High-performance Algorithms for Double Difference Data Processing

H. Boomkamp, J. Dow

For most POD systems, processing times and memory requirements are a quadratic or even cubic function of typical process size parameters like the number of processed ground stations, the data-rate, or the number of estimated parameters. Routine processes at the Analysis Centres are usually dimensioned to take maximum advantage of the available computer resources, which means that the remaining capacity for processing more stations, higher data rates or LEO satellites, is limited.

At ESOC new algorithms are being developed for processing large quantities of double difference observations in a highly efficient manner. The main incentive for this development has been the need for processing high-rate data in LEO applications, leading to large amounts of double difference combinations in a single POD process. The essential property of this new algorithm is that its processing times and storage requirements form a square-root function of the number of processed double difference measurements. This means that the POD process actually becomes more efficient with increasing numbers of tracking stations or satellites.

The logic behind the algorithm will be explained, and some examples will be shown of large POD processes that now become feasible.

Combined Solutions GPS+LEO

R. König, C. Reigber, S. Zhu

GPS data from ground- and from space-based receivers together with non-GPS observations can be reduced in an integrated adjustment to improve the reliability and accuracy of all estimable parameters. The strengths of the various data types are discussed. Based on

some example computations with CHAMP, GRACE and SAC-C observations, the benefits of the integrated approach for LEO orbit accuracy and geocenter and low degree Earth parameters are demonstrated.

Aspects of Large Station Networks for GPS Orbits and Clocks

T. Herring

In this talk we focus on the effects of large scale ambiguity resolution and the problems encountered with both clock solutions and ambiguity resolution due to biases in pseudo-range data. These biases arise from mixing receiver types and some receivers show anomalous pseudorange behavior in conditions of rapid ionospheric fluctuations. These anomalies most likely arise from over smoothing of the pseudoranges and affect sites mainly in the polar regions where robust ambiguity resolution is most desirable.

Routine Processing of Combined Solutions for GPS and GLONASS at CODE

U. Hugentobler, S. Schaer, R. Dach, M. Meindl, C. Urschl

At CODE final, rapid, and ultra rapid products are computed. All products are a result of a fully combined GPS and GLONASS data analysis and all orbit products contain GLONASS orbits. Despite the large network processed - CODE routinely processes more than 150 stations for the final and 100 stations for the rapid solution - tracking problems occasionally may affect the POD solution. The reduced tracking of unhealthy satellites - GPS or GLONASS - can be recognized in an orbit solution of reduced quality. The processing scheme used at CODE for analyzing data from a large network tracking two constellations is presented, including figures concerning data volume processed and number of parameters estimated. Issues concerning monitoring of the quality of tracking data and products are addressed.

Ultra-rapids and Ultra-rapids Predictions for GPS

J. Douša, L. Mervart

The presentation consists of two main parts: a) a general reflection of the ultra-rapid orbits and b) the real implementation and use at Geodetic observatory Pecny - a new analysis centre for the IGS ultra-rapid product.

The ultra-rapid orbits were motivated by near real-time GPS precise processing requirements. They has been produced in IGS since 2000 and naturally they has aimed to integrate the applications of the rapid and predicted orbit products. The latter were already replaced by the ultra-rapids, what can be expected for the rapids after reaching its quality. The summary of accuracy assessment and various applications as well as the difference in the basic features and procedures of the product generation will be outlined. Though the IGS ultra-rapid orbits perform very well, there is a room for the further improvements - in completing the product for all GPS satellites and integrating other GNSS satellites, in setting a good quality indicators for the prime orbit usage, in increasing of the product upgrade rate etc.

Since 1999, Geodetic observatory Pecny (GOP) is involved in the GPS ground-based meteorology and thus GOP has been motivated for the use of precise orbits in near real-time. The routine for ultra-rapid orbits using Bernese GPS software was developed in 2000 and tested on a routine basis from 2001. A very short description of GOP approach and the summary of the results will be presented together with the motivation and outlook.

GPS LEO POD Activity at CGS

A. Nardi, G. Bianco

ASI-CGS is involved in the IGS LEO Pilot Project as Associate Analysis Center. In the framework of the Pilot Project, CHAMP and JASON-1 LEO missions have been selected, respectively, for the first and second comparison campaign promoted by ESOC. Two sets of orbits for each satellite with a full dynamic approach have been produced at ASI-CGS. A description of analysis approach and models adopted is the topic of the poster.

Activities at the CODE Analysis Center

S. Schaer, U. Hugentobler, R. Dach, M. Meindl, H. Bock, C. Urschl, A. Jäggi, P Fridez, G. Beutler

An overview of the analysis activities at CODE will be given. This includes in particular GPS/GLONASS-combined analysis, generation of ultra-rapid orbit product, handling of satellites being repositioned, SLR-based validation of CODE GNSS orbit products. Specific issues relevant to the IGS are addressed.

