Basics of Satellite Navigation – an Elementary Introduction

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Basic principles

- 1.1 Definitions
  - Satellite geodesy (SG) comprises all techniques to solve the principal tasks of geodesy with the aid of artificial satellites.
    - geometrical SG (positioning, navigation) → Helmert
    - dynamical SG (gravity field) → Bruns

Basic principles - Definitions

– The basic vector equation reads

$\underline{\%}^S = \underline{\%}_R + \%\underline{\%}$

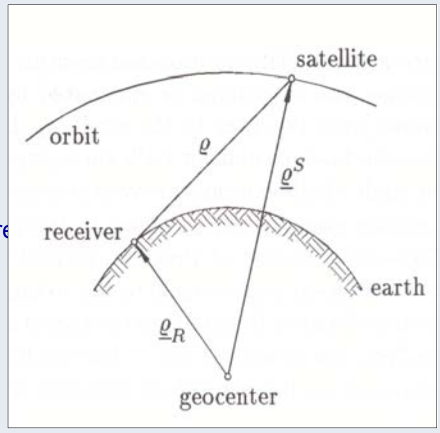
with

$\underline{\%}^S$ … geocentric position vector of the satellite

$\underline{\%}_R$ … geocentric position vector of the receiver

% … distance between re and satellite

$\underline{\%}$ … unit vector from the receiver to the satellite



Basic principles - Definitions

- The basic equation can be written in the form
  $\% = \| \underline{\%}^S - \underline{\%}_R \|$
  if only distances (ranges) % are observed.
- Restrictions in this course:
  - geometrical observables are considered only
  - no measurements between satellites (SST) are considered
  - no measurements between terrestrial sites are considered

  Thus, only measurements between the set of receivers and the set of satellites are considered.

Basic principles - Definitions

- Terminology
  - Positioning: the vectors $\underline{\%}^S$ are assumed to be known (→ operational SG)
  - Orbit determination: the vectors $\underline{\%}_R$ are assumed to be known (→ tracking stations).

Basic principles - Definitions

- Position vector of the satellite $\underline{\%}^S = \underline{\%}^S(t)$ depends on time since
  - satellite is moving in the orbital plane
  - orbital plane rotates with respect to the earth
- Position vector of the receiver $\underline{\%}_R$:
  - constant → static application
  - time dependent → kinematic application

    (note the difference between the terms „kinematics“ and “dynamics“)

Basic principles

- 1.2 Development of SG
  - Historical review:
    - 1946: stellar triangulation (Väisälä)
    - 1957: Sputnik was launched on 4th of October
    - 1965: first global network established by the USA
    - 1967: civilian use of the first operational Doppler system (NNSS, Navy Navigation Satellite System, also denoted as TRANSIT)
    - 1973: conceptual phase of the Global Positioning System (GPS)
    - 1984: begin of civilian use of GPS
    - 1995: full operational capability of GPS
    - 1996: full operational capability of GLONASS (the Russian counterpart of GPS)
    - 1999: first concept for Galileo

Basic principles - Development

- 01.05.2000: final deactivation of the selective availability
- 2000: Compass (Chinese GNSS programme) is launched
- 2002: Galileo programme was officially launched
- 2004: launching of the 50th GPS satellite
- 2005: launch of the first IIR-M GPS-satellite (new M-signal and 2nd civil signal L2C)
- Dec. 2005: launch of 1st Galileo test satellite GIOVE-A
- April 2008: launch of 2nd Galileo test satellite GIOVE-B
- 2010: again full operational capability of GLONASS
- 2011: launch of the first four Galileo satellites (hopefully!)

Basic principles - Development

- Future:
  - Global Navigation Satellite Systems (GNSS) by integrating GPS, GLONASS, Galileo, Compass, etc., and geostationary (or inclined geosynchronous) satellites
  - European contributions are EGNOS (GNSS-1) and Galileo (GNSS-2)
- Accuracies (global scale)
  - 1955: ± 100 m — astro-geodetic measurements
  - 1965: ± 10 m — direction measurements
  - 1975: ± 1 m — laser measurements
  - 1985: ± 0.1 m — TRANSIT
  - 1995: ± 0.01 m — GPS
  - 2015: ??? — GPS + Galileo + GLONASS + Compass

Basic principles - Development

- Advantages of satellite geodesy:
  - no line-of-sight problem between terrestrial stations
  - three-dimensional concept
  - global coordinate system
  - high accuracy

Basic principles - Development

- Operational satellite geodesy (e.g., GPS)
  - Pros
    - global system
    - all-weather system
    - all-time system
    - real-time capability (→ navigation)
  - Cons
    - dependence on (non-civil) system operator
    - no liability
    - signal blockage
    - low navigation performance (→ availability, continuity, integrity)

Basic principles

- 1.3 Observables
  - Unit vector (direction) from R to S: %
    - interesting from a historical point of view
    - very expensive equipment
    - limited (and low) accuracy

Basic principles - Observables

- Radial velocities (range rates)
  - Doppler frequency is proportional to the radial velocity % between transmitter and receiver

$$\% = \frac{d\%}{dt} = k¢\,f$$

  - Applications
    - positioning
    - velocity determination

Basic principles - Observables

- Ranges
  - Observation techniques
    - optical (laser) versus radio based
      Loosely speaking, optical ranges are more accurate and radio-based ranges are weather independent.
    - pulses versus phases
    - one-way versus two-way

Basic principles - Observables

- Distinguish
  - Ranges %
  - Pseudoranges R

    In the one-way concept two clocks are used. Due to synchronization errors pseudoranges R = % + Δ% instead of ranges % are obtained
  - Range differences
    - » integrating range rates
    - » differencing (pseudo) ranges

      - Doppler concept: one station, two satellites

      - Interferometric concept: two stations, one satellite

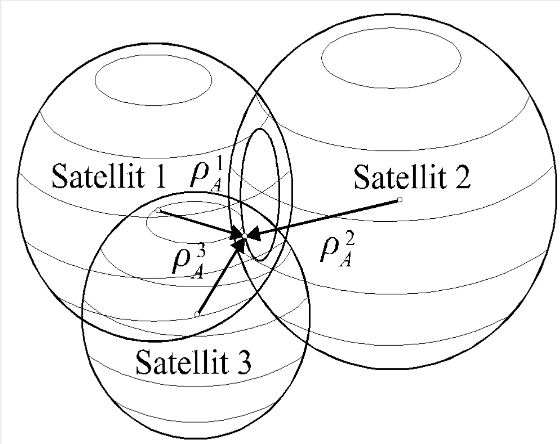
      (The vector between the two stations is denoted baseline.)

Basic principles

- 1.4 Intersection with ranges
  - Geometry
    - ranges: intersection of three spherical shells (concept of 3D-trilateration)
    - pseudoranges: determination of a sphere tangent to four spheres with biased radii
    - range differences:
      - Intersection of three hyperboloids (Doppler concept)
      - Intersection of three spherical shells (interferometric concept)

Basic principles - Intersection

Intersection with ranges (b)



Basic principles - Intersection

Intersection with pseudoranges