The Application and Optimization of Phase Method in Laser Distance Measurement

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Abstract. At present, photoelectric detection technology has become a hot spot in the field of automation technology, which is very active in the process of industrial automatic assembly detection. Laser ranging technology is a kind of technology that USES photoelectric technology to measure the distance without contact. In order to improve the flexibility of assembly and the adaptability of products, this paper adopts the non-contact detection method of laser ranging for the distance and length detection of the interior decoration covering parts of the emu passenger room. This method can avoid the disadvantages of manual detection and realize the purpose of high-speed, high-precision and non-contact detection.

Keywords: Laser, Phase, Ranging

1. Introduction
Laser ranging technology refers to the use of laser pulse or continuous wave laser beam fired at the target to measure the distance of the target distance measurement technology. Essentially, they calculate the distance between the emission point and the object to be measured by using the information difference between the emitted laser and the received laser.

2. The Principle and Characteristics of Laser Ranging
Compared with other ranging methods, laser ranging has the following advantages: (1) The high precision of laser ranging has nothing to do with the operator's experience and the measured distance, and the error only depends on the accuracy of the instrument and external conditions at that time. (2) The rangefinder is small in size and light in weight. Because the laser has good directivity, it can emit extremely narrow beam with a small optical emission antenna. (3) High resolution, strong interference ability, narrow beam and short pulse width, so that its transverse and longitudinal target resolution greatly improved, and not subject to circuit interference and ground wave interference. Laser ranging system is generally composed of laser transmitting part, laser receiving part, control system, power supply and other parts.

Laser has the advantages of directivity, coherence, monochromatism and high brightness, and can achieve different range and high precision measurement in distance measurement. Laser ranging measurement is convenient, simple to use, non-contact and high precision, widely used in all walks of
life. There are many kinds of laser ranging methods, some are suitable for short distance measurement, some are suitable for long range ranging, some are suitable for high precision measurement, the following is a brief introduction of different laser ranging methods.

1. Pulse laser ranging. The laser pulse duration is short and the divergence Angle is very small, which can make the energy very concentrated. Therefore, in the case of cooperative targets, pulsed laser ranging can measure a large distance. Pulsed laser ranging can measure the distance by receiving the reflected signal from the diffuse reflection of the laser by cooperative targets. The principle of pulsed laser ranging is to measure the distance by measuring the time it takes the laser to go back and forth between the distances to be measured.

2. Trigonometric laser ranging refers to a triangular optical path system that combines the laser source, the reflected surface of the measured object and the photoelectric receiving system [1]. The ranging system structure is simple and easy to implement, so it has a wide range of applications in practice, especially after the advent of high directional, high monochromatic, high brightness laser, coupled with the latest photoelectric scanning technology and the gradual development of photoelectric detector, triangulation laser ranging has been applied more.

After the laser beam is focused through the lens, it illuminates the surface of the measured object. After scattering by the surface of the object, part of the light is received by the photoelectric receiving system. The main function of the lens is to make the light-sensitive surface of the measured object be able to image clearly. If the object has a certain position change, the distance of the spot moving on the photosensitive surface can be obtained according to the triangle similarity principle. On the contrary, the distance of the spot moving on the photosensitive surface can also be obtained if the distance of the spot moving on the photosensitive surface is known. Triangulation laser ranging is mainly used in the distance measurement of micro displacement, measuring range between 1mm-300mm, accuracy up to 500nm level.

3. Interferometry Laser ranging is based on the principle of optical interference, the use of interferometer distance measurement. It can be seen from the principle of interference of light waves that two light waves with the same frequency and fixed phase difference, and the vibration direction of the two light waves is the same or the vibration direction has a small Angle, the two light waves overlap each other, the phenomenon of light interference will occur.

4. Laser ranging by phase method. Phase type laser ranging is by measuring the distance between the phase change after a indirect method of measuring time for high precision of distance measurement, which is used by the modulated laser light emitted by a back and forth between the measured distance of the change of phase, according to the wavelength of light wave modulation and phase change in quantity to calculate the distance of light wave propagation [2]. Phase laser ranging is suitable for the measurement of medium and short distance, and the measurement accuracy can be up to the millimeter level, so it is widely used in all walks of life and daily life. The measurement distance required in this paper is 30m, and the accuracy is up to the millimeter level.

