Development of Laser Measurement to Space Debris at Shanghai SLR Station

Zhang Zhongping, Deng Huarong, Tang Kai, Wu Zhibo, Zhang Haifeng

(Shanghai Astronomical Observatory of Chinese Academy of Sciences)

zzp@shao.ac.cn

Abstract

Shanghai SLR station which is one station among International Laser Ranging Network has realized the technology of laser measurement to space debris in 2008. According to characteristics of laser echoes from space debris and the experiences of practical measuring activities, the improvements of laser system, laser detector and spectrum filter are performed for laser detection to space debris. The significant achievements have been made with the routine measurement to space debris and the measured distance is from 500km and 2600km with Radar Cross Section (RCS) of >10m^2 to <0.5m^2. The development of laser measurement to space debris are underway, such as the near infrared wavelength laser signal, multi-telescopes receiving laser echoes, SNSPD technology, in order to make the better performance of laser ranging to space debris.

1 Introduction

With development of global space technology, more and more spacecrafts are launched into space and lots of space debris orbiting the Earth, such as rocket bodies, unused satellites, debris from collision between spacecrafts, is produced. Space debris has become the vital factors threatening the safety of active spacecrafts on orbit for all space-faring nations in recent decade years [1]. High precision measurement and accurate catalogue for space debris are required for any effort towards debris surveillance and collision avoidance [2]. The space-active countries in the world make great efforts to reduce space debris in cooperation with international community and provide the supports to develop kinds of high precise measuring techniques for reliable and accurate catalogue of space debris to avoid collision.

Among the techniques of observing space debris, laser ranging technology is one kind of real time measurement with the precision of decimetres, higher one or two orders of magnitude than microwave radar and optical-electrical telescope. In the past years, several countries in the world, such as Australia, Austria, France, China, have been doing researches on laser measurement to space debris [3-4]. As the new application of laser technique, Shanghai Astronomical Observatory (SHAO) of Chinese Academy of Sciences (CAS) has been developing the technology of laser measurement to space debris since 2006 and the first experiment of laser measurement to space debris was successfully performed at SHAO in July 2008[5]. During the past nearly ten years, laser ranging system have been upgrading and the ability of measuring space debris is also increased obviously [6-7]. Since 2014 , the new set of 532nm wavelength laser system with the output power of more than 60W at 200Hz repetition rate was installed in SHAO and the low dark noise APD detector and narrow bandwidth spectral filter were also applied for increasing the ability of laser echoes detection. The more achievements have been made through adopting these system configurations to verify the feasibility of applications of laser measurement system in high accuracy of laser-measured space debris orbit.

2 Laser measurement system updated for space debris laser ranging

2.1 High power laser system with 200Hz repetition rate

The laser echo signals from space debris are reflected as the way of diffuse reflection and the laser signal strength received by detection system on the ground is very weak, so the high power laser system with good beam quality, narrow divergence, is very important for collecting enough echo signals from space debris, especially for observing targets with the far distance and small size.

The lamp pumped laser system with low repetition rate was used during 2008-2012 in SHAO. Limitation of its working mode and the performances of high stability, it is very difficult to be achieved while increasing its output power. The high pulse energy will easily make the components (laser system, transmitting optical mirror) more damageable. So for high power laser system, the optimized way of realization is to increase the repetition rate and decrease the pulse energy.

With increasing repetition rate of laser system, the amount of dark noise of detector is also increased more and that will affect the detection of weak laser echo signal from space debris. While using low repetition rate laser system, the output power of laser and number of echoes will be limited and decreased. Hundreds of hertz of laser system may be more suitable for measuring space debris. The experiments of laser measurement to space debris by using the demonstrated 200Hz repetition rate laser system of ~50W have been performed in SHAO in 2013[7] and the excellent measuring results have been obtained.

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In 2014, one new set of 200Hz repetition rate laser system with the power of more than 60W, made by domestic institute is installed in SHAO. The main performances of laser system are as following:

1) Power: >60 W
2) Wavelength: 532nm
3) Pulse width: =8ns
4) Precision of pointing: =50μrad
5) Beam quality(M^2): =3.5

Figure 1 shows the optical principle of laser system and figure 2 gives the setup of high power laser system and laser beam.

