Sensors & Transducers, Vol. 164, Issue 2, February 2014, pp. 249-255

Sensors & Transducers

Research and Analysis Laser Target Optics Characteristics and Signal Recognition Processing in Detection Screen System

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Received: 20 November 2013 /Accepted: 28 January 2014 /Published: 28 February 2014

Abstract: In order to improve the measurement accuracy of the laser measurement distance system, this paper study the laser target optics characteristics based on the laser detection principle in the laser measurement distance system. A calculation model of laser reflective echo signal is put forward by analyzing the influence factors on the detector output value, and discuss the relationship between the distance from the detector to the target, the laser wavelength, the Transmission power of laser and the detector output power, the radiation intensity, and use the Fisher identification and modulus maxima method based on wavelet analysis to distinguish and identify the received echo signals. By the theoretical calculation and experimentation, the result shows the laser target optics characteristics are consistent with the calculation method of radiation. The real reflective signal can be identified by using wavelet transform, and the numerical value of the distance between the target and the detector is larger, the numerical value of echo signal will be smaller. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Target optics characteristics, Detection distance, Signal recognition processing, Detection screen system.

1. Introduction

With the rapid development of modern construction, a high precision measurement in measuring the height, length and width of the industrial buildings is more and more important, so as getting the transportation hubs parameter in transport systems. Currently, the method of obtaining the distance in the system often adopts laser measurement distance method [1]. Due to the variability in environment and diversity in measurement objectives, the accuracy in laser measurement distance system is affected greatly. Especially in the field tests, there are many influential factors, such as lighting, terrain, reflective surface of target [2]. The accuracy in laser measurement distance system depends on the echo signal characteristics of target, echo signal of target may be buried in noise and it is difficult to identify the real useful signal when the noise in external environment is big. Therefore, we research echo characteristics of the laser target and identification of the signal by the detection principle of laser measurement distance system. Then, we provide the analysis and research to improve the accuracy of laser measurement distance system. For the signal processing of laser measurement distance system, in reference [3-5], they proposed many factors that affect the precision

about the short-range measurement distance system in impulse-type laser measurement distance system, they mainly discussed influencing factors about the identification in moment and the measuring accuracy of time interval in reference [6]. In the meanwhile, they also had studied the relevant improvement measures. However, these methods do not systematically analyze the echo characteristics in detection system. The paper based on the perspective of principle of laser detection by using the wavelet signal processing methods to study the echo characteristics of the laser target and identification of the signal in order to improve the detection performance of detection system.

2. The Principle of Optics Detection Analysis in Screen Detection System

The impulse-type laser measurement distance system is mainly using the time difference between transmitting laser pulse signal and receiving laser echo signal of target to measure the distance between the laser emission source and target. The principle of impulse-type laser detection system is shown as follows, see Fig. 1:

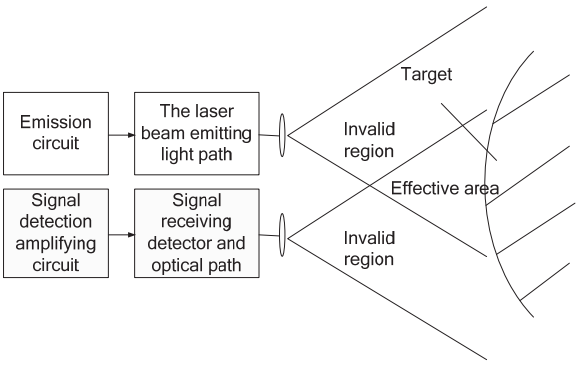

Fig. 1. Detection principle diagram.

