Development Update
Navigation and Positioning in China

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During the past 15 years, China has steadily accelerated its activities in the realm of satellite navigation and positioning. Researchers from leading GNSS engineering centers in Wuhan provide an overview of these efforts.

Development of satellite-based positioning and navigation technology has greatly reformed conventional spatial determination practices and enabled advancement of the digital infrastructure in China. This kind of progress is continuing with the improvement of related techniques.

This article will provide an update on China's GNSS-related activities in recent years, including research on novel positioning approaches, collaborations between China and international sectors, and, finally, some brief comments on the prospect for China's Beidou navigation and positioning system.

China's CORS Network

Beginning in 1990, the mode of continuously operating reference station (CORS) using GPS was first applied by NASA's Jet Propulsion Laboratory (JPL) and MIT to the research of plate tectonics in southern California, USA. This innovation successfully helped geologists to deepen their understanding of seismic faults because more continuous spatial information can be obtained than ever before.

From 1997 to 2000, as a key state scientific project, the Crust Motion Observation Network of China (CMONOC) was implemented, composed of 25 CORS stations and 1,000 regional network stations. Very long baseline interferometry (VLBI) and satellite laser ranging (SLR) equipment was coupled in some of the CORS stations. Based on CMONOC, researchers achieved significant seismic motion results about continental plates. CORS has subsequently been employed by numerous agencies and organizations in China and has become popular in many fields, including guidance of aircraft similar to the U.S. Wide Area Augmentation System (WAAS) approach procedures.

In contrast to preliminary stages, evolution of networks and communications have enabled CORS to become a leading support component for the national temporal and spatial information infrastructure. CORS is now implemented at many of China's main cities, such as Shenzhen, Chengdu, Beijing, Shanghai, and Guangzhou.

Among these, the Shenzhen CORS system was started in 1999 as a paradigm of comprehensive service network and spatial data infrastructure in China. (See Figures 1 and 2.) The system was designed and implemented in a flexible form of network and wireless communication to perform a variety of positioning and navigation services in both real-time and postprocessing.

The project was jointly accomplished by the GNSS Engineering Research Center, Wuhan University, and Shenzhen Municipal Bureau of Land Resources and Housing Management. It is aimed at applications for surveying and mapping, urban planning, resource management, transportation monitoring, disaster prevention, and scientific research including meteorology and ionosphere scintillation.

FIGURE 1 Shenzhen CORS station established in China

In this way, the Shenzhen CORS network is acting to energize the booming economy of this young city. With rapid development of CORS construction in China, these stations are expected to operate within a standard national specification and to play vital roles in realization of the "digital city" in terms of real-time and precise positioning and navigation.

Based on CORS stations properly distributed throughout China, some of these facilities are aligned with stations installed with other spatial observing technologies such as SLR, VLBI and DORIS (Doppler Orbitography and Radio-positioning Integrated by Satellite, a system maintained by France). These sites are serving for satellite orbit determination and, when combined with multiple spatial technologies, have created a dynamic and multi-dimensional terrestrial reference frame for China.

