

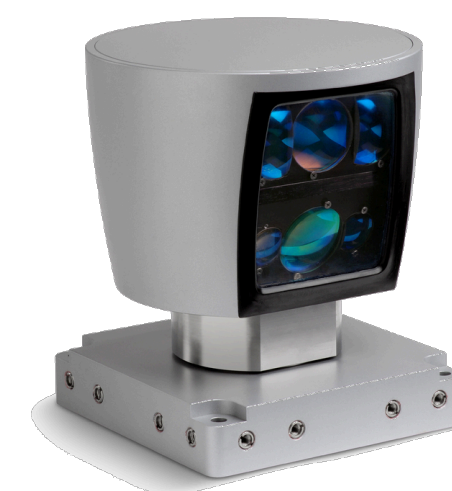
Single-Pixel Amplitude-Modulated Time-of-Flight Camera

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Motivation

Depth sensors are an increasingly critical component in a number of applications, from autonomous road vehicles and robotics to augmented reality systems. Individual depth sensing elements are more expensive than standard camera pixels, leading to an inherent tradeoff between sensor resolution and cost.

Many commercial depth-sensing devices, such as automotive LIDARs, approach this problem by using mechanical motion to sweep or scan a small number of active depth elements across the scene. For example, Velodyne's high resolution LIDAR contains 64 vertical pixels that are rapidly rotated to image the scene.



Velodyne LIDAR

Another approach to depth sensing has been to use custom silicon sensors that perform time of flight ranging. While quite effective for certain range problems, the inherent inflexibility of a custom chip limits design cycles and modifications to change range, power, modulation type, or other important performance parameters.

