Design of performance test system for ultraviolet ICCD detector

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ABSTRACT

With the continuous development of ultraviolet technology, the working band of UV detector is more controllable and optional, and the sensitivity has been greatly improved, so it has been widely used in ultraviolet camera, flame detection, welding detection and other fields with its unique advantages, it is of great significance to study the performance of ultraviolet detector parts. In this paper, we designed a set of evaluation and testing devices for detecting the signal-to-noise ratio, resolution, dynamic range and other parameters of ultraviolet ICCD (intensified charge-coupled device) detector after carrying out theoretical evaluation of ultraviolet detection and imaging photoelectric system and studying its related testing technology. In this paper, firstly we analysed the definition and the testing principle of the ultraviolet ICCD detector’s relevant parameters, such as signal-to-noise ratio, resolution, dynamic range, and designed the relevant algorithm model on the basis of that, then designed the supporting related hardware such as: Uniform light source system, test target, dark box, video processing acquisition system, etc. Secondly, based on LabVIEW platform, the software of related data acquisition and analysis is developed, and the video real-time display is realized, and finally the test experiment of signal-to-noise ratio, resolution and dynamic range is carried out to evaluate the performance of UV ICCD detector.

Keywords: UV-Imaging-Technology, UV-ICCD, Radioactivity, SNR, Dynamic range, Resolution

1. INTRODUCTION

With the increasing demand of UV ICCD detector in the domestic market, it is urgent to develop UV ICCD detector with superior performance, so the technology of performance Test and evaluation of UV ICCD detector is mastered. It is of great significance to design a set of devices that can be used by users and researchers to test the performance of UV ICCD detector parts. This UV ICCD detector performance test system mainly designed for the important parameters: signal-to-noise ratio, resolution, dynamic range. We designed a suitable algorithm model on the basis of the definition and measurement principle of those important parameters of UV ICCD. Finally we designed a set of UV ICCD detector performance test device. Design index: The signal-to-noise ratio test range is 0~75 dB, the resolution test range is 1~70 lp/mm, the dynamic range test range is $10^{-14}$W/cm$^2$~$10^{-8}$W/cm$^2$, and finally the experimental test and analysis are carried out to verify the test performance of the device.

2. PRINCIPLE OF TEST SYSTEM FOR ULTRAVIOLET ICCD DETECTOR PARTS

UV ICCD detection device is a kind of imaging device which is coupled with ultraviolet image intensifier and visible CCD imaging system, so the performance of UV ICCD detector is characterized by three parameters: resolution, signal-to-noise ratio and dynamic range, in order to scientifically evaluate the performance parameters of UV ICCD detector, the establishment of the resolution algorithm model, signal-to-noise ratio algorithm model and dynamic range

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algorithm model is the theoretical and principle basis of this set of systems.

2.1 Principle of resolution Testing

Resolution is the minimum variation value of the measured parameters that can be observed. The resolution characterizes the ability of the system to distinguish image details, and UV ICCD as an imaging device, the resolution naturally becomes an important evaluation parameter[1].

According to the structural composition of UV ICCD, this set of test system selects the evaluation model of image resolution: the pattern of standard test target is focused on the cathode surface of the tube, and observe the line logarithm of the black and white equal-width rectangular stripes that can be distinguished by each millimeter from the screen, the unit is line pairs/mm (lp/mm)[2-3]. The calculation formula is as follows:

\[
R = f_1 \frac{N}{f_2}
\]

Among them, \(R\) —— Resolution of UV ICCD detector parts, the unit is lp/mm;

\(N\) —— Linear logarithm observed on standard test targets, the unit is lp/mm;

\(f_1\) —— Front Objective focal length, the unit is mm;

\(f_2\) —— Rear imaging Objective focal length, the unit is mm.

2.2 Signal-to-noise ratio testing principle

Signal-to-noise ratio is a performance parameter that characterizes image noise characteristics, that is ratio of mean square root noise value in average and dark background of system output signal, expressed in decibels (dB)[4-5]. Because the ultraviolet ICCD is a photoelectric device which is coupled with the ultraviolet image intensifier and CCD, there are different degrees of noise in the photoelectric conversion of each component part, and the output image quality is reduced by the noise interference, so the signal-to-noise ratio is also a very important evaluation parameter.

