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SPIE.

Event: SPIE OPTO, 2022, San Francisco, California, United States

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ABSTRACT

By combining a Micro Electro Mechanical System based resonant mirror and a Digital Micromirror Device, we demonstrated a large scan angle, fast scan rate, and high resolution beam steering for the lidar applications. The proposed optical architecture preserves a large Etendue of DMD-based diffractive beam steering with a synchronized short pulsed laser to transition of micromirror array while increasing angular resolution.

Keywords: lidar, DMD, MEMS mirror, solid state lidar, Etendue, beam steering, time of flight

INTRODUCTION

Laser beam steering technology is essential for applications that utilize Light Detection and Ranging (LIDAR) systems such as autonomous vehicles. Fast scan rate, large scan angle, large beam size, and high resolution are important aspects required for an advanced LIDAR system. Our group previously demonstrated a Digital Micromirror Device (DMD) -based diffractive beam steering and lidar system with a wide field of view and fast scan rate [1]. In the approach, un-explored transitional states of the micro mirrors between on- and off- states, typically with time scale of μs, was used. By illuminating the transitional state between -12 and +12 degrees of tilt with a nano second laser pulse, the tilt angle of micromirror is effectively "frozen". Consequently, the array of tilted mirrors forms a blazed grating with variable blazed angle. In this manner, the spatial light modulator is turned to be an efficient diffractive beam steerer. Thanks to the reflective spatial light modulation, the technique can be applied for wide range of wavelength. Across visible to infrared spectrum, programming timing of nano second pulse to the mirror transition makes this technique usable not only for infrared beam steering but also for image steering, for example displays for Augmented Reality (AR) and holographic displays [2, 3].

For laser beam steering for lidar applications requires a large etendue which is a product of the beam area and angular throw [4]. The diffractive beam steering limits steering angle within several which is governed by blazed grating equation. The limitation was addressed by employing multiple laser sources [5], and by employing holographic beam steering to increase the number of steering angles to order of thousands [2].

As an alternative and complements to those beam steering approaches by employing DMD, we present a large Etendue, solid-state-lidar with MEMS-resonant mirror assisted diffractive beam steering by DMD. MEMS based resonant mirror was incorporated to increase the number of scanning points for fine beam scanning. The fine beam steering pattern is diffractively duplicated over multiple diffraction orders. The hybrid MEMS-DMD beam steering approach increases the resolution when detecting an object while keeping the large Etendue of DMD, high diffraction efficiency and especially large angular throw.

In this paper, in section 2, we overview the optical architecture of the MEMS-DMD hybrid transmitter, followed by experimental demonstration of beam steering at wavelength of 905nm. In section 3, we demonstrate a live image reconstruction by detecting the target's distance and location by using the beam steering setup.

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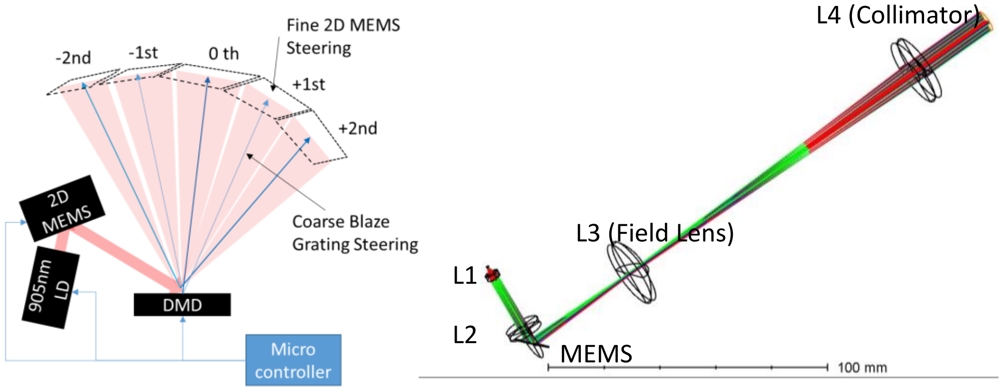
Emerging Digital Micromirror Device Based Systems and Applications XIV,
edited by John Ehmke, Benjamin L. Lee, Proc. of SPIE Vol. 12014,
1201407 · © 2022 SPIE · 0277-786X · doi: 10.1117/12.2608501

OTPICAL ARCHITECTURE

MEMS resonant mirror assisted beam steering

Figure 1a shows a schematic diagram of the MEMS resonant mirror assisted diffractive beam steering system. The system consists of 905nm nanosecond pulsed laser, MEMS resonant mirror (MEMS, Mirrorcle #S30262), and a DMD, a 1024 x 768 DMD chip (DLP 7000, Texas Instruments) with micromirror pitch of 13.6μm (corner to corner) is used for coarse scanning.

