Mid-infrared nano-imaging : a neural network approach

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References

Framework

Metasurfaces

A metasurface is a two-dimensional, ultrathin material composed of **subwavelength** structures, which allows for the manipulation of the phase, polarization, and amplitude of light [1].

Inverse design in nanophotonics

Inverse design is a method where desired outputs and/or functionalities are specified first and based on them a design and/or structure is made. This technique is being applied in nanophotonic structures [2].

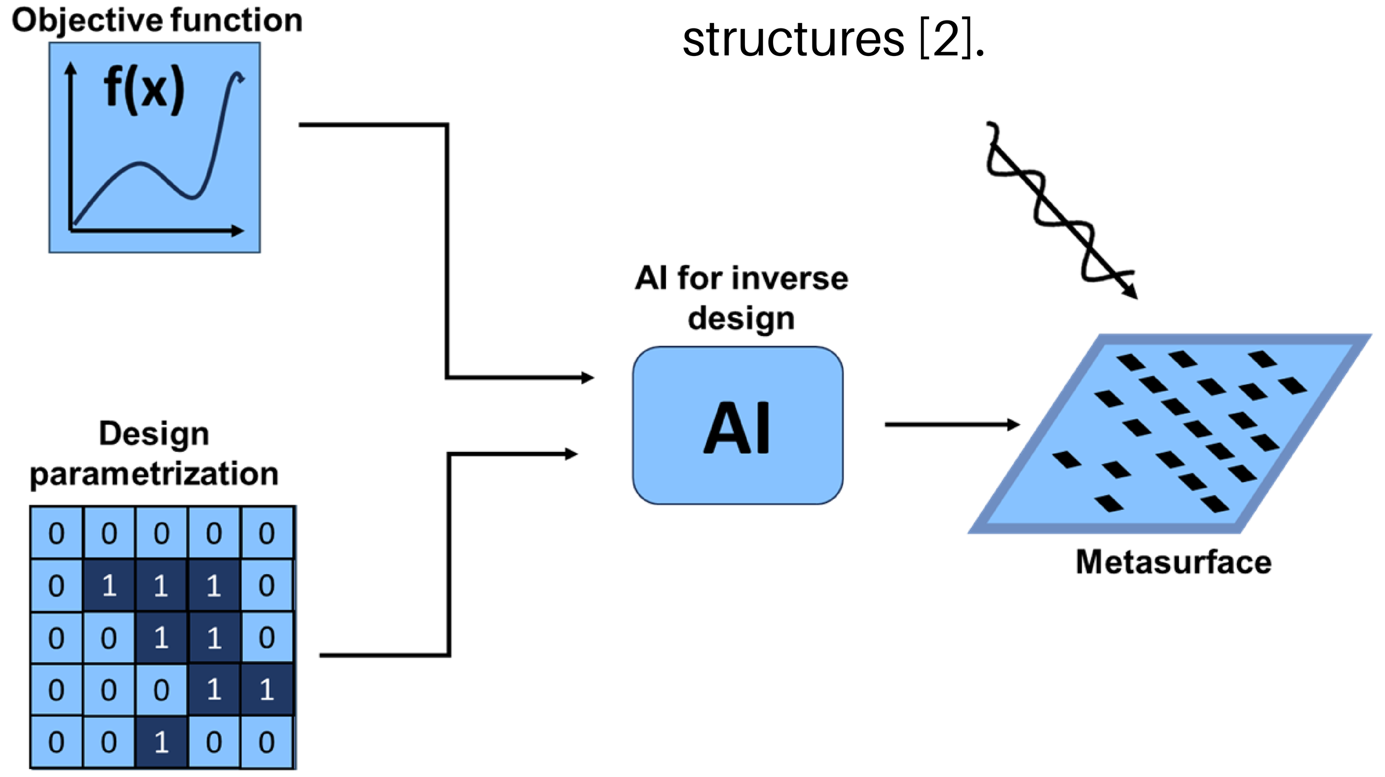

Figure 1. Representation of how a metasurface may be designed with inverse design [3].

