Optical and optoelectronic properties of light-screen under large detection area

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When the detection area of light-screen becomes larger, the optical and optoelectronic properties of light-screen will be affected and weaken its detection sensitivity. To improve the detection sensitivity and performance under the large detection area light-screen, this paper analyzes and designs a new light-screen based on array emitting diode and array receiving detector, studies the optical and optoelectronic properties of array emitting diode and its distribution of light energy, sets up the optoelectronic properties calculation model from which the array emitting diode's transmitting power and detection output signal, provides light energy distribution mathematical model. Through simulation calculation and contrast experiment, the results show that the detection performance of new design large detection area light-screen has improved obviously, and the calculation model of optical, optoelectronic properties and light energy distribution in detection screen area is correct and feasible.

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1. Introduction

In the range test field, the flying target's dynamic parameters restricts the development of weapons, such as target's flight speed, flight direction angle, target coordinates etc. The change of these parameters will heavily affect the weapons' emission properties and damage the performance, so the target's flight parameters acquisition is an important technical index in the range test [1-2]. At present, the light-screen is often used in the range test field. The light-screen uses light-emitting tube and the receiving pipe with corresponding wave length to form the detection screen, it belongs to the active mode test system, and it's not affected by the sky background light [3]. When the target passes the detection screen, the luminous flux which the target has covered is reflected to the photosensitive surface of receiving photosensitive element [4-6], and the photosensitive element perceives the variation optical information, in order to get the corresponding target information, the signal processing method can be used, at last, combining with the spatial relations of multi-detection screen, we can get the dynamic parameters of the target. Because the light-screen can work in all-weather condition, it can meet the test requirements of indoor and outdoor. However, due to the optical and optoelectronic properties of emitting diode and receiving detector, the detection area of light-screen is very small, the detection area usually is $1.5m \times 1.5m$, and it cannot meet the current requirements [7-8]. As a result, it is very necessary to design a new large detection area light-screen, this paper researches on photoelectric and optical properties of large detection area light-screen.

2. Design and analysis of large detection area light-screen

To realize the large detection area light-screen, we use array super bright white light-emitting diodes as light source, and use high sensitivity receiving detector to receive target information when target passes detection screen, the Fig. 1 is the design principle of the large detection area light-screen. The length of array light-emitting diodes and array receiving detector is the same, the elongate lens converges the light of emitting diode to form line light source in photosensitive surface of the receiving detector, it is propitious to improve the detection sensitivity of light-screen.

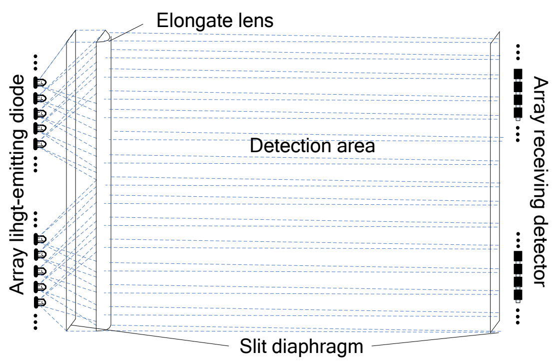


Fig. 1. The design principle of large detection area light-screen.

In order to improve the testing accuracy in multi-across light-screens system, we utilize slit diaphragm to improve and design its detection area. The slit diaphragm is designed in front of array emitting diode and array receiving detector. The length of the slit diaphragm is equal to the length of array emitting diode; the width of the slit diaphragm determines the thickness of the light curtain which closely to the light-screen's performance. In regard of the design requirements that the thickness of the light curtain must be smaller than the length of the flying target, the width of the slit diaphragm must be very small, the width of the slit diaphragm is 2mm. In order to ensure that the light curtain's energy distribution is uniform, it needs to optimize each of light-emitting diode's spacing d . Optimum spacing increases with the half intensity angle, and with the increase of half intensity angle, optimum spacing gradually stabilized. As a result of using elongate lens to converge and receive light energy, this new light-screen can form the large detection area; it can realize more than $3m\times 3m$ detection area. To improve the detection sensitivity and performance of large detection area light-screen, we must research its optical and photoelectric properties of detection screen.

