Bifocal Metalens for Depth Sensing

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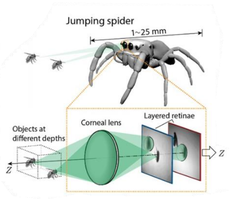
MOTIVATION

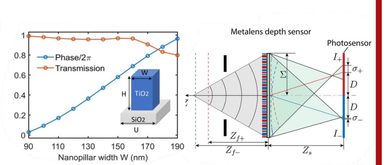
Achieving reliable depth perception poses a significant but essential challenge across various computational imaging domains. Absolute depth estimation from single images without priors is not possible. In the natural world, the jumping spider (Salticidae) utilizes multifocal layered retinae to capture multiple images of a single scene simultaneously. These images are then analyzed to gauge depth by leveraging the defocus cues present within them.

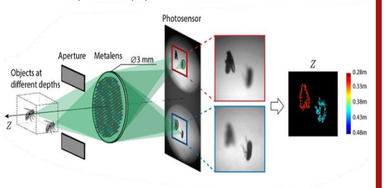


RELATED WORKS

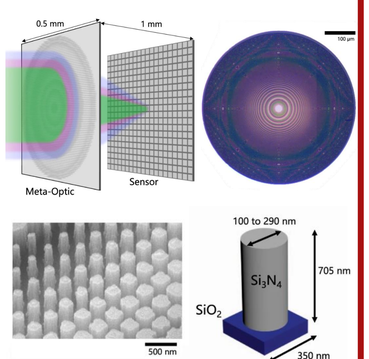
- Guo et al. proposed a metalens depth sensor with two interweaving phase profiles that creates two images of the same scene with different amounts of focus. [1]
- Depth is estimated from the degree of differential blurring:

$$Z = \left(\alpha + \beta \frac{\delta I}{\nabla^2 I}\right)^{-1}$$



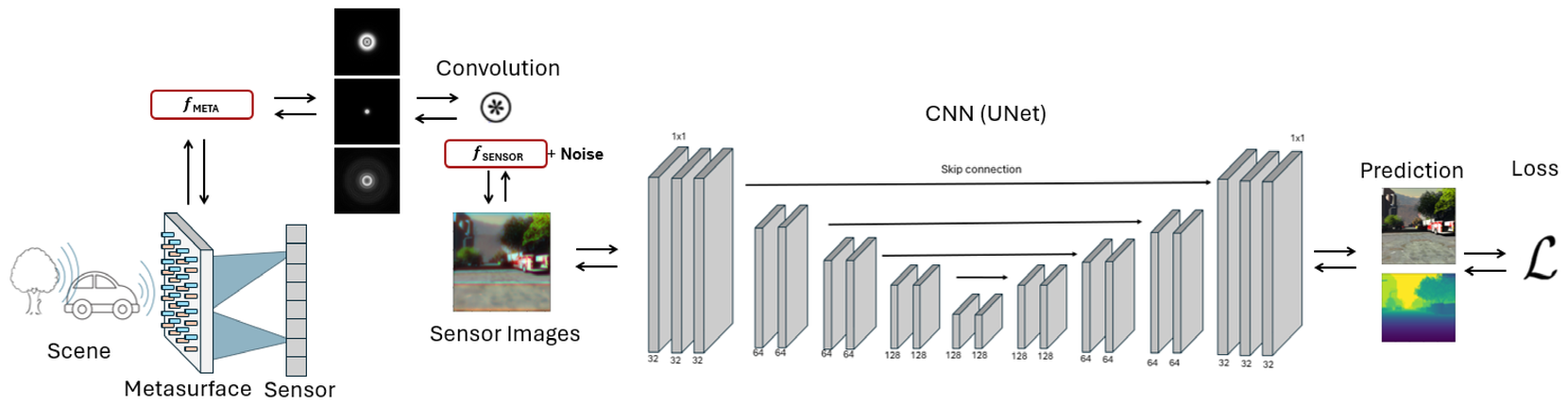


- Tseng et al. developed a fully differentiable neural network that allows for simultaneous learning of metasurface parameters with an image reconstruction algorithm. [2]



NETWORK ARCHITECTURE

$$PSF_z = f_{META}(z, \mathcal{P}_{META})$$



RESULTS

Metasurface parameterization

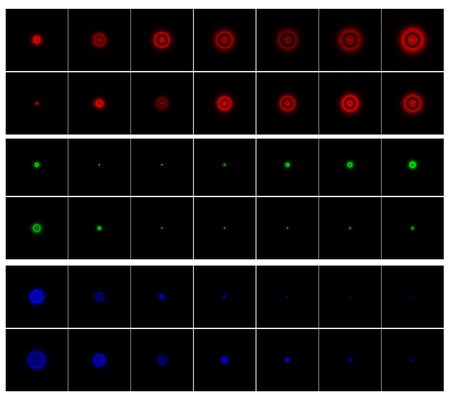
$$\phi(r) = \sum_{i=0}^{n} a_i \left(\frac{r}{R}\right)^{2i}$$

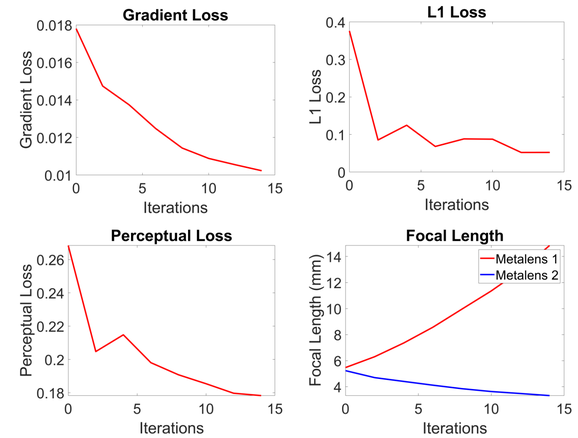
$$\mathcal{P}_{META} = \{a_i\}$$

Depth image formation model

$$\boldsymbol{o} = f_{UNET}(\mathcal{P}_{UNET}, f_{SENSOR}(\boldsymbol{I} * f_{META}(Z, \mathcal{P}_{META})), f_{META}(Z, \mathcal{P}_{META}))$$

$$PSF_z = f_{META}(z, \mathcal{P}_{META})$$





FUTURE WORK

Our future work will consist of implementing a spatially-varying PSF for more accurate large FOV imaging. In addition, the future model will accommodate shifted phase profiles for the two metasurfaces in order to realistically model the formation of two images on the sensor.

REFERENCES

[1] Guo, Qi, et al. *Proceedings of the National Academy of Sciences* 116.46 (2019): 22959-22965.

[2] Tseng, Ethan, et al. *Nature communications* 12.1 (2021): 6493

[3] Ikoma, Hayato, et al. *2021 IEEE International Conference on Computational Photography (ICCP)*. IEEE, 2021.