COSPAR Report to United Nations 2004: Satellite Dynamics

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The COSPAR Panel on Satellite Dynamics (PSD) is concerned with the determination of the position, velocity and orientation in space of artificial and natural satellites around the Earth or in the outer space. This is done using geodetic tracking data as well as dynamic models. The numerous measurements techniques used are now well organized into international scientific services taking care of continuous tracking networks, geodetic products as well as research activities. Concerning model accuracy, significant improvements were made recently for the gravity field model following the first results of the GRACE mission. Precise navigation to other planets is also studied.

The following report highlights representative activities of this panel and provides general information on related international aspects.

Tracking systems and International Services

Several tracking systems can currently be used to estimate satellites orbits (position and velocity at every epoch) around the Earth:

- GPS (higher altitude satellites transmitting radio-electric signal to be deciphered by specific receivers on the ground on in space),
- DORIS (a sort of inverted GPS system, with ground beacons transmitting radio-electric signals to low altitude satellite equipped with appropriate receiver, potentially allowing a real-time on-board orbit determination using the DIODE system),
- SLR (ground observatories generating laser pulses to be reflected on satellites equipped with retro-reflectors and measuring the difference in time between the transmission and the reception on the ground of the optical signal),
- VLBI (radio-observatories making radio-electric measurements on natural radio sources, such as quasars)

In the past few years, all these techniques have organized themselves into scientific services: IGS for GPS since 1994, ILRS for SLR since 1998, IVS for VLBI since 1998 and more recently IDS for DORIS in 2003. These new type of international services organize the data collection, generate international standards and specifications for observation or file exchange formats. They also compute geodetic products such as precise coordinates of ground tracking stations, Earth rotation parameters, etc. For example, the IGS computes and widely distributes precise orbits of all GPS satellites obtained in a post-processing mode. These so-called IGS final orbit, based on a weighted average of individual solutions coming from 8 different international groups, now reach a precision of 2 or 3 cm for the radial component. They are used for all type of scientific applications. All these services participate in the IERS service in charge of celestial, terrestrial reference frames and Earth rotation.

These international services do not have an administrative existence as such but they are based on a real scientific international cooperation based on best effort basis. However, due to their high level of redundancy (many institutions perform the same task in parallel), their effectiveness and operational level is very high leading to an increasing number of users of all kinds, especially in the case of GPS. These services can be considered as the backbone of the recently created project GGOS (Global geodetic Observing System (GGOS) of the International Association of Geodesy (IAG).

The Russian GLONASS system (another satellite navigation system, very similar to GPS and part of the IGS as such) is also capable to be used for precise orbit determination of low Earth orbiting satellites. In the near future (around 2008), the additional European system Galileo could also be used alone or in combination with the already existing Global Navigation Satellite Systems such as GPS and GLONASS.

Other technique, such as the German PRARE system have been successfully developed and used in the case of the ERS-2 mission.

Some altimetric missions carry several of these systems on –board their satellite: GPS+SLR+DORIS for TOPEX/Poseidon and Jason, SLR+DORIS for ENVISAT. The optimum combination of simultaneous tracking system is an ongoing research activity in order to increase the accuracy and/or the integrity of the results. Several groups have demonstrated a 1-cm radial performance.

Another specific research activity concerns the precise determination of the attitude of the satellite (3-axis orientation in space).

More recently, a specific interest has been found in multiple satellite computations in the case of satellite constellations or even for precise navigation in the case of satellite formation flying.

Gravity Models and Non-Gravitational Forces

The precision of the satellite orbit results depends on the precision of the tracking measurement but also on the accuracy of the models used in the orbit estimation process. For a long time, our limited knowledge on the Earth's gravity field was a clear limiting factor for the lower orbiting satellites.

After the launch of the dedicated GRACE mission in March 2002, new gravity field models were derived from the University of Texas (Austin, USA), GeoForschnungZentrum (Postdam, Germany) and the Jet Propulsion Laboratory

(Pasadena, USA) improving the accuracy of the gravity field models and consequently the accuracy of the estimated orbits. The first release of the new gravity field model using only a month of GRACE data had a better accuracy compared to all previous models, even when based on decades of other satellite data even with the recent CHAMP mission. Furthermore, it now allows the scientists to have access to the time-varying parts of the Earth gravity field. These variations are due to changes in the mass of the oceans, the atmosphere or the solid Earth. The measurement of these variations gives us some new type of information for hydrology and climatology studies. GRACE data is based on the precise relative range measurements between 2 identical satellites following each other in free fall.

