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Technical Aspects and Progress of Korean SLR Systems

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Abstract. *Korea Astronomy and Space Science Institute (KASI) has been developing two satellite laser ranging (SLR) systems: mobile and fixed SLR system, called ARGO-M and ARGO-F, respectively. The ARGO-M is now in normal operation at KASI headquarter with the station code of DAEK from International Laser Ranging Service (ILRS), which will be moved to Sejong site for the establishment of the fundamental station. So Korea became the 25th country that operates SLR system in support of the international laser tracking network. The ARGO-F will be developed in 2016 and then installed at the Gamak site which is about 150km far from Sejong site. It was demonstrated that ARGO-M has good ranging performance at the level of a few mm in terms of single-shot ranging precision.*

Introduction

Korea Astronomy and Space Science Institute (KASI) has been developing one mobile and one fixed satellite laser ranging (SLR) system since 2008 for the space geodesy research and precise orbit determination, called ARGO-M and ARGO-F, respectively. The ARGO-M has been successfully developed and is now in normal operation at KASI headquarter with the station code of DAEK from International Laser Ranging Service (ILRS), as shown in Figure 1. The ARGO-M is designed to enable 2 kHz laser ranging in both daytime and nighttime tracking for satellites between 300 km and 25,000km altitudes, which has the bistatic optical path with 40 cm receiving and 10 cm transmitting telescope. The analysis shows that ARGO-M has good ranging performance at the level of a few mm in terms of single-shot ranging precision. The ARGO-M will be moved to Sejong site in 2014 to establish the fundamental station. The combination of ARGO-M with very long baseline interferometry (VLBI) and global navigation satellite system (GNSS) at the Sejong site will contribute a core global geodetic observing system (GGOS) space geodesy site.

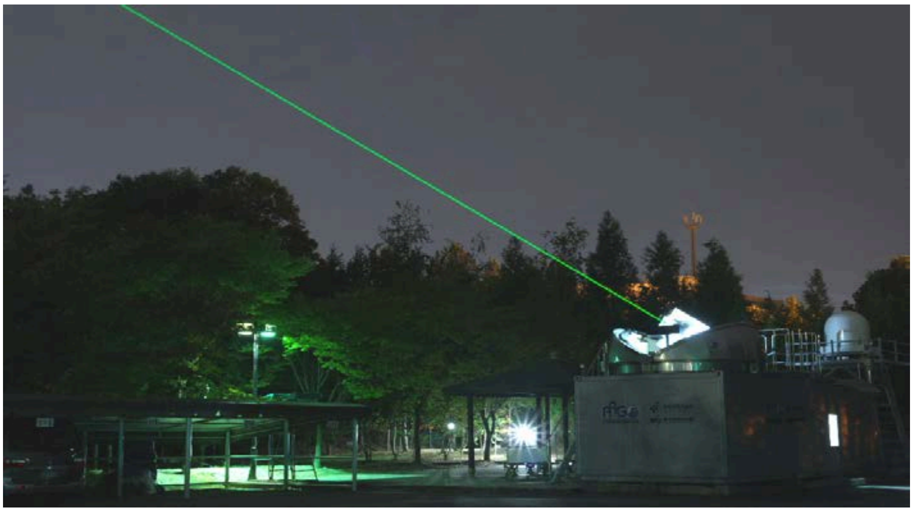

Figure 1. Satellite laser ranging of ARGO-M at KASI headquarter

The ARGO-F has the common coude optical path with 100 cm telescope, whose ranging precision is required to be less than 3mm for normal point (NP) of LAGEOS satellite. It is designed to be a fully automatic remote operation. The ARGO-F has two functions: satellite laser ranging up to geostationary satellites and space objects imaging using an adaptive optics. Additionally, it will be upgraded to space debris laser ranging using high power laser in 2017. The ARGO-F is now in the phase of system design, which will be developed in the first quarter of 2016 through cooperation of a foreign institute.

Technical Aspects of ARGO-M

The ARGO-M consists of six sub-systems: optical system, optoelectronic system, laser system, tracking mount, operation system and dome. In addition, it has also the laser hazard radar to monitor airplanes, the ground target to calculate the system delay, and weather sensors to correct the atmospheric delay and refraction based on Marini-Murray model (Marini and Murray, 1973). The ARGO-M has three rooms: laser, operation and accessory room. There are the steel pier of tracking mount, laser, optical table and ground target pillar in the laser room. The operation system and many electronics including event timer, tracking mount servo system are installed in the operation room. Two air conditioner are installed to maintain a constant room temperature in both laser and operation room for normal operation of laser and electronics. There are a uninterrupted power supply (UPS), power distribution unit and surge protection device in the accessory room. The system configuration of ARGO-M is shown in Figure 2 and the internal structure in Figure 3.