The high frequency impulse-type sequence of laser beam is transmitted by the emission circuit. The divergence angle of laser beam is compressed through the lens, then, the laser beam started flying, the diffuse reflection be occurred after encountered obstacles. The reflected laser in effective area returned to the receiving detector, we obtain the integrate echo signal of target by using the photoelectric conversion circuit and amplifier rectifier filter circuit [7]. We put the laser feedback timing module in the detection circuit: a laser beam is reflected by the plane mirror which is in front of the lens, then the laser beam enter into the laser feedback timing module, then, the laser beam pass through the photoelectric conversion circuit and amplifying circuit, the level signal is sent to the start-timing module of time-digital conversion chip; the receiving laser echo signal of target passing through amplifying circuit is changed into a level signal, then the lever signal is sent to the end-timing module of time-digital conversion chip, the whole measurement process is completed. Here, L is the distance to be measured. T is the double test time which is used from the laser emission point to the object. C is the laser speed in air (assuming the measured environmental parameters have been set), n is the atmospheric refractivity, then we can obtain the formula of the distance from the laser emission point to test target position, the formula is $L = CT/2n$.

In the principle of laser measurement distance system, whether we can detect the useful signal is related to the laser echo signal strength of target. The echo signal of the target is affected by external influences because of the variability in environment, then the laser measurement distance system will lose efficacy, so the echo signal detection of this system is the important parts of the design. This paper based on the principle of laser measurement distance system, we establish the characteristic model of the reflective surface by the curvature features of surface on target, signal processing is as the core to identify the echo signal.

3. Research Target Optics Characteristics in Detection System

3.1. The Radiation Characteristics on Target

By calculating and analyzing the radiation from surface element of the target, we can see the spectral radiant exitance of surface element varies with wave length values. We can gain that the surface spectral radiance exitance of target is M_λ by the Planck's law [8, 9].

$$M_e = \varepsilon \frac{a_1}{\lambda^5 (e^{a_2/\lambda T} - 1)}, \tag{1}$$

where ε is the reflectivity of the surface element, T is the temperature of the surface element, λ is the laser radiation wavelength, a_1 and a_2 are the radiation constant, $a_1 = 3.74\times16^{-16}\left(\mathrm{Wm}^2\right)$, $a_2 = 1.43879\times10^{-2}\left(\mathrm{mK}\right)$.

In order to make the detector obtaining effective spectral radiant flux from the target, the spectral radiant flux of the detector on the target for each surface element must be calculated. Then add up all the spectral radiant flux of each surface element to the detector in a certain way.

We define that the overlap area of transmitting and receiving light path of the laser measurement distance system is effective area. The photosensitive window of the detector receive radiation flux in any surface element (i, j) in the effective area is M_{ij}. Then the radiation flux M about this surface element in the echo of target field is

$$M_{ij} = \beta_{ij} M , \quad (2)$$

where β_{ij} is angular coefficient of surface element (i, j) about acceptance point of detector.

$$\beta_{\mathrm{ij}} = \cos\theta_{ij} / \pi R^2 , \quad (3)$$

where θ_{ij} is the angle between two lines. One of lines is from the point of receiving area on the detector to the surface element of target, another line is normals of objective surface. The range of the angle is half of the field of the effective area. According to echo characteristics, we establish a calculation model about echo information, showing as Fig. 2, $Q(x, y)$ is the position of detection receiver. Assuming that the target is at the origin of the coordinate, its reflection energy of the surface element $A_{i,j}$ in the coordinate system is $Q_{(i,j)}(x, y)$, according to the calculation principle of the radiation fluxes about echo, the radiation flux of current surface element can be calculated by

$$M_{Q_{(i,j)}(x,y)}(\lambda) = \varepsilon \cdot A_{ij} \cdot \frac{a_1}{\lambda^5 (e^{a_2/\lambda t_{ij}} - 1)}, \quad (4)$$

where t_{ij} is the temperature of the surface element (i, j), we put formula (4) into formula (2), and gain spectral radiant flux, it can be expressed by

$$M_{\mathrm{ij}}(\lambda) = \varepsilon \beta_{\mathrm{ij}} A_{ij} \frac{a_1}{\lambda^5 (e^{a_2/\lambda t_{ij}} - 1)} \quad (1)$$

