

Non-uniformity Correction DRM – Towards Traceable Thermal Imaging with Uncertainty Budgets for Non-Uniformity Corrected Thermal Imagers

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Abstract

The data reference method (DRM) is a method developed at PTB for determining and correcting the non-uniformity of two-dimensional resolution cameras. The method is based on an intended horizontal and vertical displacement of the camera in front of a radiation source and the successive recording of several (at least three) offset images of the radiation source. DRM is a scene-based method and does not require any reference sources. As a result, the DRM provides both the non-uniformity of the IR camera system used and the radiation distribution of the radiation source under consideration. To determine the non-uniformity of the IR camera, relative information about the response behaviour of the individual detector elements in relation to a freely selectable reference detector element is used, which is derived from the offset image recordings. However, if the ITS-90 traceable temperature of the radiation source observed by the reference detector element is known, the thermal imaging camera can be calibrated traceably.

1. Introduction

The data reference method (DRM) [1] is a procedure that makes it possible to calibrate thermographic cameras even on inhomogeneous radiation sources, so that the requirements on the calibration source used can be significantly reduced without the achievable uncertainty of the calibration deteriorating as a result. The main contribution of the data reference method in the calibration process is the improved determination of the non-uniformity of the response behavior of the thermographic camera over the observed image field almost independently of the quality of the spatial temperature homogeneity of the calibration source used.

While in theory, the method is not introducing any sort of additional uncertainty, in reality there are some restrictions that impair the achievable results. The main error sources are the temporal stability of the source and the thermal imager, i.e. the drift, the positioning precision when taking the images, and the short-term stability of the measurement. However, under typical conditions in a thermometry lab [2] the DRM significantly improves the performance of any thermal imager. In the following the performance of the DRM will be discussed using the example of a blackbody at 100 °C following [2].

In this work, we will discuss how these main uncertainty contributions when performing the DRM can be detected, how they can be corrected and give practical tips when performing the DRM. Furthermore, we will compile an uncertainty budget with uncertainty estimations for exemplary calibration conditions. In the EPM JRP “23IND11 ThermoSI - Thermometry with embedded SI traceability for industrial applications” [3], we will employ a scene-based correction method for non-uniformity even when there is a non-uniform scene and identify the limits when there are e.g., sharp edge temperature changes that cause artefacts. The results will be compared with an ex-situ (i.e. using a reference scene without sharp temperature gradients in the lab) non-uniformity correction. The preparatory work described here is fundamental for the successful implementation of the DRM approach in the project. [4]

2. Limitations of the DRM

When applying the DRM, three images of the observed scene are taken. From these three images an equation system is obtained to calculate both the non-uniformity of the thermal imager and the true temperature distribution of the scene. However, the corrected pixels contain information from other pixels of the imager which can create artifacts when applying the DRM.

2.1. Influence of Positioning Accuracy

When taking the three images of the scene, the thermal imager must be shifted from the initial position by an identical integer number of pixels in horizontal and vertical direction. Artefacts caused by an inaccurate positioning are proportional to the displacement and the temperature difference. Hence, for a blackbody in accordance with [4] at 100 °C and a non-uniformity of ± 200 mK the requirements for the positioning accuracy are relaxed. For the typical conditions at PTB a pixel wide step on the sensor equals approximately a shift of the camera position in the order of little less than a millimeter. Figure 1 shows the calculated temperature error caused by the DRM plotted over the displacement, assuming that the blackbody is working at 100 °C, the ambient temperature is at 20 °C and each pixel is “underfilled”.





Figure 1 Simulated influence of the positioning accuracy assuming a blackbody at 100 °C in compliance with VDI/VDE 3511 Blatt 4.6 [2] and a maximum non-uniformity of the radiation temperature of ± 0.2 K.

2.2. Influence of Noise on the DRM

The influence of (white) noise on the DRM has been examined and a typical artefact related to noisy input images on the DRM has been found. Figure 2 shows the calculated temperature distribution of PTBs Cesium heat-pipe blackbody at 400 °C. The calculation shows artefacts that begin in the center of the image, the reference pixel of the DRM, and radiate outwards towards the edges. However, the influence of noise on the DRM can be easily corrected by averaging either the input images or the DRM results.

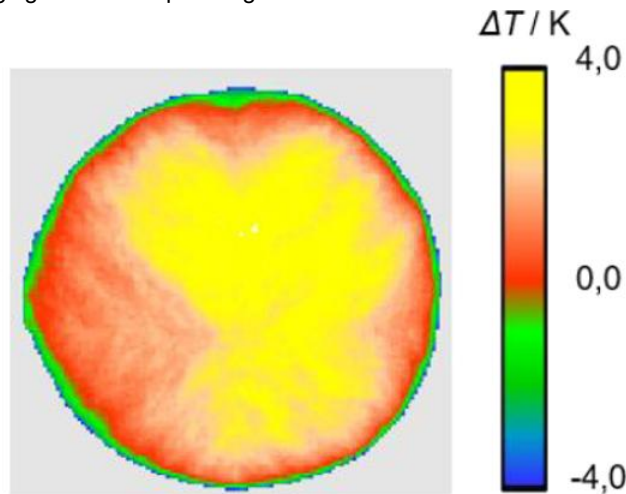


Figure 2 The calculation of the temperature distribution of a scene shows artefacts that begin in the centre of the image, the reference pixel of the DRM, and radiate outwards towards the edges when the input images of the DRM are plagued with temporal (white) noise.

