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Light Guide Plate Illumination by Laser through Optical Fiber

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 phase randomizing deformable mirror enables effective reduction of speckle noise in a direct view display illuminated by a single laser source through multimode optical fiber. We discuss some additional benefits arising.* ***Keywords:*** *laser illumination, optical fiber, direct view display, speckle reduction.*

1 Background

The improved spectral characteristics of lasers versus LEDs, resulting in a broader color gamut, is perhaps their most well-understood advantage in image display applications. The work described herein is motivated by other characteristics of lasers which make them advantageous for light guide plate illumination of direct view displays, in particular their greater optical power and their low étendue. Greater optical power means fewer sources are required and low étendue means efficient coupling into optical fiber is possible so that the sources can be located somewhere other than the edge of the light guide plate. Benefits arise for a variety of back-lit and front-lit illumination approaches, including those which use blue sources to stimulate emission of red and green from phosphor or "quantum dot" sheets and strips.

Of course the problem of speckle [1], which can seriously degrade image quality, must be considered. Direct view displays have certain characteristics which result in less speckle than with projection displays: the pixellated display and the light guide plate are smooth compared to a relatively rough projection screen; and there is no projection lens whose diffraction limit reduces the effectiveness of speckle reduction techniques. When many mutually non-coherent laser sources are used, these characteristics contribute to there being no speckle visible to the observer, as is demonstrated in the *Real LaserVue* series of LCD televisions commercialized by Mitsubishi Electric Corporation [2].

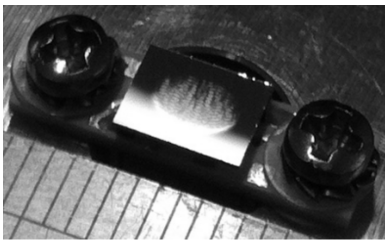

Fig. 1: Model uDM2 miniaturized deformable mirror with fully integrated 5 V control electronics. Elliptical area of 3.0 mm by 4.5 mm is actuated at hundreds of kHz resulting in randomly-distributed surface deformations which achieve effective inter-modal dispersion in waveguides and the generation of uncorrelated speckle patterns.

2 Objective

To investigate the significance of the speckle problem arising in light guide plate illumination by a single laser source through multimode optical fiber, and whether it can be mitigated through the use of DYOPTYKA's phase-randomizing deformable mirror technology.

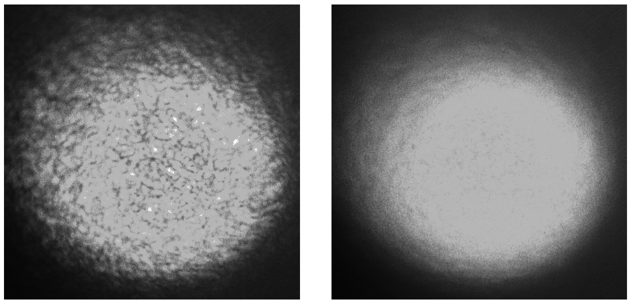

Fig. 2: Illumination from the exit face of a multimode fiber of core diameter 105 µm, 0.22 N.A., and length 3 m. Deformable mirror model uDM2 located between laser source and fiber-coupling lens. Insertion loss due to mirror is nearly 0 dB thanks to high reflectivity dielectric stack coating and low angular randomized divergence without scattering. [Left] Mirror inactive: modal structure visible. [Right] Mirror active: improved homogeneity of intensity.

3 Apparatus

A front-lit electrophoretic display from an Amazon Corporation *Kindle Paperwhite* was illuminated through multimode optical fiber by a highly coherent 532 nm SHG laser with 0.2 nm spectral linewidth. Fiber and deformable mirror are described in Figures 1 and 2. The exit face of the fiber was butt-coupled against the entrance face of the light guide plate where the original LEDs had been removed, see Figure 3. 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. A sheet of printer paper was arranged after the exit face of the light guide plate to demonstrate the higher contrast speckle arising from a relatively rough surface.

4 Results

Figure 4 shows display appearance with deformable mirror inactive and active. Image quality is unacceptable in the former case and very significantly improved in the latter. Although the quantitative metric of speckle contrast ratio [1] is often used to compare such imagery, we do not do so here because the subjectivity in our arrangement of the camera means ratios cannot be compared in a meaningful way.