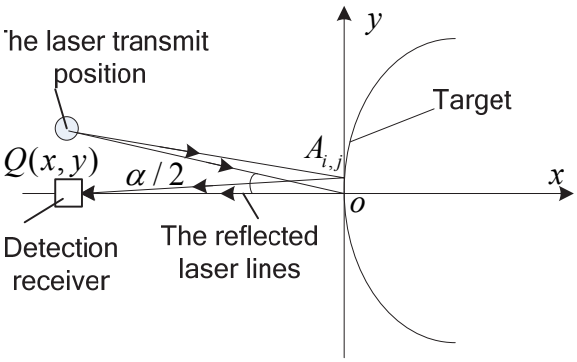

Fig. 2. The echo characteristic diagram.

In (5), the spectral radiant flux contributed to the detector from any surface element of the target can be got. The radiation of all surface elements project to the receiving surface of photoelectric detector. The total spectral radiant flux is equal to superposition of all surface elements.

$$M_e^{'}(\lambda) = \sum_{i,j} M_{ij}(\lambda), \quad (6)$$

Here, $M_e^{'}(\lambda)$ is the total spectral radiant flux of $a \times b$ surface element of target. According to above calculation, $L_{\mathrm{e}}(t, \lambda)$ is radiation brightness of surface on target in a moment at $\lambda_1 \sim \lambda_2$ [10], $L_{\mathrm{e}}(t, \lambda)$ can be expressed by

$$L_e(t, \lambda) = \frac{1}{\pi} \int_{\lambda_1}^{\lambda_2} M_e^{'}(\lambda) d\lambda \quad (7)$$

Based on the target radiation brightness, we suppose that the effective radiated power received by detector is ϕ_e, ϕ_e can be expressed by

$$\phi_e = \frac{A_1 A_2}{\mathrm{R}^2} \int_{\lambda_1}^{\lambda_2} L_e(t, \lambda) d\lambda , \quad (8)$$

where A_1 is the area of target radiation source, A_2 is the sensitive area of detection receiver, R is the distance between the detector and target.

3.2. Analysis on Target Reflection Characteristic

The illumination of laser emission source whose luminous intensity is I at the distance R from the laser emission source to target is $E^{'}$, $E^{'}$ can be expressed by formula (9).

$$E^{'} = \frac{\Phi}{dA^{'}} = \frac{Id\Omega}{dA^{'}} = \frac{IdA^{'}\cos\theta}{dA^{'}R^2} = \frac{I}{R^2}\cos\theta , \quad (9)$$

where I is the luminous intensity, θ is the angle between the radius vector R from laser source to target center and the normals of the surface.

Luminance L is constant, the radiator which L is regardless of the direction is known as the cosine radiator, or Lambertian radiator [11-12]. The luminous flux that emitted by this kind of radiator in cube angle element $d\Omega$ is proportional to the cosine of the angle of inclination on light-emitting surface.

$$d\Phi = L\cos\theta dA d\Omega \quad (10)$$

For the cosine radiation surface, its luminance L has the following relationship with the radiance M, it can be expressed by

$$L = \frac{M}{\pi} \quad (11)$$

When the cosine radiation surface is not luminous surface but illuminated surface, then the relationship between luminance L and intensity of illumination is as follows:

$$L = \frac{\varepsilon}{\pi} E , \quad (12)$$

where ε is the reflectivity of the target.

The luminance L of the light-emitting surface element has the following relationship with luminous intensity [13]:

$$L = \frac{I}{dA \cos\theta} , \quad (13)$$

where dA is the surface element area of the light-emitting source.

Namely, the luminance of the surface element is equal to the luminous intensity on unit area in the normal direction.

