UNC CHARLOTTE

GPU Accelerated Compressive Imaging System

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Motivation

We develop a new GPU accelerated compressive imaging system that is based on single-pixel camera architecture which provides a great opportunity to design a high-resolution imaging systems for scenarios that ordinary high-resolution sensors are very costly or impractical such as hyperspectral imaging systems. One major obstacle for employing this technique is very high computational requirement of the recovery algorithm to generate the original high-resolution image. In our proposed system, by parallelizing the recovery algorithm and implementing it on an NVidia GPU we achieve the required speedup to make our compressed imaging system suitable for practical applications.

Compressive Imaging

Compressive Sensing (CS) is a growing field based on the fact that a small number of linear projections of a sparse or compressible signal contain enough information to recover the original signal. CS provides a framework for sensing of finite dimensional vectors and analog signals predicting that sparse high-dimensional signals can be recovered from highly incomplete measurements by using computational power for reconstruction. CS combines sampling and compression into a single non-adaptive linear measurement process.

One particularly intriguing area that utilizes compressive sensing technique is compressive imaging method and especially single-pixel camera. Single-pixel camera architecture provides a framework to develop high-resolution imaging systems for scenarios that ordinary high-resolution sensors are very costly or impractical such as hyperspectral, shortwave infrared, and terahertz imaging systems.

Single-pixel architecture consists of two primary steps, namely measurement generation (Figure 1) and image recovery (Figure 2).

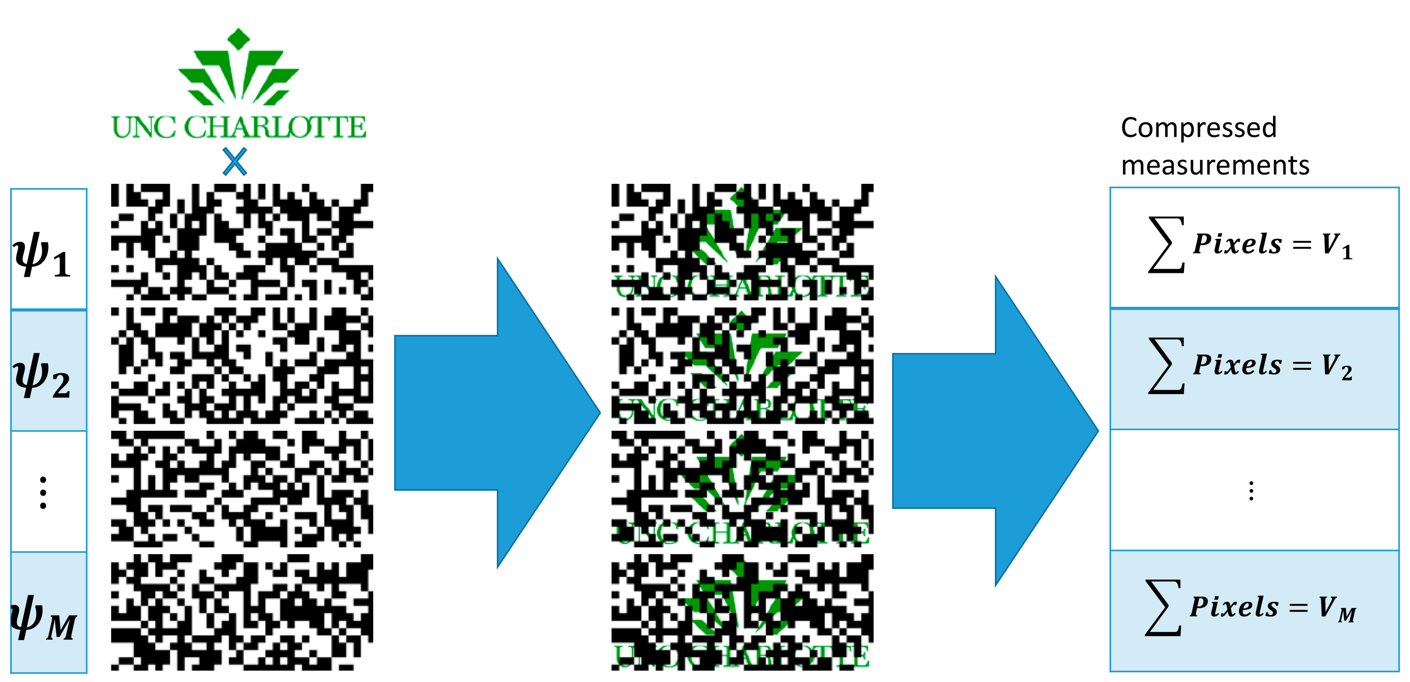

Figure 1: Measurement generation step of compressive Imaging

Measurement generation step contains a Spatial Light Modulator (SLM), optical system, a single detector, an analog-to-digital convertor, and a digital storage. The SLM modulates the incoming light according to some particular patterns and optical system focuses the transmitted light from the SLM onto a single detector. Therefore each measurement is the result of the inner product of the scene image and SLM's patterns. The SLM's patterns are chosen so that the recovery is mathematically possible.

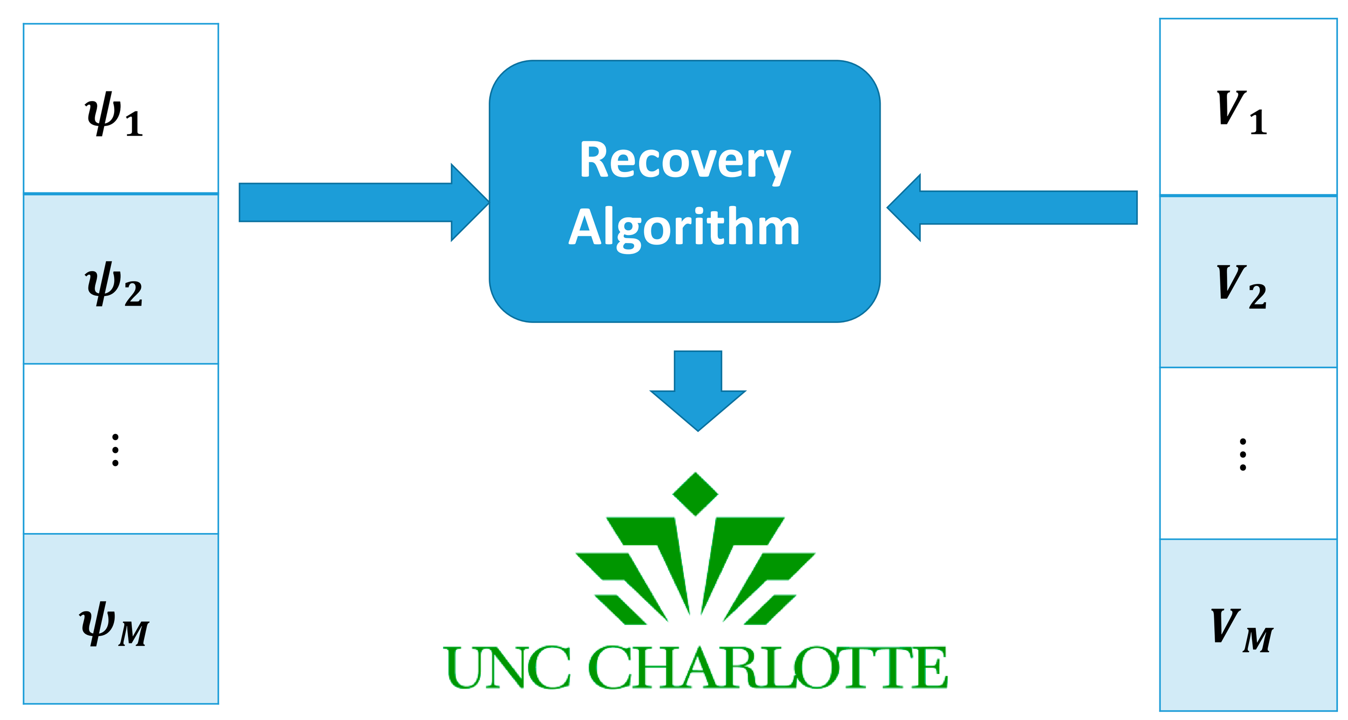

Figure 2: Recovery step of compressive Imaging

Figure 3 shows schematic of our hardware implementation for hyperspectral Imaging where a one-pixel spectrometer is used to create high-resolution hyperspectral images.

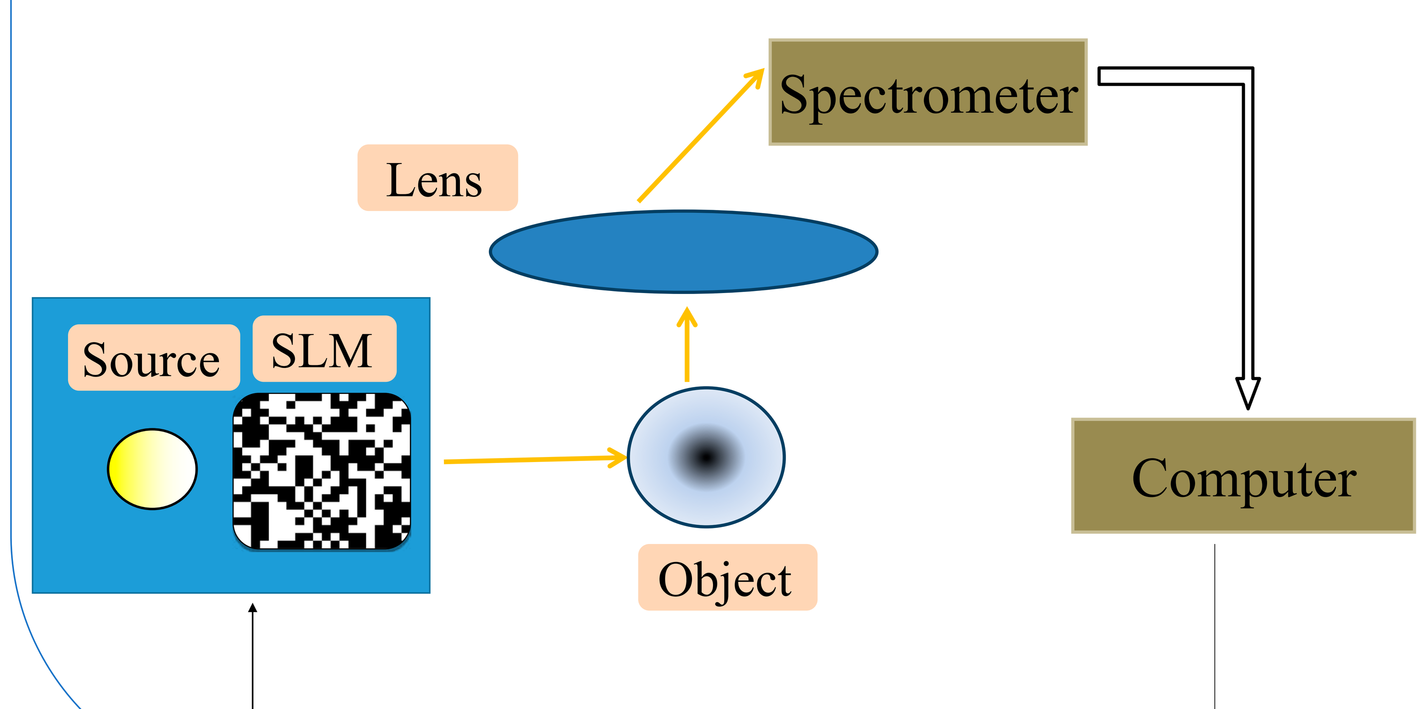

Figure 3: Compressive hyperspectral Imaging

Parallel Recovery algorithm

To reconstruct the high-resolution image from the compressed measurements, a recovery algorithm is required. Because the dimensionality of recovery algorithm is very high, designing an efficient recovery algorithm is very challenging and majority of proposed standard techniques are unable to solve these problems both accurately and efficiently.

NESTA algorithm that is based on Nesterov's work is a gradient recovery method that is shown to have optimal convergence rate. Although compare to other recovery algorithms, NESTA is fast, accurate, and robust; in current implementation it is not fast enough to be used in real world applications.

We modify the NESTA algorithm to parallelize its different parts and achieve high speed requirement for building a usable high resolution single-pixel camera. We implement this parallelized algorithm both on an Intel CPU (using TBB library) and an NVidia GPU (using CUDA + cuSparse) and show that, based on our results, how high dimensionality of the recovery problem makes GPU implementation appropriate choice for our application.

Experimental results

Figure 5 and figure 6 show recovery result of one of our experiment for hyperspectral imaging. For this experiment permuted Hadamard codes are used as measurement matrix. After applying recovery algorithm to compressed measurements that are generated using a one-pixel spectrometer, high-resolution images for every wavelength as well as high-resolution spectrums for every pixel are accessible.

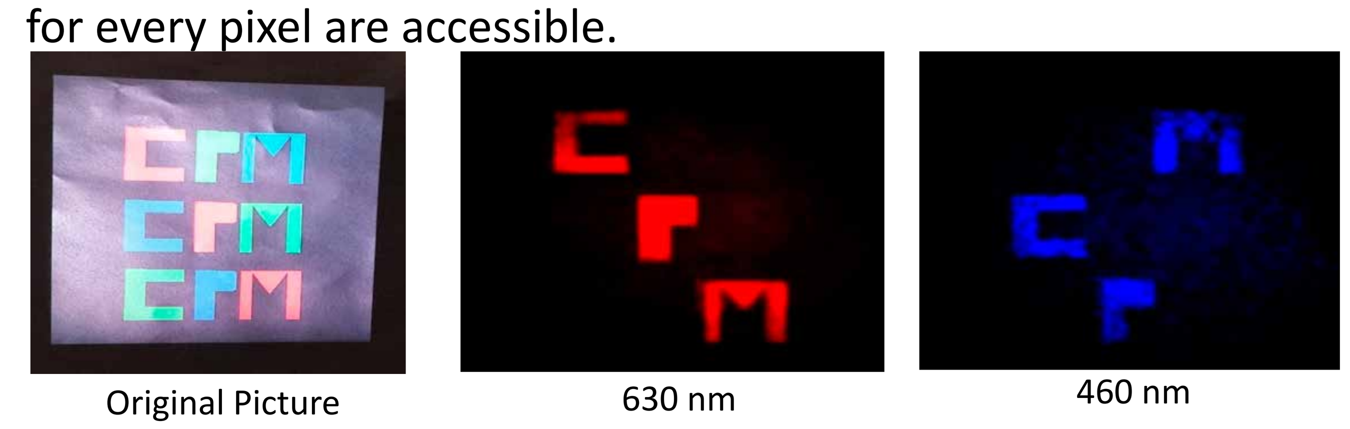

Figure 5: After recovery, high resolution images for every wavelength is available

