates from measurements
- measurements have errors
- *realize* coordinate frame that fits data best (e.g, least-squares)
- World Geodetic System 1984 (WGS84) one such realization
- GPS provides position in WGS84 ECEF coordinate frame
- Scientists use ITRF (International Terrestrial Reference Frame)

Coordinate system which is space-fixed

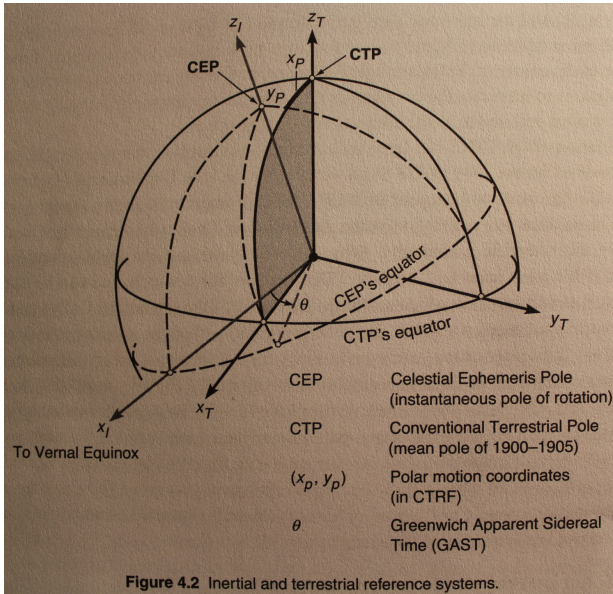
- Earth within: conventional inertial reference system (CIRS)
- express forces, acceleration, velocity, position vectors
- inertial reference system defined as stationary / constant velocity in space
- define origin at center of mass
- z-axis is axis of rotation
- x-axis in equatorial plane pointing to vernal equinox (intersection of equatorial plane w/ plane of rotation around sun)
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Again . . . easy, right?

Coordinate Systems 6/11 – CIRS

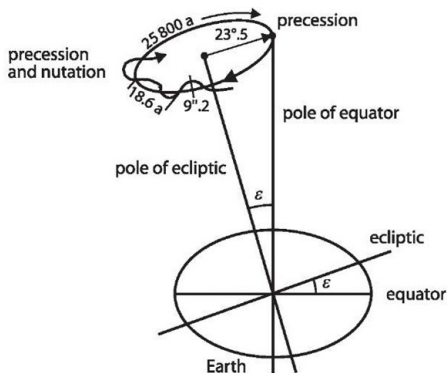


What are potential issues?

Coordinate Systems 7/11 – CIRS

What are potential issues?

- *varying speed around sun*: think as inertial coord sys over short time
- *axis of rotation not fixed*: precession (26 kyrs), nutation (18.6 yrs)
- well understood – can be traced to any epoch



source: <http://what-when-how.com>

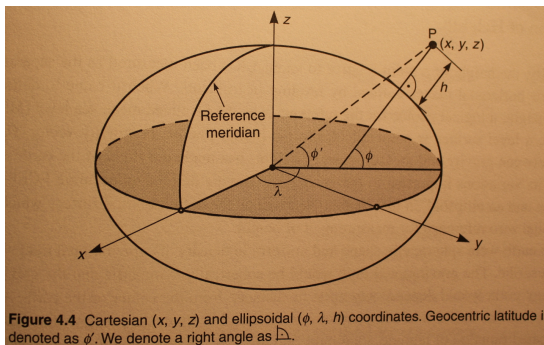
Cartesian coordinates not intuitive to convey position

(Any guess where we are: $X=-1353856.8945$, $Y=314830.6876$,
 $Z=-6205742.1059$)

- how about latitude, longitude, height?
- Earth is rough, need smooth model; easy to characterize: ellipsoid
- origin Earth's center of mass
- z-axis = axis of revolution of ellipsoid
- need to specify semi-major/minor axis (a,b), or flattening
 $f = (a - b)/a$
- WGS84: $a = 6378137.0m$, $1/f = 298.257223563$

Coordinate Systems 9/11

- *geodetic latitude*, ϕ : angle in meridian plane, between equatorial plane and line that's normal to tangent at P
- *geodetic longitude*, λ : angle in equatorial plane, between reference meridian and meridian plane through P
- *geodetic height*, h : measured along normal to tangent at P; no physical meaning!



- first definition of absolute height relative to mean sea level (MSL)
- recall previous slide: height measured along normal to level surface (tangent at P)
- perpendicular to gravity vector! . . . understanding gravity is important!
- all points with same value of gravity potential: *equipotential surface*
- equipotential surface with best fit to MSL is *geoid*
- orthometric height $H = h - N$, shown on topo maps.

Coordinate Systems 11/11 – HEIGHTS

- orthometric height $H = h - N$, shown on topo maps.