The problem

Difficulties in the fabrication of ultra-compact mid-IR imaging systems

- Conventional optics require the use of many refractive elements, which are bulky and complicate the process of reducing the focal length.
- Aberrations in current metasurface imaging (wavelength).
- Other methods such as lens-less cameras and computational imaging have low spatial resolutions .

[4]

The solution

Inspired by *Neural nano-optics for high-quality thin lens imaging* [4] an end-to-end imager system is proposed. The system is mainly made up of two things:

- Optimized metasurface structure
- Neural feature-based reconstruction algorithm

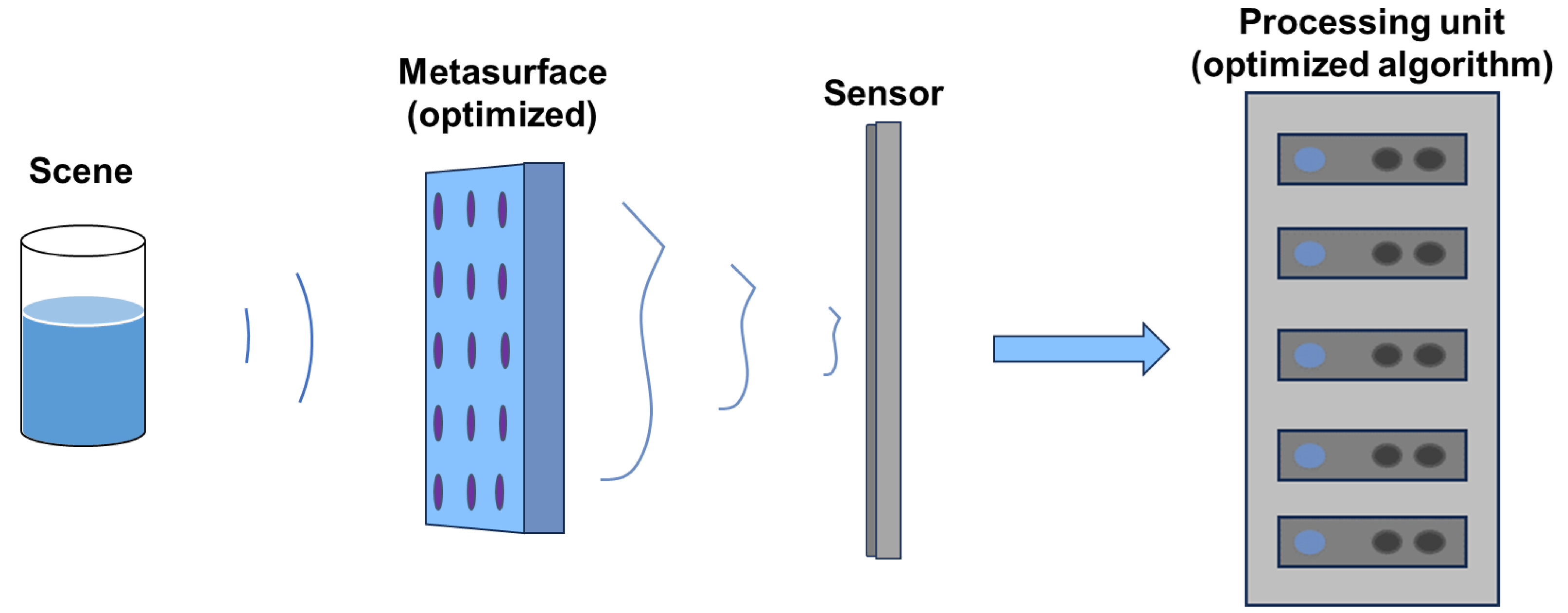

Figure 2. Representation of how the system can be implemented. Note that the elements that are proposed are the optimized metasurface and the optimized algorithm that works with the data acquired by a sensor.

How does it work?

