Hanshan Li, Zhiyong Lei, Zemin Wang, Junchai Gao
School of Electronic Information Engineering, Xi'an Technological University, Xi'an, China

Research on Objection Information Extraction Arithmetic in Photo-electric Detection Target Base on Wavelet Analysis Method

***Abstract:** To improve measurement precision and solve the question on projectile information extraction when projectile go through detection screen of photoelectric detection target, the wavelet analysis method was applied to process its information and look for its starting time in screen. The detection principle of photoelectric detection target was analyzed, the characteristic of wavelet analysis method and LMS adaptive filtering algorithm were used to research and analyze the output signal of photoelectric detection target. According to the output signal characteristic of photoelectric detection target, the wavelet transform modulus maxima theory and singularity position point were applied to search out signal's start moment that projectile flying through detection screen, and ensure start moment and calculate time value between detection screens. Base on test velocity principle and experimentation, wavelet analysis method is compared with the traditional nose trigger extraction method, the precision of measuring velocity is less than 0.2%, which verifies wavelets analysis method to extract the photoelectric detection target detection information is feasible and correct.*

***Streszczenie.** W artykule analizowane są metody analizy obrazu detekcji fotoelektrycznej w przypadku poruszającego się szybko obiektu, takiego jak n. pocisk. Do analizy wykorzystano transformatę falkową oraz algorytm filtrowania LMS. (**Badania możliwości ekstrakcji informacji z obrazu czujnika fotoelektrycznego przy wykorzystaniu transformaty falkowej**)*

Keywords: wavelet analysis method, photoelectric detection target, projectile, information extraction
Słowa kluczowe: analiza falkowa, obraz czujnika fotoelektrycznego

1.Introduction

Photoelectric detection target is a detection instrument and its core of the detection is photoelectric detector, it can work normally under passive and active light source, no matter what kind of light source, its principle is the same, namely, when projectile flying detection screen, the image facula of projectile make the photoelectric detector output an instant change signal, the signal was processed and output a pulse in detection circuit [1]. The multi-screen measure system use these signal to calculate and process projectile parameter. However, the tradition photoelectric detection target has many shortcomings, such as, the detection sensitivity low, the structure complex, operation discommodiousness, and so on [2], which affect the detection performance and using. According to the measurement of projectile parameter requirements, we can design multi-screen measure system based on single photoelectric detection target and set up projectile dynamic parameter measurement mathematical model, for example, the use of two photoelectric detection target in space make their screen parallel which can measure the projectile flying velocity; using four or six photoelectric detection target make their screen form intersection layout can gain projectile two-dimensional coordinates and fire target density, and so on [3]. But, there are some demerits in measure system of photoelectric detection target, such as, its precision low, layout difficulty, especially, measurement precision restrict its development.

to improve the measurement accuracy of photoelectric detection target measure system, projectile information extraction is crucial in photoelectric detection target. When the screen geometric array was ensured in multi-screen measurement system, measure parameter's precision were infected by between the timing precision in detection screen, and the influence factors have the timing precision, detection screen thickness inconsistencies and flight projectile not vertically go through detection screen, those influence factors will cause output signal difference in output detection circuit, if using conventional extraction timing signal position algorithm will cause very big error, conventional extraction method have projectile's tail trigger, nose trigger, middle trigger [4-5]. Those information extraction methods will lead to different screen between the timing errors, because the output signal are inconsistent when projectile flying different detection screen and make extract timing signal start position exist difference.

In this paper, wavelet transform method was applied to analyze the output signal timing position information extraction to avoid bring error by using the same comparison voltage values to extract information insufficient.

2. The theory on projectile information acquisition

The PDT is mainly composed of the optics lens, the slit diaphragm, the photoelectric detection component, the processing circuit[6], it may described by figure 1.The lens can gain the image information of flying projectile under a distance, which is very key detection parts in photoelectric detection target's design, it is advantageous to collect incident light energy. The silt diaphragm is a parts to form the detection screen, when projectile flying the detection screen, the photoelectric detection component will gain the variation light signal, this signal is disposed and turn to a impulse signal, this signal is used to touch off the timer instruments, which offer the time to the measurement parameter system, and combine the geometry structure of across screen measure system to calculate velocity and coordinate when projectile passing screen.

