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Super-resolution based on laser Flying Spot technique coupled with IR thermography

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Abstract

A super-resolution method based on laser Flying Spot technique and InfraRed (IR) thermography is proposed. The thermal resolution given by an IR camera is limited by the pixel dimensions of the camera. The objective of this work is to achieve a better resolution through the displacement of a laser spot that is smaller than the pixel. The study of the thermal response and the knowledge of the laser displacement inside the camera pixels enable a first step toward the thermal super-resolution. The methodology of this technique and a first numerical example are presented in this paper.

1. Introduction

One of the limits of IR thermography is the relatively coarse spatial resolution. In the last years, a number of super-resolution algorithms have been developed which allow to enhance the resolution of the images. They can be divided in two main different categories [1]: single-image or multiple image-based algorithms [2, 3]. In this paper we propose a methodology with the laser Flying Spot technique [4].

2. Methodology for the super-resolution with Flying Spot technique

The objective of this work is to achieve a resolution smaller than the camera pixel resolution through the displacement of a laser spot that is smaller than the pixel. The dimension of the final resolution is then given by the dimension of the laser spot. Each laser impact creates a heat source delivering a pulse of heat quantity $Q(J)$ at the surface which depends on the thermal properties of the sample. For a laser impact located at $(x = x_i, y = y_i)$ and delivered at time $t = t_i$, the 2D heat problem for a sample of dimensions L_x and L_y can be written by Equation 1,

$$\begin{cases} \dfrac{\partial T(x,y,t)}{\partial t} = a_x \dfrac{\partial^2 T(x,y,t)}{\partial x^2} + a_y \dfrac{\partial^2 T(x,y,t)}{\partial y^2} + q_0(t_i) f(x_i, y_i) \\ \left.\dfrac{\partial T(x,y,t)}{\partial x}\right|_{-L_x/2} = \left.\dfrac{\partial T(x,y,t)}{\partial x}\right|_{L_x/2} = \left.\dfrac{\partial T(x,y,t)}{\partial y}\right|_{-L_y/2} = \left.\dfrac{\partial T(x,y,t)}{\partial y}\right|_{L_y/2} = 0 \\ T(x,y,t=0) = 0 \end{cases} \tag{1}$$

where a_x, a_y ($\mathrm{m^2 \cdot s^{-1}}$) are the diffusivities along each of the x, y directions of space, respectively. $T(x, y, t)$ is the thermal response at the surface of the studied material. $q_0(t_i)f(x_i, y_i)$ represents the temporal and spatial repartition of the heat source created by the laser impact. As a first estimation, in this work the study is only made along one direction (*i.e.* the laser displacement is made only along one direction). Moreover, it is considered that the energy is homogenously distributed by the laser spot. Then, each laser excitation is considered as a temporal Dirac, and the time τ between two neighbouring impacts is deliberately chosen high so that the influence between impacts can be neglected on the thermal response. The methodology for the thermal super-resolution is illustrated on figure 1 with an example.

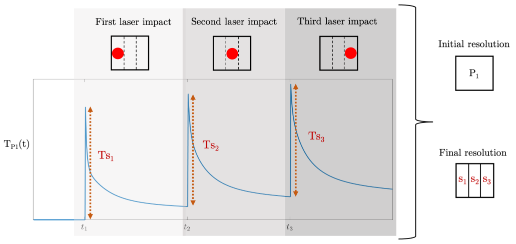

Fig. 1. *Schema of the methodology for the super-resolution with laser Flying Spot technique.*

On this example, the study is made on a unique camera pixel P_1. Three laser impacts will occur at time t_1, t_2 and t_3, at three consecutive positions. The thermal response is measured by the camera pixel P_1. As the position and time of each laser impact is known, the thermal super-resolution is made by working on each time interval $[t_i, t_{i+1}]$. The value Ts_i

on each sub-pixel s_i is determined by calculating the difference between the maximum temperature value on the time interval $[t_i, t_{i+1}]$ and the temperature value at time t_i. The final resolution is then higher than the initial one.
It is important to note that the values Ts_i don't represent the accurate temperatures of each sub-pixel s_i, however this method enables a cartography of thermal properties of a sample with a resolution higher than the camera resolution and consists then to a first step toward the thermal super-resolution.

3. First numerical results

In this part a first numerical example is performed. The studied sample, illustrated on figure 2.b is a homogeneous 1D-material with a local change of thermal propriety (here represented with a change of diffusivity) . This "defect" is smaller than the camera resolution, which is represented on figure 2.a. On this example, three laser impacts are consecutively made on each pixel. The "real" thermal response (sub-pixel) is calculated with a 2D finite difference numerical method, and the "measured" thermograms of each pixels P_i of the camera, illustrated on figure2.c are calculated by performing the mean of temperatures of each sub-pixels. The proposed methodology is then performed with the the measured thermograms P_i and the obtained results are given by the figure 2.d. First, it can be seen on this example that the position of the localised defect (change of diffusivity), of dimension smaller than the camera pixel, is succesfully retrieved. Indeed, the temperature variation at the defect position is higher than in all the others sub-pixels. On figure 2.d other temperature variations are visible, even though there is no thermal propriety difference. These variations, smaller than the one at the defect position are due to the laser position inside the pixel as well as the diffusion phenomenon. Indeed, for each laser impact, the heat will diffuse along each direction on the sample. Indeed, if the laser spot is made on the edge of the pixel, a large part of the heat will diffuse on the neighbouring pixel, whereas if the laser spot is made on the center of the pixel the heat will take more time to reach the edge. Therefore, the maximum temperature variation will be higher for the central laser impacts for identical thermal properties.

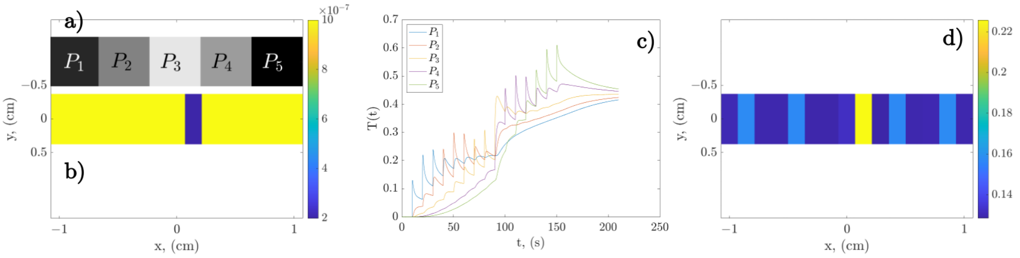

Fig. 2. ***(a)*** *Representation of the five pixels of the camera.* ***(b)*** *Diffusivity repartition of the studied sample.* ***(c)*** *Thermograms for the five pixels P_i represented on (a).* ***(d)*** *Thermal maps obtained with the proposed super-resolution methodology.*

4. Conclusion

A super-resolution method based on laser Flying Spot technique and InfraRed (IR) thermography is proposed. The objective of this work is to achieve a better resolution than the IR camera resolution through the displacement of a laser spot that is smaller than the pixel. The study of the thermal response and the knowledge of the laser displacement inside the camera pixels enable a first step toward the thermal super-resolution.

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