The image formation model $\mathbf{O}^{(i)}$ can be described as a deconvolution function that is made of:

- Fully Convolutional Neural Networks (CNNs)
- A feature propagator that uses a deconvolution method

The problem can be expressed mathematically as:

$$\{\mathcal{P}^*_{\mathrm{META}}, \mathcal{P}^*_{\mathrm{DECONV}}\} = \underset{\mathcal{P}_{\mathrm{META}}, \mathcal{P}_{\mathrm{DECONV}}}{\arg\min} \sum_{i=1}^{M} \mathcal{L}(\mathbf{O}^{(i)}, \mathbf{I}^{(i)}).$$

Where $\mathcal{L}$ is the loss function, $\mathbf{O}^{(i)}$ is the image formation or the output of the model, $\mathbf{I}^{(i)}$ corresponds to an image, and $\{\mathcal{P}^*_{\mathrm{META}}, \mathcal{P}^*_{\mathrm{DECONV}}\}$ are the results [4].

This optimization problem can be solved with the following tools:

- Tensorflow
- First-order stochastic gradient optimization

Results

The obtained results are:

- Parameters that define the physical structure of a metasurface $\mathcal{P}^*_{\mathrm{META}}$
- Parameters of the algorithm (neural networks parameters, parameters of the feature propagator) $\mathcal{P}^*_{\mathrm{DECONV}}$

Note: With this information is possible to fabricate the metasurfaces and test their proficiency, as it is done in [4].

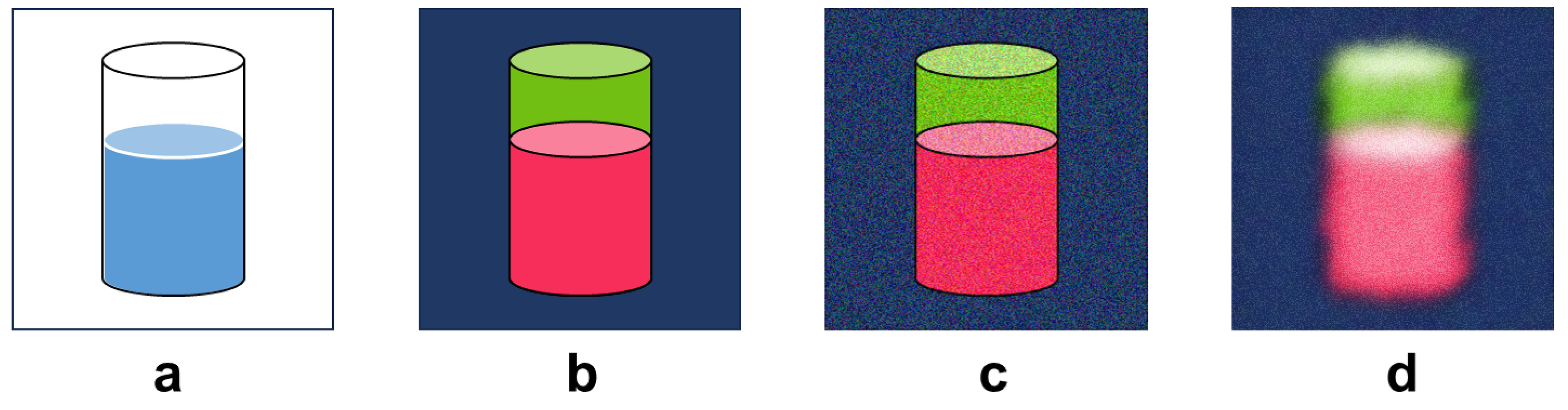

Figure 3. a) is a scene that you would see with your eyes (visible light). b) is what a high-quality regular size thermal camera would capture. c) is what is expected to be obtained if good values of the parameters are obtained. d) is what would be obtained if you used unoptimized parameters values.

Due to time constraints it was not possible to obtain results.

Future scope of the technology

Fabrication of ultra-compact mid-IR imagers can be helpful in the development of a variety of systems. Following are some examples of these systems and lists of possible applications.

Ultra-compact optical communication systems

Useful in:

- Space exploration
- Healthcare
- Optical computing
- Consumer electronics
- Wearable devices

Ultra-compact thermal imaging systems

Useful in:

- Medical diagnosis
- Building inspections
- industrial monitoring
- Military and law enforcement
- Wildfire research