Zernike basis single-pixel imaging

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INTRODUCTION & AIM

Building upon the experimental verification of the imaging efficiency of the Fourier Single-Pixel Imaging with Compressed Sensing (SPI-CSS) system, this discussion focuses on the implementation of Single-Pixel Imaging using Zernike moments as orthogonal bases (P-SPI). In this scheme, the modulated light field must satisfy the Zernike polynomials. By repeating the steps of the Fourier single-pixel imaging experiment to record light intensity, an iterative summation is performed by multiplying the Zernike polynomials with the Zernike moments to reconstruct the target image. Experimental results demonstrate that P-SPI can also effectively reconstruct images at low sampling rates. Furthermore, compared to F-SPI, P-SPI exhibits superior robustness against background noise within the SPI-CSS framework, an advantage that extends the applicability of P-SPI in complex environments. The principle of image reconstruction is as follows.

$$A_{nm} = \frac{n+1}{\pi}\int_0^{2\pi}\int_0^1 Z_{nm}^*(r,\theta) f(r,\theta) r d\theta dr$$

$$I_{nm} = \iint f(x,y)\cdot P_{nm}(x,y)dxdy$$

$$P_{nm}(x,y) = P_{nm}(r,\theta) = \begin{cases} R_{nm}(r)\cos(m\theta)\; m \geq 0 \\ R_{nm}(r)\sin(m\theta)\; m < 0 \end{cases}$$

$$f_{re}(x,y) = \sum_n [\frac{2(n+1)}{\pi}(\sum_{m>0} I_{nm}P_{nm}(r,\theta) - \sum_{m<0} I_{nm}P_{nm}(r,\theta) + \frac{I_{n0}}{2}P_{n0}(r,\theta))]$$

