A heating window effect imaging experiment and its analysis

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ABSTRACT

In high speed flight, the aero-optical effect greatly affects infrared imaging system. An experiment investigating heating window radiance was conducted based the fluid computational simulation results. The paper gave the facilities needed and the procedures for experiment performance. The experiment data was analyzed by means of target signature evaluation principle, target contrast, SNR, gray level correlation index and gradient correlation index was computed from 4-bars infrared image. The results showed that the image region of interest was greatly affected by the heating window radiation. And some pre-processing skills should be introduced before implementing the target recognition and tracking algorithms. It is meaningful for validating performance of infrared imaging system with non-cooling window and to development methods of suppressing the hot dome radiation to reduce the image degradation.

Keywords: infrared imaging system; high heating window effect; aero-optical effect

1. INTRODUCTION

Flight at high speeds through at the dense atmosphere of low altitude is characterized by high aero-kinetic heating. The heating can cause image blur. The signal to noise of image is greatly affected and even submerged by white thermal noise. The function of tracking precision and target recognition is lowered by the effect. Large heating of the window significantly affects the performance of infrared imaging system, leading to major design problems of high IR imaging system.

One of means to resolve heating window problem is to add cooing facility. But cooling kit is complicated, large and low reliable. These flaws make it challengeable for applying to compact imaging system. So, the window without cooling kit is always the prior choice to deal with the infrared imaging system design for high Mach flight. The window heating effect as one of most important aero-optical effect problem is attracting scholars and engineer's attention at high Mach flight. The paper is to design a experiment to quantify effect of heating window about 623K.

2. METHODS

2.1 Experiment design

Firstly the temperature distribution is computed by fluid computational software with window material, structure data, thermal physical data and flight parameters etc. Considering the CFD method computation error and the real flight condition, It will be reasonable for set the temperature of stagnation point to lower than 500^{o}C. The paper is to set stagnation point 350 ^{o}C as a study case.

The parameters of imaging system study case used in the experiment as follows: (1) infrared detector: Mid-wave, MCT, 320×256; (2) Frame frequency: 50Hz; (3) Window material: sapphire; (4) Optical system F#:2; (5)Integration time: 4ms.

In order to acquiring the infrared image with heating effect, an simulation experiment is designed as figure 1 shows. The furnace is used to make the window temperature rise to about 623K. The heating window is put on the shelf in front of imaging system. The imaging system was connected to computer by LVDS channel and RS422. RS422 is used to control integration time, frame frequency, NUC and monitor cooling state of imaging system, etc. The raw 14-bit raw image data is transferred to computer by LVDS. By adjusting the position of off-axis mirror, the blackbody with 4-bars can be imaged clearly by infrared system. The monitor is connected to imaging system by PAL video format.

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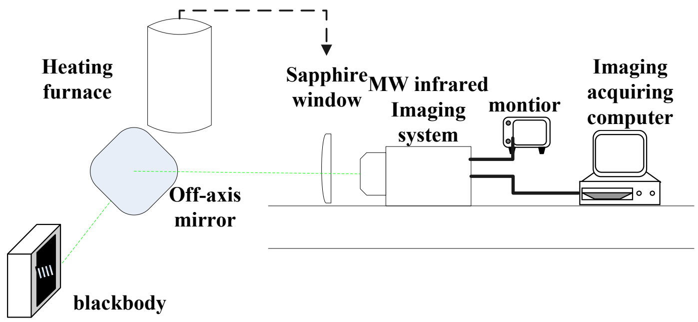


Figure 1 The sketch map of high heating window experiment

The experiment procedures are as follows: (1) the NUC was done by two-point correction means; (2)adjust 4 bars temperature difference to 5K; (3) The integration time was set to 4ms; (3) record the infrared image with non-heating window (4)Window is put into the furnace, and the temperature was adjusted to 623K. (5)Window was kept to 623K for 10 minutes; (6) Put the window in front of imaging system; (7)began to record the images with heating effect. Image recorded with heating effect was as figure 2 showed. The image center which is always the region of interest was brighter than the fringe. It means that target ROI was highly affected by thermal effect. It's important to quantify that effect and specify the effect on the target recognition and target tracking algorithms.