The Intensity of illumination generated from surface element dA to the surface element $dA^{'}$ is E, the distance between surface element dA and the surface element $dA^{'}$ is R.

$$E = L \frac{dA \bullet \cos\theta \cos\theta^{'}}{R^2} = L d\Omega^{'} \cos\theta' , \quad (15)$$

where θ is the angle between center radius vector of surface element dA and normals of unit surface, $\theta^{'}$ is the angle between Center radius vector of surface element $dA^{'}$ and normals of unit surface [11, 12], $d\Omega^{'}$ is the cube angle between the center of dA and the center of $dA^{'}$.

$$d\Omega^{'} = \frac{dA \cos\theta}{R^2} \quad (15)$$

Combined with the analysis of the laser target radiation flux and the target surface luminance in reflection field, the output voltage signal can be calculated by using function relationship between the input radiation flux and the output signal strength of the detector after getting the effective radiation flux.

4. The Identification of the Target Signal

The output signal of the detector contains high frequency and low frequency signals, etc. Usually the low frequency part in circuit processing can be eliminated by the filter circuit, the transient high frequency components can also be appropriate eliminated by using the principle [13] of band-pass filter circuit. However, the echo signal of target is also a kind of high frequency signal, so we need detect and extract a certain band-pass output signal. Therefore, according to the principle of wavelet transform, we need to focus on the characteristics of band-pass frequency in the extraction process of the echo signal of target characteristics. As an example of three layers of wavelet decomposition, we exclude more than half of locking frequency wavelet coefficients which is h_1, only extract the wavelet coefficients which are h_2, h_3, h_4. Using frequency band energy as feature, we construct the feature vectors: $E = (E_0, E_1, E_2)$.

After detector receives the echo signal, the recognition of output analog signal from detection circuit can be thought of as two kinds of discriminant problem, in order to identify the echo signal of target quickly, we choose Fisher discriminant method. The thought of Fisher discriminant method is: Two n-dimensional samples be projected to a certain direction, and we use variance analysis to make the dates separated between one projected dates and the samples as much as possible, a linear discriminant function is obtained from Fisher criterion [14], this function is:

$$f(x) = M^T X = M_1 x_1 + M_2 x_2 + ... + M_n x_n , \quad (16)$$

where $M = (M_1, M_2, M_3, ..., M_n)^T$, M is the discriminant coefficient vector, $X = (x_1, x_2, x_3, ..., x_n)^T$, X is the characteristic vector.

To determine the echo signal of target from the output signal of the detection circuit, we put forward two discriminate models. Description of the theory of the two discriminate models is: there are two sample populations that are B_1 and B_2. B_1 is the sample population of background signal, B_2 is the sample population which contains the echo signal of target, characteristics vector of the two sample populations is n-dimensional vector X. For a given new sample, we need to determine that the new sample belongs to B_1 or B_2, namely, we need to determine the signal is the background signal or echo signal. Assuming the average of the two sample population are k_1 and k_2, the corresponding discriminant function values are $M^T k_1$ and $M^T k_2$. If $M^T k_1 < M^T k_2$ and $M^T k_1 < f_0(x)$, we determine that the sample belong to B_1; if $M^T k_1 \geq f_0(x)$, the sample is B_2. $f_0(x)$ is the threshold point, $f_0(x)$ can be the average or weighted average of $M^T k_1$ and $M^T k_2$.

We construct the feature vector $X = (E_0, E_1, E_2)$ by using characteristic from the energy of the signal band, the characteristic is obtained by only extracting wavelet coefficients

which are h_2, h_3 and h_4 in three layer wavelet decomposition from the principle of wavelet transform. Although the extracted part of wavelet coefficients can not accurately restore the original target of echo signal, the identification problem for the echo signal of target does not need to restore the original signal, we have only to extract the signal characteristics of target accurately and efficiently for identification. In order to ensure real-time of the algorithm, we reduce the number of feature dimension under the effective wavelet decomposition, so we improve the identification real-time of the echo signal [15, 16].

