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Diode laser reliability in dynamic laser speckle application: Stability and signal to noise ratio

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ABSTRACT

The biospeckle, or dynamic laser speckle, is used as a potential tool to monitor activity in many biological and non-biological materials from agriculture to medicine, and it is usually based on the use of He-Ne and diode lasers, the latter of which has great potential to be embedded in portable equipment. Some queries about the stability of the diode laser were raised, such as the real influence of the mode hopping phenomenon as a drawback in solid-state devices in comparison to the well-known He-Ne lasers, and thus we decided to test it. In addition, we present an alternative way to enhance the stability and the signal-to-noise ratio of the information using a relative index rather than the absolute and single data traditionally provided and analysed. We compared the He-Ne and diode lasers using a power light sensor, and the usual dynamic laser speckle indexes (DLSI). We tested both cases using a clean and inert surface, as well as a drying paint process. To test the relative index, we used two different temporal series of speckle patterns and created a signal-to-noise ratio in dB, using a drying paint process, and in a raw data of a drying paint process associated to a drop of alcohol. The results show that the stability of the diode laser is greater than that of the He-Ne laser in all cases, breaking the paradigm of the stability of He-Ne devices. The signal-to-noise ration showed reliable results when the named dynamic laser speckle relative index (DLSRI) in dB was adopted.

1. Introduction

Dynamic laser speckle (DLS) is an interferometric technique that is based on the measurement of speckle pattern changes over time to classify the activity of a biological and of a non-biological material. Its application is widespread in science from medicine to agriculture [1]. For example, it is applied in monitoring the motility of frozen bovine semen [2], in monitoring of blood flow [3,4], in bacterial chemotaxis [5], and in the measurement of activity of different types of cells, among many other applications [6,7].

The early knowledge of the stability of He-Ne lasers [8,9] established this device as a reference in DLS applications, such as in blood flow monitoring [10,11], studies of chemotaxis [12], fruit and seed analysis [13,14], water quality [15], and many other applications [16,17]. However, the use of diode lasers can also be found in many applications, such as in monitoring blood flow in animals [18,19], in fruit properties [20], in edible films associated with minimally-processed food [21], among many others. In turn, the use of both, diode and He-Ne lasers, in the same assay, can be found in bull's eye rot monitoring in apples without distinguishing them in the data [22].

The diode laser has been applied in interferometric applications [23], however the queries about its stability when applied in DLS arose when the mode hopping effect was pointed out for the first time by means of simulations [24], and presenting this effect as spontaneous. The instability of diode lasers was attributed to two phenomena, jittering and mode hopping [25], where mode hopping could cause a violent increase of fluctuations affecting the beam emission. The mode hopping phenomenon was attributed to competition between modes linked to the saturation of non-linear gain [26].

Apart from those doubts, at least one work has compared a diode laser with a He-Ne laser regarding the light intensity in the speckle patterns [27] without reference to the stability, and

Abbreviations: DLS, dynamic laser speckle; DLSI, dynamic laser speckle indexes; DLSRI, dynamic laser speckle relative index; CCD, charge-coupled device; AVD, absolute values of the differences; THSP, time history speckle pattern; COM, co-occurrence matrix; ROI, region of interest.

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additionally attributing the difference between both types of lasers to the lower coherence, wider bandwidth, and more irregular beam shape of the diode laser than the He-Ne device [27,28]. Neglecting the queries of possible stability problems, diode lasers are used in commercial equipment to monitor the dynamics of drying paint in the paint and ink industries [29].

Since dynamic laser speckle is sensitive to tiny variations of light scattered from illuminated surfaces [30], the hypothesis of the variation of laser intensity in diode lasers regarding its great potential in portable equipment must be evaluated. Thus, this work compares the He-Ne laser with a diode laser, considering their stability from the DLS point of view using a photo-sensor and a traditional DLS setup. In addition, a proposal to stabilize the ripple outcomes was tested a relative index named here as the Dynamic Laser Speckle Relative Index (DLSRI) in dB.

2. Materials and methods

2.1. Specimen

Drying paint is a well-known phenomenon used to evaluate the reliability of dynamic laser speckle approaches [31,32], since its dynamics can be modelled and presents a reduced variability when compared to biological material.

Two types of drying paint samples were used. The first was an acrylic white ink painted over a stable surface where the beam was shone onto a Region of Interest (ROI) of about 4.5 cm^2 in the middle, and spread over the same amount of material, creating a homogeneous layer. The environment was maintained with a temperature of 22–23 °C and 51–53% of humidity. The second analysis was carried out using raw dynamic laser speckle images of a surface where two distinct dynamic processes occur, a drying acrylic white ink covering a coin, and a drop of alcohol over that; the coin was on an inert table [33].