3. The optical and optoelectronic properties of array emitting diode and array receiving detector

According to the design of light-screen, in order to improve its detection sensitivity and performance, it needs to consider the optical and optoelectronic properties of light-emitting diode. Since the array emitting diode of detection screen uses of luminance tube, every light-emitting diode is pn junction structure. According to the light-emitting diode's working principle can know that it will produce minority carrier injection after adding to a positive voltage, the photons is aroused by the radiation recombination luminescence of minority carriers. But in certain conditions, the photon density S determines the output power of the light-emitting diode P , for the light-emitting diode, it's important to determine the number of photons which is aroused by the radiation recombination of minority carriers [9]. Because the light emitting area is mainly concentrated on the active region of detection area of light-screen, it's the critical work to analyze the density of excess carrier and total photons of array emitting diode's active region, then proceed with the steady-state analysis for the rate equation [10].

$$I_{LED} = R_n(n)qV_{act} + R_r(n)qV_{act} \tag{1}$$

$$h = \tau_{ph}\beta_{sp}R_r \tag{2}$$

R_r is the net recombination rate of direct radiation of the detection area, R_n is its net recombination rate of composite center, n is the density of excess carrier of its active region, V_{act} is the active region's volume, I_{LED} is the current of the array emitting diode, h is the density of total photons, β_{sp} is the light-emitting diode's Spontaneous emission coefficient, τ_{ph} is the photon lifetime.

For the array emitting diode, non-radiative recombination mainly arises from the composite center, which is non-equilibrium carriers going through the forbidden band of E recombination centers for the capture compound into phonon, while the non-radiative also contains Auger recombination. The net recombination rate in the recombination centers of the light-emitting diode R_n can be calculated by

$$R_n = \frac{C_n C_p C_t (N_0 + P_0 + n)n}{C_n(N_0 + n_1 + n) + (P_0 + p_1 + p)} \tag{3}$$

$n_1 = n_i e^{\frac{E_t - E_i}{KT}}, p_1 = n_i e^{\frac{E_i - E_t}{KT}}$, C_n , C_p are the capture coefficients of the electrons and holes, C_t is interface trap density of states, E_t is recombination center energy level, E_i is intrinsic Fermi level, n_i is intrinsic carrier concentration[11]. Assume $C_n = C_p = C$, $n_0 + n = p + p_0$, R_r is given as follows:

$$R_r(n) = \frac{2B_r n_i \exp\left[\frac{qV}{2k_0T}\right]}{CN_{t,LED} + 2B_r n_i \exp\left[\frac{qV}{2k_0T}\right]} \times \frac{I_{LED}}{qV_{act}} \tag{4}$$

B_r is the composite coefficient of light-screen's detection area, n_0, p_0 are the equilibrium electron and hole density, $N_{t,LED}$ is interface trap density of states of array emitting diode.

According to the $I-V$ characteristics of semiconductor and the analysis of array light-emitting diode, and then the $I-V$ characteristics of array emitting diode can be deduced [12].

$$I_{LED} = I_D + I_R = \frac{D_n}{L_n} \times \frac{n_i^2 q}{N_A} \exp\frac{qV}{kT} + \frac{qn_i dCN_{t,LED}}{2} \exp\left[\frac{qV}{2kT}\right] \tag{5}$$

Because the luminescence of the light-emitting diode mainly comes from the diffusion current, while the non-radiative recombination mainly comes from the recombination current.

$$\frac{R_r(n)}{R_n(n)} = \frac{2B_r n_i \exp\left[\frac{qV}{2k_0T}\right]}{CN_{t,LED}} = \frac{I_D}{I_R} = \frac{2n_i D_n}{L_n N_A dCN_t} \exp\left[\frac{qV}{2k_0T}\right] \tag{6}$$

Simplify (6), according to the theory of semiconductor, substituted (3) and (4) into the original expression of effective optical power, the effective optical power of light-emitting diode can be calculated by

$$P = \eta Achv\tau_{ph}\beta_{sp} \times \frac{2\sqrt{D_n} n_i \exp\left[\frac{qV}{2k_0T}\right]}{N_A d\sqrt{CN_{t,LED}} + 2\sqrt{D_n} n_i \exp\left[\frac{qV}{2k_0T}\right]} \times \frac{I_{LED}}{qV_{act}} \tag{7}$$

