A Laser Ranging System Using Chaotic Light

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Abstract – A novel laser ranging system using chaotic laser as probe light source is designed and presented. The system is made up of five components: chaotic light source, transmitter, receiver, data acquisition unit and data processing unit. Chaotic light is generated by an 808 nm, 500 mW, single-mode laser diode with optical feedback cavity. Single target detection and multi-target detection are experimentally realized by correlating the chaotic reference light and the reflected or backscattered probe light. The performances, including the resolution of 18 cm within at least 130 m range and the sensitivity of −20 dB, are achieved and analyzed.

Key words* – *laser ranging; chaotic laser; optical feedback; laser diode

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Laser ranging technique has wide applications in military and civil fields[1-4]. In the traditional laser ranging setup, its light source is usually performed with either a short-pulse laser or a modulated Continuous-Wave (CW) laser. For the short-pulse technique, the distance is obtained by measuring the time-interval of the light pulse from transmitting to receiving, known as the time-of-flight method. The spatial resolution, limited by the pulse-width and the receiver's bandwidth[5], is typically in the range of meters. Long-range measurements (e.g., lunar[6] or planetary ranging) can be achieved by using high-peak-power short-pulse laser. However, some drawbacks of this technique are evident, such as high price, large size and inconvenience of operation.

In comparison, the modulated CW technique, utilizing an external modulator to modulate the phase of CW laser, is developed in many fields. The light reflected or scattered from the target shifts in phase compared with the transmitting light, which is just proportional to the distance between the transmitter and the target. But the resolution is determined by the bandwidth of modulated waveform[5]. Besides, the problem of interference from the same systems involves a great many difficulties for both of short-pulse and modulated CW techniques. Takeuchi et al. proposed[7] Pseudorandom code modulating CW lidar, which can eliminate the interference by each system's unique code. But limited by the modulation speed and pseudorandom code rate, so expensive random-code-generator becomes necessary in order to achieve high spatial resolution.

A laser diode has been found to emit the ultra-wideband chaotic light characterized by the noise-like waveform and the δ-function-like correlation trace by means of either direct-modulation[8,9], optical injection[10], optical feedback[11,12], or optoelectronic feedback[13]. In 2001, range measurement using a chaotic laser was first proposed by Myneni et al[14], and then the concept of the chaotic lidar was proposed and a proof-of-concept experiment was designed by Lin et al[15]. The chaotic laser is split into the probe light and reference light and the range can be achieved by correlating the reference light with the delayed probe light reflected or backscattered from the target. Benefiting from the broad bandwidth of the chaotic laser, the high spatial resolution is obtained easily. Furthermore, this technology is highly resistant to mutual interference from a similar system since the laser source produces a unique chaotic laser signal.

In this paper, a practicable range-finding system is constructed by utilizing a laser diode with optical feedback as the light source. Capabilities of single target and multi-target detection of the designed system are tested. Its spatial resolution, maximum detection range and sensitivity are analyzed experimentally.

1 System composition

As shown in Fig. 1, the chaotic laser ranging system consists of five components: chaotic source, transmitter, receiver, data acquisition unit and data processing unit. The chaotic light generated by the chaotic source is split into the reference light and the probe light via a Beam Splitter (BS). The reference light is focused by a converging lens and detected by a Photodetector (PD). The probe light is transmitted to the target through the transmitter. The reflected or backscattered light is collected by the receiver and detected by another identical PD. Two

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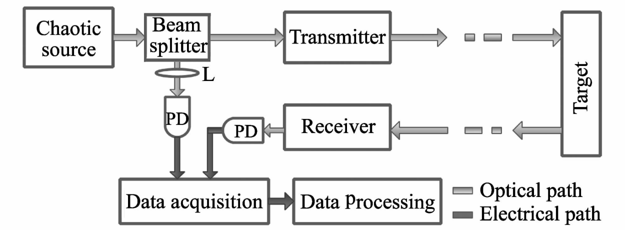
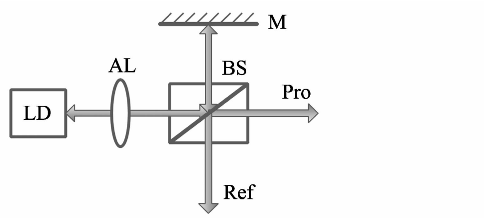
converted electrical signals are stored by the data acquisition unit. In the data processing unit, the reference light and the echo probe light are correlated, and the target position is achieved from the position of the main peak of the cross-correlation trace.