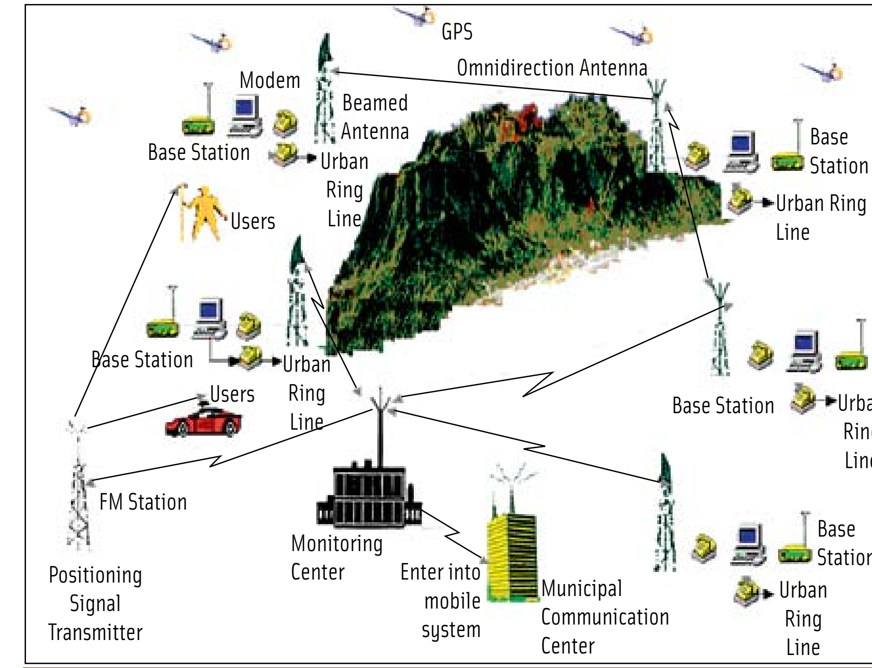

FIGURE 2 Lay out of CORS network in Shenzhen

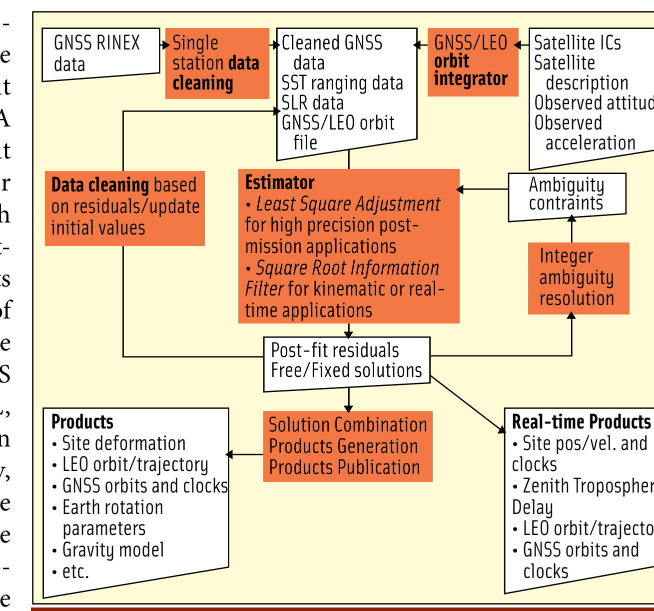

FIGURE 3 Schematic design of PANDA software for satellite orbit determination

PANDA & Orbit Determination

With funding support from relevant authorities, Wuhan University has developed a scientific software called PANDA (for Position and Navigation Data Analysis) that comprehensively analyzes multiple spatial observations and autonomously determines satellite orbits. Figure 3 shows the data processing scheme of the PANDA software.

The software can currently accommodate observations including GPS and SLR and produce long baseline and satellite orbit outputs. PANDA can perform orbit determination for GPS and low earth orbiting (LEO) satellites, and its results can match those of such agencies as the International GNSS Service (IGS), JPL, Scripps Institution of Oceanography, the European Space Agency (ESA), the U.S. National Geodetic Survey, the Center for Orbit Determination in Europe (COD), Germany's GeoForschung Zentrum (GFZ), and Canada's Energy, Mines and Resources (now Natural Resources Canada) facility (EMR).

Figure 4 compares the IGS and PANDA orbit determination root mean square (RMS) fits of GPS orbits with the results from IGS Analysis Centers. Figure 5 compares PANDA range residuals to the Gravity Recovery And Climate Experiment-A (GRACE-A) satellite with the satellite elevations computed by SLR stations.

