

Speckle Reduction Within A Single One Microsecond Laser Pulse

Fergal P. Shevlin

DYOPTYKA, 7 Westland Court, South Cumberland St., Dublin 2, Ireland.

Keywords: Laser illumination, speckle reduction, projection display.

Abstract

DYOPTYKA's innovative solution for the reduction of speckle noise in projection displays, using a phase randomizing deformable mirror, is shown to achieve good performance both within a single 1 μ s pulse duration and through sequences of such pulses.

1 Background

Well-known advantages of using laser sources for the illumination of both large and small projection displays include: improved image *brightness*, improved optical *efficiency* due to their low étendue, wider color *gamut*, and reduced *size* of both illumination and projection optical systems. [1, 2, 3]

In addition, there are less well-known advantages due to the ability of most laser sources to generate short pulses: the freedom to *optimize* the peak power and/or energy efficiency; improved image *contrast* through illuminating the microdisplay only once its pixels have fully changed state; elimination of the *rainbow effect* that can arise through the field-sequential mixing of color fields by enabling very high temporal frequency mixing of color bit planes instead; and the introduction of angular diversity between mutually-incoherent pulses to further reduce speckle contrast.

The main disadvantage of using laser sources in imaging applications is the *speckle* noise observed in the image. This can be reduced by generating a sequence of uncorrelated speckle patterns which sum to an image with reduced speckle contrast ratio. The most effective conventional technique for generating uncorrelated speckle patterns is to move a diffuser in the illumination optical system. The distance by which the diffuser must move relates to the spatial extent of its coherence area and the spatial resolution of the observer at the diffuser. [4]. A realistic distance is at least 3 μ m. To generate 100 uncorrelated speckle patterns within a 1 μ s laser pulse duration would require movement at a speed of $100 \times 3 \mu\text{m}/1 \mu\text{s} = 300 \text{ m/s} \approx \text{speed of sound}$. Ob-

viously this would be impractical in most projection display optical systems.

The diffuser could be moved at a lower speed so as to generate a single uncorrelated speckle pattern for each individual pulse. However this would necessitate reducing the number of pulses per unit time and so make pulsed illumination less advantageous.

DYOPTYKA has developed an innovative alternative technique for generating uncorrelated speckle patterns [1, 2]. It uses a deformable mirror which can be actuated at hundreds of kHz, see Figure 1.

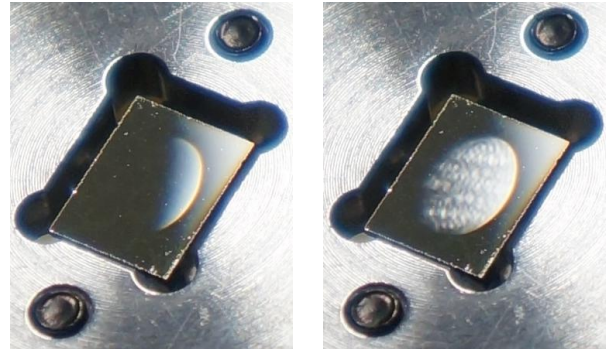


Figure 1: DYOPTYKA's miniaturized deformable mirror with elliptical active area of 3.0 mm by 4.5 mm and dielectric stack coating for high reflection efficiency. [Left] Deformable mirror inactive. [Right] Deformable mirror active, showing the randomly-distributed surface deformations which lead to the generation of uncorrelated speckle patterns.

2 Objectives

There were two objectives for this study: (i) to determine whether the deformable mirror can be used to reduce speckle within a single 1 μ s laser pulse duration; (ii) to determine whether individually reduced speckle patterns are sufficiently uncorrelated to sum to a further reduced speckle pattern.

3 Apparatus

The optical systems used to undertake experimentation are shown and described in Figure 2. A low angle stationary diffuser was located before the deformable mirror to distribute the illumination over its active area. A cascade of two low angle stationary diffusers were located after the deformable mirror to further develop the speckle pattern. Note that the apparatus was not designed to create and observe imagery with a fully-developed speckle contrast ratio of 100%. Rather its purpose is to allow the observation of differences in speckle contrast ratio. Also note that there is no projection lens or screen.