Array receiving detector converts optical signal to current signal or voltage signal after receiving the optical signal. The receiving detector's photosensitive surface is irradiated by the incident light, stirring up carriers in its interior [13]. Because of the response speed, the receiving detector only responds to absorbed light intensity or the average photon number within several cycles, so the carrier's generation rate G is proportional to the incident light power, $h\upsilon$ is the energy of each photon.

$$G = \frac{\eta P}{h\upsilon} \tag{8}$$

Because every carrier which is generated by irradiation passing the space charge layer with the average flowing velocity, the instantaneous electric current which all carriers contribute to the detection circuit is

$$\bar{i} = \sqrt{2}\alpha G q \Gamma(\omega) = \sqrt{2}\alpha \frac{q\eta P}{h\upsilon}\Gamma(\omega) \tag{9}$$

$\bar{i}$ is the average optical current of the detection circuit, G is the generation rate of the receiving detector's carrier, η is quantum efficiency (the probability of one photon excites carrier), α is the modulation depth of the detection circuit, $\Gamma(\omega)$ is its transport factor[14].

Thus, for the large detection area light-screen, the root cause of the detection performance degradation is related to the number of carrier of light-emitting diode has reduced, and the number of the carrier is related to the forward voltage of light-emitting diode. For the array emitting diode, the main factor which affects the number of the carrier is the stability of the forward voltage between pn junction, according to (4), (8) and (9). There is a relationship between the luminous intensity and the forward voltage, when the electron diffusion length, electron diffusion coefficient, acceptor concentration, active layer thickness, effective area of the active layer, power of each photon, optical efficiency, speed of light are known, the output power of light-emitting diode and the forward voltage is exponential function. Because the effective optical current is the same as input current of the light-screen, the receiving detector's current is proportional to the light curtain's light emitting power. All of these will affect the system's detection performance and reduce the capture rate. In order to insure that every light-emitting diode is able to irradiate stably, the stable voltage should be provided, and only in this way can the detection performance be stable.

4. The calculation of luminous flux on the array receiving detector's photosensitive surface

For array receiving detector, when the target passing the detection area of the light-screen, the target shades the ray which comes from the array emitting diode; it will cause the luminous flux to a momentary change on the photosensitive surface. Setting an initial value Φ_0, when the luminous flux caused by flying target is larger than the initial value ($\Phi > \Phi_0$), the detection circuit will output a voltage signal, and then the transient pulse signal is outputted at the terminal of the circuit. The amount of the abrupt change luminous flux is proportional to the amount of luminous flux shaded by the target. There is a closed relationship between the abrupt change luminous flux of array receiving detector and the detection performance of light-screen. The amount of the abrupt change luminous flux can be obtained by calculating the amount of the shaded luminous flux. The method dividing the target's surface into a plurality of small element can be used to analyze the shaded luminous flux. It's easy to use this method to obtain the amount of the luminous flux on array receiving detector's photosensitive surface.

In order to calculate the luminous flux caused by flying target, it needs to calculate the luminous flux shaded by every element of target' surface, and add up all elements' shaded luminous flux in a certain way. The luminous flux which any element contributes to the array receiving detector's photosensitive surface is M. According to Planck's law, the luminous flux can be obtained.

$$M = \varepsilon \Delta S \frac{c_1 \cos\theta'}{\lambda^5\left(e^{c_2/\lambda T} - 1\right)\pi l^2} \tag{10}$$

T and ε are the element's temperature and emissivity, λ is the wavelength of the light source, c_1 and c_2 are constant, $c_2 = 3.74\times10^{-16} W/m^2$, $c_2 = 1.43879\times10^{-2} m/K$ [15], θ' is the intersection angle of the line which from the point on array receiving detector's photosensitive surface to target's element and the element's normal, ΔS is the area of any element.

For every element of the target, the shaded luminous flux maps to the photosensitive surface, it's the summation of multiple elements' imaging spot. According to the calculation method of luminous flux, the obtained effective luminous flux at $\lambda_1 \sim \lambda_2$ is:

$$\Delta\Phi = \frac{S_1 S_2}{\pi l^2}\int_{\lambda_1}^{\lambda_2} \sum M d\lambda \tag{11}$$

S_1 is the superficial area of the target, S_2 is the area of the photosensitive surface. $\Delta\Phi$ is the obtained effective luminous flux when the target passing the light-screen, the process that the target flies into the light curtain is divided into three parts. It begins from the front of the target, the central part, at last, the end of the target. Therefore, luminous flux caused by flying target on the photosensitive surface is related to target's temperature, the distance from the array emitting diode to the array receiving detector and the area of array receiving detector's photosensitive surface.

