Design and Optimization of LiDAR Beam Scanners

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Abstract

Light detection and ranging (LiDAR) technologies are being used in the industry to generate 3D images by emitting a laser to measure a scene of interest point-by-point. The goal of this research is to determine how to improve the efficiency of mechanical and solid-state scanners and understand the correspondence and trade-off between each design. The galvanometer mirror was examined through a physical model along with mathematical derivations to demonstrate the relationship between the light beam diameter, scan angle range, and the mirror shapes and sizes. For the solid-state focal plane switch array beam scanner, we developed an optical measurement procedure to characterize the relative position between the lens and the chip, and designed an optomechanical package by computer-aided design software to ensure the correct lens and chip positions to achieve the best beam quality and the highest optical power efficiency.

Introduction

- 2D Galvanometer Mirror Scanner
  - Tradeoff between the mirror size and scanning speed

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Figure 1 - Galvanometer scanner uses two mirrors to steer light beam

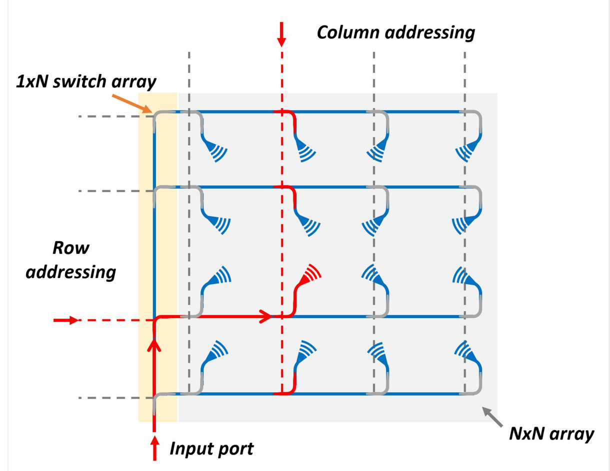
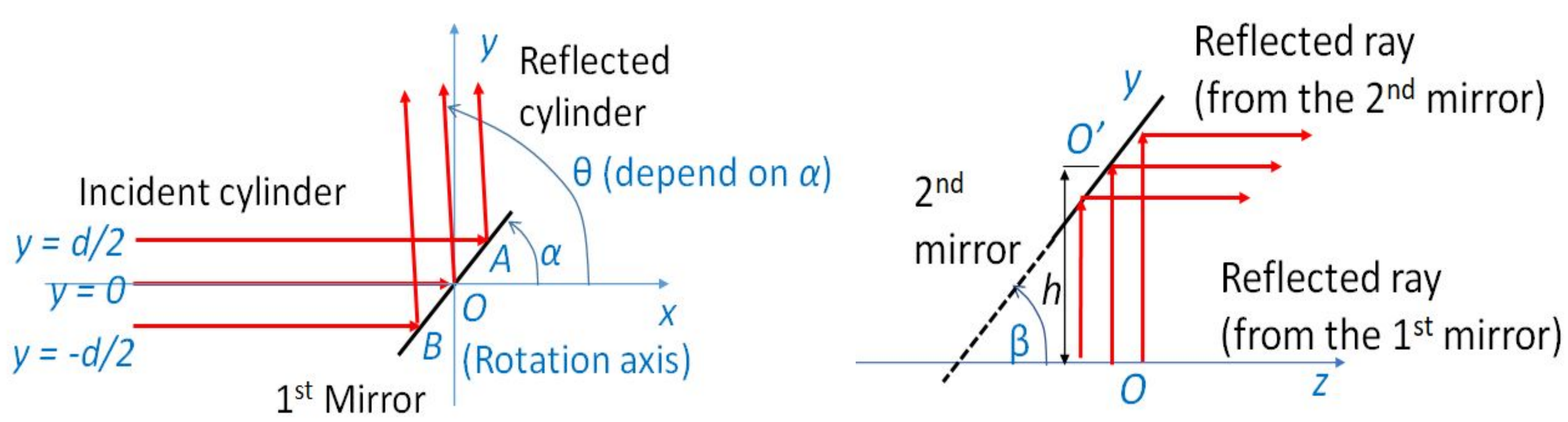


Figure 2 - Gratings in each unit cell are controlled by a MEMS switch

- MEMS-Based Focal Plane Switch Array
  - Gratings that emit light into freespace by 2D array
  - Cheaper production and higher efficiency
  - More suitable for autonomous vehicle application

