Geodetic Sensor Systems and Sensor Networks: Positioning and Applications

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Abstract

This contribution focuses on geodetic sensor systems and sensor networks for positioning and applications. The key problems in this area will be addressed together with an overview of applications. Global Navigation Satellite Systems (GNSS) and other geodetic techniques play a central role in many applications like engineering, mapping and remote sensing. These techniques include precise positioning, but also research into non-positioning applications like atmospheric sounding using continuously operating GNSS networks. An important research area is multi-sensor system theory and applications to airborne and land-based platforms, indoor and pedestrian navigation, as well as environmental monitoring. The primary sensors of interest are GNSS and inertial navigation systems. Furthermore, Interferometric Synthetic Aperture Radar (InSAR) is recognized as one of the most important state-of-the-art geodetic technologies used for generation of Digital Elevation Models and accurately measuring ground deformations.

Keywords

Current research issues • GNSS • InSAR

1 Introduction

Global Navigation Satellite Systems (GNSS) play a central role in many applications like engineering, mapping and remote sensing. These techniques include precise positioning, as well as applications of reference frame densification and geodynamics, to address the

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demands of precise, real-time positioning of moving platforms. Recognising the role of continuously operating GPS reference station network, research into non-positioning applications of such geodetic infrastructure is also pursued, such as atmospheric sounding. Thereby, other geodetic techniques should be considered as well.

An important research area is multi-sensor system theory and applications, with a special emphasis on integrated guidance, navigation, positioning and orientation of airborne and land-based platforms. The primary sensors of interest are GNSS and inertial navigation systems; however, the important role of other techniques used for indoor and pedestrian navigation, and environmental monitoring is also recognized.

Furthermore, Interferometric Synthetic Aperture Radar (InSAR) is recognized as one of the most important state-of-the-art geodetic technologies with applications like generation of Digital Elevation Models and accurately measuring ground deformations.

This contribution gives an overview of state-of-the-art technology and research issues for GNSS, multi-sensor systems and InSAR, respectively.

2 GNSS

2.1 High-Precision GNSS

Recent research and development activities in the field of high-precision GNSS have been in great extent driven for improved system performance with signals from multiple constellations and increased system cost-effectiveness and availability of high-precision GNSS. Some research subjects important to high precision GNSS applications are addressed in the following.

2.1.1 Augmentation with Multiple GNSS Signals

There are significantly increased efforts toward augmenting GPS-based systems with multiple GNSS signals. This comes with demands to further improve the positioning accuracy and reliability and increase continuous precise positioning availability in less desired observing environments such as urban canopy where significant signal blockages would make GPS-alone positioning very difficult (Cai and Gao 2009). Data processing technologies to support multiple GNSS signals from modernized GPS, GLONASS and Galileo systems are highly demanded. Benefits to system's robustness are particularly of interest to practical applications. This requires efforts to develop new signal combination strategies, modeling techniques and quality control measures (Feng and Rizos 2009; Fernandez-Plazaola et al. 2008).

2.1.2 Integration of PPP and Network-RTK

While Network RTK continues to receive increased adoption as more and more network infrastructures are being deployed and PPP is recognized as an attractive alternate to many high-precision applications, there are increased interests to integrate the two for combined advantages. Integration of PPP with Network RTK techniques may lead to improved position accuracy and reliability, operational flexibility and efficiency, particularly reduction in convergence time and network reference station density (Wubbena et al. 2005; Dixon 2006; Feng et al. 2007). State space corrections to support both Network RTK and PPP and their seamless integration should be investigated.

2.1.3 PPP for Single-Frequency Receivers

PPP was initially designed based on the use of dual-frequency GNSS receivers since dual-frequency observations are necessary in order to remove the effect of ionospheric refraction which is the biggest error source after the application of precise orbit and clock corrections. Increased research and development activities have been found in recent years towards single-frequency PPP. This is largely driven by the fact that the majority of GNSS applications are based on low-cost single-frequency receivers. Such efforts have already brought significant progress in methodology and product development of single-frequency precise point positioning based on precise correction data from the International GNSS Service (IGS) as well as Satellite-based Augmentation Systems (SBAS) (Chen and Gao 2008; Zhang and Lee 2008; Van Bree et al. 2009). Further, there is a great potential to significantly improve positioning accuracy with cheap GNSS chipsets. Technologies to process biased and noisy GNSS observations will be highly demanded and should be investigated.

