

## Postprint: Design and Implementation of a Single-Transmit-Multiple-Receive Laser Ranging System at Yunnan Observatories

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### Abstract

Ultra-weak signal detection technology is of significant importance for deep-space laser ranging and space debris laser ranging. This study has researched and implemented a kilohertz-rate one-transmitter-multiple-receiver laser ranging technology, encompassing optical path design and implementation as well as computer control system development, and applied this technology to the laser ranging system at Yunnan Observatory for validation. The results demonstrate that the system operates normally and has successfully achieved one-transmitter-two-receiver laser ranging for medium- and high-orbit satellites.

### Full Text

## Design and Implementation of Single-Transmitting and Multiple-Receiving Laser Ranging System at Yunnan Observatory

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### Abstract

Extremely weak signal detection technology is of great significance for deep space laser ranging and space debris laser ranging. This paper presents the research and implementation of a kilohertz-rate single-transmitting and multiple-receiving laser ranging technique, including optical path design and implemen-

tation as well as the development of a computer control system. The technology was applied to and verified through the laser ranging system at Yunnan Observatory. The results demonstrate that the system operates normally and has successfully achieved single-transmitting and twin-receiving laser ranging for medium- and high-orbit satellites.

**Keywords:** Laser Ranging; Single-transmitting and twin-receiving; kHz laser ranging; Single photon detection

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## 1. Introduction

Satellite Laser Ranging (SLR) determines the distance  $r$  between a ground station and a satellite by precisely measuring the round-trip time interval  $t$  of laser pulses traveling between them [?]. The Yunnan Observatory established a high-precision 1.2-meter alt-azimuth telescope for satellite laser ranging and officially joined domestic and international SLR networks in the same year. Supported by the China Mainland Environmental Deformation Monitoring Network, the system achieved a ranging frequency of 1-10 Hz with single-shot precision better than 3 cm. In 2010, a 10 Hz diffuse-reflection laser ranging system was successfully implemented on the 1.2-meter telescope, and echo signals from space debris were received for the first time [?].

Because laser beams reflected from space targets exhibit divergence when returning to ground stations, the laser pulses are distributed over a certain area on the ground—ranging from hundreds of meters to kilometers for targets with retroreflectors, and even hundreds of kilometers or more for debris. During laser ranging, any receiving telescope within this distribution area can detect echo photons. This characteristic enables the use of multiple telescopes to simultaneously receive laser echo photons, thereby increasing the probability of successful photon detection.

## 2. Optical System Design

### 2.1 1.2-meter Telescope Optical Path

The 1.2-meter telescope's co-optical-path laser ranging transmit-receive optical system operates as follows: Laser output from the laser source is reflected sequentially by plane mirrors to the telescope's secondary mirror, then expanded by the primary and secondary mirrors before being transmitted toward the space target. The small portion of photons reflected back from the space target returns along the same path to mirror M, then transmits directly to beamsplitter M, which reflects them into a beam reduction system before entering the single-photon detector (C-SPAD) [Figure 1: see original paper].

## 2.2 53 cm Binocular Telescope Optical Path

The 53 cm binocular telescope's split-path laser ranging transmit-receive optical system works similarly: Laser output passes through plane mirrors E, B, and A to the telescope's secondary mirror, undergoes expansion by the primary and secondary mirrors, and is transmitted to the space target. Reflected photons entering the binocular telescope are received by its primary and secondary mirrors, then reflected to a beamsplitter, followed by mirrors and a beam reduction system before reaching the single-photon detector (C-SPAD) [Figure 2: see original paper][Figure 3: see original paper].

## 3. Computer Control System

The laser ranging computer control system primarily comprises the telescope control system, laser, single-photon detector (C-SPAD), and event timer (ET). The 1.2-meter telescope co-optical-path system and the 53 cm binocular telescope system use separate lasers. Key parameters are listed in .

**Table 1. Laser Parameters**

Laser Parameter	1.2 m Telescope System	53 cm Binocular Telescope System
Energy (mJ/pulse)	[value]	[value]
Divergence Angle (mrad)	[value]	[value]

Two operational modes enable single-transmitting and twin-receiving ranging: (1) the 1.2-meter telescope transmits while both telescopes receive, or (2) the 53 cm binocular telescope transmits while both receive.

### 3.1 1.2-meter Telescope Transmitting Mode

In this configuration, a rotating shutter generates synchronization signals. Both telescopes track the space target synchronously based on orbital prediction data. The control computer generates a laser firing command at the rising edge of the sync signal. A PIN detector captures each transmitted laser pulse and outputs a start pulse to both the event timer and control computer. The red dashed line in [Figure 4: see original paper] represents the coaxial cable transmitting the 1.2-meter telescope's start signal to the 53 cm binocular telescope system. Upon receiving the start signal, the control computer calculates the predicted echo arrival time based on target orbital distance data and sends this to a range gate generator, which provides a gate signal to the C-SPAD just before echo arrival. Detected echoes are sent to the event timer for epoch recording, while the control computer acquires measurement data for real-time signal identification and display [Figure 4: see original paper].

### 3.2 53 cm Binocular Telescope Transmitting Mode

In this mode, the 53 cm laser operates with internal triggering. Both telescopes synchronize tracking based on orbital predictions. The PIN detector captures transmitted pulses and outputs start signals to the event timer and control computer. The red dashed line in [Figure 5: see original paper] shows the coaxial cable carrying the 53 cm telescope's start signal to the 1.2-meter system. After receiving the start signal, the control computer computes predicted echo arrival times for the range gate generator, which gates the C-SPAD. Echo signals detected by the C-SPAD are recorded by the event timer, and the control computer processes the data for real-time identification and display [Figure 5: see original paper].

## 4. Experimental Results

Single-transmitting and twin-receiving laser ranging experiments were conducted successfully, obtaining clear echo signals. [Figure 6: see original paper] shows control interface screenshots during ranging to the Ajisai-6 satellite at 4-5 thousand kilometers altitude, with Figure 6: see original paper displaying echoes received by the 1.2-meter telescope and Figure 6: see original paper showing those from the 53 cm binocular telescope.

[Figure 7: see original paper] presents results when the 53 cm binocular telescope transmitted and received echoes from high-orbit satellites: Figure 7: see original paper shows Compass-I3 satellite echoes received by the 1.2-meter telescope, while Figure 7: see original paper shows Galileo-201 satellite echoes received by the 53 cm telescope at approximately [distance] thousand kilometers.

The kHz single-transmitting and multiple-receiving control system effectively ranges space targets. Results with the 1.2-meter telescope transmitting [Figure 6: see original paper] indicate its system efficiency is significantly lower than the 53 cm telescope's, requiring mirror recoating to improve optical efficiency. Nevertheless, the 1.2-meter telescope successfully detected echoes from a 20,000 km laser satellite despite lower reception efficiency. The 53 cm binocular telescope transmitting mode achieved ranging data for debris within 2,000 km.

## 5. Conclusion and Future Work

Observations demonstrate that the system operates effectively. The next step will implement single-transmitting and twin-receiving ranging experiments for space debris, using either the 53 cm binocular telescope to transmit with the 1.2-meter receiving, or vice versa. The laser has already successfully obtained debris measurement data, providing a solid foundation for future work.

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