2.2. Experimental testing

The first test compared the stability of He-Ne (632 nm, 2 mW) and diode laser (532 nm, 5 mW) sources, monitored by a light power meter. The second test analysed the dynamic speckle activity in a drying paint process illuminated by He-Ne and diode laser sources, using traditional indexes of DLS analysis (DLSI).

The third test compared the traditional index with a proposed activity index in order to test the sensitivity of illumination and signal-to-noise ratio using a relative measure. The main hypothesis was: it is not the wavelength, but the stability of the tested device that matters.

2.2.1. Measurement of the power of light on a flat surface exposed to He-Ne and diode lasers

Following Fig. 1, both the beam coming from the diode laser (Z-laser, 5 mW nominal power, 532 mW) and the one coming from the He-Ne laser (Newport Corp., 2 mW nominal power, 632 mW) were expanded by a spatial filter with lenses (objective) of 40×. In both cases, incident radiation covered an area of 20 mm in diameter in the illuminated surface, larger than the area of the sensor (12 × 12 mm^2), an Optical Power/Energy Meter 842-PE (Newport Corp.), placed on the same exposed surface.

Measurements were made of radiation intensity that arrived at the sensor surface once a day for 10 days; each day the level of illumination was acquired for 10 min, taking into account the zero time, with 10 replications in each minute. The local temperature was controlled at around 22.8 ± 0.1 °C with a humidity of 52 ± 2%. A waiting time of 5, 15, and 30 min was adopted after the switching-on of the lasers.

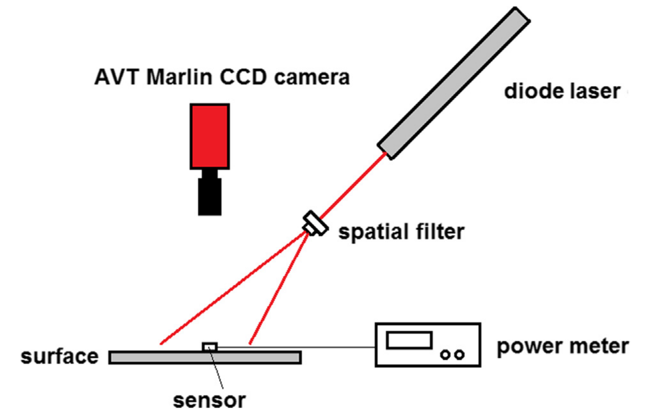

Fig. 1. Experimental configuration used to measure the power of radiation and to acquire speckle patterns using a detector as a power meter of the light in the place of the sample.

2.2.2. Measurement of the speckle noise (SN) activity and drying paint activity using a dynamic speckle setup with He-Ne and diode lasers

The experimental setup followed the same presented in Fig. 1, but without the light power meter and adding a CCD camera perpendicular to the surface (centred with respect to the sensor); thus, the camera acquired the speckle patterns generated by the illumination of the drying paint using a He-Ne laser beam (632 nm, 2 mW) and laser diode (532 nm, 5 mW). The expanded laser light was of 20 mm in diameter, presenting a monitored area of a square with edges of 12 mm.

The images were acquired by a TV Zoom Lens, with a focal length of 50 mm, numerical aperture of f/11 (*speckle size* was 13.57–13.84 μm), connected to an *Allied Vision Technologies CCD Camera* (AVT Marlin F-145B, pixel size of 4.65 μm).

A collection of 128 images (8 bits, 640 × 480 pixels) was acquired at a rate of 15 frames per second and an exposure time of 1/125 s, every minute, for five minutes. Ten replications were used to create the variation behaviour. Thus, every minute, a collection of 128 images was acquired ten times, for five minutes.

Image quality was tested to avoid speckle grains with unreliable information about the phenomena. Therefore, the setup was biased in order to avoid speckle with blurred appearance and with saturated areas, and to avoid inhomogeneity in accordance with the proposed Quality Test Protocol [34]. The image acquisitions started after 10 min of the He-Ne laser or diode laser switch-on.

2.2.3. Measurement of the speckle activity in two different drying processes

The raw data was based on the experimental setup presented in Fig. 1, with a CCD camera (mini-microscope Dinolite AM 3013 640 × 480 pixels) perpendicular to the surface of a coin placed on the table [33]. The coin was covered with ink and with a drop of alcohol in a little portion of the ink. The images were acquired using a diode laser (532 nm).

2.3. Algorithm to obtain the dynamic laser speckle index (DLSI)

2.3.1. Time history speckle pattern (THSP) and co-occurrence matrix (COM) from a set of randomly selected pixels

In most dynamic systems, the activity is not uniform on a determinate surface [7], although it had passed a homogeneity test [34]. Thus, to avoid errors and to reduce the variability, the speckle activity was quantified by means of descriptors based on temporal analysis of points randomly distributed within a region of interest (ROI) to create the Time History Speckle Pattern (THSP), keeping