In the software packages, we have considered all possible parameters such as earth orientation and right-hand circular (RHC) phase-rotation corrections, and various force models including gravity model, third-body attraction, tides, atmospheric drag, solar radiation,

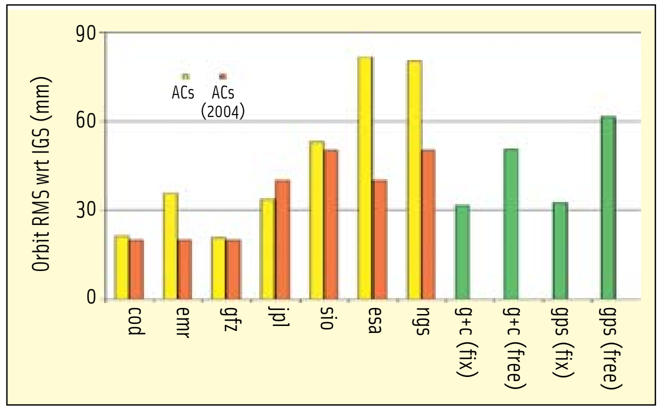

FIGURE 4 Overall PANDA orbit RMS (in millimeters) compared with the IGS final results. Green is that of PANDA, yellow is for that of the IGS Analysis Centers (ACs) over the same time, and red for ACs around the end of 2004.

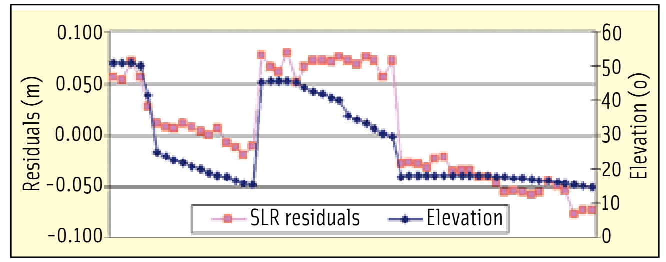

FIGURE 5 Residuals by PANDA and elevations of satellite laser ranging observations to GRACE-A

velocity impulse, and acceleration observations. Some ambiguous factors can be compensated by estimated parameters. Observation equations are generated epoch by epoch within an estimator to meet the requirement of real-time or kinematic applications.

In the future, signal observations from Galileo and other systems will be included in the software to further enrich its orbit determination capability. Some recently planned research aspects for this software may cover tropospheric delay estimation from a moving platform, onboard precise orbit determination, GPS attitude control, and gravity model recovering.

With precise orbit support and flexible services including atmospheric products by IGS and other agencies, single point positioning is also rapidly pushing towards maturity in China using refined ambiguity resolution algorithms. Research results by Wuhan University and other departments show that the accuracy for postprocessing is at the centimeter level using both dual- and single-frequency GPS receivers. Studies are focusing on compensation methods for ionospheric delay, phase unwrapping, and receiver bias–induced effects, which will lead to further refinements of this positioning approach.

To meet user requirement for accurate three-dimensional (3-D) positioning in local datums, research on refined quasi-geoids is now fully performed in most big cities in China. Tests have shown that refined quasi-geoid results can achieve levels of geoid height results with centimeter-level accuracy. (See Figure 6.) This can further enable positioning and navigation, including 3-D precise point positioning relative to local height datums by using GNSS.

