Infrared Physics & Technology 88 (2018) 174–183

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Regular article

Single pulse threshold detection method with lifting wavelet denoising based on modified particle swarm optimization

Xiaobin Xu

College of Mechanical and Electrical Engineering, Hohai University, Changzhou 213022, China

HIGHLIGHTS

- Random threshold method with lifting wavelet denoising algorithm is proposed.
- The optimal denoising performance is realized based on MPSO algorithm.
- Echo signal could be detected more efficiently using proposed method in low SNR.

ARTICLE INFO

Article history:
Received 28 August 2017
Accepted 17 November 2017
Available online 21 November 2017

Keywords:
Laser radar
Weak signal detection
Wavelet denoising
Particle swarm optimization

ABSTRACT

We proposed a single pulse threshold detection method with lifting wavelet denoising algorithm based on modified particle swarm optimization (MPSO). The detection probability and false alarm probability of single pulse fixed threshold, variable threshold and random threshold detection were simulated and analyzed. The results show that in the condition of low signal-to-noise ratio (SNR), false alarm probability can be constant, and the detection probability of the target detection could be effectively enhanced using random threshold detection. But random threshold detection method has defect. Therefore, the modified lifting wavelet adaptive nonlinear denoised algorithm was put forward with MPSO. The simulation and experimental results show that the algorithm can make up defect of random threshold detection and effectively improve the SNR of echo signal. It provides theoretical basis and implementation method for weak echo signal detection.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Laser radar (LADAR) is widely used in various fields, including remote sensing [1,2], 3D imaging [3,4], and target tracking, etc. [5]. In direct detection of laser radar, the distance between laser radar and target is calculated using time of flight (TOF) method, which measures round-trip time between short-duration emitted pulse and reflected pulse [6]. It has been noted that the precision and detection probability of TOF method is determined by SNR of echo signal, which is easily affected by detection distance, target characteristics and noise [7]. Especially, in low SNR, echo signal of laser radar is buried in noise, and the target could not be detected. Therefore, it is crucial to improve detection probability and SNR using several methods for recognizing the target.

Presently, there are a number of researches available that use statistical theory to improve the detection probability. Gatt deduced the probability of detection (PD) and false alarm (PFA) using fixed threshold for laser coherent and direct detection [8]. Moreover, he compared performance of coherent and direct detection. Compare with fixed threshold method, Johnson [9] and Wu [10,11] improved PD in low SNR using random threshold method and variable threshold method respectively. However, limitations of both methods reduced the performance margin on account of lack of denoised process for echo signals. Therefore, there are a lot of studies to improve SNR. Cao proposed a dual channel differential optical path ranging method to reduce the influence of background noise and gain high SNR at long range [12–14]. Furthermore, Kong [15,16] proposed a new method to obtain a clear 3D image despite the high noise by dividing a laser-return pulse into two Geiger mode avalanche photodiodes (GmAPDs). Both of them used differential optical method to achieve the high accuracy of laser ranging. However, the echo energy is decreased by half, and the maximum detection range is restrained owing to finite laser power. Compared with the optical method, more researches improve SNR using signal processing algorithms. Zhou, Fang and Li employed soft thresholding wavelet de-noising for lidar echo signals to realize weak signal detection, and improve the SNR [17–19]. However, limitation exists in soft thresholding method, which is not derivable at the piecewise points. The

E-mail address: xxbtc@hhu.edu.cn

https://doi.org/10.1016/j.infrared.2017.11.023
1350-4495/© 2017 Elsevier B.V. All rights reserved.

denosing performance is restricted. Chen put forward the non-uniformly spaced multi pulse algorithm, which could avoid the reduction of PD caused by superposition of false alarm [20]. But multi pulse signals could not meet the demand of high real-time condition. In summary, many methods or algorithms are used to realize extraction of weak signal using denoising, signal enhancement or statics theories individually. Under the circumstance of real-time and no losing laser energy, a new hybrid method needs to be put forward to realize extraction of signal in low SNR.

In this paper, in Section 2, the PD and PFA of single pulse fixed threshold, variable threshold and random threshold method are deduced and simulated. In Section 3, the modified thresholding function is proposed. Meanwhile, MPSO is integrated into lifting wavelet denoising algorithm to search the optimal threshold and reach optimum effect. In Section 4, experiments and simulations are verified superiority of proposed hybrid algorithm. In Section 5, conclusions are listed, which suggest the proposed hybrid algorithm can gain high SNR and improve the detection probability in the case of low SNR.

2. Statistical theory

The noisy received signal is

$$V_{sn}(t) = V_s(t) + V_n(t) \tag{1}$$

where $V_s(t)$ is laser received signal, and $V_n(t)$ is white Gaussian noise voltage.

The thermal and shot noises of LADAR system are considered as zero mean Gaussian white noises. The probability density function of noises can be presented as

$$p(V_n(t)) = \frac{1}{\sqrt{2\pi}\bar{V}_{n1}} e^{-\left(\frac{V_n^2(t)}{2\bar{V}_{n1}^2}\right)} \tag{2}$$

where $\bar{V}_{n1}$ is root mean square (RMS) voltage of system noise without received signal.