METHOD

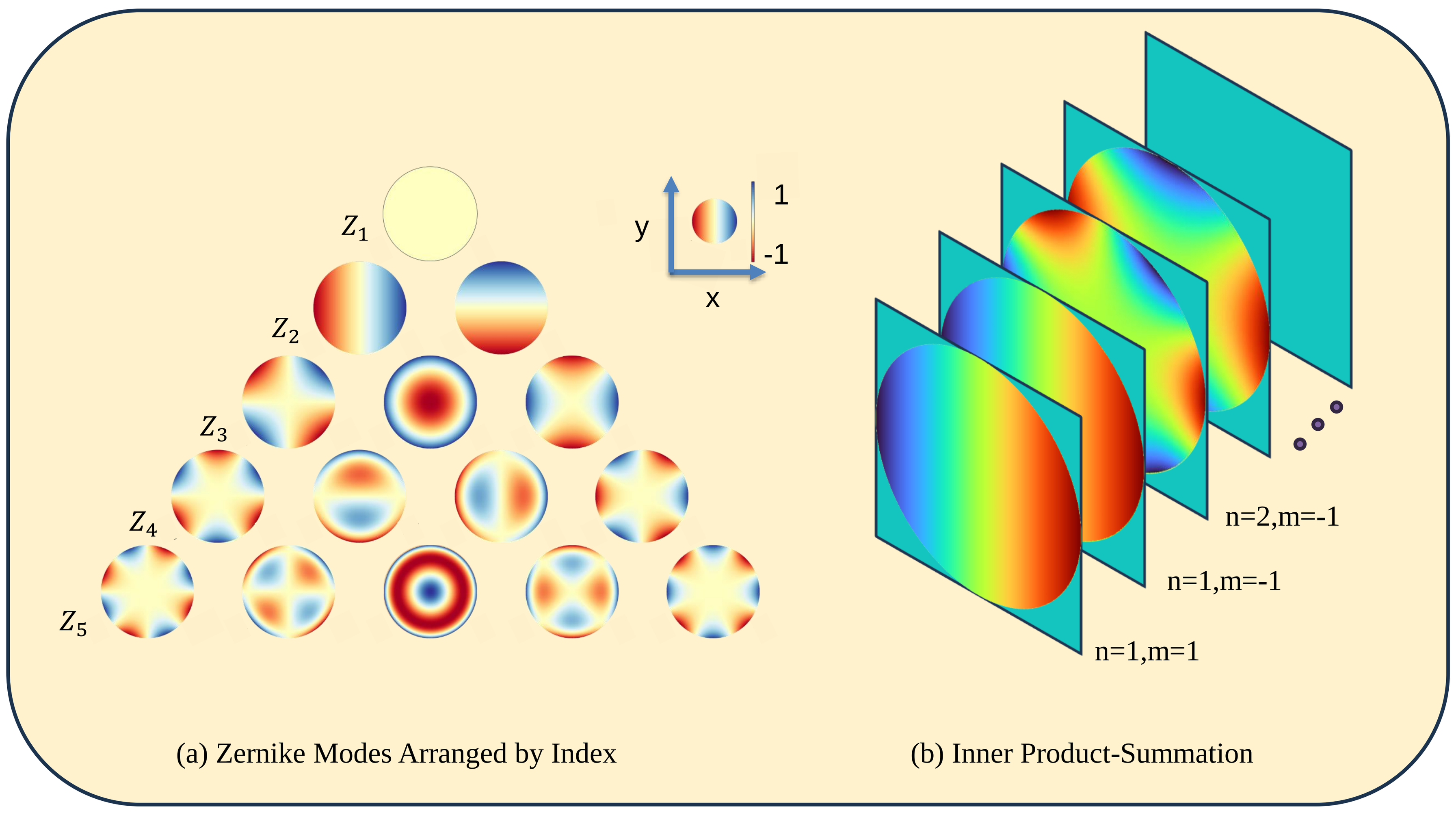

Figure1 Zernike mode and linear superposition

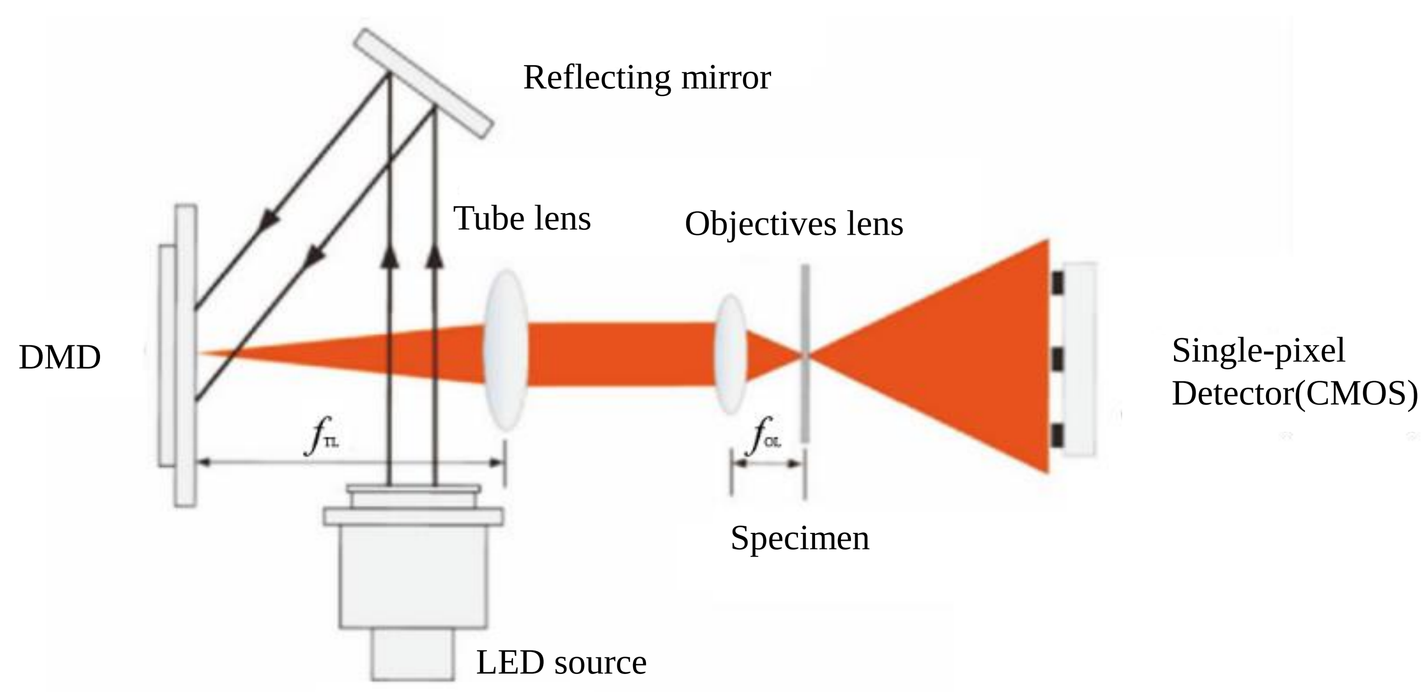

Figure2 Simulation Diagram of Experimental Apparatus

An LED light source is used to reflect onto the Digital Micromirror Device (DMD), thereby modulating the Zernike mode light field. This modulated light is then focused onto the focal plane where the sample is located by the optical setup. Subsequently, a single-pixel detector records the light intensity. Finally, the object image is reconstructed through a linear superposition of the inner product of the light intensity weights and the mode patterns.