A köhler illumination optical system design was implemented after the diffusers so as to illuminate the target grating with a reasonably homogenized intensity distribution. An appropriate neutral density filter was located before the grating to prevent transmission of low-coherence non-modal illumination from the laser diode.

4 Results

Figure 3 shows imagery acquired with single $1\mu\text{s}$ pulses. A significant reduction in speckle contrast ratio was observed, from approximately 40.7% to approximately 5.9%. The speckle contrast ratios calculated for a number of different $1\mu\text{s}$ pulses with the deformable mirror active and inactive are shown in Table 1. Figure 4 shows imagery acquired from a sequence of 25 pulses each of $1\mu\text{s}$ duration. The imagery acquired with other sequences of individual $1\mu\text{s}$ pulses is shown in Figures 5 and 6.

Pulses	DM Inactive	DM Active
1	40.72%	5.93%
1	40.75%	6.25%
1	40.65%	5.92%
1	40.70%	6.06%
1	40.82%	5.75%
1	40.73%	5.48%
1	40.85%	5.78%
1	40.84%	5.87%
1	40.71%	5.50%
4	40.63%	4.05%
9	40.60%	3.30%
16	40.58%	3.00%
25	40.56%	2.81%

Table 1: Speckle contrast ratios calculated for individual pulses (above) and sequences of pulses (below) with the deformable mirror (DM) inactive and active.



Figure 2: [Top] Apparatus to validate laser pulse duration: Nichia NDB7875 445 nm laser diode with collimating lens, deformable mirror, beamsplitter, photodiode, oscilloscope, and CCD camera. Roithner EU-38-TTL diode driver PCB and Agilent 33210A signal generator not shown. [Bottom] Apparatus to observe speckle in an acquired image: laser diode with $1\mu\text{s}$ pulses, low angle diffuser (stationary,) deformable mirror with a 380 kHz base actuation frequency, two low angle diffusers (stationary,) collector and condenser lenses and apertures in a Köhler configuration, neutral density filter, 10 mm diameter illumination on metal-on-glass Moire Grating (40 line pairs per mm,) camera with $6.45 \times 6.45 \mu\text{m}^2$ CCD pixel size and approximately $1.5\times$ magnification through $f=55\text{ mm}$ lens at aperture stop $f/8$.

5 Discussion

It is clear that a significant reduction in speckle contrast can be achieved over such short pulse periods. Since the deformable mirror was operated with a 380 kHz base actuation frequency, we are confident that a further significant reduction in speckle contrast ratio will be achieved with a base actuation frequency closer to 1 MHz which is possible with the

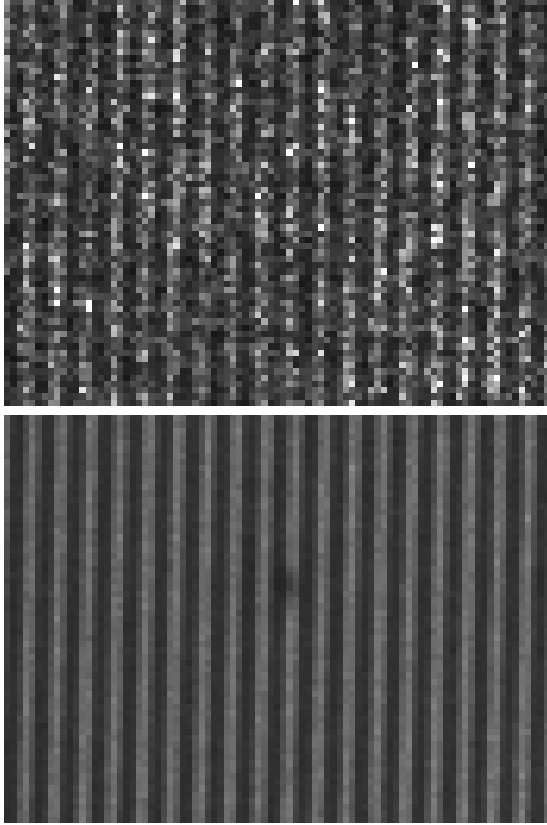


Figure 3: Regions of Grating imagery when illuminated by single $1\text{ }\mu\text{s}$ pulses. [Top] Deformable mirror inactive. Speckle contrast ratio is approximately 40.7%. [Bottom] Deformable mirror active. Speckle contrast ratio is approximately 5.9%.

existing device.