We provide that characteristics vector of n_1 times observation data of detection system background signal is $X_1^{(1)}, X_2^{(1)}, \cdots, X_{n1}^{(1)}$, characteristics vector of n_2 times observation data of containing the echo signal is $X_1^{(2)}, X_2^{(2)}, \cdots, X_{n2}^{(2)}$, we obtain linear discriminant function [16] by Fisher criterion:

$$f(x) = M^T X = M_0 \mathrm{E}_0 + M_1 \mathrm{E}_1 + M_2 \mathrm{E}_2, \quad (17)$$

In (17), $M = (M_1, M_2, M_3, ..., M_n)^T$, M is the discriminant coefficient vector, we can judge whether the echo signal of target exist by combined with the discriminant rules.

5. The Experiment and Analysis

We make quantitative analysis about the output power, radiation intensity and other parameters, using different laser wavelength and transmission power of laser transmitter in the laboratory on the basis of the above principle.

Assuming γ is the detector response rate. $\gamma = 7 \times 10^2 V/W$, A_1 is the source area of target radiation, $A_1 = 9 \times 13\, cm^2$, A_2 is the sensitive element area of detection receiver, $A_2 = 2.4 \times 2.8\, mm^2$, ε is reflectivity of the target, ε=0.75. We select two kinds laser transmitter to experiment and analysis. The transmission power of laser transmitter are 30 mW and 50 mW respectively, the distance *R* from the detector to the target changes between 0 to 4 m. The relationship between the corresponding output power P_{out} and R is shown in Fig. 3; the wavelength λ changes between 0.4 to 1.2 um, the relationship between the corresponding output power P_{out} and λ is shown in Fig. 4.

We still select two kinds laser transmitter to experiment and analysis. The transmission power of laser transmitter are 30 mW and 50 mW respectively, the distance *R* from the detector to the target changes between 0 to 4 m, then the diagram between the radiation intensity L_e and distance *R* is shown in Fig. 5; the wavelength λ changes between 0.4 to 1.6 um, so the diagram between the radiation intensity L_e and λ is shown in Fig. 6.

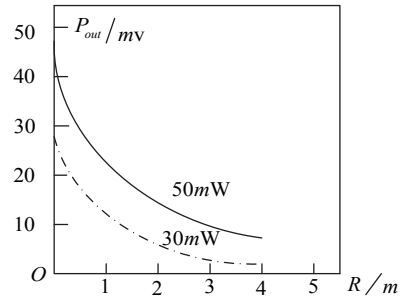

Fig. 3. The output power varies with the distance R.

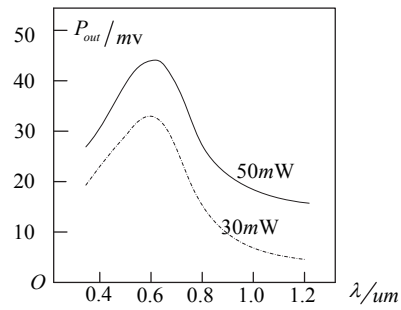

Fig. 4. The output power varies with wavelength.

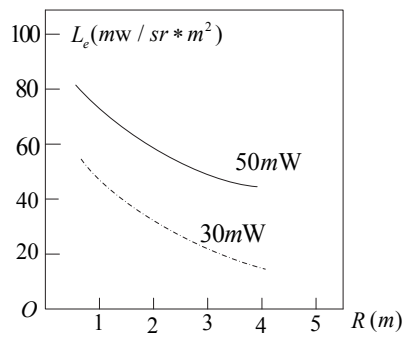

Fig. 5. Radiation brightness varies with distance *R*.

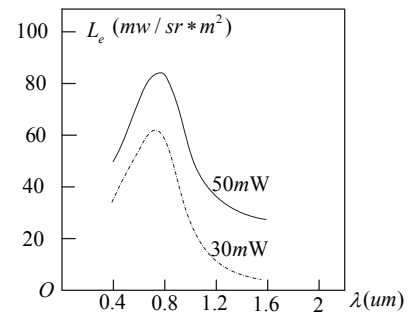

Fig. 6. Radiation brightness varies with the wavelength.

