Optical Neural Network

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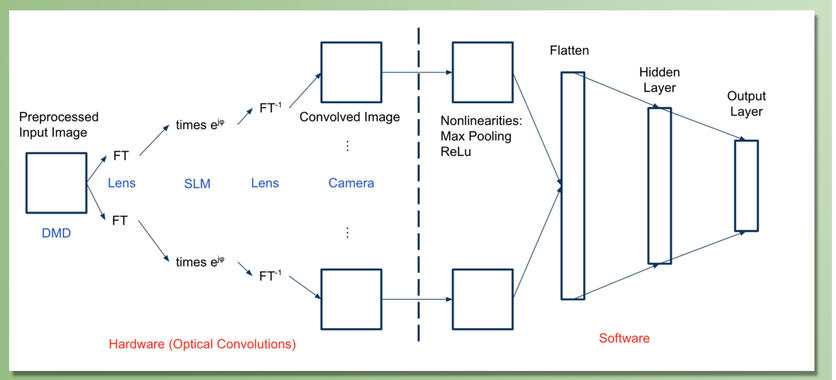
Background

GreeNN is an optical version of a convolutional neural network, designed with the goal of reducing the carbon footprint of image classification. Increasing the complexity of computations for image classification in traditional silicon based hardware is associated with a significant energy cost. The team's solution implements the most computationally intensive task in free space optics with high energy efficiency. Throughout the year, the concept has been tested on handwritten character images, showing potential for application on more sophisticated datasets.

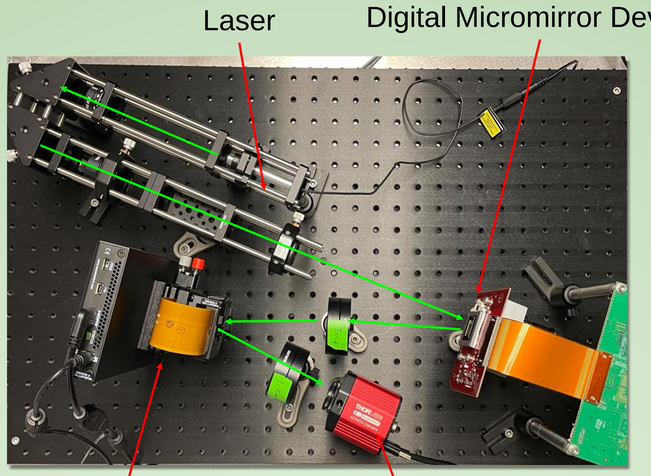
System Overview

- The system interfaces an expanded laser beam onto a digital micromirror device (DMD)
- The DMD encodes the image data and reflects it through a 2 focal length (2f) system, which transforms the information in the image into the spatial frequency domain
- With the image in the frequency domain, a spatial light modulator (SLM) applies a phase mask, which performs a convolution in order to extract desired information
- The modulated image is sent through another 2f system, before it is received by the camera in the spatial domain
- Lastly, the captured image is sent through the remaining layers of the neural network

System Block Diagram

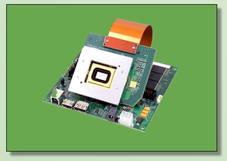


Optical Layout



Key Hardware Components

532 nm Laser Diode
The setup includes a 532 nm coherent green laser diode which is used as a light source.

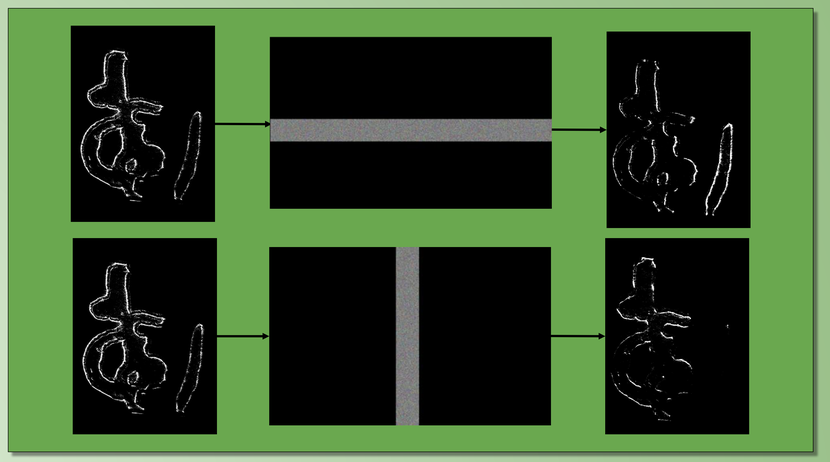


Digital Micromirror Device
The DMD encodes the 1920 x 1080 image to be classified onto the laser beam.

Spatial Light Modulator
The SLM applies a convolutional mask to the phase of the image. Its resolution is 1920 x 1200 and refresh rate is 60Hz.

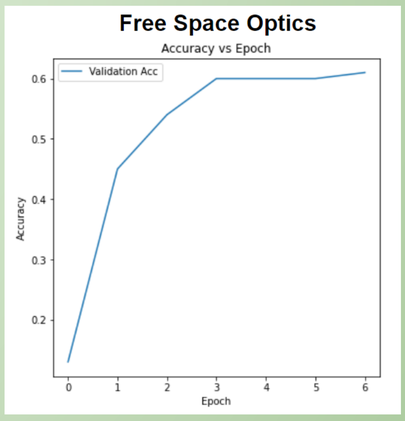
Scientific CMOS Camera
The sCMOS camera captures the convolved image at 165 frames per second with resolution 1920 x 1080.

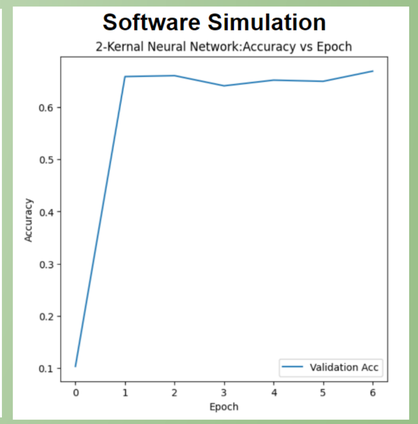
Optical Filtering



- Each phase mask applied at the SLM extracts certain features from the input image
- The figures above show the edge detection functionality of a vertical and horizontal filter on a character from the KMNIST handwritten Japanese character dataset

Accuracy Performance





- The figures above display the accuracy of classifying KMNIST images with the neural network integrated with free space optics (two optical filters on the SLM) and the simulated neural network in software (2-kernel convolution)
- The accuracy after six epochs with the free space optics is about 63%, which is comparable to the simulated software result

Acknowledgements
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