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The GEODYN Precision Orbit Determination Software

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Overview

GEODYN-II is NASA's state-of-the-art geodetic parameter estimation and precision orbit determination (POD) system, developed at Goddard Space Flight Center and maintained within the Geodesy and Geophysics Laboratory. GEODYN supports POD and geodetic parameter estimation for both Earth orbiting and planetary/planetary body missions.

It implements a comprehensive set of high-fidelity force models for integrating satellite orbits. GEODYN supports approximately 100 measurement types, including support for Global Navigation Satellite System (GNSS), Satellite Laser Ranging (SLR), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), Very Long Base Interferometry (VLBI), landmark (camera data), landmark crossovers, radar and laser direct altimeter ranging, and dynamic altimetry crossovers.

Force and Measurement Modeling

GEODYN contains detailed force and measurement models, including:

- GEODYN can model/estimate an offset vector between the origin of tracking stations and the center of mass of the Earth.
- Detailed surface modeling at tracking stations (Earth Tides, Pole Tide, Ocean loading, Atmospheric and Hydrological loading).
- Detailed tidal force modeling.
- Detailed forward modeling of time variable gravity from various sources including atmosphere.
- Detailed modeling of the effect of polar motion on C21 and S21 gravity coefficients.
- Various atmospheric refraction models for laser and radiometric data.
- Estimation of time correlated parameters: empirical accelerations, drag coefficients, solar radiation coefficients, and tropospheric scale.
- Allows for a reduced dynamic approach to orbit determination when dense tracking is available.
- Detailed satellite surface force modeling or accelerometer data can be used and calibrated.
- Attitude and thrusting events can be accommodated with:
  - Parameters that describe an instantaneous change in position and/or velocity
  - Finite Burn parameters that model a thrusting event over a user specified interval. The magnitude and orientation of the thrust as well as the mass loss of the satellite can evolve over the interval.
- Detailed surface topography modeling for land and ocean including ocean tides (for altimetry measurement modeling).
- Capability to estimate and model parameters to refine altimeter pointing.

Measurement Types

GEODYN supports a wide range of measurement types for both Earth and planetary missions, including metric, PCE, optical, VLBI, and altimetry:

- **Metric**: Range and range-rate measurements and their combinations. This includes GNSS, SLR, and DORIS measurements. GEODYN's architecture allows all of these measurement types to share common code, for example the uplink station to satellite leg of a 2-way SLR measurement uses the same code as a 1-way DORIS measurement. Just a few examples of metric measurements supported by GEODYN are listed below. The T indicates a tracking station, and the S indicates a satellite. The numbers indicate unique stations or satellites, and GEODYN supports up to three of each:
  - One-way range or range-rate (S1 → T1)
  - One-way intersatellite range-rate (S2 → S1)
  - Two-way range or range-rate (T1 → S1 → T1)
  - Three-way range or range-rate (T2 → S1 → T1)
  - Three-way satellite-satellite relay range (S2 → S1 → T2)
  - Singly differenced one-way range ((S1 → T1) − (S1 → T2))
  - Doubly differenced one-way ranges (e.g. see Figure 1) ([(S2 → T1) − (S3 → T1)] − [(S2 → S1) − (S3 → S1)])
- **PCE**: Measurements of the position and velocity of the spacecraft.
- **Optical**: Landmark (camera data) and landmark crossovers.
- **VLBI**: The delay between the arrival of the signal from a radio source at two tracking stations.
- **Altimetry**: GEODYN supports both radar and laser altimetry. Multiple beams are supported, and GEODYN can estimate pointing parameters. Crossovers (altimetry height differences) between altimetry passes can also be used. The precise crossover location is determined dynamically based on the current iteration's orbits and pointing parameters.

