Mark Galperin

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Hello!

I am an engineer interested in all facets of electromechanical design. In this portfolio, I will show samples of work from…

1. **My current mechatronics work at the Ruta Lab**
2. **The ongoing research from my MS thesis**
3. **My mechanical engineering capstone project**
4. **My design capstone project from Northwestern**

Mechatronics Engineer @ The Ruta Lab

The Ruta lab at The Rockefeller University is a neuroscience laboratory studying the neural basis of behavior in fruit flies. As the sole engineer of the lab, I direct the design, programming, and validation of experimental rigs that record the behavior of fruit flies in a "virtual reality" environment.

Mathew Septimus, *Seek*

Why study flies?

Fruit flies (*Drosophila*) are a favorite model organism for biologists due to their well-understood genetics and easy husbandry, though there has been a recent explosion in using them as a model for behavioral neuroscience.

Flies have roughly 10^5 neurons (compare with ~86×10^9 neurons in the massive human brain), small enough to feasibly study but still large enough to produce complex behaviors like **a courtship ritual** and **following turbulent odor plumes** to find food.

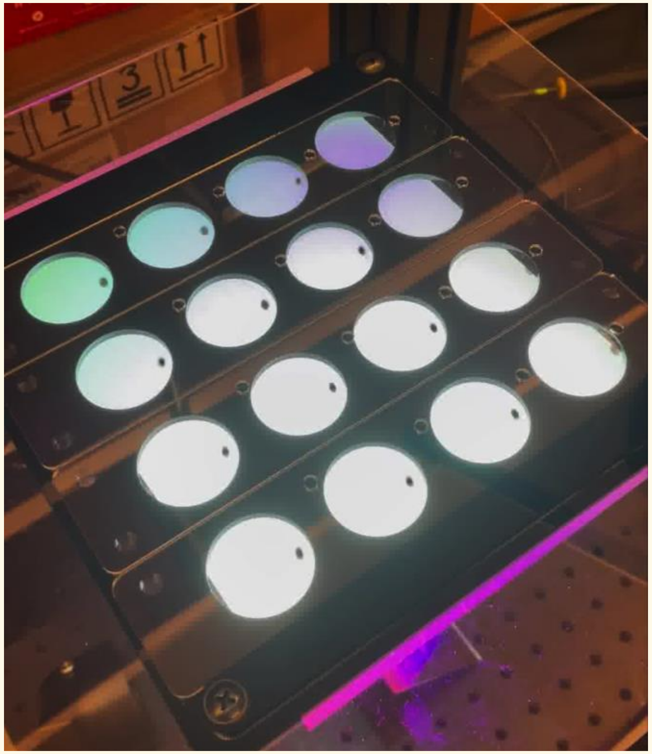
In the Ruta lab, I worked across multiple domains to build and program experiments that study these behaviors. I learned to prototype systems quickly and iterate them according to the experimenters' feedback. I manufactured components, ran an in-lab makerspace, and aided in all aspects of hardware and software development.

Projector Systems

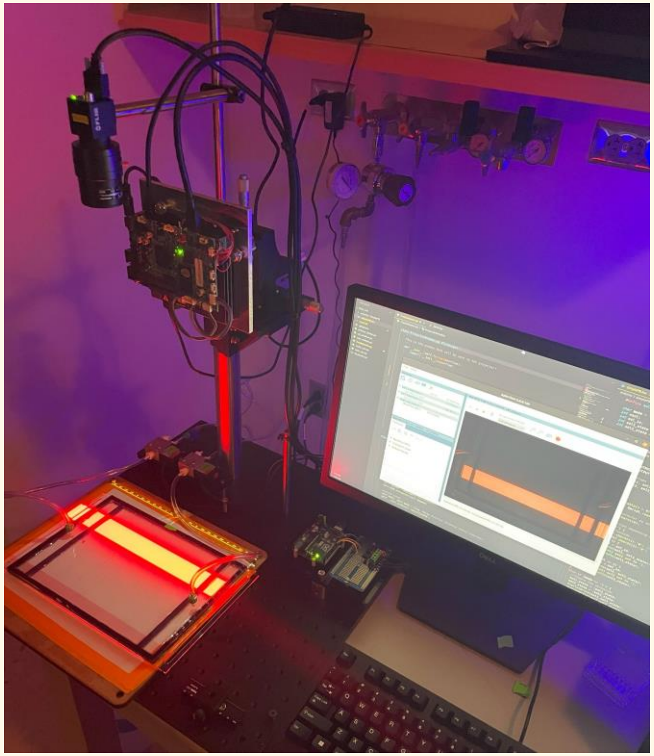
To study the fly courtship ritual and olfactory navigation, **the lab needed a way to deliver a dynamic stimulus to a free-walking fly**. To this end, I designed multiple systems that use a projector to illuminate the surface a fly walks on while using a camera to capture its movements.

