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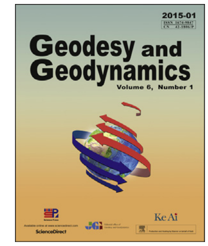

Progress of the satellite laser ranging system TROS1000

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ABSTRACT

The mobile satellite laser ranging system TROS1000, successfully developed in 2010, achieves a high repetition rate and enables daytime laser ranging. Its measurement range has reached up to 36000 km with an accuracy as precise as 1 cm. Using recent observations in Wuhan, Jiufeng, Xianning, and Rongcheng, Shandong, we introduce the progress made using this mobile observation system.

1. Introduction

Following the creation of the small mobile satellite ranging system TROS-I [1], the Institute of Seismology, China Earthquake Administration, successfully developed a large-scale mobile satellite laser ranging (SLR) system in 2010 called TROS1000. In this system, instrumentation was mounted on a large unpowered trailer of 15 m in length, 2.5 m in width, and 15 tons in weight. The trailer requires outside power to be relocated, such as provided by a semi-tractor (Fig. 1). In the center of the trailer, we used fiberglass to construct a dome. When conducting observations, the dome will automatically open, and when the turntable observation space opens, satellite tracking measurements can start (Fig. 2).

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Fig. 1 – TROS1000 being towed.

The main instrument is composed of a 1-m-diameter altazimuth telescope, a 1-m-diameter main receiving telescope, and a 23-cm-diameter laser transmitter, equipped with a damping system for transportation and a detachment support system for observations [2]. The laser-ranging system uses a built-in mini kHz laser, whose adjustable range of emission frequency is 0–10 kHz and whose largest single pulse energy is 1.5 mJ. A range gate generator and high-precision event timer are used to meet the high repetition frequency (kHz) laser ranging technology requirements. The entire electronic control system is installed inside the telescope turntable, which is remotely controlled by a computer through a wireless transmission, so the connection is simple and easy to operate.

Daytime satellite laser ranging technology has always been a goal of research and development in China. The Chinese science project "Crustal Movement Observation Network of China" included this technology as a basic requirement for updating the SLR network. TROS1000 has achieved this goal by successfully acquiring daytime observational data, with a

Fig. 2 – Auto-opening dome and the measurement.

measurement range reaching 36000 km (the altitude of geosynchronous satellites) and single shot measurement accuracy of 1 cm.

2. New features of TROS1000

2.1. *Overall structure*

Unlike TROS-I, TROS1000 uses a large 1-m-diameter turntable and has been provided with a large trailer as its main means of transport [3]. Its structure is shown in Fig. 3. Its main devices have been completely integrated. All operations are controlled by the computer's wireless network, which greatly reduces the time spent preparing the instrument, the connection complexity, and the difficulty of operation, as well as the burden placed on personnel, thereby improving observation efficiency.

Additional instruments can also be connected with various devices; these include high-power lasers and large-caliber receiving systems for performing future extensions of the work, such as observing more distant targets or noncooperative target ranging. With the development of technology, the degree of automation and remote control will both improve.

Large truck transport can provide more space to work and perform maintenance. The instrument also has the advantage of easy installation at the observation station, reducing instrument preparation time, and, if conditions permit, equipment installation. Determination of reference points and commissioning of the receiving system can be completed in a single day. However, the large vehicle body needs a suitably large location, increasing the difficulty of selecting the appropriate site. Consequently, there will be a continuous need to change sites and seek appropriate new locations.

2.2. *Kilohertz ranging*

The kHz ranging control system consists of a cross-signal range gate generator and a Time-to-Digital Converter (TDC) integrated chip precision event timer based on field-programmable gate array (FPGA), enabling fully realized kHz laser ranging functionality with a high-repetition-rate laser. The target capture rate, ranging echo rate, and the amount of observational data have been significantly improved [4,5].

