Technical Report 24

A Reference Object Technique for Emissivity

Measurements with the Thermographic Camera

Barry A. Sabol

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ABSTRACT

Two simple methods of measuring the emissivity of objects with the Inframetrics Model 525 Thermographic Camera are developed. The use of appropriately chosen reference objects eliminates the need for precise setup, calibration curves, camera spectral response, and elaborate computations. Results from a variety of measurements are in reasonable agreement with published values.

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I. INTRODUCTION

This memo reports on progress in measuring the emissivity of mirrors and other objects with the Inframetrics Model 525 Thermographic Camera. The goals that initiated this line of research are: (1) the need to develop the ability to monitor the emissivity of the aluminized surface of the MMT primary mirrors over time to help determine when realuminization is necessary and (2) the need to determine reasonably accurate values of emissivity for objects and materials in the telescope chamber in order to understand and control the thermal environment of the chamber.

To date, the camera experiments were done at room temperature (MMTO offices) without the benefit of an elaborate bench setup. The objective was to develop a working method of measuring emissivity which would culminate in a consistent measure of a difference between silver-coated glass ($\in \approx 0.01$) and aluminum-coated glass ($\in \approx 0.02$). The rationale was that if this measurement could be done in a loosely controlled environment, then measurements of portions of the primary mirror surface using similar techniques may be possible.

The results show that this particular measurement (silver vs. aluminum) is possible but requires considerable attention. The room temperature emitted power levels of evaporated silver and aluminum are near that of blackbody liquid nitrogen (the camera limit) and the errors due to setup and orientation in the laboratory's high level of background emission appear to be comparable in magnitude to the power differences sought. Nevertheless, primary mirror emissivities have been measured with this technique and the results reported in another memo (Reference 1). Here, we concentrate on the basic technique.

The camera is designed to measure temperature differences using a reference source and estimated emissivities. The best results and simplest calculations occur when most of the objects in view and the background are nearly at room temperature (why this is so will be discussed later). The manufacturer's manual is very unsatisfactory in providing methods to deal with scenarios that deviate from the ideal scenario. Blackbody calibration curves in high and low temperature ranges are provided but cannot be used for the applications we envision without a good understanding of radiation theory and the camera spectral response. Indeed the camera, in its more popular applications, is designed to bypass the need for a full radiation theory treatment.

Progress has been made on a "first principles radiation theory" approach using a hypothetical spectral response for the camera (unpublished, informal report - Reference 2). We have recently received the optical transmittance and detector response curves for the camera from the manufacturer and hope to formalize that report in the future.

This report discusses the development of two simple techniques to measure the emissivity of mirrors and other objects to a useful degree of accuracy, requiring no knowledge of the camera spectral response, no elaborate setup, and no calibration curves. One technique is useful for gross measurements in the range $0.10 < \epsilon < 1.0$ and employs a reflected hot source (cardboard and a heat gun will suffice). The other technique is useful for finer measurements in the range $0.01 < \epsilon < 0.20$ (mirrors and metallic objects) and uses reflected cold sources (liquid nitrogen in flat plastic containers). Both methods require some homemade emissivity reference surfaces and the second requires a temperature probe capable of making relative measurements to a precision of a tenth of a degree Celsius.

II. THERMOGRAPHIC CAMERA OPERATION

The basic camera operation is described in the Operations Manual (Reference 3). Here we are interested only in how to use the LINE SCAN function.

The IMAGE function (see the camera front - Figure 1) gives a TV picture with brightness indicating relative radiant power. The LEVEL control must be adjusted to bring out the desired object. The LINE SELECT function gives the same picture but with a bright horizontal line across it (Figure 2). The vertical position of this line is controlled by the LINE POS knob. The idea is to find the objects to be measured on the screen and adjust the field of view (FOV control—like a zoom) to best frame these objects. Move the bright line to the desired position for horizontal profile and turn to the LINE SCAN function to display a graph of the radiant power. The horizontal axis of the graph corresponds to what is seen in IMAGE or LINE SELECT mode and the vertical axis expresses radiant power seen by the detector (Figure 2). In LINE SCAN, eleven horizontal graticule lines are superimposed on the screen to give ten equal divisions.

To explain the use of the SCALE control (10°, 20°, 50°, 100°, 200°, and 500°) and the LEVEL control, it is useful to present the following analogy. Imagine that the power outputs of all objects that the LINE SCAN crosses are immediately graphed. Such a graph with objects at a large range of temperatures might look like Figure 3 with the bottom corresponding to the radiant power emitted by liquid nitrogen and the scaling changing slowly along the vertical axis. The SCALE setting is at 10° (the most sensitive). The hatched area corresponds to what is displayed—call it the "window." The LEVEL control moves the window up and down the graph. The LEVEL is, however, not calibrated; *i.e.*, relating one position of the LEVEL with another is possible, but for the greatest accuracy all measurements should be made within the window at one position of LEVEL. The SCALE control compresses the whole graph (as SCALE is increased) so that more of it fits into the window. The values given to the SCALE control (10°, 20°, 50°, etc.) are misleading. They would be better labeled (1x, 2x, 5x, etc.). The temperature label is accurate only for blackbodies in the neighborhood of 30°C. In this temperature range, one division on the 10° scale corresponds to 1° blackbody temperature difference. On the 20° scale, one division corresponds to a 2° blackbody temperature difference, and so on.

One doesn't ordinarily think of equal intervals of radiant power corresponding to equal intervals of temperature because of the Stefan-Boltzmann Law $R = \epsilon \sigma T^4$. However, because this law uses the Kelvin scale, small portions of the curve look linear. That is, for all practical purposes, in the interval 20°-40°C (293°-313K°) equal temperature intervals correspond to equal intervals of radiant power. The camera is arranged so that one division equals one degree of blackbody temperature difference near 30°C but the correspondence would be different in another temperature range.

It is important to note (for the next sections) that equal graticule divisions correspond most closely to equal intervals of radiant power on the 10° scale. The higher scales will be increasingly less linear. An experiment to test this linearity is reported in the Appendix.

Polaroid Camera Accessory

A Polaroid camera attachment using Type 107 (3000 ASA) film is also included and is useful for recording the LINE SCAN traces for off-line quantitative analysis. The camera has two unfortunate characteristics: (1) an internal light meter controls the shutter and (2) the recorded image is distorted. Practice dictates that, for LINE SCAN photos, the brightness must be set to a level that is below that used for normal viewing. If too bright, the shutter control often doesn't work properly and portions of the picture are cut off. Even when the brightness is properly set the picture shows curved graticule lines. We have made an overlay whose lines are similarly curved to aid in quantifying the LINE SCAN trace. While not perfect, it is better than trying to "eyeball" to a tenth of a division.