L: converging lens; PD: photodetector

Fig. 1 Block diagram of the chaotic laser ranging system

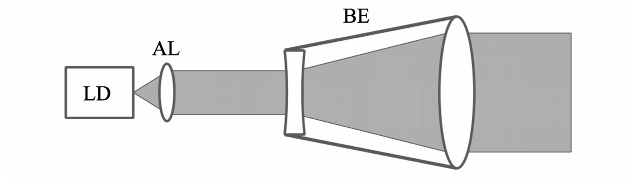
A laser diode with external optical feedback cavity is utilized to realize the chaotic laser source. As shown in Fig. 2, the chaotic laser is generated by an 808 nm, 500 mW, single-mode Laser Diode (LD, LT-LD80500) with optical feedback from a silver-coated Mirror (M) with 96% reflectivity. The mirror is placed at a distance of 10 cm from the LD to reduce the system's size, and the feedback strength can be adjusted by a diaphragm. The R/T ratio of the beam splitter (Newport 05BC16NP. 6) for 808 nm is 30: 70. Therefore the maximum feedback strength is about 9% if the reflective mirror is totally reflected, excluding the loss of the Aspheric Lens (AL, Thorlabs A414TM-B). The chaotic light output is collimated by the AL and split into the reference light and the probe light by the BS. The characteristics of chaotic light emitted from the chaotic laser depend on the controllable operational parameters, i. e., the pump current, the optical feedback strength and the delay time of the feedback.



LD: Laser Diode; AL: Aspheric Lens; BS: Beam Splitter; M: Mirror; Pro: Probe Light; Ref: Reference Light

Fig. 2 Schematic setup of the chaotic source

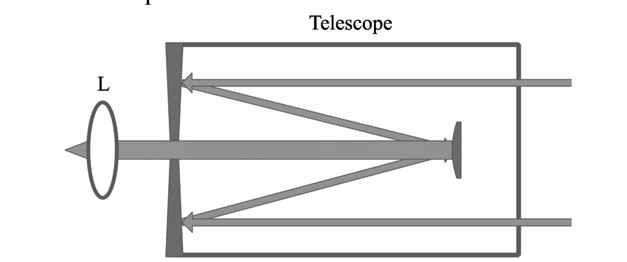
Fig. 3 shows the schematic setup of the transmitter. The transmitter consists of two parts: the collimating lens and the beam expander. The angles of divergence of the laser diode in the system are 10° and 40°, and the collimating lens is just the AL in the chaotic source, with N-SF57 glass, 650 ~ 1 050 nm anti-reflected coated, 0.47 numerical aperture and 3.30 mm effective focal length. After collimation, the laser coupling efficiency is 86.06% with 12.8 and 1.93 mrad divergence angles. It is still broad for applying into practice so the Beam Expander (BE, Thorlabs BE10M-B) is necessary, with 10 times magnified and 650 ~ 1 050 nm anti-reflected coated. Through the BE, the angles of divergence are compressed to 0.48 and 1.25 mrad which are good enough for the ranging system.



LD: Laser Diode; AL: Aspheric Lens; BE: Beam Expender

Fig. 3 Schematic setup of the transmitter

The receiver is an important part of the laser ranging system, which critically influences the overall performance. Fig. 4 depicts the schematic setup of the receiver. A Maksutov-cassegrain telescope (BOSMA- β) is applied into our chaotic laser ranging system with 9 cm receiving aperture and 1.2 m focal length. As shown in Fig. 4, the echo light is collected by the telescope and eventually converged by a lens to the photosensitive surface of the detector.



L: converging lens

Fig. 4 Schematic setup of the receiver

In our chaotic laser ranging system, two photodetectors (Electro-Optics Technology EOT-2030) have 1.2 GHz bandwidth and 0.4 A/W at 808 nm peak response. Waveforms of the reference signal and the echo probe signal detected by two PDs are displayed and recorded on a digital phosphor oscilloscope (Tektronix TDS-3052) with 500 MHz bandwidth and 5 Gs/s sampling rate. The communication between the oscilloscope and the computer is achieved via a GPIB card and a data cable (Agilent 82357B); the data processing of the cross-correlation, calculated by the computer; the real-time ranging, carried out by the assistance of the platform of LabVIEW.

