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Beam Quality-Preserving Speckle Reduction for Scanned Laser Displays

Fergal Shevlin
DYOPTYKA, 7 Westland Court, South Cumberland St., Dublin 2, Ireland.
Phone: +353-1-4434614; Email: fshevlin@dyoptyka.com

Abstract: *We demonstrate how our deformable mirror can be used to achieve some reduction of speckle noise without significantly increasing laser beam divergence.* ***Keywords:*** *laser beam, scanning, speckle reduction.*

1 Background

It has been proposed that scanned laser beam pico-projectors should have spot sizes of approximately 0.5 mm diameter at 0.5 m distance and 1.0 mm diameter at 1.0 m distance [1]. This implies approx. 1 mrad beam divergence which is close to the visual acuity of the typical human eye. Any technique used for the reduction of speckle [2] should not increase beam divergence or image resolution will be reduced.

DYOPTYKA has developed an innovative phase-randomizing deformable mirror (see Figure 1 [Left]) which has proven to be effective for speckle reduction in microdisplay-based projectors [3]. However it introduces too much beam divergence when introduced in a simplistic way into the beam path (see Figure 1 [Right].) Therefore we have devised an alternative means of incorporating it into the beam path, as shown in Figure 2 [Left].

Although the deformable mirror has also proven to be effective within 1 μs laser pulse widths [4], the display period of an individual scanned pixel is much shorter, as explained in Figure 2 [Right]. However it may be possible that speckle patterns generated at neighboring row pixel positions are highly correlated such that speckle contrast can be reduced by effecting a change of speckle pattern between them. The work described herein is the first step towards investigating this possibility.

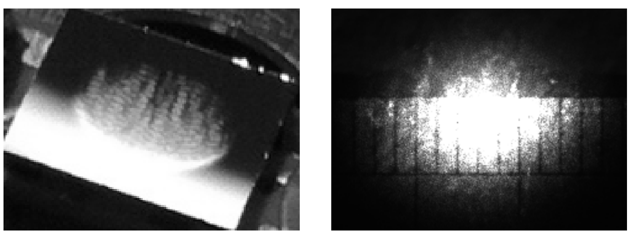

Fig. 1: [Left] Miniaturized deformable mirror model uDM2 with fully integrated 5 V control electronics. Elliptical area is actuated at hundreds of kHz resulting in randomly-distributed surface deformations which facilitates the generation of uncorrelated speckle patterns. [Right] Spot of approx. 9 mm diameter on diffusing materials at 850 mm distance which shows beam quality-damaging effect of uDM2 configured for minimum randomized divergence of approx. 8 mrad of approx. 1 mm diameter incident beam.

2 Objective

To investigate whether appropriate beam quality can be preserved and whether some speckle reduction can be achieved when using DYOPTYKA's phase-randomizing deformable mirror in a DVD pick-up assembly-inspired optical system. The size of the spot focused onto the deformable mirror should be at most a few

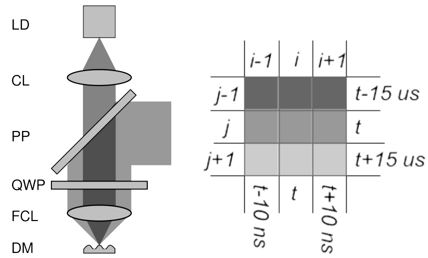

Fig. 2: [left] DVD pick-up assembly-inspired optical system for integration of the deformable mirror such that beam quality is preserved. Labels: LD–laser diode(s;) CL–collimating lens(es;) PP–polarizer plate; QWP–quarter wave plate; FCL–focusing and collimating lens(es;) DM–deformable mirror. [Right] If pixels are displayed in raster scanning order at HDTV resolution of 1920×1080 at 50 Hz, neighboring pixels in rows above and below the center pixel (i, j) are displayed approx. 15 μs before and after it, whereas neighboring pixels in columns left and right of the center pixel are displayed approx. 10 ns before and after it.

μm. This means that the dynamic process available for speckle reduction is the redistribution of illumination around the entrance pupil of the collimating lens by the randomized travelling and standing waves on the surface of the deformable mirror.

3 Apparatus

As shown in Figure 3. For ease of assembly we used GRIN lenses although achromatic conventional lenses could have been used instead. Due to the use of a fiber-coupled laser source and various imperfections in the apparatus, we estimated that the spot size on the deformable mirror is at least 10 μm. This means that the requirements listed in Section 1 could not be satisfied but we felt that the apparatus was reasonable for proof of concept experimentation. See Figure 4 for further details. Camera lens focal length, f/# and image magnification were chosen such that speckle in the acquired image was evaluated subjectively to be similar to that seen by an observer in reality. The deformable mirror was operated such that it increased the divergence of the reflected beam by approx. 80 mrad.

4 Results

Figure 5 shows how beam circularity is actually improved through the action of the deformable mirror without any significant increase in beam divergence. This could be due to the decrease of the effective f/# of the collimating lens. Figure 7 shows that there is an observable reduction in the speckle generated at the projected spot with when the deformable mirror is active.

