Research on a new photoelectric detection method to anti-muzzle's flame or light disturbance and projectile's information recognition in photoelectric detection target

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This paper researches a new photoelectric detection method to weaken or eliminate the influence of the muzzle's flame or light in photoelectric detection target. According to the work principle of photoelectric detection target in muzzle, paper researches the output signal characteristics of muzzle's flame or light, analyzes the differences between flying projectile's information and muzzle's flame or light, proposes double array photoelectric detector that was divide into master detection area and slave detection area to design detection screen, set up the design model of anti-muzzle's flame or light disturbance by the relation for flame or light signal, projectile's information and circuit noise signal, and study the algorithm of projectile information recognition and time extraction when projectile passing through the detection screen. Through experiment and analysis, the results show the new design method of photoelectric detection target can weaken muzzle's flame or light disturbance and recognize projectile's information.

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1. Introduction

In shooting range, the velocity and coordinate of flying projectile are very important indicator in gun-muzzle, the multi-screens measurement system that consist of four or six photoelectric detection target is a test instrument, which can test projectile's velocity, flying coordinates and density [1-3], and photoelectric detection target uses the sky as its work background light, if projectile flies into its detection screen, the photoelectric detector will gain the projectile's information, because photoelectric detection target is composed of an imaging lens, the slit diaphragm, a photoelectric detector and a processing circuit [4-6]. Because of the slit diaphragm function, photoelectric detection target can form a certain thickness detection screen, when projectile passes through detection screen, the detection circuit will output a transient change signal, this signal was turned into pulse signal by amplifying and disposing method [7]. Thus, we can use this output pulse signal to start or stop chronograph in multi-screens measurement system and gain projectile's velocity, coordinate and density. The photoelectric detection target has many merits, such as, detection area is rather larger, detection distance is far away, and it can repeat work and don't need artificial light [8-10]. However, when photoelectric detection target was use to test projectile's velocity or coordinate in muzzle, the muzzle's flame or light is very strong, which will impact projectile's information recognition and processing, and photoelectric detection target cannot work usually. Because the view filed of photoelectric detection target is larger, it still is an very important photoelectric detection instrument in shooting range, it is very necessary to research a new technology and method to weaken or eliminate muzzle's flame and light disturbance, In this paper, based on the principle of photoelectric detection target, we adopt double array photoelectric detector to design its detection circuit, and give out the processing method of projectile's information recognition.

2. The existent problem and characteristics of muzzle's flame or light when measure projectile's velocity in muzzle

2.1 The existent problem on measurement projectile's velocity in muzzle

In muzzle, we usual use two photoelectric detection targets to test muzzle projectile's velocity; Fig. 1 is the sketch map of projectile's velocity measurement. Two photoelectric detection targets form parallel screen and their distance is *S*, when gun shoots projectile, photoelectric detection targets gain projectile's information in detection screen, and then, we use chronograph to gain the projectile's flying time between two photoelectric detection targets, suppose, t is time that projectile pass through two detection screen, and $V=S/t$, V is projectile's flying velocity.

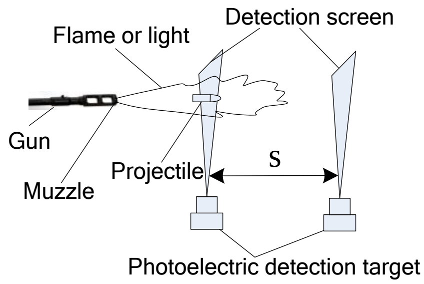

Fig. 1. The sketch map of projectile's velocity measurement principle.

From Fig. 1, we see the flame or light and flying projectile will appear at the same time in detection screen, and the fight or flame lasted a long time, which influence photoelectric detection target recognizes projectile's information. To eliminate this influence, the traditional method is layout photoelectric detection target at furthest from the muzzle, but, with the enlargement of distance between muzzle and photoelectric detection target, projectile's velocity will bring error, the measurement data are not real the muzzle projectile's velocity, so, we need to study anti-light and flame disturbance technology and projectile's information recognition method.

Photoelectric detection target is mainly composed of an optical lens, slit diaphragm, photoelectric detector and processing circuit. Because of the slit diaphragm, photoelectric detection target can form a certain thickness detection screen, when projectile flies into detection screen, the detection circuit will output a transient change signal [11-12]. Fig. 2 is the sketch map of photoelectric detection target.

