Development of a Micro-Camera Array for Neural Imaging

Pratt Fellow: Eric Wahlstedt

BME Advisor: Dr. Roarke Horstmeyer

Motivation for Research Project

- The mouse is one of the most widely used models for studying mammalian neuronal circuits [2]
- In order to precisely identify neural circuits associated with certain behaviors, a head-fixation method is often used
- In this method, the skull of the mouse is surgically exposed, and the mouse is temporarily fixated to a device where imaging can occur [2]

Figure 1: A head-fixated mouse in a caddy [2]

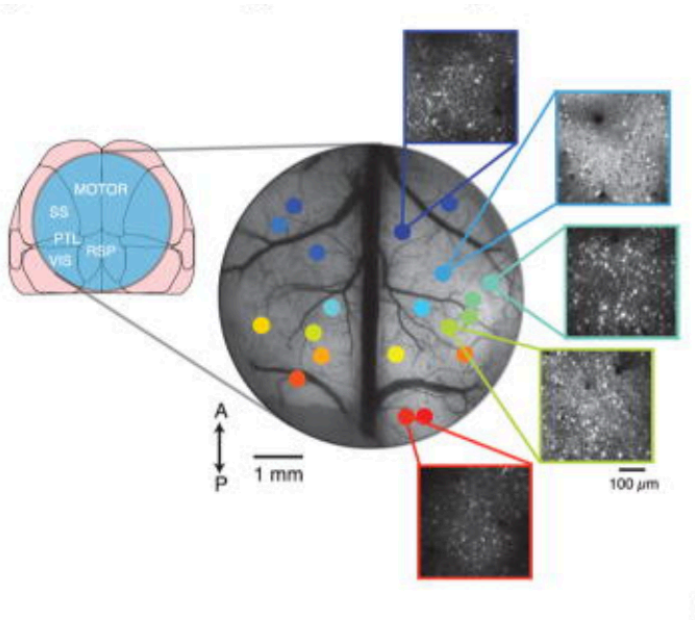


Figure 2: Wide-field fluorescent imaging through a 7 mm window in the dorsal cortex [1]

Motivation for Research Project

- Researchers seeking to image brain activity in mice as they move about, socialize, and perform complex tasks cannot use the head-fixation method
- Hardware, like the mounted miniaturized light-field microscope (MiniLFM), allows for neural activity to be recorded as the mice move around [4]
- These devices are often hindered by a small field of view (MiniLFM FOV is $700 \times 600 \times 360\ \mu m^3$) [4]