Fig. 3: [Top] Laboratory implementation of optical system shown in Figure 2: 635 nm laser delivered through single mode fiber with GRIN collimator for beam diameter of approx. 0.5 mm at 20 mm distance; polarizing beam splitter; achromatic quarter wave plate; GRIN focusing/collimating lens with 0.23 pitch and effective focal length of 1.85 mm; uDM2 deformable mirror; kinematic mount for precise alignment of uDM2. [Bottom] Additional components: 0.5 mm aperture-limiting stop in kinematic mount; smooth paper screen at approx. 115 mm from beam focusing/collimating lens; lens of camera for imaging of spot on screen.

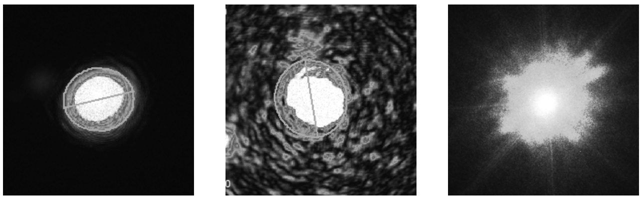

Fig. 4: [Left] Profile of collimated beam reflected on its first pass through the polarizing beam splitter, i.e. without reflecting off the deformable mirror. Diameter is approx. 770 μm at 53 mm distance. [Center] Profile of collimated beam reflected on its second pass through the polarizing beam splitter. Diameter is approx. 1000 μm at 53 mm distance. Various misalignments and imperfections in the deformable mirror arm of the optical system result in degraded beam quality and some high angle scattering. [Right] The effect of high angle scattering at the paper target. Pixel size would be increased and image resolution degraded unless scattering is blocked by an aperture or not reflected by the MEMS scanning mirror.

5 Conclusions and future work

We are satisfied that some speckle reduction can be achieved while preserving the beam quality necessary in a scanned laser beam pico-projector. The next step is to use a MEMS scanning mirror after our apparatus so that we can evaluate whether any speckle reduction is observable in a two-dimensional image.

[1] Freeman, M., Champion, M., and Madhavan, S., "Scanned laser pico-projectors: Seeing the big picture (with a small device)," *Optics and Photonics News* , 28–34 (May 2009).

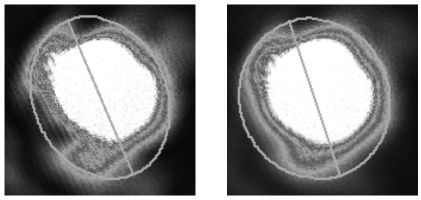

Fig. 5: [Left] Profile of collimated beam having reflected off *inactive* deformable mirror and having passed through aperture-limiting stop. Diameter is approx. 1360 μm at 280 mm distance. [Right] Profile under same conditions except with deformable mirror *active.* Note improved beam circularity and reduced contrast of interference fringes (from beam profiler protective window) which is indicative of reduced coherence.

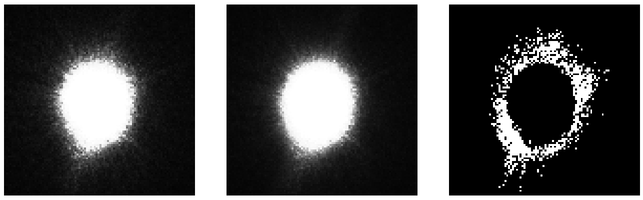

Fig. 6: [Left] Spot with diameter of approx. 0.6 mm on paper target at 115 mm distance with deformable mirror *inactive*. Although camera sensor is saturated there is some speckle visible around edges. [Center] Spot under same conditions but with deformable mirror *active.* Less speckle is visible both in camera image and with naked eye. [Right] Thresholded absolute difference of *inactive* and *active* spot images.

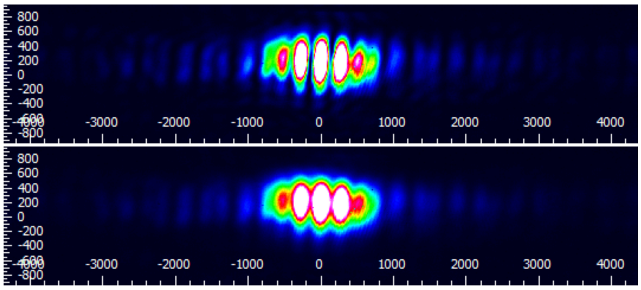

Fig. 7: Fringes due to double slits 100 μm wide with 300 μm spacing located 125 mm from Thorlabs Beam Profiler camera. Exposure period is 20 μs. Without slits, beam profiler software estimates beam diameter as approximately 1200 μm in diameter. [Top] Deformable mirror inactive, strong fringe contrast. [Bottom] Deformable mirror inactive, reduced fringe contrast implies reduction of spatial coherence.

[2] Goodman, J., [*Speckle phenomena in optics*], Roberts and Company, Colorado, USA (2007).

[3] Shevlin, F., "Speckle reduction in laser-illuminated picoprojectors," in [*MOEMS and Miniaturized Systems XI*], Schenk, H., Piyawattanametha, W., and Noell, W., eds., *Proc. SPIE* **8252** (2012).

[4] Shevlin, F., "Speckle reduction within a single one microsecond laser pulse," in [*International Display Workshop/Asia Display, (IDW/AD'12)*], Institute of Image Information and Television Engineers (ITE), Society for Information Display (SID) (2012).