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Image Reconstruction from Deep Diffractive Neural Network

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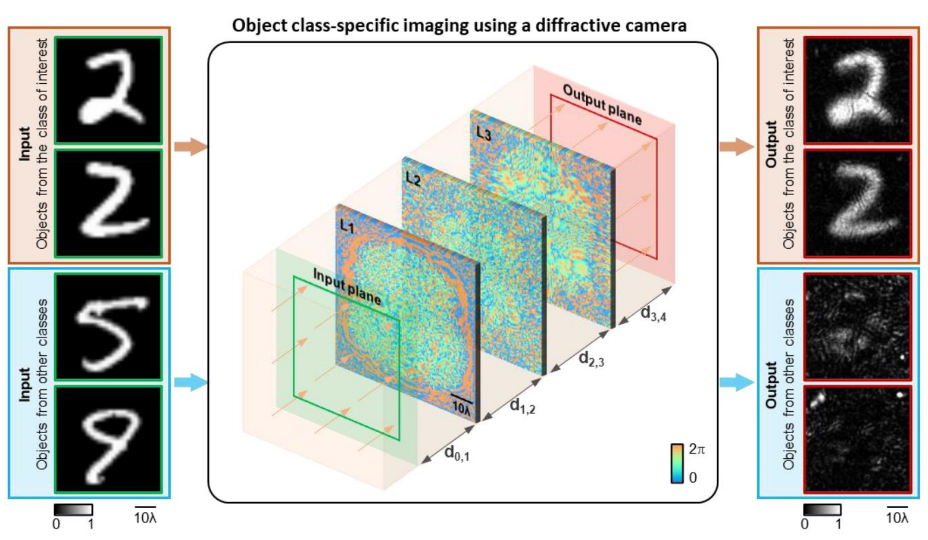
Introduction

- Privacy protection is a growing concern in the digital era, with machine vision techniques widely used throughout public and private settings. Existing methods address this growing problem by encrypting camera images or obscuring/blurring the imaged information through digital algorithms.
- A different approach, presented in [1], suggested a camera design that optically erase unwanted objects and images only wanted, 'target', objects. Thus, unwanted objects are not captured in the camera sensor. This camera, perform class-specific all-optical imaging, is built upon deep diffractive neural networks [2], a new deep optical computing framework.



Class-Specific Imaging using a diffractive camera [1]

Goals

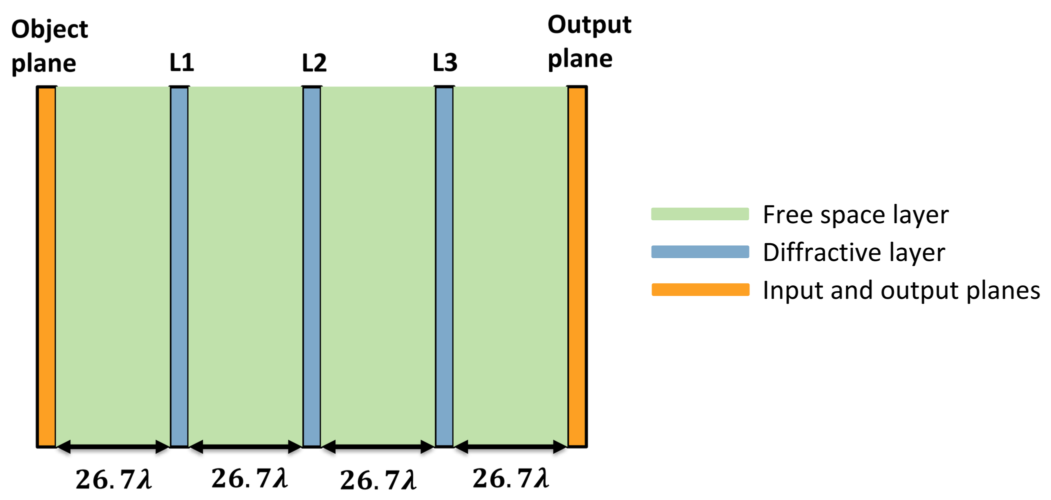
- Recover the lost information from the optical network output.
- Reconstruct an optically erased image using a neural network, thus validate if this camera design is robust to privacy attacks.