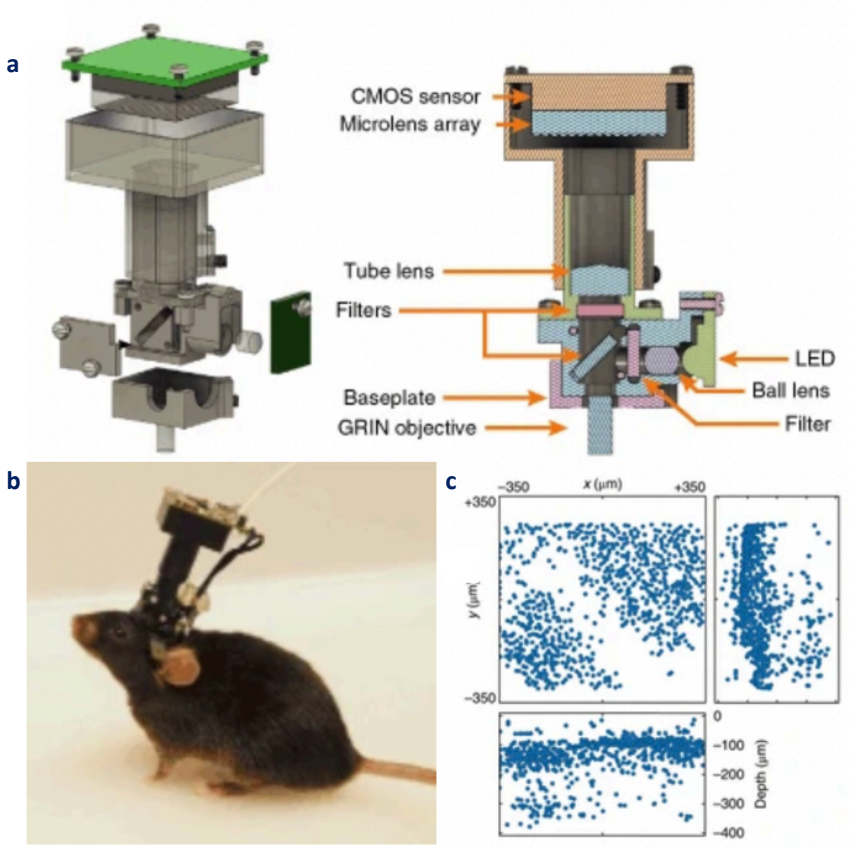


Figure 3: a) Explosion and section diagrams for the MiniLFM. b) Adult mouse with mounted MiniLFM. c) Neural positions obtained through SID analysis [4]

Pratt Fellows Project Goal and Objectives

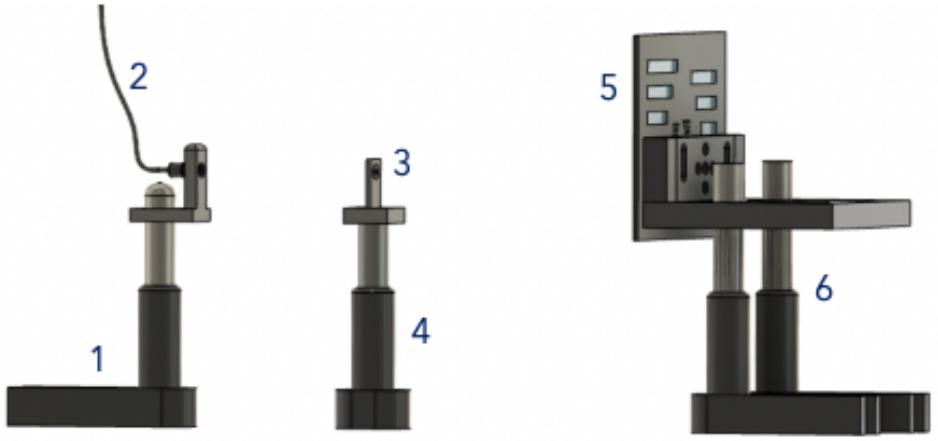
The primary goal of this project was to overcome field of view limitations experienced by current micro-cameras, while not sacrificing the resolution of the image, by creating a tiled array of micro-cameras.

Objective 1	Objective 2	Objective 3
Find camera with a width < 5 mm capable of imaging at micrometer resolution	Model and 3D print a device capable of holding an array of the micro-cameras	Stitch images taken by individual cameras from the array into a single uniformed image

Methods for Objective 1

To determine which sensor and lens to use, an experiment was developed where:

1. A lens was placed a fixed length away from a USAF resolution target
2. A sensor was moved until the image of the USAF target was in focus
3. The resolution and field of view of the sensor and lens were determined from the image



Components of Experiment

1. Thorlabs Holder for Sensor
2. DEPSTECH Camera Sensor with USB cable
3. Lens
4. Thorlabs Holder for Lens
5. Mounted USAF Resolution Target
6. Thorlabs Holder for USAF Target

Figure 4: CAD Model of Experimental Setup

Results for Objective 1

- The camera and sensor combination that yielded the best results was a DEPSTECH NTC50HD-5M endoscope camera
- The camera had a width of approximately 3 mm
- The resolution was found to be 8.76 micrometers and the field of view was 3.48 mm by 1.96 mm