Although the pulses generated by gain-switching the laser diode are known to have random phases with respect to one another, they do not lead to the generation of uncorrelated speckle patterns which sum to an image with reduced speckle contrast ratio with the deformable mirror inactive. This is not a new observation but it is well-supported by the results shown herein. The image shown in Figure 4 [Top], which is averaged from 25 pulses is nearly indistinguishable from the image shown in Figure 3 [Top] which is from just a single pulse. Further support is provided by the speckle contrast ratios shown in Table 1 (“DM inactive” column.)

It is known that the use of multiple mutually-incoherent laser sources can lead to reduced speckle contrast if their angular separation is larger than the N.A. of the observation optical system. It is possible that very small tip and tilt modes of mirror deformation, subsequently magnified by the Köhler illumination optical system, leads to there being sufficient angular separation between mutually-incoherent pulses

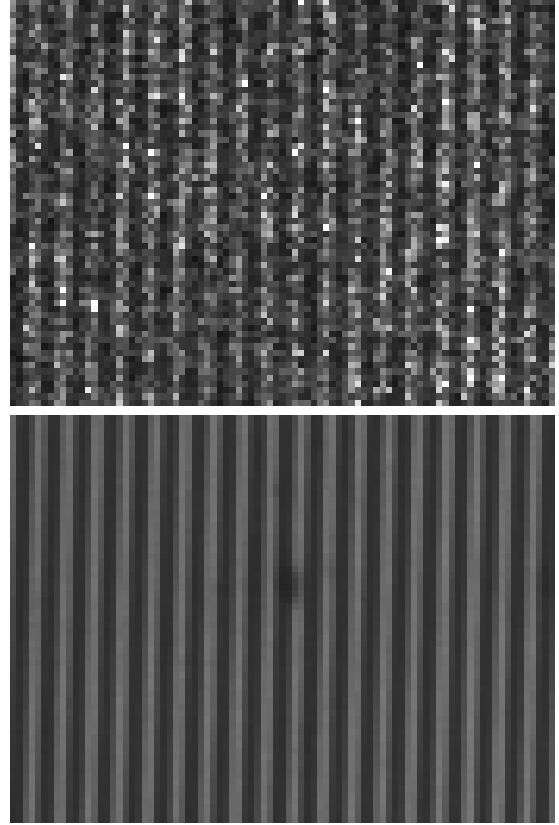


Figure 4: Averaged regions of grating imagery illuminated by 25 single $1\text{ }\mu\text{s}$ pulses. [Top] Deformable mirror inactive. Speckle contrast ratio is approximately 40.6%. [Bottom] Deformable mirror active. Speckle contrast ratio is approximately 2.8%.

from the same laser source for uncorrelated speckle patterns to arise. This will be investigated in future work.

6 Originality

It is the author’s understanding that this is the first time significant speckle reduction has been achieved within a single $1\text{ }\mu\text{s}$ laser pulse without using a complex optical system or multimode optical fiber to greatly elongate the optical path length and without operating the laser source in a special way so as to reduce its spatial or temporal coherence. This paper is the first publication of this result.

7 Conclusions

DYOPTYKA’s deformable mirror makes it practical to operate lasers in pulsed mode in projection displays of all kinds. This should help lasers to take one step closer towards widespread usage as the most appropriate solid-state source of low-étendue illumination.