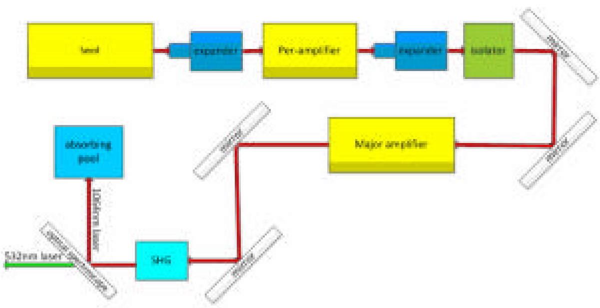

Figure 1 The optical principle of laser system

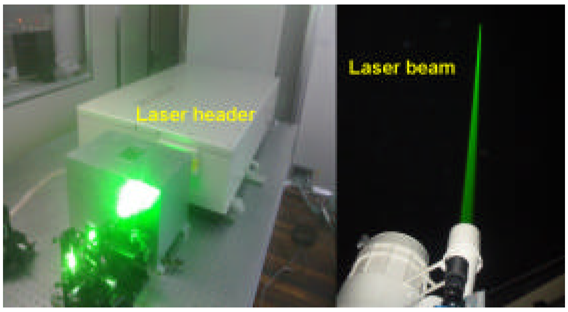

Figure 2 The new set of high power laser system and laser beam

2.2 Low dark noise APD detector

The high power laser system helps to solve number of laser returns from space debris. But two key problems for laser measurement to space debris still exist:

1) Not good precision of orbit prediction. It is difficult to acquire targets and make range gate control.

2) Noise from background and detector. For hundreds of hertz of laser system the dark noise still higher orders of magnitude than that of low repetition rate.

For increasing the ability of measuring space debris, especially for farther and smaller space debris, it is vital to reduce the level of noise detection to make large scale of range gate adjustment and obtain laser returns with high ratio of signal to noise.

During the previous experiments of measuring space debris, the high precision of SPAD detector was used and its dark noise is high for high repetition rate.

The low dark noise APD detector with high detecting efficiency is adopted in SHAO for detecting laser echoes from space debris. Its main performances are following.

1) Diameter of Chip: 500um;

2) Dark noise: 18kHz@ 200Hz;

3) Detecting efficiency: >40%@532nm

Figure3 shows the principle of APD detector and the relation of detecting efficiency to wavelength of light. The detecting efficiency is more than 40% for 532nm wavelength laser signal. The equipment of APD detector shown in Figure4 has made the great contribution to laser echo detection from space debris.

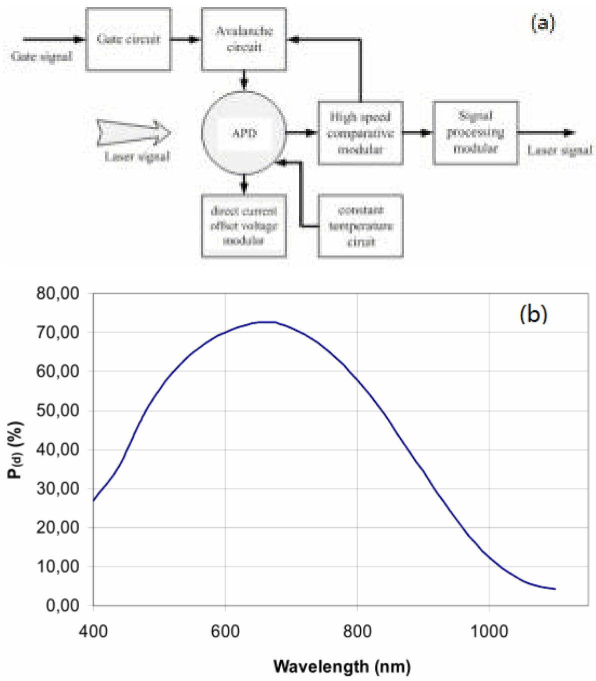

Figure3 The principle of APD detector (a) and detecting efficiency vs. wavelength of light (b)

