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Invited Paper

Light intensity independence during dynamic laser speckle analysis

Renan Oliveira Reis [a], Hector J. Rabal [b], Roberto A. Braga [a,*]

[a] Universidade Federal de Lavras, Departamento de Engenharia, CP3037, Lavras, MG, Brazil

[b] Centro de Investigaciones Ópticas (CCT CONICET La Plata-CIC) and UID Optimo, Departamento de Ciencias Básicas, Facultad de Ingeniería, Universidad Nacional de la Plata, P.O. Box 3, Gonnet, La Plata 1897, Argentina

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ABSTRACT

We explore some different normalizations of current dynamic laser speckle activity measures searching for their performance with respect to the illumination inhomogeneity of the samples. Inertia Moment and Average Value of Differences of the co-occurrence matrix are compared using a paint-drying case study on a uniform sample where attenuation in a portion of the illuminated area is introduced using a neutral density filter. In this way, all environmental conditions being equal but non-uniform illumination permits the comparison on a better approximation to objectivity. The results presented show that it is possible to mitigate the effects of the illumination in the activities measured by the dynamic laser speckle.

1. Introduction

Dynamic laser speckle analysis is conducted by means of image processing of the speckle patterns in order to evaluate their level of changes with time, which can be expressed by means of graphical and numerical outcomes. Graphical outcomes are normally adopted where the aim is to create a map of activity displaying regions with different activities. In turn, numerical outcomes are adopted when the observed area is considered homogeneous, thus without significant changes of activity.

In numerical approaches, some dynamic laser speckle applications use second order statistics such as autocorrelation analysis [1,2], or the Inertia Moment and its variation Absolute Value of the Differences [3,4].

In the Inertia Moment (IM) and in the Absolute Value of the Differences (AVD), analysis of the data is done by means of the co-occurrence matrix obtained from the time history of the speckle pattern [5], originally proposed through a series of texture evaluation operations [6].

The final values of the IM and AVD are presented with respect to the grey level distribution of the points in the co-occurrence matrix around its principal diagonal, defined (using a mechanical analogy) as Eq. (1).

$$\mathrm{IM}=\sum\sum\left(\frac{M_{ij}}{Norm}\right)(i-j)^2 \tag{1}$$

where M_{ij} are the entries in the co-occurrence matrix defined as the number of times that a grey level i is followed in time by a grey level j and $Norm$ is a normalization constant of the data, which is the sum of each row of the M_{ij} so that the sum is then forced to be 1 [3]. Then, the coefficient of the squared difference can be interpreted as an estimation of the conditional probability of the intensity transition $i \to j$ *given that the first occurrence was i*. So, the result of the calculation is the contribution of that row to the IM, which is the mean value of the magnitude $(i-j)^2$, also *given that the first occurrence was i*. In order to compare alternatives we will call this normalization *local line normalization (LLN)*.

In the AVD, the difference is the substitution of the square operation by the absolute value of the differences between i and j.

In [7] a different normalization was proposed in order to enhance the robustness of the procedure, thereby reducing the effect of the variations of the intensity in some areas of the image, such as when one illuminates a round object or even an irregular object that should have the same activity in all regions of the image. We will call this normalization *whole image normalization (WIN)*, defined by dividing each matrix entry by the total number of occurrences. Then this weight factor becomes an estimation of the probability of the difference $(i-j)$ independently of the value of i. The IM or AVD defined with this normalization is the mean value of $(i-j)^2$, or $|i-j|$ respectively, that is, the intensity change for any value of the first intensity i.

In the IM, those occurrences that are far from the principal

* Corresponding author.
E-mail addresses: robertobraga@deg.ufla.br, robbraga@gmail.com (R.A. Braga).

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diagonal are weighted by the square or absolute operation. Occurrences on the diagonal do not add to the result, as they represent no changes between consecutive frames in the time history.

It can be seen that the results rely heavily on intensity measurements that are affected by the registering medium. Digital cameras, which use charge coupled devices (CCD) arrays to register the scene, as occur with CMOS sensors, in digital cameras suffer with the nonlinearities during the assembling and storage [8]. One reason for the nonlinearity is due to the saturation point, where pixels with irradiance above the limit are set to the maximum value represented by the limit. In addition, the variation of the light in the sample can be attributed to other factors, among them the distribution of the intensity of the light in the laser beam, that can spread over the surface as a Gaussian function, i.e., more light in the center with a reduction in the surrounding circles.

The two normalizations give different results, as for the first to become equal to the second, each row should be multiplied by the probability of i appearing as the first element, that is, by the first image histogram.

The second normalization [7] is not dependent on the histogram of the first image, and it is somewhat immune to offsets subtraction. That is, when the observed phenomenon is the same in the whole illuminated area, two THSPs where some rows are more illuminated (by stray light or by some irregularities in the sample surface) should give similar results.