Fig. 3: Light Guide Plate illuminated by laser though multimode optical fiber. Camera lens $f = 12.5\,\mathrm{mm}$ and $f/11$. [Top] With additional broad spectrum incandescent bulb illumination of apparatus and 100 ms camera exposure period. [Middle] With laser illumination only, deformable mirror inactive, and 10 ms exposure period. [Bottom] As above but with deformable mirror active.

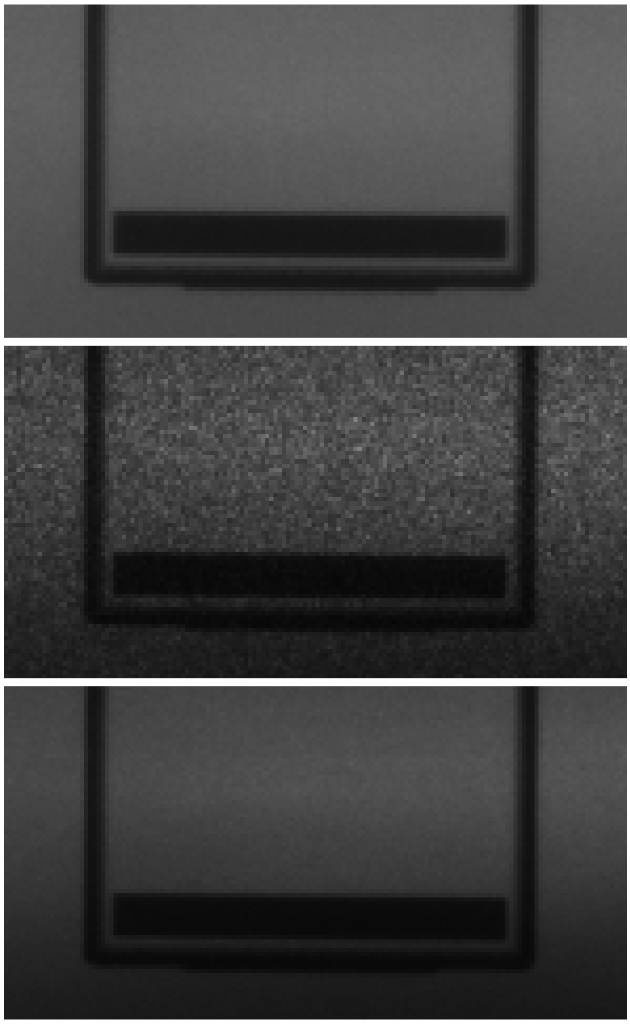

Fig. 4: Regions of the display from the corresponding images shown in Figure 3. [Top] Any speckle is indistinguishable from camera noise due to the low intensity of the laser versus the incandescent illumination. [Middle] Significant speckle is visible. It is particularly disturbing because it changes with head or eye motion. [Bottom] Only a small amount of speckle is visible.

5 Discussion

Even less speckle can be expected with a broader spectral linewith laser diode source which, for example, could be the blue used to stimulate emission of red and green. We have already published some relevant material [3].

Since the small fiber exit face requires only a small aperture for significant optical power to enter the light guide plate, it should be possible to achieve even illumination of edge-mounted strips of phosphor or "quantum dots" through the light guide plate rather than from behind the strips. Hence edge-mounted strips could be deposited on highly reflective mirrors to reflect illumination that would otherwise be lost.

Another advantage of the small fiber exit face is that it should be practical to use a cylindrical microlens optical system to greatly increase the divergence of the illumination at the entrance of the plate so as to minimize bezel size. Also the thickness of the light guide plate can be reduced since it does not have to match LED dimensions.

6 Conclusions

We have demonstrated that illumination homogeneity appropriate for good image quality in direct view displays can be achieved despite the use of a single laser source and multimode optical fiber which would otherwie result in irregular illumination due to modal structure.

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

[2] Nakano, N. et al., "Development of the backlight using laser light source for LCD," in [*Second Laser Display Conference, LDC '13*], Optical Society of Japan, Japan Society of Applied Physics (2013).

[3] Shevlin, F., "Speckle reduction for illumination with lasers and stationary, heat sinked, phosphors," in [*International Display Workshop/Asia Display, (IDW/AD'13)*], Institute of Image Information and Television Engineers (ITE), Society for Information Display (SID) (2012).