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Li Song, Edmund Y. Lam, "Masked coherent diffractive imaging with ADMM-based phase retrieval," Proc. SPIE 12608, Biomedical Imaging and Sensing Conference, 126080B (20 September 2023); doi: 10.1117/12.3007506

Event: Optics and Photonics International Congress, 2023, Yokohama, Japan

Masked coherent diffractive imaging with ADMM-based phase retrieval

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ABSTRACT

The use of prior knowledge is important for effective phase retrieval in biological imaging using coherent light. We design a new algorithm based on alternating direction method of multipliers (ADMM), where physical constraints in the imaging system are used as prior knowledge. Experimental results where we apply the method on a masked coherent diffractive imaging (CDI) system show the efficiency of our algorithm.

Keywords: Phase retrieval, ADMM, CDI, physical constraints

1. INTRODUCTION

Nowadays, lensless imaging system is a popular topic in biological imaging, since it has the potential to lead to higher imaging resolution with a larger space–bandwidth product, compared with the general lens-based setup.[1] The light propagation step related to diffraction can encode the object information into the diffraction patterns in the far field.[2]

Among various lensless imaging systems, coherent diffractive imaging (CDI) is now widely used for micro-scale imaging, particularly in biomedical applications.[3] The setup is very simple. Coherent light can transmit through the object, then propagate to the far field. We can capture the far-field diffraction pattern, which is the modulus of the Fourier transform of the light field in the object plane.[4]

A computational step known as phase retrieval is then required to decode the diffraction pattern, and then we can obtain the images of the target objects, such as tissues or cells. Prior knowledge about the object is very important in various phase retrieval algorithms. In CDI, it is possible to incorporate some pre-designed components in the imaging setup, and they can be used as strong physical constraints in the algorithm design.[5] The augmented imaging system is often called masked CDI.

2. IMAGING SYSTEM AND ALGORITHM DESIGN

This section describes the masked CDI system and our phase retrieval algorithm based on alternating direction method of multipliers (ADMM).

2.1 Imaging system

In masked CDI, some pre-designed masks can be set in the CDI system. A typical setup is shown in Fig. 1. In this setup,[5,6] a dual pinhole mask is set near the object plane, such that the object plane is separated into a static area and a dynamic area. During the imaging process, the cells are in the dynamic area, whose information can be time-variant, but the static area is fixed, and we can know the size and location of the pinhole in advance. This kind of physical constraints can provide help to the phase retrieval algorithm design.

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Biomedical Imaging and Sensing Conference, edited by Toyohiko Yatagai, Proc. of SPIE Vol. 12608, 126080B · © 2023 SPIE · 0277-786X · doi: 10.1117/12.3007506

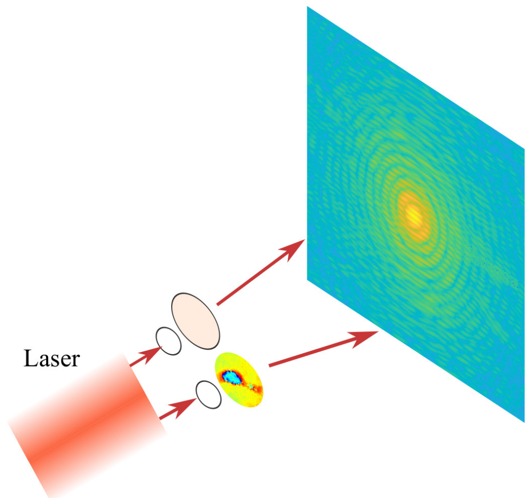


Figure 1. A typical masked CDI: the *in situ* CDI setup[5,6]

2.2 Algorithm design

Mathematically, the imaging system can be described as

$$\boldsymbol{y} = |FP(M_s\boldsymbol{r} + M_d\boldsymbol{x})|, \tag{1}$$

where $\boldsymbol{y}$ is the vectorized diffraction pattern, F is the discrete Fourier matrix, P is the probe matrix, M_s and M_d are the masks related to the static area and dynamic area, respectively, $\boldsymbol{r}$ is the reference pattern and $\boldsymbol{x}$ is the vectorized object image.

Since the problem is ill-posed, a regularization function $f(\boldsymbol{x})$ is required to find a proper one from all the possible solutions. Now the optimization problem is

$$\begin{array}{rl} \text{minimize} & f(\boldsymbol{x}) \\ \text{subject to} & \boldsymbol{y} = |FP(M_s\boldsymbol{r} + M_d\boldsymbol{x})|. \end{array} \tag{2}$$

Now it is a standard minimization problem and we can use ADMM[7] to solve this inverse problem. The regularization function is designed according to the structure tensor.[8] Finally we can find a solution with the simplest structure.

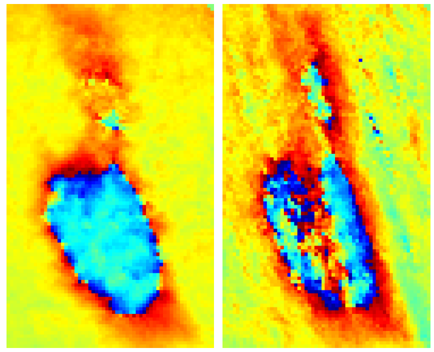
3. GLIOBLASTOMA EXPERIMENT

In this section, *in situ* CDI is adopted to monitor the status of glioblastoma cells. A 543 nm He-Ne laser with a 5 mW power is used to generate a collimated beam with a diameter of 800 µm. A dual pinhole aperture with two 100 µm circle holes spaced 100 µm apart is directly illuminated. One pinhole is placed in front of the cells and another pinhole is focused on the region without any cells. The illumination was incident onto the sample 400 µm downstream of the aperture. Objective lens with 35 mm focal length is placed just downstream of the cells. Finally a CCD detector with 1340×1300 pixel resolution and 20×20 µm pixel size is used to capture the images at the back focal plane of the lens. A 5×5 ptychographic scan is required for each image.

In the glioblastoma imaging experiment, the phase image shows the status of glioblastoma cells. We can clearly see in Fig. 2 that our result can show the shape of the cell clearly while the result from the baseline method[6] has much more noise.

4. CONCLUSIONS

In this study, we show that incorporating coded masks in the CDI system can help with the phase retrieval process. When designing phase retrieval algorithms, we can use prior knowledge embedded in the masks as strong physical constraints, leading to high-quality reconstruction results.



(a) (b)

Figure 2. Imaging results for the same diffraction pattern with different methods(phase reconstructions). (a) our method, (b) baseline method.[5]

Acknowledgement

The work is supported in part by the Research Grants Council of Hong Kong (GRF 17200321) and the University of Hong Kong (104006536).

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