Speckle reduction within nanosecond-order pulse widths for flash lidar applications

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Abstract: *Our innovative deformable mirror technology is shown to be effective for the reduction of speckle contrast within pulse durations of approximately* 6 ns. *It can be used to improve the spatial and temporal resolution of flash lidar distance measurements.*

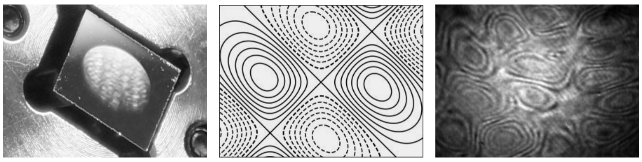

Fig. 1: [Left] Small deformable mirror in an active state. Randomly-distributed surface deformations are excited at very high frequencies in the 3 mm × 4.5 mm elliptical region. Reflection efficiency is approx. 99% and damage threshold is approx. 6 W. [Center] Contour plot of simulated deformations. As heights change over time the curvature of each region is reversed such that directions of reflection are changed. [Right] Microscope interferometer image showing fringes resulting from actual mirror deformations.

1 Introduction

To achieve good spatial and temporal resolution of range estimation, flash lidar systems illuminate the scene with pulses of ns-order duration. For consumer applications, arrays comprising thousands of coherent VCSEL emitters on a single small chip are used at kHz repetition rates. Although their pulses are mutually-incoherent, inhomogeneity and speckle are evident in acquired imagery. The cause is insufficient angular separation of emitters relative to the angular extent of the sensor pupil [1]. An effective technique for improvement is to generate multiple uncorrelated speckle patterns that are integrated by the sensor. For time-of-flight measurement, these patterns should be generated within the durations of single pulses so as to preserve temporal resolution. The high speed required precludes the use of conventional approaches such as moving diffusers.

DYOPTYKA has developed an innovative phase-randomizing deformable mirror technology [2], see Figure 1. It can be used to reduce speckle contrast and to improve homogeneity with excellent optical efficiency and at very high speed.

2 Objectives

To demonstrate how our deformable mirror can be used to improve the spatial and temporal resolution of flash lidar distance measurements through the reduction of speckle contrast by generating multiple uncorrelated speckle patterns within ns-order pulse widths.

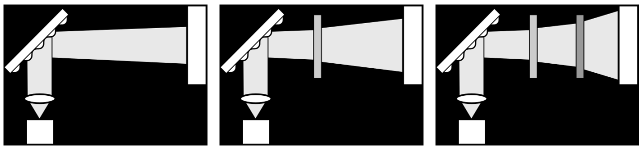

Fig. 2: [Left] Multimode 520 nm laser diode: Thorlabs NPL52C generating approx. 6 ns pulses at 2 Hz; collimating lens; Deformable mirror operating at approx. 1.67 MHz; Thorlabs BC106-VIS beam profiler. [Center] With RPC Photonics EDS 10 deg square light-shaping diffuser at approx. 20 mm distance from mirror. [Right] With additional 1500 grit ground glass diffuser, Thorlabs DG10.

3 Apparatus

Several configurations of the experimental apparatus are shown in Figure 2. Although a visible wavelength was used for convenience, similar performance is expected with the NIR of typical lidars. The light-shaping diffuser is similar to those used with VCSEL arrays for compact and efficient homogenization of illumination. The purpose of the ground glass diffuser is to simulate a rough surface on an illuminated target.

The actuation frequency of the deformable mirror is sufficient for local changes of slope to sweep reflected light across the diffuser(s) over distances greater than the correlation length of surface roughness. If separation between diffuser and mirror is reduced, the magnitude of local slope change should be increased. This is possible through operating the mirror at different frequencies and/or amplitudes.

4 Results

Imagery acquired with different configurations are shown in Figures 3–6. In each [top, left] image, the deformable mirror is inactive and some undesirable consequences of coherent illumination are evident. Each [top, right] image is an average of a large number acquired when mirror active. Their homogeneity is due mainly to uncorrelated speckle patterns being generated at a frequency at least equal to the pulse repetition rate. Speckle contrast C is quantified as the ratio of standard deviation of pixel intensity to mean intensity.

The [bottom, left] images of figures 4–6 are extracts from full images when mirror inactive such that individual pixels are easily visible. The C values of extracts and full images

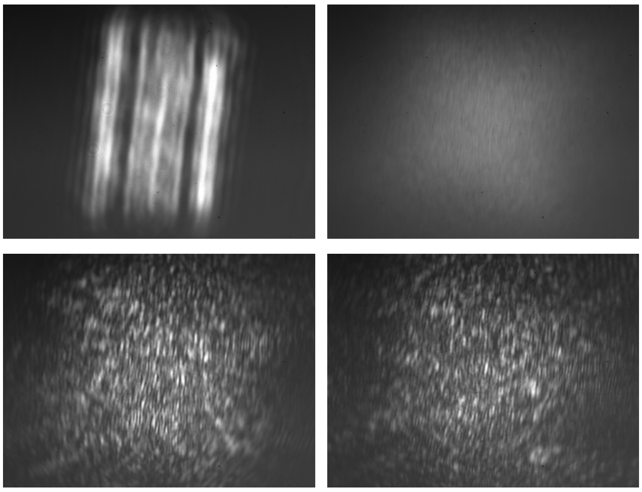

Fig. 3: Without diffuser(s.) [Top, left] Multimode emission pattern when deformable mirror inactive; [Top, right] Average of 88 images when mirror active. Demonstrates that mirror effects on different pulses are not highly correlated. [Bottom] Effects of active mirror on two 6 ns pulses.

