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Advanced Illumination Pattern in Fourier Ptychographic Microscopy

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Abstract: A quasi-circle structure based illumination design for Fourier Ptychographic Microscopy is presented. The number of required LEDs can be reduced by 50% while maintaining the same reconstruction performance compared to the conventional regular square structure.

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1. Introduction

FPM is a recently reported wide-field, high-resolution microscopy technique that attracts a lot of attention [1]. Its strategy is to illuminate the sample from different angle using LED array and capture a series of low resolution pictures sequentially. By stitching them iteratively in Fourier domain, a high-resolution complex field can be reconstructed. We propose an advanced illumination pattern to reduce the number of LEDs required during the capture, thus the imaging speed of FPM can be further improved.

To improve the performance of FPM, previous work can be roughly classified as two categories: systematic error correction, and data acquisition time reduction. For the first example, X. Ou in [2] and Z. Bian in [3] corrected the systematic error by reducing the influence of inaccurate pupil function estimation and the illumination intensity fluctuation. For the second category, L. Bian *et al.* [5] applied a content adaptive method which only illuminated the most informative parts of the spectrum, and saved 30% - 60% of the data acquisition time. In [6], Y. Zhang *et al.* proposed a self-learning based strategy which used a low resolution image of normal illumination angle to determine the importance of each part and only exposed the selective angles, saving 70% time compared to the conventional strategy. The limitation of these two methods is that they require prior knowledge of the sample.

In this paper, we propose an advanced LED pattern to accelerate the process of image acquisition in FPM. We redesign the regular square LED panel using a quasi-circle structure as shown in Fig.1. This method does not require any information of the sample beforehand to achieve a high-efficient data acquisition. Moreover, high-quality image reconstruction demands to maintain a steady field illumination intensity for different images. In our design, it is easier to control the exposure time for each LED, since all the LEDs at a specific radial position have the same illumination intensity to the sample with the same exposure time. The number of required LEDs in our numerical FPM simulations can be reduced by 50% with the same reconstruction RMSE, as compared to the conventional structure.

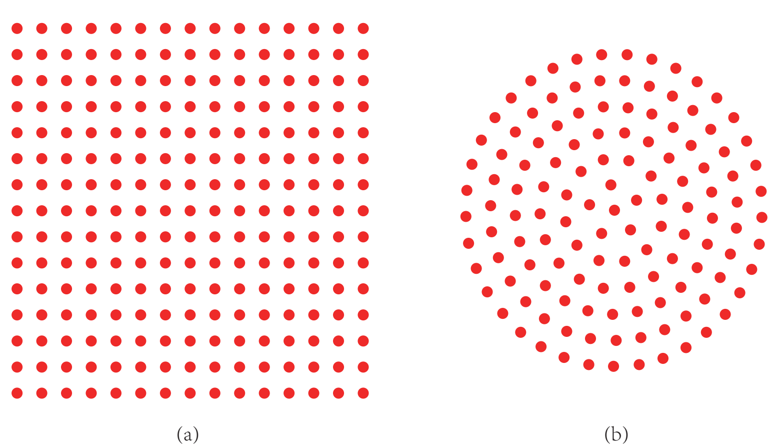

Fig. 1. The structure of the LED panel. (a) The conventional array structure with 225 LEDs; (b) The optimized quasi-circle structure with 129 LEDs

2. Illumination Strategy

In FPM, there are two main factors that influence the quality of the reconstruction: the overlap between adjacent LED illumination and the total area that all the LEDs cover in Fourier space. They are determined by the distance of adjacent LEDs and the largest incident angle in the system, respectively. With a certain number of LEDs, it is obvious that the more area covered in Fourier domain, the higher the reconstruction resolution will be. However, the overlapped area between adjacent LEDs should be large enough, otherwise they will be independen leading to a bad reconstruction performance. Clearly there is a tradeoff in LED distribution design.

Without any prior knowledge, we propose a quasi-circle LED structure for general use. The LED pattern consists of a series of concentric circles. In each circle, the LEDs are placed evenly. Following is our detailed method to optimize the distribution of these LEDs in the abovementioned structure:

Firstly, we need to determine the radius of each circle. According to [7], the more overlap in the adjacent LEDs, the more accurate the reconstruction result will be, and a ratio of 35% is necessary for a successful reconstruction. We choose 56% as a safe overlap ratio, since the RMSE tends to be stable in our model when the overlap ratio is larger than 30%. We set the distance corresponding to this ratio as the radius r of the first circle. Then the radius of other circles are $2r$, $3r\cdots$, successively.

