Study on the Method of Evaluating the Interference Effect of Laser on CCD Detector Based On Image

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Abstract. Along with laser countermeasure technology is widely used in the field of photoelectric detector, how the interference and damage degree of laser to detector, when the damage threshold is reached and how to make objective evaluation is a very concern of the people. And therefore, it has important significance to carry out the laser interference and damage experiment of photoelectric detector and propose an objective and reasonable evaluation of Ajamming effect. Combined with typical image evaluation methods such as structural similarity, correlation measurement, feature point analysis and cross entropy, this paper systematically studies the interference effect evaluation technology of laser interfered CCD detector, and finally summarizes the development trend of the interference effect evaluation technology of laser interfered CCD detector.

1. Introduction
With the development of laser technology, the interference and damage ability of the laser to the photoelectric detection system has attracted extensive attention. The evaluation of its interference effect has become an important research topic. Its research value comes from the following three points: (1) to guide the improvement of laser interference technology and the development of laser interference equipment; (2) to guide laser protection of photoelectric detection equipment; (3) to evaluate the anti-interference capability and secondary capture capability of the guidance weapon [1].

The technology has been studied for several decades, but many problems and difficulties remain. Especially when the background noise is strong, the background intensity or the spot position changes, and the determination of the interference success threshold has not been solved. In view of these problems, domestic and foreign scholars have conducted a series of studies, but most of them focus on the mechanism of laser interference, the construction of relevant laser interference experiments and the establishment of interference effect evaluation model [2]. In terms of image quality evaluation, most of the studies focus on the characteristics of human vision and the mechanism of visual attention, while the analysis of laser interference effect from image perspective is relatively rare.

2. Research status
Since the 1970s, the United States has invested a lot of money in the construction of high-energy laser experimental facilities and the detection equipment of laser irradiation photoelectric sensor at the White Sands Range in the United States to study the damage effect and mechanism of laser on optical
elements and photodetectors [3, 4]. Therefore, a large number of scientists, represented by experimental physicist Bartoli, conducted a large number of experiments on laser damage detector target [5, 6] and obtain the damage threshold of various detectors.

Besides, Meyer et al. [7] research interference of CO2 laser on HgCdTe and PbSnTe infrared detector, and the interference mechanism of photoelectric detector is analyzed accordingly. Hamid et al. [8] analyzed the from the aspect of statistical evaluation. Zhou Wang and Alan conducted interference image quality evaluation from the structure of images mainly based on human vision [9].

From the point of view of extracting image features, Zhao dapeng et al [10]proposed the contrast evaluation method and correlation evaluation method based on image features according to different tracking methods of the imaging guidance system.

From the perspective of image quality evaluation, Sun yunqiang of National University of Defense Technology [11] proposed the interferential image quality evaluation methods by using Fourier transform and Wavelet transform.

In addition, Guo jin from Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Science and others [12, 13] proposed various methods to evaluate the interference effect according to the change of image target feature.

Shao xiaopeng from Xi ‘an University of Science and Technology and others [14]proposed an evaluation method based on image cross entropy, which can not only evaluate the effect of interference, but also get the threshold of successful laser interference accurately.

Although the research on the evaluation of laser interference effect is early and some achievements have been made in recent decades, there are still many problems and difficulties still to be solved, and the development and application of the theory are extremely challenging.

3. **Classification of image-based methods for evaluating the interference effect of laser on CCD detector**

![Figure 1](image-url)

**Figure. 1** Classification of image-based methods for evaluating the interference effect of laser on CCD
For the imaging system, the final information provided to the operator or system is an image information, so the image quality reflects the damage degree of laser interference to some extent. Therefore, the effect of laser interference can be evaluated from the perspective of image quality evaluation, which can accurately reflect the degree of laser interference and damage to photoelectric imaging devices. The specific classification is shown in Figure 1 based on the research of scientific research institutions and scholars in recent years.