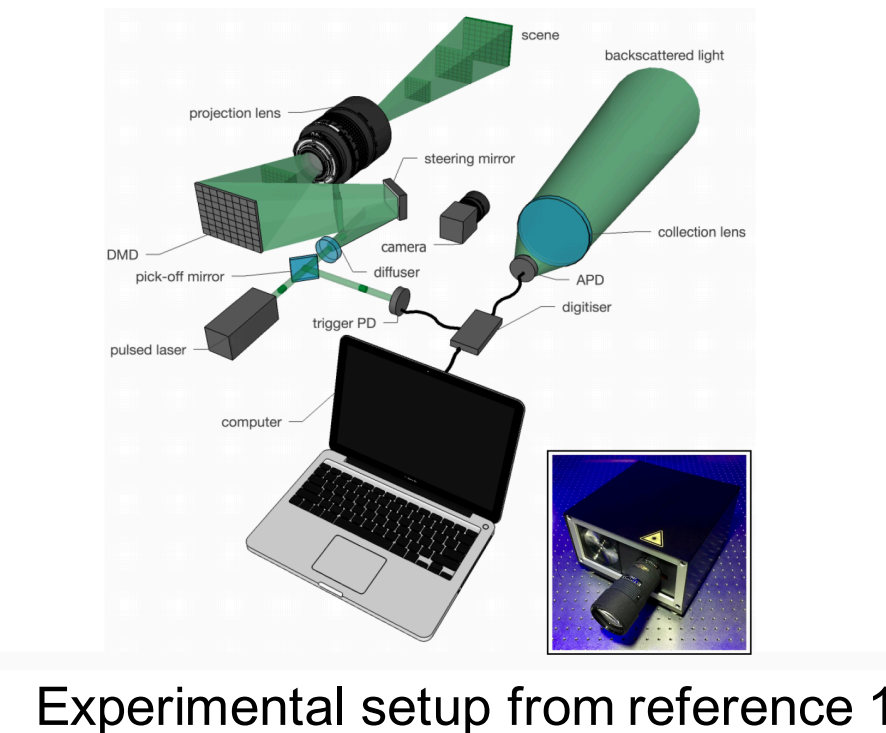


Microsoft Kinect 2

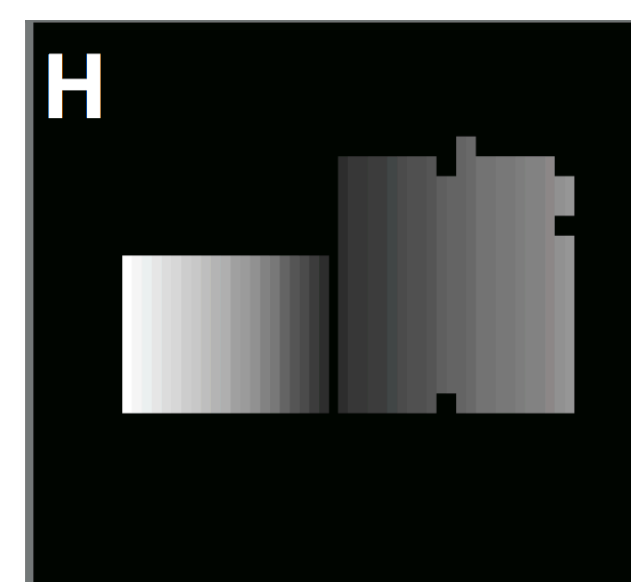
Related Work

The recent development of single pixel cameras and compressive sensing algorithms has opened a new avenue to develop depth cameras that use a single image sensor to acquire the range data. Past research into single pixel depth cameras has used a spatial light modulator (typically a DMD) to send a patterned pulse of light into the scene, and capture the return pulse using an avalanche photodiode (APD) or photo-multiplier tube (PMT). These devices send their signals to specialized highly time resolved circuitry to directly measure time of flight for each return pulse.

While effective in reducing the number of active elements while preserving high resolution with a spatial light modulator, the reliance on fast pulsed lasers and high time resolution photon counters increases complexity and cost, limiting the practical use of these depth cameras.