2.1.4 Quality Control for High-Precision GNSS

Quality control is not new but becomes increasingly important for modern high-precision GNSS systems. This is particularly true for real-time systems such as Network RTK, PPP and other real-time systems

(Aponte et al. 2009). Quality measures should be developed to assess differential GNSS correction data and position solutions. Advanced techniques to ensure high reliability of on-the-fly ambiguity resolution are still a significant challenge for current high-precision RTK systems. This becomes even more critical when signals from multiple GNSS constellations are combined.

2.1.5 Availability of Precise Correction Data

Precise orbit, clock and further ionospheric correction data are essential for PPP and they will also contribute to RTK systems. Precise orbit and clock products have improved significantly in recent years and they are freely available over the Internet from organizations such as IGS. IGS real-time products are expected to be available in the near future. Further, ionospheric correction data is critical for single-frequency PPP and is highly demanded by the industry for product development. Increased availability of precise correction data will accelerate the development of real-time PPP products and reduce the time to market of new high-precision GNSS technologies.

2.2 Atmosphere Modelling

2.2.1 Ionosphere

The past years have seen an increasing effort in the collection of experimental data for monitoring of TEC and ionospheric scintillation studies. This effort has resulted in the deployment of dedicated networks of ground GNSS and scintillation receivers, at high and mid latitudes. There is also effort by means of satellite missions. For example, in situ measurements from GRACE K-Band ranging and CHAMP planar Langmuir probe (PLP) have been used for the validation of the International Reference Ionosphere (IRI); and occultation data used in combination with GNSS and satellite altimetry aiming at a combined global VTEC model (e.g. Todorova et al. 2008; Mayer and Jakowski 2009).

There has been effort put on enhancements in the spatial and temporal representation of TEC/VTEC, globally, regionally or locally. Another issue is that near- and real-time applications require the dissemination of predicted values of TEC. This brings to mind the SBAS, based on continental networks but regional or local systems may also support these applications.

Investigation into multi GNSS constellation and higher order (e.g., 3rd) determination TEC seem to be gaining momentum. Higher order ionospheric delay terms, which have been mostly disregarded in the dual-frequency world, can be taken into account in a multi-frequency reality, see e.g. (Hoque and Jakowski 2008; Hernández-Pajares et al. 2007).

2.2.2 Troposphere

The increasing use of Numerical Weather Models (NWM) has helped enhancing the prediction of neutral atmospheric models (Boehm et al. 2006). It has also become a source of neutral atmospheric delay that can be directly applied in GNSS processing, including PPP. If from one side NWMs contain a more realistic temporal representation of the delay than prediction models, from the other side the extraction of this information requires ray-tracing through the neutral atmosphere, a time consuming task if done properly. Fast and accurate algorithms are of fundamental necessity (Hobiger et al. 2008).

There has been an increasing emphasis of neutral-atmosphere delay monitoring by ground GNSS and satellite missions, with radio occultation consolidating itself as a solid technique (Wickert et al. 2009).

There is a continuing effort towards enhancements in the spatial and temporal representation of the neutral-atmosphere including its azimuthal asymmetry. Several models incorporating gradients, spherical harmonics, tomography, have been further tested including information from NWMs (Ghoddousi-Fard et al. 2009; Rohm and Bosy 2009).

2.3 GNSS Reflectometry

Reflected signals are normally a nuisance in case of precise positioning applications, since only the direct signals should be used for ranging. Recently, however, the GNSS reflected signals have given birth to new applications for various environmental remote sensing applications in atmosphere, ocean, land and cryosphere, e.g. (Jin and Komjathy 2010).