3.1. Evaluation method of laser interference effect based on error statistics

Hamid et al. analyzed the image quality from statistical evaluation and put forward the evaluation method based on the error signal to noise ratio. The method evaluate image quality by calculating pixel gray level difference between mass reduction image and original image, the mean square error (MSE) and peak signal-to-noise ratio (PSNR) is a commonly used method, its computation formula, respectively, such as type (1), (2) shown below:

\[ MSE = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} (f(i,j) - f'(i,j))^2}{M \times N} \]  

\[ PSNR = 10 \times \log\left(\frac{l \times l}{MSE}\right) \]  

Where, \( f(i, j) \) represents the grayscale value of the original image, \( f'(i, j) \) represents the grayscale value of the degraded image, \( M \) and \( N \) represent the size of the image, and \( l \) represent the highest grayscale series of the image.

Error statistics based method is simple and strict mathematical expressions, but they were generally reflect the difference of original image and mass reduction image. As long as the pixel gray value in the original image is different, this method will think image quality drop, so when light spot position changes, the evaluation method will appear deviation [15-17].

3.2. Evaluation method of laser interference effect based on edge information

3.2.1. Evaluation of structural similarity based on gradient features

In recent years, Zhou Wang and others [18] propose an image quality evaluation method based on structural similarity (SSIM), which evaluates the image quality with the correlation degree of two images. The evaluation parameters include the luminance comparison, contrast comparison and structure comparison of the two images. The evaluation quantity is shown in equation (3):

\[ f_{SSIM}(x, y) = [l(x, y)]^{\alpha} [c(x, y)]^{\beta} [s(x, y)]^{\gamma} \]  

For luminance comparison:

\[ l(x, y) = \frac{2\mu_x \mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1} \]  

Contrast comparison:
\[ c(x, y) = \frac{2\sigma_x \sigma_y + C_2}{\sigma_x^2 + \sigma_y^2 + C_2} \]  

(5)

Structural comparison:

\[ s(x, y) = \frac{\sigma_{xy} + C_3}{\sigma_x \sigma_y + C_3} \]  

(6)

In the formula, parameters \( \alpha, \beta, \gamma \) are weight adjustment for luminance, contrast and structural information. The mean intensity of image block \( x \) and block \( y \) are \( \mu_x \) and \( \mu_y \); The standard deviation of the image block \( x \) and block \( y \) are \( \sigma_x \) and \( \sigma_y \); \( C_1, C_2, \) and \( C_3 \) are constants introduced to avoid a zero denominator.

This method considers the advanced features of human visual system and ignores the image structure internal point drift error or space that may occur, but in the laser interference image, the light spot in the image of a local area only cause local serious distortion, and generally uniformly distributed noise impact on image quality is different, resulting in the SSIM algorithm accuracy in evaluating image quality of laser interference is low.

The effect of the interference laser on the performance of the imaging system is mainly reflected in the mask of the image information acquired by the light spot, while most of the tracking algorithms are based on edge extraction for the target extraction, so the change of edge details is particularly important for the accurate extraction of the target. A series of methods for evaluating the effects of laser interference based on edge information are proposed.

2. Structural similarity evaluation method based on gradient features (GSIM)

Fan yong, Qian fang et al. proposed the structural similarity evaluation algorithm based on gradient features (GSIM) on the basis of SSIM algorithm \([19]\). GSIM evaluation quantity is shown in equation (7):

\[ M_{GSIH}(x, y) = \left[ I(x, y) \right]^\alpha \left[ c(x, y) \right]^\beta \left[ d(x, y) \right]^{\gamma} \]  

(7)

Among them, luminance comparison function, contrast comparison function and structure comparison function are all improved on the basis of equations (4), (5) and (6):

\[ I(x, y) = \frac{2L_x(i, j)L_y(i, j) + T_i}{L_x^2(i, j) + L_y^2(i, j) + T_i}, \]

\[ c(x, y) = \frac{2C_x(i, j)C_y(i, j) + T_3}{C_x^2(i, j) + C_y^2(i, j) + T_2}, \]

\[ d(x, y) = \frac{2G_x(i, j)G_y(i, j) + T_i}{G_x^2(i, j) + G_y^2(i, j) + T_3}, \]

The GSIM highlights the impact of image edge structure and local detail loss on image quality by extracting gradient features from images and calculating the definition comparison function \([20]\). Experiments show that this algorithm can overcome the influence of background inconsistency on image quality, and the evaluation result can reflect the effect of laser interference more accurately.

3.2.2. Evaluation quantity based on similarity of edge strength. In the complex photoelectric environment, the application effect of the evaluation method based on structural similarity is not good,
hence Sun xiaoquan et al [21, 22] propose a method for evaluating the interference effect based on the similarity of edge strength.