Under the same focus condition, the longer of slit diaphragm, the wider of detection view, but the length of photoelectric detection component and the lens parameter have limit, the slit cannot infinite or the random length, generally the length of slit diaphragm and photoelectric detection component's photosensitive length is equal .

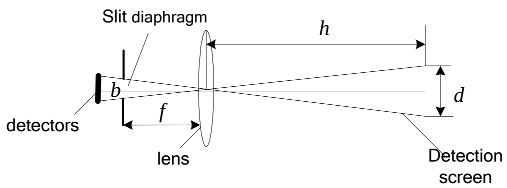

Fig.1 The work principle on photoelectric detection target

The width of silt diaphragm affect the thickness of PDT, and the thickness screen affect the measure precision, when the focus of lens f was ascertain, if h is distance between projectile and lens, d is the thickness in distance h， b is width of silt diaphragm. d may be expressed by formula (1).

(1) $$d = h \cdot b / f$$

From formula (1), we know the d has proportional with h and b.

The photoelectric detection component is the most important in detection system; it will direct impact on the detection performance of photoelectric detection target[7]. According to its detection structure, we select appropriate optics detection component to design detection system.

When the projectile passes different detection screen thickness, there are three states between projectile length and screen thickness, the relation between the output current and time also have three states base on projectile length and screen thickness. According to fig.1, when $d < l$, l is length of projectile, the output DC level is very low, the amplitude of analog signals that photoelectric detector converted also is lower, because the projectile's image facual that photoelectric detector collect is very small, it show that is not make full use of the projectile length; when $d = l$, the output DC level is enhanced and reach the maximum value, the amplitude of analog signals also is maximum, because it is make full use of the projectile length; when $d > l$, DC level still are increased, but the analog signal amplitude are no further increase, the detection sensitivity may be put down. So, the parameter of slit diaphragm is very important in design.

From above analysis, because the height of flying projectile is different and projectile flight path have a certain angle, which will make the output signal also is difference. If we use conventional extraction timing signal position algorithm will make the timer causes big error between different screens, so, it is necessary to research a new method to extraction timing signal position to improve measurement precision. Follow, we introduce wavelet analysis method to extract projectile going through screen start information.

3. Wavelet transform principles and detection signal processing arithmetic

3.1 Wavelet transform

Supposed, $\psi(t) \in L^2(R)$， $\hat{\psi}(t)$ is its FFT，when $\hat{\psi}(t)$ meet the permit conditions[8]:

（2） $$C_\psi = \int_R \frac{|\hat{\psi}(\omega)|^2}{|\omega|} d\omega < \infty$$

Here, $\psi(t)$ is called a basic wavelet or mother wavelet, if the function of $\psi(t)$ is extended or translated, we will gain a wavelet series:

（3） $$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}} \psi(\frac{t-b}{a})$$

a , $b \in R$, $a \neq 0$. a is a telescopic factor, b is shift factor. For the discrete case, the wavelet sequence will transform to formula (4):

（4） $$\psi_{j,m}(t) = 2^{-j/2} \psi(2^{-j} t - g)$$

In formula (4), j is scale indicator, g is position indicator. For any function $f(t) \in L^2(R)$, its continuous wavelet transform can be expression (5).

(5) $$\psi_{a,b} \geq \frac{1}{\sqrt{|a|}} \int_R f(t) \psi(\frac{t-b}{a}) dt$$

According to the wavelet multi-resolution characteristics, if $x(t)$ is output signal of photoelectric detection target, we will $x(t)$ divide into two intersectio space decomposition step by step in $L^2(R)$, each input signal is decomposed into high-frequency detail signal and the low frequency approximation signal, output sample frequency will be halved, their basic relation can be expressed by formula (6) and (7)[9].

(6) $$x_{j+1,k}(t) = \sum_m g(m-2k) x_{j,m}(t)$$

(7) $$y_{j+1,k}(t) = \sum_m h(m-2k) x_{j,m}(t)$$

Here, $x_{j+1,k}(t)$ is approximate output signal in j+1 class, $y_{j+1,k}(t)$ is output signal in j+1 class, {$g(k)$} is two scale sequence, it was seen as a low-pass filter coefficient, {$h(k)$} is a high-pass filter coefficient, the entire process form a group of multiple sampling filter signal, formula (8) is *Mallat* reconstruction expression.

