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4. KSP SLR SYSTEM
4.1 DESIGN CONCEPT OF THE KSP SLR SYSTEM

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ABSTRACT

Multiple Satellite Laser Ranging (SLR) systems developed for the Key Stone Project have unique features in accuracy and automation which are needed for SLR in 21st century so that they can be used as a high yield geodetic calibrator for geodetic applications and missions in space. The four stations are designed to be un-manned and connected by a dedicated digital communication line to a central station, to monitor and control the equipment as not only four sets of SLR, but also as a single instrument of all four or more SLRs.

Keywords: SLR, Accuracy, Remote control, Space Geodesy

1. Introduction

The Key Stone Project (KSP) was initiated in 1993 by the Communications Research Laboratory to establish four state-of-art geodetic fiducial sites around metropolitan Tokyo, for monitoring site displacement very precisely by using space geodetic techniques of the Very Long Baseline Interferometer (VLBI) and Satellite Laser Ranging (SLR) systems. It aims to accurately see signs of major earthquakes with millimeter accuracy on displacement of station positions, namely, Kashima, Koganei, Miura and Tateyama. Figure 1 shows a schematic geography of the KSP stations.

The KSP SLR project is an extension of a research project of SLR for highly precise space- and- time measurements in an optical communication center[1] from 1989, and it also aims to apply monitoring a regular site displacement with increasing accuracy and higher automation. The design and construction of KSP SLR station started in 1995.

There are reviews and scope for the next generation of SLR[2][3][4], and actual projects for developing new SLR systems have been in progress in Italy[5], Germany[6] and Unites States[4].

KSP SLR system has incorporated a wide range of new technologies, including telescopes, domes, lasers, timing systems, calibration system as well as automation and remote control system.

This paper describes the KSP SLR system and some of new technologies utilized in KSP.

2. The Major Design Concept

2.1 Accuracy

Modern SLR has pursued ranging precision to 1 cm or better, thanks to instrumentation such as ultra-short pulsed laser and high speed detectors. However, the preci-

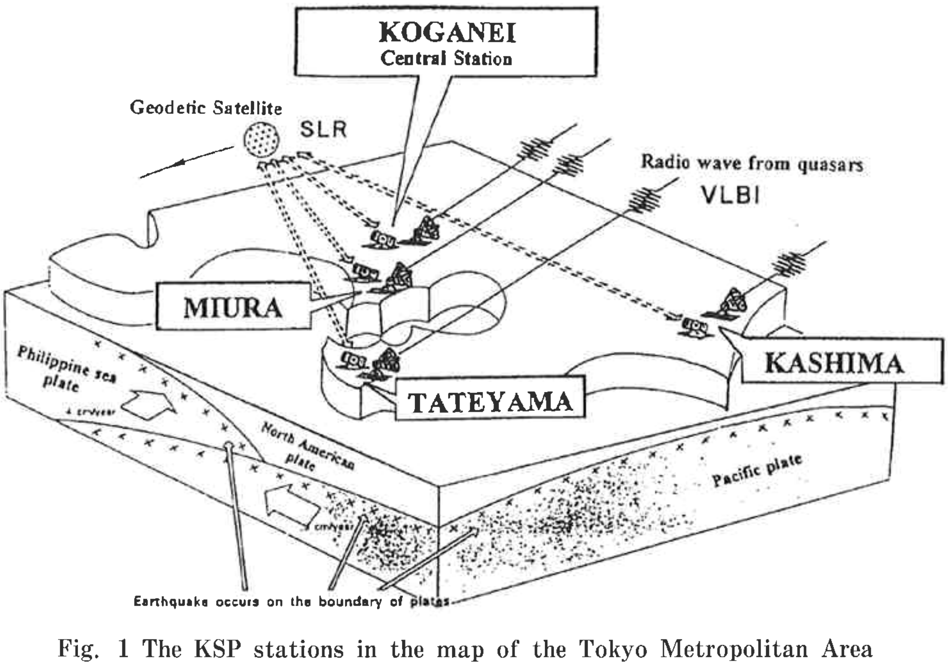

Fig. 1 The KSP stations in the map of the Tokyo Metropolitan Area

Table 1 Factors affecting SLR ranging accuracy

	Factors	Description
1	Instrument type and location	Record of station instrumentation / configuration and its change.
2	Survey accuracy	Survey accuracy between local (ground) target and instrumental reference point.
3	Accuracy of "geometric" corrections	Accuracy of "geometric" corrections that need to be applied. For example the "offset axis" correction when the telescope axes do not intersect, or the "parallax" correction needed when the ground target is very close, or the "Transmit/Receive" correction in single-telescope systems using a rotating mirror to switch between transmit and receive paths.
4	Optical and cable delays	Accuracy of determination of all the optical and cable delays within the system. Normally, it is the function of the calibration scheme, to calibrate these delays in their entirety, if symmetry of the system between calibration and satellites assumed.
5	Timing system accuracy	Timing system accuracy, whether it be a time interval counter or an event timer. For 1 mm ranging to geosynchronous satellite, the time base needs to be correct, not merely stable, to 3 parts in 10^{11}. Normal ground target ranging cannot cover the range of time intervals required, so additional calibration is required.
6	Accuracy of atmospheric corrections	Different models are needed between ground target ranging and satellite ranging. The accuracy of the meteorological sensors must be assured, especially for barometric pressure; they require periodic external calibration.
7	Environment effects	For example changing temperature affecting cable delays, timing system frequency, metal expansion in the telescope. Often, but not always, they are compensated by the calibration method.
8	Return signal characteristics	Especially signal strength level effects, detector jitter, discriminator walk, pulse rise times, wavelength filtering and detector response. Conventionally, whenever possible, all parameters are made equal for both ground target and for satellite ranging. But it is not always possible.
9	Configuration differences	Configuration differences between ground and satellite ranging, for example the parallax and T/R asymmetry referred to above, insertion of neutral density filters, altering detector power supply voltages or discriminator thresholds, etc.
10	Method of application of calibration results	Some systems can calibrate in real time and apply corrections shot-by-shot; others perform a session of ground target ranging once per hour and interpolate to each normal point epoch. The way that a representative value is computed is becoming important, too; A study on filtering methods and whether the mean, mode, or leading-edge half-max of the signal distribution should be adopted.
11	Eccentricity accuracy and stability	Eccentricity accuracy and stability, between the instrumental reference point and the fundamental mark.

sion represents an internal consistency of a set of measurements of the quantity, distance or range, commonly expressed as "single shot precision", i.e. rms deviation of separate measurements about their own mean value, and as "normal point precision", i.e. the rms deviation of the means of sub-sets of the measurements about their overall mean. Neither of these dispersion measures bears any necessary relationship to accuracy.

The accuracy, on the other hand, means the degree to which the measurement of a quantity agrees with its true value. It is affected by un-modeled or unknown systematic errors, and is often very difficult to assess. Referring to station performance(7) in the past and to on-line global orbit analysis on World Wide Web(8), uncorrected range bias and its instability are very difficult to control, as they are reported often varying over a few cm or more. Common, though imperfect, methods for assessing laser ranging accuracy include range bias results and agreement with ground target surveyed distances.

Table 1 lists the possible factors affecting SLR ranging accuracy.

The keys to preserve accuracy lead into design in the system are to provide picoseconds epoch timer and frequency source to ensure ultimate accuracy available, and to provide a redundant means to calibrate a system delay to check each other, by multiple reference targets and independent calibrators(9).

One of demonstrations for calibration of the four KSP SLR systems (except telescopes) were the experiment which they were collocated at one place and tested so that no bias among them produced(10).

We use a conventional model for atmospheric correction by single color observation, except for the system at Kashima which has an upgrade path for multiple wavelength ranging capability to asses atmospheric model error.

2.2 Automation

Since KSP demands the regular monitoring of site displacement with high-temporal resolution and the increasing number of missions and satellite for SLR in various fields, the system needs to be capable of continuous observation with maximum efficiency and tolerance as long as the weather permits. The station itself should be designed in an autonomous manner on a base of an option of local- and remote (via communication link)-manual operation. The key ideas and components in the design of KSP SLR which used to load a human activities are as follows:

(1) Sealed Dome

The possibility of down time due to the environment such as temperature and precipitation must be minimized. To keep the highest performance of the telescope and optics in a long run, KSP dome(11) is fully sealed and optical interfaced to outside by a ranging window made of high-quality glass. Because there is no possibility of weather intrusion, this reduces the mechanical corrosion in the dome, and to make it fail-safe during power failure.

