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About the dynamic characterization of micro-bolometric infrared cameras

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ABSTRACT

This work describes two methods for the dynamic characterization of a microbolometer infrared camera. The time constant, parameter commonly used for microbolometers dynamic performance identification, has been addressed in literature with studies mainly focused on theoretical computation and only seldom supported by testing activity. In this paper, alternative methods for the dynamic characterization of infrared sensors are presented and related uncertainty budgets are assessed. The infrared camera NEC TH7102WX has been tested with the proposed methods and results have been compared. The microbolometer behavior has proved to strongly deviate from the common first order model so that the time constant is no more a characterizing parameter. Depending on the definition of "equivalent time constants", the measured parameters changed by more than 50%, with values ranging between 30 and 50 ms.

1. Introduction

Uncooled microbolometers have been developed since the 1980s aiming at producing low cost IR imaging systems mostly for military applications [1,2]. Thanks to their small size, high reliability, low power consumption, possibility to be used at ambient temperature and most of all the dramatic cost reduction, in the last years they have experienced wide spreading in many industrial and civil applications, such as search and rescue [3], environmental protection, driver's vision assistance [4], energy conservation, fire detection [5] and medical imaging [6,7].

A resistive microbolometer absorbs infrared radiation from the observed scene and changes its electrical resistance according to its temperature increase. Change of the resistance is usually sensed by biasing the sensor through a constant current or voltage. The sensing element is by design thermally insulated from the supporting structure whose thermal conductivity determines the detector sensitivity and its dynamic performance [8]. Improving the thermal insulation increases the microbolometer sensitivity at the detriment of the dynamic response therefore, a trade-off between these opposite requirements is performed. At present, VOx microbolometer arrays are the state of the art in infrared uncooled technology thanks to their high sensitivity, even though currently and likely in the near future, a-Si and new silicon based materials are the most common thanks to their lower cost and easier manufacturability [9]. The dynamic performances of microbolometers have been already addressed in literature, e.g. in Refs. [2,4,10–15] and [16–19] or [20], highlighting time constant ranging between 10 and 30 ms, mainly derived from theoretical computation and seldom supported by any testing. To achieve signals compatible with traditional analogic video standards sampling rate of 30 Hz or 60 Hz are quite common, despite only the lowest time constants mentioned above allow exploiting the sampling rate without major dynamic errors. In conclusion, sampling rate is not an indicator of the actual dynamic performances for this kind of instruments and the time constant is not commonly indicated among the instrument characteristics. Thus, an experimental characterization is generally required.

This work describes two methods for the assessment of the dynamic characteristics of a microbolometer, which are derived from the commonly adopted methods for the determination of the time constant in first order systems. Both methods have been applied to a TH7102WX NEC infrared camera equipped with a 320 × 240 pixels microbolometer. The paper is organized as follows: Section 2 introduces and describes the methods used for the dynamic characterization and provides the related uncertainty budgets. Section 3 shows test results that are discussed in Section 4. Conclusions are eventually drawn in Section 5.

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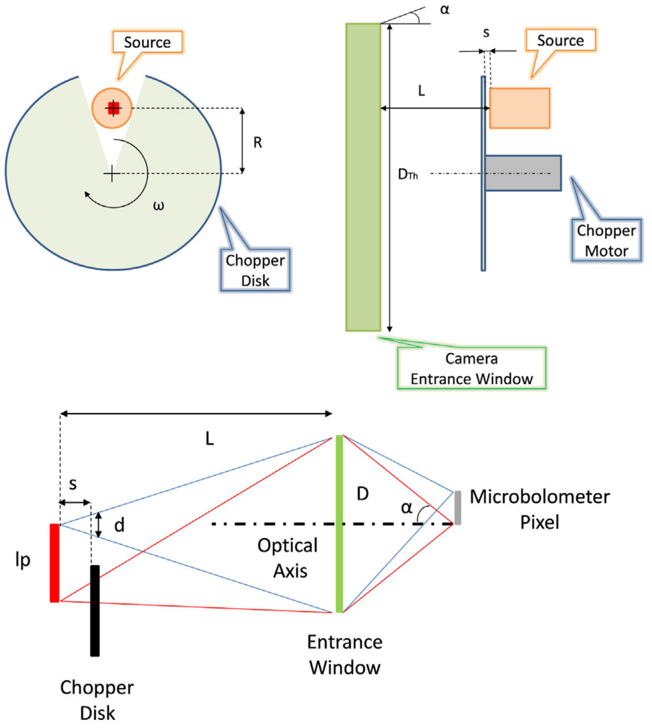

Fig. 1. Setup for the microbolometer dynamic calibration. (Bottom) Schematic to evaluate the time of the ramp signal.

