Research Article

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Design of pulse laser high-precision ranging algorithm under low signal-to-noise ratio

https://doi.org/10.1515/phys-2022-0210
received May 23, 2022; accepted October 11, 2022

Abstract: Because the traditional pulse laser high-precision ranging method has the problems of low ranging accuracy and long ranging time, a pulse laser high-precision ranging algorithm under low signal-to-noise ratio is proposed. Based on the analysis of the basic principle of pulse laser ranging, the pulse laser signal under low signal-to-noise ratio is obtained by modeling the pulse laser echo analog signal waveform. The wavelet denoising method of improved threshold function is used to denoise the pulse laser signal under low signal-to-noise ratio. According to the processing results, the pulse laser high-precision ranging is carried out through sinusoidal amplitude time conversion. The simulation results show that the proposed algorithm has high precision and short ranging time.

Keywords: low signal-to-noise ratio, pulsed laser, high-precision, ranging, threshold function, wavelet denoising

1 Introduction

In modern national economic development and national defense construction, distance measurement has always been a very important research field, such as military application, CAT alignment with weapon system, target tracking, gun shooting, and ballistic guidance. In the direction of civil production and construction, there are land highway measurement, lathe mechanical parts processing, house height and width measurement, building alignment, *etc.* [1]. With the emergence of laser and the development of laser technology, because laser has the characteristics of good directivity, high brightness and single wavelength, laser is used to measure distance. This ranging technology is called laser ranging. Compared with the traditional optical ranging system, the laser ranging system has the characteristics of simple system, convenient operation, high measurement frequency, and less affected by the weather. Compared with microwave ranging technology, laser ranging system obviously has the advantages of long measuring distance, high precision and strong anti-interference (ambient weather). Compared with radar ranging, laser ranging system has high resolution, high precision, and good adaptability. Therefore, now laser ranging technology gradually replaces other ranging methods, and laser rangefinder has become the most ideal instrument for high-precision and long-distance ranging because of its compact structure and convenient carrying [2]. The laser ranging system uses laser as the medium for distance measurement. The system emits laser to the target or detection area to be measured. After being reflected by the target, the optical receiving unit receives the echo signal, and then obtains the distance to be measured through data processing. According to the realization principle of laser ranging, it can be divided into triangular ranging method, pulse ranging method, interference ranging method, and photon counting ranging method. According to the distance to be measured, laser ranging can be divided into short-range, medium range, and long-range. The classical laser ranging methods include two categories: interferometric ranging method based on optical interference principle and non-interference ranging method based on non-optical interference principle. Among the laser non-interference ranging methods, the two most representative ranging methods are pulse time-of-flight ranging method and modulated wave phase ranging method. Laser interferometric ranging method can also be divided into two methods: swept frequency interferometric ranging method and multi wavelength ranging method. Different laser ranging methods have their own advantages in practical application. The measurement accuracy of optical interference ranging method is relatively high, and the pulse time-of-flight ranging method can realize a large range of distance measurement, and has good anti-interference

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ability and measurement accuracy [3]. At present, the two most widely used and technologically mature ranging methods are photon counting method and pulse time-of-flight ranging method: photon counting method obtains distance information by returning the statistics of the number of photons, while the pulse laser ranging obtains distance information by measuring the time interval between the emission and reception of laser pulses, and the commonly used laser ranging system mainly uses pulse time-of-flight ranging method for ranging [4]. Pulsed laser refers to the light generated and amplified by stimulated radiation, that is, the light amplification of stimulated radiation. It is characterized by excellent monochromaticity, minimal divergence, and high brightness (power). Laser generation requires three elements: excitation source, gain medium, and resonance structure.