The first projector system I built projects the image of a "fictive female" onto a grid of chambers, causing male flies to engage in a courtship ritual. This system has caught the attention of outside labs and is in the process of being replicated by engineers at the Janelia Research Campus. You can see it in action at **www.tinyurl.com/projectionsystem**

More recently, I made a projection system **with more emphasis on precision** to study a fly's ability to follow odors to find food. Using a genetic tool that stimulates flies' odor sensation when under red light, this system creates a "fictive plume" of odor that the fly will follow. The system consists of a camera, a projector, a laminar flow chamber, and a system of solenoids to control airflow. I used ROS2 to make the system software modular and fast, created calibration routines to align the coordinate systems of the camera and projector, and wrote a custom GUI to allow easy control over system function.



Courtship Projection system



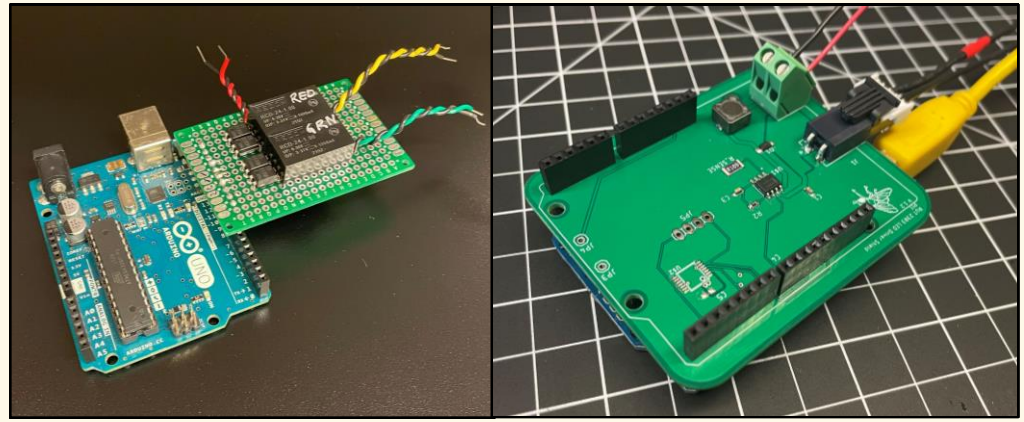
Olfactory Navigation Projection system

Ruta Lab contd.

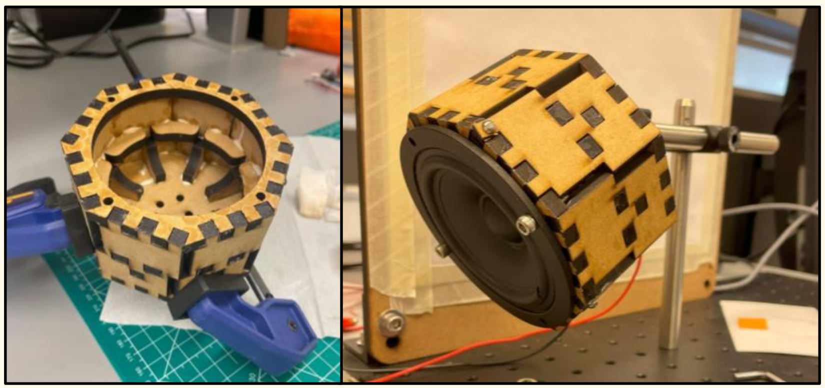
Manufacturing hardware and electronics

Taking advantage of a small manufacturing resource center on campus, **I manufactured custom parts using rapid prototyping techniques** (3D printing, laser cutting)**, conventional milling,** and **collaborated with machinists to produce CNC-milled parts**.

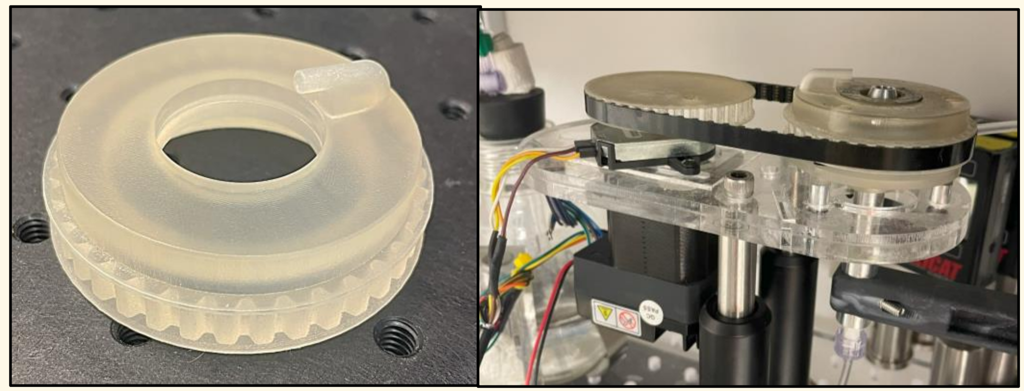
I also made circuits for driving high-current, high-intensity LEDs and interfaced them directly with Arduino boards. In collaboration with an electrical engineer on campus, **I helped produce a custom PCB Arduino shield** which improved power output and brightness resolution in a convenient package.