(2) Diode Pumped Laser

We know from our experience that one of major component on which loads maintenance activities in SLR was the laser. Even in the present generation (referred commonly as the third generation) of SLR system which developed from 1980's to early 1990's, and mostly used an active-passive Nd:YAG Laser pumped by flash lamp, the laser needs to take a regular maintenance, typically once several weeks or more frequently. For the stable and high-performance of the laser with pulse shape and energy with longer mean time between maintenance break, we adopt the diode pumped laser as oscillator and regenerative amplifier(12) that has come to available.

(3) Eye-safe

The SLR, especially in urban area demands the operation in accordance with safety regulations. The typical laser used in SLR has a mode-locked high-power laser, of a class 3B or more(13), and has potentials of dangerous exposure in the beam out of the telescope. KSP SLR adopted an infra-red aircraft detection laser(12)(14), as a second laser superimposed in the ranging laser to prevent the laser beam from contacting aircraft and local personnel.

(4) Network and Software

The concept of SLR network has been developed in the last decades under international cooperation, ILRS (International Laser Ranging Service)(15). It includes stations, operation centers, analysis centers and the regional networks such as NASA (National Aeronautics and Space Administration) network, EUROLAS (European Laser Tracking Network) and WPLTN (Western Pacific Laser Tracking Network). The KSP SLR system has the function to interface to the ILRS. The KSP SLR system is designed to operate as not only four sets of SLR, but as a single instrument of all four or more SLRs by networking with each other.

It has an operation center in Koganei that controls and monitors all of the KSP stations using a 128-kbps communication network(16). Any status and operational parameters that affect the system accuracy and performance should be monitored and recorded by computer.

3. Overview and Specification of the KSP SLR

Figure 2 illustrates the KSP SLR system including the dome building and trailer box housing laser and electronics. The mobile trailer box (dimension: 7.5 × 2.4 × 2.2m) is adopted because all the electronics (except telescopes) can be moved to a remote place in a package or they can be exchanged/collocated with each other for the purpose of calibration or repair.

Major specifications for each subsystem are summarized in Table 2.

The system is capable of tracking satellites that altitude is from 300km to 36000km during night time and also day time.

The single shot and normal point precision for LAGEOS are 12mm and 2mm, respectively.

The system has capability of synchronous ranging which enable multiple stations simultaneous ranging to the same satellite providing another method of short arc solution and application such as to time transfer experiment(17).

Table 2 Summary of Specification for each subsystem

Sub-systems	Specifications	
Ranging Laser	Oscillator	Diode pumped YAG series 131, 100 MHz, 1064 nm (Lightwave)
	Regenerative amplifier	Diode pumped YAG(EOS) and Pockels-Cell pulse-slicer
	Amplifier	Flash lamp pumped 2-stage double passes (Spectra Physics)
	Wavelength	532 nm(Second harmonic of Nd:YAG 1064 nm)
	Energy	50 mJ/pulse (nominal)
	Pulse width	50 ps (FWHM)
	Repetition rate	10, 20 (nominal), 10, 50, 100 Hz
T/R optics	Focus	T/R Common Coude System
	T/R shutter	Optical
	Spectrum filter bandwidth	0.3 nm
	Beam divergence	Afocal(Diffraction limit), 30 arcsec (Max)
	Primary mirror	Diameter:75 cm, focal length:3186 mm, Aluminum coated
	Field of view at Coude focal point	Koganei: 40 arcsec, Others: 60 arcsec
	Transmitting efficiency (532 nm)	Kashima: 24 %, Others: 30 %
	Receiving Efficiency (532 nm)	Kashima:6%, Others: 7.5% (Before Detector)
	Guiding camera	General purpose camera: Wide view CCD camera Coude camera: integrated digital CCD (1 arc minute)
Telescope mount	Type	Azimuth-Elevation Mount
	Invariant point	Az-El orthognality: ±5 arcsec Offset: 0.1 mm rms
	Drive range	Azimuth: ±270 degree, Elevation: −20 to 90 degrees
	Drive speed	12 deg/sec
	Pointing precision	2.5 arcsec rms
Detectors	Type	Cooled silicon SPAD (Single Photon Avalanche Photodiode) and MCP (Micro Channel Plate)
	Quantum efficiency	20 % (SPAD)
	Bias correction for receiving amplitude	Correction model applied to SPAD output by amplitude information deduced by MRCS
Dome building	Dome type	Sealed Type, Azimuth-Rotor Drive
	Air conditioning	Temp:23±2 deg C, Humidity: 40 % Temp:23±1 deg C, Humidity: 40 % (Laser Room)
Timing system	Source of frequency and time (10 MHz and 1 PPS)	GPS Time Reciever: TrueTime XL-DC Hydrogen Maser (Anritsu)
	Epoch timer and controller	Vernier : 4 channel built in MRCS (Master Ranging Control System)
	Synchronous ranging	10 ns rms at a satellite
Ground targets	Type and number	Long pillar:3, Level pillar:2 , Short pillar (monument):3
	Structure	Pile under ground, Invar rod on the ground
	Survey	1.5 mm rms
Meteorological sensor	Temperature	±0.1 degree, 2 units:
	Barometer	±0.15 h Pa, 3 units
	Humidity	±2 %, 2 units
	Others	Precipitation sensors
Network	Type	Dedicated digital circuit (128 kbps) Data: 64kbps, Still picture: 64 kbps
Safety	Aircraft sensor	ADL (Aircraft Detect Laser)
	Surveillance TV camera	Four TV cameras
	Passive sensor	IR sensors (at doors and rooms)