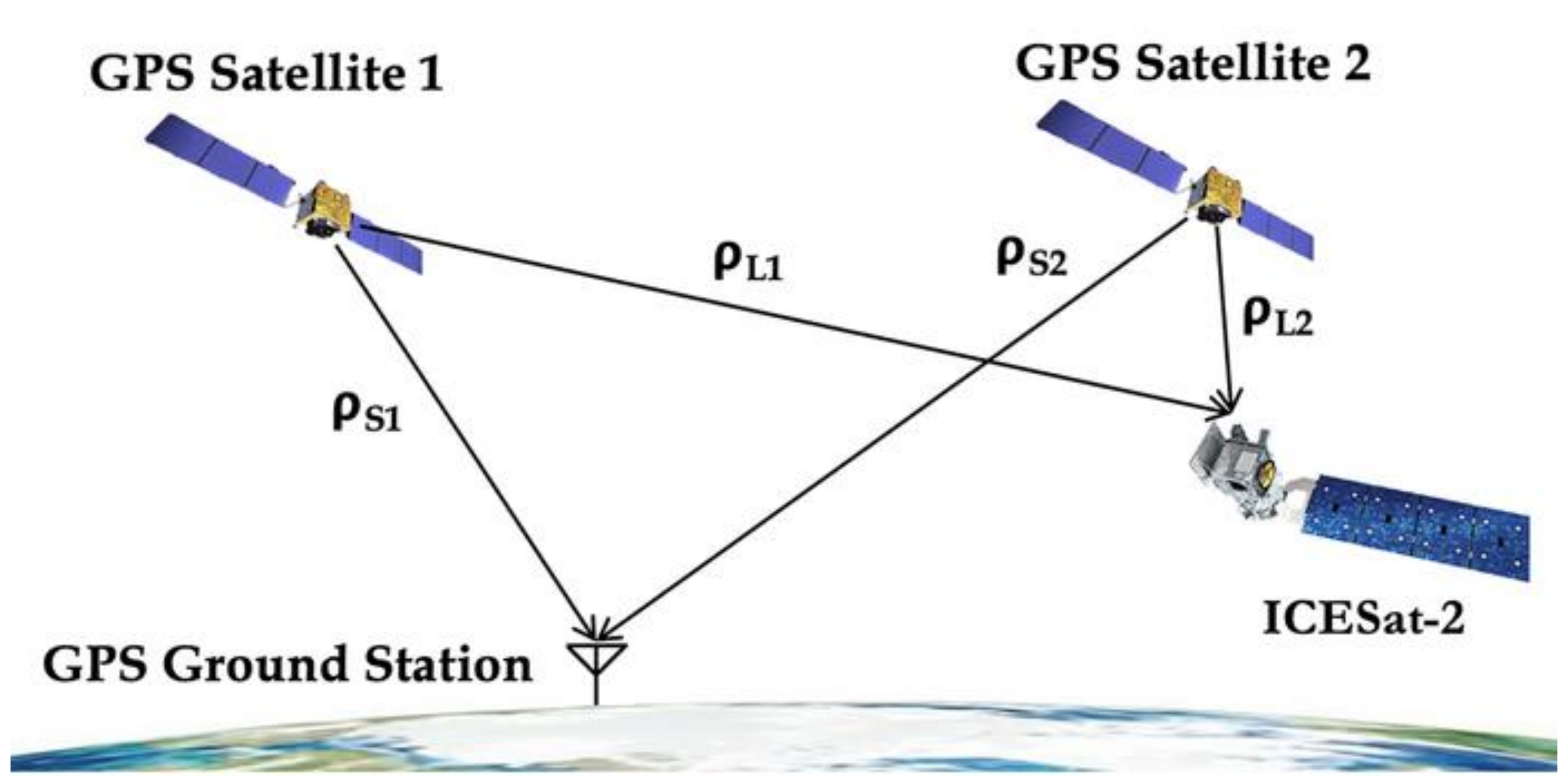

Figure 1: A doubly differenced one-way range as used in ICESat-2 precision orbit determination (Thomas et al., 2021).

Parameter Estimation

- GEODYN can estimate over 90 types of parameters.
- For planetary missions, the trajectory of the orbited body can be determined along with the orbiting satellite.
- GEODYN has various capabilities for dealing with weak normal matrices:
  - If the normal matrix is determined to be positive definite, Cholesky decomposition is used. Otherwise, a slower LU factorization method is used that can invert some normal matrices that are not positive definite due to errors caused by finite precision arithmetic.
  - The user can request the use of a Square Root Information Filter (SRIF) approach to parameter estimation, using a QR decomposition to improve numerical stability at the expense of computation time.

Applications

GEODYN is currently used for the Precision Orbit Determination (POD) that sets the observational reference frame for many of NASA's most important operational Earth science missions including ICESat-2 (Thomas et al., 2021), GEDI (Thomas et al., 2020), GRACE-FO, Sentinel-6A, and Jason-3 (Lemoine et al., 2023). GEODYN plays critical roles in calibrating the laser ranging and pointing biases for ICESat-2 and GEDI, as well as producing the normal equations to estimate time variable gravity from the GRACE and GRACE-FO inter-satellite ranging (Luthcke et al., 2013).

GEODYN has also supported numerous planetary missions. During the GRAIL (Lemoine et al., 2013) mission it was used for POD and to estimate a lunar gravity field to spherical harmonic degree and order 1200. The OSIRIS-REx mission used GEODYN (Mazarico et al., 2017) to estimate the gravity field of the asteroid Bennu and the center-of-mass to center-of-figure offset in order to ensure an accurate approach for sample collection.

GEODYN is frequently used for mission simulations as it can assess parameter observability and quantify expected errors and overall performance. For example, GEODYN is being used to simulate time variable gravity recovery from a future gravity gradiometer mission.

References

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