Basics of Satellite Navigation – an Elementary Introduction

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CONCEPT OF GPS

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Concept of GPS

- 2.1 Initial objectives
  - Definition given by Wooden (1985) reads:

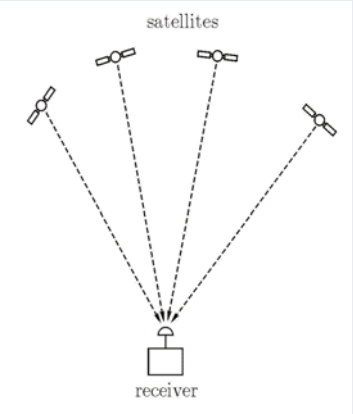
    „The Navstar Global Positioning System (GPS), is an all-weather, space-based navigation system under development by the Department of Defense (DoD) to satisfy the requirements for the military forces to accurately determine their position, velocity, and time in a common reference system, anywhere on or near the Earth on a continuous basis.“

Concept of GPS - Initial objectives

- Goals
  - primarily dedicated for military users
  - civilian use was the first productive application of GPS (Macrometer receiver!)
- Pseudoranges are derived from
  - travel time of the (coded) signal (code pseudoranges)
  - phase measurements on the signal (phase pseudoranges)

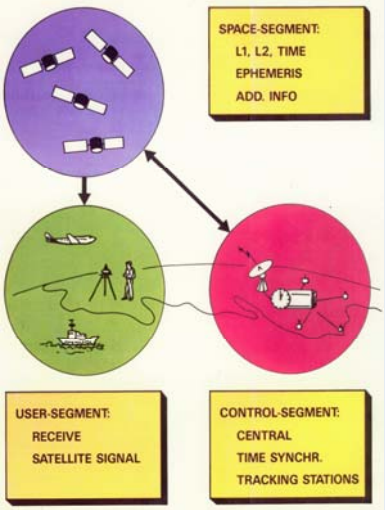
Concept of GPS - Initial objectives

In both cases, the clocks of the receiver and the satellite are employed. An imperfect synchronization results in clock errors. In the case of code pseudoranges, 4 unknowns (3 coordinates plus clock error) must be determined and, thus, 4 satellites are necessary for real-time solutions.



Concept of GPS - Initial objectives

The three segments of GPS



Concept of GPS

- 2.2 Space segment
  - 2.2.1 Constellation
    - The nominal constellation consists of 24 (almost evenly spaced) satellites which provide global coverage with four to ten simultaneously observable satellites.
      - nearly circular orbits
      - altitude of about 20200 km (→ period of 12 sidereal hours)
      - six orbital planes with four satellites each
      - orbital inclination of about 55°

Concept of GPS - Space segment

Concept of GPS - Space segment

– 2.2.2 Satellites
  • General remarks
    – The satellites have radio transceivers, atomic clocks, computers and various ancillary equipment on board
    – Each satellite broadcasts a message for the determination of the satellite position in space (“broadcast ephemerides”)
    – The auxiliary equipment comprises solar panels for power supply and a propulsion system for orbital manoeuvres.

Concept of GPS - Space segment

• Satellite categories
  – Block I satellites → history (1978-1985)
  – Block II and IIA satellites,
    » mean mission duration of 6 years
    » Block II satellite signals were restricted by Selective Availability (SA) and are still affected by the Anti-Spoofing (A-S) capability.
  – Block IIR satellites
    » replacement of Block II/IIA satellites
    » design life of 10 years
    » first launch in 1997
    » hydrogen masers
    » improved facilities for communication
    » capable of intersatellite tracking

Concept of GPS - Space segment

– Block IIR-M satellites
  » launches 2005-2009
  » design of life time 13 years
  » second civil signal on L2 (L2C)
  » 3 Rb-atomic clocks
– Block IIF satellites
  » “follow on” satellites with a design life of 15 years
  » launches from 2009 onwards
  » third civil signal (L5)
– Block III satellites (future generation: 2014 and onwards)

Concept of GPS - Space segment

- Satellite signal
  – The satellite signal is controlled by atomic clocks.
  – Each Block II/IIA satellite has two rubidium and two cesium clocks on board.
  – Frequency stability of these clocks is in the range of 10^{-13} to 10^{-14} over one day.
  – A fundamental frequency of f_0 =10.23 MHz is generated.
  – After multiplying this frequency by 154 and 120, the two carriers

    L1 = 1575.42 MHz

    L2 = 1227.60 MHz

    in the L-band are obtained. A third carrier L5 = 115 f_0 will be available in the future. Note the advantages of the multi-carrier approach.