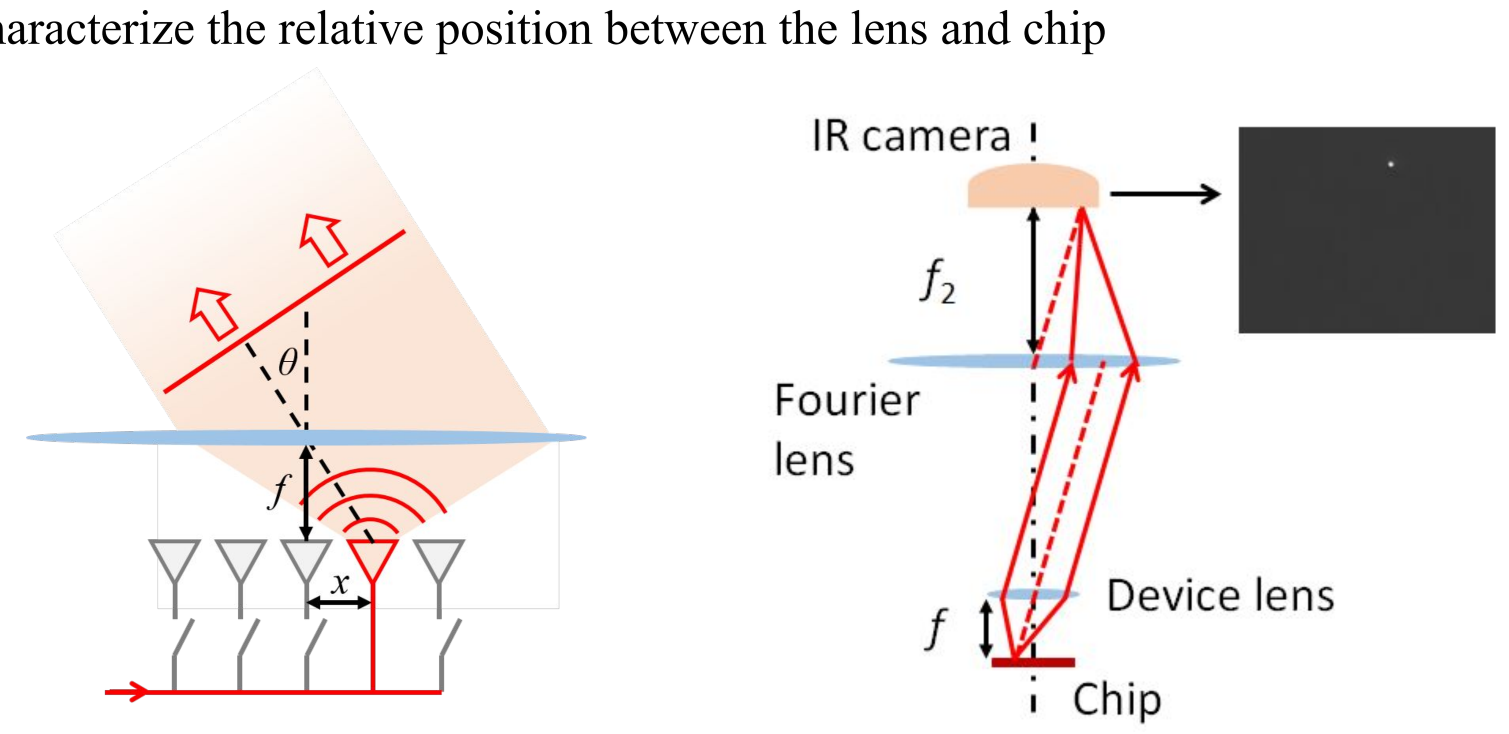
Methods: Galvo Mirror

- Galvanometer mirror was examined through a physical model along with mathematical derivations to demonstrate the relationship between each parameter
  - Light beam diameter, scan angle range, and mirror size



Methods: Focal Plane Switch Array

- A 2D focal plane array was analyzed through a geometrical optics model to determine the the relationship between the lens properties and the output beam properties.
  - Potential alignment errors between the chip and lens were examined
    - Out of focus, lateral offset, and tilted angle of chip with respect to principal axis of lens
  - A second lens and an Infrared camera was used to perform optical measurements and characterize the relative position between the lens and chip



