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Analysis and modeling of aerothermal radiation based on experimental data

Li Liu [a], Weihua Meng [b], Yun Li [c,*], Zhiyong Zuo [a], Xiaobing Dai [a]

[a] National Key Laboratory of Science and Technology on Multi-Spectral Information Processing, School of Automation, Huazhong University of Science and Technology, Wuhan 430074, China

[b] China Airborne Missile Academy, Luoyang 471009, China

[c] Key Laboratory of Ministry of Education for Image Processing and Intelligent Control, School of Automation, Huazhong University of Science and Technology, Wuhan 430074, China

HIGHLIGHTS

- High-temperature radiation characteristics of infrared window were studied in depth.
- Aerothermal radiation degraded images were analyzed and modeled at multiple scales.
- The aerothermal degradation characteristic database was created.
- The image correction model can effectively improve the degraded image quality.

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ABSTRACT

The effect of aerothermal radiation on the performance of an airborne infrared imaging system is becoming a crucial issue in the development of electro-optic systems. In this paper the high-temperature radiation characteristics of infrared window are studied in depth, and a multi-scale analysis model of aerothermal radiation degraded images is presented. The presented model adopted a least-squares fitting method to simulate the salient characteristics of the aerothermal radiation degraded images. The aerothermal radiation degradation characteristic database containing characterizing parameters of degraded images was created. Through optimization selection, the characterizing parameters were used to correct the degraded images in the real aerothermal environment. The experimental results show that the model is effective in the aerothermal radiation degraded image correction, and improves the quality of the aerothermal radiation degraded image.

1. Introduction

Flight at high supersonic speeds through the atmosphere is characterized by high aerothermal rates and gas compression in front of the missile. Large density variation and heating of the window significantly affects the performance of a vehicular infrared (IR) sensor, leading to major design problems of IR seeking missiles. Density fluctuation of the strong incoming flow causes changes in the local index of refraction of the flow field, and leads to the boresight error, imaging blurring, and jitter [1,2]. Aerodynamic heating effect results in a sharp increase in the background level seen by the forward-looking infrared system [3]. Aerothermal environment around the infrared imaging seeker in supersonic flight is shown in Fig. 1.

Nowadays, IR tactical missiles have been widely applied whose IR systems are capable of effective operation in much more severe flight environments. The durability and survivability of the window plays a major role in defining the flight envelops of these missiles. As the IR window heats up, its self-emission may adversely impact the operation of the seeker system in a high-speed flight situation. The added background-induced noise lowers the effective performance of the system in terms of detection range, resolution and tracking capability [4].

In the past a large effort has been devoted to weaken the aerothermal radiation effect. Firstly self-compatible variable–frequency variable integration time rapid imaging infrared technology has been widely adopted to prevent the detector from saturating and improve image quality well. In the terminal guidance phase, the IR image sharpness is improved due to lowering the detector's integration time [5]. Secondly, a development effort is underway by the window cooling technology program to design an actively cooled window system for use on hypersonic interceptor forebodies [6]. The cooling system provides window

* Corresponding author. Address: Room 1008, Technology Building, No. 1037, Luoyu Road, Hongshan District, Wuhan 430074, Hubei Province, China. Tel.: +86 27 87541761.

E-mail address: yun_li2010@163.com (Y. Li).

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temperature control through film cooling using supersonic gas or liquid droplet coolants ejected over the surface of each window. Another innovative approach is presented which can enhance the aero-optics performance by internal window cooling [7]. Finally, optical filtering and optimization design of optical system are means of bettering IR system performance in the aerothermal environment. In addition other methods proposed in [8–12] are used to tackle imaging blurring and geometric distortion.

In this paper, a multi-scale analysis modeling method of the aerothermal radiation degraded images is presented. The model adopts a least-squares fitting method to simulate the main characteristics of the degraded images at multiple scales, and then the aerothermal radiation degradation characteristic database is used to correct the degraded images in the aerothermal environment.

In Section 2 we obtain the crucial characteristics of aerothermal radiation degraded images from the aerothermal tests. Section 3 is dedicated to discuss the general framework of the multi-scale analysis model and the important findings from the analysis model. In Section 4, the image correction model based on the aerothermal radiation degradation characteristic database is introduced. Finally, some conclusions are drawn.

2. Experimental investigations

2.1. Window heating experiment

To investigate the effect of aerothermal radiation on IR imaging system operating in the 8–12 μm band, the IR window heating experiment has been designed. The scheme of the experimental setup used in the window heating experiment is presented in Fig. 2. Our aim is to analyze the effects of radiation from different IR windows on IR imaging system considering the varying angle between the optical axis and the heated window. The main experiment equipments consist of a thermometer, a heat box, a collimator, a blackbody with a target wheel and an IR imaging system. The test equipment recorded the IR image sequences from the IR imaging system in this experiment.

2.2. Electric arc wind tunnel experiment

The electric arc wind tunnel experiment [13] has been designed to emulate the aerothermal effect in front of IR imaging seeker in supersonic flight. There are two main steps in the experiment. The first step was mainly to measure IR window temperature and to test the durability of the IR window under the high

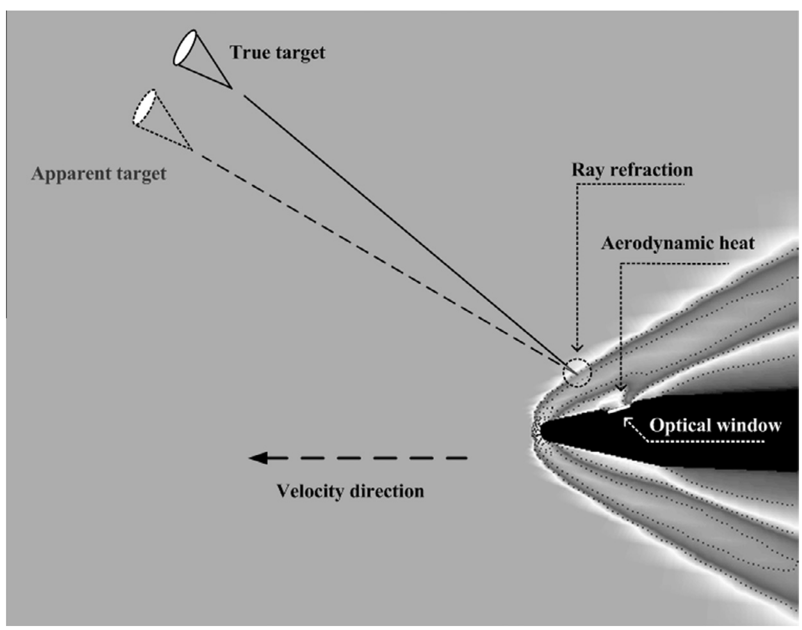

Fig. 1. Aerothermal environment around the infrared imaging seeker in supersonic flight.

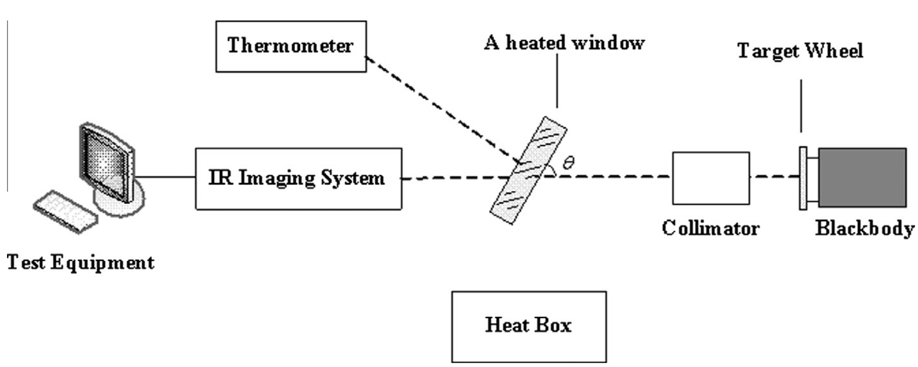

Fig. 2. Experimental setup in the window heating experiment.