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Characterization of speckle patterns generated by a semiconductor laser with optical feedback for speckle reduction in retinal imaging instruments

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ABSTRACT

We study experimentally the operating conditions of a semiconductor laser diode subjected to different amounts of optical feedback in order to find a stable and cost-efficient solution for speckle reduction in double-pass retinal imaging.

Keywords: speckle reduction, double pass imaging, eye optical quality

1. INTRODUCTION

The double pass (DP) imaging technique is a diagnostic method used to obtain an overall estimation of the optical quality of an eye, containing information on scattering as well as higher order aberrations.[1] In DP imaging, the point spread function (PSF) of the eye is determined by recording the image of a point source on the retina. A collimated light beam is directed into the eye, where it passes the ocular media, is reflected at the retina, then passes through the ocular media again in reverse direction and is finally recorded after exiting the pupil. The low reflectivity of the retina requires the use of laser light and therefore, DP images suffer from speckle noise.[2] Several approaches have been proposed to reduce speckle, including the use of a rotating diffuser or a vibrating mirror.[3,4] These methods have the drawback that can lead, over time, to the misalignment of the optical components of the system. An alternative approach is based on the use of low-coherence light to illuminate the retina. We have compared three semiconductor based light sources (a laser diode, a superluminiscent LED and a LED) and found that the SLED gave a similar degree of speckle as the LED, which we attributed to their similar spectral bandwidths.[5]

Here we explore the use of chaotic laser light, emitted by a semiconductor laser with optical feedback,[6] as a possible cost-effective speckle reduction solution. Early work[7] demonstrated the applicability of this technique in a multimode fiber-illuminated laser-diode microscope: optical feedback induces a multimode spectrum that changes in time and produces uncorrelated speckle patterns, which can be averaged by recording the image with long enough exposure time. We use this approach to generate speckle patterns and then quantify the degree of speckle. We also explore the effect of direct modulation of the laser current for further speckle reduction.

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2. EXPERIMENTAL SETUP

Our experimental setup (layout shown in Fig. 1) uses a semiconductor laser diode (685 nm, Thorlabs HL6750MG) as light source which can be subjected to optical feedback by reflecting part of the light back into the lasing cavity. In addition to the optical feedback, we can directly modulate the laser pump current. We couple the light out of the feedback path by a beamsplitter and introduce it into a multimode optical fiber (diameter 0.2 mm, Thorlabs M72L02) so it can be delivered to future experiments. In this experiment we do not need any more optical elements, like for example a ground glass disk, to create speckle. Due to interaction of different modes within the fiber, a speckle pattern is visible at its exit, which we image onto a screen that we record with a CMOS camera (IDS UI-1220LE).

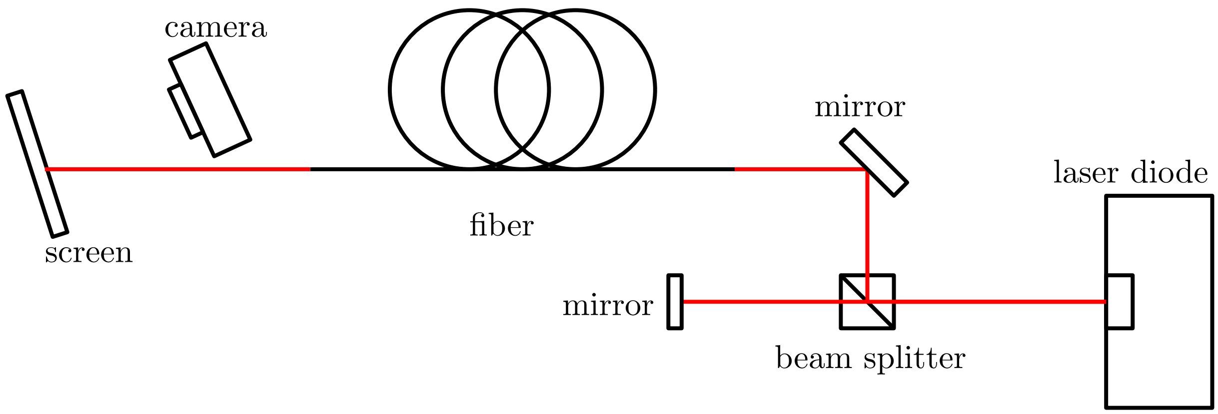

Figure 1. Experimental setup for measuring the speckle contrast in images recorded at the end of a multimode fiber.

3. RESULTS

Fig. 2 shows two images recorded without and with optical feedback (exposure time of 45 ms). We quantify the degree of speckle by the speckle contrast, $C = \sigma_I/\langle I\rangle$, which is reduced from $C = 0.41$ to $C = 0.30$ (within the white circles) when the laser is subject to optical feedback. A detailed characterization of the amount of speckle reduction and the identification of the optimal feedback configuration conditions is in progress. The influence of current modulation for further speckle reduction is also being investigated.

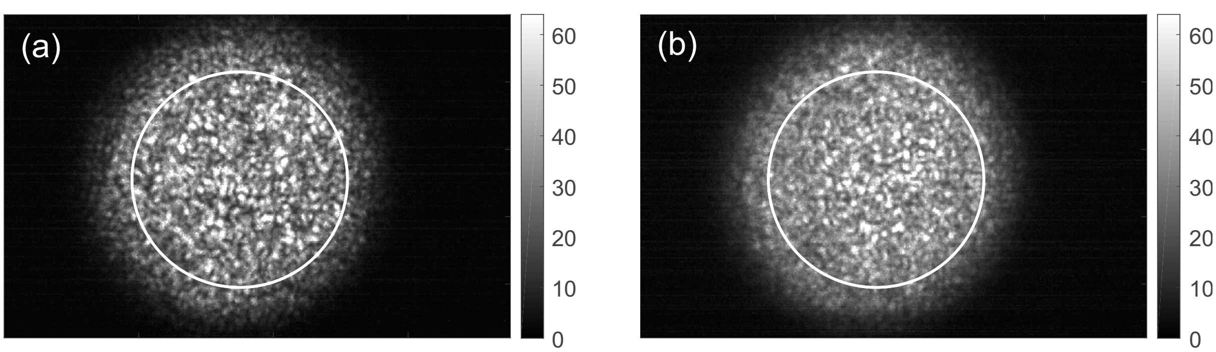

Figure 2. Speckle patterns with intensity indicated in gray-scale. Arbitrary units. Source: laser diode; (a) no feedback, (b) with optical feedback.

4. CONCLUSION

The chaotic, low coherent light emitted by a laser diode with optical feedback is an interesting, cost-effective and all-optical approach for reducing speckle in double pass retinal images.

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