Figure 4 The equipment of APD detector

2.3 Narrow bandwidth spectral filter

Through using APD detector, the dark noise can be decreased. But the noise from sky and targets also make some influences on laser detection because of high detection efficiency. The narrow spectral filters are commonly used for decreasing the level of background noise in laser measurement system through utilizing the mono-chromaticity of laser signal. For that, the high efficiency narrow bandwidth spectrum filter is adopted to reduce the strength of background noise. The main characteristics of the filter are following and Figure 5 gives the transmissivity of narrow bandwidth spectral filter.

1) Center wavelength: 532nm;

2) Band width:±1nm;

3) Transmittivity (532m light): >90%.

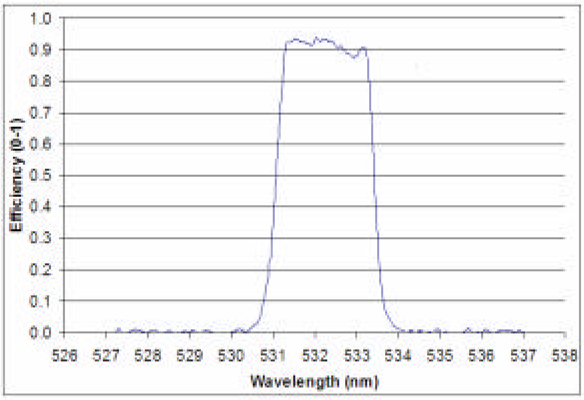

Figure5 The transmissivity of bandwidth spectral filter

3 Results of Laser measurement to space debris from SHAO in 2016

The new set of 200Hz repetition rate laser system provide the excellent laser signal source, and the APD detector and spectral filter effectively reduce the influences of the noise on laser echoes detection. All of the above components are key factors for laser measurement to space debris. With these configurations and the existing laser tracking system with the aperture of 60cm telescope and 5 microradian tracking precision, the laser measurement campaign was performed by using TLE orbit prediction to further promote development of the high precise laser measurement technology since 2015. The measuring results, more than 300 objects (Rocket body, Radar Calibration objects, and Debris targets) with total of 800 passes of laser data, were obtained for space debris. Figure6 gives range residuals of one pass of laser data from debris of SCOUT_R/B with NORAD 02180, RCS 0.6 m^2, 359 laser echoes within 1.41 minutes and the measured distance between 1000 km to 1130 km.

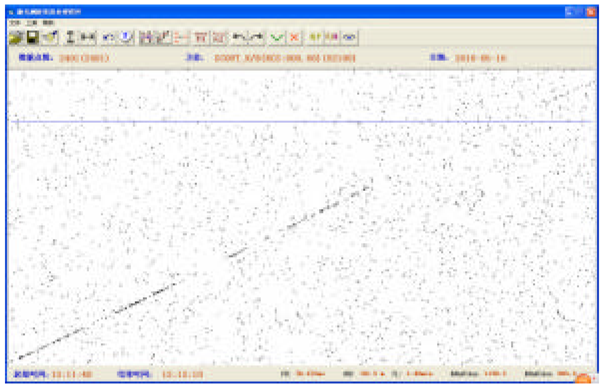

Figure6 The range residual of debris of SCOUT_R/B (NORAD 02180)

Among the measured targets, the measured distance is from 500 km and up to more than 2600 km, RCS from >10m^2 down to < 0.5 m^2 (Figure 7). Up to 42 passes of targets were successfully tracked during a single evening session and hundreds of laser echoes were collected in the most passes. Laser tracking of space debris in SHAO can routinely be performed from the measured results.