The search for a greater independence of the biospeckle laser results concerned with the level of illumination in the sample led to a proposal [9] modifying the Fujii algorithm [10] (Eq. (1)), and another that proposed a pre-processing approach of the image using normal vectors [11]. Both works dealt with the enhancement of the equalization of the contrast of different areas within an image. However, they did not investigate the results numerically and subjective judgment of graphical outcomes cannot express the actual efficiency.

In this work we test the influence of the illumination inhomogeneity in dynamic laser speckle patterns using numerical analysis on actual experimental data. This is done using a similar measurement to that proposed by Fujii [10], described by:

$$F(x, y)= \sum_k \left| \frac{I_k(x, y) - I_{k+1}(x, y)}{I_k(x, y) + I_{k+1}(x, y)} \right| \tag{2}$$

where $I_k(x, y)$ is the intensity in pixel (x,y) and frame k of a stack of images of dynamic speckle and the bars indicate an absolute value.

2. Methodology

We tested the traditional approaches for numerical analysis of the dynamic laser speckle and some new variations in regions differing only in their illumination conditions. A local change in illumination should be of no consequence to the results, provided that the linearity of the CCD detector can be assumed.

Eqs. (3) and (4) present the Inertia Moment (IM) and Average Value of Differences (AVD) algorithms using a mimic concept adopted from the Fujii algorithm (1), including a denominator in the traditional method required in order to obtain a measure independent of the illumination units.

$$New\ \text{IM}= \sum \sum \left(\frac{M_{ij}}{Norm} \right) \frac{(i - j)^2}{(i + j)^2} \tag{3}$$

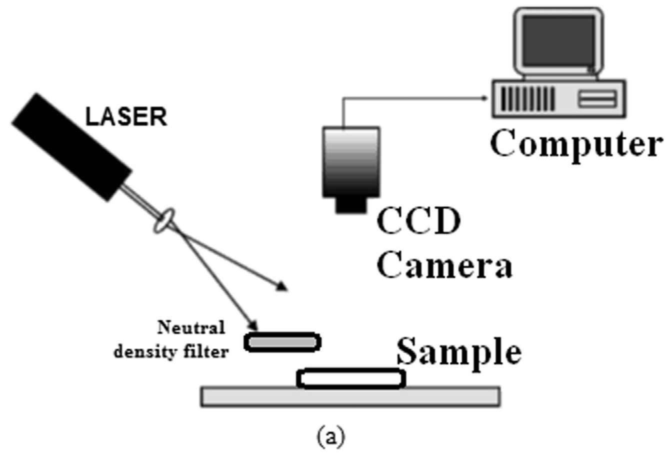

Fig. 1. Experimental configuration of the data acquisition with a neutral density filter creating a dark area in the speckle pattern of paint drying on a plate.

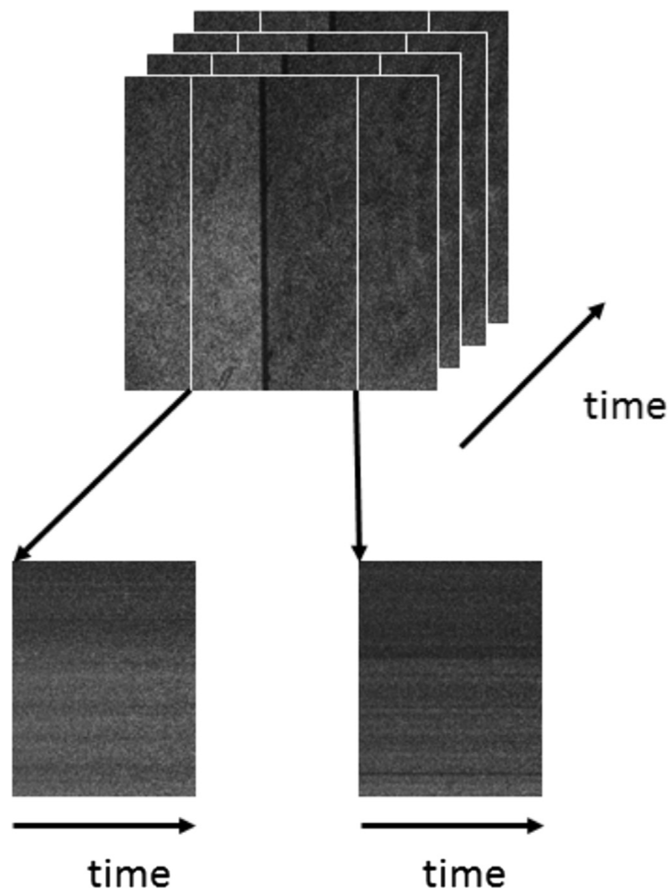

Fig. 2. Construction of the two Time History Speckle Patterns (THSP) using one column from the dark region in one and one column from the light one in the other.

$$New\ \text{AVD}= \sum \sum \left(\frac{M_{ij}}{Norm} \right) \frac{|i - j|}{i + j} \tag{4}$$

By using these expressions, constant attenuation factors due to inhomogeneous illumination on otherwise equal activity regions should be canceled out.

One additional change, in Eqs. (3) and (4), was analyzed and it consisted in raising to power p the values i and j before their use in