SAND2017-7592C

Optimized Algorithm for High Efficiency Atom Transport

Zane Crawford[1] and Michael Martin[2]

[1] Department of Computational Mathematics, Science, and Engineering, Michigan State University, East Lansing, Michigan 48823 USA
[2] Sandia National Laboratories, Albuquerque, New Mexico 87185 USA

Sandia National Laboratories

Exceptional service in the national interest

Abstract

Current work at Sandia National Laboratory targets the creation of arrays of neutral atoms, which could be used to enable quantum technologies such as quantum computation, quantum simulation, and entanglement-enhanced sensors. An outstanding challenge for this work is creating arrays of atoms in a repeatable way, with no missing atoms. In this work, computer-generated holograms will be used to pattern a light field to create the desired pattern of atoms with the goal of dynamically adjusting to stimuli, such as a desired arrangement of atoms. This is achieved using iterative Fourier transform algorithms, but is computationally intensive. To reduce the time to solution, the procedure to create the holograms is accelerated through the use of graphics processing units (GPUs). A study on the performance of this method is presented with respect to quality of the holograms and the time to solution. Experimental results are also presented to show the utility of the method.

Problem Statement

In phase-only digital holography, one illuminates a discrete 2D phase mask with weakly structured input illumination, such as a Gaussian beam. From the properties of scalar diffraction theory, and by utilizing a single-lens, placed a focal distance from the phase mask, the image plane is related to the phase mask via a scaled Fourier transform. By controlling the phase mask in the Fourier plane, one can achieve arbitrary intensity patterns with high accuracy.

This work seeks to achieve:

- Accurate image with respect to the target image
- Small deviation in Intensity between traps
- Reduced time to creation of image from calculation of target image's associated phase mapping to physical image