Deep Diffractive Optical Camera Design

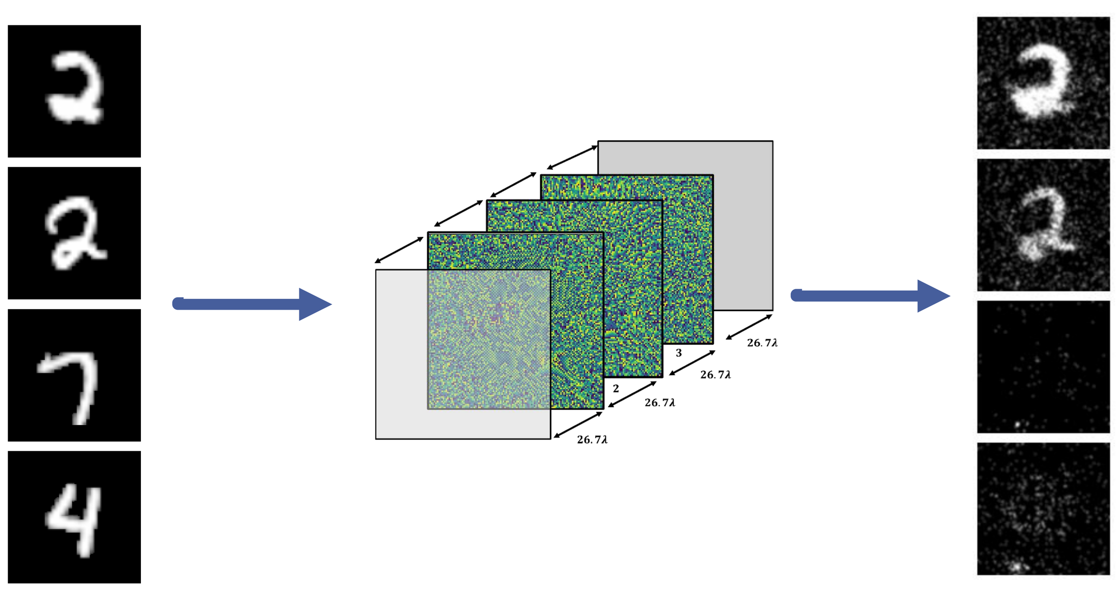
- The diffractive camera is built using deep diffractive neural network layers, which are free space propagation layers and diffractive, phase modulation, layers.
- **Free space propagation layer:**
  - Rayleigh-Sommerfeld transfer function:
    - $H(f_x, f_y) = \exp\left(jkz\sqrt{1-(\lambda f_x)^2-(\lambda f_y)^2}\right)$
  - Free space propagation operator:
    - $\mathbb{P}_{d_{l-1,l}}\left(u^l(x,y)\right) = \mathcal{F}^{-1}\{\mathcal{F}\{u^l(x,y)\}H(f_x,f_y;d)\}$
    - Where $u^l(x,y)$ is an electromagnetic field.
- **Diffractive layer:**
  - Phase modulation operator:
    - $t_l(x,y) = \exp\{j\phi_l(x,y)\}$
    - Where $\phi_l(x,y)$ is a learned phase function.
- Overall, the complex optical field at the output plane of N layers diffractive camera:
  - $o(x,y) = \mathbb{P}_{d_{N,N-1}}\left(\cdots\left(\mathbb{P}_{d_{0,1}}\left(u^0(x,y)\right)\cdot t_1(x,y)\cdot \ldots \cdot t_N(x,y)\right)\right)$
- The output image is created from the field intensity:
  - $I(x,y) = |o(x,y)|^2$

Diffractive Camera Design

- The given diffractive camera, suggested in [1], is built from three diffractive, phase modulation, layers and four free space propagation layers:



- Using the MNIST dataset and '2' as the target class, where all other digits are non target data classes, thus our goal is to optically erase them.

