Research on column channel gain non-uniformity of simulate detector

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Abstract: Assumed that the response to the blackbody radiation of the same temperature are equal for each pixel, each column of the infrared detector should have the same gain. But in practice, due to the defects of the production process and the material components of the focal plane array, the response of each pixel is not identical, meanwhile the channel gain of each column is not the same. The column channel gain non-uniformity of the readout circuit of the IRFPA was mainly studied. A lot of actual data was used for column channel output response curve fitting. Then, according to the data, the model of the polynomial curve simulate detector with column channel gain non-uniformity was deduced, and the precision analysis of the fitting curve was did, where a hypothesis testing method was used to verify whether the polynomial model was fit for the column gain of actual detector in global. Finally, a good simulation to the gain non-uniformity of each column was achieved.

Key words: column channel gain; non-uniformity; simulate detector; curve fitting

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模拟探测器列通道增益非均匀性研究

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摘 要: 在理想情况下,红外探测器的每一列应该具有相同的增益,如果假设每个像素点对相同的黑体辐射温度响应都相等,则最终输出的图像应为一幅非常均匀的图像,但在实际情况中,由于红外探测器焦平面的制作工艺水平以及焦平面材料组分的缺陷, 每个像素点对黑体辐射的响应不会完全相同,同时,每个列方向上通道的增益大小也不会完全相同,特别是当列与列之间的差异较为明显时。因此,主要对红外探测器焦平面读出电路中列通道的增益非均匀性情况进行了分析, 根据分析结果推导出模拟探测器列通道增益非均匀性的模型,并对拟合曲线进行了精度分析。

关键词: 列通道增益; 非均匀性; 模拟探测器; 曲线拟合

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0 Introduction

While observing the original image output of the infrared detector, the responses of the pixels in the column direction of the image change slightly(without considering certain pixels which is in the case of blind element in the column direction), but the responses of the pixels in the row direction change greater. So the image seems to be subdivided into many columns. A major cause of this situation is that non-uniformity exists in the gain of each column channel of the readout circuit of the infrared detector focal plane[1-2]. Ideally, each row of the infrared detector should have the same gain. Assumed that each pixel in response to the same temperature of a blackbody radiation is equal, the final output image should be very uniform. But actually, due to the defects of the production process and the material components of the focal plane infrared detector, the response of each pixel is not identical to the same blackbody radiation. Meanwhile, the channel gain of each column is not the same, especially when the differences between columns are more obvious. Because of the technical defects of domestic design and production process, the performance of the domestic detector seriously lags behind that of developed countries, simultaneously the product yield is low, expensive, which is not conducive for numerous scientific research institutions to join to study. Therefore, in this paper, based on the KGC04 infrared focal plane detector, which was made by a research institute in China, the research on the column channel gain non-uniformity was conducted, and the model of the polynomial curve simulate detector with column channel gain non-uniformity[3-4] was established. Moreover, the fitting curve was analyzed precisely, where a hypothesis testing method was used to verify whether the polynomial model was fit for the column gain of actual detector in global. The basis of the analysis was used to get the theoretical model, design and produce a set of simulation of the various detector system for actual detector simulation in all directions. Thus, it was able to detect the quality of all sorts of function circuit without attaining practical detector, which can greatly short the development cycle, and can ensure the backend of tested circuit with good quality.

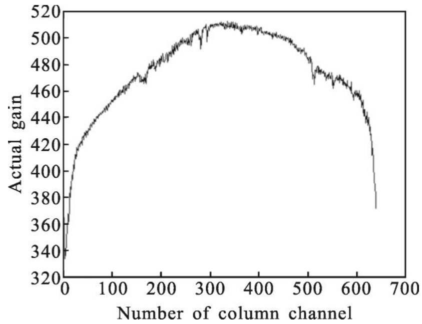
1 Discussion of column channel gain curve fitting

