Project Proposal: Neuro Nano-Optics-Based Bifocal Imaging

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1. Motivation and Background:

Visual depth sensors play a crucial role in various fields, ranging from medical diagnostics to autonomous vehicle navigation. However, existing imaging systems often face limitations in achieving both depth sensing and high-resolution color imaging simultaneously. Inspired by recent works in end-to-end optical design for differentiable cameras and displays, our project aims to develop a compact nano-optics-based bifocal depth sensing system. This system will leverage neural networks for joint optimization and differentiable nano-scatterer simulations to computationally model multicolor bifocal imaging systems with superior depth sensing and resolution capabilities.

2. Related Works:

Traditional imaging techniques through wavefront encoding [4] have been limited by the trade-off between depth-of-field and imaging performance. Recent advancements in meta-optics and computational imaging have shown promise in overcoming these limitations and provide further miniaturization. Current meta-optics can efficiently modulate the wavefront and polarization of light over a large bandwidth. Even though a single metalens is fundamentally limited by aberrations at large apertures and low f-numbers, recent work has shown that integrating a differentiable meta-optical image formation model with deconvolution algorithms in an end-to-end optimization model greatly improves the imaging performance of the meta-lens [1]. With such a framework, the physical structure of the meta-lens is modified in conjunction with a neural feature-based image reconstruction algorithm, which greatly improves the image quality. Our project builds upon these foundations to propose a novel neuro nano-optics-based approach for bifocal depth sensing.

3. Project Overview and Milestones:

Week 1: Neural Network Learning

- Learn about and reproduce the results of neural networks for end-to-end optimization with metasurfaces in [1].
- Understand differentiable nano-scatterer simulation techniques. We plan to keep the pre-calculated phase-to-structure/structure-to-phase parameters in [1] for this, at least for a start.
- Define/create the bifocal imaging system's training data and loss function based on previous works [2] and start to integrate this with the model in [1].

Week 2: Model Development and Training

- Develop the computational model for multicolor bifocal imaging with depth sensing. We may start with a single color for faster computation and compare it to the benchmark performance in [2].
- Train the neural network model on an end-to-end optimization process using the defined training objects and loss function.
- Evaluate the performance of the trained model on various depth imaging objects.

Week 3: Evaluation and Comparison

- Compare the imaging results with existing depth imaging techniques [4].
- Prepare the poster presentation and final project report.

4. References:

[1] Tseng, E., Colburn, S., Whitehead, J., Huang, L., Baek, S. H., Majumdar, A., & Heide, F. (2021). Neural nano-optics for high-quality thin lens imaging. Nature communications, 12(1), 6493.
[2] Guo, Q., Shi, Z., Huang, Y. W., Alexander, E., Qiu, C. W., Capasso, F., & Zickler, T. (2019). Compact single-shot metalens depth sensors inspired by eyes of jumping spiders. Proceedings of the National Academy of Sciences, 116(46), 22959-22965.
[3] Fan, Q., Xu, W., Hu, X., Zhu, W., Yue, T., Zhang, C., ... & Xu, T. (2022). Trilobite-inspired neural nanophotonic light-field camera with extreme depth-of-field. Nature communications, 13(1), 2130.
[4] Colburn, S., Zhan, A., & Majumdar, A. (2018). Metasurface optics for full-color computational imaging. Science advances, 4(2), eaar2114.
[5] Arbabi, A., & Faraon, A. (2023). Advances in optical metalenses. Nature Photonics, 17(1), 16-25.
[6] https://github.com/princeton-computational-imaging/SeeThroughObstructions