Figure 2. System configuration of ARGO-M

The ARGO-M is designed to enable 2 kHz laser ranging in both daytime and nighttime tracking for satellites equipped with laser retro-reflector array (LRA) at altitude of 300 to 25,000 km. It has the bistatic optical path employing the 40 cm receiving and 10 cm transmitting telescopes. For the daytime tracking and 2 kHz laser ranging, the ARGO-M is adapting the event timer, the spatial and narrow band-pass filter and the high energy laser with 2.5 mJ energy per pulse at 2 kHz. The laser beam size is expanded 15 times by two beam expanders in the transmitting optics and 3 times in the transmitting telescope. The beam divergence is adjusted in the range of 5 to 200 arcsec by changing the position of concave in the transmitting telescope, which is depending on the satellite altitude.

The receiving telescope is a Ritchy-Chretien optical system where the primary and secondary mirrors are hyperboloids. The system F ratio (aperture to focal length ratio) is F/10.3 and the primary mirror has 1.5 of F ratio. The iris, spatial filter has three kinds of field of views (FoV, 30", 150" and 300") and one blocked spatial filter used for sun shutter to protect C-SPAD against direct sun light: 30" for daytime, 150" for dawn and twilight, and 300" for nighttime observation. The C-SPAD is made by Peso Consulting in Austria is used, and PCO 1600 and Watec WAT-120N models are also used for daytime and nighttime cameras, respectively.

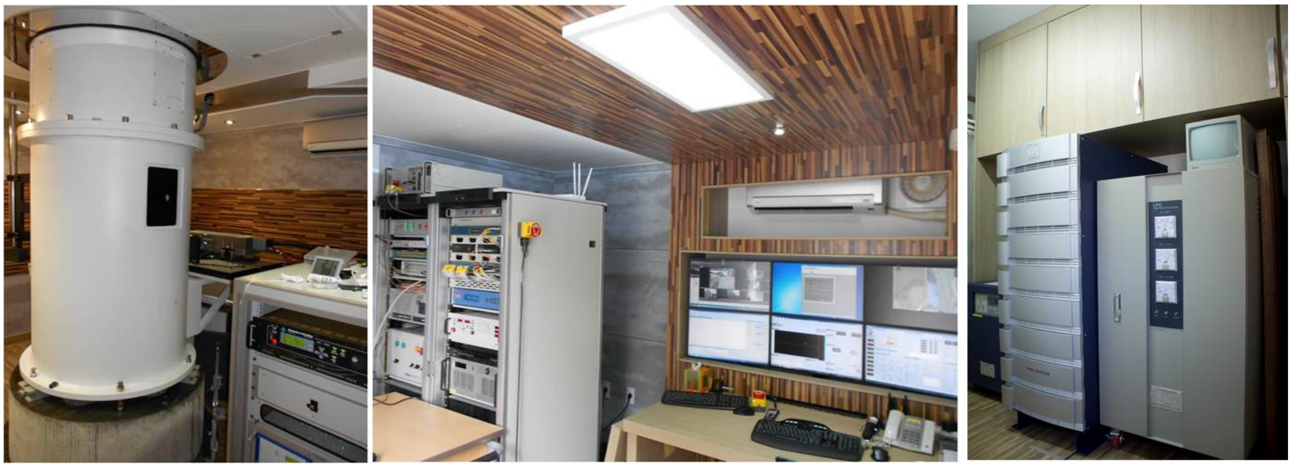

Figure 3. Internal Structure of ARGO-M, laser room(left), operation room(middle), accessory room(right)

In the satellite ranging, the optoelectronic controller generates laser fire command and range gate (RG) for C-SPAD activity based on the predicted time of flight (TOF) and start signals information, which is implemented by field programming gate array (FPGA) board for the fast functional operation. But in the case of ground calibration, it generates laser fire command and RG directly without any information of TOF and start signals because the stop pulse arrives at the C-SPAD earlier than the RG signal due to short distance of the ground target. The ARGO-M uses the Event Timer A033-ET(Institute of Electronics and Computer Science, Latvia) which records the epochs of start and stop signals and then puts them into buffer for the implementation of kHz laser ranging. The laser system is required to be compact size, small pulse width and kHz repetition rate for ARGO-M as well as high energy per pulse in order to increase the link budget (Lim et al. 2010). So the ARGO-M uses RGL-532 model(Photonics Industries, USA) for laser system. The operation system monitors the status of five sub-systems, equipment and sensors. In addition, it controls the environmental factor and sub-systems for observation, and generates the final observation products such as raw data and NP data through polynomial fitting. The interface diagram of operation system is shown in Fig. 4. The detailed description of optical and optoelectronic system are given by two literatures (Nah et al. 2013, Lim et al. 2011). The major specifications of ARGO-M and ARGO-F are shown in Table 1.