When the luminous flux is larger than the initial value

($\Delta\Phi > \Phi_0$), the detection circuit outputs a voltage signal. The amplitude of the signal which is photoelectric conversion outputted can be calculated.

$$V = \sigma \cdot \gamma \cdot \Delta\Phi \cdot R \tag{12}$$

σ is the magnification of detection circuit, R is the equivalent resistance of current-voltage conversion, γ is the array receiving detector's light sensitivity. According to (12), the amplitude of the output signal is proportional to the effective luminous flux of array receiving detector; it's also proportional to the superficial area of the target. After getting the effective luminous flux, the function relationship between the amplitude of the output signal and the effective luminous flux of array receiving detector can be used to analyze the performance of light-screen.

5. The light energy distribution of large detection area light-screen

5.1 The characteristics of the light energy distribution in large detection area

In practice, the decay of the light energy occurs in the light-screen's detection area, and the situation is more obvious with the increase of the detection range. In order to solve the decay of the light energy of the detection area, we can add elongate lens in front of the slit diaphragm, which can reduce the decay of the light energy within a certain range. The light energy distribution of the large detection area light-screen will affect the detection sensitivity of the detection system.

The single light-emitting diode's irradiation range on the photosensitive surface of the receiving detector can be calculated, the light solid angle of the light-emitting diode is θ. According to the detection distance, we chose the light-emitting diode which the divergence angle is 30°. Fig.2 shows the schematic diagram of the light-emitting diode irradiation, the distance from it to the array emitting diode of the light-screen is l, length unit is m.

$$S = 2 \times l \times \tan\frac{\theta}{2} \tag{13}$$

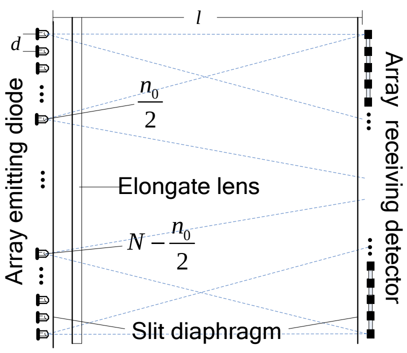


Fig. 2. The schematic diagram of the light-emitting diode irradiation.

For the array emitting diode, each of the light-emitting diode's spacing is d (center distance), every receiving detector is closely arranged to form the array receiving detector. The number of the receiving detector irradiated by every light-emitting diode's shining area is:

$$n_0 = \frac{2 \times l \times \tan\frac{\theta}{2}}{d} \tag{14}$$

At the both ends of the array emitting diode in the light-screen detection area, the first light-emitting diode is opposite to the first receiving detector, the maximum irradiation range of the first light-emitting diode can reach to the $n_0/2$ th receiving detector, the maximum irradiation range of the second light-emitting diode can reach to the $n_0/2+1$ th receiving detector, for the $n_0/2$ th light-emitting diode, to sum up, it can irradiate n_0 receiving detectors. Therefore, the light energy which from the $n_0/2$ th receiving detector to the $N-n_0/2$ th receiving detector is even distribution, but the first one to $n_0/2-1$ th one and the $N-n_0/2+1$ th to the N th receiving detector is not even distribution. In a word, the both ends of the light energy of the detection area of the light-screen are not even distribution, while the middle part is even distributed.

5.2 The calculation of the light energy distribution in large detection area

Within the solid angle range of the light-emitting diode, its brightness is equal. Therefore, light-emitting diode belongs to the uniform diffuser. According to the Lambert's law, on the vertical exposure surface of light-emitting diode, the luminous intensity in each direction is equal to the luminous intensity in elevation direction multiplies by its direction cosine [16].

The cross section of elongate lens is hemicycle. Assuming that S is the width of the slit diaphragm, the width of the elongate lens is equal with the width of the slit diaphragm. The refractive index of elongate lens is n_{12}, θ_1 is the angle of incidence, θ_2 is the angle of refraction, such as Fig. 3.

