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Census Transform Based Optical Flow for Motion Detection during Different Sinusoidal Brightness Variations

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Abstract. This work is a first approach of the implementation of a specific Optical Flow algorithm for motion detection in cases where the brightness variation is represented by a sine wave, whose characteristics vary across the different image sectors. The final goal would be the implementation of such an algorithm in thermal films recording a component undergoing a sinusoidal load. Mapping the motion field all over the thermal video time history, and deriving it in order to obtain a strain map, would enable both the simultaneous measurement of stress (by performing Thermoelastic Stress Analysis) and strain by a unique video, and the possibility of stress calibration, thus linking the digital levels in output to real stress values. In this scenario, the authors present the implementation of Census Transform based Optical Flow on a simulated video, where the brightness variation is modeled like the superimposition of sine waves equal for all pixels and different Gaussian spatial distributions frame after frame. The latter is used for creating different sine patterns for each image sector.

1. Introduction

During the last decades, Non Destructive Testing procedures are gaining a significant role both in industrial and in research fields. In this scenario, the possibility of measuring stress concentrations during a dynamical mechanical test is very useful since it allows to highlight unpredictable stress patterns in a specific structure due, for example, to particular manufacturing processes such as 3D printing [1]. Such kind of patterns can be evaluated through Thermoelastic Stress Analysis (TSA) [2],[3],[4],[5],[6] which gives as output a thermal film where the temperature variation corresponding to the load frequency is directly linked to the stress variation during the test. Obviously, a calibration procedure aiming at finding the calibration factor allowing to convert temperature [°C] in stress [Pa] is required. Usually this procedure is performed through a strain gauge rosette, by measuring the strain distribution that will be put into relation with the stress thanks to the material constitutive equations [5],[6]. Unfortunately, this calibration methodology is invasive, thus not feasible for some applications. Another solution could be the application of Digital Image Correlation [4],[7] on thermal images by using a specific emissivity pattern as speckle. Again, this technique requires a sort of surface treatment to generate the mentioned speckle, and this is not always applicable. Therefore, in this work the authors perform a first approach that in the future will enable the evaluation of strain maps from thermal films, thus providing both a reference for calibration and the additional information about strain useful for mechanical considerations. In this work a specific Optical Flow algorithm has been chosen for reaching the fixed goal. However, most of the existing Optical Flow codes exploit gradient based methods, i.e. they assume that each point of a framed object conserves its brightness during the video sequence. On the contrary, in our case the intensity of each pixel varies both for the thermoelastic effect itself (a structure compression generates a temperature increasing revealed by the thermal camera, and vice-versa) and for the framed object is moving at the load frequency. Therefore the Horn and Schunk method [8] and Lucas-Kanade one [9] seem not to be suitable for the application. In literature some authors tried to overcome the brightness variation problem, see for example [10], [11], but none of them fits well our needs, because they address to correct the typical illumination changes that can occur during a test conducted by optical systems. Therefore, they are not able to take into account the combined effect of displacement and temperature-stress variation. For these reasons, in this work it has been decided to exploit another approach for Optical Flow estimation: the Census Transform [12],[13], which in some way tolerates a certain amount of brightness variability given by the defined input parameters. In order to follow a step-by-step approach, in this work we considered a simulated video sequence where we try to reproduce conditions similar to those involved in a Thermoelastic test, where the intensity of each pixel follows a sine wave (without considering background noise) whose amplitude is different from a component region to another due to the different stress distribution across the component. Hence, we generated a video sequence by taking a thermal frame and applying both a known horizontal displacement, and a sinusoidal brightness variation for each pixel, whose amplitude varies from an image region to another, according to a Gaussian distribution, whose standard deviation changes according to a sine law in turn. At this point, the Census Transform code, which will be described in the following section, has been applied, thus providing an estimation of the displacement time histories, reconstructed thanks to the method proposed in [13].

2. Materials and Methods

In the following the authors demonstrate the feasibility of the application of Census Transform to obtain a displacement field from a thermal video sequence. The algorithm, developed in Matlab environment, has been applied to a simulated motion video starting from a thermal image. In the first section the evaluated thermal video sequence will be described.

2.1 Simulated video sequence

The considered thermal image is reported in Figure 1.