Assumed that the response of each pixel of the infrared detector to the same blackbody radiation has the same value, thus the column channel non – uniformity of the output image is caused by the gain non – uniformity of the column channel. Therefore, as long as to calculate the value of the input and the output we can get the gain value on each column, and the actual non – uniformity of column channel can be obtained. But there are two difficulties in the practical analysis[5-6]: (1) There are many parameters of the imaging process of the infrared detector, so it is difficult to calculate the input and output accurately, thus it is difficult to calculate the gain directly; (2) Each pixel to the same blackbody radiation response value is not identical, but this assumption may have certain error in the practical analysis, so it is necessary to inspect the rationality of the hypothesis. Therefore, in this analysis, a lot of actual data for column channel output response curve fitting was used. As the gain on the column channel will not change according to the radiation of the blackbody, the final fitting slope can approximate represent for the gain of the current column. But the value is a dimensionless value, not a real gain value, so it can only be used as the same amount of the degree of non-uniformity of each channel gain change.

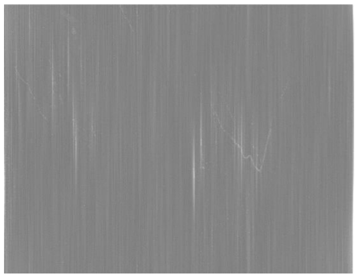
In the experiments with certain temperatures, due to the nonlinearity of the actual response, using linear fitting(the principle of two-point correction) will cause certain fitting error. The fitting error is also a dimensionless value, which means the numerical difference sum between the original response curves and the fitting curves is in the selected temperature range[7-8]. The average value of the response of each channel in the selected temperature range can be calculated. The accuracy of the linear fit on each channel can be obtained by comparing the fitting error of each channel.

In actual analysis, the response value can be got when the radiation temperature ranges from 30 ℃ to 80 ℃, 50 frames were collected from each collection point temperature and were averaged to eliminate noise, then the fitting was done according to the above analysis. The column channel gain non-uniformity was concluded as shown in the Fig.1(a), among which fitting error of fitting gain units is LSB.

As can be seen from the gain variation, the actual detector channel gain at both ends is smaller than that of the middle. This means, even all pixel points have the same response for the same external radiation, the final output is not a uniform image. It will appear lower response on both sides and higher response in the center. Actually, each pixel has different response values for the same external radiation. In addition, changes in the column channel gain will bring in more non-uniformity[9-10], which can be verified from Fig.1(b). In Fig.1(b) it can be seen that the response on both sides are darker than the center, which matches the change of the actual testing data. It is important that the blackbody radiation temperature in the experiment cannot be too high, because in that case, the brightness of the actual detector pixel will change too much because of its nonlinear response between different levels, which will increase the difficulty to analysis the result of the column channel gain non-uniformity of the detector. It is hard to tell whether the pixel brightness changes are caused by the nonlinear response of channel gain or the non-uniformity of the column channel gain. So the blackbody temperature was set as 30 ℃ during the experiments.



(a) Actual column channel gain



(b) Image of the ideal simulation

Fig.1 Comparation of variation of column channel gain and the image of the ideal simulation

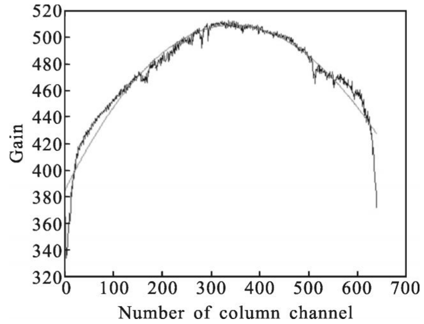
In order to simulate the behavior of the actual detector better, polynomial fitting was used according to actual data, and we got the following expression:

$$Y=aX^3+bX^2+cX+d \qquad (1)$$

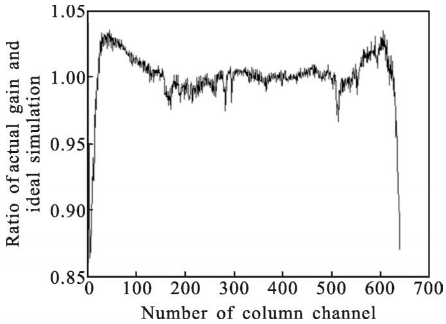
Among them, the parameters of a, b, c and d are not identical for different detectors, which decide the curve vertex positions and opening size. So the gains on the column direction are different. The steeper the shape of the curve is, the more different the column channel gains are.