2.3. *Tracking system*

We developed a fully digital satellite tracking system that uses a high-precision optical encoder position sensor and a pulse-width-modulated drive to improve tracking accuracy and reduce the drive power. Through the unique driving torque motor and photoelectric encoder installation design and layout, we optimized the lead slip ring current and reduced interference, allowing the turntable to be rotated at any angle continuously, without leads or any other restrictions, which greatly facilitates the tracking start and end time control processing and also reduces the likelihood of failures [6].

2.4. *Daytime ranging*

The resolution from the range gate based on the FPGA can reach up to 1 ns. This can be further improved with a precision delayer, which can limit the intense noise encountered during daytime ranging. Additionally, a narrowband filter and a pinhole light bar limit noise from the wavelength of light and spatial aspects, respectively, reducing the noise during daytime ranging to an acceptable level. Coupled with satellite tracking forecast accuracy and improved accuracy of the turntable, this enables ranging during the daytime.

3. Observational results

The main observational task at Jiufeng was to debug and to optimize the mobile satellite laser ranging system TROS1000 during 2011. During this time, because of poor

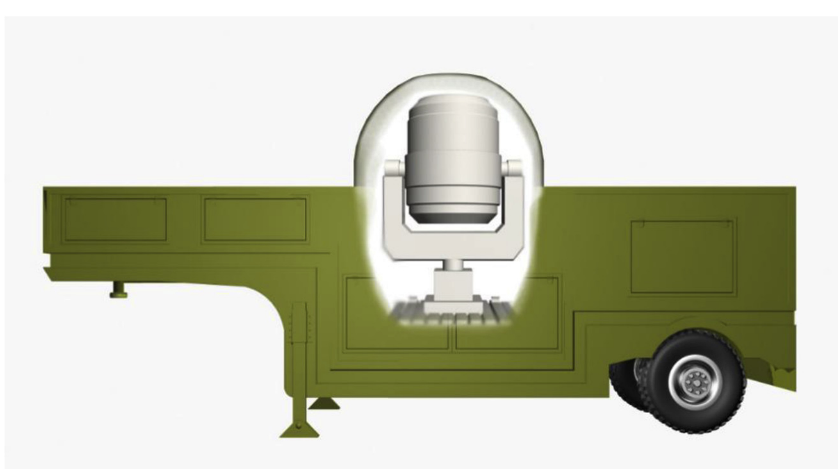

Fig. 3 – Diagram of the system.

weather conditions, we rarely had the chance to perform observations. Even though the satellites could be observed, we hardly ever obtained sufficient data, especially during the daytime. All of the satellites were tested and observed while we put more efforts into satellites such as Ajisai.

In 2012, when the first formal observation was carried out in Xianning City, Hubei, we made a permanent marker TG7 near the mobile observation station for memory. To accomplish coordinate differences surveying, we used two GPS receivers, which were, respectively, installed on TG7 and the mobile system TG5, combined with the continuous GPS observation station XNXN on April 9, 2012. The three stations observed satellites simultaneously for a day. The calculated coordinates are listed in Table 1.

The Beidou second-generation satellite, which has an orbital altitude of 36000 km, and the QZS satellite were successfully observed in Xianning. The total number of observation paths was 487, and observation data for different satellites are listed in Table 2.

As planned by the Monitoring Network of Continental Tectonics in mainland China (CMONOC), the satellite laser ranger TROS1000 arrived in Shandong province to perform its observation mission. TROS1000 set off for the Rongcheng seismographic station on May 17, 2013, by way of four provinces, Hubei, Anhui, Jiangsu, and Shandong, for a total journey of >1500 km. Rongcheng City is located in the easternmost end of the Chinese coastline, surrounded by sea on three sides. Carrying out mobile observations here would help perfect the distribution of the SLR monitoring network and help maintain the stability of the observational network. The Rongcheng seismographic station is a key digital seismic station and a base station of the CMONOC. The addition of a mobile SLR observation system will enrich the observational methods of Rongcheng station.

