Improvements to Spatial Frequency Modulated Imaging

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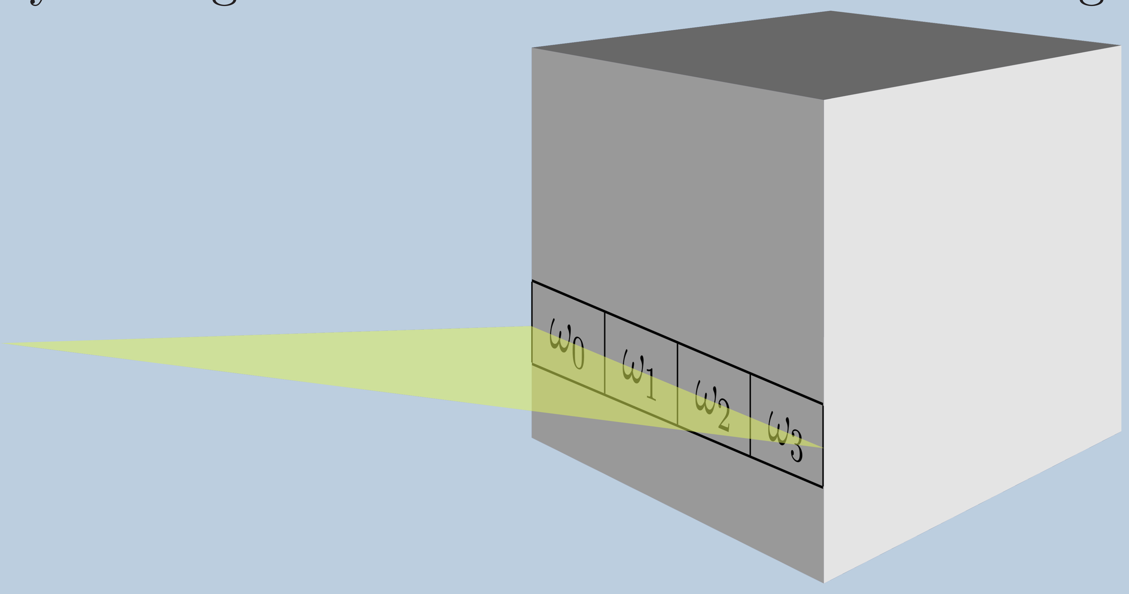
Abstract

This team's project was primarily to provide simulation software to compare the output predicted by an ideal system to actual data collected from these systems once they have been constructed, and to produce software to implement photon counting on the output of SPIFI systems. The advantage of 2D SPIFI is to enable the system to scan the object much faster by eliminating the current need to scan over the object by expanding the spatial frequency modulation. The advantage of photon-counting is that one can immediately resolve which part of an object a particular photon scanned, eliminating the need to do some signal processing on SPIFI signals.

Background

SPIFI is a revolutionary imaging technique that allows a line to be scanned across an object by a single laser at one time, without using a raster pattern along the line. In particular, it is impressive because a full, two-dimensional image can be extracted from light collected at a single point. Traditionally, scanning more than a single point at a time would require multiple collectors to be able to resolve which photons were used to scan what part of the object (e.g. using a camera). SPIFI enables scientists to scan objects with one collector by encoding this information in a frequency change that maps directly to a line on the object. The focus of this project is to expand the capabilities of SPIFI by adding another dimension to this encoding.



References

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[2] Glenn D. Boreman et. al. *Use of spatial light modulators in frequency modulation reticle trackers*, Optical Engineering, November 1990