3. Application examples

3.1. Correction for “Dead Pixel” and Non-uniformity

A typical application of the DRM is the correction for false reading pixels. Figure 3 a show the thermal image of PTBs water heat-pipe blackbody operating at 50 °C. The thermal imager is equipped with an MCT sensor and is working in a wavelength range around 7 μm . The image contains an easily visible structure and false reading and non-responding pixels. After applying the DRM (Figure 3 b), the true temperature distribution of the blackbody can be calculated, and the false-reading pixels can be adjusted. Applying this method at a temperature of the blackbody of 100 °C improved the maximum radiation temperature difference in the central area of the image by a factor of more than 14 and the standard deviation of the radiation temperature could be improved by a factor 26.

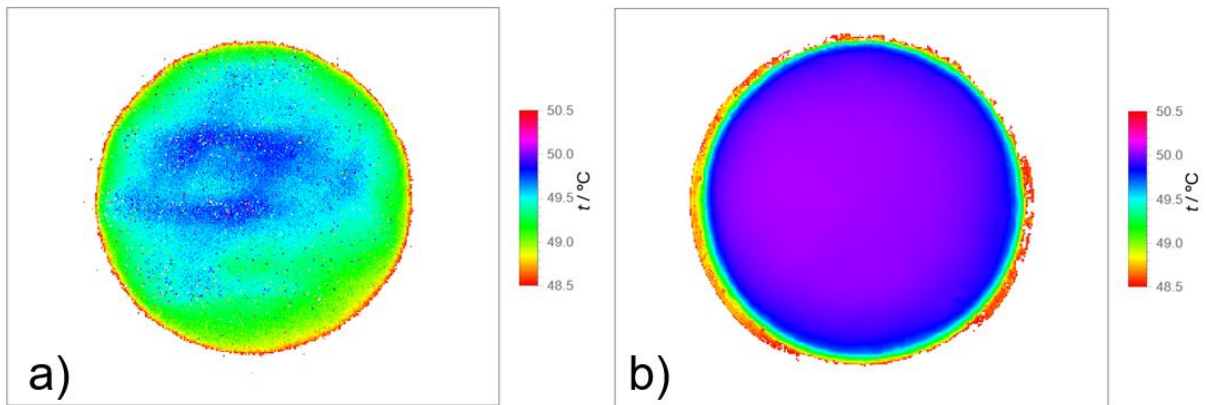


Figure 3 a) Uncorrected Image of PTBs water heat-pipe blackbody at 50 °C. **b)** True temperature distribution of the water heat-pipe blackbody calculated with the DRM [1].

3.2. Correction for Vignetting

Vignetting or lens fall-off is an effect that is caused by the solid angle of a pixel decreasing from the center of the image field towards the edge [5]. With the DRM, this effect can be accounted for as this behavior is static and can be treated as a detector non-uniformity. Figure 4 a shows the uncorrected image of a high-temperature thermal imager with an InGaAs sensor heavily affected from vignetting and read-out artefacts. Figure 4 b shows the calculated non-uniformity correction for the thermal imager containing the vignetting correction and correction for the read-out artefacts.

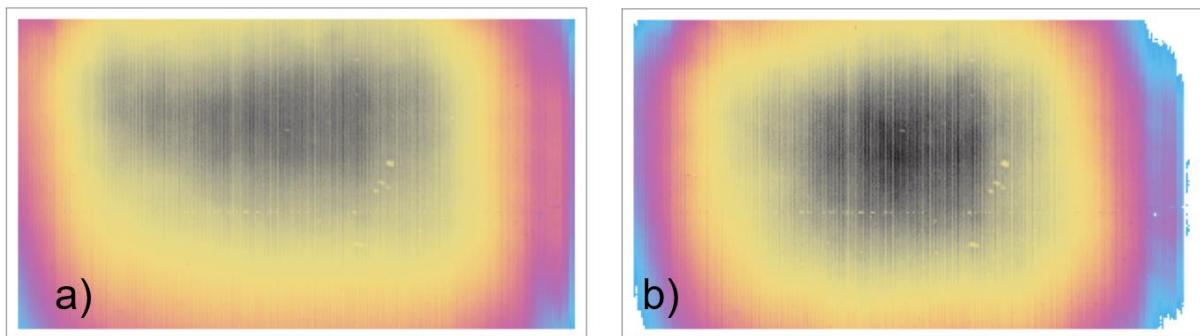


Figure 4 a) Uncorrected thermal image of an InGaAs high-temperature thermal imager. The image is heavily affected by vignetting and read-out artefacts. **b)** Non-uniformity correction containing the lens roll-off (vignetting) and the read-out artefacts.

4. Summary

The DRM provides a robust, fast method to correct for typical errors in thermography such as false reading pixels, size-of-source effect or vignetting. The demands on the positioning accuracy are feasible for typical calibration labs, and the method is useful in many spectral ranges.

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References

- [1] Sebastian König, et al., "Nonuniformity determination of infrared imagers by detecting radiance temperatures with the Data Reference Method" Proc. SPIE 10789, Image and Signal Processing for Remote Sensing XXIV, 1078904 (9 October 2018); <https://doi.org/10.1117/12.2325598>
- [2] VDI/VDE Richtlinie 3511 Blatt 4.6, „Temperature measurement in industry - Radiation thermometry - Setup and use of calibration radiators“, ICS 17.200.20, (2019)
- [3] <https://thermosi.eu/>
- [4] I. Mueller, et al., "Traceable Thermal Imaging", TEMPMEKO 2025, Reims, France, <https://www.tempmeko-ishm2025.com/inscriptions/en/scientific-program/detailed-program/31>
- [5] Helmut Budzier, "Radiometrische Kalibrierung ungekühlter Infrarot-Kameras", TUDpress 2014