In the field of pulsed laser ranging, since the first ruby pulsed laser ranging came out in 1961, it has gone through nearly 60 years of development. In the early stage of development, the research of various countries mainly focused on the optimization of system structure and device performance, and realized the optimization of handheld, security and other systems. In the later stage of development, people mainly focus on the signal processing of the ranging system to further improve the ranging performance of the ranging system [5]. At present, lidar is widely and deeply used in the fields of unmanned driving, storage alarm, UAV, intelligent control and so on. People have higher requirements for Lidar ranging performance, especially ranging accuracy. Ref. [6] proposes a fast and high-precision pulse laser ranging algorithm based on the Vernier principle. By combining the sinusoidal reference time interval measurement method and the Vernier clock-controlled pulse emission technology, the high-precision ranging of moving targets is realized. Taking the sinusoidal signal as the benchmark, the flight time between the laser pulse from the rangefinder to the target is measured, which is used as the initial value of estimating the target distance, and the Vernier clock is used to control the pulse emission technology. Selecting the linear segment at the 0 point of the sinusoidal signal as the timing feature point, high-resolution measurement results can be obtained. Taking the cursor time corresponding to the timing feature point as the pulse fixed-point transmission time, the fast and high-precision ranging can be realized after taking the average value through multi pulse measurement. Ref. [7] can accurately detect the characteristics of signal singularity based on wavelet transform. Wavelet transform algorithm can be applied to calculate the singularity of the echo signal in pulse laser ranging. Through the combination of mexh wavelet transform method and DSP technology, the measurement error can be effectively controlled with the help of laser ranging algorithm. Theoretical simulation shows that the ranging accuracy can be improved on the basis of mexh wavelet change method, the wavelet transform algorithm is based on the improvement of Mallat algorithm. Taking the quadratic spline wavelet as the wavelet base, the signal singularity can be well detected. One layer wavelet transform is selected, and the accuracy in pulse laser ranging is 0.21 M. The actual distance of the target can be measured accurately through the wavelet transform modulus maximum algorithm. Although the above two algorithms have completed pulsed laser high-precision ranging, for long-distance targets with low signal-to-noise ratio, the ranging time is long, resulting in low ranging efficiency. Ref. [8] proposes a pulse laser ranging algorithm based on differential signal time discrimination method, analyzes the factors affecting the accuracy of pulse laser ranging, and considers that the time sloshing caused by amplitude time walk effect and rise time walk effect is the most important factor affecting the ranging accuracy. Through the analysis, it can be seen that the designed differential signal time discrimination circuit can effectively improve the ranging accuracy and meet the design requirements. In the experimental test, the single ranging error of the differential signal time discrimination circuit for different distances within 70 m is kept within 9 mm. In contrast, the single ranging accuracy range of the single ended signal time discrimination circuit is [−12 mm, 11 mm]. The experimental results show that the ranging accuracy is significantly improved compared with the single ended signal single ranging error. Ref. [9] proposes a pulse laser ranging algorithm based on sinusoidal amplitude time conversion. Taking sinusoidal signal as time reference, frequency doubling and clock phase separation technology are adopted. By adjusting pulse emission delay, the timing point of echo pulse is controlled to fall in the $0 \sim \Pi/4$ interval of reference sinusoidal wave, and then piecewise linear interpolation is carried out for this interval to convert the change in sinusoidal amplitude into timing time, so as to realize high-precision ranging. However, the above two algorithms have low precision in pulse laser high-precision ranging for long-distance targets with low signal-to-noise ratio, resulting in poor ranging effect.

Aiming at the long-distance target with low signal-to-noise ratio and based on the problems existing in the above algorithm, a pulse laser high-precision ranging algorithm under low signal-to-noise ratio is proposed.

The effectiveness of the algorithm is verified by simulation experiments, and the problems existing in the traditional algorithm are solved.

2 High precision ranging algorithm of pulsed laser under low signal-to-noise ratio

2.1 Principle analysis of pulse laser ranging

2.1.1 Basic principle of pulsed laser ranging

Due to the rapid development of semiconductor lasers, at present, the laser pulse width can reach very narrow (several ns to tens of ns), and the energy is concentrated, and its instantaneous power is large. During short-range ranging, even for the target without reflection device, only the laser echo signal reflected from the target diffuse reflection can be used for ranging [10]. If there is a reflector, it can reach a very long range. The principle of pulse laser ranging is shown in Figure 1. When the laser rangefinder is aligned with the target, the laser will emit single or multiple strong and narrow laser pulses. The laser pulses compress the emission angle after focusing and collimating by the emission optical system. At the same time, a small part of the light is received by the photodetector (avalanche diode or photomultiplier tube) after beam splitting and converted into a current signal as the reference signal for transmission, the current is sent to the timing unit to amplify the time interval [11]. Due to the diffuse reflection of the target surface, when the laser pulse reaches the target, it enters the time interval measurement unit after atmospheric attenuation and target diffuse reflection. The time interval analyzer stops the timing unit by focusing the receiving lens and filtering the stray light by the narrow-band filter, photodetector conversion, amplification processing circuit, and detection circuit. The target distance is obtained by measuring the flight time between the laser pulse and the measured target.