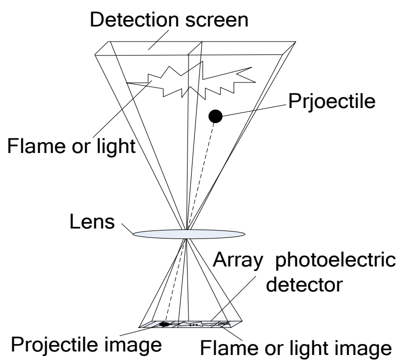

Fig. 2. The detection principle sketch map of photoelectric detection target.

In Fig. 2, when the gun shoots projectile, the photoelectric detector of photoelectric detection target gain the signal of projectile's information and muzzle's flame or light at the same time, two kinds signals will output together in detection circuit, such as Fig. 3. The flame or light signal make the out signal amplitude augments, but, the projectile's signal is opposite with flame or light, it is dark signal. Because the flame and light signal is more obvious, and it more than real projectile's signal, it's very difficult to distinguish the real projectile signal from flame and light disturbance in traditional photoelectric detection target, and it make traditional photoelectric detection target do not work normally. To eliminate or weaken muzzle's flame and light disturbance, we adopt the double array photoelectric detector to design a new photoelectric detection target based on the characteristics of the muzzle's flame or light signal.

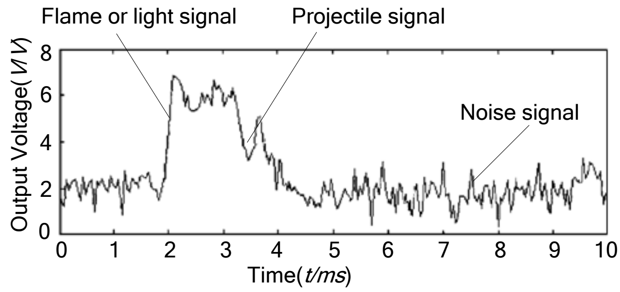

Fig. 3. The output signal containing both the flame or light and the projectile signal.

2.2 The characteristics of muzzle's flame or light signal in detection screen

When photoelectric detection target was used in muzzle, there are many influence factors, such as, the responsivity of photoelectric detector, the noise of amplification circuit, the vibration of launch gun, flame or light, and air turbulence, and so on [13]. Those factors will seriously disturb or weaken the work performance of the photoelectric detection target. For photoelectric detection target, if there are no projectile or flame and light in detection screen, the detection circuit only outputs noise signal, as shown in Fig. 4, the amplitude of the noise signal is only related to the sky background illumination and circuit noise oneself. Sky background illumination is stronger, noise signal amplitude is higher [14-15].

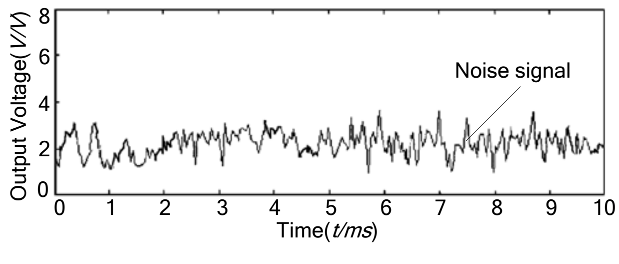

Fig. 4. The output noise signal in detection circuit.

When the gun shoots projectile in a moment, the photoelectric detector will detect the flame or light information in whole detection screen, the output signal is added by the natural background light, the muzzle's flame or light and projectile's information,

Because the velocity of muzzle's flame and light is more than the projectile's, it makes the output signal of muzzle's flame or light is super to the projectile's, from Fig. 3, we know the signal width of flame or light is more than projectile's. If we do not eliminate or weaken flame or light disturbance in muzzle, those disturbances will affect the detection performance of photoelectric detection target and test accuracy in milt-screen measurement system.

3. The design method on anti-flame and light disturbance in photoelectric detection target

Based on the array photoelectric detector to design detection system, we divide the array photoelectric detector into three detection area, they are the master detection area and two slave detection areas, as shown in Fig. 5, the master detection area forms the main detection view field in photoelectric detection target where is projectile's detection area. In the design of optical detection system, the number of master detection area should be larger than the slave detection area, when the gun launches projectile, master detection area and two slave detection areas both obtain flame or light signal, but, the master detection area not only receives muzzle's flame or light signal but also captures the projectile's information, two slave detection areas only gain flame or light information, we use this characteristic to design detection circuit. In the single array photoelectric detector, if the parameters that we choose are not appropriate in detection circuit, the flame or light cannot be eliminated effectively, at the same time, we cannot design the size of master detection area equal to two slave detection area, thus, the main detection view cannot meet the measurement demand. To improve this shortcoming, we adopt double array photoelectric detector to design detection system, as shown in Fig.5.