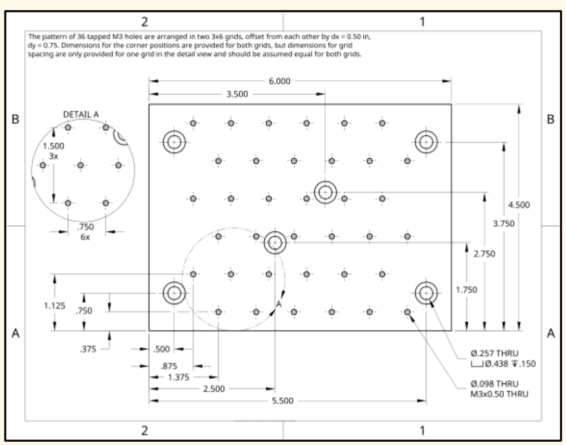
LED Driver shields (prototype, final board)



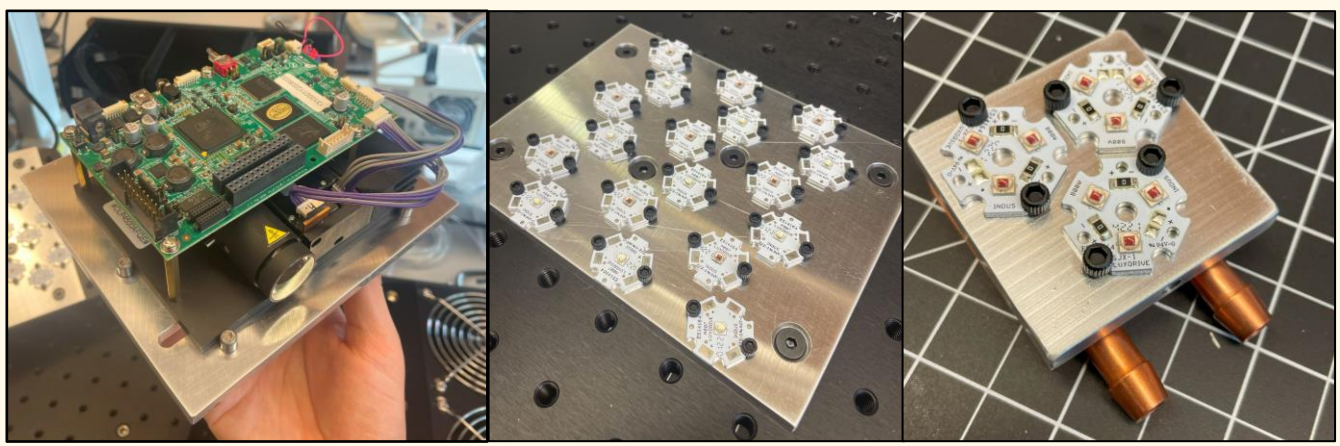
Laser-cut MDF for sound insulation



3D-printed, mill-finished parts for olfactory VR



Drawings for manufacturing



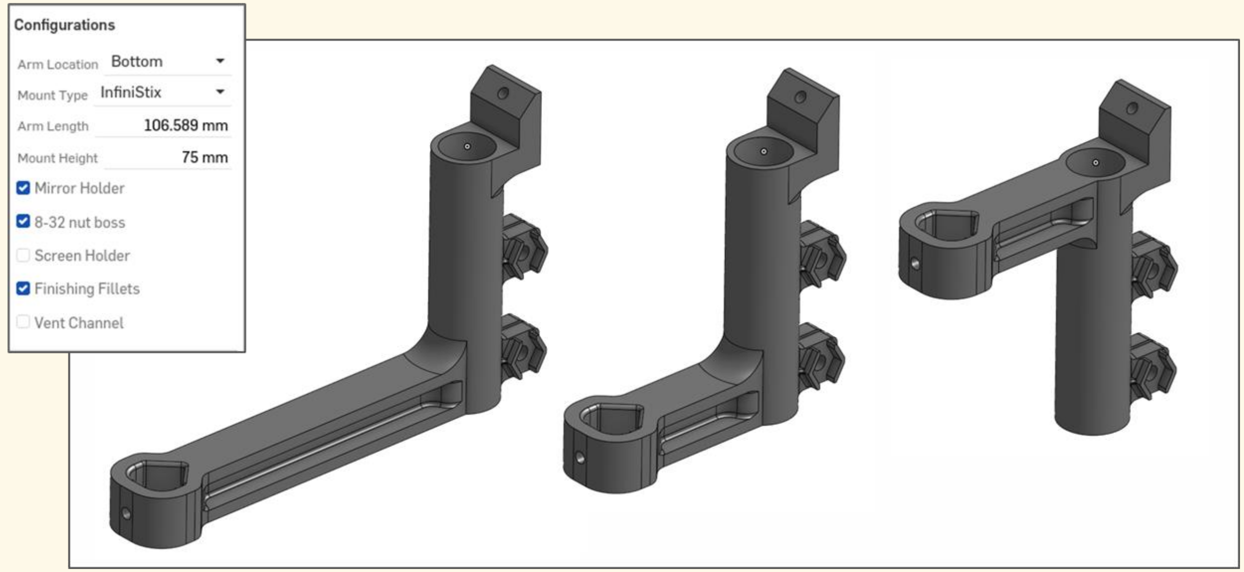
Custom aluminum fixtures for projector alignment and high-power LEDs