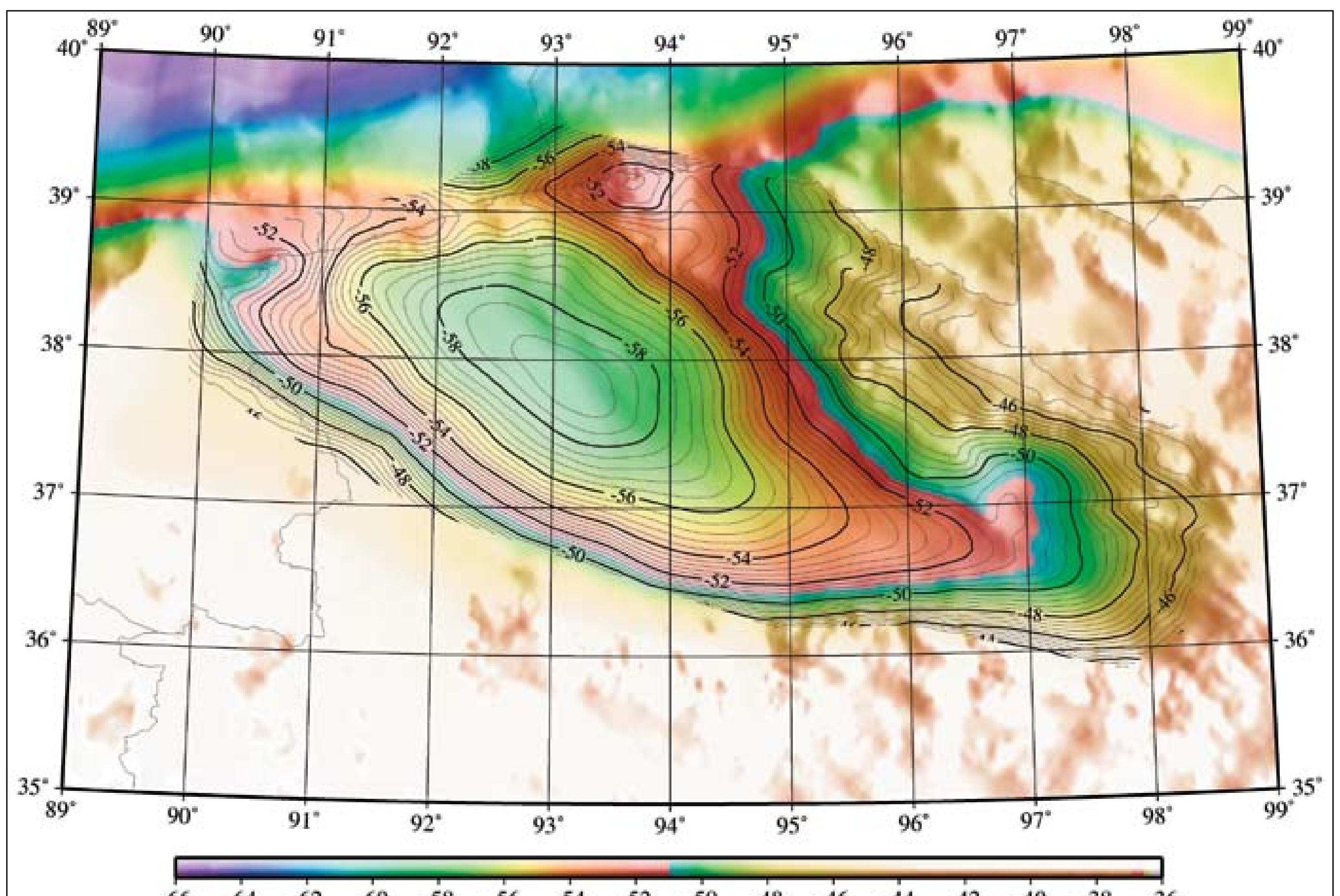

FIGURE 6 Quasi-geoid heights in western China, scale in meters with resolution of 1 minute 30 seconds by 1 minute 30 seconds (courtesy of School of Geodesy and Geomatics, Wuhan University, 2005)

International Cooperation

Apart from research based on current satellite navigation systems, international collaborations on use of other satellite systems, especially Galileo, form an important aspect of China's GNSS-related activities. Following an official agreement between China and the European Union reached in October 2003, the Ministry of Science and Technology of China (MOST), European Commission (EC) and ESA established the Chinese-Europe GNSS Technology Training and Corporation Center (CENC), which is headquartered at MOST.

A technology cooperation agreement on Galileo was signed in October 2004 in which representatives from related ministries, industrial sectors, and universities participated. Several seminars have been held on China-Europe Galileo collaboration and satellite navigation industry development, aimed at promoting this cooperation.

