Study and comparison of uncooled IRFPA cameras dynamic performances using a newly designed rotating-aperture thermal target test bench

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Abstract

This work presents a rotating-aperture thermal target test bench designed to generate controlled and repeatable apparent motion of thermal pasterns without moving the heat masses. The setup combines temperature-regulated panels with a weight balanced rotating disk containing apertures. It is used to compare a conventional uncooled camera with a Fast-Pixel prototype 1 featuring a reduced thermal time constant of 5 ms. The acquired thermal infrared image sequences are assessed using quantitative image-quality metrics, including RMSE, RMS contrast, SSIM, and Laplacian-based sharpness indicators. The results show that the Fast-Pixel camera preserves image quality more effectively as rotational speed increases.

1. Introduction

Uncooled microbolometer IRFPAs have become a key technology for thermal imaging systems thanks to their compact size, low power consumption, and cost-effective operation. Unlike cooled detectors, their simple operation reduces system complexity and maintenance, making them suitable for industrial monitoring, transportation, robotics, surveillance, and autonomous systems. Despite these advantages, the thermal time constant of microbolometer pixels remains a key factor limiting image quality in dynamic scenes. In particular, the thermal response time of the detector introduces a delay between incident infrared radiation changes and the measured signal, which can distort the recorded representation of rapidly varying thermal targets. This limitation becomes critical when observing moving hot targets [1].

Recent developments aim to improve the dynamic behavior of uncooled infrared cameras by reducing the detector thermal time constant and increasing the frame rate [2, 3]. Nevertheless, comparing camera dynamic performance in real operating conditions remains difficult because the observed thermal patterns depend on target geometry, speed, distance, viewing angle, reflections and environmental conditions. A laboratory setup capable of producing controlled and repeatable dynamic thermal scenes is therefore needed to provide a consistent basis for quantitative comparison of camera performance.

This paper presents a rotating-aperture thermal target test bench for the dynamic characterization of uncooled infrared cameras. The bench produces reproducible dynamic thermal scenes with controlled thermal and motion parameters, enabling consistent quantitative comparison of camera performance.

2. Rotating-aperture thermal target test bench

The dynamic thermal scene is produced by a rotating-aperture placed in front of two temperature-regulated sources. As the disk rotates, the apertures periodically expose parts of the heated panels to the infrared camera, generating a controlled apparent motion of thermal targets along a circular trajectory in the image plane.

The adopted design allows to act on both thermal and kinematic contributions. The heated panels define the temperature level and thus the surface radiation level, while the rotating aperture disk modulates the visibility of the panels.

The thermal sources are coated with Nextel Velvet 811-21 paint to provide stable infrared emissivity value within our operative temperature range. Heating is supplied by MINCO HAP6948-1 All-Polyimide elements equipped with PT1000 sensors. The temperature of each panel is independently regulated by a closed-loop PID controller, allowing symmetric or asymmetric thermal-source configurations up to 50 °C. The rotating disk is driven by a brushless motor through an ESCON 50/5 motor driver, whose speed is controlled by an embedded ESP32-based architecture. The same system also provides wireless supervision, remote adjustment of temperature and speed setpoints, and monitoring of the main operating variables.

3. Image acquisition and analysis methodology

Two uncooled infrared cameras were considered: a conventional commercial camera and the first Fast-Pixel prototype developed within the BRIGHTER project. Both cameras use a 1280×1024 IRFPA microbolometer with a 12 μm pixel pitch. The Fast-Pixel prototype halves the thermal time constant of the commercial camera, from approximately 10 ms to 5 ms [2]. Image sequences were acquired at several frame rates and rotational speeds. For each frame-rate setting,

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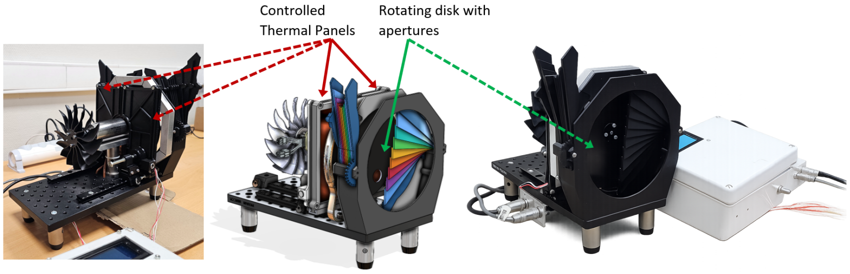


Fig. 1. *Dynamic thermal target generation test bench (from left to right): Rear view, CAD model, and front view of the experimental setup, showing the controlled thermal panels, selector gate, and rotating disk with two calibrated apertures.*

a static reference image was first recorded before dynamic acquisition.

