# Simultaneous thermal and kinematic full-field measurements on optimal patterns based on infrared images and spectral analysis

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## Abstract

A method is proposed to measure simultaneously temperature and strain fields at the same location and time on optimal patterns, using a single high-resolution infrared (IR) camera. The kinematic field is measured by Localised Spectrum Analysis (LSA), and the thermal field is obtained from IR imaging. The impact of brightness and contrast changes on LSA is discussed, as well as the extraction of the temperature field from surfaces with non-uniform emissivity. The method is then applied to study the phase transformation of a shape memory alloy during heating and cooling cycles. In the end, the method enables extracting richer dataset per camera, which is of great interest for identification purposes. It also enables calculating energy balances, which is valuable information to study the thermomechanical couplings within materials.

## Introduction

Being able to measure both temperature and strain fields at the same location and time is particularly appealing in experimental mechanics. It enables studying thermomechanical couplings and makes it possible to compute key information, like energy balances, that are valuable inputs for studying mechanisms like phase transformation or fracture energy. Being able to measure thermal and kinematic fields reliably with high resolution also makes it possible to reduce the number of experiments needed for materials characterisation and go towards sober experimental campaigns, which falls within the “Materials testing 2.0” concept recently introduced in the community [1, 2].

Yet, measuring simultaneously and with high resolution thermal and kinematic full-fields is not straightforward because significantly different conditions are required for each method. Concerning the kinematic methods, a maximal gradient of grey level is usually sought in the images in order to obtain the best metrological performances [3]. This is opposed to infrared (IR) thermal measurements, where a well-known and uniform emissivity on the sample surface is usually sought. Another contradiction between kinematic and thermal methods is that the former is usually based on the optical flow conservation assumption in the images, which may not be respected if the temperature varies during the test.

Several methods have already been proposed to measure the two fields on the sample surface during a test, but no one enables having these two fields with high spatial resolutions. In some studies, both IR and standard cameras were used [4]. Data interpolations were performed for the modality fusion to obtain the two sought fields at the same location and time, which is a source of errors. Other research teams directly performed DIC on IR images to avoid interpolation [5], but with poor spatial resolution and non-optimised patterns. In [6], a novel method proposed to combine thermographic phosphor (TP) paint and Digital Image Correlation (DIC) for simultaneous temperature and strain measurements with a standard camera, allowing to benefit from high resolution images. The drawback is that the pattern obtained with such paint was coarse since spray painting was difficult. This leads to significantly lower metrological performance of the kinematic field.

In was shown in [3] that the optimal pattern for kinematic full-field measurements is the chequerboard, in order to maximise the grey level gradients in the images. However, such a pattern is difficult to analyse with DIC because of its periodicity. In this work we propose to combine IR imaging with Localised Spectrum Analysis (LSA) to enable working on chequerboard patterns. LSA is a full-field method which was especially formulated to analyse periodic patterns in the frequency domain in order to take profit of their optimal grey level gradients [7]. Coupling LSA with IR imaging, would enable obtaining temperature and strain fields simultaneously with high metrological performance on controlled patterns for the very first time.

## Methods & Results

In this work we propose to combine LSA and IR thermography to measure thermal and strain fields simultaneously on optimal patterns (*i.e.* chequerboards), with high resolution and reliability. The method is applied on a shape memory alloy (SMA) sample to study the thermomechanical couplings during its phase transformation activated in the temperature range [-1; 40] °C. Martensitic microstructure evolution (phase nucleation and interface propagation) under loading (thermal or mechanical) will be tracked and analysed.

Even though optical flow conservation is not a major hypothesis in LSA as it is in DIC (since LSA considers the information encoded in the phase), heterogeneous brightness and contrast changes may induce biases in the displacement field computation. As a first step, the impact of brightness and contrast changes on LSA is numerically and experimentally investigated. It is shown that even under heterogeneous brightness and contrast changes, negligible impact on the displacement field obtained is obtained.

As a second step, the impact of a heterogeneous emissivity on the sample surface will be presented. Fig. 1 shows an example of an image obtained at the beginning of the test, where the temperature is expected to be homogeneous throughout the sample. The temperature heterogeneities in Fig. 1 are thus only due to different emissivities between the white and black squares. A procedure will be presented to show how to deal with such non uniform surfaces to extract properly the temperature field from it.

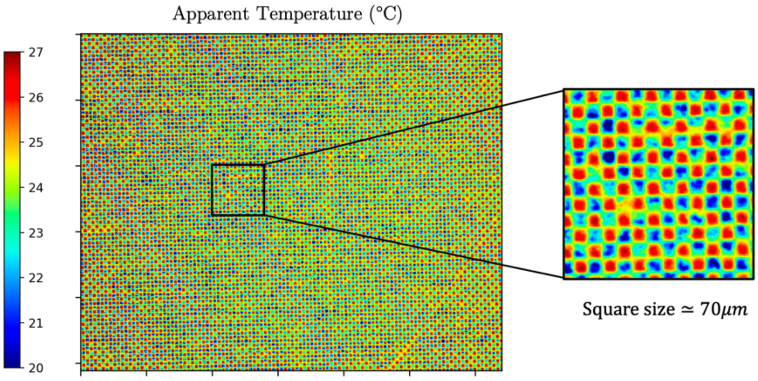

Figure 1: Apparent temperature field obtained at the beginning of the test from the IR camera.

The application of the method to study the phase transformation of a shape memory alloy will be presented. The sample is made of a single crystal of Cu-Al-NI SMA. A fine chequerboard pattern (see Fig. 1) is deposited on the sample surface using white paint and a laser engraver. The specimen is then set onto a heating-cooling device to thermally load the sample, and images are recorded with a high-resolution IR camera. The austenite-to-martensite and martensite-to-austenite phase transformations is activated in the material upon cooling and heating, respectively. The measurement method is then applied to obtain the heterogeneous thermal and kinematic fields on the sample surface during the test, with no interpolation, and with high metrological performance on the displacement field, since the pattern is optimal.

In the long term this coupled measurement method would enable going toward energy balance calculations, which is of great interest to study thermomechanical couplings, like the memory effect occurring during the phase transformation of SMAs.

## Conclusion

A novel method is presented to extract displacement and temperature fields from optimal patterns by combining LSA with IR imaging. This enables obtaining the best metrological performance on the displacement field, since an optimal pattern is used. This also avoid doing any interpolation between the two kinds of fields. Finally, it is worth noting that obtaining temperature and strain fields would make it possible to reduce the number of experiments needed for materials characterisation and go towards sober experimental campaigns, which falls within the “Materials testing 2.0” concept.

In the long term, such results would enable computing energy balances during the test, which is highly valuable to study thermomechanical couplings. This would indeed for example help understand how much energy is required for a phase transformation to occur, and what changes can be expected in the material’s properties.

## References

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