3. Ranging Mode Selection
According to the different ways of ranging realization, the current mainstream laser ranging can be divided into pulse laser ranging, phase laser ranging, triangulation laser ranging and interferometry laser ranging. The former two are widely used, while the latter are used in a relatively small proportion.

The pulse method belongs to the time of flight method. The measurement principle of this method is that the distance is measured according to the round-trip flight time of the laser line [3,4]. The pulse method directly measures the transmission time of the laser, while the phase law is based on the phase indirect measurement. Phase method and pulse method are two different ranging methods, which have their own advantages and disadvantages for different working situations and different accuracy requirements:

1. Pulse method is mainly used in long-distance laser ranging application. It is characterized by strong anti-interference ability and high precision. The measurement precision of the current
mainstream pulsed laser ranging products can reach centimeter level. The measurement accuracy of pulsed laser rangefinder system mainly depends on the bandwidth of receiving channel, rising edge of laser pulse, signal-to-noise ratio (ratio of peak signal current to root-mean-square value of noise current) and time interval measurement accuracy. The key is how to accurately and stably determine the starting and ending time and accurately measure the laser flight time \( F \), which correspond to the time discrimination unit and time interval measurement unit respectively. On the other hand, atmospheric refractive index is also affected by ambient temperature, pressure and atmospheric turbulence. At present, pulsed laser ranging has been widely used in topographic survey, engineering survey, cloud and aircraft altitude survey, tactical frontier ranging, missile navigation orbit tracking, artificial earth satellite ranging, distance measurement between the earth and the moon and other aspects.

(2) The phase method calculates the distance represented by the phase delay according to the wavelength of the modulated wave by using the phase change of the modulated signal during the laser space propagation. It realizes the distance measurement by substituting the indirect method of the phase delay measurement for the time change required by the direct measurement of the laser round trip. Phase method laser ranging is often used for small range ranging (generally used for ranging products within 100 meters), has a high measurement accuracy (measurement accuracy can reach the millimeter level), and the design is relatively simple. However, in addition to the external factors such as atmospheric temperature, air pressure and humidity, phase modulation influences the precision of laser ranging as well as the optical emission power, average number of measurements, modulation frequency and stability of the range finder. In addition, the electronic noise, especially the coherent noise introduced by high power modulation, has great influence on the detection accuracy. Moreover, if the photovoltaic signal and the modulation source have the same frequency, the measurement accuracy will be limited.

By comparing the above two methods, the type of phase laser ranging can be used in short distance measurement, and measurement accuracy can be to millimeter level, so the requirement is designed according to the distance of the laser ranging system performance indicators: the measuring distance of 30 m, the precision of millimeter, focus on analysis method of phase laser ranging system design, the following phase system analysis method theory.

4. Principle of Laser Ranging by Phase Method
Laser phase distance measurement, the measurement system are laser measure system to a back and forth between the target object to be tested by the way, so the method of phase distance measurement, the measurement of phase difference caused by laser is a back and forth the continuous laser amplitude modulation, the determination of modulated light that passes through in the process of phase change back and forth can take the time and distance.

Figure 1. Schematic diagram of phase laser ranging principle
As shown in Figure 1, if the distance between the laser emission point and the laser reflection point (lifting vessel) is set as \( x \), the laser velocity is set as \( c \), and the time between the laser and the target is set as \( t \), then:

\[
t = \frac{2x}{c}
\]  

(1)

If the modulated wave frequency is set as \( f \) and the phase difference between the transmitting and receiving is \( \varphi \), then:

\[
\varphi = 2\pi ft = \frac{4\pi fx}{c} = 2\pi N + \Delta \varphi
\]  

(2)

Where, \( N \) is the number of complete periodic waves, \( \Delta \varphi \) is the residual phase of insufficient periodic waves. Thus, it can be solved that:

\[
x = \frac{\varphi c}{4\pi f} = \frac{c}{2f} \left( \frac{2\pi N + \Delta \varphi}{2\pi} \right) = \frac{c}{2f} \left( N + \Delta N \right)
\]  

(3)

Where, \( L_3 = c / 2f \) is called measuring ruler or scale, \( N \) is the whole ruler, \( \Delta N = \Delta \varphi / 2\pi \) is the residual ruler.