This set of devices redefines an algorithm model for estimating signal-to-noise ratio SNR of images:

\[
SNR = 20 \log_{10} \left( \frac{S}{N} \right)
\]

Among them, \(S\) —— The average of an image signal, defined as the difference in the grayscale value of an image with a bright dark background;

\(N\) —— Noise mean square root value, defined as the value of the mean square root that deviates from the average of the signal.

2.3 Principle of dynamic range testing

Dynamic range refers to the ratio of the maximum to the minimum working radiation illumination or the ratio of the full charge capacity of the image sensor to the dark current capacity. UV ICCD not only requires the ability to collect high-quality images, but also requires a wide range of radiation illumination at work, so the dynamic range is also an important evaluation parameter.

The device uses the following algorithm model to estimate the dynamic range of ultraviolet ICCD:
Among them, \( S \)——Indicates the average value of the ICCD output signal when the saturation is in light;
\( N \)—— Represents the mean square root value of noise when there is no light.

3. THE TEST SYSTEM COMPOSITION OF ULTRAVIOLET ICCD DETECTOR

The technical specifications of the UV ICCD detector test system are as follows:
1) Test spectral range: 200~300nm, and 254nm, 260nm, 280nm monochrome radiation wavelength optional;
2) Limit detection minimum radiation intensity (integral ball out of the light): \( 1 \times 10^{-14} \text{W/cm}^2 \);
3) Dynamic range test (integral ball out of the light): \( 10^{-14} \text{W/cm}^2 \sim 10^{-8} \text{W/cm}^2 \);
4) Signal-to-noise ratio test Range: 0~75 dB;
5) Resolution Measurement range: 1~70 lp/mm.

The test system of ultraviolet ICCD detector is mainly composed of ultraviolet uniform light source system, target, ultraviolet imaging optical system, test black box, power supply, video acquisition and processing system and test software. Basic composition schematic diagram is shown in the Fig. 1:

![Basic composition schematic diagram](image)

Fig. 1 Basic composition schematic diagram

Ultraviolet uniform light source system produces uniform ultraviolet light with specified radiation illumination value; The ultraviolet optical Imaging system will project the uniform ultraviolet spot of the test target onto the ICCD detection surface to be measured; The video output end of UV ICCD is connected to the video acquisition and processing system, and the image acquisition and signal processing are carried out by the test software.

3.1 Key hardware design of test system

3.1.1 Uniform Light Source System

The uniform light source system needs to meet the output monochrome wavelength optional, adjustable radiation intensity, uniform radiation intensity, with a high dynamic range of monochrome ultraviolet uniform spot, and has a radiation intensity indicator device, can monitor the intensity of light hole light of the system in real time, and provide data interface to communicate with the computer. Uniform light source system includes ultraviolet light source, monochrome filter, neutral attenuation tablets, adjustable aperture, integral ball, radiation intensity indicator device, Composition diagram is shown in the Fig. 2:

![Composition diagram](image)

The spectral range of the uniform light source system of this set of test system is 200nm~300nm, monochrome UV radiation wavelengths are 254nm, 260nm and 280nm optional, the output radiant power density at the point of Integral ball outlet is \( 10^{-14} \text{W/cm}^2 \sim 10^{-8} \text{W/cm}^2 \) continuous adjustable, the uniformity of radiation illumination is better than 95%. There is a connection structure between the light source and the integral ball, and 4 slot slots are designed in the connection structure to place the bezel, monochrome filter, attenuation tablets, target. The monochrome filter changes the
composite ultraviolet light output from the light source to monochrome ultraviolet light, the radiation intensity of the input integral sphere is coarse and fine-tuned by the neutral attenuation plate and the adjustable aperture, the integral ball is used to further attenuate and homogenization the monochrome ultraviolet radiation, so as to output the monochrome ultraviolet uniform spot at the outlet of the light source system, the radiation illumination meter consists of a detector and a signal detection device, which is used to monitor the output monochrome ultraviolet radiation intensity of the system in real time, and can communicate with the computer and transmit the radiation intensity data.