In the future, the GOCE mission, schedule for launch in 2006, will also improve our knowledge of the Earth gravity field. It should also help in better defining the geoid surface (an equipotential surface of the gravity field that can be approximated by the mean surface of the oceans). This should provide enhanced information on the Earth's interior itself (location of the masses and their inhomogenities inside the Earth).

As the gravity field models is no more a limiting factor for precision, all other surface models are now studied in great details. For low earth orbiting satellites our knowledge of the atmospheric density and its geographical and temporal variation is still not sufficient to model the atmospheric drag forces at the ultimate precision. This is special true during exceptional events such as geomagnetic storms caused by higher solar activity.

Furthermore, a regain of interest has been found in studying force models such as solar radiation pressure or the thermal effects on complex shaped satellites. Specific models have been derived for some satellites.

Other models and corrections

Besides force models used in the dynamic orbit determination process, several other models of corrections and standards are used. An on-going research activity is required to continuously improve their accuracy.

For example, specific corrections are required in order to take into account the signal delay when passing the atmosphere. For the upper part of the atmosphere, called ionosphere, the correction can be precisely measured using a double frequency technique. For the lower part of the atmosphere (troposphere) a combination of models and empirically estimated additional parameters can be used. However, this information has also other scientific applications in meteorology (weather prediction) as well as in climatology (long-term evolution of the global climate).

More recently, a large research activity has been devoted to better understand and model small delay variations in the antennas (on the ground or on-board the satellite) due to phase center variations. This has been studied for GPS and DORIS and some correction models have been proposed based on the analysis of long-term residual time series.

Precise tracking station coordinates from all techniques is also a strong requirement for precise orbit determination. Fortunately, a homogenized set of coordinates is available internationally from the ITRF successive realizations.

Space Exploration

Techniques used for navigation of space probes and position or orientation determination are very similar to techniques used for artificial satellite orbit determination around the earth and previously discussed. Consequently, navigation of probes (around Mars or Neptune), orbital maneuvers using the Moon as a natural sling-shot or Planet gravity fields determination are also part of the satellite Dynamic COSPAR group.

Conclusions

The COSPAR Satellite Dynamic group has a wide range of research activities in the field of natural or artificial satellite orbit determination. A large international cooperation exist at all level: from tracking network management and data dissemination to model improvements using dedicated space missions. Most precise results show in 2004 a 1-cm precision at least for the radial component of the satellite orbit, usually using several techniques in a combined adjustment.

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List of Acronyms

CHAMP	Challenging Mini-Satellite payload for Geophysical Research and Applications
COSPAR	COmmittee on SPAce Research
DIODE	DORIS Immediate Orbit DEtermination
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
EGNOS	European Geostationary Navigation Overlay System
ERS	European space agency (ESA) Remote sensing Satellite
ENVISAT	ENVIronment SATellite
GFZ-1	First Satellite of GeoForschnungsZentrum Potsdam
GLONASS	(Russian) Global Navigation Satellite System
GGOS	Global Geodetic Observing System
GNSS	Global Navigation Satellite System
GOCE	Gravity field and Ocean Circulation Explorer
GPS	Global Positioning System
GRACE	GRAvity recovery and Climate Experiment
IAG	International Association of Geodesy
IDS	International DORIS Service
IERS	International Earth rotation and Reference system Service

IGLOS	International GLOnass Service
IGS	International GPS Service
ILRS	Internatinal Laser Ranging Service
ITRF	International Terrestrial Reference Frame
IVS	International VLBI Service
LAGEOS	Laser GEOdynamics Satellite
LEO	Low Earth Orbiting (satellite)
PRARE	Precise RAnge and Range rate Equipment
PSD	(COSPAR) Panel on Satellite Dynamics
SLR	Satellite Laser Ranging
TOPEX	(Ocean) TOPographic EXperiment
VLBI	Very Long Baseline Interferometry
WAAS	Wide Area Augmentation System