![Figure 2. Calculation scheme of edge strength of target image](image)

The edge intensity of each pixel in the image is represented by the direction derivative of a certain direction. The edge intensity value of each pixel in the image is:

\[ E(r, i) = \alpha E_{1}^{1,3}(r) + \beta E_{2}^{2,4}(r) \]  

(8)

Where, \( \alpha \) and \( \beta \) are weights corresponding to edge strength in different directions.

Equation (8) is used to calculate the similarity between the edge intensity of the target image and the background image. The more similar the target to the background, the better the interference. This method is applicable to the interference effect evaluation of a single target in a complex background.

3.3. Evaluation method of laser interference effect based on correlation measurement

Cheng Xiangai et al. from NUDT proposed a correlation measurement method based on vision weight by using Fourier transform and Wavelet transform [23, 24].

The flowchart of evaluation method based on Fourier transform is shown in figure 3:

![Figure 3. Evaluation process of vision weight relevancy based on Fourier transform](image)

The original image and the interference image were subjected to multistage Fourier transform respectively. According to the human visual contrast sensitivity band pass model, we establish the contrast sensitivity function used by the band pass filter to carry out vision weight processing on each sub-band after image decomposition. Finally, the original image and the degraded image are performed with correlation calculation, and the evaluation quantity of visual weighted relevancy based on Fourier transform FWC is obtained, as shown in equation (9):

\[ FWC(f, f') = \frac{\sigma_y + a}{\sigma_y + \sigma_y' + a} \]  

(9)

Where, \( \sigma_y = \frac{1}{mn} \left( \sum_{i}^{m} \sum_{j}^{n} (f_{ij} - \overline{f}_{ij})^2 \right)^{\frac{1}{2}} \), \( \sigma_y' = \frac{1}{mn} \left( \sum_{i}^{m} \sum_{j}^{n} (f'_{ij} - \overline{f'}_{ij})^2 \right)^{\frac{1}{2}} \).
\( f_0 \) and \( f'_0 \) is the gray matrix of the original image and degraded image processed by vision weight, \( \overline{f}_i \) and \( \overline{f'}_i \) are mean value, \( \alpha \) is a constant.

The process of the evaluation method based on wavelet transform is as follows: first, the original image and degraded image are decomposed by three wavelets, and the correlation degree of each corresponding sub-band is calculated. The vision weight coefficient is determined by calculating the correlation degree of the sub-band corresponding to the target image with the same subjective quality. The correlation degree of each sub-band to the original image and the degraded image is weighted summation, that is, the total amount of WWC is obtained.

The advantages and disadvantages of the two methods are compared as shown in table 1.

**Table 1. Comparison of evaluation methods based on Fourier transform and Wavelet transform**

| Advantages | Evaluation method based on Fourier transform | Evaluation method based on wavelet transform |
|------------|---------------------------------------------|---------------------------------------------|
|            | (1) simple to calculate and easy to implement; | (1) better human visual characteristics simulation; |
|            | (2) conducive to solving the background brightness problem and the impact of different heavy frequency laser interference problems | (2) enlarge the edge or frame information; |
|            | | (3) overcome the impact of inconsistent background intensity on the evaluation results |
| Disadvantages | (1) Cannot reflect the influence of different interference positions on the evaluation results. | (1) the determination of visual weighting coefficient will introduce error; |
|            | (2) the cut-off frequency of the band-pass filter will be different for different images | (2) much more complex |

3.4. Evaluation method based on feature point distribution characteristics

The core of photoelectric imaging equipment is target detection, recognition and tracking, and the performance of detection, recognition and tracking depends on the strength of image target features.

3.4.1. Evaluation method based on feature point distribution characteristics. Guo jin et al. established an image quality evaluation model from the perspective of feature point change before and after interference, and proposed an algorithm for feature point similarity evaluation. Firstly, the feature points of the original image and the interference image were extracted with the accelerated segmentation test feature algorithm, and their feature point maintenance degree \( m(x, y) \) and feature point stability \( s(x, y) \) were calculated at the location of the target area, and the brightness distortion degree \( l(x, y) \) and contrast distortion degree \( c(x, y) \) were defined. The normalized evaluation quantity FPSIM is obtained by multiplying the four evaluation factors.