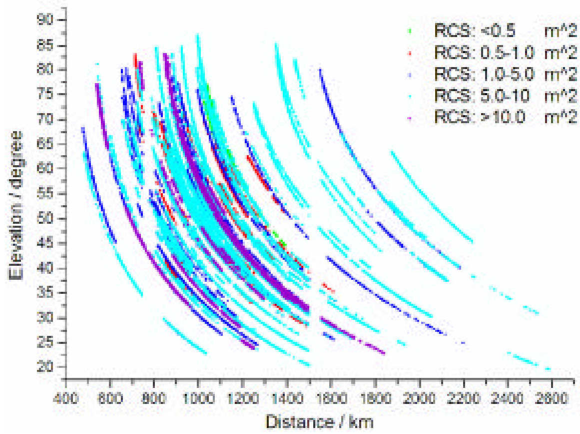

Figure7 The distance of measured targets vs. elevation for different radar cross section

The advantages of laser measurement technology present the data precision. Due to the pulse width of laser signal, detecting precision of detector, irregular size of targets, the measuring precision of laser data will be at the level of meters or sub-meters which has the relations to size of targets under certain configurations of laser system and detector. Figure8 shows the relations of precision vs. radar cross section derived from the measured data.

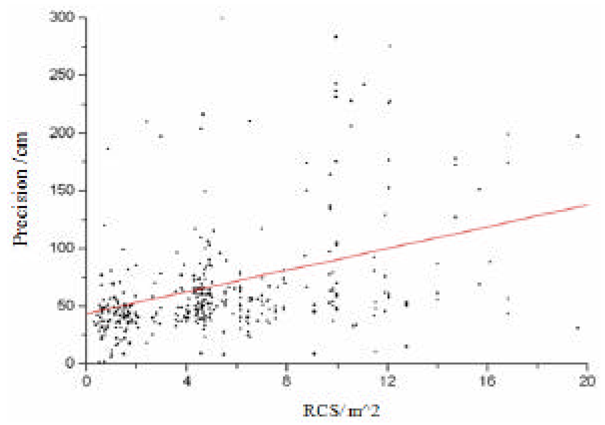

Figure 8 The measuring precision of laser data vs. Radar cross section of space debris

The measuring precision of laser data shown in Figures 8 appears the obvious relation to the radar cross section of objects because of irregular shapes and rotation. The precision of laser data will be within 1 meter for most of targets with RCS of < 10m^2. Even though for large RCS, the precision of laser data will be not over 3 meter which is still higher one order magnitude than that of general microwave radar and optical-electrical telescopes.

4 Developments of laser ranging technology for tracking space debris

4.1 Near infrared wavelength laser measurement to space targets

Compared to the green laser signal, the near infrared laser has higher laser power, less atmosphere attenuation and weaker background light in daytime. For subsequent application in debris laser ranging, some experiments are done at Shanghai SLR station. Figure 9 shows the ranging result by using 1064nm laser signal seen in the lower left corner for monitoring the laser pointing.

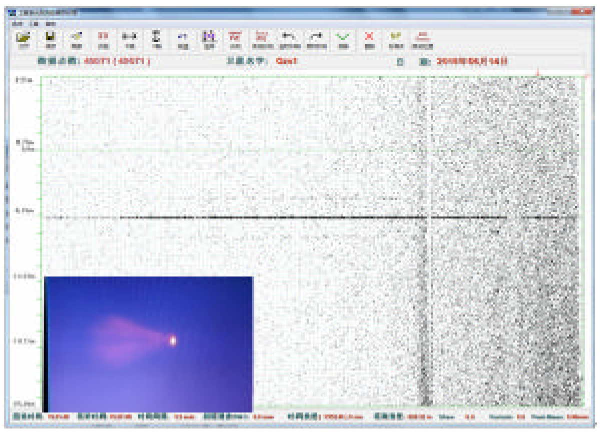

Figure 9 The measuring results from Qzs1 satellite by using the 1064nm wavelength laser signal

4.2 Multi-telescopes to receive laser echoes

For laser measurement adopting large aperture of telescope will help to increase the ability of detecting laser echoes from the far distance and small size targets. According to laser link equation the number of laser echoes received by one large aperture of telescope can be equivalently achieved by using multi-telescopes.

