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Phase retrieval with multiple sensor masks

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Abstract: Since single sensor mask may cause information lost during phase retrieval, we refer to the Monte Carlo method to design multiple binary sensor masks for one diffraction pattern, leading to the enhanced phase retrieval result.

1. Introduction

Coherent diffractive imaging (CDI) [1] is a powerful lensless imaging system that can achieve high imaging resolution. Coherent light transmits through the object, and the intensity of the light wave is captured in the far field. According to the Fraunhofer diffraction equation, the captured diffraction pattern is the squared Fourier modulus of the object.

Phase retrieval (PR) algorithms are required to reconstruct the image of the target object from the captured diffraction patterns. Prior knowledge is important to solve this ill-posed and non-convex inverse problem. Different properties of the target object, such as the support, size and shape, can be used as prior knowledge in conventional PR algorithms. With reference to the design of computational imaging systems, we can incorporate coded masks into the CDI system [2–4]. In this paper, based on the sensor mask design in [3], we use a group of binary masks generated by Monte Carlo method for one diffraction pattern, which can improve the quality of the phase retrieval results without capturing more diffraction patterns.

2. Method

When the resolution of the imaging sensor is high, the size of the diffraction pattern can be very large. If we solve the PR problem related to this diffraction pattern directly, the number of pixels whose phase information need to be retrieved will be large. Binary sensor masks can be incorporated to discard some of the pixels, then the scale of the PR problem is reduced [3].

The mathematical model for CDI with a sensor mask can be described as

$$z(\hat{x},\hat{y}) = |m(\hat{x},\hat{y})\mathscr{F}\{v(x,y)\}|, \tag{1}$$

where $z(\hat{x},\hat{y})$ is the masked diffraction pattern, $m(\hat{x},\hat{y})$ is the binary sensor mask, $\mathscr{F}$ is the oversampled Fourier transform, and $v(x,y)$ is the image of the target object. For one sensor mask, since some of the pixels are lost, they may not contribute to the final PR result. To solve this problem, we can use multiple binary sensor masks with the same sampling rate. When the number of the sensor masks is large enough, all the pixel values in the high-resolution diffraction patterns can be used in the PR process. With a similar notation, the mathematical model can be described as

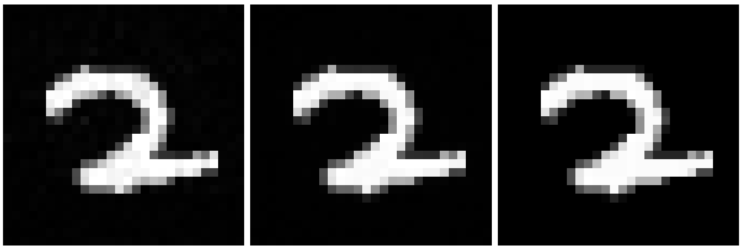
$$z_k(\hat{x},\hat{y}) = |m_k(\hat{x},\hat{y})\mathscr{F}\{v(x,y)\}|, \quad k = 1,2,\cdots,N, \tag{2}$$

where N is the number of sensor masks. For each mask $m_k(\hat{x},\hat{y})$, we can use the PR algorithm (Algorithm 1 in [3]) to do reconstruction based on $z_k(\hat{x},\hat{y})$ and obtain an estimation $\hat{v}_k(x,y)$, then we calculate the average of all the successful estimations and give the enhanced final result.

3. Results

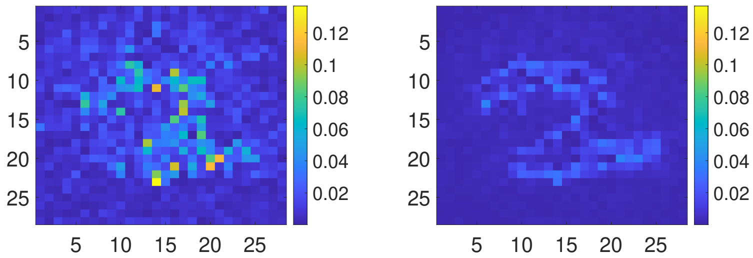
For numerical simulations, the ground truth image $v(x,y)$ comes from the MNIST dataset, whose size is 28×28. After the oversampled Fourier transform, the simulated diffraction pattern has 128×128 pixels. For the single-mask case, we refer to the setup from the conclusions in [3], where the sampling rate is set as 70%. For the multi-mask case, the same sampling rate is used. In this experiment, the number of sensor masks is set as 10. Since the selection of different sensor masks is independent, then for each pixel in the diffraction pattern, the probability that it is not selected by any sensor mask is 0.3^{10}, which is less than 10^{-5}.

Quantitative evaluations with the peak signal-to-noise ratio (PSNR) and structural similarity index metric (SSIM) are summarized in Table 1. Ten sensor masks are randomly generated, then we do phase retrieval



(a) Single sensor mask (b) Multiple sensor masks (c) Ground truth

Fig. 1. Visual results of different setups.



(a) Single sensor mask (b) Multiple sensor masks

Fig. 2. Difference maps between the results of these setups and the ground truth image.

and obtain 10 reconstruction results. For the single mask case, we calculate the PSNR and SSIM of all the 10 results respectively, then the average PSNR and SSIM are regarded as the quantitative results of this setup. For the multiple sensor masks setup, we calculate the mean image of the 10 reconstructions as the final result, then we calculate the PSNR and SSIM of the mean image for evaluation. Since parallel computing can be used for phase retrieval, these two setups require the same processing time. The proposed setup with multiple sensor masks can achieve higher PSNR and SSIM than the single mask setup.

Table 1. Quantitative evaluations of the PR results from different setups.

Setup	PSNR (dB)	SSIM
Single sensor mask	35.76	0.9472
Multiple sensor masks	**41.36**	**0.9631**

Some visual comparisons are shown in Fig. 1 and 2. We can see that the reconstruction result from our setup is more similar to the ground truth image than the original setup.

4. Conclusions

In this work, we propose a new CDI setup with multiple sensor masks generated by the Monte Carlo method. Numerical experiments show that this setup can achieve higher imaging quality than the original setup with only single sensor mask.

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