Concept of GPS - Space segment

- Two pseudorandom noise (PRN) codes are modulated onto the carriers
  - » C/A-code (Coarse/Acquisition-code), also designated as Standard Positioning Service (SPS), is modulated upon L1 only (→ denial of accuracy).
  - » P-code (Precision-code), also designated as Precise Positioning Service (PPS), is encrypted to the Y-code and modulated on both carriers L1 and L2 (→ accessible for military users only).
  - » In the future, the C/A-code will also be modulated onto the L2 and L5 carriers.
- Note that in the near future some new code types will be applied.
- A data message (satellite ephemerides, system time, satellite clock bias, etc.) is also modulated onto both carriers.

Sidestep #1 - Keplerian orbit

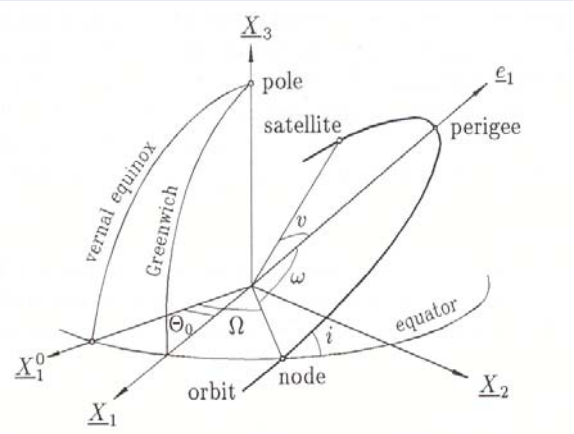
Newton (1642 – 1727)

- The solution was found analytically!
- The six (Why?) integration constants of the equation of motion correspond to six orbital parameters.

Ω	…	right ascension of ascending node
i	…	inclination of orbital plane
!	…	argument of perigee
a	…	semimajor axis of ellipse
e	…	numerical eccentricity of ellipse
T_0	…	time of perigee transit

Sidestep #1 - Keplerian orbit

Keplerian orbit

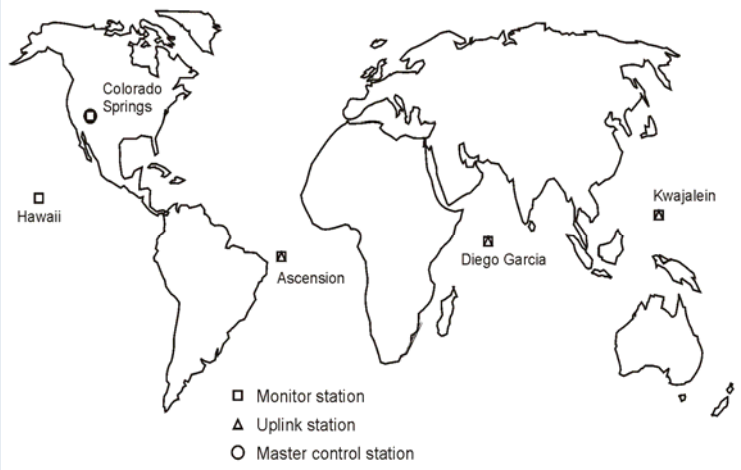


Concept of GPS

- 2.3 Control segment
  - 2.3.1 Master control station
    - Located at Schriever Air Force Base (AFB), formerly known as Falcon AFB, Colorado Springs, Colorado.
      - collects the tracking data from the monitor stations
      - calculates the satellite orbits and the parameter of the satellite clocks
      - passes upload data to one of the three ground control stations
      - controls the system

Concept of GPS - Control segment

Operational control segment (OCS)



Concept of GPS - Control segment

- 2.3.2 Monitor stations
  - The operational control system (OCS) consists of five monitor stations to generate broadcast ephemerides. They are located at Hawaii, Colorado Springs, Ascencion, Diego Garcia, and Kwajalein.
    - measure continuously the dual-frequency pseudoranges to all satellites in view
    - smoothed data are transmitted to the master control station

Sidestep #2 - Dissemination

- Tracking networks (examples):
  - Control segment of GPS
  - Regional active control systems (e.g., Canada, Australia)
  - CIGNET (Cooperative International GPS Network)
  - IGS (International GNSS Service for Geodynamics)

Sidestep #2 - Dissemination

IGS tracking network (May 1995)

Concept of GPS - Control segment

- 2.3.3 Ground control stations
  - Three ground control stations located at Ascencion, Diego Garcia and Kwajalein.
    - ground antenna
    - satellite ephemerides and clock information are uploaded to each GPS satellite.
  - Note: A densification of the OCS is currently under way. In the context of the accuracy improvement initiative (All), another 14 monitor stations shall be added, controlled by the National Imagery and Mapping Agency (NIMA).

Concept of GPS

- 2.4 User segment
  - 2.4.1 User categories
    - military user
    - civilian user
  - 2.4.2 Receiver types
    - C/A-code pseudorange receivers
    - C/A-code carrier receivers
    - P-code receivers
    - Y-code receivers

examples