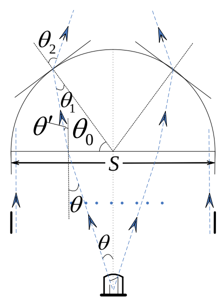


Fig. 3. The sketch of cross section when the light passing the elongate lens.

The light's direction of propagation happens to change after passing the elongate lens; it causes the luminous intensity to change. After the light passing the elongate lens, luminous intensity can be calculated as follows.

$$I' = I\cos\theta\cos\left(\theta - \arcsin\frac{\sin\theta}{n_{12}}\right)g\cos\left\{\arcsin\frac{\sin\left(\frac{\pi}{2}-\theta_0-\arcsin\frac{\sin\theta}{n_{12}}\right)}{n_{12}}-\frac{\pi}{2}-\theta_0-\arcsin\frac{\sin\theta}{n_{12}}\right\} \quad (15)$$

I is the luminous intensity of the light source, I' is the luminous intensity of light-emitting diodes' light after two times refraction, θ_0 is the angle between the line which from the center of elongate lens to the light's exit point and the horizontal line. In this way, the luminous intensity in a solid angle can be calculated.

For the middle section of the detection area where light energy is even distributed, the obtained light energy of array receiving detector can be calculated. Each light-emitting diode can irradiate n_0 receiving detectors; it is the symmetrical distribution, regarding the receiving detector which is opposite to the light-emitting diode as the symmetry center. For the receiving detector which isn't the vertical exposure, it needs to be multiplied by its direction cosine. The obtained light energy of each receiving detector's calculation formula is described as formula (16).

$$E_{\text{unifromity}} = 2I'\frac{A}{l^2}\left[1+\sum_{1}^{N-n_0}\int_{\arctan\frac{n_0}{2}}^{\arctan\left(N-\frac{n_0}{2}\right)}\cos\theta d\theta\right] \quad (16)$$

For the area which light energy is uneven distributed, their calculation is exactly the same. The first receiving detector can receive $n_0/2$ light-emitting diodes' light energy, which is $E_{\text{uniformity}}/2$. The second receiving detector can receive one more light-emitting diode's light energy than the first receiving detector, the third receiving detector can receive one more than the second receiving detector, and so on. Therefore, the obtained light energy from the second receiving detector to the $n_0/2$-1 th receiving detector.

$$E_{\text{non-uniformity}} = \frac{E_{\text{uniformity}}}{2} + I'\frac{A}{l^2}\sum_{1}^{\frac{n_0}{2}-1}\int_{\arctan 2}^{\arctan\left(\frac{n_0}{2}-1\right)}\cos\theta d\theta \quad (17)$$

According to the formula (16) and formula (17), the total of the light energy received by array receiving detector can be calculated.

$$E = E_{\text{uniformity}} + 2E_{\text{non-uniformity}} \quad (18)$$

As a result, the light energy of detection screen is related to the luminous intensity of the light source I, cross-sectional area of the slit diaphragm A, each of light-emitting diode's spacing d, the distance between array emitting diode and array receiving detector l. By installing the elongate lens, the light energy's attenuation was reduced; it leads to the stability of the light energy. Therefore, it is necessary to consider the effects of these factors for improving the performance of light-screen, to design the uniform and stable light curtain.

6. The experiment and simulation

6.1 Simulation and calculation

In order to verify the correctness of the theoretical analysis, it has to do some experiments and simulation to verify the research results.

According to the optical properties of light-emitting diode in this paper, light emitting power is proportional to the irradiative recombination rate. So in the same conditions, the amount of the light power is mainly decided by the ratio of compound and diffusion current, which is associated with the positive bias voltage of light-emitting diodes. According to the formula (4), (5), (6) and (9) can be obtained: the rate of diffusion current directly affected by the interface trap density of states of array emitting diode N_t, the more bigger N_t is, it means irradiative recombination rate of light-emitting diode is lower and output power is also lower. The luminous power of light-emitting diode is directly influenced by the applied voltage, and the luminous power has an effect on the output current of detection circuit. The relationship between current of light-screen's detection circuit and the voltage of array emitting diode is shown in Fig. 4.