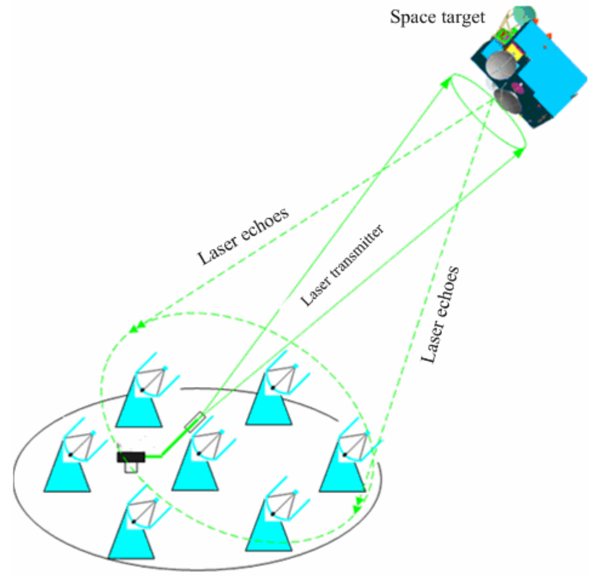

Figure10 The multi-telescopes to receive laser echoes

Through updating the receiving system for laser measurement at 1.56m aperture of astronomical telescope about 50m far from 60cm SLR station in Shanghai SLR station, the demonstrated experimental system based on 1.56m/60cm dual-receiving telescopes is established to provide the platform for studying on the technology of multi-telescopes receiving laser echoes to verify the feasibility of the equivalent receiving ability produced by one large telescope.

4.3 Superconducting Nanowire Single Photon Detection in laser ranging

As the development of laser ranging technology in space debris observation and weak echo signal detection, the requirements of detectors with performances of lower dark current, higher quantum efficiency are put forward. The superconducting nanowire single-photon detector (SNSPD) has become one of most competitive detectors, because of its outstanding performances of wide spectral response range, high detection efficiency (75%) and low dark count rate (0.1Hz), as well as small timing jitter (60ps). For validating the feasibility of SNSPD in laser ranging, the breadboard SNSPD have been made with the cooperation of the institute of Chinese Academy of Sciences and the trial-SLR measurements have been performed through Shanghai SLR station. The principle and major performances of SNSPD and preliminary measuring results are performed in laser ranging and the measuring results can be seen from figure 11 for Glonass-122 satellite. It is expected that the SNSPD detector can held the position in SLR with the continual improvement of SNSPD techniques.

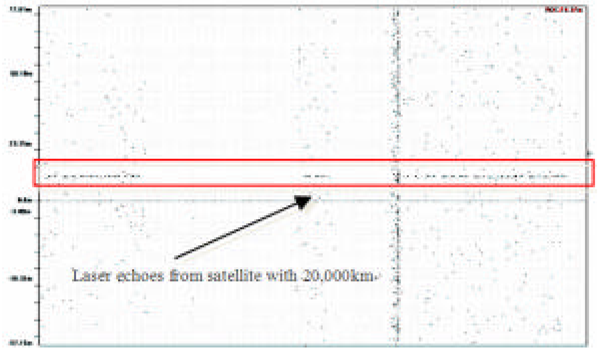

Figure 11 The measuring results for Glonass122 satellites by using SNSPD detector

5 Summary

Through updating laser measuring system at the aspects of high power laser system, APD detector and narrow band filter, the new achievements have been made to further develop the technology of laser measurement to space debris in SHAO. With the laser power of 60W@200Hz at the 532nm wavelength and aperture of 60cm telescope, the hundreds of passes of laser data from space debris were obtained in the distance between 500km and 2600km with RCS of from>10m2 to <0.5 m2 and the success rate of measured passes of 80%. Up to 42 passes could be measured within one evening session by using TLE orbit prediction and the precision of laser data relative to size of space debris is also acquired and the average precision is less than 1m RMS. It is referred from the new measuring results that the ability of laser measurement to space debris in SHAO has been increased more. It can also be as the essential high accuracy measurement orbital technology in the future activities of space debris surveillance. Some developments, such as infrared laser of ranging, multi-receiving telescopes of ranging and application in SLR are expected to improve the ability of debris laser ranging in SHAO.

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