In Fig.5, master detection area is single array photoelectric detector that locates middle in whole photoelectric detector; the slave detection area is double array photoelectric detector that locate two side in photoelectric detector, the area A is master detection area, it is consisted by using 12 small units detector, each units detector photosensitive area is $2.5mm \times 2.5mm$, and adjacent space between two detectors in master detection area is $0.1mm$, area B and C are double row small units detector that form the slave detection area, each side slave detection area is composed of 6 small units detector, each unit detector photosensitive area is $1.8mm \times 1.8mm$, adjacent space between two detectors in slave detection area is $0.05mm$, this design of photoelectric detection target ensures the photosensitive area of master detection area is close to slave detection area, which can weaken and eliminate the flame or light disturbance effectively and recognize projectile's information. From Fig. 5, we know the double array photoelectric detector has detection blind area between two adjacent photoelectric detectors, to eliminate the detection blind area, we use the deviating focusing technique to design its optical system in new photoelectric detection target, the principle of the deviating focusing technique is the double array photoelectric detector leaves focus plane a distance, it make the facula size of projectile's image more larger and ensures photoelectric detector can gain any position information, which improve the capture rate and detection sensitivity.

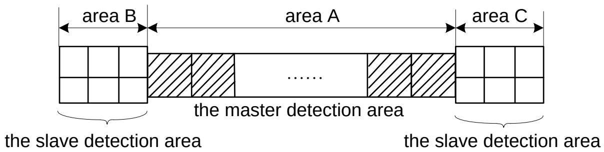

Fig. 5. The sketch map of double array photoelectric detector.

Area B and C are connected together to form slave detection signal in detection circuit, area A independent form the master detection signal. According to the design of area A, if we choose the focus of lens is 50mm, then, the main detection field view about is 36.5^{o} that is more than the traditional detection view of photoelectric detection target. Supposed, $y_1(t)$ is the output signal of the master detection area, $y_2(t)$ is the output signal of the slave detection area, and then:

$$y_1(t) = A \cdot [f_1(t) + f_2(t) + f_3(t)] + N(t) \tag{1}$$

$$y_2(t) = B \cdot [f_2^{'}(t) + f_3^{'}(t)] + N^{'}(t) \tag{2}$$

In (1) and (2), $f_1(t)$ is the function that contains projectile's information in master detection area, $f_2(t)$ is the function that contains flame or light information in master detection area, $f_3(t)$ is the function that contains vibration signal in master detection area. A is the magnification amplifier in master detection area, $f_2'(t)$ is the function that contains flame and light in slave detection area, $f^{'}{}_3(t)$ is the function that contains vibration signal in slave detection area, B is the magnification amplifier in slave detection area, $N(t)$ and $N^{'}(t)$ are the detection circuit noise signal function of master detection area and slave detection area respectively. If the performance of master detection circuit and slave detection circuit are coincident, then, $N(t) \approx N^{'}(t)$, $A \approx B$, the output signal of whole detection circuit can be calculated by formula(3).

$$y(t) = y_1(t) - y_2(t) = Af_1(t) + \Delta f_2(t) + \Delta f_3(t) + \Delta N(t) \tag{3}$$

$y(t)$ is the output signal of whole detection circuit , $\Delta f_2(t)$ and $\Delta N(t)$ are the output signal on flame or light and noise signal respectively in subtraction circuit.

$\Delta f_3(t)$ is the output signal on vibration signal in subtraction circuit. It is obviously that $Af_1(t) > \Delta f_2(t) + \Delta f_3(t) + \Delta N(t)$, if $\Delta f_2(t)$ and $\Delta f_3(t)$ is very small, then, $y(t) \approx Af_1(t) + \Delta N(t)$, therefore, $y(t)$ is not contain flame or light information and gun's vibration signal, if we select the appropriate threshold voltage, $\Delta N(t)$ can be eliminated, and the output signal in detection system only has projectile's information, it reach weaken or eliminate the disturbance of flame or light and vibration.

Based on the principle of double array photoelectric detector to design detection system, we design detection circuit according to Fig. 6.