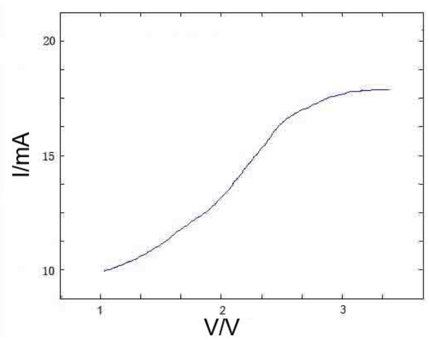


Fig. 4. The relationship between the current of detection circuit and the applied voltage of array emitting diode.

According to the figure, with the increase of applied voltage, the output current of detection circuit is growing accordingly. According to the formula (7) to (9), this is because when the bias voltage increases, and the irradiative recombination rate of light-emitting diode is improved, it leads to the increase of the luminous power of light-emitting diode and the number of carrier of receiving detector manifold, result in the detection circuit output current is increased. According to the formula (5), when the applied voltage reaches a certain value, the luminous power of light-emitting diode is reduced under the influence of temperature, etc., which keeps the trend in the current of detection circuit grows slowly. Therefore, the current of detection circuit is proportional to the applied voltage of detection screen.

In order to verify the light energy distribution of detection screen, using software to simulate the light energy distribution of detection screen. The effective detection area is $3m\times3m$. The result of the simulation is shown in Fig. 5.

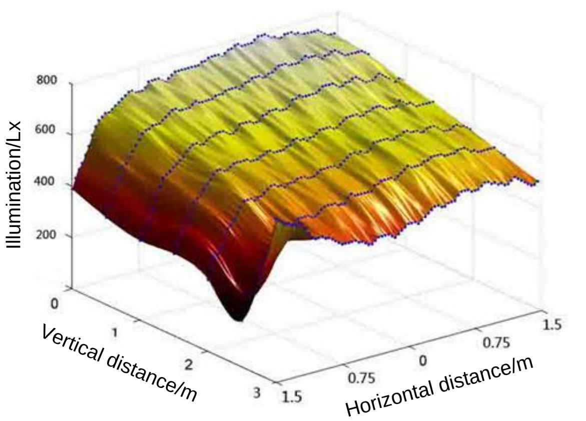


Fig. 5. The light energy distribution of $3m\times3m$ detection area light-screen.

As can be seen from the figure, the characteristic of the detection area's light energy distribution is that the light energy is strong in the middle of the detection area, and becomes weak in both edges of detection area. Along the horizontal direction, in middle part of detection area the light energy is strong; both edges are weak. Along the vertical direction, the farther away from the array emitting diode, light energy's attenuation in the center is slower than the edge. Light energy's attenuation is slower in the center; near the edge of the detection area the attenuation is obvious. If the detection area of light-screen is greater than $3m\times3m$, the light energy distribution law is very similar to Fig. 5. With the increase of the detection distance, the light energy decreases significantly. It will affect the detection performance and test precision, because the light energy is weak. It can be seen that the simulation of light energy distribution is consistent with the theoretical calculation of the light energy distribution.

6.2 Experiment and analysis

In order to verify whether the design can meet the requirements, the experiment makes a comparison between $3m\times3m$ detection area light-screen's detection performance and $1m\times1m$ detection area light-screen's detection performance. Two kinds of the light-screens are in order of precedence; the center of the detection screen must be in the same level. A rectangular coordinate system is established, the center of the screen target detection area as the origin, detection region is divided into four regions. Fig. 6 is the layout schematic of $3m\times3m$ and $1m\times1m$ detection area light-screen.

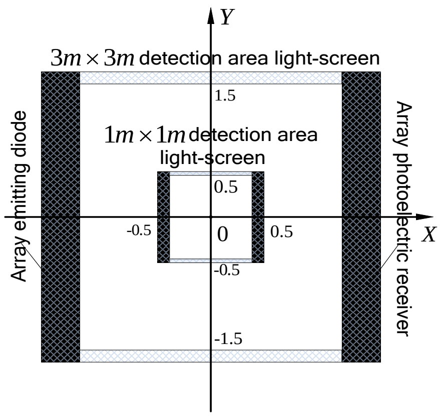


Fig. 6. The placement of $3m\times3m$ and $1m\times1m$ detection area light-screen.