Since LEDs cannot be too close in a real system, we set a clearance between any adjacent LEDs in our model. According to the size of the LED panel and the given clearance, we can determine the number of circles and the number of LEDs in each circle, respectively. Then we arrange the LEDs from inside to outside. For each circle, the LEDs are positioned evenly. The rotation angle of the outer circle is optimized to maximize the overlapped area between current circle and all the inside circle.

After these procedures, an optimized LED panel structure will be obtained, as shown in Fig.1.

(a) (b) (c)

Fig. 2. The simulation of the reconstruction (a) The origin low resolution image; (b) The construction image of conventional strategy (225 LEDs); (c) The construction image of optimized strategy (129 LEDs)

3. Simulation Result

In this section, we validate our model by experimenting on different input pictures and comparing the RMSE (normalized) of the reconstruction between our structure and the conventional one. We use the same reconstruction algorithm as proposed in [1]. The reconstruction result of one image is shown in Fig.2.

Picture	Boat	Terrace	Elaine	Lena
RMSE of conventional structure(225 LEDs)	0.0405	0.0362	0.0483	0.0122
RMSE of optimized structure(129 LEDs)	0.0152	0.0266	0.0154	0.0099

Table 1. the RMSE comparison between conventional structure and the optimized structure in vary images

In our simulation setup, we downsample the origin image at a ratio of $1/6$ as the input low-resolution image. The number of iteration in the reconstruction algorithm is 5. Table1 shows that we can achieve the same reconstruction performance by only using half of the LEDs compared to the conventional structure. Fig.3 demonstrates that the RMSE in our design is much lower than the conventional one with the same number of LEDs. Since the reconstruction RMSE is reduced, more detail of the image can be observed.

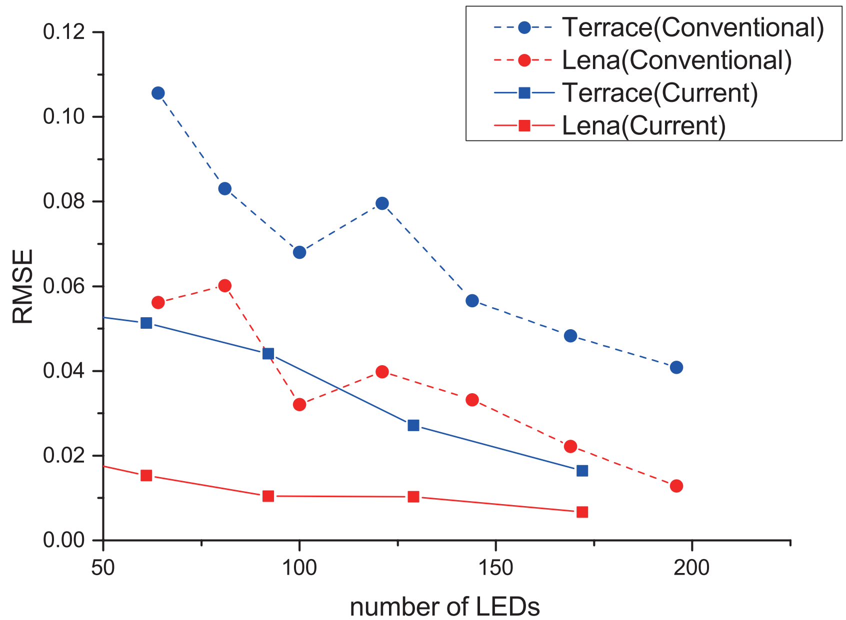

Fig. 3. The comparison between conventional structure and the optimized structure in vary images. The dashed lines represent the conventional structure and the solid lines represent our quasi-circle structure

4. Discussion

In this paper, we replace the convention regular square LED structure with our quasi-circle one in FPM systems. As the number of required LEDs is reduced by half, the imaging speed of FPM can be improved dramatically. Furthermore, our proposed system has the potential for a better reconstruction performance since it is easier to achieve constant intensity for each LED illumination. In future, we would like to build an LED panel as proposed, accelerate FPM acquisition in real experiments.

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