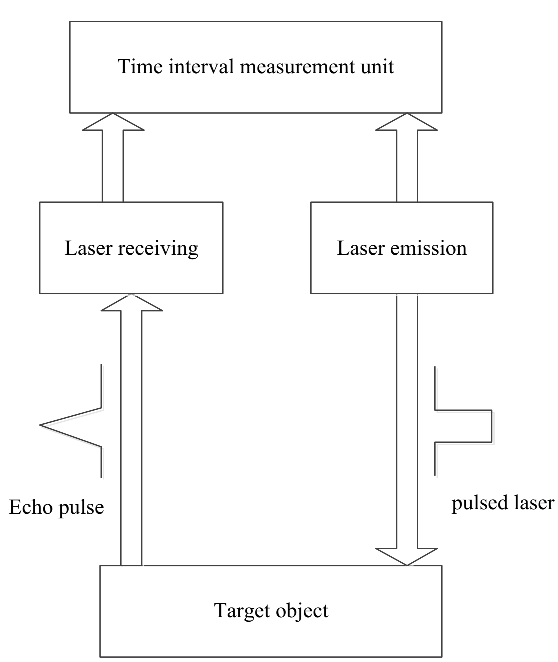

Figure 1: Schematic diagram of pulse ranging.

The propagation velocity c of laser in the atmosphere is affected by the change in atmospheric refractive index, and the error is about 1×10^{-6}, so it can be ignored. Therefore, pulse laser ranging can be expressed by the following formula:

$$L = \frac{ct}{2}, \quad (1)$$

where L represents the distance between the rangefinder and the target, c represents the propagation speed of light in vacuum, and t represents the flight time of laser pulse to and from the target [12].

2.1.2 Action distance equation

The action distance equation of laser rangefinder is an important theoretical basis for the development of laser rangefinder. It is used to estimate the maximum measurable distance and its influencing factors. It is of great significance for the selection of laser emission power, the selection of photodetector, and the design of transmitting and receiving optical system [13]. In order to derive the action distance equation, the spatial relationship between the laser beam and the target is illustrated in Figure 2. R represents the distance from the laser to the target. It is assumed that the target surface is similar to the Lambert scattering surface and the target surface area is greater than the laser spot area.

After the laser passes through the collimation of the transmitting lens and the attenuation of the atmosphere, the laser power reaching the target is

$$P_T = P_L T_E \exp(-\sigma R), \quad (2)$$

where P_L represents the peak power of laser emission, T_E represents the transmittance of the emission optical

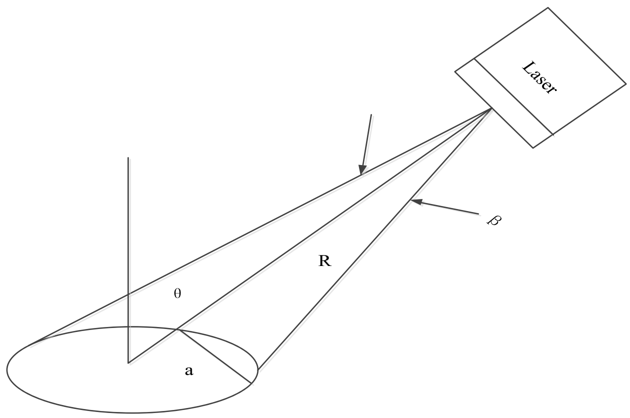

Figure 2: Spatial relationship between laser and target.

system, and σ represents the attenuation coefficient per unit length when the laser beam passes through the atmosphere [14].

After the laser reaches the target surface, it is reflected as a secondary light source. According to the definition of radiation emittance, the radiation emittance of the secondary light source is

$$M_T = \frac{P_T\rho}{A_T}, \tag{3}$$

where ρ is the target reflectivity, and A_T is the spot area of the light beam on the target surface, that is,

$$A_T = \frac{\pi\beta^2}{\cos\theta}, \tag{4}$$

where β is the laser divergence angle and θ is the included angle between the laser beam and the target normal. Because the laser divergence angle is relatively small (less than 4mrad), it is approximately $\tan(\beta/2) \approx \beta/2$.