3.1 Circular profile extraction and angular alignment

Since the aperture trajectory is circular, the dynamic thermal signature was analyzed in angular coordinates. For each infrared image, the intensity profile was obtained by interpolating the image intensity along a circular path centered on the disk rotation axis. In practice, and when additional robustness against noise or small centering errors is required, the profile may be computed from a narrow annular band around the nominal radius R:

$$p(\theta_k) = \mathrm{median}_{r_j}\, I\left(x_c + r_j \cos\theta_k, , y_c + r_j \sin\theta_k\right), \qquad r_j \in [R - \Delta R, , R + \Delta R]. \tag{1}$$

where (x_c, y_c) denotes the rotation center, θ_k the angular position, $I(x, y)$ the infrared image intensity, and r_j the sampled radii within the annular band. When comparing profiles, the median intensity level was subtracted to emphasize the angular thermal modulation and reduce the influence of the background level. For the profiles given in Fig. 2a The angular profiles obtained under static and dynamic conditions were aligned by maximizing their circular correlation.

3.2 Image-quality assessment

Image quality was evaluated inside a circular region of interest corresponding to the projected disk. RMSE and SSIM were computed with respect to the static reference image in order to quantify the deviation and structural degradation induced by motion. RMS-contrast was used to assess the preservation of thermal contrast in the dynamic image. The variance of the Laplacian was evaluated together with a Laplacian noise estimate, computed from the high-frequency residual of the image, to distinguish sharpness-related variations from noise-dominated contributions.

4. Results and discussion

Figure 2a compares the thermal signatures obtained with both cameras under static and dynamic conditions. While the static angular profiles are comparable, rotation makes the thermal intensity distribution spreads along the angular direction due to the finite detector response. This effect is more pronounced for the commercial camera, whereas the Fast-Pixel camera preserves a more confined profile, consistent with its shorter thermal time constant.

The evolution of the image-quality indicators is presented in Fig. 2b. RMS-contrast decreases with increasing rotational speed for both cameras. However, the contrast loss is lower for the Fast-Pixel camera. At 45 fps, for instance, the contrast reduction between the lowest and highest tested speeds is about 35.5% for the Fast-Pixel camera, compared with 53.5% for the commercial camera.

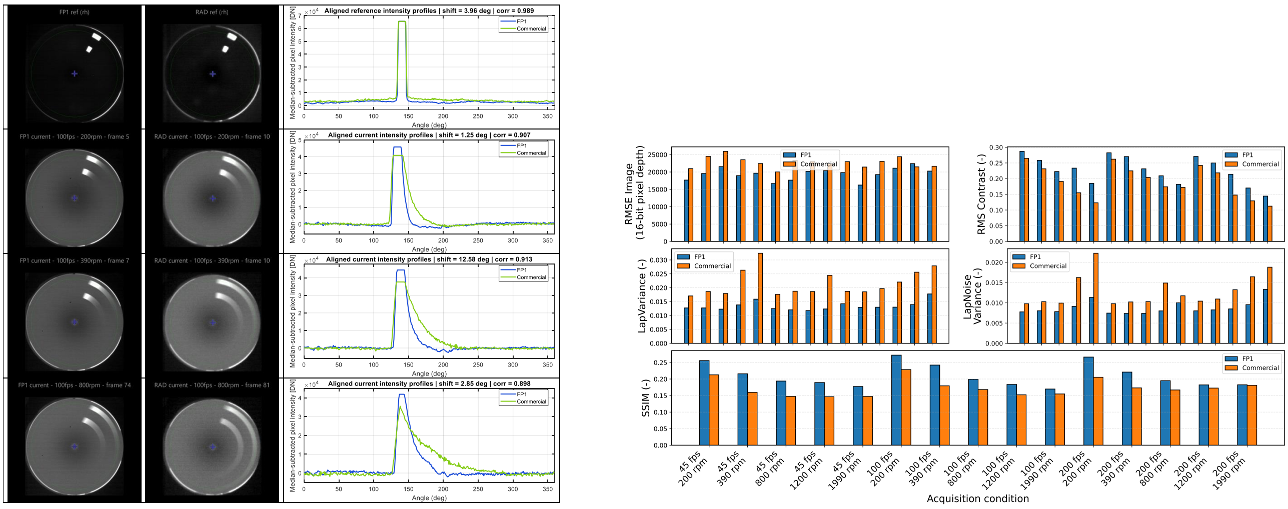
A similar behavior is observed for SSIM and RMSE, with the Fast-Pixel camera providing an average SSIM improvement of about 21% and an average RMSE reduction of about 15%.

The commercial camera shows higher Laplacian variance, but also higher Laplacian noise variance. Thus, the elevated Laplacian variance cannot be directly attributed to better sharpness and is likely influenced by high-frequency noise or camera-specific processing settings.

5. Conclusion

This work presents a in-house designed and realized rotating-aperture thermal target test bench for the dynamic characterization of uncooled infrared cameras. By generating repeatable apparent target motion over a wide speed range, the bench enables controlled assessment of motion-induced image degradation.

Tests performed with a commercial camera and the BRIGHTER Fast-Pixel prototype showed that, under the tested conditions, the prototype better preserved the thermal image features of the moving target. Compared with the commercial



(a) *Selected static and dynamic thermal images with corresponding angular intensity profiles.*

(b) *Image quality metrics as a function of rotational speed.*

Fig. 2. *Qualitative and quantitative comparison of Fast-Pixel and commercial thermal imaging under rotational motion.*

camera, it reduced motion-induced blur, leading to higher RMS-contrast and SSIM and lower RMSE with respect to the reference image.

Acknowledgments

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