A uniform horizontal displacement field has been applied to the thermal image in Figure 1. Its expression is reported below:

$$x(t) = A * \sin(2\pi f_0 t)$$

where A was set equal to 3, while the chosen frequency was 10 Hz. The reference displacement applied to the image is reported in Figure 2. At this point the authors attempted to produce a temporal and spatial brightness variation, since during a Thermoelastic test the stored radiation changes temporally for the Thermoelastic effect itself, and spatially due to the fact that the different regions of a component can be stressed differently to each other. For this purpose, it has been stated to generate a sine wave for the temporal brightness variation, superimposed to a Gaussian light distribution (as if the component would be more stressed at the centre), whose standard deviation varies sinusoidally in turn. Figure 3 shows an example of the light distribution at a certain instant of time. In the following section the algorithm applied to the thermal video will be described.

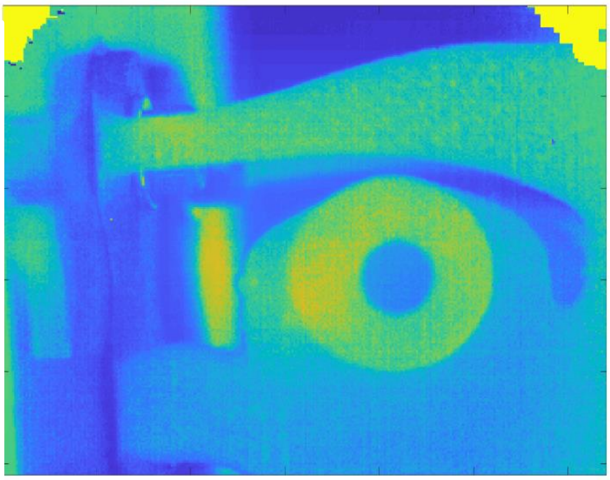

Figure 1. The considered thermal image, the video sequence has been obtained by applying a uniform displacement field to the image

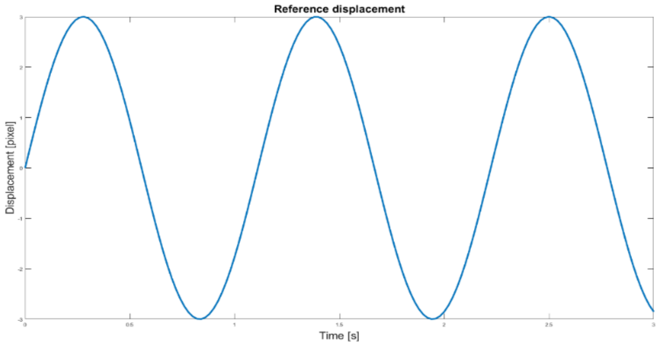

Figure 2. Sinusoidal displacement applied to the thermal image, in order to obtain the video sequence

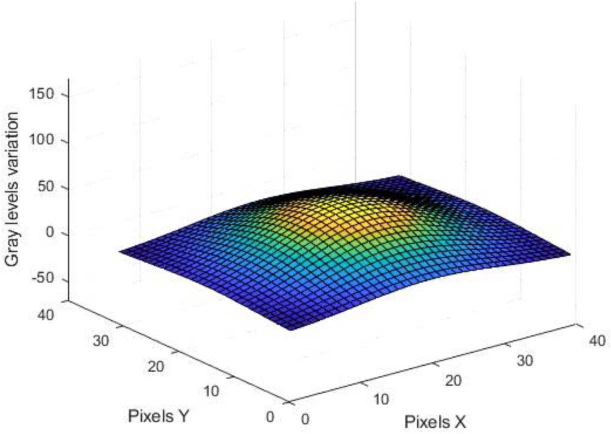

Figure 3. Variable Gaussian light distribution

2.2 The CENSUS Transform

The Census Transform is based on a non-linear transformation which associate to a pixel G a clockwise concatenation of strings representing the set of neighboring pixels whose intensity is less or more than that of G [13]. Defining a kernel that scans the overall image, the pixels surrounding the central one are numerically defined through the following digitalization:

$$\gamma(G,G') = \begin{cases} 0 & G - G' > \varphi \\ 1 & |G - G'| < \varphi \\ 2 & G' - G > \varphi \end{cases}$$

where φ is the threshold, its value depends on the format of the analysed video sequence (i.e. the number of bits of each pixel). This allows to define a signature vector for each pixel. A signature vector of length c represents n^c different patches, being n the dimension of the kernel used to construct the signature vector of each pixel. This algorithm can be used as a descriptor for image recognition or for the tracking of image features through the video sequence. In order to match the features between two consecutive images, further hypotheses are needed. The adopted algorithm is described in the flow reported in Figure 4.