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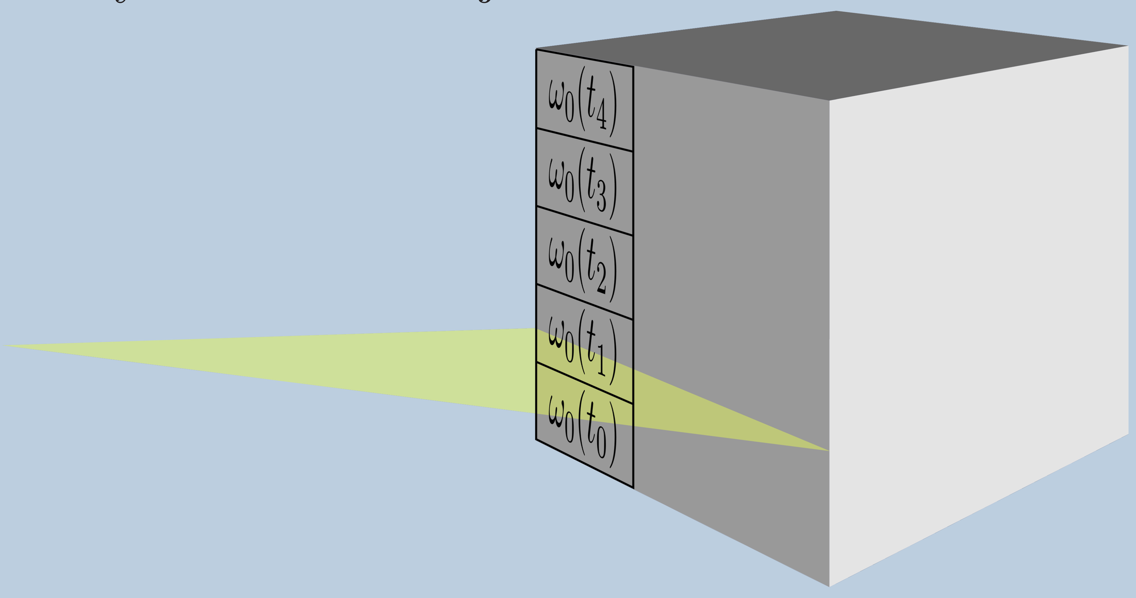
2D SPIFI

Current SPIFI techniques require scanning across an object by physically "wobbling" a mirror. 2D SPIFI would not only remove this requirement, but would allow one to scan the entire object at once, providing an $O[n]$ decrease in the time necessary to scan an object.

This basically amounts to another rotating SPIFI mask, but rather than a linear pattern, it would encode along it entire "sub-masks" so that the laser beam could be spread out into a plane instead of just a line. Essentially this replacing temporal encoding of frequency (pictured right) used in 1D SPIFI with a spatial encoding. It's actually quite analogous to the idea of 1D SPIFI as opposed to raster scans.



This team wrote software which simulated this 2-dimensional SPIFI technique as a proof-of-concept, as well as an aid to test designs for 2D SPIFI masks. Shown below is the effective spatial frequency mapping used by 2D SPIFI, alongside an input and corresponding output of the simulator (using image files as objects).

$\omega_{0,0}$	$\omega_{1,0}$	$\omega_{2,0}$	$\omega_{3,0}$	$\omega_{4,0}$	$\omega_{5,0}$
$\omega_{0,1}$	$\omega_{1,1}$	$\omega_{2,1}$	$\omega_{3,1}$	$\omega_{4,1}$	$\omega_{5,1}$
$\omega_{0,2}$	$\omega_{1,2}$	$\omega_{2,2}$	$\omega_{3,2}$	$\omega_{4,2}$	$\omega_{5,2}$
$\omega_{0,3}$	$\omega_{1,3}$	$\omega_{2,3}$	$\omega_{3,3}$	$\omega_{4,3}$	$\omega_{5,3}$
$\omega_{0,4}$	$\omega_{1,4}$	$\omega_{2,4}$	$\omega_{3,4}$	$\omega_{4,4}$	$\omega_{5,4}$
$\omega_{0,5}$	$\omega_{1,5}$	$\omega_{2,5}$	$\omega_{3,5}$	$\omega_{4,5}$	$\omega_{5,5}$