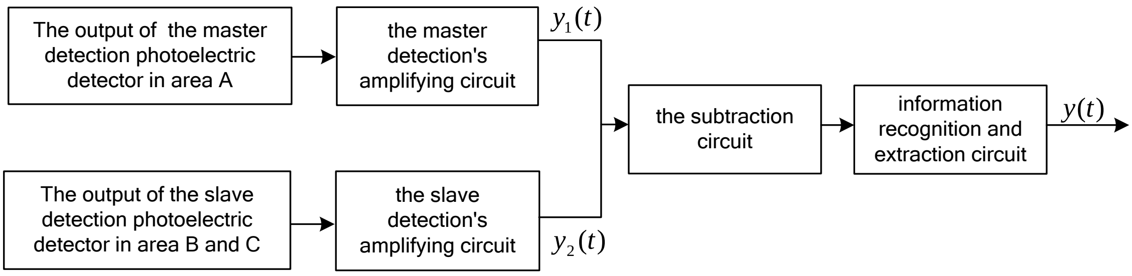

Fig. 6. The design sketch map of anti-muzzle's flame or light disturbance detection circuit design.

Area A can be considered the main detection receiving area, this area both capture projectile's information and flame or light signal. While area B and C only gain flame or light signal, when the detection signal of master detection area and slave detection area are subtracted in the subtraction circuit, the output only retain projectile's signal, and then, we gain an impulse signal by recognition and extraction circuit.

4. Projectile's information recognition and time extraction

4.1 Projectile's information recognition

To recognize projectile's information quickly, we chose *Fisher* discrimination method, the base thoughts of *Fisher* discrimination is that we set two group *d*-dimension samples, and use variance analysis method to divide them by *d*-dimensional samples projected to one direction, at last, we gain the linear discriminant *Fisher's* criterion function, this function can be expressed formula (4).

$$y(t) = W_1 t_1 + W_2 t_2 + W_3 t_3 + \cdots + W_d t_d \tag{4}$$

In (4), $W = (W_1, W_2, W_3, \cdots W_d)^T$ W is discriminant coefficient vector, $X = (t_1, t_2, \cdots, t_d)^T$, X is characteristic quantity [16].

We make the output signal of photoelectric detection target as two kinds discriminate problem. Supposed, C_1 is background signal, C_2 contains projectile's signal, and the feature vector on X are d dimension. For a new given sample, if we want to distinguish this sample belongs to C_1 or C_2 [17]. That is to say, this sample belongs to background signal or the projectile's signal. Let the average values of C_1 and C_2 are r_1 or r_2, $W^T r_1$ and $W^T r_2$ are their discriminant function values respectively. If $W^T r_1 < W^T r_2$, the discriminant rules is when $W^T r_1 < y_0$ sample belongs to C_1, or, $W^T r_1 \geq y_0$ sample belongs to C_2 , y_0 is the threshold value that' can be a simple means. According to *Fisher* discrimination method, if $y(t) \approx Af_1(t) + \Delta N(t) > y_0$, we think the output signal is projectile's information in detection system.

4.2 Projectile's information time extraction

If $y(t)$ is output function in detection circuit, we make $y(t)$ turn to discrete function $y(i)$, $i = 0,1,2,\cdots,n$, n is the length of the data acquisition. Suppose, the sample frequency of the gather system is f , $y_1(n)$ is the point *n* data, we choose y_0' as discrimination threshold value, because the amplitude of the background noise signal is generally less than y_0', if the output signal is more than y_0' , we can judge this output signal is projectile's information, such as Fig. 7 . In Fig.7, we make y_0 as a reference voltage at a certain time when projectile passes through the detection screen. If the signal amplitude of point *n* is more than y_0 , y_0 is regarded as the projectile start arrival detection screen time. The principle method is we find out the first amplitude of point n_2 that is bigger than y_0, according to the sequence of the sampling time, we also can find out the point n_3 that is less than y_0', this signal's amplitude is less than the maximum amplitude of the background noise, and then, we query from point n_2 and find out the first sampling point which its amplitude is less than y_0' , and this sample point is recorded as point n_1. By gathering these sample points, we know that the flying projectile's signal can be considered from the point n_1 start and point n_3 end.

According to *Fisher* discrimination criterion, if $W^T r_1 \geq y_0$, it belongs to C_2, the output signal is the projectile's information based on point n_1 to point n_3, and point n_1 is start time that the projectile arrive detection screen.

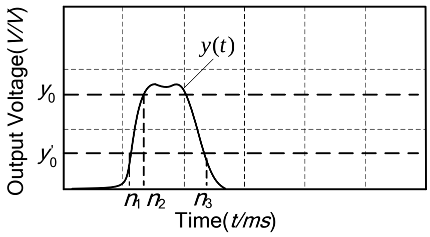

Fig. 7. The sketch map of projectile's information extraction.