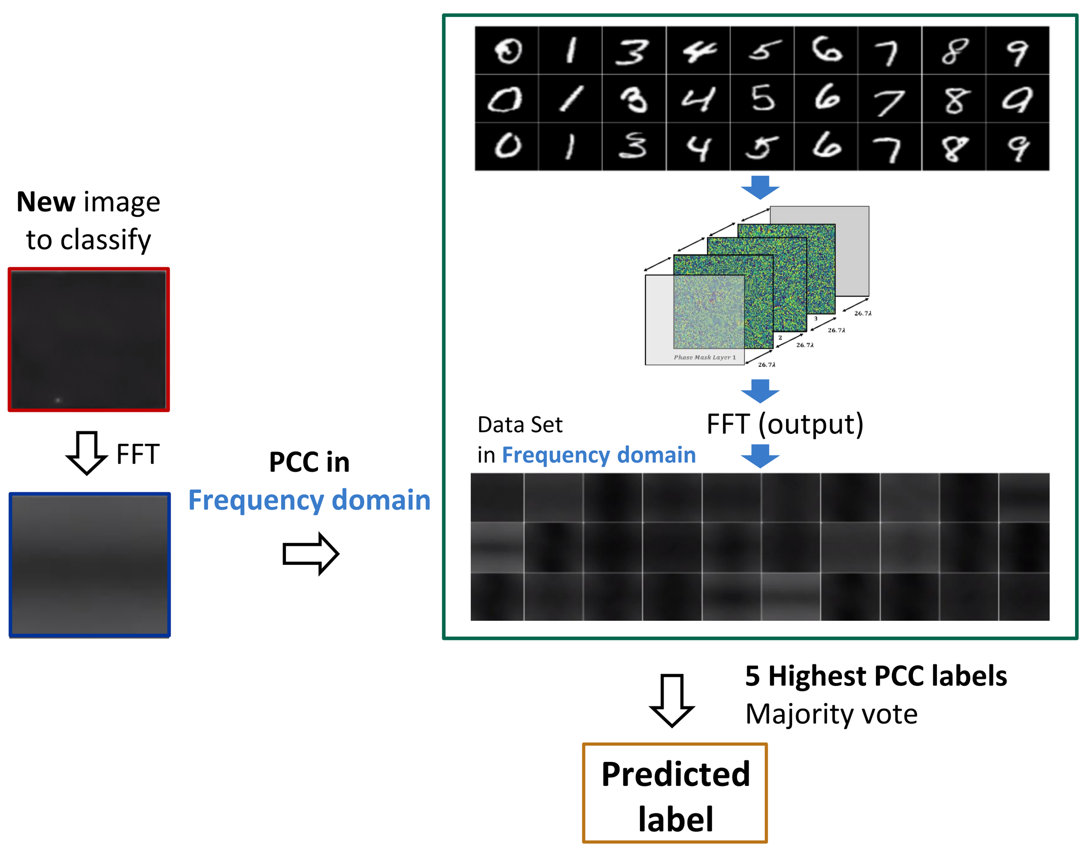


Input and output results of the diffractive camera

- Target class image has high fidelity, while non-target classes are optically erased resulting in noise-like output images.

Classification of Optically Erased Images

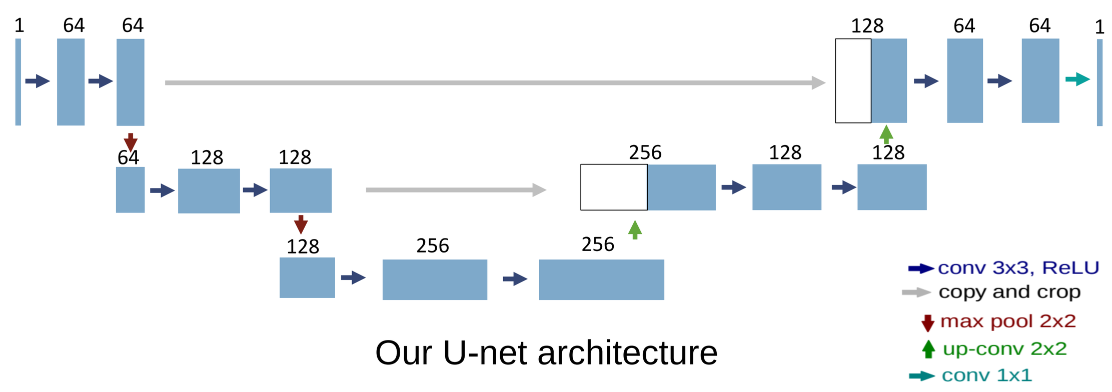
- Using MNIST images that were optically erased as a dataset, we wanted to classify a **new** optically erased image, validating that there is some information in these images.
- Classification using K-NN with Pearson's correlation coefficient (PCC) as a distance metric.
- Improved results using PCC on the real part of Fourier transform.
- Average accuracy of 94.2%.



