Advanced Technologies for Navigation and Geodesy (ADVANTAGE)

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Scope of Project

Global navigation satellite systems (GNSS) such as the US-American GPS, the Russian GLONASS, the European Galileo and the Chinese BeiDou are backbones of modern industrial societies. GNSS positioning and navigation play significant roles in many aspects of transportation. GNSS clock synchronization is a crucial component in global time transfer of Universal Time Coordinated (UTC) in various automated control and monitoring applications such as power grid infrastructures, telecommunication systems, and even financial markets. In the geosciences, GNSS technologies render continental drift velocities of a few mm to cm per year accessible for direct monitoring; they contribute to past and present gravity space missions (CHAMP, GRACE, GRACE-FO) and provide valuable input data for numerical weather prediction and climate change studies. Today the most precise geodetic reference frames are based on GNSS and other space geodetic techniques. The high relevance of geodesy for modern societies is reflected by the establishment of the “Sub-Committee on Geodesy” at the United Nations that in 2016 was tasked with the development of an implementation plan for the Global Geodetic Reference Frame (GGRF).

The development of the US-American GPS system in the 1970s was based on technologies available at that time. Estimates of receiver position and receiver clock errors relied on advances in space-borne atomic clock technology, spread spectrum signals, integrated electronic circuits, and digital signal processing. Technological breakthroughs in recent years such as the introduction of optical clocks, the development of atom interferometers, optical ranging and optical communication equipment create originative possibilities for navigation, geodesy and time metrology. The ADVANTAGE project proposes leading-edge architectures for a future European GNSS infrastructure (Kepler) which exploits the benefits of these innovative optical time and ranging technologies.

Project Objectives

The ADVANTAGE project investigates the potential of space-based optical atomic clocks, optical inter-satellite links, and atom interferometry for satellite navigation, geodesy and time metrology. The project objectives include a high-level system design, the development and testing of key components, a time transfer experiment, and the development of the algorithms and processing systems. ADVANTAGE supports and accelerates the development of optical timing and ranging technologies and develops feasible solutions for future generations of European satellite navigation systems. The research strategy focuses on system design, on developments of component technologies and on parameter estimation algorithms relevant for satellite navigation, geodesy, and time metrology.

Research Strategies

In the ADVANTAGE baseline architecture (Kepler) eight equally spaced satellites populate three Medium Earth Orbit (MEO) planes; in each of these planes the individual spacecraft are bi-directionally linked to adjacent satellites. These two-way optical links allow separating uncertainties in the spatial distance from clock biases and providing frequency transfer and clock synchronization with high precision. Furthermore, the links provide absolute ranging with µm accuracy, thus enabling unprecedented precision in along-track and radial position estimates.

Each of the MEO satellites carries a high-performance cavity- and/or iodine-based optical clock characterized by an Allan deviation at the 10^{-15} level. The optical links operate on the clock frequency and achieve a high directivity of transmission for a given instrument aperture. The individual optical clocks in the same orbital plane are merged into one composite clock. The inter-plane synchronization between the three composite clocks is guaranteed by a smaller constellation of satellites in Low Earth Orbits (LEOs), also equipped with optical terminals, that alternately establish connections to MEO satellites and relay time, frequency and data information through the optical channel with bandwidth of 100 Mbps. The Kepler space segment will thus provide the most stable system time conceived so far.

Gravitational and non-gravitational forces acting on each spacecraft are measured by high-performance inertial sensors and gyroscopes where atom interferometry is investigated as an option for future systems. The optical inter-satellite signal receiver/transmitter terminals also provide attitude information with μrad-accuracy. The navigation signals transmitted to ground are L-band radio frequency signals. The relation between optical frequencies and the L-band radio frequencies, which serves as reference for the navigation payload, is established by frequency combs on each satellite.

A crucial final task of the Orbit Determination and Time Synchronization (ODTS) processing is the estimation of the satellite orbits, the spacecrafts' attitudes, the composite time and clock offsets, inter-frequency biases, atmospheric signal propagation, and the locations of the monitoring stations. These parameters are jointly estimated in a comprehensive estimation process (e.g. Kalman filter or least-squares minimization) that includes the dynamics of the system as well as the complete set of measurements. All measurement errors as well as uncertainties in the time evolution of the system are appropriately modeled. The solutions yield Precise Point Positioning (PPP) results in near real-time and thereby enable a range of innovative applications.

ADVANTAGE will impact the future evolution of satellite navigation. The results will be transferred both to the academic world and to industries to ensure the utilization of the most promising options in future systems and applications.

Project partners and stakeholders

The ADVANTAGE project partners DLR (Prof. Günther, Prof. Braxmaier) and GFZ (Prof. Schuh) epitomize the systemic, technological and scientific expertise for the design, development and exploitation of a future space-based navigation infrastructure. Close ties exist to industries including TESAT, OHB, Airbus, Timetech and to institutions such as the EU Commission, the European GNSS Agency (GSA), the European Space Agency (ESA), the Inter-Union Commission on Geodynamics (ICG), the International Earth Rotation and Reference Systems Service (IERS) and others, which ensures that the new concepts and technologies are considered for future generation systems. The project partners cooperate with all major national, European and international groups working in the areas relevant to ADVANTAGE. At the national level these include Prof. Riehle at the PTB in Braunschweig, Prof. Lämmerzahl at ZARM and University of Bremen, Prof. Hugentobler at TU München and Prof. Ertmer at Leibnitz University Hannover. Dissemination is an important aspect of ADVANTAGE; it addresses the promotion of early career and, in particular, of female scientists.

Finally, it is noted that ADVANTAGE represents a joint effort of physicists, geodesists and engineers at the Helmholtz institutions DLR and GFZ. The project contributes to program-oriented funding programs “Space”, “Geosystem: The Changing Earth” and “Atmosphere and Climate”. ADVANTAGE utilizes synergetic effects between important elements of these POF programs and thus further strengthens the impact of the HGF.