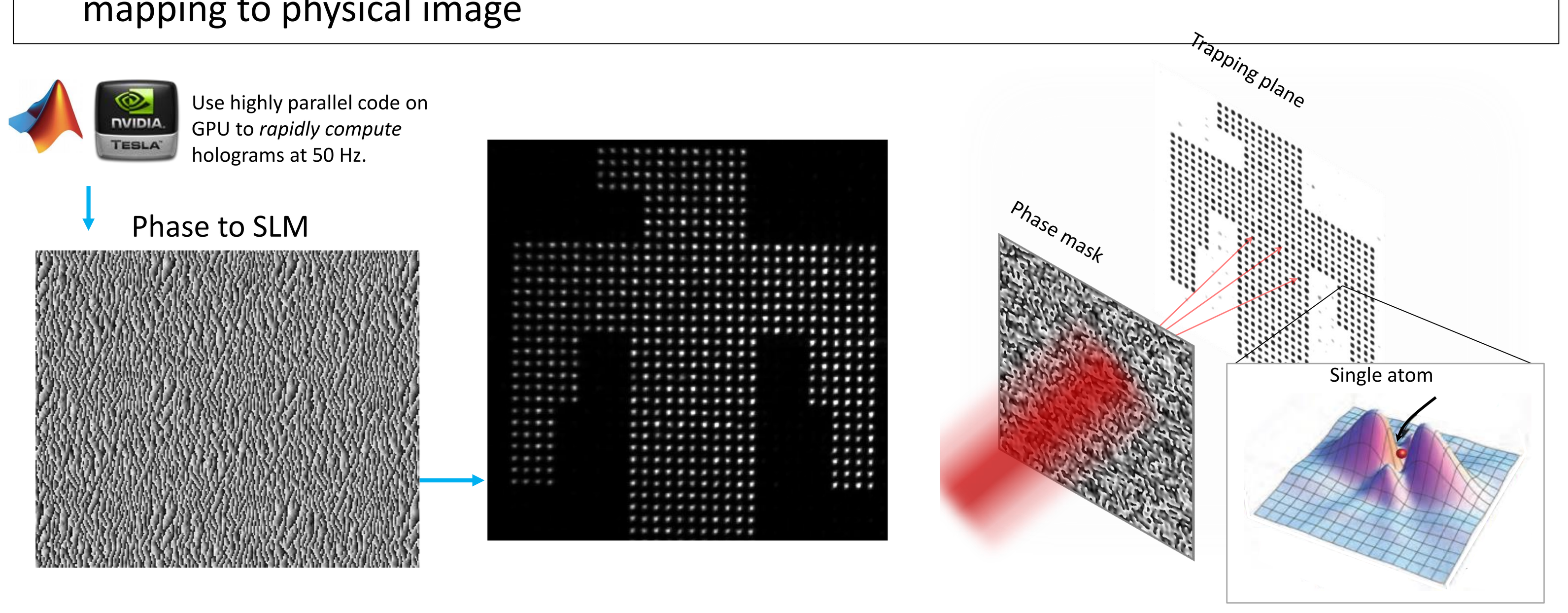


Figure 1.
The goal of this work is to use MATLAB and the Parallel Toolbox to accelerate the creation of a phase matrix that creates a desired hologram. This hologram can be used to trap a single atom.

Gerchberg-Saxton Algorithm

The phase needed to achieve the desired target image is obtained through the Gerchberg-Saxton (GS) algorithm. It is an iterative method that finds a phase mapping that will produce the desired image, although it is not guaranteed to find the optimal solution.