By the above diagram, we can get that the output power P_{out} is inversely proportional to *R*. The closer distance between target and the detector, the greater the output power; the farther the distance, the smaller the output power. The magnitude of the output power P_{out} has a maximum value in the process of changes by λ. Using different transmission power of laser transmitter, the magnitude of the output power P_{out} is also different, the bigger the transmission power, the greater the output power**.** The radiation intensity L_e and the distance *R* from the target to detector both are inversely proportional to the wavelength λ. The change rate of inverse proportion by the wavelength λ is higher than by the distance *R*. The radiation intensity L_e accompany with transmission power increases.

In order to obtain the reflected echo energy under different distances, we set a hardware platform of laser target echo detection system. It includes the laser emission system and the target echo detection system. we get the results by experiment on the hardware platform are shown in the following diagrams, we still select two kinds distance to experiment and analysis. The distance between target and detector are 3 m and 5 m respectively.

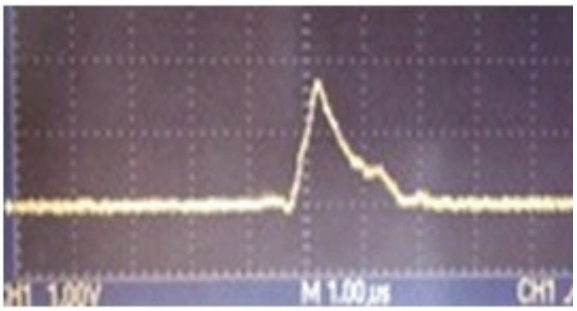

Fig. 7. Target reflect echo signal in 5 meters.

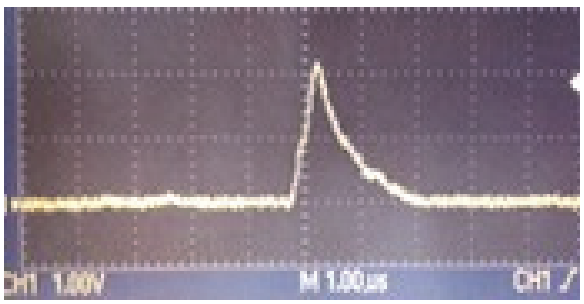

Fig. 8. Target reflect echo signal in 3 meters.

It can be seen from the experimental picture, the output voltage of detector is correlated with the distance between the target and the detector. The distance *R* is larger, the output voltage will be smaller. Increasing the detection distance of the detector, then the output voltage will be affected. The experimental data is consistent with the theoretical analysis.

6. Conclusions

We analyze the echo characteristics of laser target by the principle of target detection based on laser measurement distance system in this paper. We construct the calculation model by analyzing the factors which will affect the output voltage of detector, when the transmit power of laser is constant, the output power of the detector is inversely proportional to the detection distance, the magnitude of the output power at the change process of the wavelength has a maximum value; The radiation intensity and the distance *R* from the target to detector both are inversely proportional to the wavelength λ, but the change rate of inverse proportion by the wavelength λ is higher than by the distance *R*. With the increase of the transmit power of laser, the output power and the radiation intensity of target echo is also increased. We have verified that the experimental data is consistent with the theoretical analysis and the experiment on the hardware platform. In view of the above analysis, we provides a theoretical basis about improving performance of detection part of laser measurement distance system, and uses the Fisher discriminant method of the Wavelet analysis and wavelet maxima method for echo signal to discriminate and distinguish, and improves the reliability of echo signal. So laser detection part can provide better service for the whole laser measurement distance system.

Acknowledgments

This work has been supported by Project of the Foundation of Department Education of Shaanxi Province of China (No. 2013JK1082) and the National Natural Science Foundation of China (No. 61107079).

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