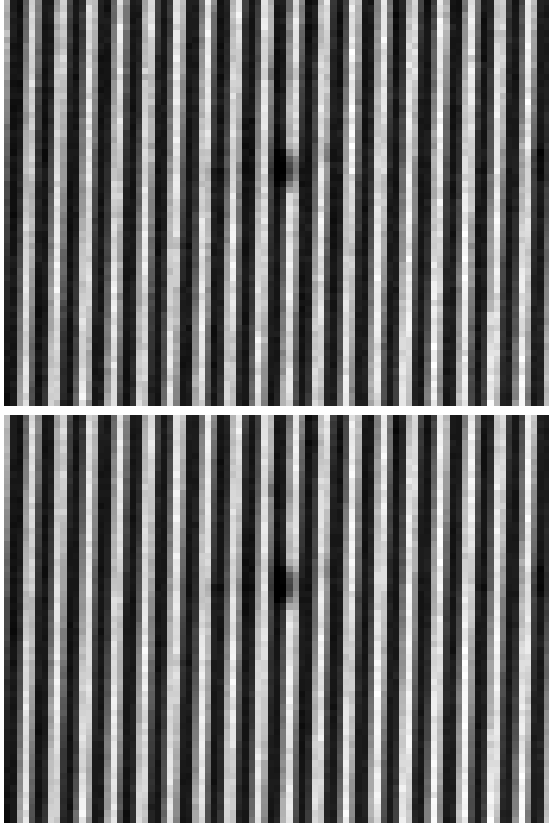


Figure 5: Averaged regions of grating imagery illuminated by sequences of 4 and 9 pulses of 1 μ s duration (top and bottom, respectively.) Note that these images were transformed by contrast-stretching to make inhomogeneities more visible to the eye.

References

- [1] Shevlin, F., “Speckle reduction for laser-illuminated microprojectors,” in [*MOEMS and Miniaturized Systems XI*], Schenk, H., Piyawat-tanametha, W., and Noell, W., eds., *Proc. SPIE* **8252** (2012).
- [2] Shevlin, F., “Speckle mitigation in laser-based projectors,” in [*First Laser Display Conference, LDC '12*], Optical Society of Japan, Japan Society of Applied Physics (2012).
- [3] Gutttag, K. M., Hurley, S., and Mei, B., “Laser+LCOS technology revolution,” in [*SID Symposium digest of technical papers*], **42**(1), 536–539, Society for Information Display (2011).
- [4] Goodman, J., [*Speckle phenomena in optics*], Roberts and Company, Colorado, USA (2007).

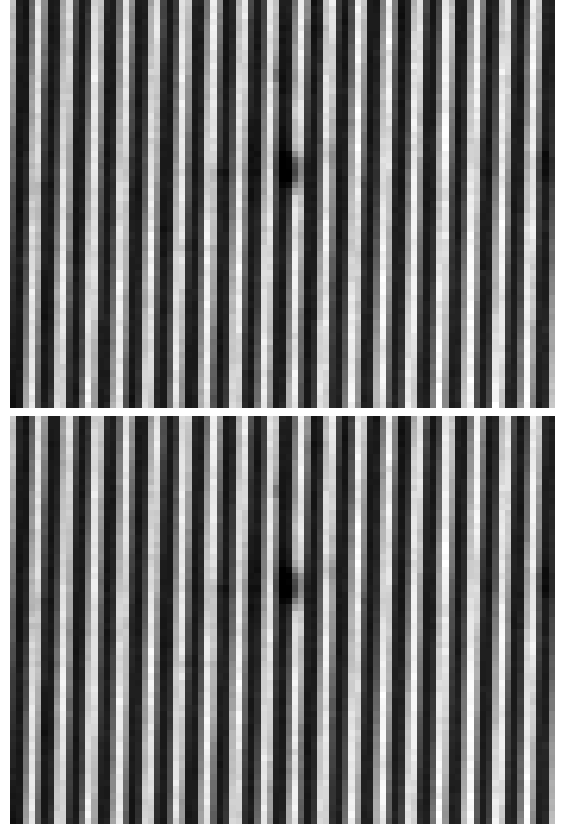


Figure 6: Averaged regions of grating imagery illuminated by sequences of 16 and 25 pulses of 1 μ s duration (top and bottom, respectively.) Note that these images were transformed by contrast-stretching to make inhomogeneities more visible to the eye.