Analysis of ARGO-M Performance

In general, SLR data quality is evaluated based on six performance parameters: average single-shot ranging precision of ground calibration, Starlette and LAGEOS satellite, average NP ranging precision of LAGEOS satellite, and short and long term bias stability. The first three parameters are obtained from NP generation during the last quarter but the last three are based on rapid orbital analysis results from various Analysis Centers (ACs), during the last quarter for the fourth and fifth parameters and the past year for the last one. The short term stability is computed as the standard deviation of the pass-by-pass range biases but the long term stability is the standard deviation of the monthly range bias estimates. In this study, three average single-shot ranging precision are used to evaluate ARGO-M measurement data quality because other performance parameters are computed by five ACs and will be given on ILRS website after several months. To compare data quality of ARGO-M with ILRS stations, measurement data set is October 1-30, 2013 for ARGO-M and the third quarter for ILRS stations.

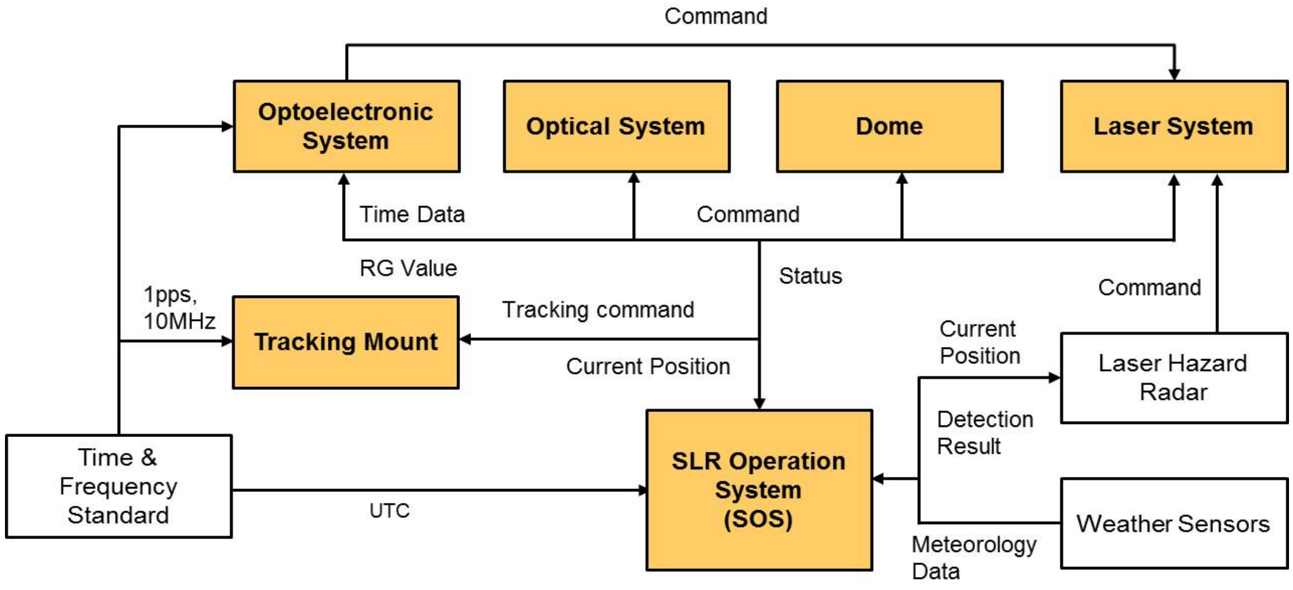

Figure 4. Interface diagram of ARGO-M operation system

Table 1. Specifications of ARGO-M and ARGO-F

Item	Parameter	ARGO-M	ARGO-F
Telescope	Optical path	Bistatic	Common Coude
	Rx and Tx telescope	40/10 cm	> 100 cm
	Primary mirror F-ratio	1.5	-
	Transmit beam divergence	5 ~ 200 arcsec	-
	Max. slew rate	20 deg/sec (Az) 10 deg/sec (El)	30 deg/sec (Az) 15 deg/sec (El)
	Tracking & Pointing accuracy	< 5 arcsec	< 1 arcsec
Detector	Type	C-SPAD	MCP-PMT or C-SPAD
	Quantum efficiency	20%	-
Laser	Wavelength	532 nm	532 nm
	Pulse energy or Power	2.5mJ @2 kHz	> 1W
	Pulse width	50 ps	< 20 ps
	Repetition rate of Operation	2 kHz	-
	Beam diameter @ Tx telescope	7.5 cm	> 50 cm
Others	Timing system	Event timer	Event Timer
	Aircraft detection type	Radar	Radar