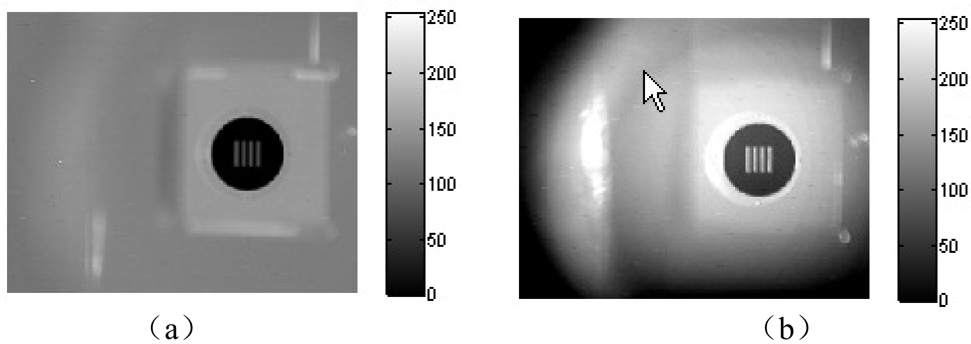


Figure 2 (a) the origin 4-bars infrared image (b) the 4-bars infrared image of high heat dome at 350℃

2.2 Experiment data analysis

2.2.1 NETD **analysis**

The target contrast was computed as formula (1) .

$$NETD = \Delta T/(S/N) \tag{1}$$

ΔT is equal to 5K; S is the average gray about 100 series image of 4 bars bright region; N is the noise of 4 bars dark region.

The NETD of imaging system without dome ia about 23.3mK; But that with hot dome about 623K is 243mK.The NETD was greatly affected by dome temperature and rise to decuple.

2.2.2 The target gray level statistical analysis

The image gray sum was calculated as figure 3(a) listed. With the window got cold, the image gray level sum decreased. And higher temperature window cause brighter image, since high temperature window radiation is more than that of low temperature according to PLUNK radiation principle. And the image gray sum was almost linear to time.

The target contrast was computed as formula (2) .

$$C = (G_T-G_B)/(G_B+G_T) \tag{2}$$

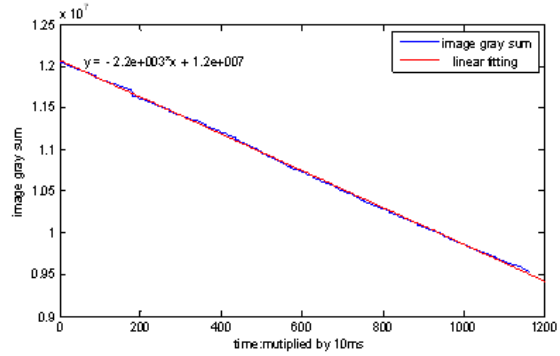
Where G_T is target gray average, G_B is ground gray average.

Figure 3(b) gives the target contrast change. As window get cold, the contrast rises. It means that high heating window radiation affects image contrast. Contrast of original image is equal to 0.025. The heating window radiation makes the target contrast decreased to about 0.0074.it is about a third of original image.

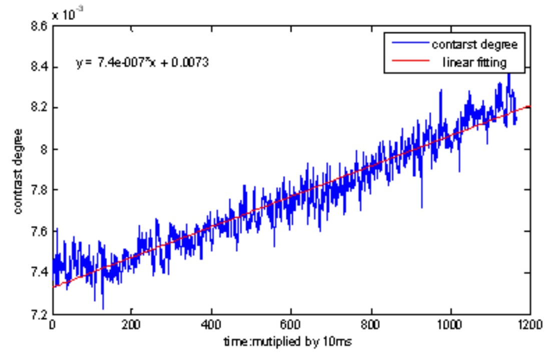
The target signal to noise can be computed as formula (3)

$$SNR=|G_T - G_B| / \sigma_B \tag{3}$$

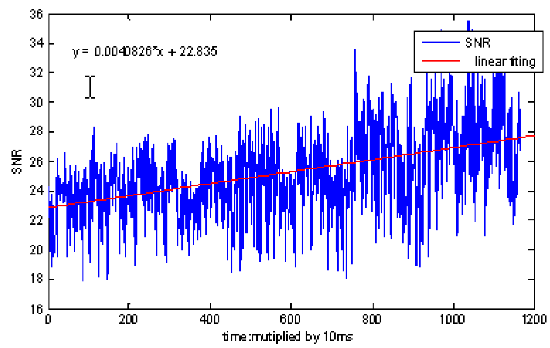
Figure 3(c) gives the target SNR change. The original image without heating effect is about 75. The heating window radiation makes the target SNR decreased to about 20. It means that SNR was greatly affected by the radiation.