3.1.2 Test target

During the signal-to-noise ratio testing of ultraviolet ICCD detector, the same image background and signal need to be detected simultaneously, and calculate the device signal-to-noise ratio parameters, therefore, the signal-to-noise ratio test target is designed as a half-moon target structure, Using ultraviolet optical imaging system, the half-moon target image is projected on the cathode surface of the ultraviolet ICCD, and the output image signal of ultraviolet ICCD is collected by video acquisition and processing system, and the background and signal of the same frame image are obtained, and the parameters of UV ICCD signal-to-noise ratio are calculated, half Moon target diagram is shown in the Fig. 3:

Resolution target is the key component of UV ICCD Resolution test, in this set of test system, the resolution target image
adopts USAF1951 resolution target standard, the scaling ratio is 1:1. Resolution target diagram is shown in the Fig. 4:

![Resolution Target Diagram](image)

**Fig. 4 resolution target diagram**

There are 8 sets of stripes on the resolution target, ranging from group No. 0 to group 7th, with 6 units per group. The resolution level dimensions are shown in the table below, the horizontal is group number, the value from 0 to 7, the longitudinal is unit number, the value from 1 to 6, the resolution target measured in the resolution range within 1~228 lp/mm, can meet the requirements of the test system.

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>2.00</td>
<td>4.00</td>
<td>8.00</td>
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<td>32.00</td>
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</tr>
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<td>2</td>
<td>1.12</td>
<td>2.24</td>
<td>4.49</td>
<td>8.98</td>
<td>17.95</td>
<td>35.90</td>
<td>71.80</td>
<td>143.60</td>
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<td>3</td>
<td>1.26</td>
<td>2.52</td>
<td>5.04</td>
<td>10.10</td>
<td>20.16</td>
<td>40.32</td>
<td>80.64</td>
<td>161.28</td>
</tr>
<tr>
<td>4</td>
<td>1.41</td>
<td>2.83</td>
<td>5.66</td>
<td>11.30</td>
<td>22.62</td>
<td>45.24</td>
<td>90.48</td>
<td>180.96</td>
</tr>
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<td>1.59</td>
<td>3.17</td>
<td>6.35</td>
<td>12.70</td>
<td>25.39</td>
<td>50.78</td>
<td>101.56</td>
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<td>1.78</td>
<td>3.56</td>
<td>7.13</td>
<td>14.30</td>
<td>28.50</td>
<td>57.00</td>
<td>114.00</td>
<td>228.00</td>
</tr>
</tbody>
</table>

### 3.1.3 Video acquisition and processing system

The video acquisition and processing system is used to collect, calculate and store the output image signal of ultraviolet ICCD. The composition diagram of the video acquisition and processing system is shown in the Fig. 5:

![Video Acquisition and Processing System Diagram](image)

**Fig. 5 the composition diagram of the video acquisition and processing system**

Because there is no video acquisition card to collect analog signal and digital signal format video at the same time, in the
video acquisition and processing system, it is proposed to use two video acquisition cards to collect PAL analog video signal and Camera Link digital video signal respectively. The control processor can read the image signal collected by the video acquisition card in real time, and at the same time carry on the calculation analysis, obtains the UV ICCD Performance parameter index, has the multi-slot, the high system bandwidth, the high running rate and so on characteristic. The storage unit can store the captured image signal, which satisfies the characteristics of large storage volume and fast storage speed.

The following figure is a physical diagram of the UV ICCD detector test System:

![Physical diagram of the UV ICCD detector test System](image)

**3.2 Software design of test system**

UV ICCD Detector test system test software using LabVIEW development platform development, the overall software design diagram is as follows:

![Overall software design diagram](image)

The software is divided into three modules, image acquisition module, data processing module, database module. The Image Acquisition module adopts high-speed data flow processing technology to realize signal high rate acquisition.
Multithreading technology to ensure that image display and data acquisition can be carried out simultaneously, including the overall image parameter settings, data acquisition and storage, real-time preservation of images. The data processing module is mainly used to calculate the signal noise ratio and dynamic range of the display ICCD camera, and according to the algorithm model in the test principle, the results are calculated and displayed. Database modules are mainly used to manage the storage of experimental data, compared to the method of file management, database data management capabilities are stronger and more systematic[6]. The following figure is a software program panel for testing performance parameters for GigE or USB UV ICCD cameras:

![Software program panel](https://example.com/software_panel.png)

**Fig. 8** the software program panel for testing performance parameters for GigE or USB UV ICCD cameras

### 3.2.1 Image Acquisition Module

The Image Acquisition module adopts high-speed data flow processing technology to realize signal high rate acquisition, and uses multithreading technology to ensure that image display and data acquisition can be carried out simultaneously. It is mainly divided into three parts: the setting of image parameters, the collection and storage of data, and the preservation of images in real time.