The ARGO-M uses only one ground target with short distance of about 100 cm from the virtual reference point of telescope for ground calibration. The ground target is installed inside the dome, which consists of prism, diffuser and neutral density filter to decrease laser power to C-SPAD. The density filter was selected so that the return rate is about 30% with 300 arcsec FoV of spatial filter in the nighttime observation. In the case of ARGO-M, the ground calibration is fulfilled before satellite tracking because it is required to be done before and after every satellite pass. The calibration correction depends not only on distance between the virtual reference point and the ground target, but also on the atmospheric condition such as temperature, press and humidity. In the process of sigma filtering, sigma value of 2.2 is used to compute calibration correction because ARGO-M is 2 kHz laser ranging system using C-SPAD detector. In the ground ranging, the average single-shot ranging precision is 5.7 mm for ARGO-M and 7.9 mm for mean of 28 ILRS stations from global report cards issued quarterly by the ILRS Central Bureau.

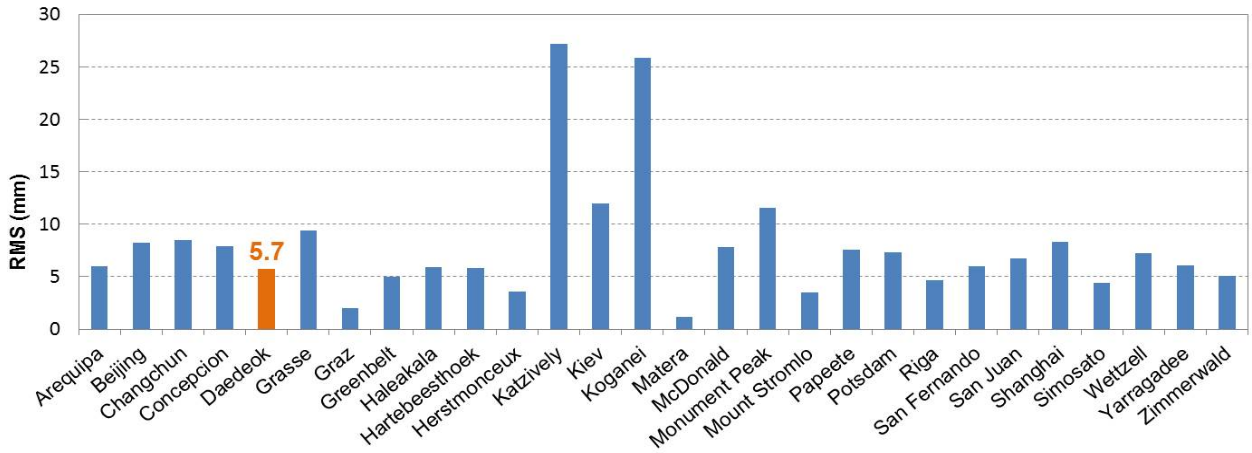

Figure 5. Single-shot ranging result of ground calibration

There are many satellites equipped with LRA for geodesy, remote sensing, navigation and scientific experiments. Starlette and LAGEOS satellites have also spherical shape covered with retro-reflectors for geodesy research. SLR data quality depends on the retro-reflectors characteristics and the accuracy to which the satellite center of mass is measured or modeled as well as SLR system performance. The single-shot ranging precisions are analyzed for Starlette and LAGEOS satellite. In the process of sigma filtering to generate NP data, sigma value is same as ground target ranging. In the Starlette satellite ranging, the average single-shot ranging precision is 9.1 mm for ARGO-M and 12.2 mm for mean of 33 ILRS stations. In the case of LAGEOS satellite, the ARGO-M has 10.3 mm of ranging precision and 32 ILRS stations have 12.9 mm as mean. These average single-shot ranging precision of ILRS stations is also given in global report cards.