After the arrival of TROS1000 and following 72 hours of preparation, the system entered its working state. By the end of 2013, we have observed satellites up to 945 paths, including near-earth satellites, Lageos, Glonass, and the Beidou navigation satellites. Observational statistics are listed in Table 3. The preprocessing results of observation data of the Beidou G1 satellite for one pass acquired in 20 min with a dwell of 10 min (for observing other satellites) on October 16, 2013, are shown in Fig. 4. We obtained 6559 effective points with a single-shot precision of 1.3 cm, corresponding to the blank space in the graph. The various Beidou satellites were observed for a total of 22 paths.

Observational tests were conducted during the daytime in Rongcheng and data from 54 passes were obtained in total. Near-earth satellites were in the majority. Because of directional trouble with turntable, fewer arc segments were observed, reducing the number of data point. Further adjustment of pointing is needed. Fig. 5 displays the actual control interface when we measured the Ajisai satellite during the daytime. Observation of this path lasted 4 min and 21140 valid points were acquired with a single precision of 2.5 cm. In addition, the HY-2A satellite was also observed for 1.2 min, yielding 2835 points with a precision of 1.1 cm, and 54 daytime passes were obtained in total. Part of the observation data of normal point in 2013 can be found in attachment 1. Corresponding GPS centering coordinate surveying data are also in it.

4. Conclusions

TROS1000 has so far executed observation tasks in Xianning and Rongcheng. In general, TROS1000 will be positioned at a station for one to two years. It is still working in Rongcheng in 2014 and likely its placement there will be prolonged. Although we have accumulated some experience in mobile SLR, observing in the daytime needs further improvement. Focusing on realizing routine measurements will sharply increase the observation data. Furthermore, TROS1000 is taking advantage of its unique characteristics to carry out observing research on special noncooperative targets (including space debris) and to expand the field of application of SLR technology.

Table 1 – Results of coordinate differences surveying of mobile SLR in Xianning.

Stations	X	Y	Z
TG5	−2280396.6838	5043439.3360	3158714.6097
TG7	−2280404.5915	5043437.7599	3158706.9101
XNXN	−2284282.5145	5043346.2259	3156155.4470

Table 2 – Statistical observation data in Xianning.

Satellite	Near-earth	Lageos	GLNS	Etalon	Giove	Qzs	Beidou	GPS	Total
Passes	94	50	252	27	7	17	22	16	487

Table 3 – Statistical observation data in Rongcheng.

Satellite	Near-earth satellites (<1000 km)	Lageos (~6000 km)	High-orbit satellites (km) 20000–36000	Total	Observation during the daytime
Passes	336	121	488	945	54

