High Accuracy Algorithm of Laser Ranging Based on Wavelet Threshold Denoising

Zhihui DAI, Wenbin LI, Jiangming KAN, Chaoyi ZHANG※

***Abstract*—**In the dynamic laser ranging process of wireless remote control forest fire vehicle measuring obstacle, the effective signals were usually affected by the obstruction, reflection and other conditions of environment in the transmission process, the fire engine can not acquire the echo signals. In order to solve this problem, a new method which based on wavelet transform was proposed to obtain the time interval accuracy of echo signal. The echo signal noise of dynamic pulse laser was processed. Aim at the advantages and disadvantages of tradition soft and hard threshold denoising method, a new threshold function was proposed, and a new design method of wavelet optimal decomposition level was constructed. Based on this method, the new threshold function was compared with the soft and hard threshold function under simulation experiment. Experiments show that accuracy of laser ranging system can achieve 0.1m, which satisfied the fire with electro-optical observation and aim system equal or less than 0.5m ranging accuracy requirement, achieved the purpose of noise reduction. The new threshold function had obvious improvement compared to the soft and hard threshold function, and it was a more flexible choice between them.

***Keywords*—**Laser ranging, echo noise, wavelet transform, threshold function

I. Introduction

In the forest fire fighting process, the target obstacle safe distance measurement was an important part of security. Forest wireless remote control fire fighting vehicle used photoelectric detection system, calculated the effective safety distance from the target object (such as trees, buildings, etc.) by laser ranging, so as to be able to make the quickly decision and judgement. The accuracy of laser ranging was very important for the safety of whole detection system [1-2]. Some detected targets cannot be effectively reflected electromagnetic wave signal, laser range finder cannot directly measure it, so wireless remote control fire engine was around the object location, and taken this as the basis for calculation safety distance of the fire truck to the target. Forest fire truck on judgment of obstruction in the ranging accuracy, but also required ranging system could be used to measure the efficiency of larger measurement range, so wireless remote control forest fire engines ranging probe improved laser ranging and also needed to take into account the measurement range, which on the fire truck laser measured from the safety distance design to increase the difficulty [3-5]. This paper was based on the forest fire engine system structure and working principle, designed movement of wireless remote control fire engine control system, applied to forest security ranging system installed in the fire vehicle motion control platform. Through the motion coordination system, wireless remote control was realized, an effective solution solved the fire brigade and fire control technicians dangers at the scene.

At present, the research of laser measuring safe distance, common methods included: the ranging controller timing clock frequency was improved to promote measurement precision [6−7], but frequency increasing caused jitter signal distortion larger, with detection error data increasing. And the current improvement measurement algorithm included: wavelet transform analysis method [8−9], Kalman filter [10−11], least squares method [12−13] contours of target buildings or obstacles to make accurate measurements. And from the count quantization error can be effectively reduced to proceed, such as simulation interpolation method [14−15], parallel counting method [16−17] and so on, these methods usually subjected to noise, interference and conversion condition control, resulting in inaccuracy of measurement. In recent years, due to the digital signal processing technology and related chip, greatly improved the photoelectric response time and distance measurement accuracy, based on DSP, FPGA, such as the laser distance measuring instrument.

In this paper, some factors that affect the accuracy of dynamic ranging are analyzed on the basis of improving laser ranging. In the moving process of fire engines, target peripheral obstruction and laser ranging probe was relative motion, a laser range finder pulse signal cycle was very short, which required signal processing the shorter response time. The effective transmission signal will generally be obstacle in the environment such as interference, reflection and other conditions, making the fire engine cannot get echo signal. In order to solve this problem, a method based on wavelet transform was proposed to obtain the time interval accuracy of echo signal to achieve the purpose of reducing noise. Wavelet denoising algorithm can retain original signal characteristics, the principle was to put wavelet space and original signal space mapping relations as a function approximation principle. The method can accurately measure the arrival time and fast response of echo signal in order to improve the ranging accuracy.

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II. Laser Ranging Precision Measurement

A. Factors of Affecting Laser Ranging Accuracy

The pulse laser ranging principle was to measure the time delay between transmitted pulse and echo pulse T_d , and then measuring the object distance with the speed of light c and T_d , which was $s = c \cdot T_d / 2$. The accuracy of T_d will be greatly affected by the distance measurement.