A High Precision Analytical Surface Force Model for GPS Block IIR Satellites

M. Ziebart, S. Adhya, A. Sibthorpe, S. Edwards, P. Cross

This paper discusses the development and testing of an analytical high precision non-conservative force model for the GPS Block IIR spacecraft, carried out at University College London. The computation uses a suite of newly developed techniques that model precisely the dynamic effects on the spacecraft due to solar radiation pressure (SRP), thermal re-radiation, radiation both emitted and reflected by the Earth and the transmission of microwave signals by the satellite antenna array. In the modelling process the complexity of the spacecraft structure is retained – that is, no structural simplifications are made. The environment of the satellite as modelled is based upon in-situ measurements of the respective radiation fluxes by space-based probes. Additional precision has been gained from modelling eclipse transition times based on an oblate Earth and from introducing a reduced solar flux model during passage through the penumbral regions. Model testing is based on numerical integration of the spacecraft model using an 8th order embedded Runge-Kutta integrator with adaptive step size control and using GRACE gravity field coefficients to 15 x 15.

Weighted mean RMS orbit prediction errors (when comparing the integrated trajectory with the precise orbits) for the month of March 2001 using all available GPS IIR satellites over 12 hour arcs were 0.14 m in height, 0.07 m across track and 0.51m along track. These results have been obtained purely from

numerical integration of the differential equations of motion derived from analytical models alone – no empirical estimation has been applied.

High and Low POD using GPS at CNES/GRGS

S. Loyer, F. Perosanz, S. Bruinsma, F. Mercier

GINS is a multi-technique POD software developed at CNES/GRGS. An overview of its capabilities will be given by presenting results of the processing of one year of GPS/IGS data for orbit, station coordinates and polar motion estimation - GPS and laser tracking data of PRN 35 and 36 - two years of CHAMP GPS and laser data - DORIS, laser and GPS data from JASON on a test period.

Orbit Determination of Low Earth Satellites at AIUB

A. Jäggi, H. Bock, U. Hugentobler, G. Beutler

The poster presents activities at the Astronomical Institute of the University of Berne (AIUB) in the field of precise orbit determination (POD) for Low Earth Orbiters (LEO) using the GPS. They range from efficient and robust LEO POD, orbit modeling using stochastic accelerations, to combined processing of GPS and LEO orbits using double difference observations in a global network.

NRCan Analysis Centre Contributions to the IGS: 1994 – 2004

B. Donahue, Y. Mireault, C. Huot, P. Tétreault, J. Kouba

As part of Natural Resources Canada (NRCan), Geodetic Survey Division's (GSD) primary role is to maintain, continuously improve, and facilitate efficient access to the Canadian Spatial Reference System (CSRS). The CSRS provides a frame of reference for latitude, longitude, height and gravity used as the basis for the nation's georeferencing and related geoscience needs. As such, it provides the foundation for coordinate-based information systems, enabling the integration and interoperability of applications and data with a spatial component. In the early 90's, the growing demands of GPS users resulted in a new focus for the Division, a focus on supporting users' needs for positioning from space. The Canadian Active Control System (CACS) was established during the 1990's to facilitate GPS user access to the CSRS. NRCan's participation in the IGS enables an efficient way of providing, for all Canadians, a positioning and navigation spatial referencing infrastructure based on modern technologies and international standards.

NRCan has been an IGS Analysis Centre (EMR) since the 1992 initial IGS pilot phase and provided the initial Analysis Centre Coordination for the IGS. This poster lists some of NRCan's milestones and accomplishments throughout the past ten years as well as on-going activities and plans.

Kinematic Orbits for LEO Satellites - a New Product

D. Svehla, M. Rothacher

The CHAMP satellite mission opened a new era in the high precision orbit determination (POD) of LEO satellites. The high performance of the Blackjack GPS receiver on-board present geodetic missions allows for the first time a purely kinematic orbit determination of LEO satellites with the same level of accuracy (2-3 cm) as that of the common reduced-dynamic approach. Kinematic orbit determination can be defined as an estimation of satellite positions epoch by epoch using solely GPS measurements without making use of any information on satellite dynamics or force models. Therefore, kinematic POD is fully independent of orbit height and forces acting on the satellite, e.g. gravity field, air-drag, solar radiation, albedo etc. From this point of view and considering the high accuracy, kinematic POD is a very appropriate POD strategy for Earth observing satellites, where air-drag and gravity field perturbations become more difficult to model or estimate.