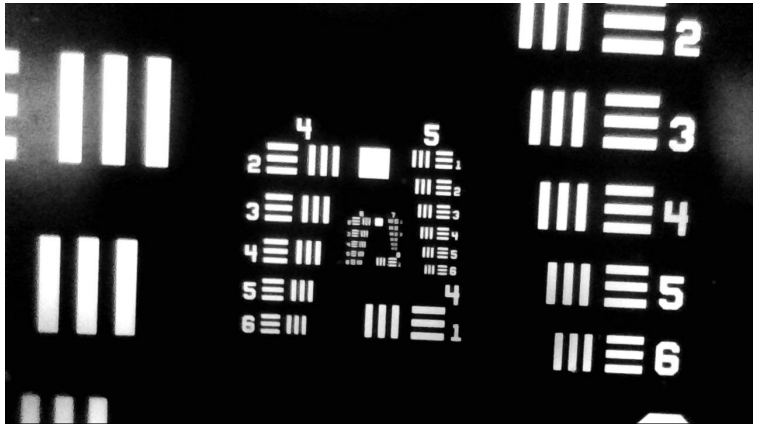


Figure 5: Image Taken using DEPSTECH NTC50HD-5M Endoscope Camera

Methods for Objective 2

The next objective of the project involved the creation of a device capable of holding an array of the selected DEPSTECH NTC50HD-5M endoscope cameras

1. Fusion 360 was used to create 3D models for holders

2. Ultimaker Printers from the Duke CoLab were used to create custom 3D printed holders for arrays of cameras

Results for Objective 2

- To maximize the overlap between each of the cameras in the array, the holder was designed to allow the cameras to rest side by side
- A small hole, seen in Figure 6, was left in the side of the model to allow it to be attached to a Thorlab post
- An iterative design method was used to craft the holders because the 3D printed holders often did not have the same dimensions as the CAD models

Figure 6: CAD Model for 2x2 Array Holder

Figure 7: 3D Printed Holder for a 2x2 Array

Methods for Objective 3

After 3D printing the holder, 4 endoscope cameras were placed into the 2x2 array. In the experiment shown below, images were collected from each of the individual cameras. The primary objective for this experiment was to stitch each image from the 4 cameras into a single image. Modified feature based panoramic imaging stitching MATLAB code was used to create the stitched image.

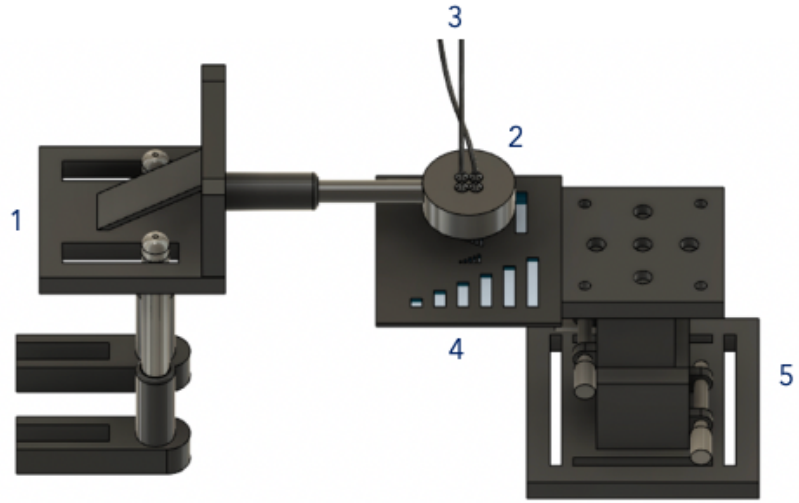


Figure 8: CAD Model of Experimental Setup

Components of Experiment

1. Thorlabs Platform used to mount 3D printed holder
2. Custom 3D Printed Holder
3. 2x2 Array of DEPSTECH Cameras and attached USB cables
4. USAF Resolution Target
5. Thorlabs Platform for USAF Resolution Target

Results for Objective 3

- The resolution for the cameras, shown in Figure 9, was 35.08 micrometers and the field of view of each individual camera was 7.13 mm by 4.01 mm
- The stitched image, shown in Figure 10, has a resolution of 35.08 micrometers and a field of view of 9.80 mm by 6.68 mm