Experimental setup from reference 1

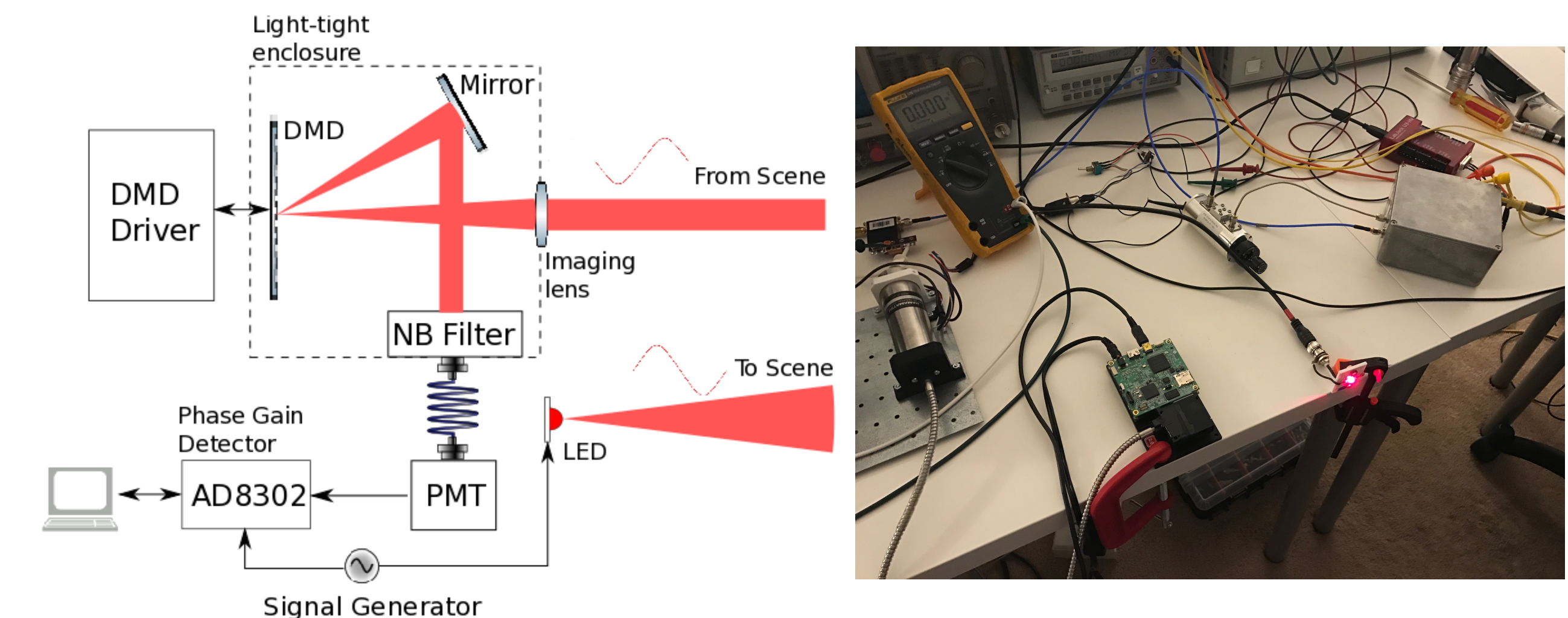


Example scene reconstruction from reference 2

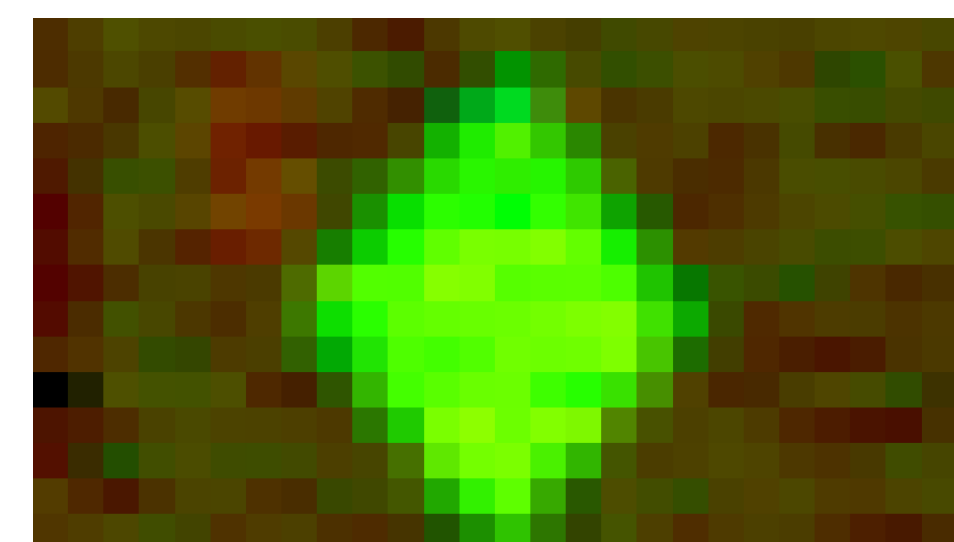
New Technique

Our approach uses a TI DMD (Digital Micromirror Device) as a spatial light modulator, but differs from previous work in using sinusoidal amplitude modulation (at 10MHz) rather than nanosecond pulses. Using amplitude modulation allows for the use of a simple phase/gain detector rather than a time correlated photon counter and enables the use of an LED rather than a laser, which allows greater powers to be projected safely into the scene.

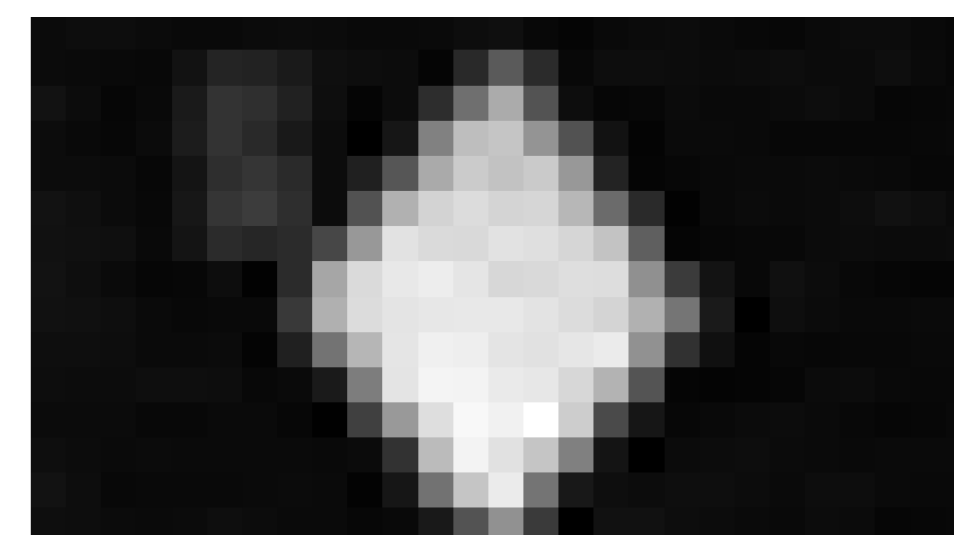
We use both raster masks and Hadamard matrix masks to encode scene information and compare the results. Currently we use the full Hadamard basis set; future work will include compressive sensing using a subset of the basis.