PFA is

$$P_F = \int_{V_{th}}^{\infty} p(V_n(t))dV_n(t) = \frac{1}{2} - \frac{1}{2} erf\left(\frac{V_{th}}{\sqrt{2}\bar{V}_{n1}}\right) \tag{3}$$

If fixed threshold method is used, the PD is [21]

$$P_D = \int_{V_{th}}^{\infty} p(V_{sn}(t))dV_{sn}(t) \tag{4}$$

It is assumed that the received signal is

$$V_s(t) = V_P \exp\left(-\frac{(t-t_e)^2}{2\sigma_e^2}\right) \tag{5}$$

where V_p is peak voltage of received signal, σ_e is pulse width of received signal, and t_e is peak time.

By substituting Eq. (5) into Eq. (4), the PD is

$$P_D = \frac{1}{2} + \frac{1}{2}\mathrm{erf}\left(\left(V_P \exp\left(-\frac{(t-t_e)^2}{2\sigma^2}\right) - V_{th}\right) \Big/ \sqrt{2}\bar{V}_{n2}\right) \tag{6}$$

where erf() is the error function, and $\bar{V}_{n2}$ is RMS voltage of system noise with received signal. The threshold-to-noise ratio (TNR) is defined as the ratio of threshold voltage to the equivalent RMS voltage of system noise in this paper.

The effective detection probability is defined as the maximum detection probability at the peak time, and the probability density function of the noisy received signal is

$$p(V) = \frac{1}{\sqrt{2\pi}\bar{V}_{n2}} \exp\left(-\frac{(V-V_p)^2}{2\bar{V}_{n2}^2}\right) \tag{7}$$

PD is

$$P_D = \frac{1}{2} + \frac{1}{2}\mathrm{erf}\left(\frac{V_P - V_{th}}{\sqrt{2}\bar{V}_{n2}}\right) \tag{8}$$

2.1. Variable threshold detection

According to decision rule, which is known as *Bayes rule* for H_0 verse H_1, minimizing the average cost C_m, which could achieve the best detection of signal status, is [22]

$$C_m = c_{00}P(H_0) + c_{01}P(H_1) + \int_{R_1} [P(H_0)(c_{10} - c_{00})p(k|H_0)] - [P(H_1)(c_{01} - c_{11})p(k|H_1)]dk \tag{9}$$

where $P(H_j)(j = 0, 1)$ is prior probability when hypothesis H_j is true, $c_{ij}(i, j = 0, 1)$ is cost factor of a decision, and R_1 is observation space when hypothesis H_1 is true.

Then the optimal decision type under Bayes decision rule is [22]

$$\lambda(k) = \frac{p(k \mid H_1)}{p(k \mid H_0)} \underset{H_0}{\overset{H_1}{\gtrless}} \frac{P(H_0)(c_{10} - c_{00})}{P(H_1)(c_{01} - c_{11})} = \eta \tag{10}$$

where $\lambda(k)$ is likelihood ratio, and η is likelihood ratio threshold.

According to the maximum likelihood principle of binary signal, the prior probability $P(H_j)(j = 0, 1)$ is equal. $c_{ij} = 1 - \delta_{ij}(i, j = 0, 1)$, where $\delta_{ij} = 1, i = j$; $\delta_{ij} = 0, i \neq j$, $\eta = 1$.

By substituting Eqs. (2) and (7) into Eq. (10), the Eq. (10) is rewritten as [10]

$$l(V) = \ln\lambda(V) = \ln\frac{1}{\sqrt{2\pi}\bar{V}_{n1}}\exp\left(-\frac{V^2}{2\bar{V}_{n1}^2}\right) - \ln\frac{1}{\sqrt{2\pi}\bar{V}_{n2}}\exp\left(-\frac{(V-V_p)^2}{2\bar{V}_{n2}^2}\right) \underset{H_0}{\overset{H_1}{\gtrless}} 0 \tag{11}$$

The Eq. (11) can be simplified as

$$(\bar{V}_{n2}^2 - \bar{V}_{n1}^2)V^2 + 2VV_p + 2\bar{V}_{n2}^2\bar{V}_{n1}^2 \ln\frac{\bar{V}_{n1}}{\bar{V}_{n2}} - V_p^2 = 0 \tag{12}$$

We can rewrite the Eq. (12) as

$$a_T V_T^2 + b_T V_T + c_T = 0 \tag{13}$$

where $a_T = (\bar{V}_{n2}^2 - \bar{V}_{n1}^2)$, $b_T = 2V_p$, $c_T = 2\bar{V}_{n2}^2\bar{V}_{n1}^2\ln(\bar{V}_{n1}/\bar{V}_{n2}) - V_p^2$.

The solution is:

$$V_T = \frac{\sqrt{b_T^2 - 4a_T c_T} - b_T}{2a_T} \tag{14}$$

2.2. Random threshold detection

The Neyman-Pearson criterion requires that the false alarm probability is lower than a specified value α [22]. α is substituted into Eq. (3)

$$\frac{1}{2} - \frac{1}{2}\mathrm{erf}\left(\frac{V_{th2}}{\sqrt{2}\bar{V}_{n1}}\right) \leqslant \alpha \tag{15}$$

To maximize the detection probability, the Eq. (15) is rewritten as

$$\frac{1}{2} - \frac{1}{2}\mathrm{erf}\left(\frac{V_{th2}}{\sqrt{2}\bar{V}_{n1}}\right) = \alpha \tag{16}$$

2.3. Simulation experiment analysis

The parameters are set as: $V_{th} = 0.2$ V, $\bar{V}_{n1} = 0.05$ V, $\bar{V}_{n2} = 0.055$ V, $\alpha = 10^{-4}$. Detection probabilities of different

Download English Version:

https://daneshyari.com/en/article/8146133

Download Persian Version:

https://daneshyari.com/article/8146133

Daneshyari.com