2. Material and methods

2.1. Background

Step input response is a simple technique commonly exploited to extract the dynamic characteristics of mechanical, electrical and thermal systems. For thermal imaging systems, as the microbolometer tested in our study, this input can be obtained by moving a hot source in the FOV (Field of View) of the system looking to a colder background. Alternatively, to avoid moving the source, a shutter mechanism can be employed: the source is positioned behind the shutter that cyclically opens and closes a window so that in the camera FOV the hot source alternates with the cold shutter blade. A scheme of the setup is shown in Fig. 1. A chopper generates a square wave like signal whose frequency is proportional to the disc angular speed. This periodic input is commonly used in infrared detectors testing to differentiate between the dark current signal, due to the detector noise, and the true signal [21]. Anyway, if the chopper opening and the sensor output are measured, the frequency response function (FRF) $H(i\omega_p)$ of the microbolometer can be computed through their Fourier Transforms:

$$H(i\omega)=\frac{O(i\omega_p)}{I(i\omega_p)} \tag{1}$$

where $O(i\omega_p)$ and $I(i\omega_p)$ are respectively the FFTs (Fast Fourier Transforms) of the sensor and the chopper signals and ω_p is the angular frequency.

If the microbolometer can be modelled as a first order system, its FRF can be-written as:

$$H(i\omega_p)=\frac{O(i\omega_p)}{I(i\omega_p)}=\frac{k}{1+i\omega_p\tau} \tag{2}$$

where k is the detector sensitivity and τ is the microbolometer time constant. If ω_p varies in the range of interest, τ and k can be retrieved with Eq. (2) from a parametric fit of experimental data.

The measured signal can be analyzed in the time domain as well. In case of an ideal step input measured time response is expected to be an exponential as in the following:

$$T(t)=T_f+(T_i-T_f)e^{\frac{t}{\tau}} \tag{3}$$

where T_i and T_f are the initial and final temperatures. Rewriting Eq. (2) in logarithm scale, one can write:

$$Z(t)=\ln\left(\frac{T(t)-T_f}{T_i-T_f}\right)=\frac{-t}{\tau} \tag{4}$$

where the slope of $Z(t)$ provides the reciprocal of τ. The slope can be obtained from the best fit of $Z(t)$ [22].

Summarizing, both approaches can be applied to derive the microbolometer time constant from the measured response to a step temperature input.

2.2. Setup design

The setup exploited a “Scitec 300D” chopper with the two apertures rotating disc that has an outer diameter of 102 mm. One of the two sectors was eventually shut to provide a single aperture of 90° angular span. The distance of the source from the chopper rotation axis was 40 mm. The source was an aluminium cylinder of 20 mm diameter, heated at different temperatures through an electrical film resistor. The source temperature was measured by a K type thermocouple incorporated in the cylinder whose surface was coated with the high emissivity paint Electrodag501®.

In order to achieve a step input close to the ideal one, the rise time (i.e. the time taken by the shutter border to sweep across the pixel area) should be negligible in comparison with the expected time constant. The chopper disc tangential speed depends on its angular speed ω_{ch} and on the distance R of the source from the chopper rotation axis:

$$v=\omega_{ch}R=2\pi f_{ch}R \tag{5}$$

The pixel size l_p can be determined by the focal distance L and the instrument IFOV (Instantaneous Field of View) 2α:

$$l_p=\tan(\alpha)L \tag{6}$$

Moreover, an additional distance, identified in Fig. 1b as d, has to be covered to complete the microbolometer pixel release. This distance depends on the distance s between the source and the chopper disc as:

$$d=\frac{D}{L}s \tag{7}$$

where D is the entrance diameter of the infrared camera.

Combination of above defined contributions leads to the definition of the rise time as:

$$t_p=\frac{lp+d}{v} \tag{8}$$

In order to reduce as much as possible t_p the setup designer has three possibilities:

- reducing L to the minimum one allowed by the tested camera in order to decrease the pixel size l_p; and
- increasing the tangential speed v by enlarging the distance R or the chopper frequency; and
- reducing the distance s between the chopper disc and the source.

In order to avoid aliasing problem the maximum camera sampling frequency limits the chopper frequency; in our case, the maximum sampling rate is 30 Hz.

Anyway, if t_p is one order magnitude lower than the microbolometer time constant, the discrepancy between real and