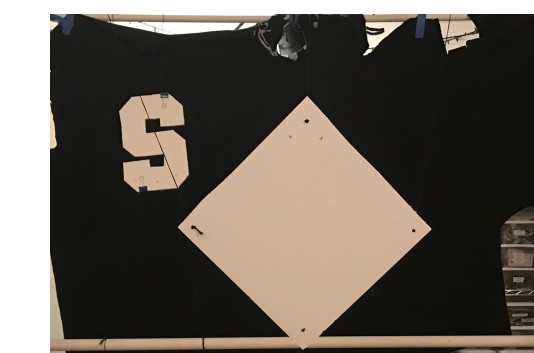
Experimental Results



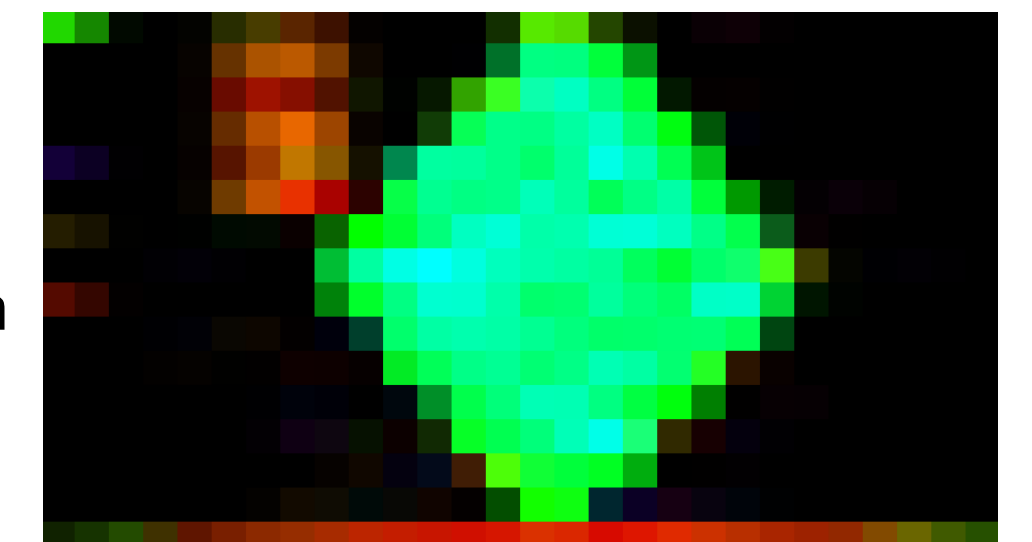
Raster Depth



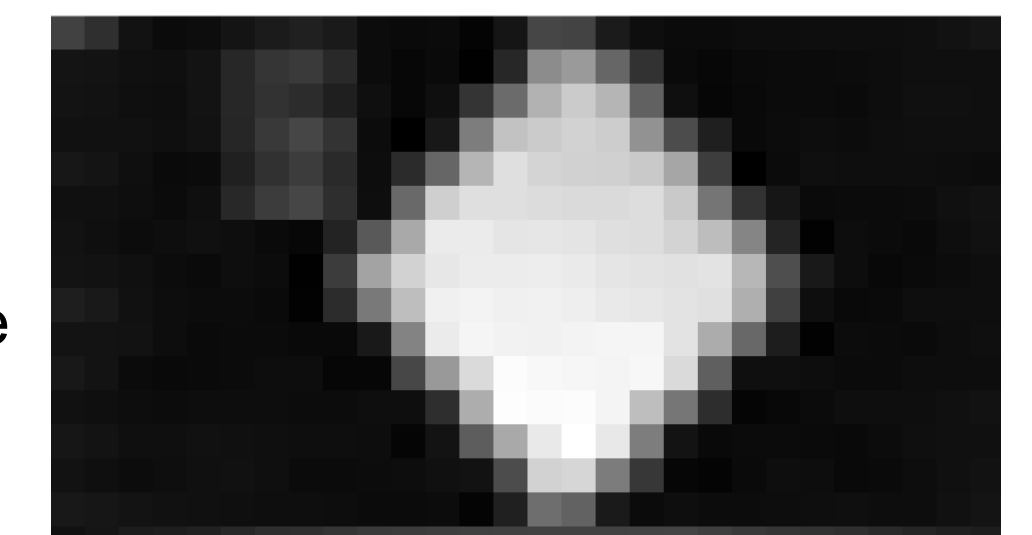
Raster Amplitude



Scene



Hadamard Depth



Hadamard Amplitude

References

1. Edgar, Matthew P., et al. "Real-time 3D video utilizing a compressed sensing time-of-flight single-pixel camera." *SPIE Nanoscience+ Engineering*. International Society for Optics and Photonics, 2016.
2. Kirmani, Ahmed, et al. "Exploiting sparsity in time-of-flight range acquisition using a single time-resolved sensor." *Optics Express* 19.22 (2011): 21485-21507.

Acknowledgements

We would like to acknowledge the support and advice of our project mentor Matthew O'Toole and Professor Gordon Wetzstein. We also would like to acknowledge Ben Johnson (Stanford M.S. EE 2013) for his tremendous support and advice, including providing the PMT, Phase/Gain measurement board, fiber and RF accessories, workspace, and lab equipment used in this project.