(8) $$x_{j+1,k}(t) = \sum_k x_{j,k}(t) g(m-2k) + \sum_k y_{j,k}(t) h(m-2k)$$

According to formula (8), we can gain original signal $x(t)$ in photoelectric detection target.

3.2 LMS adaptive filter arithmetic on projectile signal

The principle of LMS adaptive filter can be shown by figure 2, which is composed by two parts. One is adjustable weights of the transversal filter, their weights can be expressed by using $\omega_1(n), \omega_2(n), \ldots, \omega_M(n)$ at the time of n ; Second is weight adjustment mechanism by using LMS adaptive algorithm. LMS adaptive transversal filter is a closed system, its weight vectors are related to input data and output signals[10]. Suppose, $x(t)$ is output signal of the photoelectric detection target, $x(n)$ is its discrete function in figure 2, its vector can be expressed by equation (9).

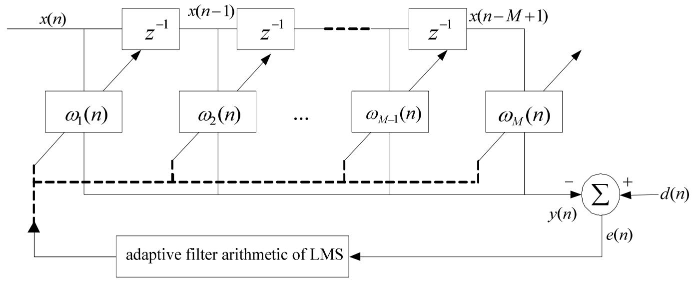

Fig.2 The principle of adaptive transversal filter

(9) $$X(n) = [x(n) \quad x(n-1) \quad \ldots \quad x(n-M+1)]^T$$

If $W(n)$ is filter parameter vector, and $y(n)$ is its output, $d(n)$ is their output error.

(10) $$W(n) = [\omega_1(n) \quad \omega_2(n) \quad \ldots \quad \omega_M(n)]^T$$

(11) $$y(n) = \sum_{i=1}^{M} \omega_i(n) x(n-i+1) = W^T(n) X(n) = X^T(n) W(n)$$

(12) $$e(n) = d(n) - y(n) = d(n) - W^T(n) X(n)$$

We can use the least mean square (LMS) algorithm to gain the optimal weight coefficients of filter and improve detection signal in photoelectric detection target. The output of the filter mean square error $E[e^2(n)]$ can be expressed by equation (13).

(13) $$E[e^2(n)] = E[d^2(n)] - 2P^T W + W^T R_x W$$

In (13), P and R_x are called as cross-correlation vector of the desired signal and the input signal and correlation matrix of the input signal respectively, $P = E[d(n)X(n)]$, $R_x = E[X(n)X^T(n)]$.

B. Widrow and M. E. Hoff put forward the minimum mean square error (LMS) algorithm, their iterative formula can be expressed by equation (14)

(14) $$W(n+1) = W(n) - 2\mu e(n)X(n)$$

Here, μ is constringency factor, it denotes a physical quantity of iterative speed fast and slow, it is very key to select the value of μ, the bigger this value, the shorter adaptive time, and the faster adaptive process, but ,when μ is larger that will cause larger amount of imbalance, it make measurement system instable, when μ is smaller that make system stable and reduce amount of imbalance, adaptive process is correspondingly lengthened, so, the select of μ must meet the require of measurement system, under meeting precision condition, we should reduce adaptive time, if we want to make LMS algorithm converges to the mean value, μ must meet the condition of $0<\mu<2/\lambda_{max}$, λ_{max} is the largest eigenvalue of matrix R[11].

