MEMS-based Imaging LIDAR

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Abstract: Micro Electro Mechanical System (MEMS) is a pathway for high performance yet cost effective Time-of-Flight based LIDARs while satisfying trade-offs in performances, such as field-of-view, angular and range resolution, scanning speed and power consumption.
OCIS codes: (280.0280) Remote sensing and sensors; (280.3400) Laser range finder; (280.3640) Lidar; (070.6121) Spatial light modulators; (230.1950) Diffraction gratings; (050.1970) Diffractive optics.

1. Introduction

Designing LIDAR system involves a complex trade-off among optical performances contrary to each other such as maximum range, field of view (FOV), angular and range resolution and scanning speed. They are balanced to achieve application specific values, for example, it is believed that for automotive safety applications, time-of-flight (TOF) based LIDARs having a range of 10-50 m, and angular resolution of < 0.1 degrees with > 100 degrees FOV are needed with high enough frame rate > 15 fps. Those requirements determine selection of optical architecture, lasers, detectors and electronics. In LIDARs the optical architecture is primarily determined by how the angular location of objects are determined. For a short range (<10 m) applications, an imaging lens is employed for a flash LIDAR. Returning light from “flood” illuminated objects is detected 2-dimensional sensor array such as a gated CMOS array, or single detector with field selection device. For the optical architecture, FOV is passively selected by the 2D array or FOV selection device with an imaging lens which enables completely non-moving LIDAR. For even longer range finding applications, the flash architecture is no more valid since returning photon scales (distance)$^{-4}$ in the system. For long range applications, angular location of objects is determined by which to/from direction laser is launched/received [1]. Thus beam steering technologies takes an essential role for long range LIDARs. Mechanical and completely non-mechanical scanning methods exist, but current technologies have limitations in scan speed and/or supported wavelengths [2, 3]. One of the most promising technologies is Micro Electronic Mechanical System (MEMS) for example resonant mirrors; however, it is in general subject to tradeoff between maximum scan rate and maximum beam diameter.

Here, we overview a recent development of new type of diffraction based beam steering and FOV selection technology that can be used in LIDAR systems that leveraging a commercially available and mass produced Digital Micromirror Device (DMD, Texas Instruments).

2. High Efficiency Angular Beam Steering using DMD for Spatial Light Modulation

DMD devices are generally utilized for binary, spatial light modulation, where the mirrors are either set to an “on” position at +12° rotation angle or an “off” position at -12° rotation angle. Our method makes use of this previously unused “on” to “off” transition state of the mirrors, which we experimentally measured to be about 2.4 µs. A short-pulsed laser is then directed onto the DMD while the micromirrors are in this transition state. If the pulse is much shorter than the transition time, the micromirrors are effectively “frozen” at an angle between their “on” and “off” states. The DMD thus acts as a high efficiency blazed grating where the blaze angle is digitally programmable by controlling the timing of the laser pulse impinging on the DMD. The micromirror tilt angle can then be programmed to steer the incoming beam of light into one of the supported diffraction orders.

3. Experimental Beam Steering Results

Three different types of light sources have been angularly steered [4]. Fig. 1 shows a “long exposure” picture of one left to right scan sequence for the three light sources. The first used a collimated 905nm pulsed laser illuminating entire area of the DMD which could be scanned across five discrete diffraction orders (Fig. 1a). The second source was a quasi-collimated green LED which confirmed that beam scanning is also practical for incoherent, quasi-monochromatic sources (Fig. 1b). The third source was a 532nm pulsed laser focused onto a single DMD pixel to remove the diffraction grating effects (see Fig. 1c). The 3rd example creates a continuously scanned but diverging beam.

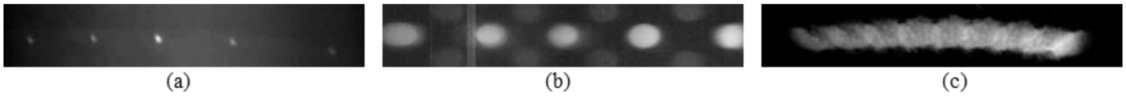

Fig. 1. Three "long exposure" images showing scanning using (a) a 905nm collimated laser, (b) a quasi-collimated green LED, and (c) a 532nm laser focused onto a single DMD pixel.

4. Single-chip LIDAR System Based on DMD Beam Steering

Since DMD beam steering requires the use of short pulsed lasers, it has an intrinsic affinity to Time of Flight (TOF) based LIDAR systems. As a proof of concept, we constructed a scanning LIDAR system featuring a 905nm pulsed laser and a single DMD chip as both the transmitting and receiving optic. Figure 2a shows the complete physical layout of this LIDAR system. The laser has a 30° incident angle to the normal of the DMD which allows scanning to one of five diffraction orders. A custom 3D printed holder, shown in Fig. 2b, spatially isolated the outgoing laser pulses from the incoming optical path to Avalanche Photo Detector (APD) while still allowing incoming pulses to be detected. The novel DMD based beam steering allows beam steering over a wide 48° field of view. This technique allows for MEMS based beam steering with a large beam diameter equal to the size of the DMD chip. When implemented into a scanning LIDAR system, a scan speed of 3.4k points/sec was demonstrated over a range of 50cm with accuracies of less than 1cm.

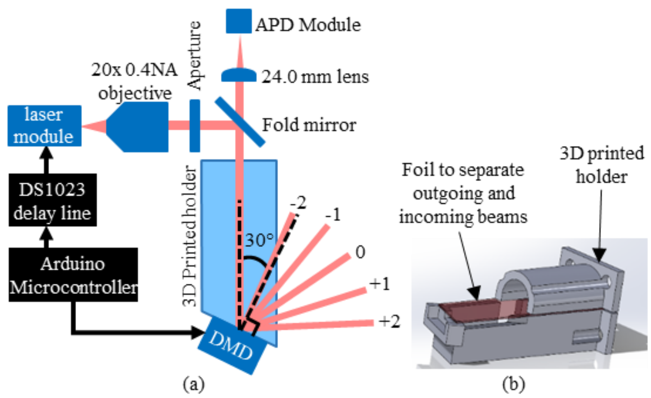

Fig. 2. (a) depiction of the physical LIDAR setup and (b) a depiction of the 3D printed mount.

5. Conclusions

The MEMS based diffraction beam steering method employing short pulsed lasers has an affinity to TOF based LIDARs. It enables fast scanning speed, comparable to refresh rate of DMD device ~23KHz. We'll address system scaling analysis to reach >100 m range with scan speeds of >10k points/sec and < 1° angular resolutions over a 50° full field of view by introducing the most recent progress including, multi-beam LIDAR [5], and light recycling beam steering [6].

6. References

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