According to the magnitude of the phase displacement measured by the formula, the residual ruler value \( \Delta N \) can be known. The whole size \( N \) can only be determined by selecting multiple appropriate ruler frequencies. The selection of ruler frequency is one of the key factors to promote the accurate positioning of the container.

Accuracy is higher, because the laser ranging system reach the mm level, the system selects the TDC - GP2 sensor is through phase laser ranging method, by measuring the modulation signal of the continuous transmission of back and forth on the distance under test to indirectly measure the signal propagation time, phase change measurement point obtained measured the distance between the target and the car.

This paper only analyzes the laser ranging system based on the principle of phase method, as shown in Figure 2. The laser ranging system mainly includes phase measurement unit, transmitting unit and receiving unit, and the content of the paper mainly involves phase measurement unit [5,6].

![Figure 2. Laser ranging system](image)

5. Phase Method Laser Ranging Algorithm
The core of phase method laser ranging is to measure the phase difference between the feedback loop and the receiving loop. The error of phase measurement directly affects the measurement accuracy. In the real phase difference measurement, the data acquisition module should be used for data acquisition
of both feedback and receiving signals. Since the modulation signal frequency of the modulated laser is relatively high, the data acquisition should meet the Requirements of Nyquist sampling theorem, that is, the sampling frequency of the data acquisition module is very high, which is not conducive to data acquisition. Secondly, the phase change is related to the frequency of the signal, that is, the lower the frequency is, the longer the period is, and the longer the time required for the phase change is, so it is more convenient to measure the phase of the signal. Therefore, the phase measurement accuracy of the low-frequency signal is higher than that of the high-frequency signal. Based on the above two reasons, it is necessary to convert the high frequency signal into the low frequency signal, and the phase of the converted low frequency signal remains unchanged, and then carry out the phase difference measurement of the low frequency signal, which is the difference frequency phase measurement.

The modulating signal of the modulated laser is the main frequency signal, and the main frequency signal is set as:

\[ E_0(t) = A_0 \cos(2\pi f_0 t + \varphi_0) \]  

The local oscillator signal is:

\[ E_1(t) = A_1 \cos(2\pi f_1 t + \varphi_1) \]  

The received signal after a distance of laser transmission is:

\[ E_R(t) = A_R \cos(2\pi f_{R0} t + 2\pi f_{R1} t + \varphi_0) = A_R \cos(2\pi f_0 + \varphi_0 + \Delta \varphi) \]  

After the feedback signal passes through the mixing circuit, the signal is:

\[ E_{L0}(t) = A_{L0} \cos[2\pi(f_0 - f_1) t + (\varphi_0 - \varphi_1)] \]  

After the received signal passes through the mixing circuit, the signal is:

\[ E_{L1}(t) = A_{L1} \cos[2\pi(f_0 - f_1) t + (\varphi_0 - \varphi_1) + \Delta \varphi] \]  

It can be seen from the above formula that the phase difference of the two signals after mixing is the same as that of the two signals before mixing, which is the principle that the mixing circuit only changes the frequency but does not change the phase. Therefore, adding differential frequency phase measurement into the circuit of phase laser ranging system can not only ensure the portability of data collection, but also improve the accuracy of distance measurement.

6. Conclusion
The principle and characteristics of laser ranging system are discussed respectively, the phase method and pulse method of two mainstream laser ranging methods are compared, according to the performance index of the research system, the application of phase method is determined to carry out systematic research, and the theoretical research of phase method laser ranging is carried out. The content of this paper is the theoretical basis of the designed laser ranging system, which provides a theoretical basis for the follow-up research.

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