Through signal filter processing, and then, base on the modulus maxima of wavelet transform theory [12-13], we can looking for the start position of output signal singularity in photoelectric detection target. According to the modulus maximum amplitude, which will be changed with the scale rule, if n_0 is the mutation point in $x(n)$, then the point of n_0 in various scales near $\left|W_{2^j} x(n)\right|$ would have a local maxima, and this value will turn to small with the scale j, its maximum value point will converge to n_0, therefore, in measurement system of photoelectric detection target , we are combined with the filtered output signal and use the method of modulus maximum value of wavelet transform to detect projectile signal mutation point when projectile flying detection screen. This method can identify the projectile start position, and through the acquisition system sampling rate, we can calculate accurately the time value between detection screens to improve precision in measurement system.

3.3 the Analysis on detection signal modulus maximum and singularity

According to the theory of wavelet transform, the change rule of modulus maximum amplitude that along with the scale variation is decided by a signal in the mutation point of Lipschitz index α . Lipschitz index α is a measurement that denotes function local properties in maths. Supposed, n is non negative integer, $n < \alpha \le n+1$, if A and $B_0(>0)$ are two constants, $p_n(B)$ is polynomial of n, which make any $B \le B_0$ meet expression (15).

(15) $$\left|x(t_0+B) - p_n(t_0+B)\right| \le A\left|B\right|^{\alpha}$$

And then, the signal of $f(x)$ is Lipschitz index α in x_0 position, if the expression (15) come into existence to $x_0 \in (a,b)$, and $x_0 + B \in (a,b)$, we call $f(x)$ and α are coincident in betweent a and b. $p_n(t)$ is $x(t)$ the Taylor series expansing expression in t_0 position, $x(t)$ can be expressed by formula(16).

(16) $$x(t) = x(t_0) + a_1 B + a_2 B^2 + \cdots + a_n B^n + O(B^{n+1})$$

Supposed, $\psi(t)$ is continuously differentiable in time, and its attenuation rate is $O(1/1+t^2)$ in infinite distance, when t locate interval of $[a,b]$, and $f(t)$ meet Wavelet transform condition, which can be expressed by formula (17).

(17) $$\left|W_a f(t)\right| \le m a^{\alpha}$$

Here, m is constant, and then, when $a = 2^i$, formula (17) will turn to (18).

(18) $$\left|W_{2^j} f(t)\right| \le m(2^j)^{\alpha}$$

In formula(18), $j\alpha$ combine j and α , which give out the change rule between j and α , Then, the corresponding signal singularity characteristic based on wavelet transform modulus maxima changes should also satisfy this rule, When $\alpha > 0$, wavelet transform modulus maxima will augment with the j augmentation; or, $\alpha < 0$, wavelet transform will minish with the j lessening, if $\alpha = 0$, wavelet transform modulus maxima is not change.

According to the modulus maximum amplitude as the scale variation, if the time t_0 is mutate point of $f(t)$, then, all scale in $\left|W_{2^j} f(t_0)\right|$ near will bring local maximum under the time of and the scale of j will turn small that maximum converges to t_0 .Therefore, we can make use of the modulus maximum of wavelet transform to look up all the mutation point to detect the information that projectile flying detection screen start time. That is to say, the maximum value of wavelet transform modulus detect the projectile go through the detection screen that will bring mutation point to judgment its start time to calculate the time between two photoelectric detection target.

4 The projectile signal start position extraction algorithm

According to the modulus maxima of wavelet transform and measurement system of photoelectric detection target, we analyze the projectile information extraction method by using the parallel screen that can measure projectile's velocity; its measurement principle can be shown by fig.3. $x_1(i)$ and $x_2(i)$ are original signal from detection circuit, $y_1(i)$ and $y_2(i)$ are their filter output signal, $y_1(i)$ is start signal, $y_2(i)$ is stop signal, $i = 0,1,2,\cdots,n$. Suppose, f is the sampling frequency of the system, $y_1(n)$ and $y_2(n)$ are number n point output signal. Usually, the output signal value of photoelectric detection target is more than background noise signal, if A'' is the maximum value of noise signal, fig.3 is result on two output processing signal of photoelectric detection target.

In fig.3, we select a reference voltage A' as benchmark, when the voltage amplitude on the number n

sampling points of $y_1(n)$ or $y_2(n)$ is more than $A^{'}$, this point was regarded as a projectile signal arrival.

