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Characterization of bio-dynamic speckles through classical and fuzzy mathematical morphology tools

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ABSTRACT

In this paper we characterize dynamic speckle signals, obtaining selective information through the differentiation of morphological patterns of the temporal history of each pixel, using the morphological granulometric function. This method is applied to the analysis of images of apples and corn seeds. Studies on the first ones were focused on the activity on their surface, related to healthy and damaged areas, while for seeds on the viability of the embryo and endosperm. Subsequently, the analysis was repeated using fuzzy mathematical morphology techniques, comparing the results obtained by both methods.

1. Introduction

When a surface that has physical or biological activity is illuminated by coherent light, such as a laser, the scattered light displays a granular structure, i.e. presenting randomly distributed light and dark spots, which change over time, giving a visual effect of "water boiling". This effect is known as "dynamic" speckle or "bio-speckle". This phenomenon has been studied in various types of biological samples, such as fruits [15] and seeds [7]. Various methods and techniques have been developed for measuring the activity of a speckle pattern [8,1], but, in most cases, the results consist of a single image, with no analysis of the temporal information. Subsequently, selective filtering techniques were used for studying the bio-speckle signals through spectral decomposition [16,11]. Going in the same direction, we introduced recently a new method for bio-speckle analysis based on the morphological spectrum obtained by morphological granulometry [4,3,5].

This technique is based on the theory of mathematical morphology (MM) [14,17], which is a powerful set of tools for digital image processing. These techniques allow enhancement of diffuse areas, object segmentation, edge detection and structures analysis via the use of operators or filters. This discipline is based on sets algebra and can be also be used as a tool for signals analysis. The techniques, initially developed for binary images, were also extended to the field of gray level images. Another approach to extend binary operators to gray level images, the fuzzy mathematical morphology (FMM), is based on fuzzy sets theory. Often, the fuzzy operators result more robust than classical morphological operators [6].

When illuminated by a laser light, fruits show an speckle activity that can be related to the degree of maturity, turgor pressure, damage, age and mechanical properties. For this reason, it is interesting to develop numerical methods which allow to extract useful information of the speckle image sequences.

On the other hand, the study of the feasibility of germination is an important topic in production and marketing seeds.

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They have been developed many tests to determine strength and viability of seed germination. Other studies about the reliability of the tests and equivalence between them also exist [12]. In this context, the evaluation of laser interferometry techniques as tools for seeds analysis is worthy to take into account.

In this paper, we apply MM and FMM filters to biological samples of red delicious apples, as a tool for the diagnostic of early damage of the surface of the fruit, and to corn seeds, to study its performance in the germination process.

2. Methods

2.1. Dynamic speckle

When a surface, that has a certain physical or biological activity, is illuminated by a high coherence light beam, the scattered light by the surface has a granular structure composed of small bright and dark areas, randomly distributed, which change over time, producing an visual effect as a boiling liquid.

Fig. 1 shows a typical image. This effect, known as “dynamic speckle”, is a result of coherent light scattering by objects that exhibit some level of activity. These type of images present variations in the local intensity corresponding to the level of biological activity in the area under observation. Fig. 2 shows the temporal evolution of the intensity of a sample pixel, or gray levels, in a typical sequence of dynamic speckle images. Due to the stochastic nature of the signal, it would be impossible with the naked eye recognize the correspondence of this with any particular area of a biological sample.

The dynamics of the speckle effect is usually quite complex due to multiple physical mechanisms involved [18], but the activity evaluation can help to recognize the complex processes occur in a biological sample.

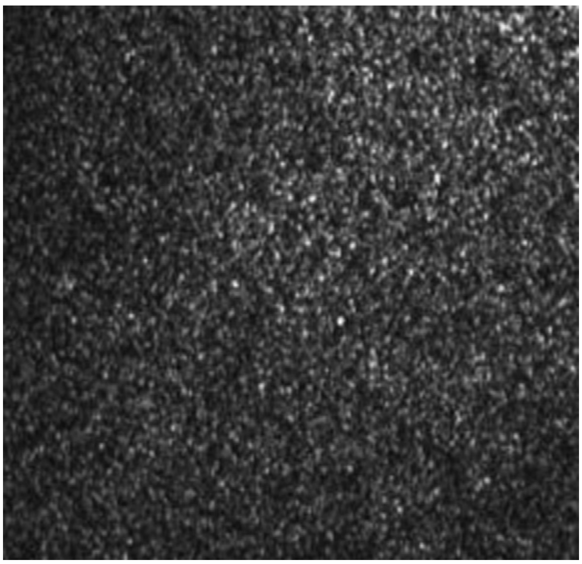

Fig. 1. Typical speckle pattern.

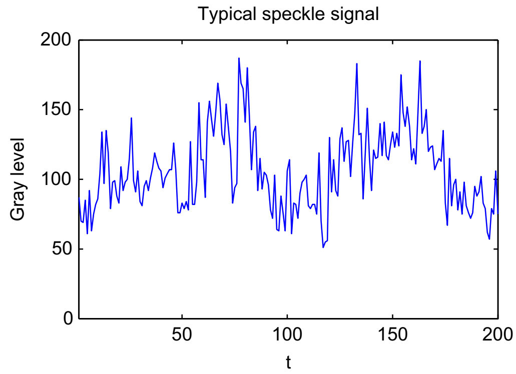

Fig. 2. Typical temporal evolution of a bio-speckle.

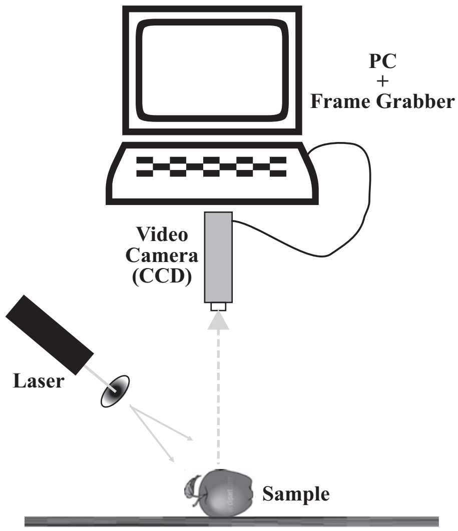

Fig. 3. Experimental speckle bank.

2.2. Experiments

The test bank used to obtain the images is shown in Fig. 3. We used a low-power He–Ne laser (5 mW, $\lambda = 633$ nm) to illuminate the samples, using a divergent beam expanded to encompass a wide region. Subjective speckle images were formed by a objective (usually $f = 50$ mm, $f/\# = 16$). Thus, measurement of average speckle grains covered several pixels. For the experiment with apples, an inert reference object was added in the images. Successive images were stored on a PC by a CCD camera connected to a acquisition board. Low lighting levels were used so that the effect of irradiation on the sample was negligible. The laser illumination was adjusted to keep constant the average intensity in the image throughout the test.

To study variations of the speckle phenomenon in the surface of the fruit, a controlled hit was applied to the healthy apples. That hit was caused by a falling steel ball ($dm = 21.9$ mm, $weight = 33.6$ g) from a height of 20 cm of fruit surface. The damage in the sample could not be appreciated by simple visual inspection. Images were