- **There is information in the optically erased images!**

Image Reconstruction using U-net

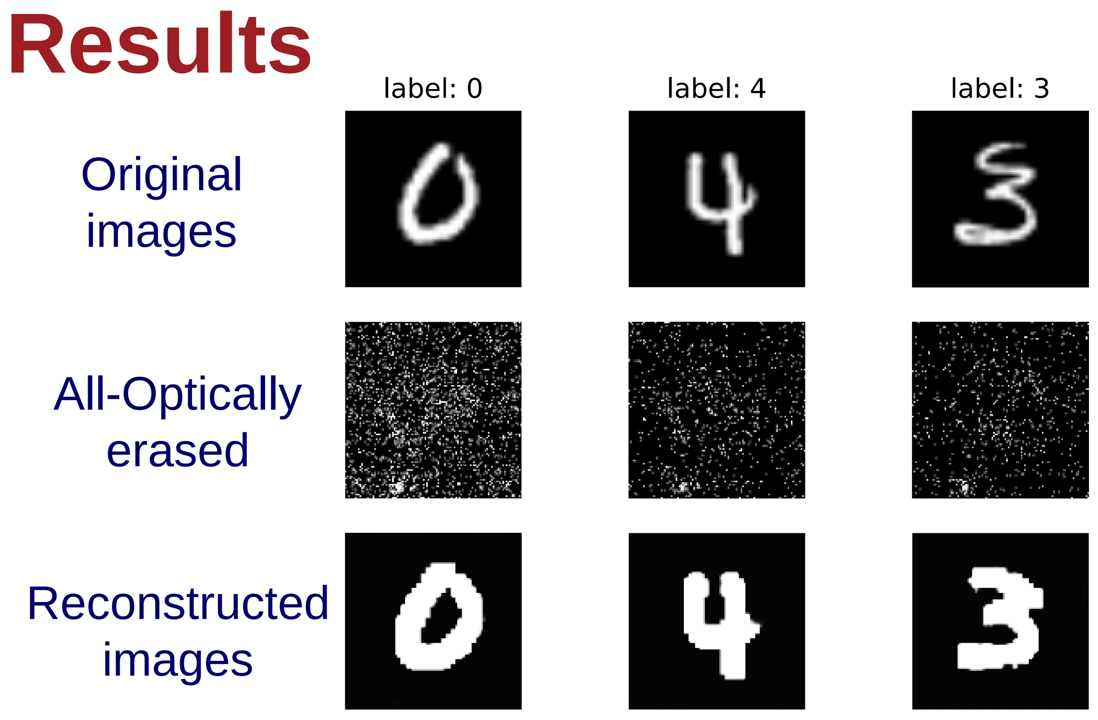
- After demonstrating that the optically erased images contain information, we wanted to reconstruct these images.
- We modified the U-net [3] architecture and used it to reconstruct the optically erased images.



Our U-net architecture

- We used Normalized MSE as a reconstruction objective, between the all-optically erased MNIST images and the ground truth images from the MNIST data set.

Results



Conclusions

- Successful classification of MNIST images from all-optical erased images using K-NN.
- Successful image reconstruction of MNIST images from all-optical erased images.
- **The optically erased images contain information!**
  The optical erasure of information can be reversed!

References

[1] Bai, B., Luo, Y., Gan, T., Hu, J., Li, Y., Zhao, Y., & Ozcan, A. "To image, or not to image: class-specific diffractive cameras with all-optical erasure of undesired objects." eLight, (2022).

[2] Lin, X., Rivenson, Y., Yardimci, N. T., Veli, M., Luo, Y., Jarrahi, M., & Ozcan, A, "All-optical machine learning using diffractive deep neural networks". Science, (2018).

[3] Ronneberger, O., Fischer, P., & Brox, T. "U-net: Convolutional networks for biomedical image segmentation." MICCAI, (2015).

Image-reconstruction-from-DDNN

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