- *Image filtering*: A low-pass filter with a 3x3 mean filter was applied to the video before applying the CENSUS algorithm, in order to reduce the thermal images noise.
- *Scanning of Image 1:* Computation for every pixel in Image 1 of its signature vector
- *Scanning of Image 2:* Computation for every pixel in Image 2 of its signature vector
- *Search for correspondence between Image 1 and Image 2:* search for pixels in Image 2 having the same signature vector as the pixels in Image 1.
- *Correspondence hypotheses*: each pair of pixels of two consecutive images with the same signature vector represents a correspondence hypothesis.

Therefore, in order to achieve biunivocal correspondences between the features in the two images and to correctly reconstruct the displacement of the detected features, more hypothesis are needed.

1. The first step is to filter out all the features which do not contribute to any meaningful correspondence, for example the uniform patches (which often correspond to the background) are removed.
2. All the pixels that have more than a fixed number of correspondence are not considered as significant for the displacement computation, and so they are removed. Hypotheses are only generated if there are few elements (Figure 5).
3. The third filter uses illumination and geometric constraints. In the described case study, an intensity change of 20% of the central pixel was allowed and the maximum displacement vector length was set to 10 pixels.

By means of the application of this three hypothesis, it has been possible to select the right correspondences (Figure 6) and to compute the associated displacement vectors for each pair of images in the video sequence.

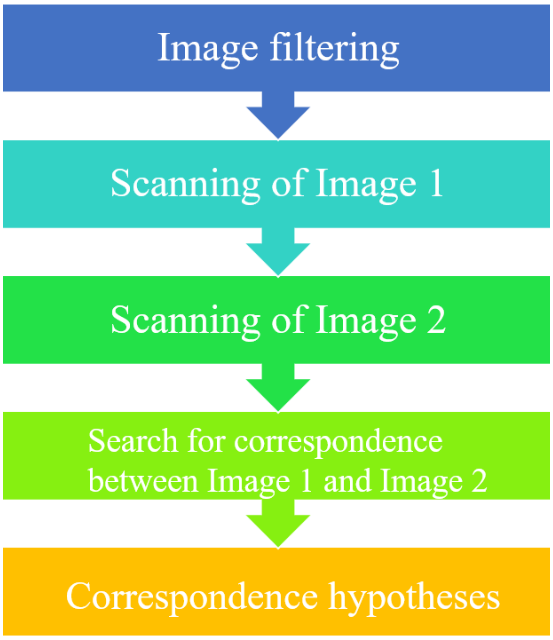

Figure 4. Flow chart of the developed code

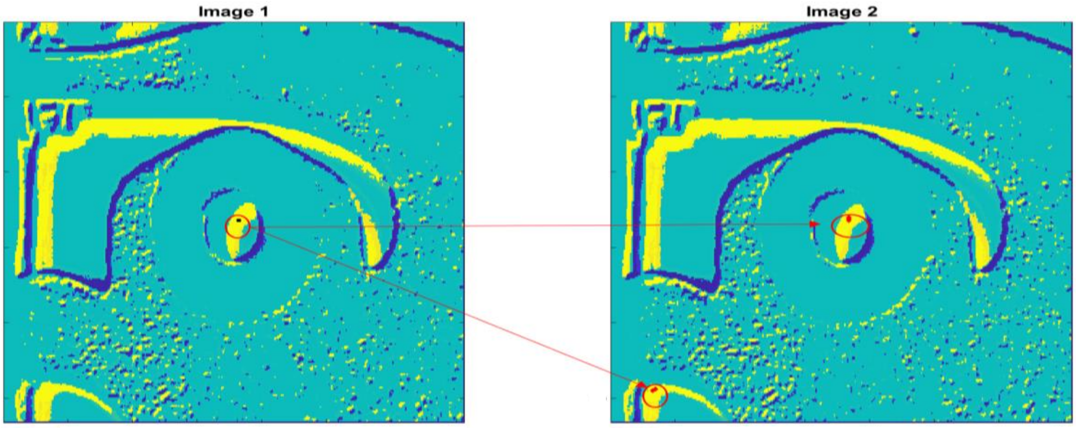

Figure 5. The black, circled pixel in Image 1 has 6 correspondence hypothesis in Image2

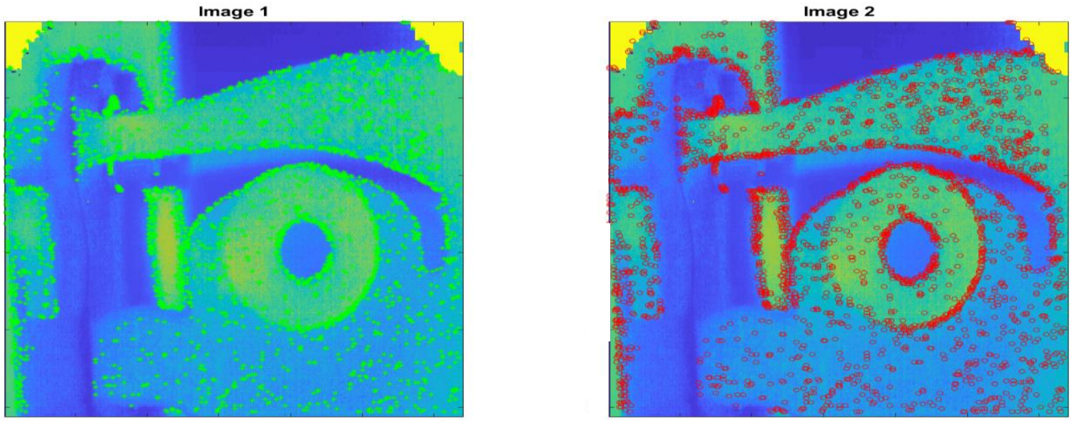

Figure 6. The correspondence between figure 1 and figure 2

3. Results

The displacement between each of the *n* features resulting from two consecutive images has been compared with the value of reference displacement at the correspondent instant of time. Results are reported in Figure 7 and described below in terms of percentage of correct matches on the total amount of detected features.

Max value: 99.27%
Mean value: 98.41 %
Min value: 96.74 %
Standard deviation: 0.52 %

As shown in Fig. 7, the developed code is able to correctly reconstruct the displacement time history and additionally, a sub pixel analysis could enable the very correct feature tracking.

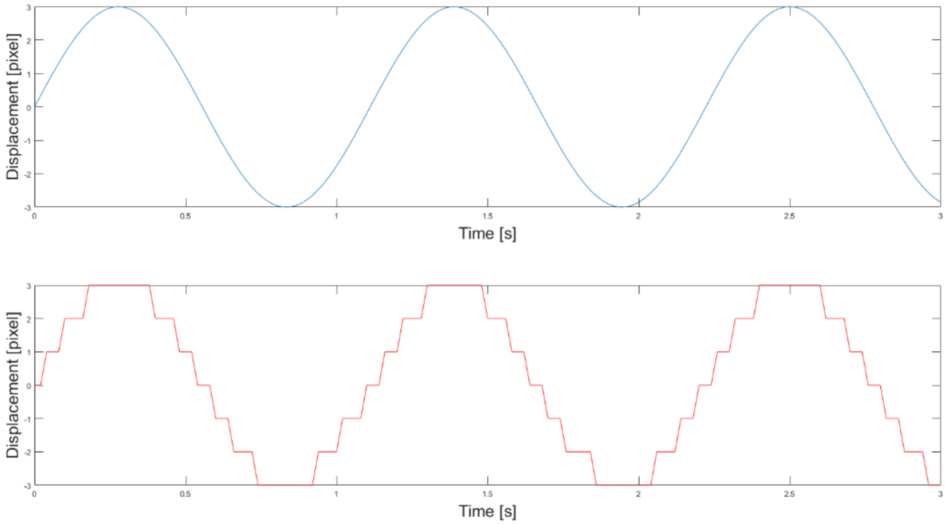

Figure 7. *Comparison between the reference displacement and the time history of one of the detected features.*

4. Conclusions

The present work is a feasibility study of the application of the CENSUS Transform based optical flow for videos simulating ideal brightness variations that may occur during a Thermoelastic Stress Analysis. This first approach is addressed to a further implementation on real thermal videos acquired during dynamical load conditions of an inspected structure in order to enable the stress calibration without the strain gauge rosette use, and in a second step the simultaneous stress and strain-full field evaluation. The obtained results confirm the code robustness in terms of radiation changes, encouraging its implementation on a real application. As further developments, the subpixel analysis will be able to be implemented only after a robust computational optimization.

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