At present, counting measurement method was mainly used in calculation T_d , the specific realization was: the laser emission counter from laser main pulse began counting (denoted as C_{send}), and by the echo pulse to counter stopped counting (denoted as $C_{receive}$), by this two difference multiplied by counting clock cycle was the time delay T_d , that is:

$$T_d = T \cdot (C_{receive} - C_{send}) \qquad (1)$$

Where T is clock cycle. The counter counts were from the start of main laser wave pulse, and in fact, a laser pulse in amplitude and time, there were two kinds of influencing measurement error factors: one was the laser echo by obstructions, around the object reflection effect and the pulse echo frontier was not strictly a square wave, it was some distortion, so when the echo pulse and setting threshold value were compared, allowed the exceed threshold value pulse to start counter, there was distortion of echo pulse trigger counter timing error exists, resulted in pulse echo amplitude different trigger instability. At present, there were some methods to solve these problems, such as constant time trigger [18], arithmetic timing trigger [19] and so on. Another factor was the count quantization error, because the main laser wave and echo front arrival time cannot be synchronized with clock counting, so there must be a random error between laser pulse and technology clock, i.e. count quantization error [20], then main wave probe laser emission and pulse echo produced certain error, affected the measurement accuracy. The relationship among main wave, received echo and counting clock was shown in Fig.1.

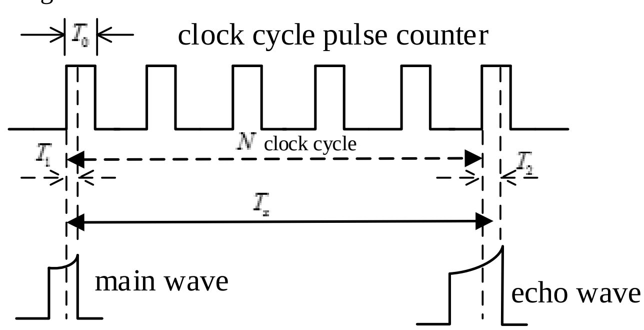


Fig.1 Laser main wave, echo and counter clock sequence

In Fig.1, counter clock cycles was T_0 , the time interval between main wave and echo was T_x , the time interval between main wave front and the first effective counting pulse was T_1 , time interval between echo frontier and last count pulse was T_2 , in the counting pulse sequence N , T_x was:

$$T_x = NT_0 + T_1 - T_2 \qquad (2)$$

Where, T_1 and T_2 value were random variation, i.e. count quantization error. Under normal circumstances, the approximation was $T_x = NT_0$.

B. Laser Ranging Accuracy Improvement

Restrictions to reduce the count quantization error, the most direct way was to increase the counting pulse frequency, but it also increased by a variety of factors, for example, if the count quantization error was restricted about 0.1M by ranging accuracy, to which required counting pulse frequency 1500MHz. This was very difficult to achieve, and the resulting electromagnetic interference, circuit complexity and other issues will be very difficult to solve, so by improving the counting pulse frequency method to improve the accuracy was not realistic, only through a certain method for real-time measurement of counting process to quantify the error in each round, and then the counting result was modified in order to acquire more accurate measurement results.

In this paper, the digital insertion method was used to realize the accurate measurement. As shown in Fig.2, the basic principle of this method was: under the precise clock pulse signal, the coarse counter recorded the number of integer clock pulse cycle between the start pulse signal and end pulse signal, coarse counter output $t = NT_0$ to the buffer, and a margin less than a clock pulse cycle between the measured start and end time, was sent to the interpolation unit for precise calculation, the interpolation units were output T_1 and T_2 to buffer cache, finally, the processor calculated $T_1 - T_2$, the coarse counter output t was modified to obtain accurate time interval results. The significant advantage of this method was that it can satisfy the requirement of range and resolution.

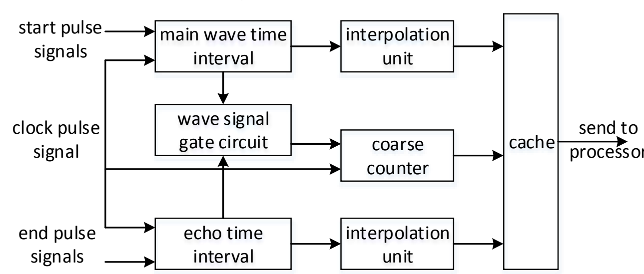


Fig.2 Schematic diagram of digital interpolation method

As far as possible, in order to improve the counting pulse frequency, and no circuit influence such as electromagnetic interference, increased circuit complexity, this paper set the counting pulse frequency as 150 MHz, which was a pulse cycle corresponds to 0.5m distance accuracy. The counting pulse frequency was set up by the circuit. Interpolation unit was used to realize precise measurement of key components, and the method of delay line interpolation based on programmable logic device was adopted.

III. Wavelet Denoising Principle

This paper was established on the dynamic distance measurement method, the measured object was relative motion with the laser ranging probe. And the laser ranging finder pulse signal cycle was very short, which required signal processing shorter response time. The echo signals usually received noise signal interference in the return trip, which making the receiver cannot acquire accurate echo signals. This was needed to improve the signal to noise ratio (SNR) to reduce the echo signals' time interval and promoted the measurement accuracy. Using wavelet denoising algorithm, from the view of signal analysis, its denoising was equivalent to low pass filter, which can suppress the noise, accurate the echo signals arrival time, and retain the original signal's characteristics. From the numerical point of view, it can be considered as a function approximation, which was based on the using of wavelet function to carry out the rules, such as stretching and translation, to find the best original function approximation.

A. Decomposing of echo signal

One-dimensional signal model with noise can be expressed as:

$$s(k) = f(k) + \varepsilon \cdot e(k) \quad , \quad k = 0,1,\cdots n-1 \qquad (3)$$

Where, $s(k)$ was the echo signal, $f(k)$ was the useful signals, and $e(k)$ was the noise signals. $e(k)$ usually was expressed as high-frequency signals. In practice, $f(k)$ usually was the low frequency signals or some more stable signals. The principle of denoising principle was: first, the signals were taken wavelet transform, the decomposition process was shown in Fig.3. Decomposition was a three layer structure, the noise signals frequencies were mainly concentrated in high frequency $e_1(k)$, $e_2(k)$ and $e_3(k)$, which should accord to the size of amplitude and frequency, through frequency filtering to achieve noise reduction purposes. The specific method was setting frequency threshold value, dealing with coefficients of decomposed signal's wavelet form, then the signals were reconstructed. The process of denoising was actually an effective suppression of signal in the invalid frequency components, reappeared the signal's useful frequency components.

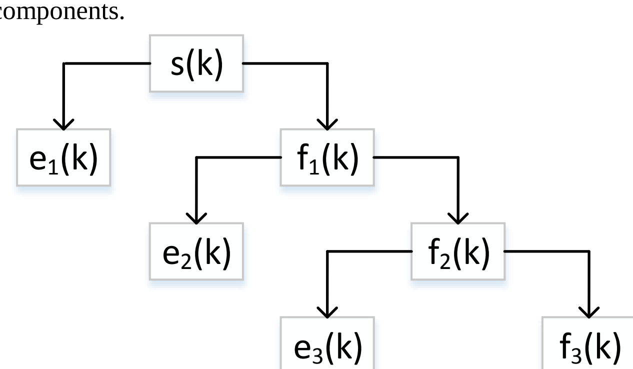


Fig.3 Signal's three layer wavelet decomposition

B. Wavelet de-noising threshold function and its improvement

According to the above principle, using wavelet denoising threshold selection algorithm which based on soft threshold and hard threshold was proposed by Donoho[21] and others. The method not only can effectively suppressed the noise, but also can very good restored characteristics of origin signal peak reduction. On the basis of this paper, a new threshold function of wavelet denoising method was proposed, and acquired a good denoising effect.

First, the hard threshold function method was that the following threshold function constructed, as the wavelet coefficient of the selection rules:

$$w_{ab} = \begin{cases} w_{ab}, |w_{ab}| \geq \lambda \\ 0, |w_{ab}| < \lambda \end{cases} \qquad (4)$$

Where, λ was the wavelet transform coefficient, w_{ab} was the wavelet transform coefficients, and w_{ab} was the wavelet coefficients by which processed the threshold. From Eq.(4), when the wavelet coefficient w_{ab} was less than a certain threshold value, the noise component can be 0, and the noise reduction was achieved.

Secondly, according to the performance of the wavelet and noise statistical characteristics, the soft threshold function method can set the appropriate threshold to eliminate the noise, and recover the performance of wavelet method. Its construction threshold function was as follows:

$$w_{ab} = \begin{cases} sgn(w_{ab}) \cdot [|w_{ab}| - \lambda] \quad , |w_{ab}| \geq \lambda \\ 0 \quad , |w_{ab}| < \lambda \end{cases} \qquad (5)$$

Where $sgn(w_{ab})$ was the symbolic function, if wavelet coefficient was greater than the threshold, we used the threshold to reduce processing, wavelet coefficients less than the threshold was 0.

In addition to the hard and soft threshold method, some scholars put forward some improvement measures, such as the improvement of mode square threshold function [22], the method of improving soft and hard compromise[23]. Although the hard threshold and soft threshold methods were better, and the noise reduction algorithm in laser ranging had a good application, but its own function still had a large error, which restricted the development of further noise reduction. In the hard threshold function, the wavelet coefficients were not continuous in the setting of the threshold value. In soft threshold function, the wavelet coefficients were processed by the soft threshold function, which made the difference between the initial wavelet coefficients and quality of signal reconstruction. In practical application, the threshold function of one order or higher order were calculated, soft thresholding function did not have operation and continuous function derivation, it also limited the application of soft threshold function.

In view of existing problem with hard threshold and soft threshold to the noise function, this paper presented a new thresholding function, this function was constructed based on the corresponding improvement with original function, and solved the hard thresholding wavelet coefficients not continuous problem, soft threshold's w_{ab} and w_{ab} deviation, and the problems of continuous function derivation, the new threshold function expressions were as follows:

$$w_{ab}=\begin{cases} sgn(w_{ab})\cdot\left[\,|w_{ab}|-\dfrac{\lambda}{\ln(\dfrac{|w_{ab}|-\lambda}{|w_{ab}|-n\lambda})}\right] & ,|w_{ab}|\geq\lambda \\ w_{ab}^{\frac{1}{\lambda}\ln(\left|\frac{\lambda}{w_{ab}}\right|^{n}+\varepsilon)} & ,|w_{ab}|<\lambda \end{cases} \quad (6)$$

(1) when $|w_{ab}|\geq\lambda$, set $e=\frac{|w_{ab}|-\lambda}{|w_{ab}|-n\lambda}$, then $n=\frac{e-1}{e}\cdot\frac{|w_{ab}|}{\lambda}+\frac{1}{e}$, assumption that $\alpha=\frac{e-1}{e}\cdot\frac{|w_{ab}|}{\lambda}+\frac{1}{e}$, then with λ changing, $n\in(1,n)$. By Eq.(6), we can see that the new threshold function was continuous, which was accordance with soft threshold function. In the high-order missile, Eq.(6) satisfied when the wavelet coefficients $|w_{ab}|\geq\lambda$, it had high order derivative characteristics, which made the new threshold function in the numerical calculation can be achieved. From Eq.(6), the threshold function can be obtained in the case of a lower threshold λ, which was similar to the hard threshold function. Moreover, Eq.(6) had a higher flexibility than Eq.(4), especially when the wavelet coefficients $|w_{ab}|$ were equal to the threshold value λ. After threshold function processing, the wavelet coefficient w_{ab} was approximately equal to w_{ab}, rather than 0. By observing Eq. (6), the following can be obtained.

$$\lim_{n\to 1} sgn(w_{ab})\cdot\left[\,|w_{ab}|-\frac{\lambda}{\ln(\frac{|w_{ab}|-\lambda}{|w_{ab}|-n\lambda})}\right]=sgn(w_{ab})(|w_{ab}|-\lambda) \quad (7)$$

$$\lim_{n\to\alpha} sgn(w_{ab})\cdot\left[\,|w_{ab}|-\frac{\lambda}{\ln(\frac{|w_{ab}|-\lambda}{|w_{ab}|-n\lambda})}\right]=w_{ab} \quad (8)$$

Eq. (7) under the condition of infinite n, i.e. $n\to 1$, the new threshold function was equivalent to the soft threshold Eq. (5), and Eq. (8) under the condition of $n\to\alpha$, the new threshold function was equivalent to the hard threshold Eq. (4). Therefore, the new threshold function expression only need to change n 's value according to actual situation can better achieve noise reduction.

(2) when $|w_{ab}|<\lambda$, the new threshold function expression $w_{ab}^{\frac{1}{\lambda}\ln(\left|\frac{\lambda}{w_{ab}}\right|^{n}+\varepsilon)}$ was a function of n time, it was a high order derivative. From Eq. (6), when $|w_{ab}|<\lambda$, there had $\ln(\left|\frac{\lambda}{w_{ab}}\right|^{n}+e)>1$, thus $w_{ab}^{\frac{1}{\lambda}\ln(\left|\frac{\lambda}{w_{ab}}\right|^{n}+\varepsilon)}\neq 0$. This overcame the truncation error caused by hard threshold and soft threshold method, which was well approximated and preserved the information of original signals.

IV. Simulation Result Analysis

A. Testing & Simulation of echo signal

In this research, the SNR was defined as:

$$V_{SNR}=10\lg\left[\frac{\sum_{n=0}^{N-1}s^{2}(\mathrm{n})}{\sum_{n=0}^{N-1}[s(\mathrm{n})-\tilde{s}(\mathrm{n})]^{2}}\right] \quad (9)$$

Where $s(\mathrm{n})$ was the original signal, $\tilde{s}(\mathrm{n})$ was the estimated signal after wavelet denoising. Using MATLAB, the echo signal was processed by the laser range finder on the fire truck, and the signal was white noise, the SNR was 18.6339dB.

The threshold was based on hard threshold function, soft threshold function and this paper's new threshold function, the parameters of echo signal with noise were selected as α =0. 3, k =0. 9, n =15. The number of wavelet decomposition layer number was given in this paper (section 3.A). The simulation experiment was carried out. The wavelet base was $e_1(k)$, and the result was shown in Fig.4.

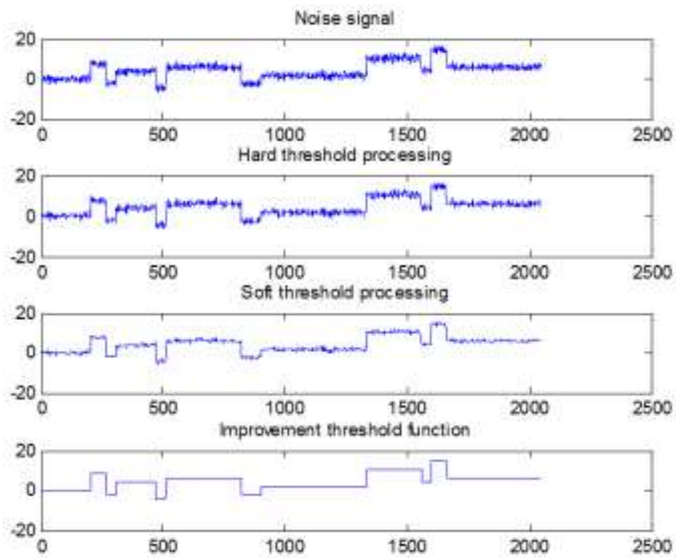


Fig.4 The processing effect of echo signal with noise by different threshold method

From the results of Fig.4, the improved algorithm of threshold function can achieve satisfactory results in the field of signal denoising, and the signal of hard threshold denoising was still obvious. But hard threshold can preserve the singular point of signal. Therefore, the improved wavelet denoising algorithm can well balance the advantages of soft and hard threshold algorithm, to achieve the good effect of denoising.

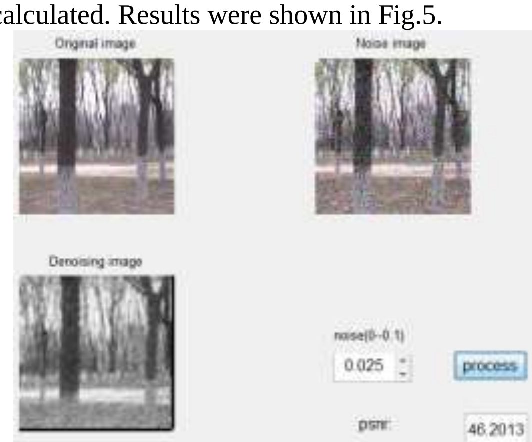
Table 1 Peak signal to noise ratio of various algorithms to denoising

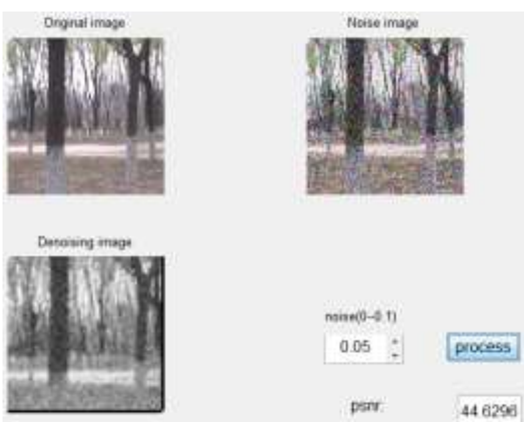
Gauss noise	0.025	0.05	0.075	0.1
Hard threshold processing	20.12	16.78	14.32	12.07
Soft threshold processing	24.87	19.98	17.73	14.58
Improvement threshold function	25.67	23.83	22.91	20.18

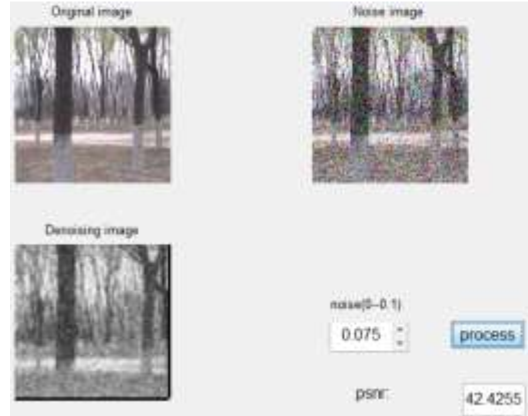
Table 1 was the test of each algorithm peak signal to noise ratio (PSNR) value, the variety of threshold method value described noise peak value. The better denoising effect, the SNR was higher, and the power of noise was smaller. By Table 1's PSNR analysis, for the processing of different Gauss noise, the signal of using wavelet de-noising effect was obvious. The signal was more close to the original data.

B. Testing & Simulation of image denoising

In addition, this paper also used the threshold method to deal with the image data, the method can also deal with the image data collected from fire engine, and the role of target object was accurate positioning and reduction. MATLAB was used to process a noise picture and noise reduction, we set the noise properties of image between 0 and 0.1 (not zero), wavelet transform was used to its hierarchical processing, the scale vector and improved threshold vector were set (see Eq. (8)), the updated wavelet decomposition structure was taken threshold processing, then taken the median filter, and finally get the noise image. PSNR value was calculated. Results were shown in Fig.5.







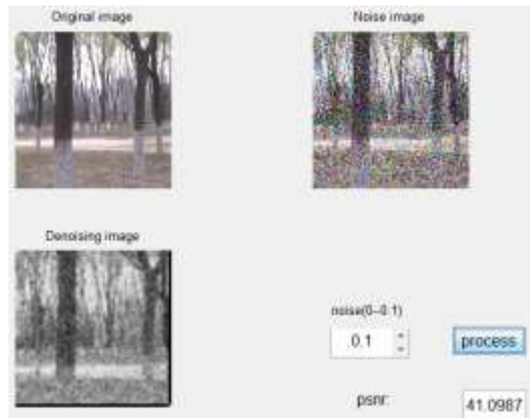


Fig.5 Processing effect of image signal with noise by improvement threshold method

From Fig.5, it can be seen that the threshold function on the image's SNR effects was also good, with the noise increasing (from 0.025 to 0.1), image signals are less clear, but through the wavelet transform and the threshold processing functions, the screening was finally obtained the picture quality was closer to the original data, little change in error, which in the fire truck to target obstacle monitoring mobile environment, fast processing took pictures with good reduction.

V. Conclusion

In this paper, the high accuracy algorithm of laser ranging was designed, which was based on wavelet theory. A new threshold function was proposed, which was based on this method. In range test of laser ranging system, the establishment of sectioned linear fitting to the measured data was modified, ultimately through verification test shown that, the accuracy of laser ranging system can achieve 0.1m, meet the fire with electro-optical observation and aiming system was equal to or less than 0.5m, ranging accuracy requirements. In this paper, the new threshold function had obvious improvement compared to the soft and hard threshold function, it was a more flexible and favorable choice between them, and it had a broad application prospect in engineering practice.

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