5. Experiment and analysis

Based on the above design principles and method on a new photoelectric detection target, we choose a lens that focus is 50mm, its optical aperture is 1/2, and select 24 units double array photoelectric detector with high responsivity and low noise. The design method of photoelectric detection target can be seen in Fig. 6 and Fig.7. Here, we choose 12 units detector to design master detection area that locate in middle area in whole photoelectric detector, and then, the detection field view is 36.5^o in main detection screen. Slave detection area is composing of double array photoelectric detector that every row is 3 units detector in area B and area C. According to the master-slave detection area photoelectric detector parameters, the total length of the photosensitive surface about is 42.4mm, so, we design slit diaphragm length is 43mm, the total detection view is 45.9^o in detection screen.

To verify the new design technology and method, we use new photoelectric detection target to capture projectile information in muzzle under certain experiment based on Fig. 1 and gather detection signal, Fig. 8 is output signal containing both the flame or light and the projectile in master detection area, the flame or light signal make the out signal amplitude augments, but, the projectile's signal is opposite with flame or light, it is dark signal.

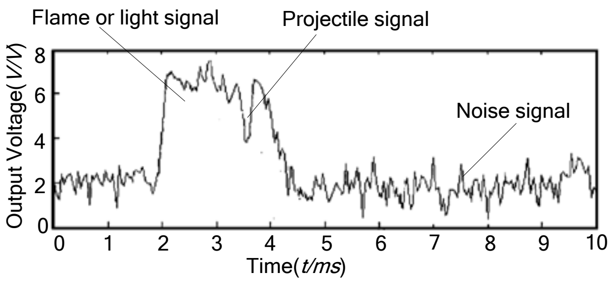

Fig. 8. The output signal on contains flame or light and projectile's information.

Fig. 9 is output signal by subtraction circuit and reverse processing circuit, it is very obvious that flame or light signal was weakened, but, projectile's signal still exists, and if we select appropriate threshold value voltage and the time information will be gained between two parallel detection screens when projectile passing through their detection screen by using above recognition and extraction algorithm.

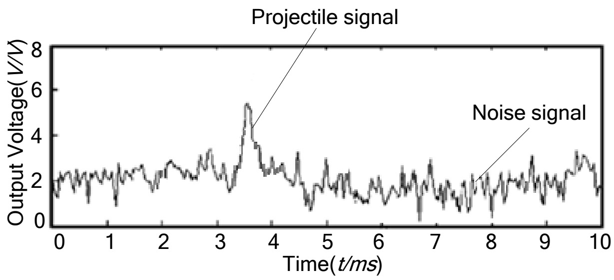

Fig. 9. The output signal of projectile's information by subtraction circuit processing.

We use new design photoelectric detection target and traditional photoelectric detection target to measure flying projectile's velocity in muzzle, the distance between two new design photoelectric detection target is 6.835*m*, and the distance between two traditional photoelectric detection target is 5.886*m*, Table 1 is their test data, *t* and *v* are the data of gathering time and velocity in new photoelectric detection target measurement system, t' and v' are the data of gathering time and velocity in traditional photoelectric detection target measurement system. From Table 1, the result shows that of new photoelectric detection target measurement system is very stable, its error is relatively smaller, but, because of flame or light influence, the traditional measurement system is not stable and the data is not correct, the design technology and method on new the photoelectric detection target are scientific and feasible.

Table 1. The test data on new and traditional photoelectric detection target measurement system.

Num	t (*ms*)	$v(m/s)$	t' (*ms*)	$v'(m/s)$
1	9.464	722.18	3.367	1747.92
2	9.337	732.01	10.018	587.53
3	9.372	729.25	3.917	1502.41
4	9.408	726.46	0.869	6770.59
5	9.361	730.11	8.557	687.85
6	9.407	726.58	8.553	688.17

For conventional weapons, the projectile velocity will be reduced 10%-15% per kilometer, if the projectile velocity is 1000 m/s, and then, when the distance is 30m from the muzzle to the first photoelectric detection target, the projectile's velocity about is 955m/s to 970 m/s, therefore, If we layout photoelectric detection target at furthest from the muzzle, the velocity error about is 10m/s to 15m/s in theory, if the projectile's velocity increase, the velocity error will enlarge. From Table 1, we know that the projectile's velocity is not stable in traditional measurement system, so, it is very necessary to improve traditional photoelectric detection target.

6. Conclusions

Based on the muzzle's flame or light signal characteristics, we design a new photoelectric detection target by using double array photoelectric detector, and analyze its design principle, give out design scheme and signal recognition and processing algorithm, and so on. Through experiment and analysis, the results show the new design method of photoelectric detection target can effectively weaken muzzle's flame or light disturbance and recognize projectile's information. Those design method provides a new thinking to gain flying projectile's velocity and coordinate in muzzle. Those technology and method also can apply in light screen or laser screen measurement system that also is test instrument in weapon.

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