Here we discuss the accuracy of the fitting curve. First of all, plot the fitting curve in the figure of the actual detector column channel gain, as the following Fig.2.

It can be seen from Fig.2 (a), the average fitting error of each channel′s mean value is less than 10%, which means the data matches well. So the linear fitting of each channel in the table was considered as close to the ideal response of original detector, therefore, the calculated gain coefficient of every line represented the actual column channel gain detector.



(a) Comparison of the actual gain and the ideal simulation



(b) Ratio of the actual gain and the ideal simulation

Fig.2 Fitting curves of the column channel gain

In the figure, the purple curve is the polynomial fitting curve. It can be seen from this figure, the curve model performances well over a wide range, but it performances not so good on both sides of the fitting. That is to say, when the polynomial curve model is used to simulate the detector, the simulation image is more smooth on both sides, which cannot reflect the real situation well. But in the most of the middle area, the curve model can reflect the actual circumstances of the actual detector better. In the experiment, when using the computer to simulate, there is some more accurate curve model matching better on both sides, but the curve will become more complex, or the highest exponent of the expression will be higher. Although such simulation performance is better, it is very difficult for the central processing unit (CPU) to calculate. It can also affect the simulation of the detector system output frame rate if the computing time is too long. So after comprehensive consideration, the cubic polynomial model was selected to fit the column channel gain non-uniformity.

2 Accuracy analysis of the curve fitting of the column channel gain

Here needs to calculate the fitting accuracy of this polynomial model. First, we calculated the current fitting parameters *a*, *b*, *c* and *d*, then this curve model was used to calculate the ideal gain value of the simulate detector according to the channel sequence. Thus, the gain ratio of each channel between the actual data and the ideal data of the detector can be got. Finally hypothesis testing was used to verify the effectiveness of the fitting curve. Figure 2 (a) is the data contrast between actual gain and the ideal simulation, and Fig.2(b) shows the calculated ratio.

The ratio data of Fig.2 is quite important. A hypothesis testing method was used to verify whether the polynomial model was fit for the column gain of actual detector in the mass. First of all, the gain value of perfect model should be equal to the gain value of the actual detector on the same column, but this is obviously impossible. So if the polynomial model is true, the ratio of such two gain value should be 1 in the total range, i.e., the overall mean of the ratio is 1. Here three different samples are used to test whether the hypothesis was established.

The process of hypothesis testing was as follows: firstly assumed that

$$H_0{:}\,\mu=\mu_0;\ H_1{:}\,\mu\neq\mu_0;\ \text{where}\ \mu_0=1 \tag{2}$$

And the total variance $\sigma^2=0.000\,4$, take the significance level $\alpha=0.05$, and then if H_0 is correct, the test statistic variable U follows the standard normal distribution:

$$U=\frac{\overline{X}-\mu_0}{\sigma/\sqrt{n}}\sim N(0,1) \tag{3}$$

For a given significance level α, check the standard normal distribution table, the critical value $Z_{\frac{\alpha}{2}}$ can be got and the confidence interval is

$$\Phi\left(Z_{\frac{\alpha}{2}}\right)=1-\frac{\alpha}{2} \tag{4}$$

So the rejection region of H_0 is the interval $(-\infty, -Z_{\frac{\alpha}{2}}] \cup [Z_{\frac{\alpha}{2}}, +\infty)$, if $|U| \geqslant Z_{\frac{\alpha}{2}}$, then reject H_0; else if $|U| \leqslant Z_{\frac{\alpha}{2}}$, then accept H_0.