### 3.2.2 Data processing Modules

The data processing module is mainly used to calculate the signal-to-noise ratio and dynamic range of the ICCD camera, and the algorithm programming control is the MathScript node in LabVIEW. Its advantage is that it can be programmed using a text-like mathematical programming language similar to MATLAB, then instrumentation m file syntax script in LabVIEW environment by adding knobs, buttons, sliders, graphics and other user controls and displays, the formation of both graphics, but also text of the "mixed programming" way to simplify the programming language, improve operational efficiency. The signal-to-noise ratio algorithm flow is shown in the following figure:
The signal-to-noise ratio algorithm flow is shown in the following figure:

![Fig. 9 the signal-to-noise ratio algorithm flow](image)

The dynamic range algorithm flow is shown in the following figure:

![Fig. 10 the dynamic range algorithm flow](image)
3.2.3 Database modules

Because LabVIEW software does not realize the function of direct interface with Universal database, this set of test system uses LabVIEW's free toolkit LabSQL to access the database. LabSQL uses ADO and SQL language (structure query language) to access the database, it has the advantages of simple programming language, simple structure, easy to understand, easy to operate, can easily access the database in LabVIEW. The following figure is a flowchart of LabVIEW's connection to the database:

![Flowchart of LabVIEW's connection to the database](image)

4. EXPERIMENTAL RESULTS AND ANALYSIS OF ULTRAVIOLET ICCD DETECTOR TEST SYSTEM

In order to test the test effect of the test system of Ultraviolet ICCD detector, the signal-to-noise ratio, dynamic range and resolution of single MCP UV ICCD camera operating in imaging mode were tested by this system, and several sets of contrast experiments were designed, and the three parameters were evaluated and analyzed in combination with the experimental data.

4.1 Test results and analysis of signal-to-noise ratio of ultraviolet ICCD detector

In order to analyze the influence factors of the signal-to-noise ratio of ultraviolet ICCD, the irradiance of the cathode surface of 1UV180157 UV ICCD camera is changed under the condition that the environmental background and other conditions are unchanged, and the irradiance is slowly reduced from the maximum irradiance value, and the signal-to-noise ratio under different irradiance values is tested, and the average value is measured multiple times under the same irradiance.
Table 2 Signal-to-noise ratio of 1UV180157 camera under different irradiance values

<table>
<thead>
<tr>
<th>Radiation Illumination Value ((10^{-11}\text{W/cm}^2))</th>
<th>SNR (dB)</th>
<th>SNR (dB)</th>
<th>SNR (dB)</th>
<th>平均值 (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.6</td>
<td>42.66</td>
<td>42.72</td>
<td>42.47</td>
<td>42.6167</td>
</tr>
<tr>
<td>10.3</td>
<td>36.82</td>
<td>37.26</td>
<td>37.17</td>
<td>37.0833</td>
</tr>
<tr>
<td>10.0</td>
<td>32.89</td>
<td>33.01</td>
<td>32.90</td>
<td>32.9333</td>
</tr>
<tr>
<td>7.55</td>
<td>17.34</td>
<td>17.31</td>
<td>17.31</td>
<td>17.32</td>
</tr>
<tr>
<td>6.01</td>
<td>14.71</td>
<td>14.74</td>
<td>14.70</td>
<td>14.7167</td>
</tr>
<tr>
<td>5.28</td>
<td>13.70</td>
<td>13.73</td>
<td>13.75</td>
<td>13.7267</td>
</tr>
<tr>
<td>3.7</td>
<td>11.63</td>
<td>11.59</td>
<td>11.54</td>
<td>11.5867</td>
</tr>
<tr>
<td>2.22</td>
<td>7.98</td>
<td>7.95</td>
<td>7.90</td>
<td>7.9433</td>
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<tr>
<td>1.59</td>
<td>5.06</td>
<td>5.07</td>
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<tr>
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<td>2.39</td>
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<td>0.85</td>
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<td>0.41</td>
<td>0.4067</td>
</tr>
<tr>
<td>0.81</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
<td>0.0233</td>
</tr>
</tbody>
</table>

