Statistical properties of speckle patterns in dependence of laser parameters and image acquisition time

Donatus Halpaap,[1,2,*] Jordi Tiana-Alsina[2], Meritxell Vilaseca[1] and Cristina Masoller[2]

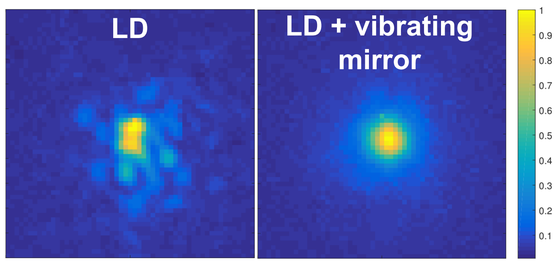
[1] Centre for Sensors, Instruments and Systems Development (CD6)
[2] Nonlinear Dynamics, Nonlinear Optics and Lasers group (DONLL)
Universitat Politècnica de Catalunya, Rambla Sant Nebridi 22, 08222 Terrassa, Barcelona, Spain
[*] donatus.halpaap@upc.edu

Abstract

Speckle patterns are an optical artifact of grains that appears when coherent waves interfere with each other and that is often undesired in imaging. In other applications relevant information can be extracted from speckle patterns.
We are interested in a cost-effective way of speckle reduction for double-pass retinal imaging [1].
We present the statistical properties of speckle patterns generated by a multimode optical fiber from a 685 nm laser diode source at different pump currents. Additionally, we examine the effect of camera exposure time on measured speckle.

Motivation & Goal

Double pass (DP) technique:
→ Overall estimation of the optical quality of an eye. [2]



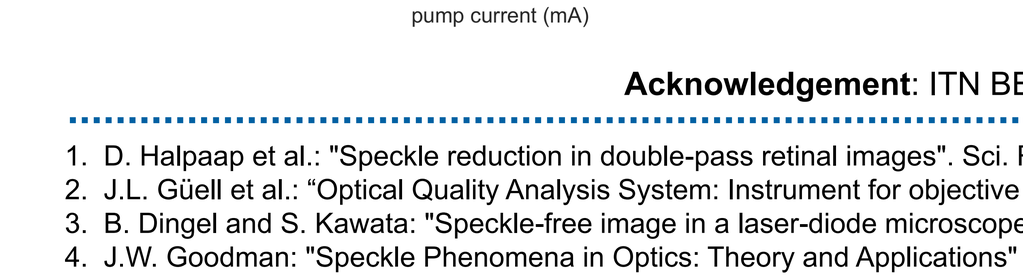
Problem:
Retina is relatively uneven.
→ coherent laser light leads to **speckle in the DP image** which hinders its interpretation

Goal:
Reducing speckle in DP images without mechanically moving parts.

Ideas:
- Broaden laser diode spectrum by optical feedback [3].
- Operate laser diode close to threshold (pump current $I_p \approx 26.7\ mA$)

Experiment & Methods

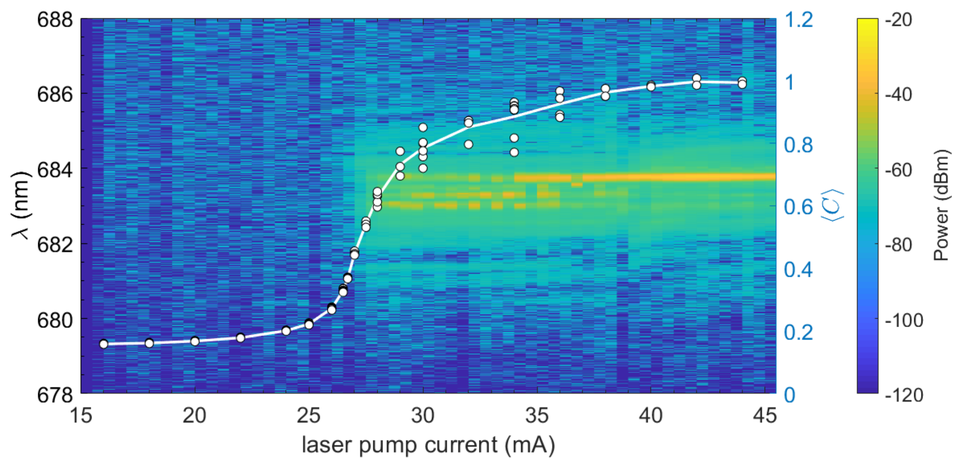
- Studying influence of pump current & camera settings on speckle.