In experiment, using rifle to shoot at the detection area of light-screen ($-0.5m\le x\le0.5m, -0.5m\le y\le0.5m$) and recording the amplitude of output voltage signal of two light-screens. Test is divided into two groups, each group performed ten times, and Table 1 is the amplitude of output voltage signal when gas bullets go through two kind light-screens. V_1 is output voltage of $1m\times1m$ detection area Light-screen; V_2 is output voltage of $3m\times3m$ detection area Light-screen.

Table 1. The amplitude of output voltage signal about two kind light-screens.

No.	*x* (m)	*y*(m)	V_1 (mV)	V_2 (mV)
1	0.25	-0.25	3930	4125
2	-0.20	-0.23	4980	4290
3	0.32	-0.30	4096	4367
4	0.30	-0.25	4247	4486
5	-0.15	0.15	4878	4946
6	0.15	-0.30	4216	4452
7	-0.25	-0.33	5168	5279
8	0.10	0.25	4586	4798
9	0.40	-0.35	4012	4229
10	-0.42	-0.40	3987	4214

According to Table 1, the amplitude of output voltage signal of $3m\times3m$ detection area light-screen is greater than the amplitude of output voltage signal of $1m\times1m$ detection area light-screen wherever the gas bullets went. The experimental results show that the detection performance is improved after ameliorating the design of light-screen. As can be seen from the table, the amplitude of output voltage signal which is obtained by shooting at the district near the light source is slightly larger than the amplitude of output voltage which is obtained by shooting at the district far away from the light source. The results indicate that the attenuation of light energy exists in detection area with the increase of detection range, and the theory of the light energy distribution's characteristics is verified again. After ameliorating the design of light-screen, the attenuation of light energy is not obvious; the light energy distribution is more homogeneous.

In the same conditions, using rifle range to shoot at the detection area of light-screen $-1.5m \le x \le -0.5m, 0.5m \le x \le 1.5m, -1.5m \le y \le -0.5m, 0.5m \le y \le 1.5m$ and recording the amplitude of output voltage signal of $3m \times 3m$ detection area light-screen. By comparing the amplitude of output voltage signal of $3m \times 3m$ detection area light-screen under the different area, it can be used to analyze the detection performance large detection area light-screen; Table 2 is the test results when gas bullets go through $3m \times 3m$ detection area light-screen (out of $1m \times 1m$ detection area light-screen).

Table 2. The amplitude of output voltage signal in $3m \times 3m$ detection area light-screen.

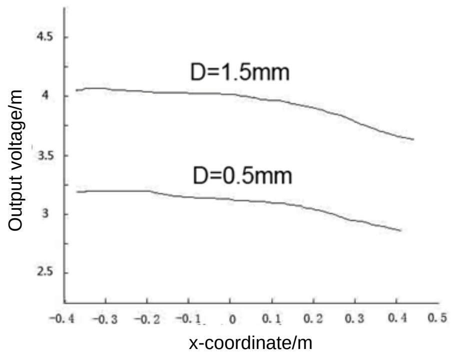
No.	x(m)	y(m)	V_2 (mV)
1	1.3	1.5	4718
2	-0.9	1.1	4812
3	-1.2	-0.9	5187
4	1.0	-1.2	4264
5	1.3	1.4	4968
6	-0.6	-1.0	5023
7	-0.9	0.6	5177
8	0.6	0.6	4688
9	1.4	-1.1	4741
10	-1.3	0.9	5159

According to the comparison between Table 1 and Table 2, the data of $3m \times 3m$ light-screen under the different area are similar, so the result proves that the detection performance after ameliorating the design can meet the requirement of large detection area light-screen.

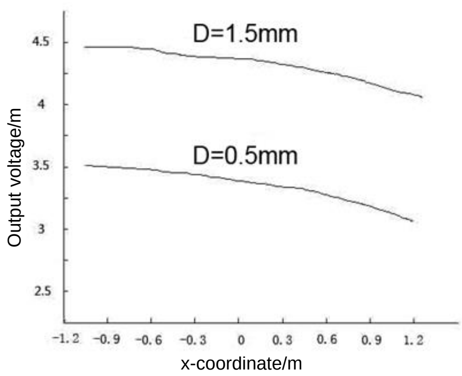
By analyzing the two groups of data measured in experiment, the amplitude of output voltage signal of $3m \times 3m$ detection area light-screen is greater than the amplitude of output voltage signal of $1m \times 1m$ detection area light-screen wherever gas bullets went. As a result, the light-screen has a stable performance after ameliorating the design; it can meet the requirement of large detection area light-screen.