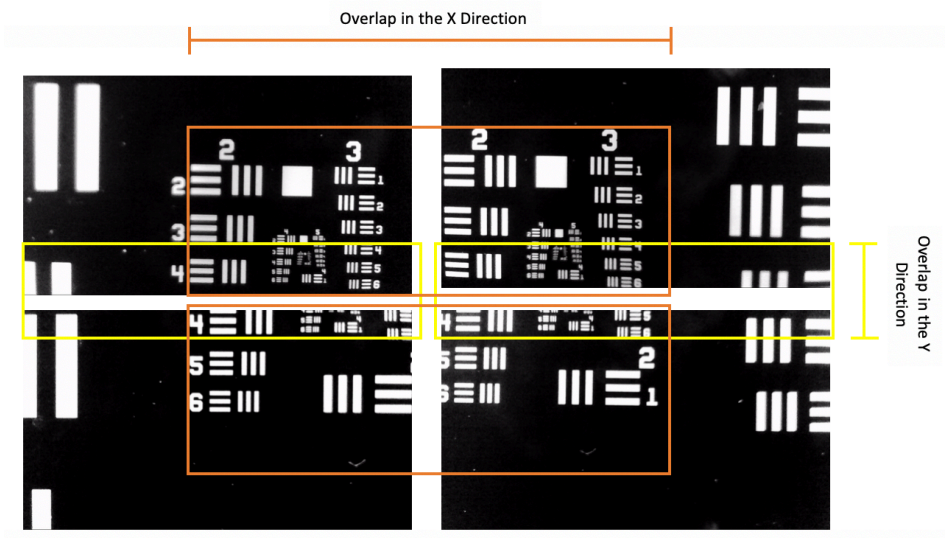


Figure 9: Images taken from 2x2 array of DEPSTECH Cameras

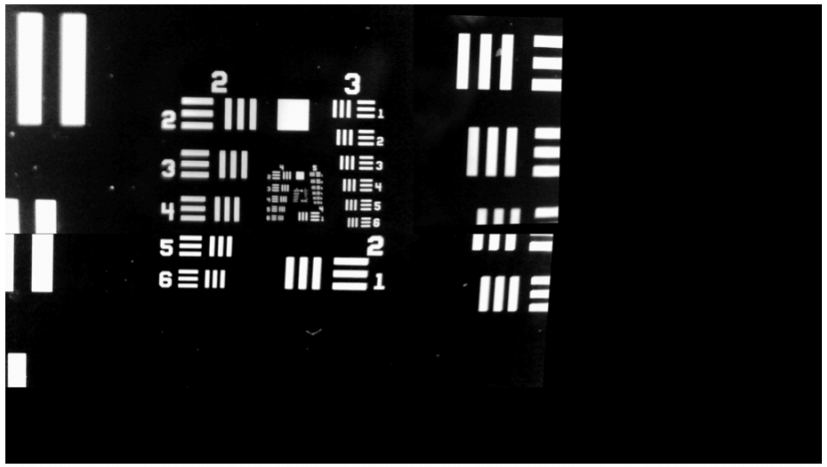


Figure 10: Stitched Image

Conclusion

This project showed that a tiled array of micro-cameras can be used to overcome the field of view limitations associated with minicameras developed to measure neural activity in free ranging mice. By growing the size of the array, a larger field of view can be obtained without sacrificing the resolution of the image. A 3x3 array prototype can be seen in Figure 11.