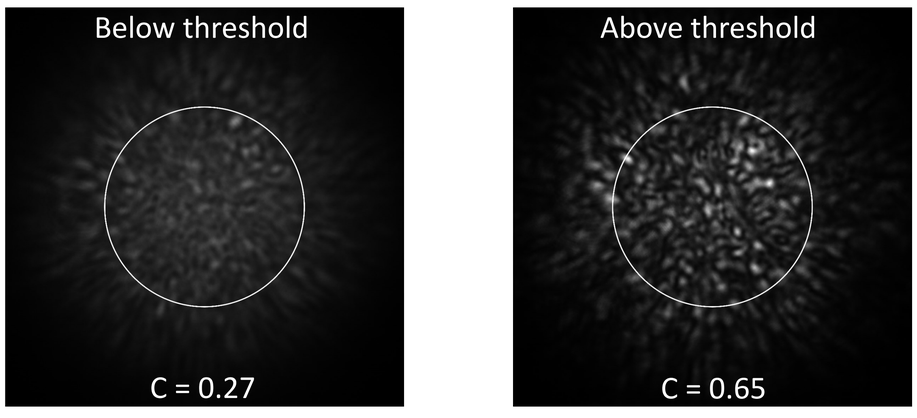


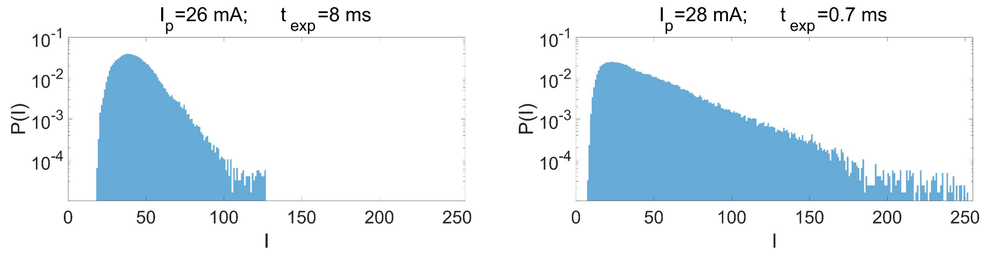
- **Speckle contrast:** $$C = \frac{\sigma_I}{\langle I \rangle}$$

- Imaging output of multimode fiber
- Varying pump current
- Varying exposure so that images are neither overexposed nor dark

Effect of pump current on speckle

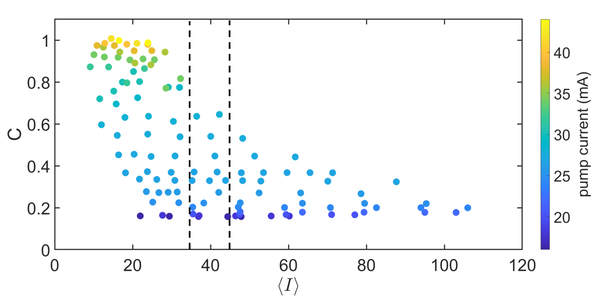




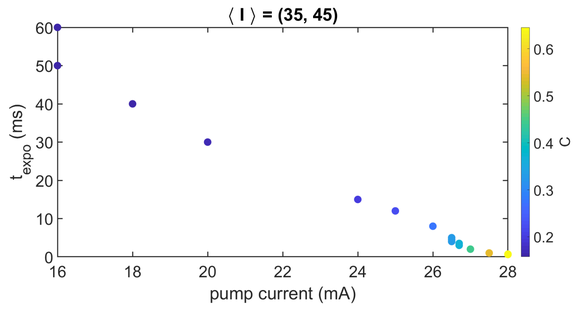


- If intensity is exponentially distributed [4], $P(I) = \frac{1}{\langle I \rangle} \exp\left(-\frac{I}{\langle I \rangle}\right)$,
$$\sigma_I = \langle I \rangle$$
$$\Rightarrow C = 1$$

- Space of C and $\langle I \rangle$ covered by varying pump current and exposure time:



- Exposure time and pump current values for $\langle I \rangle$ between 35 and 45:



Discussion and Outlook

- The speckle contrast can be tuned while keeping ⟨I⟩ constant.
- If no need for high brightness → lowering pump current under the threshold for reducing speckle.

Ongoing and future work:
- Trying double pass imaging with laser diode pumped under threshold.
- Further investigate possibilities to exploit optical chaos in order to achieve lower levels of speckle.

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2. J.L. Güell et al.: “Optical Quality Analysis System: Instrument for objective clinical evaluation of ocular optical quality,” JCRS 30 1598–1599 (2004).
3. B. Dingel and S. Kawata: "Speckle-free image in a laser-diode microscope by using the optical feedback effect", Optics Letters, Vol. 18, No. 7 (1993).
4. J.W. Goodman: "Speckle Phenomena in Optics: Theory and Applications" (Roberts & Company, 2007).