2 Experimental results

In experiments, the LD was biased at 200 mA (1.4 I_{th}, could reach 2.8 I_{th} with chaotic state if needed) with 70 mW (18 dBm) output power and the temperature was stabilized at 25 ℃. Chaotic laser could be emitted at feedback strength of 9% (−10.4 dBm) or even lower in our ranging system. The time series, power spectrum, phase portrait and auto-correlation trace of the experimental chaotic state are shown in Fig. 5(a) ~ (d) respectively. Theoretically, it can be readily derived that the spatial resolution of the proposed chaotic laser ranging method is determined by the Full Width at Half Maximum (FWHM) of correlation curve according to −3 dB criterion. As shown in Fig. 5(d), the FWHM is 1.2 ns corresponding to 18-cm resolution, and the Peak Sidelobe Level (PSL, the ratio of the maximum sidelobe to the peak of the correlation trace) is −8.49 dB.

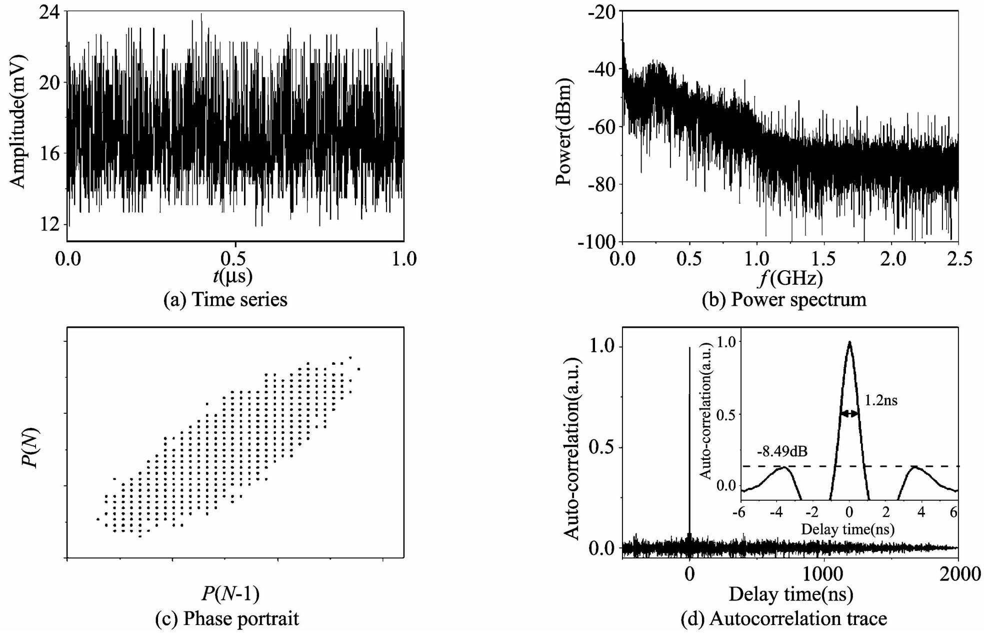


Fig. 5 Chaotic states of the signal

Naturally, the resolution is determined by the bandwidth of the chaotic laser signal because the autocorrelation function and power spectrum are Fourier transform pairs in mathematics. The high resolution indeed benefits from the broadband advantage of the chaotic light. In practice, the resolution is limited by sampling rate and bandwidth of the data acquisition unit. In fact, tens of centimeters of the resolution is sufficient for practical target detecting and can be obtained with only several hundreds MHz of detection bandwidth. In the experiments, we obtained 18 cm resolution shown in Fig. 5(d) only with bandwidth of 500 MHz and sampling rate of 5 GS/s. Thus, increasing bandwidth and sampling rate of the telectric devices provide a significant improvement in performance.

Before ranging, the zero reference position was calibrated at receiver's surface by calculating a near target, as the distance between them having been known already. The cooperative target was placed at about 40, 80 and 130 m away from the zero reference point to demonstrate the capability of the system for locating a target. From the cross-correlation traces shown in Fig. 6, we can see clearly that three peaks are located at a distance of 39.69, 79.67 and 131.70 m, respectively. And the FWHM of the peak of the target placed at 131 m is 18 cm. It is found that the power of the probe light and the peak values of correlation traces decreased with the reduction of the received light strength, while the 18 cm spatial resolution was not influenced by the distance and atmosphere. Obviously, the maximum detection range of the system was influenced by the output power of the laser, sensitivity of the receiver and dissipation of the transmission medium.