In the process of experiment, the amplitude of output voltage signal of light-screen is different because the luminous flux caused by flying target on array receiving detector's photosensitive surface is different. According to formula (12), the effective luminous flux is related to the illumination of light curtain and the diameter of target. Selected the target whose diameter are $0.5mm$ and $1.5mm$ to shoot, by using the oscilloscope to observe the voltage signal's amplitude. The data obtained are drawn into curve, Fig. 7 shows the output signal in detection area different position of different flying target diameters.

Fig.7(a) is the output signal in detection area different position under $1m \times 1m$ detection area light-screen when the diameter of flying target is $0.5mm$ and $1.5mm$, Fig.7(b) is the output signal in detection area different position under $3m \times 3m$ detection area light-screen when the diameter of flying target is $0.5mm$ and $1.5mm$.



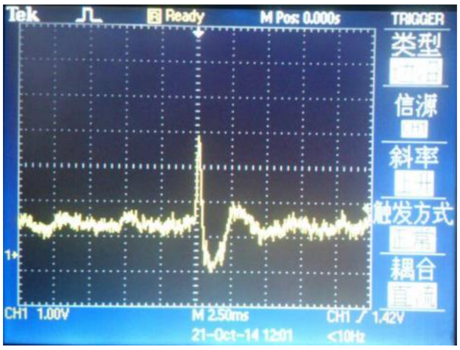
(a) $1m \times 1m$ detection area light-screen



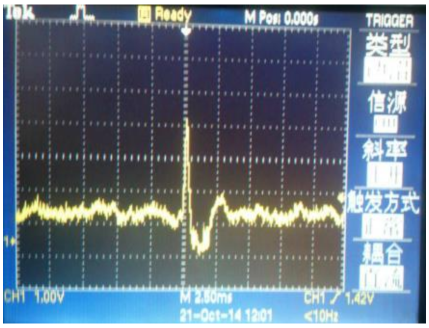
(b) $3m \times 3m$ detection area light-screen

Fig. 7. The output signal in different detection area position of different target diameters.

For the same light-screen, the greater the diameter of target is, the greater the target's surface plays a role in detection area will be, it leads to the luminous flux caused by flying target on array receiving detector's photosensitive surface become greater, the amplitude of output voltage signal is also greater. Because the light energy decays with the increase of detection range, thus, the output voltage signal's amplitude is slightly decreased. For different light-screens, because of the elongate lens makes the light more convergence than the light-screen without elongate lens, it makes the light curtain's energy uniform and stable. Fig. 8 shows the output waveform of $3m \times 3m$ and $1m \times 1m$ detection area light-screen.



(a) $1m\times1m$ detection area light-screen



(b) $3m\times3m$ detection area light-screen

Fig. 8. The output waveform of two kinds of detection area light-screen after capturing the target.

Fig. 8(a) is the output waveform of $1m\times1m$ detection area light-screen, Fig. 8(b) is the output waveform of $3m\times3m$ detection area light-screen. As a result, the amplitude of output voltage signal of $3m\times3m$ detection area light-screen is greater than $1m\times1m$ detection area light-screen in the same position.

In summary, according to the simulation and experiment, the correctness of the theoretical research is validated. As a result, it can meet the requirements of detection in large surface target after ameliorating the design of light-screen, it has a stable performance.

7. Conclusions

In order to improve the large detection area light-screen's detection performance; the detection screen's design model is reestablished through theoretical analysis. By installing elongate lens, according to the principle of converge light of elongate lens, it can avoid light energy decay of the light-screen. This paper analyzes the optical and optoelectronic properties of large detection area light-screen. The output power of light-emitting diode is related to the forward bias voltage. Research on the luminous flux caused by small element of target's surface contributes to the photosensitive surface of array receiving detector in different directions. The sum of effective luminous flux on all element surface of array receiving detector is calculated. Through analyzing the characteristics of the light energy distribution in large detection area, the calculation of the light energy distribution is obtained. Finally, the theoretical analysis feasibility is proved by experiment and simulation. This study has great significance for the optical and optoelectronic properties of light-screen; it lays the foundation of theory and practice to improve the detection performance of the detection system in real environment, which has strong practicality.

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