LUNAR LASER RANGING EXPERIMENT AT KOGANEI SLR STATION. H. Noda[1], H. Kunimori[2], H. Araki[1,3], [1]National Astronomical Observatory of Japan (2-12 Hoshigaoka, Mizusawa, Oshu, Iwate, Japan. hirotomo.noda@nao.ac.jp), [2]National Institute of Information and Communications Technology (NICT) (Koganei, Tokyo, Japan), [3]National Astronomical Observatory of Japan (Mitaka, Tokyo, Japan).

Introduction: The Lunar Laser Ranging (LLR) measures the distance between laser stations on the Earth and retroreflectors on the Moon, by detecting the time of flight of high-powered laser emitted from the ground station. Since the Earth-Moon distance contains information of lunar orbit, lunar solid tides, and lunar orientation and rotation, we can estimate the inner structure of the Moon through orientation, rotation and tide [1,2]. There are five refroreflectors on the Moon, Apollo 11, 14, 15 (U. S. A.), Lunokhod 1 and 2 (french-made, carried by former U. S. S. R.). The Apollo 15 has largest aperture among them, and almost 75 % of the total LLR data are from Apollo 15 site.

The first Japanese lunar mission, Kaguya (SELENE), successfully orbited around the Moon in 2007-2009. As the successor of Kaguya, JAXA and collaborating scientists and engineers now prepare for the SELENE-2 landing mission [3]. Lunar Laser Ranging experiment is proposed to SELENE-2, and a large single retroreflector is under development [4]. In the context of preparation for SELENE-2, a ground station in Japan is also needed to range the new retroreflector as well as existing ones. Since there is no Japanese station which can range the Moon, a precursor ranging experiment by using the Satellite Laser Ranging (SLR) facility in the NICT Koganei campus in Tokyo is ongoing.

Status of current LLR observation: Currently, McDonald Observatory (Texas, U.S.A.), Observatoire de la Cote d'Azur (France), and the Apache Point Observatory (APO) (New Mexico, U.S.A.) range the lunar retroreflectors on a regular basis. Matera (Italy) and Wettzell (Germany) have ability to range the Moon, but ranging to the Moon is not operated regularly at both station. Haleakala station (Hawaii, U.S.A.) acquired LLR data during 1985 – 1990, whose data are used for analysis, but observation is not carried out now. Hartebeesthoek Radio Astronomy Observatory (South Africa) is refurbishing an ex-French telescope for the LLR observation in the near future [5].

The number of total normal point data as of the end of 2012 is more than 18,000 and has been increasing about 300 normal points per year. APO, which has the largest telescope for LLR use (aperture of 3.5 m), has been creating more precise LLR data than before.

As lunar parameters are determined through least square fit of the LLR data, more range data may contribute to the better estimation of the lunar parameters [6]. Also, since no lunar observation has been done in Asian region, Japanese LLR station may also contribute to improve the lunar parameters, considering the distribution of the ground stations on the Earth.

System description: The SLR station in NICT Koganei (Koganei, Tokyo) has a 1.5 m Cassegrain telescope with Coude focus. Normally it is equipped with a laser with 20mJ, 20Hz repetition rate and 35 picoseconds pulse width for satellite ranging. In addition to it, a wide-pulse width laser (3 nanoseconds, which corresponds to 45 cm in 2-way range) with energy of about 350 mJ per shot, repetition rate of 10Hz, wavelength of 532 nm is introduced to detect photons from the lunar retroreflectors. As the pulse width is broad, the high accuracy ranging is not expected, therefore it is solely used for the confirmation of the optical link budget between the ground station and retroreflectors on the Moon. As the photon detector, we use a SPAD (Single Photon Avalanche Diode) and also an MCP (Micro Channel Plate) photo multiplier whose quantum efficiency is twice as much as that of the SPAD in use. For the pointing, a CCD imager is also available in the same detector box. They can be switched by reflecting mirrors. To suppress the background noise, a bandpass filter (0.3 nm FWHM, 50 % transparency) and spatial filter (pinhole) with diameter of 400 microns are installed and checked. For better link budget, the contamation of optical elements of the telescope and on the optical bench were checked. The alignment of the laser emission path with respect to the laser receiving path and laser beam divergence has been adjusted to maximize the efficiency of the laser emission.

Test observation: Trials for the lunar return have been conducted since 2013. Because the retroreflectors are small and they are not visible from ground telescopes, we point the telescope to known small-sized craters (~10 km in diameter) whose positions are known in selenographic coordinate and thus in topocentric coordinate at the observation site (prediction files are available at the POLAC website http://polac.obspm.fr/PaV/index.html). Then the offset angles in azimuth and elevation direction from the predicted pointing direction are determined so that the center of the crater comes to the center of the CCD images which are coalligned with the SPAD and the MCP. This procedure confirms the pointing of the telescope. We first try to range Apollo 15 retroreflector when it is in the night time on the Moon, because it has three times as large aperture area than Apollo 11 and 14, and the background noise is assumed to be much smaller than in the daytime on the Moon.

Development plan: As of the date of submission, the ranging to the Moon is not successful. Therefore we need to detect the return from the Apollo 15 site by using the nanosecond laser pulse for the first step. As the next step, we need to know the condition on which lunar ranging is successful in Koganei, for example, lunar phase, distance to the retroreflectors, libration angles, and atmospheric conditions. Ranging toward other retroreflectors will be carried out. After accumulation such knowledge, we will introduce shorter pulsewidth laser for more precise ranging.

References: [1] Dickey J. O. et al (1994) *Science*, 265, 482. [2] Williams J. G. et al., (2013) *LPSC* Abstract #2377. [3]Tanaka, S. et al (2013) *JpGU,* Abstract #PPS23-P10. [4] Araki, H. et al. (2013) *JpGU*, Abstract #PPS23-13. [5] Combrinck L. and R. Botha (2013) *18th International Workshop on Laser Ranging*, Abstract #13-0504. [6] Noda, H. et al. (2013) *JpGU*, Abstract #PPS03-01.