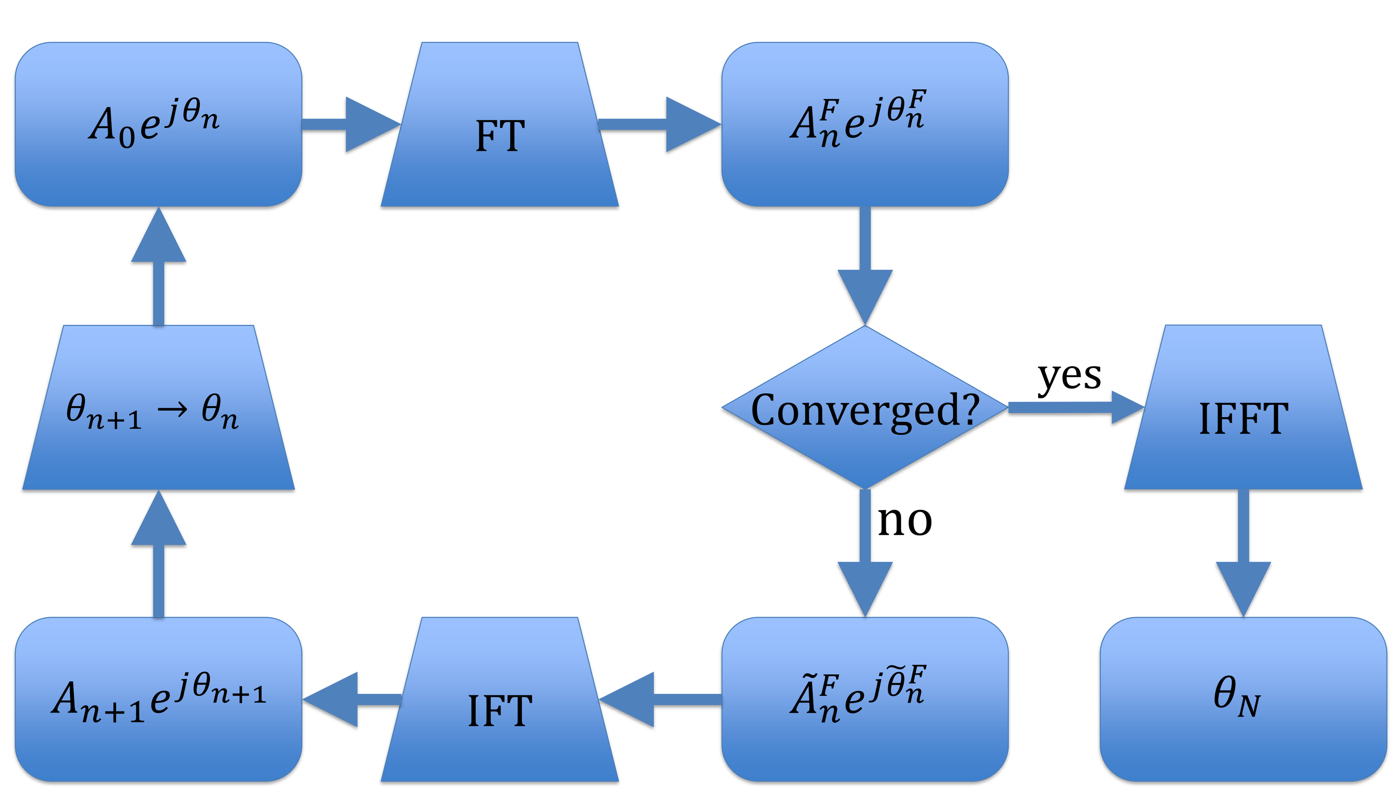


Figure 2.
The classical Gerchberg-Saxton algorithm. Each iteration applies a forward and inverse Fourier transform to the input signal. Between the transforms, the amplitude is changed until the phase applied to the SLM yields the target image, although other modifications can be made to improve the results.

Drawbacks

- Not optimal
- No constraint on the standard deviation of intensities
- No phase restriction
- Fourier transform can be accelerated from a $O(N^2)$ to $O(N \log_2 N)$ with the fast Fourier transform
- Branching decision making can increase computation time

Modified Gerchberg-Saxton Algorithm

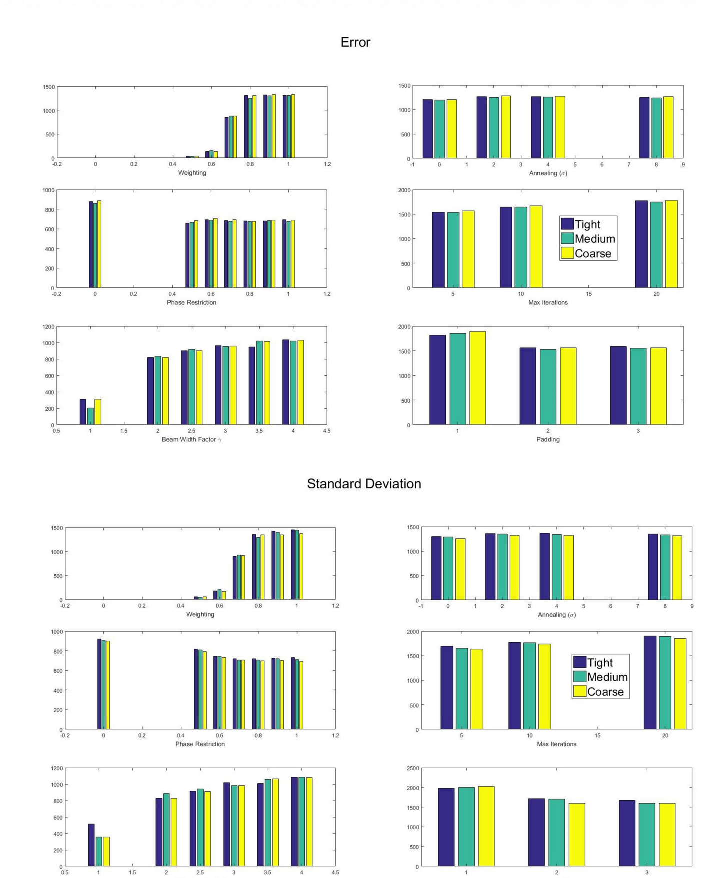
To overcome the drawbacks of classical GS algorithm, several different modifications were tested to determine optimal results.
The following modifications were tested in the GS algorithm to test their effect on accuracy, distribution, and timing

- Modified weighting: $\tilde{A}_n^F = \sqrt{I_t} - (1-\tau)A_n^F, 0 \leq \tau \leq 1$
- Phase annealing: $\tilde{\theta}_n^F = \theta_n^F + \frac{(2\pi * \mathrm{rand}(0,1) - \pi) e^{\frac{-\sigma n^2}{N^2}}}{N}, \sigma \geq 0$
- Phase restriction: $\tilde{\theta}_n^F = \begin{cases} \theta_n^F, \left|\theta_n^F - \theta_0^F\right| \leq 2\pi\alpha \\ \theta_0^F, \quad o.w. \end{cases}$
- Resolving: Run (modified) GS algorithm, then resolve with alter trap values $\tilde{I}_m = \frac{\bar{I}}{1-\beta(1-I_m/\bar{I})}$ for trap I_m from the first GS algorithm run
- FFT length
- Laser beam width: $w_0 = \frac{\mathrm{xDimension(SLM)}}{\gamma}$
- Maximum number of iterations: N

Results

Optimal Modifications

Figure 3.
Distribution of modification parameters and the likelihood that they fall within an acceptable threshold to be considered a viable hologram. The target holograms were 4x4 square meshes.