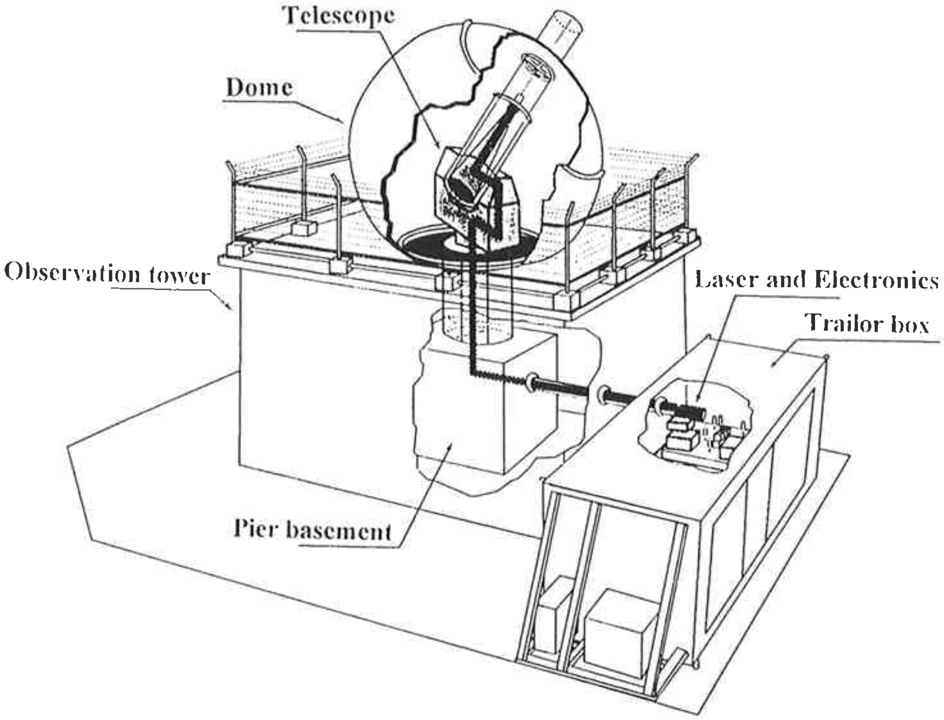

Fig. 2 Schematic view of the Keystone SLR system including the dome building and trailer box

4. Conclusion

The design and specification of the KSP SLR described here is not only requisites to fulfil the goal of KSP that monitors a fiducial points very accurately but also shows a long view of next generation of SLR where accuracy and automation are key word. The design represents also an advance in the technology to develop them in a given time schedule.

Since the project began in 1995 with contracts for four complete SLR stations, they were designed, manufactured and delivered in March 1996, and were starting to be integrated at Kashima and Koganei. The first optical link to the satellite was obtained at the end of 1996, then accuracy validation was performed in August, 1977 and continued test observation in engineering level. The four stations started to operate in September 1998.

Using the KSP SLR system as a geodetic calibrator, we are going to establish one of the highest accurate fiducial point by space geodetic techniques (GPS/VLBI/SLR) , and we would like to participate in a possible domestic and international program in the future.

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