We determined CHAMP kinematic orbits for a period of one year. A considerable number of groups already uses these kinematic positions for validation of dynamic orbits and models and, for the first time, several groups estimate Earth gravity field coefficients based on our kinematic CHAMP positions together with the corresponding variance-covariance information, making use of the energy balance approach or the boundary value method rather than the classical numerical integration schemes. The validation of gravity field models computed in such a way showed that CHAMP kinematic positions contain high-resolution gravity information and that the accuracy of the derived gravity models is comparable to that of official CHAMP models, if not better. Kinematic positions with the corresponding variance-covariance information are an extremely attractive interface between the raw LEO GPS data and gravity field models or other interesting information that can be derived from satellite orbits, because the simultaneous adjustment of model parameters (e.g. gravity field coefficients) and a huge amount of global GPS parameters, like GPS satellite clocks and orbits, zero- or double-difference ambiguities, station coordinates, troposphere parameters, Earth rotation parameters, etc. can be avoided.

In this contribution we present and discuss our POD approaches based on zero- and double-differences with and without ambiguity resolution from the point of view of accuracy and efficiency. We show how our one year of CHAMP kinematic orbits can be used for Earth gravity field determination and discuss kinematic POD in the framework of LEO missions like GRACE and GOCE. In the case of GRACE, kinematic and dynamic results for the inter-satellite baseline in space will be presented including ambiguity resolution with simulated and, if available, with the real GRACE data. Finally, we discuss the importance of IGS products for kinematic LEO POD and kinematic LEO orbits as a new product, maybe even an IGS product.

USNO Analysis Strategy Summary

V. J. Slabinski, J. R. Rohde, M. S. Carter, A. E. Myers, D. Pascu, W. H. Wooden

This poster paper summarizes data inputs, computer models, and analysis methods used at USNO to produce the daily Rapid orbits and twice daily Ultra-rapid orbits submitted to the IGS.

Large Scale GPS Processing at ESOC for LEO, GNSS and Real-Time Applications

H. Boomkamp, J. Dow

Most POD systems that are used in routine IGS processing, are large FORTRAN programs that have evolved from early generation systems over many years of use. These systems do not exploit the advantages of modern software engineering technology, and their limited processing efficiency constrains their application to emerging large-scale GPS processes, like real-time GPS, high-rate data processing or combined solutions for LEO + MEO constellations. In support of such high-performance applications, the ESOC IGS Analysis Centre is developing a new POD system based on the latest software engineering methods. Apart from efficiency improvements at implementation level, a variety of algorithmic changes has been applied to allow for larger quantities of tracking data or estimated parameters. In most cases, these changes follow generic principles like re-ordering of computations in a series of linear operations, or a shift of a workload into the domain of its first derivative, by only considering changes to a nominal process state. Examples will be given of improvements at implementation level, and at algorithmic level.

IGS LEO Pilot Project

H. Boomkamp

The Low Earth Orbiter Pilot Project wants to analyse and demonstrate potential benefits of LEO GPS tracking data for the generation of the IGS products. The processing of LEO GPS data brings a variety of technical difficulties, like the use of higher data rates and the associated increase in tracking data volume and estimated clocks or phase ambiguities. The Pilot Project intends to solve such problems as part of its analysis efforts, preferring generic methods that can also be used for future LEO missions, rather than LEO mission-specific solutions. The objectives and analysis projects of the Pilot Project will be summarized, together with some analysis results and the latest reports on the LEO orbit campaigns.

Kinematic LEO POD with Space- and Ground-Based Transceiver Constellation Tightly Coupled with GPS: Simulation Study

D. Grejner-Brzezinska, M. Bevis, C.-K. Hong, T.-S. Bae, J. LaMance, C. Rizos

GPS, commonly used for LEO OD, provides continuous and accurate offline solutions, using dynamic or reduced-dynamic models. The dynamic approach is computationally intensive and leaks accuracy when the models do not represent the forces in the spacecraft (S/C), particularly for irregularly shaped S/C in LEO orbits. An alternative, kinematic approach exploits the high GPS observation rate producing computationally efficient, discontinuous and accurate orbits. However, the kinematic approach suffers from a serious limitation: sensitivity to weak GPS/LEO/tracking station geometry.

The approach presented here improves the quality and continuity of kinematic orbit through the use of pseudolites (PL) tightly integrated with GPS at the ground tracking stations and onboard LEO S/C, which allows co-processing the GPS/PL data. In current beacon tracking systems, such as DORIS or ENVISAT, there is no integration with GPS, while JASON uses a beacon system and GPS, but the systems operate independently.

In this paper we present a feasibility study of the simulated configuration, which uses orbiting PLs. In addition, the simulation of the observing system includes ground-based PLs. A feasibility analysis of the effects of combining the orbiting and ground-based PLs with GPS for the kinematic LEO OD is carried out. A priori covariance analysis is presented to assess the model's quality and viability for improved OD. In addition, we considered the combination of GPS and Galileo.