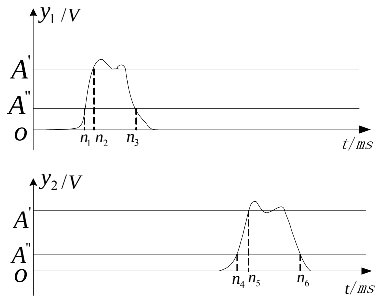

Fig.3 The output processing signal and start position extraction base on wavelet analysis method

Follow, we introduce the specific arithmetic. First, we must look for the sample point n_2 which voltage amplitude more than $A^{'}$ in output signal $y_1(n)$, according to time sequence, we look for the next sample point n_3 again when signal amplitude decline, this sample point n_3 output voltage amplitude is less than A'', A'' is just equal to the maximum value of noise signal. Second, according to the principle of looking for n_3, we look for the sample point n_5, its voltage amplitude is more than $A^{'}$ in $y_2(n)$, and then, sample point n_6 output voltage amplitude is less than A'' also. Three, we forward to find out the first sample point n_1 and n_4 during the first amplitude small than A'' in $y_1(n)$ and $y_2(n)$ respectively, the sample point begin n_1 or n_4 to end n_3 or n_6, such, we can look for the output signal mutation point n_1, n_3, n_4 and n_5 when projectile fly detection screen. So, the time value t between $y_1(n)$ and $y_2(n)$ can work out, its calculation equation can be expressed by formula (19).

(19) $$t = (n_4 - n_1)/f$$

To gain the velocity or fire coordinates that projectile go through certain plane, and according to the characteristics of measurement velocity system or across screen system, we can gain projectile's parameter, such as, projectile's velocity, projectile's fire coordinates, and density, and so on.

Base on above the principle of projectile signal start position extraction algorithm, the projectile's velocity can be calculated by formula (20).

(20) $$v = S/t$$

5. Experiment and analysis

Projectile velocity measurement system mainly is compose of two photoelectric detection target and timing signal processing instrument[14], such as fig.4. The two photoelectric detection target was placed in certain distance S, when projectile flying detection screen vertically, and each detection screen will output a stimulant signal, those signal was processing by wavelet analysis method, and gain flying time and give out velocity. Here, G_1 and G_2 are two screens of photoelectric detection target, OA is projectile flying orientation. According to the modulus maxima of wavelet transform to extraction projectile start position information method, we can find out and calculate the time between two screens, and combine the known distance S, the projectile velocity v will gain by S/t.

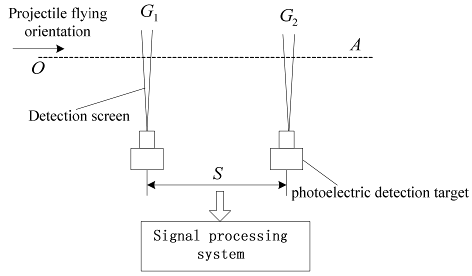

Fig.4 The principle of velocity on photoelectric detection target

According to the projectile velocity measurement principle, we use conventional projectile nose trigger method and wavelet analysis method to extract projectile into screen start time to calculation and processing projectile velocity. In a certain range experiment, we use rifle that its diameter is 7.62mm to validate that its theory velocity is about 735m/s, the target distance S is 7.8m. Table 1 is measurement result, t_1 is wavelet analysis method gain the time value, v_1 is its velocity accordingly; t_2 is projectile nose trigger method gain the time value, v_2 is its velocity accordingly.

Table 1 The data on wavelet analysis and projectile nose trigger

No.	$t_2(us)$	$v_1(m/s)$	$t_2(us)$	$v_2(m/s)$
1	10560.5	738.6	10644.1	732.8
2	10602.2	735.7	10682.0	730.2
3	10582.0	737.1	10561.9	738.5
4	10570.5	737.9	10539.1	740.1
5	10592.1	736.4	10603.6	735.6

Through comparing and analyzing, we find the result of using wavelet analysis method is steadier, the maximum value and the minimum value of the difference is less than 1.9 m/s, the error is less than 0.2%, however, the result of using projectile nose trigger method is larger changes, their maximum change is 9.9m/s, the error about is 0.43%. Therefore, the wavelet analysis processing technology in the measurement system is feasible.