Timing Results

	CPU GS Algorithm		GPU GS Algorithm	
	Unmodified	Modified	Unmodified	Modified
8 Trap Ring	2.0765 s	0.4504 s	5.9802 s	0.0611 s
4x4 Tight Square	1.915 s	0.4420 s	7.199 s	0.0604 s
4x4 Medium Square	2.2944 s	0.4446 s	5.7406 s	0.0614 s
4x4 Coarse Square	1.8184 s	0.4436 s	6.0009 s	0.0608 s
Block S	1.5068 s	0.4558 s	4.0938 s	0.0620 s
Sandia Thunderbird	1.4948 s	0.4398 s	3.7020 s	0.0613 s

Table 1.
Results show that using the modified GS algorithm will reduce time to solution. Furthermore, using GPUs with the modified GS algorithm will lead to the fastest computation. The convergence check on the GPU requires reductions which eliminates the benefit of running the algorithm on the GPU. A Nvidia Quadro P4000 was used as the GPU.

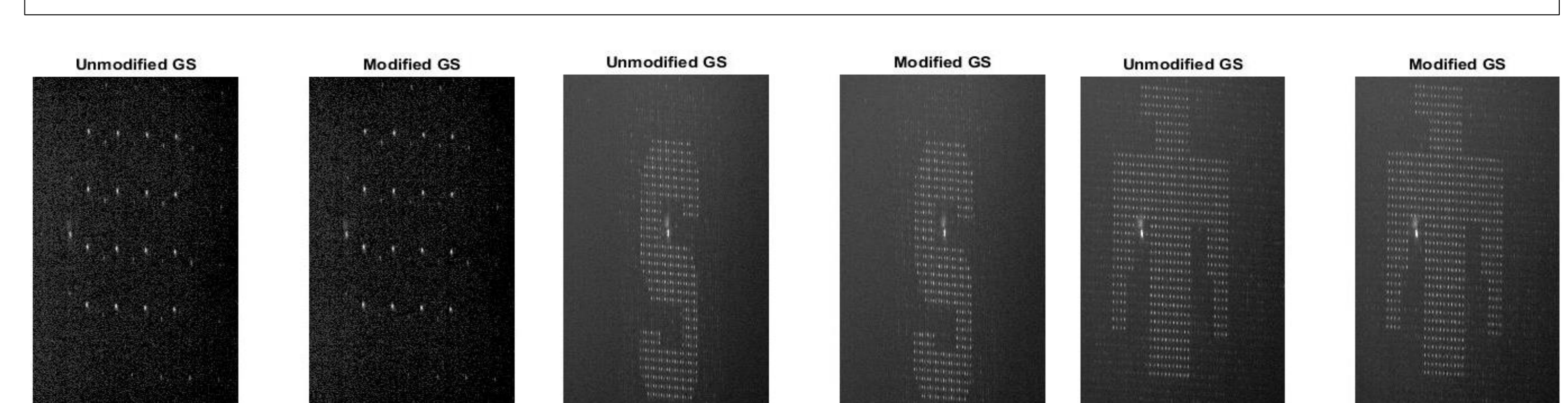


Figure 4.
Three holograms tested to confirm that the modified GS algorithm yields similar results to the classical GS algorithm for three target intensities: (a) 4x4 Coarse square, (b) MSU Block S, and (c) Sandia Thunderbird. The logarithm of the normalized intensities are presented to offset the DC bias.

Conclusion

The Grechberg-Saxton algorithm has been accelerated with GPUs, prototyped in MATLAB. A 30x speed-up is achieved with the modified GS algorithm on GPUs over the classical GS algorithm on CPU and 7x for the modified GS algorithm on CPU. In future work, the algorithm will be implemented directly in LABView utilizing GPUs to hopefully reduce overhead from calling MATLAB scripts.

This work is supported by the Department of Energy Computational Science Graduate Fellowship under grant number DE-FG02-97ER25308.
Email: crawf326@msu.edu, mmart33@sandia.gov

DOE CSGF

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration