Compressed Sensing Imaging via Beam Scanning

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Abstract: We propose a new imaging scheme of compressed sensing by scanning an illumination pattern on the object. Comparing with conventional single-pixel cameras, we expect a >50x increase in imaging speed with similar imaging quality. © 2020 The Author(s)

1. Introduction

Imaging through compressed sensing method [1, 2] has gained significant interest in recent years due to its highly efficient sampling scheme, which enables high speed imaging by using a single pixel detector [3, 4]. In single pixel cameras, the object is measured through a series of spatially known illumination patterns [typically via a digital mirror device (DMD)], and a single pixel detector is used to collect and integrate all the signal from the object (Fig. 1a). To reconstruct the image, a sizeable number of patterns are required, which limits the imaging frame rate. In this paper, we present a new compressed sensing modality which can significantly increase the imaging speed. We use a single pattern and project it onto a small subset of the object, and then scan the pattern on the object. We utilize a single pixel detector to sequentially collect the signal from different scanning positions (Fig. 1c). There are multiple advantages of this new method. (1) The imaging speed significantly increases, since it takes much less time to scan over the entire object than switching different patterns in a DMD. (2) Unlike the single pixel camera case where the patterns are typically binary, our scheme utilizes a single pattern in small geometric size, making it much more feasible to use a gray-scale illumination pattern. This provides flexibility to the pattern design and improves the fidelity of the reconstructed image. (3) The high subsampling rate in scanning also makes this new approach outperform the point scanning imaging systems (Fig. 1b) in imaging speed. We present simulation results in this paper. We show that our method has a similar reconstruction quality as the conventional single-pixel camera, but with an expected >50x faster measurement time when using a typical galvo-resonant scanning system (256x256 image, 6.25% subsampling rate). This new imaging modality can be adapted to any imaging system based on beam scanning and will play an important role in high-throughput imaging applications such as 3D imaging and functional fluorescence microscopy.

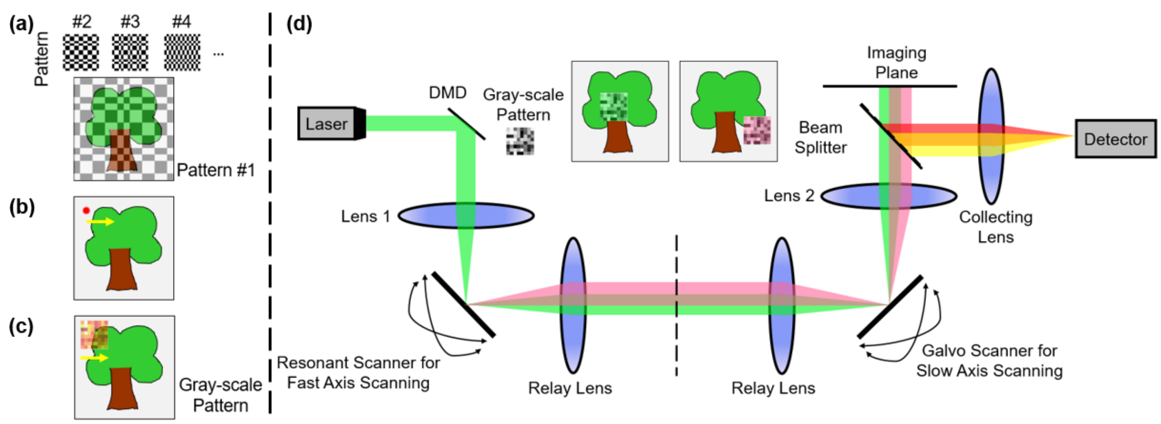

Fig. 1. Imaging methods using a single-pixel detector. (a) Conventional single-pixel cameras. (b) Point scanning. (c) Compressed sensing imaging through scanning pattern illumination. (d) Schematic of the compressed sensing imaging system using scanning pattern illumination.

2. Principle of compressed sensing through scanning pattern illumination

Our imaging modality features a mask to generate the illumination pattern and a set of scanning mirrors to scan the pattern across the object (Fig. 1d). To generate a gray-scale pattern, we use a DMD and bin multiple pixels into a super pixel. Light from a laser is first beam-expanded before it illuminates the DMD. A lens complex is used to transfer the pattern on the DMD into an intermediate image on the scanning mirrors. This intermediate image is then transferred to the sample plane with a second lens complex. With the galvo-resonant scanning system, the gray-scale pattern can be rapidly raster scanned across the object. The reflected light from the object can be collected by a single pixel detector. Once a single scan across the entire frame is completed (with the subsampling rate set by the scanner and data acquisition system), the image can be reconstructed by employing a total variation augmented Lagrangian solver (TVAL3) [5]. To improve the reconstruction quality, we further optimize the pattern by utilizing an iteratively optimized auto-encoder with samples from ImageNet for training and Set11 for testing [6].

3. Simulation results

We compare the result from our method with the conventional single pixel camera in simulation (Fig. 2). We use the optimal pattern learned by the auto-encoder algorithm for scanning and set the subsampling rate to be 6.25%, i.e. sampling 64x64=4096 scanning locations across an object with 256x256 full resolution in the scanning approach and using 4096 patterns in conventional single pixel camera case. TVAL3 is used for image reconstruction in both cases, giving rise to a PSNR of 23.26 dB and 23.45 dB in the scanning method and conventional single pixel camera method, respectively. While their imaging quality are similar, we expect a >50x increase of imaging speed in our method with a typical 8 kHz resonant scanner, comparing to the single pixel camera case using a 22 kHz high speed DMD.

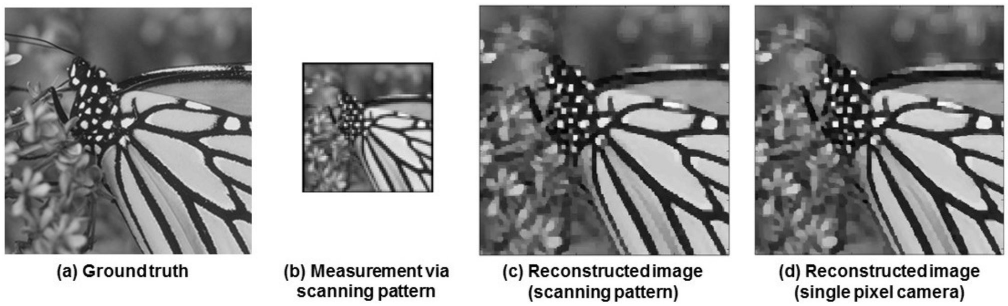

Fig. 2. (a) Ground true original object. (b) Measurement by scanning a gray-scale pattern with a subsampling rate of 6.25%. (c) Reconstruction result by TVAL3 via the scanning method. (d) Reconstruction result by TVAL3 via a conventional single pixel camera imaging approach.

For a specific subsampling rate, we study what is the optimized size of the pattern [Fig. 3(a)]. We find that the optimized size of the pattern is proportional to the subsampling stride and is slightly greater than the stride size, which is caused by the bandwidth of the gray-scale pattern and imaged object in frequency domain. We also compare the performance of our optimized pattern and an Airy disk [7], which is the point spread function (PSF) of a circular aperture. Our optimized pattern outperforms the Airy disk pattern overall [Fig. 3(b-c)].

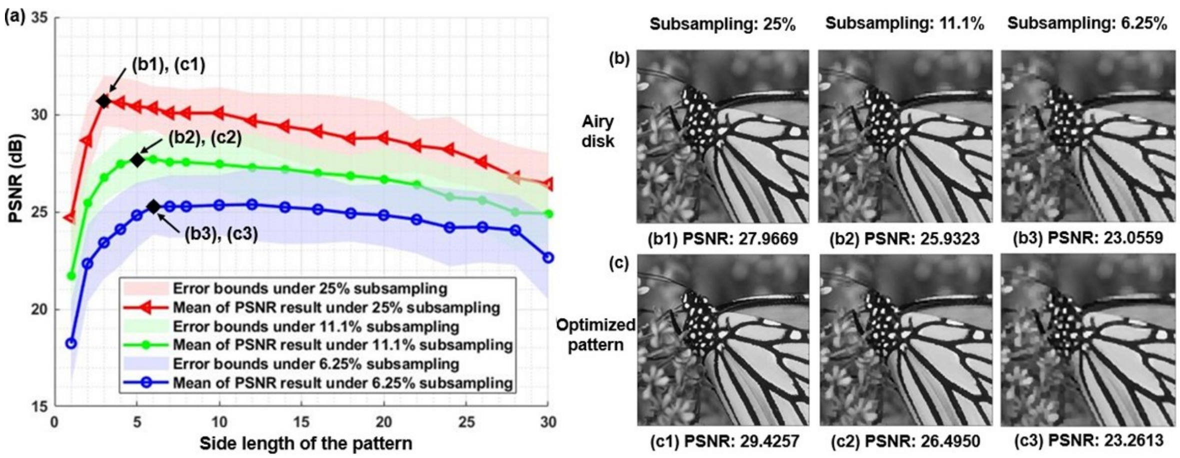

Fig. 3. (a) Comparison of PSNR for different pattern size in three subsampling rate conditions. (b) Reconstruction results when using Airy disk pattern. (c) Reconstruction results when using the optimized gray-scale pattern.

In summary, we present a new compressed imaging method by scanning an optimized gray-scale pattern on the object. This approach can significantly increase the image acquisition speed of compressed sensing (single pixel camera), while maintaining a high-quality reconstruction result.

4. Acknowledgement

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