Because this work assumes that the target surface is similar to the Lambert scattering surface, the radiant brightness is equal in all directions and has the following relationship with the radiant emittance:

$$L_T = \frac{M_T}{\pi}. \tag{5}$$

Radiance L_T is

$$L_T = \frac{4P_L\rho\theta^2}{\pi^2\beta^2R^2}. \tag{6}$$

Because the measurement distance is much larger than the distance of the optical axis of the system, we can approximate the laser echo power P_s received on the detector

$$P_s = L_T A_T \cos\theta \kappa_d T_R, \tag{7}$$

where T_R represents the transmittance of the receiving optical system (focusing lens and filter) and κ_d represents the solid angle between the detector and the target, and has

$$\kappa_d = \frac{A_r}{R^2} = \frac{\pi D_R}{4R^2}, \tag{8}$$

where D_R represents the diameter of the receiving lens and A_r represents the area of the receiving lens. Substitute Eq. (8) in Eq. (7) to obtain

$$P_s = \frac{P_L T_R T_E \rho D_R \cos\theta \kappa_d}{4R^2}. \tag{9}$$

This is the action distance equation of laser rangefinder. Its physical meaning is that the laser pulse with peak power of P_L is compressed by the transmitting optical system with transmittance of T_E and then quasi directly directed to the target. The beam emission angle is β. The laser beam passes through the atmosphere with attenuation coefficient of σ and reaches the target at a distance of R. The target reflectivity is Q. After diffuse reflection of the target, it enters the receiving optical system with transmittance of T_R through atmospheric attenuation, optical power is received by the detector P_s [15].

It can be seen from Eq. (10) that with the increase in target distance R, the target echo power received by the detector gradually decreases. When it is equal to the minimum detection power P_{min}, the detection distance reaches the maximum measurement distance R_{max}, which is easy to obtain

$$R_{max} = D_R \exp(-\sigma R)\cos\theta\sqrt{\frac{T_R\rho}{4P_{min}}}. \tag{10}$$

According to the ranging equation, in order to increase the maximum measurement distance, the peak power of laser emission can be increased, or the optical transmittance can be increased, or the size of receiving lens can be increased [16].

Pulse laser ranging technology directly measures the time of light flight, so the accuracy of timer will directly determine the ranging accuracy of the system. Assuming that for a pulsed laser ranging system, if the ranging accuracy is 1 mm, the laser round-trip distance error is 2 mm, and the round-trip time is 6.67 ps.

2.2 Acquisition of pulsed laser signal under low signal-to-noise ratio

Under the basic principle of pulse laser ranging, aiming at the target with low signal-to-noise ratio, first, the pulse laser echo analog signal waveform is modeled to obtain the pulse laser signal under low signal-to-noise ratio.

Under low signal-to-noise ratio, for pulse laser rangefinder, the received optical power can be regarded as the response of the transmitted pulse signal through the atmospheric propagation channel and reflected by the target at the distance R. There is a transfer function relationship between the received signal of APD detector and the system composed of laser rangefinder, atmospheric environment, and target.

$$P_{\text{det}}(t) = P_t(t) \ * \ h_c(t) \ * \ h_t(t), \tag{11}$$

where t represents the time, $P_t(t)$ represents the pulsed laser signal, $h_c(t)$ represents the channel space impulse response function, and $h_t(t)$ represents the target space impulse response function.

The waveform of pulse laser target echo signal can be obtained by convolution of emission signal, atmospheric propagation impulse response function, target reflection characteristic impulse response function, and other links [17]. Laser emission waveforms usually have rectangular pulse, Gaussian pulse, and negative parabolic pulse. The simplest is the shape of rectangular pulse, as shown in formula (12).

$$P_t(t) = \frac{E_t}{P_w} \star \text{rect}\left(\frac{t}{P_w}\right), \tag{12}$$

where E_t is the laser energy and P_w is the pulse time width.

The rectangular pulse model is an approximate shape of the actual pulse laser radiation. In practical application, most laser pulses can be expressed by Gaussian function.

$$P_t(t) = \frac{E_t}{\gamma_w \sqrt{2\pi}}, \tag{13}$$

where γ_w is the width parameter of Gaussian pulse waveform. Compared with rectangular pulse, this shape provides a more realistic energy pattern of laser transmitter [18].

Another model used to describe the output power of the laser transmitter is the negative parabola model. In this model, the laser power is modeled as an inverted parabola. In the negative parabola model, the pulse width is P_w, as shown in formula (14).

$$P_t(t) = \frac{3E_t}{2P_w}\left(1 - \frac{4^2}{P_w}\right)\text{rect}\left(\frac{t}{P_w}\right). \tag{14}$$

The scaling of this function ensures that the energy in the pulse is equal to parameter E_t, and the rectangular function is used to limit the strict positive value of the pulse amplitude.

Rectangular function is often used to obtain pulse laser signal under low signal-to-noise ratio.

$$P_t(t) = \begin{cases} P_0, & 0 \le t \le \iota_H, \\ 0, & \text{else}, \end{cases} \tag{15}$$

where ι_H is the half power pulse width of the emitted laser, and P_0 is the peak power of the emitted pulse laser.

2.3 Denoising of pulsed laser signal under low signal-to-noise ratio

The pulse laser signal obtained under low signal-to-noise ratio has large noise, so it is necessary to denoise the pulse laser signal under low signal-to-noise ratio [19].

A noisy one-dimensional pulsed laser signal model can be expressed as follows:

$$s(k) = f(k) + \varepsilon \star e(k), \tag{16}$$

where $s(k)$ is the shouting noise signal, $f(k)$ is the pulse laser low-frequency signal, $e(k)$ is the pulse laser noise signal, and ε is the high-frequency coefficient. Therefore, the idea of denoising processing is as follows: first, perform wavelet decomposition on the signal, such as three-layer decomposition. The decomposition process is shown in Figure 3. The noise signal is mostly contained in the higher frequency details cD1, cD2, and cD3, so the threshold can be used. Equal form processing is used to process the decomposed wavelet coefficients, and then wavelet reconstruction is performed on the signal to achieve the purpose of denoising the signal. Denoising a signal is essentially the process of suppressing the useless part of the signal and reproducing the useful part of the signal.

The threshold denoising method can not only suppress the noise almost completely but also retain the peak points reflecting the original features, which has a good denoising effect. In this study, an improved wavelet denoising method of threshold function is proposed to denoise the pulse laser signal under low signal-to-noise ratio. Good denoising effect can be obtained by using this method.

The expression of the new threshold function is as follows:

$$\hat{w}_{ab} = \text{sgn}(w_{ab}) \star \left[|w_{ab}| - \frac{\gamma}{\text{In}\left(\frac{|w_{ab}| - \gamma}{|w_{ab}| - n\gamma}\right)} \right], \tag{17}$$

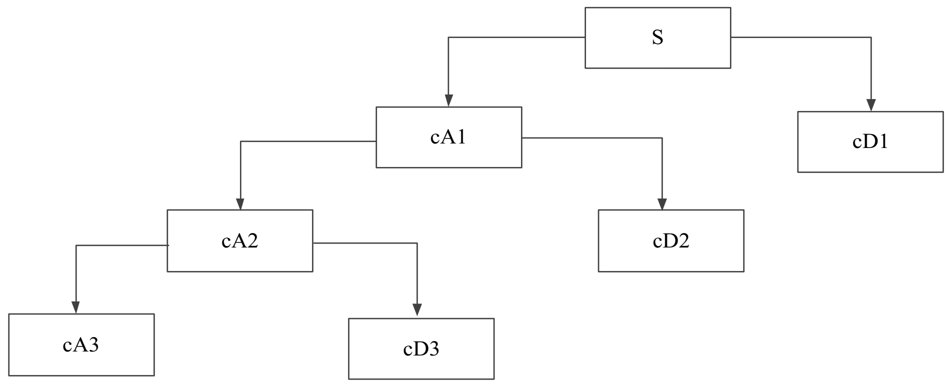

Figure 3: Three-layer wavelet decomposition of signal.

where γ is the threshold, w_{ab} is the wavelet coefficient, and $\hat{w}_{ab}$ is the wavelet coefficient after threshold processing.

2.4 Pulsed laser high precision ranging

According to the above preprocessed pulse laser signal under low signal-to-noise ratio, high-precision ranging of pulse laser is carried out through sinusoidal amplitude time conversion.

Sine wave is nonlinear, and the amplitude change rate is very small near the maximum ($\pi/2$) or minimum ($3\pi/2$), which means that a small amplitude change in these areas will correspond to a large phase change. Assuming that the distance resolution is 1 mm, it is necessary to subdivide 10,000 times the phase of a sinusoidal cycle (set the high-frequency clock frequency as 15 MHz), and the minimum amplitude resolution can be obtained as 1.974×10^{-5}. However, this small amplitude change cannot be distinguished, because the amplitude noise of sine wave in the circuit will be much greater than this minimum amplitude resolution [20–22].

Therefore, this study proposes to use the approximate linear segment of $0 \sim \pi/4$ interval as the timing characteristic point, in which the change rate of sinusoidal amplitude is large, so as to avoid the difficulty of phase subdivision caused by the small change rate of sinusoidal amplitude in $\pi/4 \sim \pi/2$ interval.

Usually, the pulse emission time is set at point 0 of high-frequency sine wave, and the echo pulse timing point corresponds to the sine wave phase in the range of $\varphi \in [0, \pi/4)$. In order to make the timing point of echo pulse fall in interval $\varphi \in [0, \pi/4)$, it can be realized by controlling the pulse transmission delay. The specific method is: first quadruple the frequency of the high-frequency sine wave, and then use the rising edge 0 point and falling edge π point of the high-frequency clock for phase splitting processing. In this way, the high-frequency clock cycle is divided into eight phase splitting intervals, and the adjacent phase splitting intervals are φ. The measurement process is divided into two steps:

1) Transmit the pulse at the 0 point of the sine wave, estimate the phase division interval where the phase $\pi/4$ is located, and determine the number of delay intervals m.
2) The pulse is transmitted at the interval point of delay m, and its distance is:

$$d = \frac{C}{2}\left(\frac{\varphi}{2\pi} - \frac{m}{8\pi}\right). \quad (18)$$

Using frequency doubling and phase separation technology will cause time offset (skew) and jitter (jitters). Time offset is a systematic error, which can be corrected by high-precision rangefinder. Time jitter belongs to random error, which can be reduced or eliminated by averaging multiple measurements.

3 Simulation experiment analysis

In order to verify the effectiveness of the pulse laser high-precision ranging algorithm proposed in this study in practical application, a simulation experiment is carried out. The construction of the experiment is to use the existing analog signal rangefinder in the laboratory, plus the analog-to-digital conversion module and FPGA development board. On the premise of not affecting the operation of the original laser rangefinder, connect the reference signal emitted by the laser to the FPGA, and connect the analog laser echo signal after APD conversion and pre amplifier amplification to the analog-to-digital conversion module and FPGA development board at the same time, and finally connect the analog-to-digital conversion module and FPGA. The serial port of the development board is connected to the computer, and the main wave and echo are directly connected to the signal processing unit for high-precision time interval measurement according to the mode selection, that is, during short-range ranging, so as to calculate the target distance. During long-distance ranging, the laser echo signal is loaded into the analog-to-digital conversion unit, and then sent to the signal processing unit for storage and processing to obtain the sampling point corresponding to the return time of the laser echo signal, the flight time is calculated according to the sampling points, and finally the target distance is calculated.

The experimental prototype includes pulse laser transmitting module (telescope optical system and optical aiming system), receiving system (auxiliary optical system), analog-to-digital conversion module, and FPGA development board. The pulse laser transmitting module and receiving system use laboratory analog signal rangefinder. The measurement environment of this experiment is shown in Figure 4.

The experimental index setting is shown in Table 1.

Figure 4: Physical diagram of pulse laser ranging.

Table 1: Experimental index setting

Parameter	Index
Laser harness	16 lines
Laser wavelength	905 nm
Laser safety level	Class I
Maximum ranging distance	200 m
Maximum measuring speed/10,000 points	32
Measurement accuracy	± 2 cm
Pulse width	30 ns
Horizontal scanning range	360°
Vertical scanning range	+15°~−15°
Power waste	6 W
Weight	550 g

Collect the original pulse laser signal, as shown in Figure 5.

Because the pulse laser has noise under low signal-to-noise ratio, the algorithm in this study is used to denoise the original pulse laser signal, as shown in Figure 6.