A single pulse of light is collimated (L1 Fig. 1b) and then converges to the MEMS mirror which steers the beam to 192 points. Between the MEMS resonant mirror and DMD, a relay optics is incorporated to match the beam size between MEMS mirror and DMD as depicted in Fig. 1b. The field lens L3 relays the MEMS mirror to DMD while combination of L2 and L4 magnifies beam size to match the MEMS mirror (3mm in diameter) size to DMD (10x14mm). After going through a field lens (L3) and a collimating lens (L4), the pulsed laser enters the DMD as a plane wave, an ideal condition for blazed grating diffraction. The micromirrors of the DMD forms a blazed grating and when the light pulse enters, it is redirected to a single diffraction order. The scanning pattern of the MEMS is duplicated for each diffraction order and yields a total of 1344 scanning points.



(a) (b)

Figure 1. (a) Schematic diagram of MEMS resonant mirror assisted Diffractive beam steering. (b) Optical relay between MEMS and DMD (not shown)

Figure 2a shows beam pattern from MEMS-resonant mirror. A total of 192 points (12 x 16) are scanned in a sequential manner. Figure 2b shows the fine and coarse steering pattern. Figure 3 shows the setup of the lidar system with transmitter DMD on the right and receiver DMD on the left.

(a) (b)

Figure 2. (a) Beam pattern from MEMS-resonant mirror. (b) Full scan pattern from MEMS-resonant mirror and DMD.

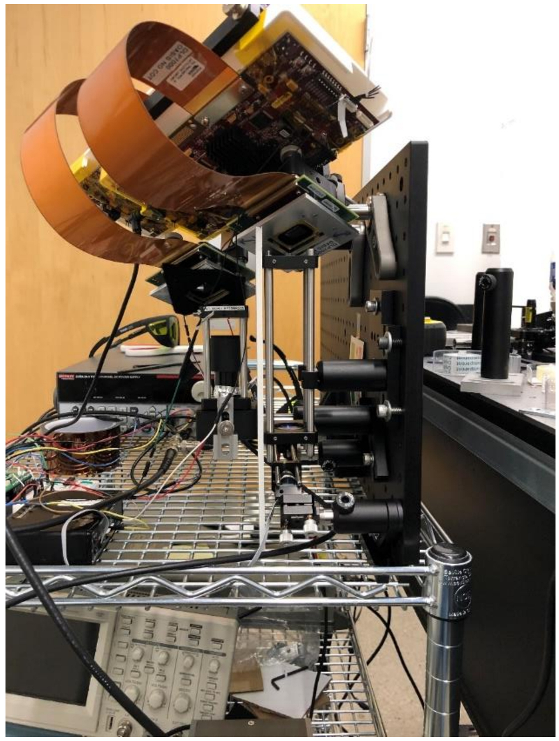


Figure 3. A photograph of the ldiar system. Transmitter DMD (right) and receiver DMD (left).

A 1024 x 768 DMD chip (DLP 7000, Texas Instruments) with micromirror pitch of 13.6μm (corner to corner) is used for coarse scanning. A single diffraction order is formed when the incident light enters the blazed grating at a blaze angle that satisfies the grating equation $dsin(-2\gamma) = m\lambda$, where d is a pixel period, γ is a tilt angle of micromirror, m is a diffraction order. Blaze angle changes as the mirrors rotate and a total of 7 diffraction orders can be obtained. Since diffraction orders are obtained through constructive interference, high beam steering efficiency can be achieved (100% in theory). A second DMD is used to receive light reflected from an object. To increase the Etendue of the receiver optics matched to the transmitter's Etendue, a second DMD detects returning signal synchronously while switching the receiver field of view (FOV) along with the transmitter FOV.

TOF electronics

The time of flight (TOF) was measured by using a time-to-digital converter (Texas Instruments, TDC7200) IC and an APD. As the laser is triggered, the Arduino microcontroller begins the timer. The reflected light from the object is then received by the APD. When the signal is received, the timer stops and the TDC measures the time of flight which are sent to the Arduino serial monitor for real time data collection. The data is converted to distance values by using the knowledge of speed of light. The distance values are then processed by Matlab and reconstructed into a 12×112 array to show "live image" of an object which illustrates object's location and distance.

LIVE IMAGE RECONSTRUCTION

Horizontal target test and live image reconstruction

A target (white cardboard, 8x1.5cm) was placed at 1m on the center of the scanning area of each diffraction order as shown in Fig. 4. The TOF of the scanning points that hit the target are measured and the corresponding distance values and location are shown in the live image reconstruction. Over the field of view (FOV) of 40 degrees, live lidar image is captured and reconstructed successfully.

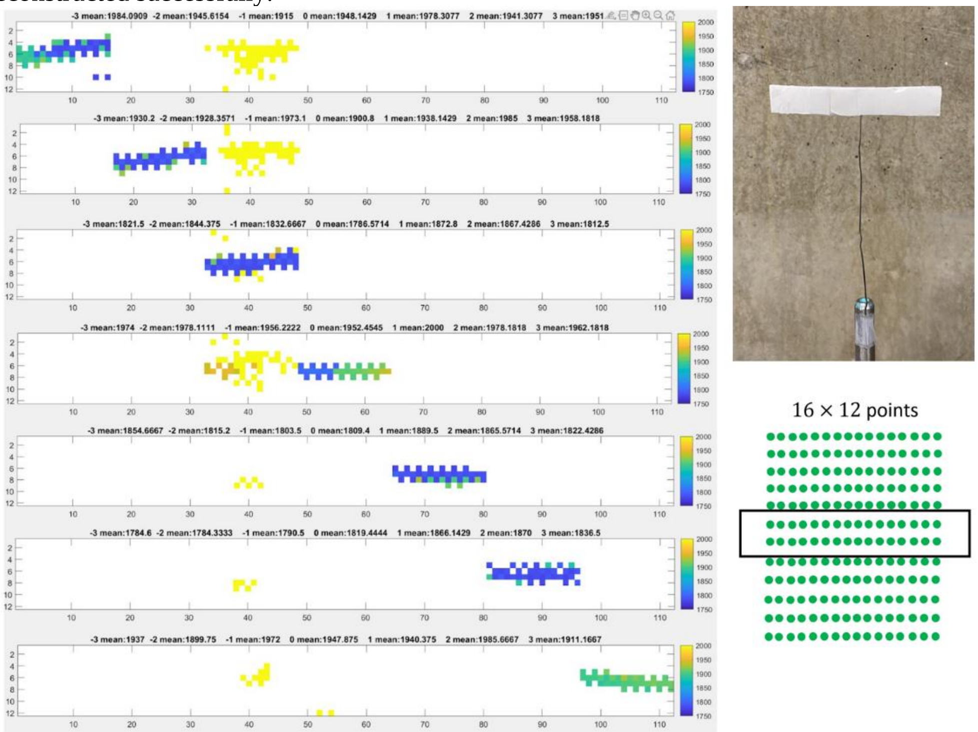


Figure 4. Still capture of the live image reconstruction with horizontal target (white cardboard).

CONCLUSION

The dual MEMS lidar system provides a way for beam steering that achieves large scan angle, fast scan rate, and high resolution utilizing commercially available DMD and MEMS based resonant mirror. The DMD provides large field of view and fast scan rate. The MEMS increases the number of scanning points which yields high resolution for object detection. These attributes allow us to reconstruct an object's location and distance which we demonstrated as a "live image".

ACKNOWLEDGMENTS

We acknowledge generous support by Semiconductor Research Corporation, Texas Instruments, Mitsubishi Electric, and Tech Launch Arizona on this study of DMD based lidar.

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