Fig. 12 Graph of signal-to-noise ratio of 1UV180157 camera changing with irradiance value

From the data in table 2 and the signal-to-noise ratio change trend graph in Figure 12, we find that the signal-to-noise ratio of the 1uv180157 camera increases as the radiation illumination value increases, and when we adjust the irradiance to \(1.06 \times 10^{-10}\text{w/cm}^2\), the value of the measured signal-to-noise ratio is 42.6167 dB, At this time the screen has appeared
saturation point, and then increase the irradiance value, the saturation point is too much, in order to protect the camera from the stimulation of strong light, the irradiance value in this state is recorded as the maximum value. Slowly adjust the variable aperture, reduce the irradiance, we found that in the $8.1 \times 10^{-12}$ w/cm$^2$ irradiance, the value of the signal-to-noise ratio is 0.0233 dB, tend to 0, the screen has been unable to distinguish between signals and noise, we will be in this state of the irradiance value is recorded as the minimum value. From the signal-to-noise ratio change trend graph, it can be seen that the signal-to-noise ratio decreases first with the change trend of irradiance value, then increases slowly, and begins to surge when saturation point appears. This shows that the factors affecting the signal-to-noise ratio parameters of ultraviolet ICCD include the input irradiance of the cathode surface.

4.2 Test results and analysis of dynamic range of ultraviolet ICCD detector parts

The working irradiance range of 1UV180157 UV ICCD tested in this experiment is $8.1 \times 10^{-12}$ w/cm$^2$~$1.06 \times 10^{-10}$ w/cm$^2$, and the image images we have collected in this range are as follows:

![Image](https://example.com/image1.png)

... (a) $1.06 \times 10^{-10}$ W/cm$^2$ ... (f) $8.5 \times 10^{-12}$ W/cm$^2$

Fig. 13 Image acquisition and change diagram of 1UV180157 UV ICCD

It is measured by experiments that the dynamic range of 1UV180157 UV ICCD is 22.33 dB, and its working radiation illumination interval satisfies the range of dynamic range test in the test index. Looking at the images collected under different irradiance values, we find that the smaller the irradiance value, the lower the brightness of the image, the more blurred the target imaging, so that the human eye can’t observe. At the highest irradiance, we find that there is a faint layer of halo at the boundary of the target image, which is due to the obvious halo of the emission spectral line of the ultraviolet ICCD assembly, and the electron scattering and surface photon scattering of the channel plate are the uncontrollable factors that cause the phenomenon. When the irradiance value decreases, the phenomenon is obviously relaxed.

4.3 Test results and analysis of the resolution of ultraviolet ICCD detector parts

This set of test system for single MCP UV ICCD detector Resolution test, in the acquisition program to collect the output image, as shown in the following figure:

![Image](https://example.com/image2.png)
Observe the image displayed in the computer software, for the USAF1951 resolution target, the distinguished line logarithm refers to the vertical two sets of stripes can be distinguished at the same time of the line logarithm, if not at the same time, it is considered that the unit is indistinguishable. In Figure 14, the resolution that our human eye can observe is the second unit in group 4th, according to the resolution corresponding to table 1, that is 17.95 lp/mm. Because the resolution is determined by visual method, the brightness, contrast and observation angle of the object will affect the observation of the resolution of the human eye, and the comparison of sensitive thresholds between the testers are also different, so the measured resolution is often an uncertain amount, so in order to better evaluate the performance of UV ICCD, We also need to study the other parameters further experimentally.

5. CONCLUSION

Based on the analysis of the parameters of ultraviolet ICCD detector and the principle of testing, the hardware and software of the performance parameter test system of UV ICCD detector are designed, and through the performance of the experimental test system, the dynamic range testing range of the designed test system is finally obtained as: $8 \times 10^{13}$ w/cm$^2$~$1 \times 10^{3}$ W/cm$^2$, signal-to-noise ratio test Range: 0–84 dB; resolution measurement range: 1–228 lp/mm, fully meet the requirements of the design indicators. This test system can reliably measure the signal-to-noise ratio, resolution, dynamic range of UV ICCD detector and provide some reference for the future of UV detector more comprehensive measurement research.

REFERENCES