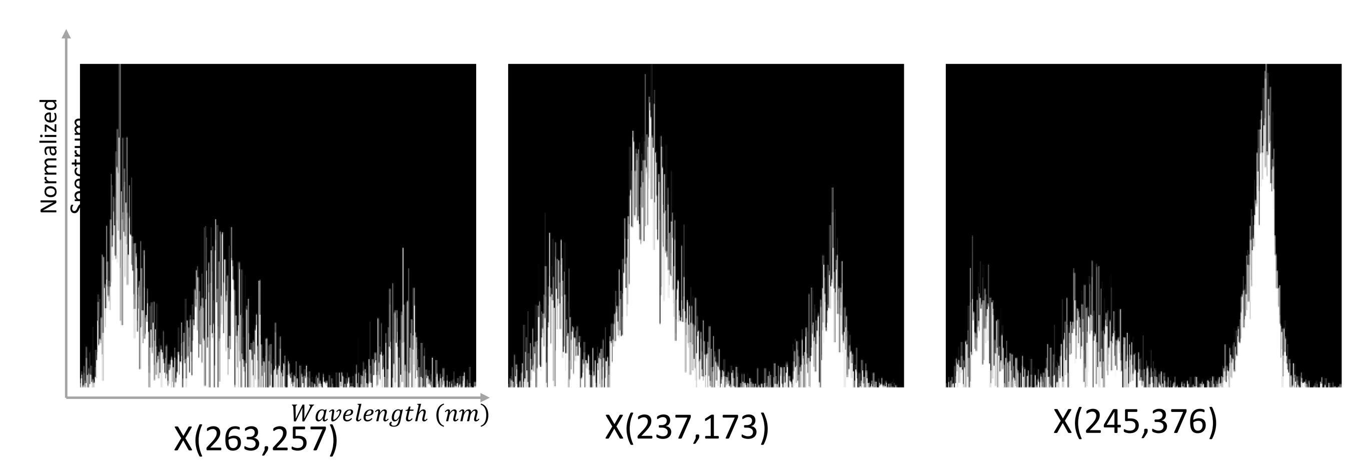

Figure 5: High resolution spectrum for every pixel

Figure 7. compares the speed of our parallel recovery algorithm implementation on a Xenon E5-2609 CPU and a Quadro K4000 GPU. As it can be seen, GPU implementation achieves more than 2x speed up.

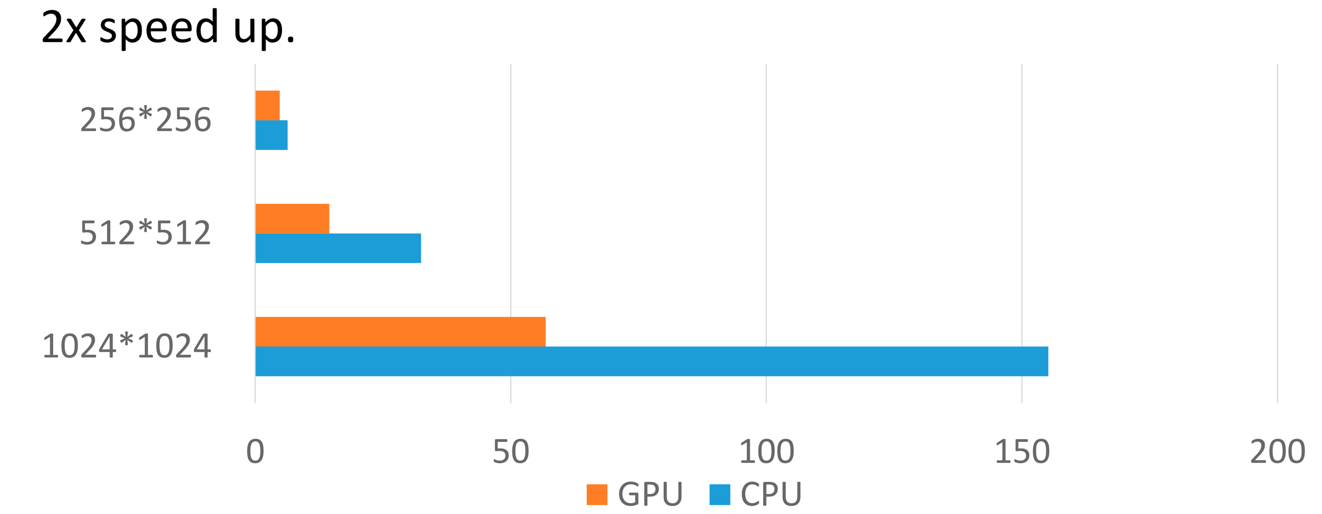

Figure 7: run time comparison of CPU and GPU implementations of parallel recovery algorithm for images with different resolutions