6. Conclusions

This paper presents wavelet analysis method to extract projectile information in photoelectric detection target, analyze its extract arithmetic, this extraction method mainly find the projectile enters the screen starting point and calculate the actual time value between, this method can reduce error by the photoelectric detection target screen inclination, illumination changes, the detection circuit parameters ,and so on. Combine measurement velocity system to analyze extraction arithmetic, through experiment to validate its validity, the measurement data of wavelet analysis method and projectile's nose trigger was compared, the error is less than 0.2%, it illuminate the wavelet analysis method is feasible in photoelectric detection target, and it can improve measurement precision. So, wavelet analysis method is not used to judge whether a certain point to a single predetermined comparison voltage value measures principle, it avoid the external factors affect photoelectric detection target measurement precision, it can better reflect the projectile into detection screen starting position. Wavelet analysis method was applied to multi-screen measurement system and gain better achievement.

Acknowledgement

This work has been supported by Project of the National Natural Science Foundation of China(61107079) and Foundation of Department Education of Shaanxi Province of China(2010JK605).

REFERENCES

[1] H.S.Li, Z.Y.Lei,Z.M.Wang. Principle and analysis of high altitude projectile location measurement using multi-screen target method. Chinese Journal of Scientific Instrument, 30(2009),No.3,621－624

[2] G.Y.Zeng, Y.Ma. Studies on measuring system of erecting target. Journal of projectile,rockets,missiles and guidance , 25(2004), No.1, 345-346.

[3] H.S.Li, Z.Y.Lei,Z.M.Wang. Analyze Two Type Sky-screens Across Screen Fire Measuring System. Journal of Ballistics, 22(2010), No.1, 29-32 .

[4]B.Feng, J.P.Ni, L.Yang. Principle of Measuring Impacting Position of Vertical Target of Site light screens[J]. Journal of Ballistics, 2008，20（1）：59-61.

[5]H.H.Li, H.Y.Gao,M.Jiang. A study on improving the performance of photo-electricity detecting of sky-screen[J]. Journal of Ballistics,19(2007),No.1,33-36.

[6]Y.G.Song,J.P.Ni, T.L.Wang. Principle of Six Screens Target Measuring System for Bullet Location and Its Error Analysis. Journal of xi'an technological university, 27(2007),No.1,19-25.

[7] H.S.Li, L.P.Lu, Z.Y.Lei. Infrared Heat Radiation Detection Performance Influence of Screen Thickness and Atmosphere on Projectile. Journal of Nanjing University of Science and Technology，35(2011),No.3, 298-303.

[8] W.G.Xia, Y.He, W. OuYang. Overview of wavelet analysis-based image fusion. Infrared and laser engineering, 32(2003),No.2,177-183.

[9] F.Y.Liao,G.S.Huang. A Comparison Study of Two Kinds of Wavelet Thresholding De-Noising. Computer engineering and applications, 40(2004),No.8,100-105.

[10] W.B.Wei,L.H.Yang, J.H.Cai. General solution of matrix extension associated with multiple channel orthonormal wavelet filters[J].Journal of math,25(2005),No.3,249-259.

[11]NI Jinping, YANG Lei. Measurement Principle for Two Kinds of Six-light-screen Array Composed by a Large Area Light Screen. Opto-Electronic Engineering, 35(2008),No.2,7-11

[12]H.S.Li, Z.H.Yuan,Z.Y.Lei. Infrared radiation characteristics analysis of high velocity projectile in detection screen.Infrared and laser engineering, 38(2009),No.5,777-781

[13]Q.S.Li. Research on miss distance in optical measurement processing. Acta Photonica Sinica, 28(1999),255-259.

[14]N.J.Ping, H.L.Hou, J.Sun. The Velocity Measurement of Projectile in End-Trajectory with Six Sky Screen System. Journal of test and measurement technology, 21(2007),No.2, 117-121

***Authors**: Hanshan Li is an associate professor of xi'an technological university,and engaging in research and development in photo electricity detection ,measurement and control technology.E-mail: lihanshan269@163.com. Zhiyong Lei is a professor in xi'an technological university, and engaging in research in computer-aided design, dynamic target test, image processing and information fusion. E-mail: leizy888@163.com; Zemin Wang, Wangzemin@163.com; Junchai Gao, gaomuyou@126.com*