RESULTS & DISCUSSION

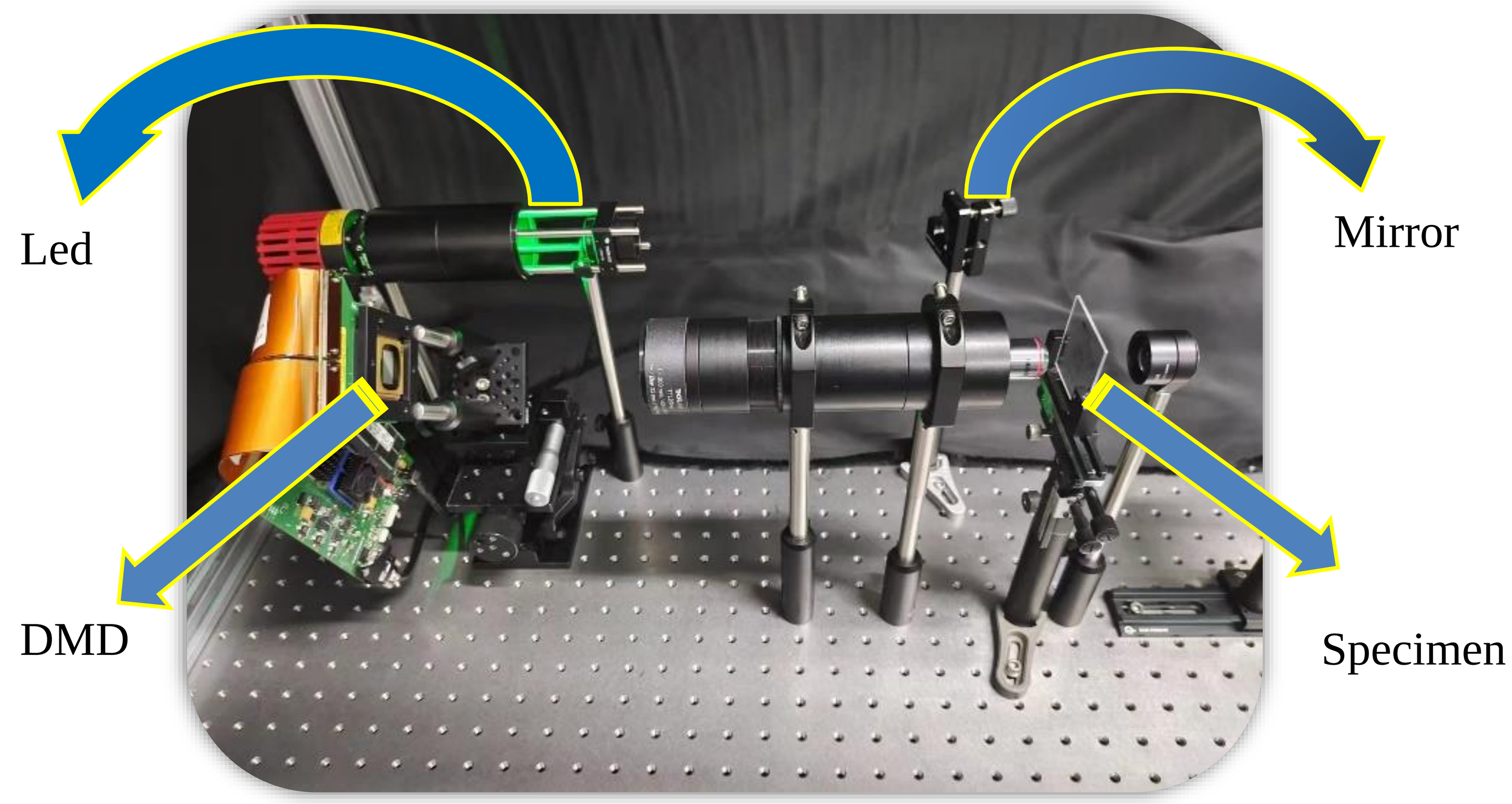

Figure3 Experimental setup diagram

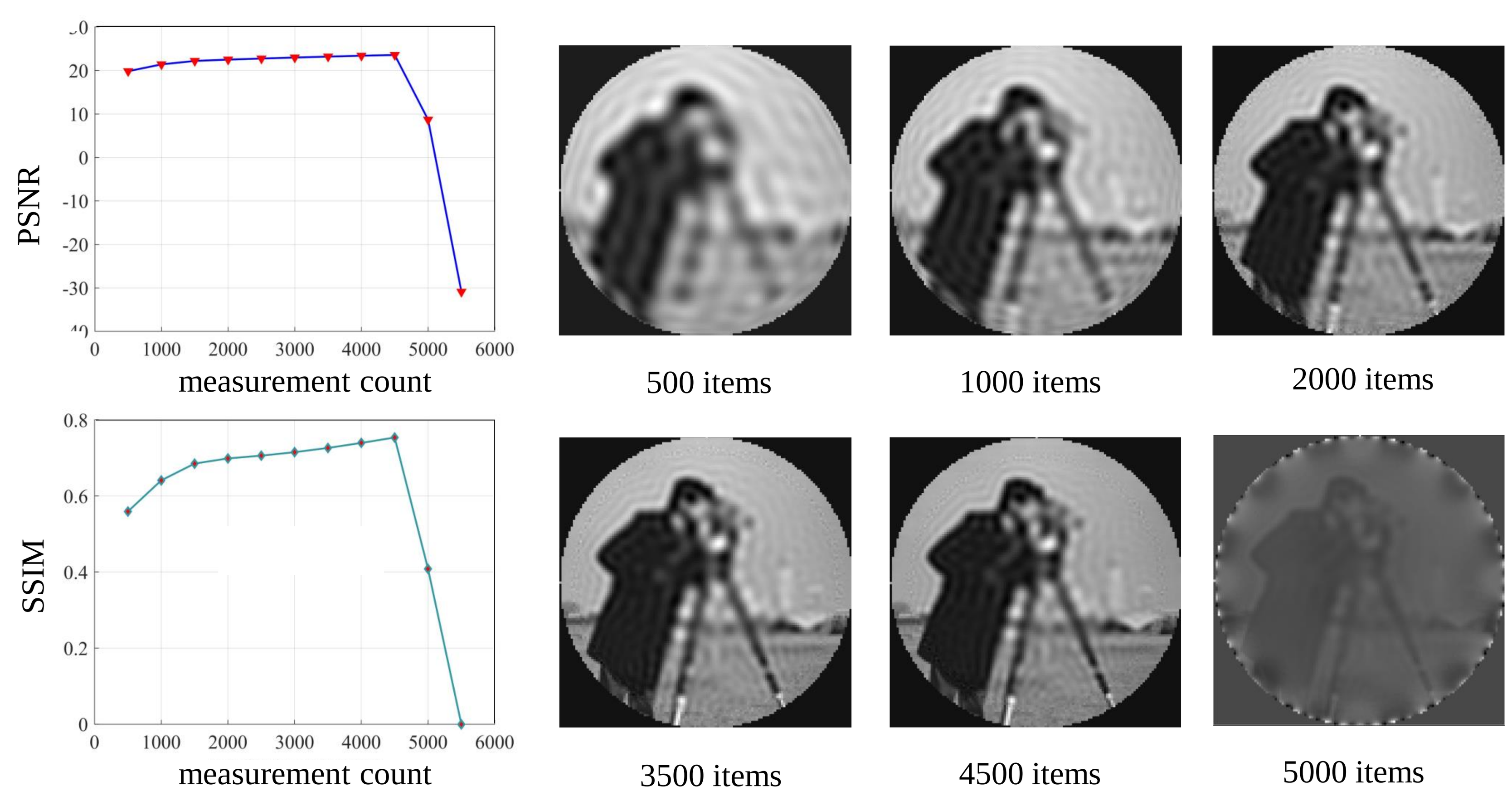

Figure3 Zernike Single-Pixel Imaging Simulation Diagram

The number of samples increases from 500 to 5500. We can observe that when the number of samples increases from 500 to 4500, the reconstructed image becomes clearer. However, when the sampling ratio exceeds 4500, the edges of the reconstructed image become blurred. The area of blurriness increases as the number of samples further increases. This is because high-order Zernike polynomials lose precision in discrete coordinates, especially on the edge area of the unit circle. As the number of samples increases, the numerical error in the reconstructed image also increases.

When the number of samples increases from 500 to 5500, the root mean square error decreases. After 5000, when the number of samples further increases, the root mean square error increases rapidly.

CONCLUSION

In our simulation experiments, we introduced SSIM and PSNR functions to evaluate the quality of the reconstructed images, which indicates that the Zernike function is only applied under the condition of low-order mode value illumination. There exists an optimal sampling value on Z-SPI where the quality of the reconstructed image is the best.

FUTURE WORK / REFERENCES

Compressed Sensing-Zernike Single-Pixel Imaging will be introduced, which further randomly selects low sampling modes, and the imaging speed can reach the product application level.

References

1.A.Khotanzad and Y.H. Hong, “Invariant image recognition by Zernike moments,” IEEE Trans. Pattern Anal. Machine Intell. 12(5), 489-497(1990).
2.G. Huang, Y. Shuai, Y. Ji, et. al., Appl. Phys. Lett. 124, 111108, (2024).