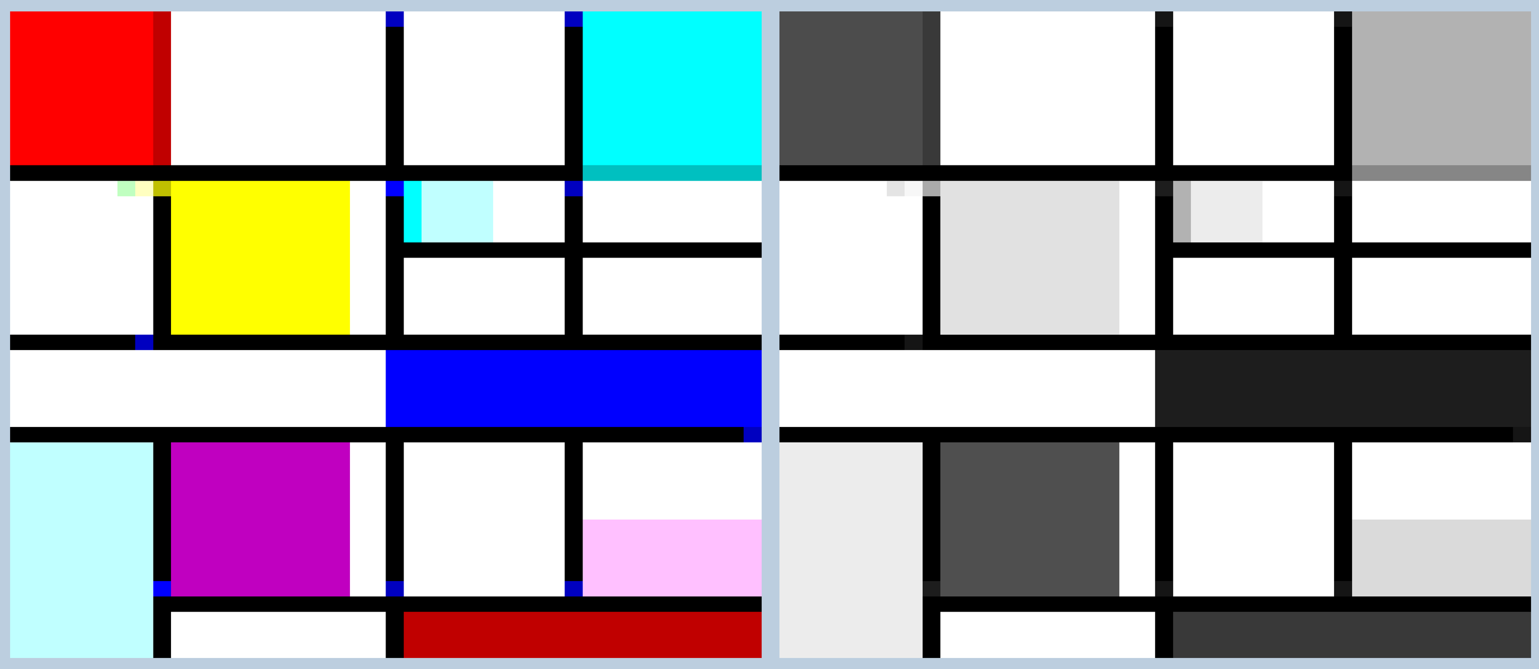
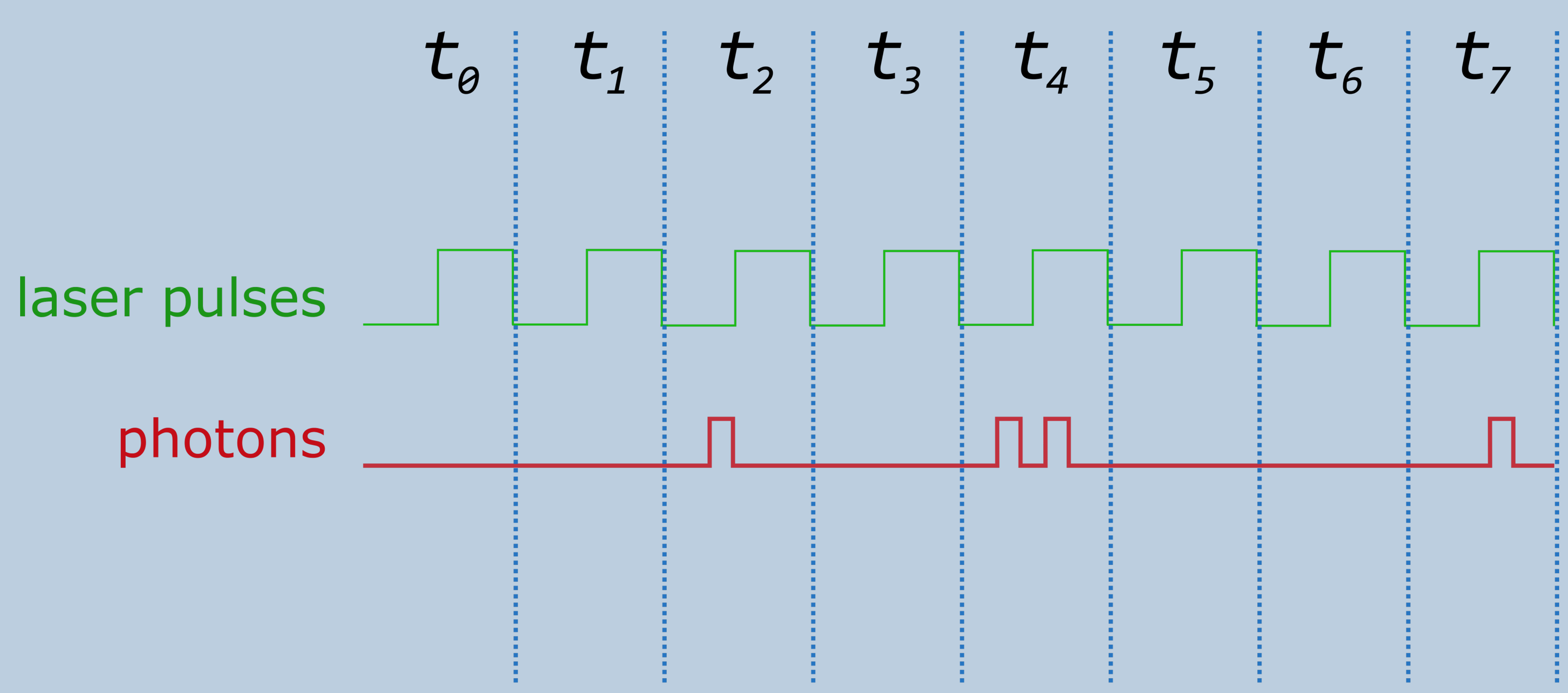


Figure 1: Left: Effective Spatial Frequency of 2D SPIFI - Center: Sample Simulation Input - Right: Sample Simulation Output

Photon Counting

Photon counting refers to analyzing the collected output of a SPIFI system (1D or 2D; both can utilize photon counting) to resolve the detection of individual photons. This allows the frequency of individual photons to be easily resolved without having to perform Fourier analysis on a signal composite of all of the photons from a single burst of the laser. This allows for imaging of an object to be performed immediately, and is a simple enough process that it can be performed on a micro-controller or field-programmable gate array (FPGA). The actual hardware chosen was an Altera^{TM} DE0-Nano FPGA. Shown below is a sample timing diagram showing how individual photons can be related to bursts of the laser.



Note that this much more sparse than one would typically expect, to make it more readable.

Software Notes

Unfortunately, the source code cannot be included here, as the research is still pending publication. At the time of publication, the source will be made available to the community along with its respective documentation. Once released, the software is provided under the GNU Public License version 3. The simulation is written in the open Python 3.5.2 standard, with a list of free and open source dependencies that will be made available at the same time as the simulation itself. The FPGA code was written using the Quartus software which is the property of Altera^{TM}, along with various pieces of supporting software each of which is subject to its own license.