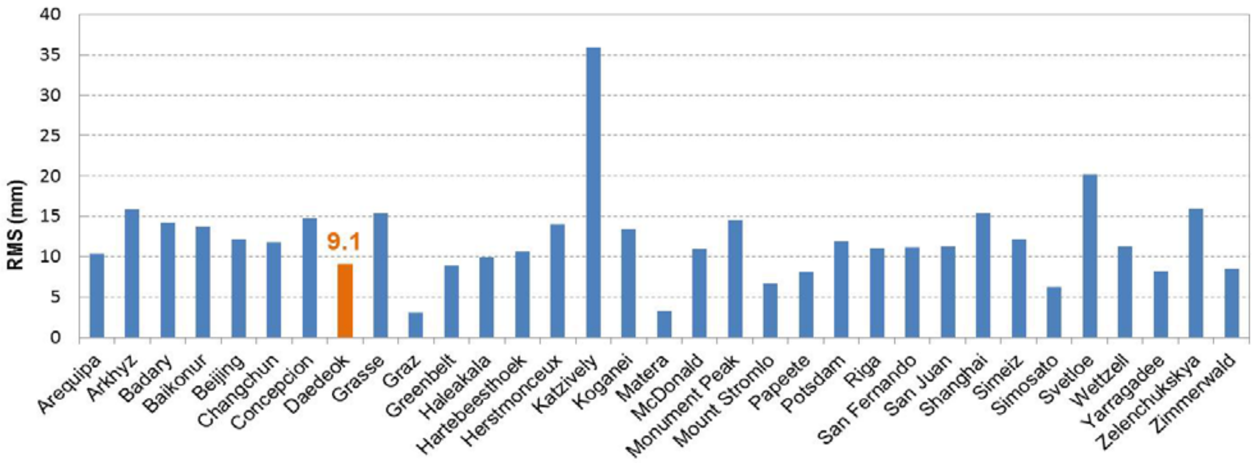

Figure 6. Single-shot Ranging result of Starlette satellite

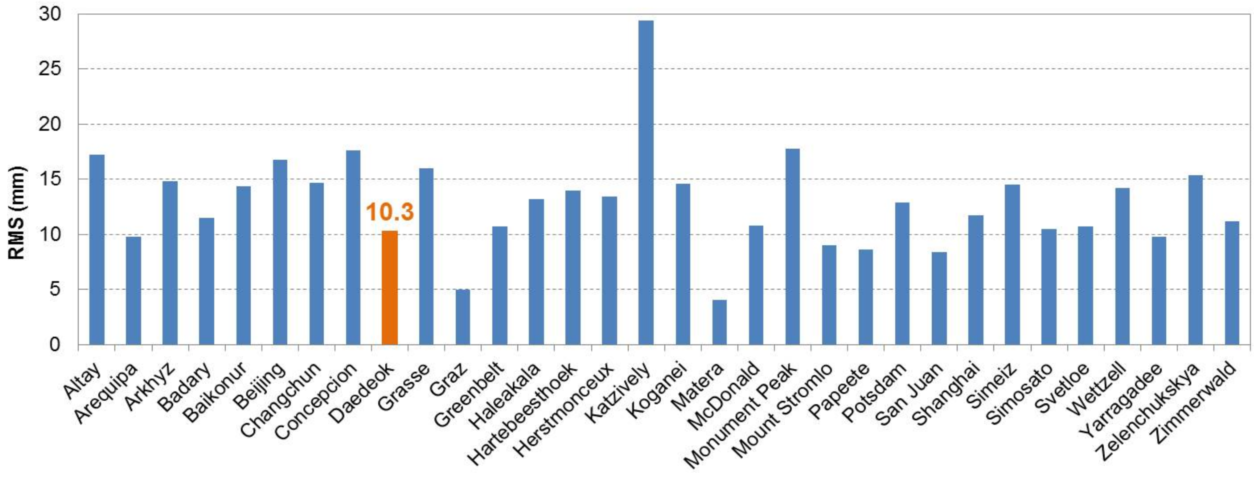

Figure 7. Single-shot Ranging result of LAGEOS satellite

Summary

Korea Astronomy and Space Science Institute (KASI) has been developing two SLR systems since 2008 for the space geodesy research and precise orbit determination: ARGO-M and ARGO-F. The ARGO-M is now in normal operation at KASI headquarter, which will be moved to Sejong site for the establishment of fundamental station. The ARGO-F is now in the phase of system design and will be installed at Gamak site in the first quarter of 2016, which will be upgraded to space debris laser ranging using high power laser in 2017. It was demonstrated that ARGO-M has good ranging performance at the level of a few mm in terms of single-shot ranging precision. The results show ARGO-M has good performance: 5.7 mm for ground calibration, 9.1 mm for Starlette satellite ranging and 10.3 mm for LAGEOS satellite ranging. The ARGO-M will be upgraded into 10 kHz laser ranging in 2014 with more compact operation system and new optoelectronic controller, which leads more returned signals and then increase ranging precision. With the high technology incorporated into ARGO-M, it is expected that ARGO-M plays an important role in the development of laser ranging data products.

Acknowledgments

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