According to Figure 6, this algorithm realizes the denoising effect of pulse laser signal under low signal-to-noise ratio. In order to verify the effectiveness of this method, the pulse laser high-precision ranging algorithm under low signal-to-noise ratio proposed in this study, the fast high-precision pulse laser ranging algorithm based on cursor principle proposed in ref. [6], and the high-precision multi pulse laser ranging algorithm based on wavelet transform proposed in ref. [7] are used to compare and analyze the pulse laser ranging accuracy under low signal-to-noise ratio. The comparison results are shown in Table 2.

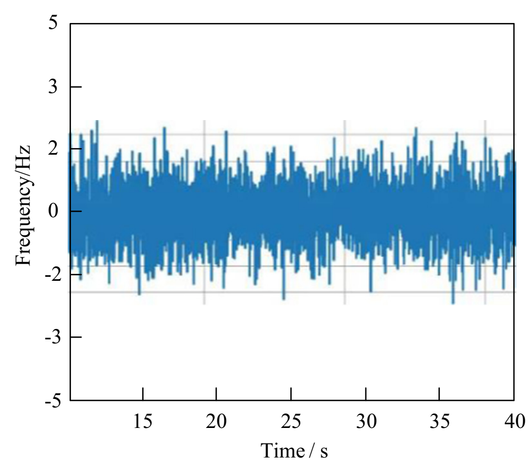

Figure 5: Original pulse laser signal.

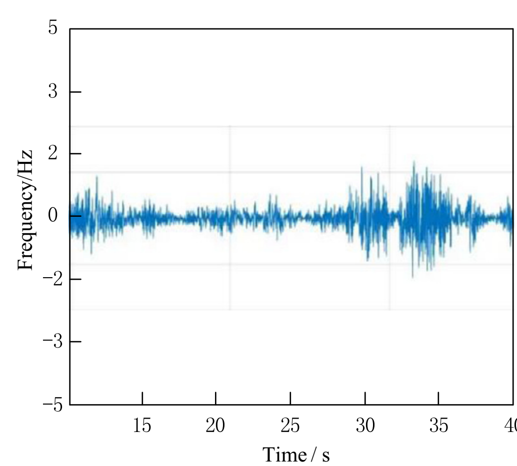

Figure 6: Signal waveform after denoising.

Table 2: Accuracy comparison of three laser pulse ranging algorithms/%

Number of experiments	Algorithm in this study	Ref. [6] algorithm	Ref. [7] algorithm
10	92.5	80.1	72.6
20	93.6	81.6	73.6
30	93.9	81.9	73.9
40	94.2	82.0	74.1
50	94.8	82.5	74.8
60	95.6	83.6	74.9
70	96.2	83.8	75.6
80	96.9	84.2	75.8
90	97.8	85.6	76.5
100	99.5	86.9	77.5

According to the data in Table 2, the pulse laser high-precision ranging algorithm under low signal-to-noise ratio proposed in this study can achieve the highest accuracy of 99.5% for pulse laser ranging under low signal-to-noise ratio, while the fast high-precision pulse laser ranging algorithm based on cursor principle proposed in ref. [6] can achieve the highest accuracy of 86.9% for pulse laser ranging under low signal-to-noise ratio. The high-precision multi pulse laser ranging algorithm based on wavelet transform proposed in ref. [7] has the highest accuracy of only 77.5% under low signal-to-noise ratio. The pulse laser high-precision ranging algorithm proposed in this study has the highest accuracy under low signal-to-noise ratio. It shows that the pulse laser high-precision ranging algorithm proposed in this study has good convergence, and the number of convergence is 100 times.

In order to further verify the effectiveness of this method, two groups of pulse laser ranging with calibration distance of 5 and 10 m are carried out by using the high-precision pulse laser ranging algorithm under low signal-to-noise ratio proposed in this study, the fast and high-precision pulse laser ranging algorithm based on cursor principle proposed in ref. [6] and the high-precision multi pulse laser ranging algorithm based on wavelet transform proposed in ref. [7], and the ranging time of the three algorithms is compared. The comparison results are shown in Figure 7.

According to Figure 7, no matter the distance is 5 or 10 m, the pulse laser high-precision ranging algorithm under low signal-to-noise ratio proposed in this study has a short time for pulse laser ranging, which shows that the application of this algorithm can improve the efficiency of pulse laser ranging.