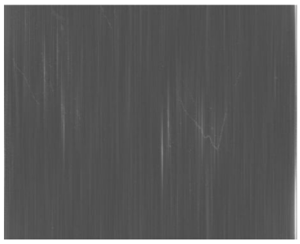
In the actual calculation, Matlab was used to do the auxiliary calculation. By using the bilateral detection function, z-test, the data in the above table can be tested in different segments. In this experiment, the data was divided into three segments, and then different hypothesis testing to these three segments. The obtained results are in the following Tab.1.

Tab.1 Results of the fitting gain ratio test of column channel

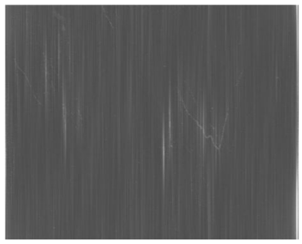
	Channel 0-100	Channel 100-550	Channel 550-600
h	0	0	0
Sig	0.276 4	0.124 9	0.586 9

The *h* in Tab.1 is the test-decision value returned from function z-test. When $h=0$, it means the hypothesis was accepted; else $h=0$ means the hypothesis was rejected. *Sig* is the least significant probability of rejecting the hypothesis, i.e., tail probability. From the results of Tab.1 it can be seen that the hypothesis was accepted in each segment, which means the original assumption that the mean of the total value was equal to 1 was established, and it showed that using the polynomial curve model to fit the gain non-uniformity of column channel was feasible. It must also be noted that the calculated results of the tail probability in different segment samples were changed greatly, i.e., the error probability of the polynomial model used in the channel 0-100 was 0.276 4; the error probability of the polynomial model used in the channel 100-550 was just 0.124 9; and the error probability of the polynomial model used in the channel 550-640 was 0.586 9. These results matched those results showed in the figure above. At the beginning and the end of Fig.2 (b), the polynomial model can not reflect the original data. Hence, from a large amount of experiments, it can be concluded that the least tail probability of the polynomial in the channel 113-524 was 0.204 2 in the best case[11-12].

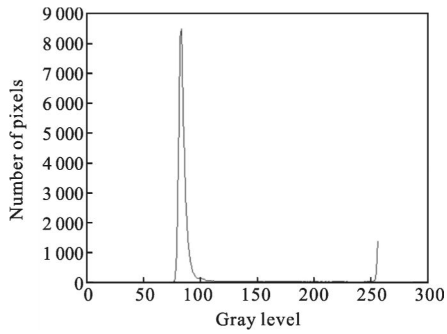
Figure 3 (a) shows the raw image with test non-uniformity, while Fig.3 (b) shows the image added



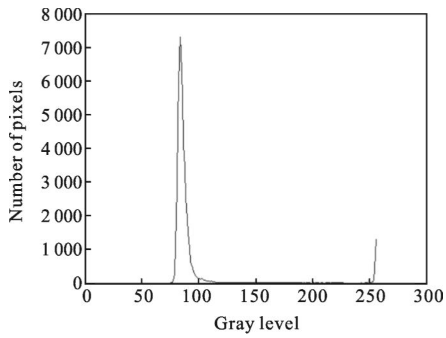
(a) Raw image



(b) Add the gain non-uniformity



(c) Histogram of (a)



(d) Histogram of (b)

Fig.3 Images of adding column channel gain non-uniformity

with the gain non-uniformity of column channel. From the comparison, the image added with the gain non-uniformity was more realistic. The differences between these two images were more apparent in the middle area and less in the ends, which made the infrared image added with the gain non-uniformity more fit for the output of actual detector and highlights the changes of each column of the actual detector.

3 Conclusion

In this paper, the research on the gain non-uniformity of column channel was conducted by the readout circuit of the infrared focal plane array. By using the polynomial curve fitting to the module of the gain non-uniformity of column channel, the gain non-uniformity model of column channel of the simulate detector was built and a good simulation to the gain non-uniformity of each column was achieved, which was caused by the column readout mode of the actual detector. This system is of great significance for the quality pre-authentication of infrared imaging electronics circuit and protecting the actual detector.

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