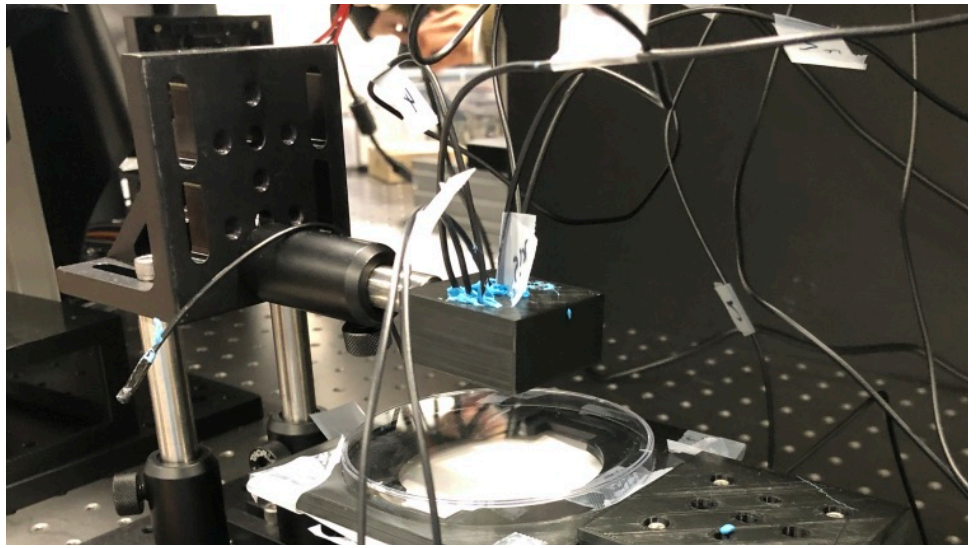


Figure 11: 3 x 3 Micro-camera array in 3D printed holder

Future Work

1. Create platform that can be rested on the head of a mouse

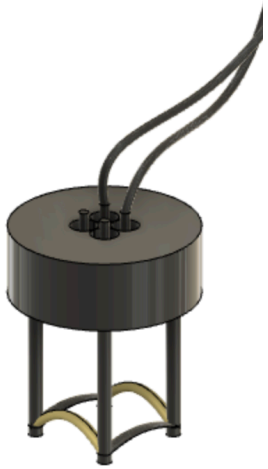


Figure 12: CAD Model for device that rests on head of mouse

2. Design and 3D print curved holders

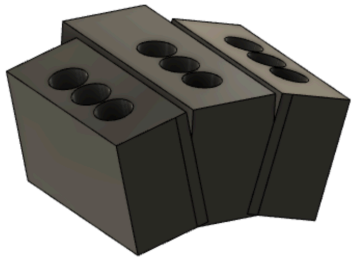


Figure 13: CAD Model of device needed to image a curved surface

3. Perfect stitching algorithm to stitch curved surfaces

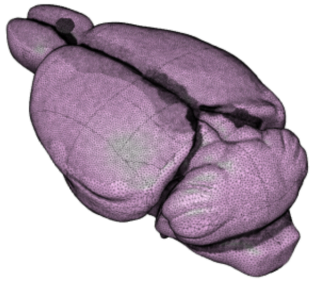


Figure 14: CAD Model of a mouse brain[3]

Acknowledgements

Thank you to Dr. Horstmeyer who helped me identify the objectives needed to complete the project and to Vinayak Pathak, Xi Yang, and Abhi Jadhav for their help overcoming challenges during the project

Sources

1. Allen, William E et al. “Global Representations of Goal-Directed Behavior in Distinct Cell Types of Mouse Neocortex.” *Neuron* vol. 94,4 (2017): 891-907.e6. doi:10.1016/j.neuron.2017.04.017

2. Guo ZV, Hires SA, Li N, O'Connor DH, Komiyama T, et al. (2014) Procedures for Behavioral Experiments in Head-Fixed Mice. PLOS ONE 9(2): e88678. https://doi.org/10.1371/journal.pone.0088678

3. Model Mouse Skull and Brain. *Thingiverse*. 2018.

4. Skocek, O., Nöbauer, T., Weilguny, L. *et al.* High-speed volumetric imaging of neuronal activity in freely moving rodents. *Nat Methods* **15,** 429–432 (2018). https://doi-org.proxy.lib.duke.edu/10.1038/s41592-018-0008-0