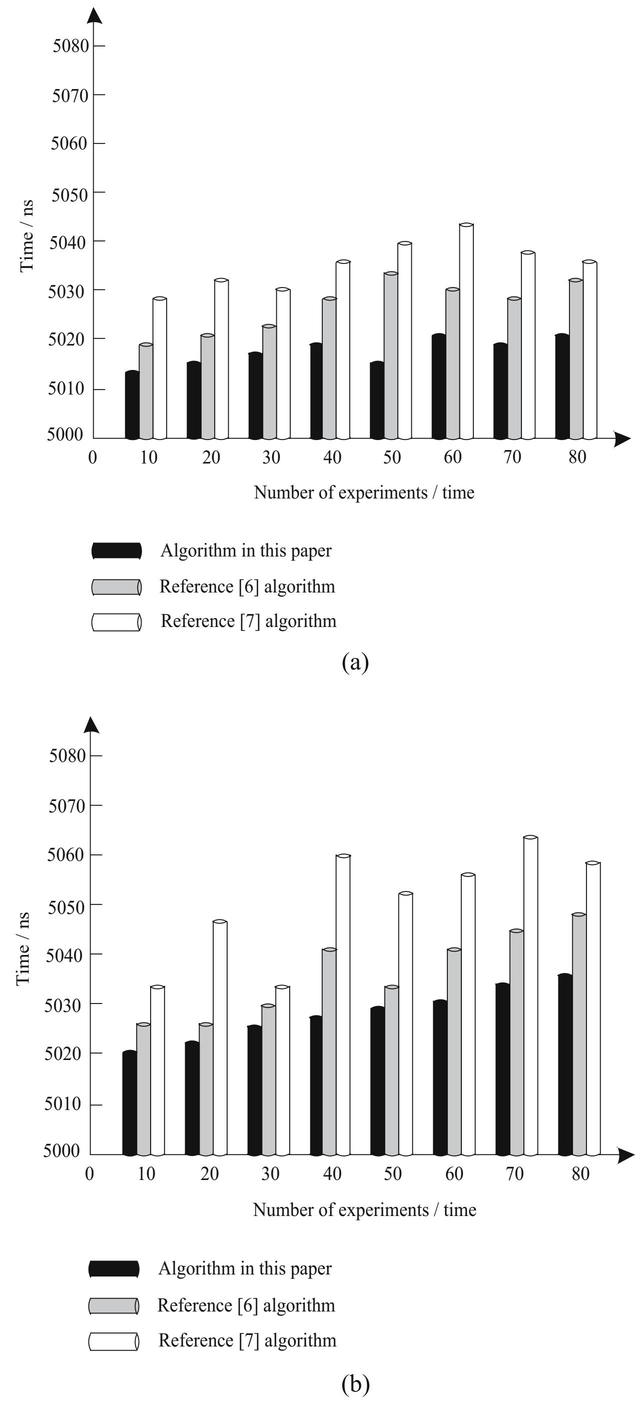

Figure 7: Comparison results of 5 and 10 m pulse laser ranging time of three algorithms. (a) Pulse laser ranging time at 5 m distance and (b) pulse laser ranging time at 10 m distance.

4 Conclusion

With the rapid development of laser technology and laser devices, the application range in military and civil fields is becoming more and more extensive. Especially in military technology, it has been widely used in many fields, such as Lidar, laser guidance, laser ranging, laser simulation, high-intensity laser weapons, laser gyro, laser bow signal, and so on. Because laser has the characteristics of strong monochromaticity, good coherence, and good directivity, laser ranging has many advantages compared with infrared ranging and microwave ranging, mainly including small volume, light weight, fast measurement speed, high resolution, strong anti-interference ability, and high measurement accuracy. According to the different mechanisms of ranging technology, laser ranging can be divided into pulse laser ranging and phase laser ranging. Compared with phase laser ranging, pulse laser ranging has the advantage of long range, but it has disadvantages in measurement accuracy. Therefore, it is of great significance to improve the accuracy of pulse laser ranging. In this study, a high-precision pulse laser ranging algorithm under low signal-to-noise ratio is proposed. The simulation results show that the algorithm has good effect and high ranging efficiency.

Funding information: This project was funded by Science and Technology Research Project of Jiangxi Provincial Department of Education "Research on Security Smart Bracelet based on cloud service (Project No: GJJ181491) and School level Youth Fund Project of Nanchang JiaoTong Institute in 2022 (Project No. XJQJ-22-05)."

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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