(a)



(b)



(c)

Figure 3 (a)image gray level sum,(b)Contrast degree and (c) SNR change with window getting cold

2.2.3 The correlation index changing analysis

Use non-average correlation method is always used to target tracking and target recognition. It can suppress the gray level offset. And when the targets vary in a limited scale and rotation, the method can still get good results.

Two correlation methods were adapted. One is the image gray level correlation; another is the gradient level correlation. The correlation index computation formula was:

$$R(u,v) = \frac{\sum_{j=1}^{M}\sum_{k=1}^{N}(f_{j+u,k+v} - \bar{f})(g_{j,k} - \bar{g})}{\sqrt{\sum_{j=1}^{M}\sum_{k=1}^{N}(f_{j+u,k+v} - \bar{f})^2}\sqrt{\sum_{j=1}^{M}\sum_{k=1}^{N}(g_{j,k} - \bar{g})^2}}$$

$$\bar{f} = \frac{1}{MN}\sum_{j=1}^{M}\sum_{k=1}^{N} f_{j,k}, \bar{g} = \frac{1}{MN}\sum_{j=1}^{M}\sum_{k=1}^{N} g_{j,k} \tag{4}$$

where, f is to be matched target area， g is target image template; $\bar{f}$ is the gray average level of to-be –matched image; $\bar{g}$ is gray average level of target image template; M,N is template size。

In gray correlation computation, the template was selected as figure 4 showed before the heating window put in front of imaging system. Gradient correlation was done before the sobel operator was implemented on both the template and to-be match image. So the correlation index curve was drawn as figure 5(a), figure 5(b) showed.

$$\begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \qquad \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

(a)

(b) (c) (d) (e)

Figure 4 (a)Sobel operator used in edge drawn;(b)origin 4-bars gray image and (c)gradient iamge;(d) 4-bars gray image and (e)gradient iamge with heating effect

In figure 5, it can be found that with the window temperature decreasing, the correlation index was rising. It means that the higher the window temperature is, the more deteriorated target signal in image became. And since edge correlation index is lower than that of gray level, it can be got that the target edge level was more affected than the gray level. So, in target match recognition algorithms chosen, it is cautious to employ the edge related methods. Or the pre-processing algorithms should be used on template and the to-be matched image.

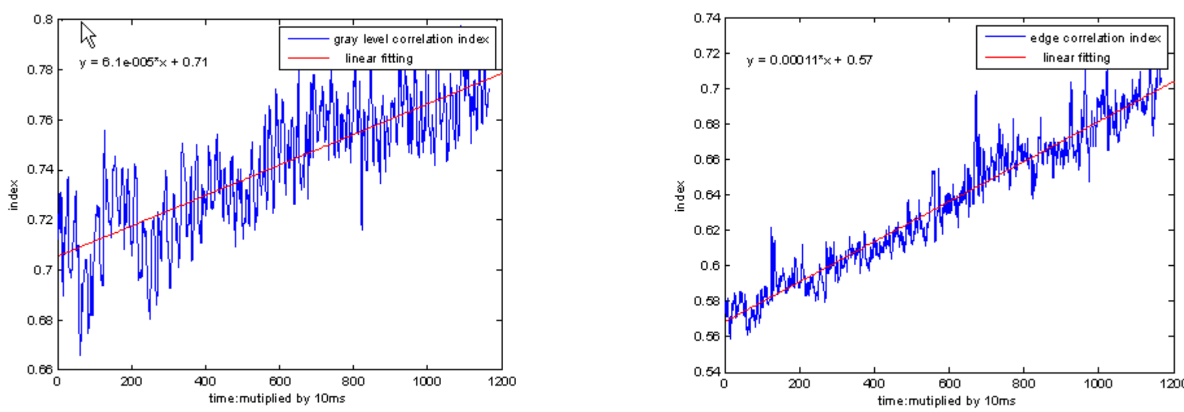


Figure 5(a)image gray correlation index,(b graidient correlation index change with window getting cold

3. CONCLUSION

The paper perform an experiment about non-cooling high heating sapphire window effect on infrared imaging in lab. The experiment was conducted according to work condition of infrared imaging system during high Mach flight. It reveals that the target contrast and SNR in image region of interest decreased caused by window radiation. And it still can be satisfied the need of system. But correlation index with the hot window differ a lot, and the edge correlation index changed severely. So, the target recognition and tracking algorithms based on the correlation method should be rectified. Some pre-processing skills should be introduced. It is meaningful for validating non-cooling window design and suppressing the hot dome radiation to reduce the image degradation.

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