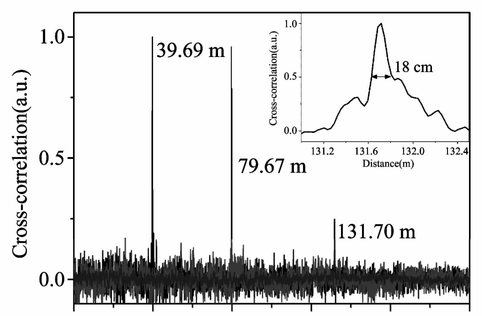


Fig. 6 Cross-correlation traces of each single target at 39.69 m, 79.67 m and 131.70 m. The inset shows the FWHM of the peak of cross-correlation trace at 131.70 m

Furthermore, we designed an experiment to demonstrate the capability of the system about multi-target real-time ranging. In the experimental arrangement, three mirrors at different places reflected part of the expanded probe light to the receiver. We see clearly thau three targets were located at 2.01, 2.58 and 3.00 m away from the zero reference point in Fig. 7. The results are in accordance with the experimental arrangements. A 3-dB criterion is set to distinguish the targets from the ground noise of the correlation traces. That is, a target can be regarded as existent if the peak value of the cross-correlation trace is above 3 dB. So the PSL of the correlation trace must be lower than −3 dB, or else the peak will become "ghost peak" which may cause misjudgment. Thus the target at 3 m is just distinguished in Fig. 7 due to the reduction of the detecting strength of the reflected light.

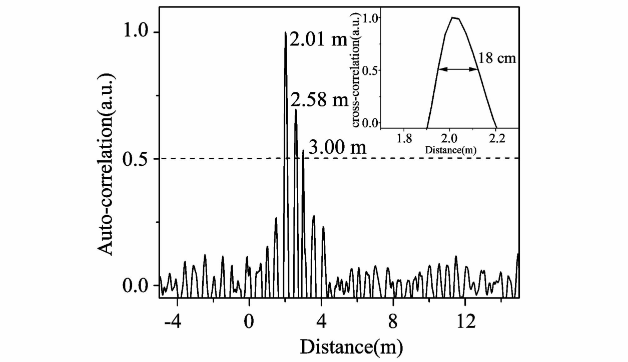


Fig. 7 Cross-correlation trace of three targets. The inset shows the FWHM of the peak of cross-correlation trace at 2 m

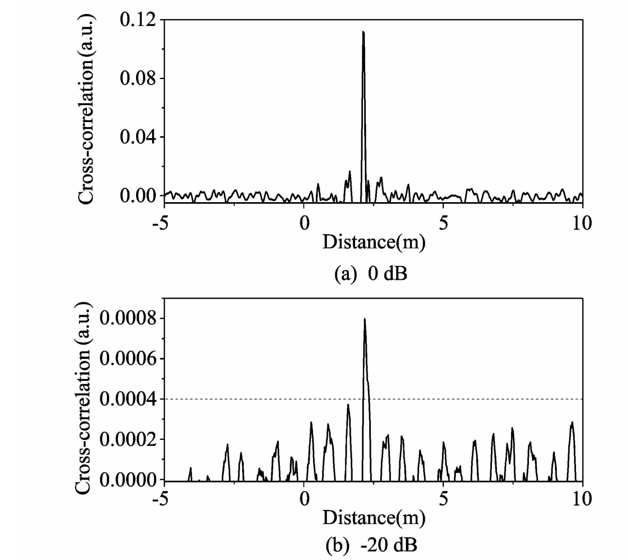


Fig. 8 Cross-correlation with different attenuation of received light's strength

The relationship between the PSL and the strength of the received light is analyzed to acquire the sensitivity of this system. In the experiment, a variable neutral density filter was addee behind the BS to acquire the sensitivity of this system. As shown in Fig. 8, the PSL increases with the received signal closed to noise and reaches to -3 dB when the attenuation is -20 dB. Therefore, the system ranging with km level will be achieved when the collimation is improved.

3 Conclusions

In conclusion, we have constructed a novel chaotic laser ranging system, utilizing a laser diode with optical feedback as its source, and every composition is described in detail. Capabilities of single target and multi-target detection of the designed system are tested. Experimental demonstrations with high power chaotic laser as light source prove that 18 cm spatial resolution can be achieved and kept in the range of 130 m at least. The sensitivity of -20 dB with cooperative target is verified. Experimental analyses illustrate that the chaotic ranging system has outstanding merits of high spatial resolution without distance-independent, simple configuration and low cost for generating chaotic light no longer needs complex devices and techniques, such as ultrashort pulse source, pseudorandom codes generation and modulation. The chaotic laser ranging technique can also be applied to fault location in transmission line, such as optical fiber or electric cable.

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