Given this mechanism, Wuhan University and the Shanghai Astronomical Observatory (SHAO) in China have collaborated with the EU to participate in the EC's 6th Framework Program (FP6). With FP6 support, a technical research and data analysis center for the Galileo system in China will be established and a plan will be implemented to develop a prototype of for a Galileo geodesy service provider.

Recently, a study has gotten under way on the potential use of combinations of three or multiple frequencies and their properties in light of the Galileo system. Research is also being conducted on the realization and improvement of the Galileo Terrestrial Reference Frame combining observations from Galileo, VLBI, SLR, DORIS, and other sources.

FIGURE 7 Blastoff of the third BD1 on May 25, 2003.

The Beidou System

China's third Beidou navigation satellite was launched into orbit on May 25, 2003 (see Figure 7). That marked the formation of a complete local satellite navigation and positioning system. This system is based on positioning principle using twin satellites first proposed in 1983. Beidou is designed to conduct all-weather navigation, positioning, timing, and communication using short messages by radiobeacons on board the satellites.

Beidou is composed of a control station, orbit network stations, calibration stations, altimetry stations, and a user transceiver unit. Currently, the system can provide positioning service with an accuracy of about 20 to 100 meters and a timing service with about 20-nanosecond precision. To improve its performance, one proposal suggests that the Beidou 1 satellite could act as communication link for an augmentation service in addition to its positioning function.

Technology schemes completed as part of the research for China's wide area differential GNSS project have laid a good foundation for enhanced real time and accurate positioning using the current Beidou system. Because Beidou's communication data link is self-contained, it can be used as link for broadcast of grid atmospheric delay corrections, ephemerides, and other corrections. As a result, real-time and precise point positioning can also be carried out based on this capability. (See Figure 8.) In this way, an augmentation system that is similar to WAAS or the European Geostationary Navigation Overlay Service (EGNOS) can be derived from Beidou in the future when an enhanced system is completed.

Considering the approaching application of Galileo and China's Beidou system, research on employment of multiple frequency signal sources to facilitate precise point positioning are also being carried out by interested departments. These research projects are discussing the opportunity brought by these signals to overcome atmospheric effects on GNSS signal propagation and to enable raw phase ambiguity resolution for combined phase observations.

In order to maintain a long-term development on the basis of full compatibility with existing and coming satellite navigation systems, various Chinese public organizations (including Wuhan University) and industrial enterprises

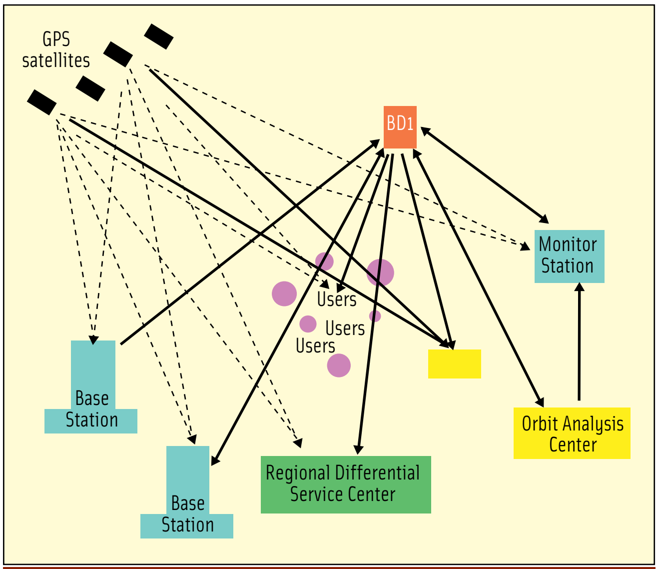

FIGURE 8 Augmentation scheme based on Beidou satellites

are undertaking initial research on compatible receiver development that can accommodate signals from GPS, GLONASS, Galileo, and Beidou. These studies will lead to convenient use of an integrated satellite navigation system for users in China.

Acknowledgements

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