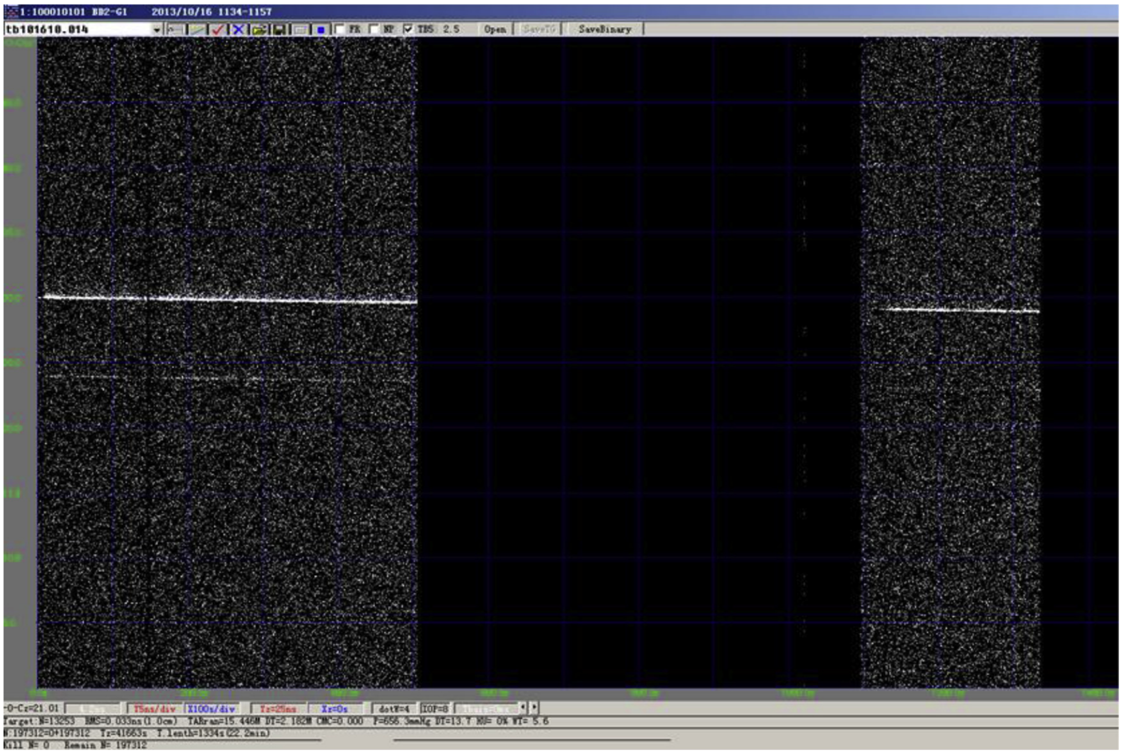

Fig. 4 – Preprocessing results of observational data from the Beidou G1 satellite.

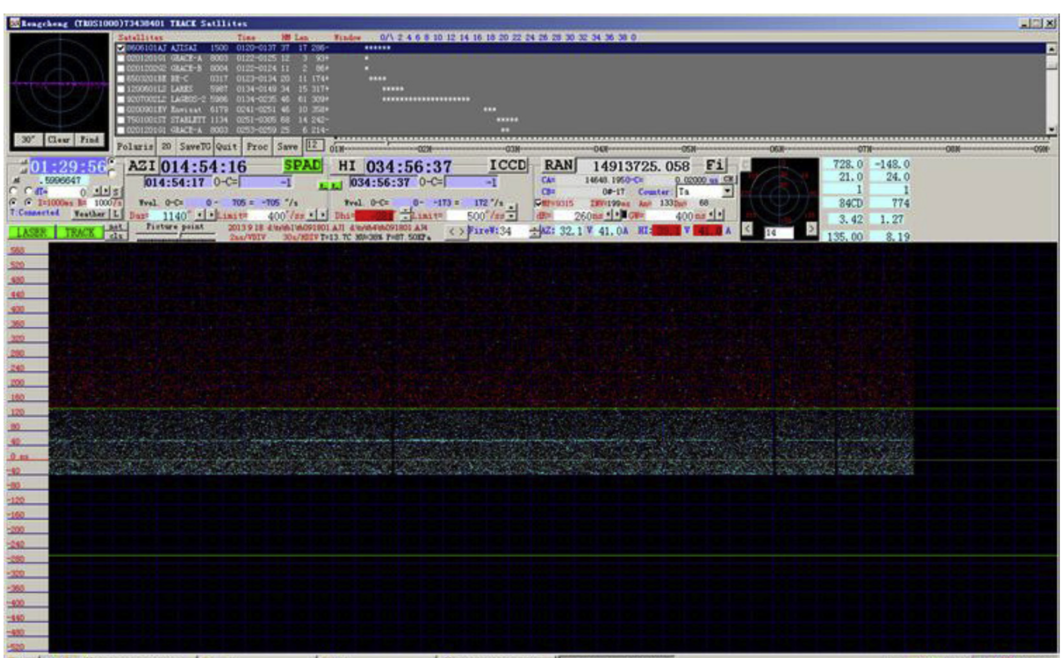

Fig. 5 – Real-time data recording screen of the Ajisai satellite during the daytime.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.geog.2014.12.004.

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The author has been engaging in development and research of system equipments. The DZR-III satellite laser ranging device (Wuhan station 7231), small scaled vehicular TROS-I satellite laser ranger (International station number 7343, 7355, 7356) and the TROS-1000 mobile satellite laser ranging instrument have been developed until now. In recent years, the author has conducted research on system equipments applied to earthquake early warning and monitoring.