3.4.2. Based on spots and image features. Qian fang et al. proposed a weighted feature similarity evaluation algorithm based on the analysis of the overall characteristics, local features of the target and the speckle distribution characteristics of the laser interfered image to evaluate the effect of laser interference.

Multiply the five evaluation factors, and then obtain the normalized evaluation index DFM, as shown in equation (10):

\[
 f_{DFM} = [(1 - N) \times D]^\alpha [S \times E \times G]^\beta
\]

Where,
On the basis of using the evaluation method based on edge information, this algorithm considers the effect of spot size, intensity and position on the evaluation results comprehensively, and can give reasonable evaluation results for images with different background intensity, spot position and clutter interference.

3.5. Evaluation methods based on information entropy

3.5.1. Method based on image entropy. Image entropy is a statistical form of image features, which reflects the amount of average information in the image [25]. For the image after laser interference, the information entropy decreases when one gray level conceals another or several gray levels. However, this method can only be analyzed from the perspective of image information loss, and cannot reflect the change of spot position and the influence of background noise on the evaluation result. Therefore, this method is only applicable for occasions where spot position is not shifted and background noise is not obvious.

3.5.2. Method based on cross entropy. Shao xiaopeng et al. from Xi'an University of Science and Technology proposed an evaluation method based on image cross entropy, and the evaluation function $H_{ce}$ is as shown in equation (11).

$$H_{ce} = \sum_{i=1}^{N} p_{Ai} \ln \frac{p_{Ai}}{p_{Bi}}$$

Where A and B are images before and after interference respectively; $p$ is the probability of any gray level appearing in an image with m×n size.

According to the experimental analysis, when the laser interference intensity is low, the correlation peak of the disturbing image and the cross entropy change of the image are small. When the interference intensity increases to a certain extent, the correlation peak disappears, and the cross entropy of the image drops sharply. It can be seen that at the critical point of successful laser interference, the cross entropy of the image has obvious change peak (maximum value), which is the threshold of whether the laser interference is successful or not, as shown in figure 4.

It can be seen that this method can not only accurately evaluate the effect of laser interference, but also obtain the threshold when the laser interference is successful.

![Cross-entropy change diagram of the image](image.png)
3.6. Summary
Table 2 shows the comparison and analysis of the first four interference effect assessment methods. The study of the evaluation method based on cross entropy is still in the initial stage, and its performance needs further experimental verification. Therefore, it is not involved in the comparison here.

Table 2. Comparison and analysis of image-based methods for evaluating the interference effect of laser on CCD detector

| Image-based method for evaluating the interference effect of laser on CCD detector | The threshold for successful laser interference cannot be obtained | The effect of different laser interference position on the evaluation result cannot be reflected | The influence of background noise is obvious | The influence of background inconsistency on the evaluation results cannot be overcome |
|---|---|---|---|---|
| Evaluation method based on error statistics | is | is | is | is |
| Evaluation method based on edge information | is | is | is | |
| Evaluation method based on correlation measurement | is | FWC: yes WWC: no | | |
| Evaluation method based on feature point distribution characteristics | is | | | |

The table 2 shows that with the deepening of the research, the accuracy of the laser jamming effect evaluation method is more and more high. It can basically solve the problems of the position of laser jamming to the evaluation results, the influence of background noise and background brightness. But the laser jamming success threshold gain has been the problem cannot be solved by the above four methods, it is also a research focus in the future.

4. Summary and Outlook
With the rapid development of photoelectric detection technology and laser interference technology, the laser interference effect evaluation technology has also achieved great development. Since the image information provided by the detector can reflect the damage degree of laser interference, image-based laser interference effect evaluation method has been widely concerned and become a research hotspot. However, due to the complexity of the background and environment of the target in the actual environment, the image-based laser interference effect evaluation method is not mature and perfect, which still needs to be constantly developed and improved.

In the actual process, laser interference is a continuous dynamic process. At present, there is little research on the method of dynamic laser interference effect evaluation. The evaluation of laser interference effect based on sequence frame images will be an important research direction in the
future. At the same time, most existing evaluation methods cannot determine the threshold value of successful interference. Therefore, more advanced evaluation algorithms and more perfect threshold determination methods of successful interference have high research value.

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