Data Results

Figure 3 - Mirror size analysis

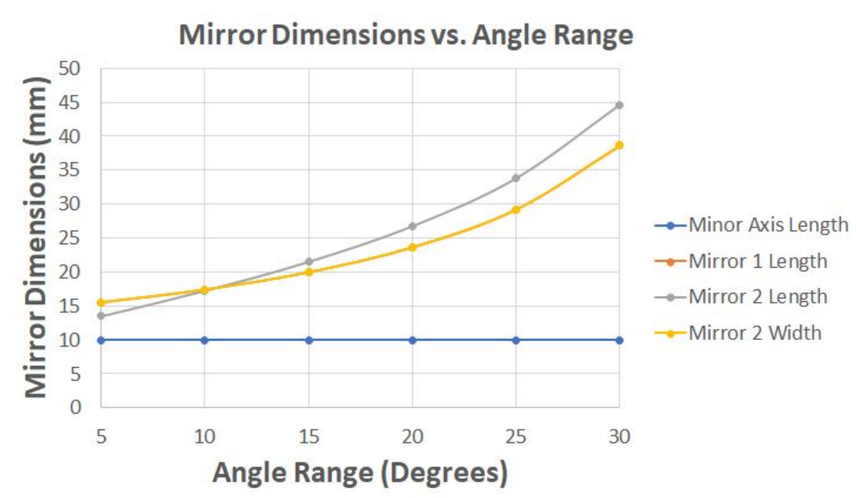


Figure 4 - Commercial product efficiency

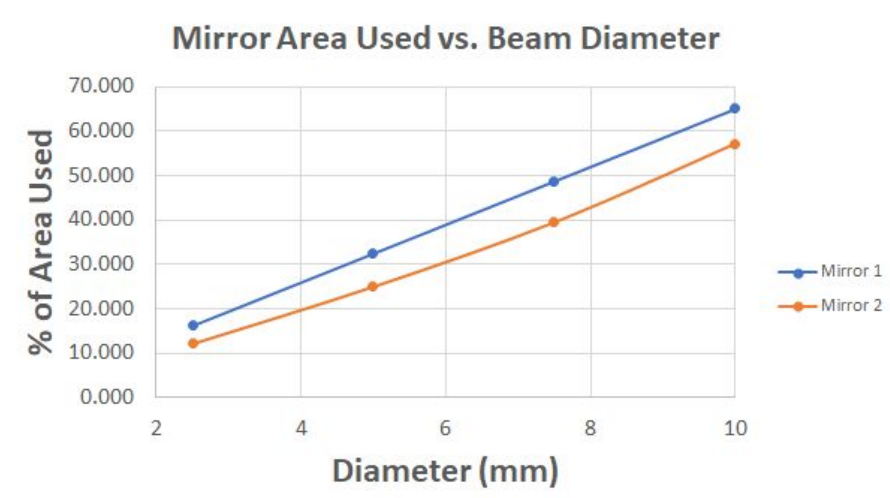


Figure 3 presents the correlation between the mirror size and scanning range of the galvo mirror. Figure 4 demonstrates the percentage of the mirror area used from a commercial mechanical scanner with varying light beam diameters.

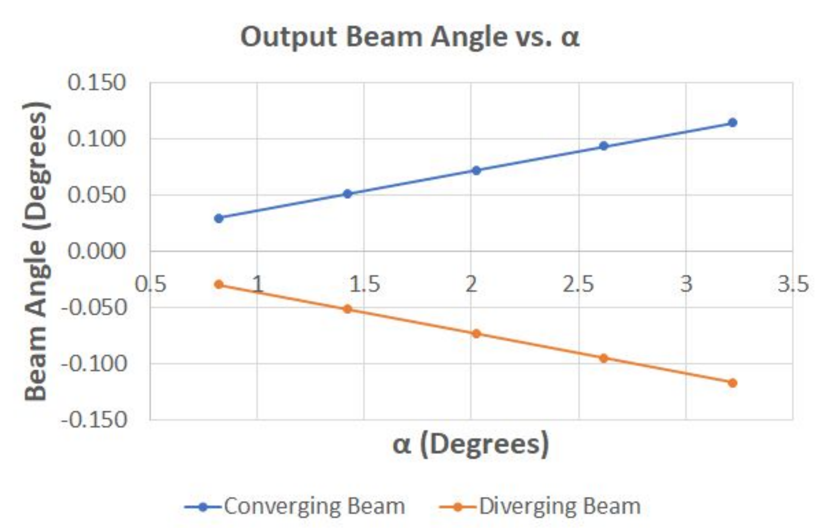


Figure 5 - Alignment error due to tilted angle of chip

Figure 5 displays one of the possible alignment errors that could occur. While the chip is tilted, each end of the chip will be out of focus with the lens, which will cause a converging and diverging beam to be emitted.

Discussion / Conclusion

In our research, we found the most efficient mirror size for mirror 1 and 2 to be elliptical and rectangular. We analyzed these mirror sizes by measuring them with respect to the angle range of each mirror. The commercial galvanometer mirror is sufficient in capturing the light at 60% efficiency with a 10 mm beam diameter. For the focal plane switch array, we analyzed the different alignment errors that can occur in our setup, and used an infrared camera with a second lens to measure these different beam behaviors. By understanding the different effects of these errors, we were able to use this knowledge to design an optomechanical package with mechanical stability that satisfies the optical requirements between the chip and lens.

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