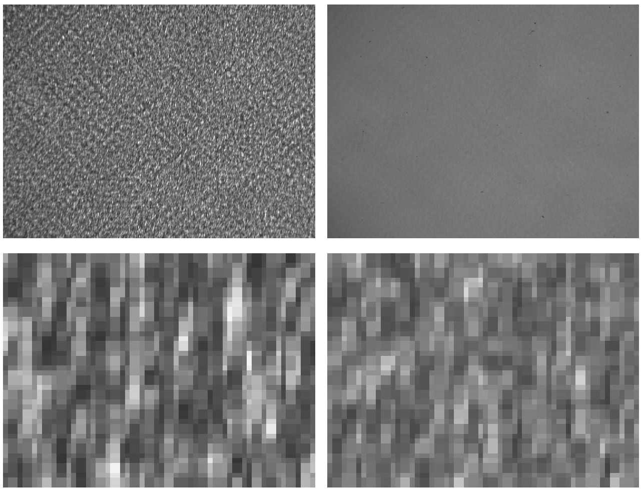

Fig. 4: With light-shaping diffuser. [Top, left] Light-shaping diffuser pattern when deformable mirror inactive, $C \approx 28\%$. [Top, right] Average of 86 images when mirror active, $C \approx 5\%$. [Bottom, left] Central region when inactive, $C \approx 32\%$. [Bottom, right] Region when active, $C \approx 21\%$.

are different due to variations of mean intensity across the field. Note that the spatial frequency of speckle is lower when diffuser is further from sensor. The corresponding [bottom, right] images show a relative reduction of speckle contrast by at least 25% when mirror active.

5 Conclusions

The observed reduction in speckle contrast confirms that our deformable mirror leads to the generation of uncorrelated speckle patterns within a 6 ns pulse duration. Further reduction can be expected through relatively straightforward modifications to device design and control electronics. We are not aware of any other compact, optically efficient

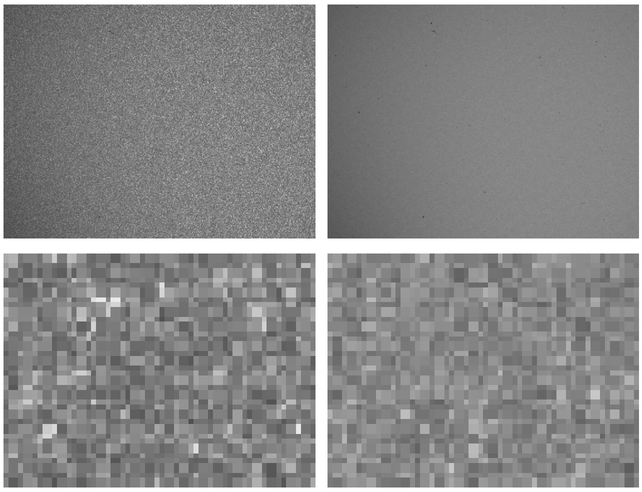

Fig. 5: With ground glass diffuser at distance of 10 mm from sensor. [Top, left] When deformable mirror inactive, $C \approx 20\%$. [Top, right] Average of 80 images when mirror active, $C \approx 9\%$. [Bottom, left] Central region when inactive, $C \approx 18\%$. [Bottom, right] Region when active, $C \approx 12\%$.

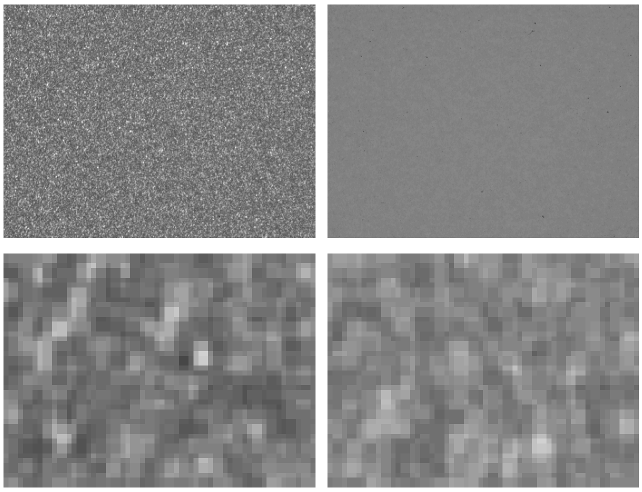

Fig. 6: With ground glass diffuser at distance of 100 mm from sensor. [Top, left] When deformable mirror inactive, $C \approx 17\%$. [Top, right] Average of 89 images when mirror active, $C \approx 2\%$. [Bottom, left] Central region when inactive, $C \approx 16\%$. [Bottom, right] Region when active, $C \approx 12\%$.

approach that can achieve such performance.

In addition to improvement of transverse spatial resolution through the mitigation of speckle artifacts, flash lidar systems should benefit from improvement of longitudinal spatial and temporal resolution since the averaging of images from many different pulses would not be necessary.

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

[2] Shevlin, F., "Phase randomization for spatio-temporal averaging of unwanted interference effects arising from coherence," *Applied Optics* **57**(22), E6–E10 (2018).