Surface multipath delay from the GNSS signal reflecting from the sea and land surface, could be used as a new tool in ocean, coastal, wetlands, Crater Lake, landslide, soil moisture, snow and ice remote sensing (e.g. Kamjathy et al., 2004). Together with information on the receiving antenna position and the medium, associating with the surface properties of the reflecting surface, the delay measurement can be used to determine such factors as wave height, wind speed, wind direction, and even sea ice conditions. Martin-Neira (1993) first proposed and described a bistatic ocean altimetry system utilizing the signal of GPS. Recently, a number of applications have been implemented using GPS signals reflected from the ocean surface, such as determining wave height, wind speed and wind direction of ocean surface, ocean eddy, and sea surface conditions.

Key topics of current research are:

- Extension of developments of current GPS reflected signal sensor techniques and their applications.
- Improvement of existing estimation algorithms and data processing for GPS reflected signals.
- Coordinated data collection campaigns and comparison with terrestrial and satellite remote-sensor observations.
- Investigation of multi-remote sensor integration and applications.

3 Multi-sensor Systems

3.1 Navigation and Mapping

Multi-sensor system theory and applications is an important research area as well. Here, we will put a special emphasis on integrated guidance, navigation, positioning and orientation of airborne and land-based platforms. The primary sensors of interest are GNSS and inertial navigation systems; however the important role of other techniques used for indoor and pedestrian navigation environmental monitoring is also recognized.

Key topics for further research in this field can be identified as:

- Technical advances in navigation sensors and algorithms, including autonomous vehicle navigation, based on:
  - GPS, pseudolites, INS, wheel sensors, ultrasonic and magnetic sensors
  - Cellular networks and their hybrid with GPS
- Technical advances in mapping sensors (CCD cameras, laser range finders, laser scanners, radar devices)
- Standardization of definitions and measurements of sensor related parameters
- Performance of stand alone and integrated navigation systems
- Non-linear estimation and information fusion methods
- Innovation in:
  - Algorithms, calibration, synchronization
  - Real-time processing and geo-referencing
  - Automated information extraction

3.2 Geotechnical and Structural Engineering

Nowadays extended multi-sensor deformation measurement systems consisting of terrestrial geodetic and geotechnical measurement as well as hydrological and meteorological instrumentation completed by the InSAR technique are mainly employed for multi-scale monitoring of landslide prone areas. Thereby InSAR is used for large-scale detection of landslide prone areas as well as for deformation measurements of the investigated landslide area. Such a complete measurement system is very suitable for the investigation of the kinematic behaviour of landslides and together with other (e.g. hydrological, meteorological, etc.) parameters for the study of the dynamics of landslides. The observation data is usually collected in GIS (see e.g. Lakakis et al. 2009; Mentes 2008) and used to develop Spatial Decision Support Systems (SDSS) and Early warning systems.

In the last years, Artificial Intelligence (AI) has become an essential technique for solving complex problems in Engineering Geodesy. AI is an extremely broad field – the topics range from the understanding of the nature of intelligence to the understanding of knowledge representation and deduction processes, eventually resulting in the construction of computer programs which act intelligently. Especially the latter topic plays a central role in applications (Reiterer and Egly 2008). Current applications using AI methodologies in engineering geodesy are: geodetic data analysis, deformation analysis, navigation, deformation network adjustment, and optimization of complex measurement procedures.

4 InSAR

Synthetic Aperture Radar (SAR) and Light Detection And Ranging (LiDAR) systems are very useful for geodetic applications, such as monitoring local area ground surface deformations due to volcanic and seismic activities, and ground subsidence associated with city development, mining activities, ground liquid withdrawal, and land reclamation.

InSAR is a very active field of research in the geo-detic research communities. The current research issues include the development of more effective methods/algorithms for InSAR solutions, the quality control and assurance of InSAR measurements, the study and mitigation of biases in InSAR measurements such as the atmospheric effects, integration of InSAR and other geodetic technologies such as GPS, and new and innovative applications of the technology in geodetic studies.

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