Ruta Lab contd.

Making CAD friendly

I wanted to introduce the lab to CAD in such a way that scientists with no background in mechanical design could produce new parts. **I used Onshape to provide a public, platform-agnostic resource** of all shared parts and assemblies in the lab. **I designed parts to be parametric and configurable using global variables accessed in forms** so the lab could edit parts and send them for 3D-printing.

I also ran a CAD workshop for the lab, covering the basics of drawings, parts, and assemblies to create a primitive robot arm by the end of the session.



A configurable part, designed for easy adjustment of critical dimensions

Building a small makerspace

I had the pleasure of overseeing a shared makerspace in the lab, which had sat dormant and disorganized before my time in the lab. The makerspace now consists of an electronics testing and soldering station, a hand tools and clamping station, ample storage for screws, optomechanical components, cables, and electronics, a heavy-duty cart for sheet materials and optical breadboards, and a test area for high-power LED rigs.

Apr 2022

May 2023

The Ruta Lab makerspace, fully stocked and operational as of 2023!

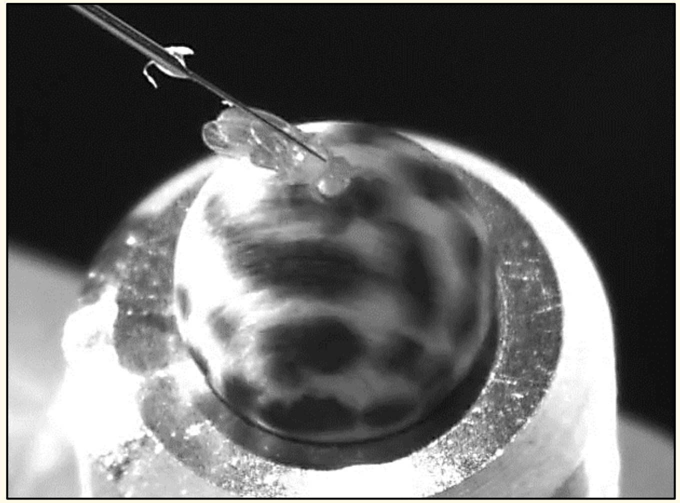
Ruta Lab contd.

Virtual-Reality Environments for Flies

The most advanced experiments in the lab involved **positioning a fruit fly above an air-suspended spherical treadmill,** providing a readout of the fly's movement as stimuli are presented to it.

These closed-loop systems are used in studying the fly courtship ritual as well as olfactory navigation.

As the mechatronics engineer, I maintained and repaired these complicated systems, adapting them to updated hardware and helping scientists make the changes they desired.



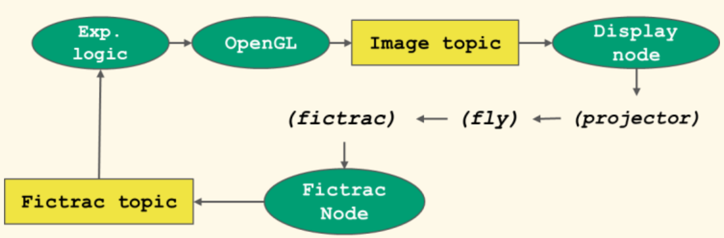
Tom Hindmarsh Sten

Chad Morton, Andrew Siliciano

Programming VR experiments with ROS2

The lab's existing software for closed-loop virtual reality experiments relied on code that was hard to re-use and difficult to introspect. Using ROS2, a performant and modular middleware for robotic systems, I have begun the process of rewriting our system software into modules that can be combined while also improving system performance with fast nodes written in C++.

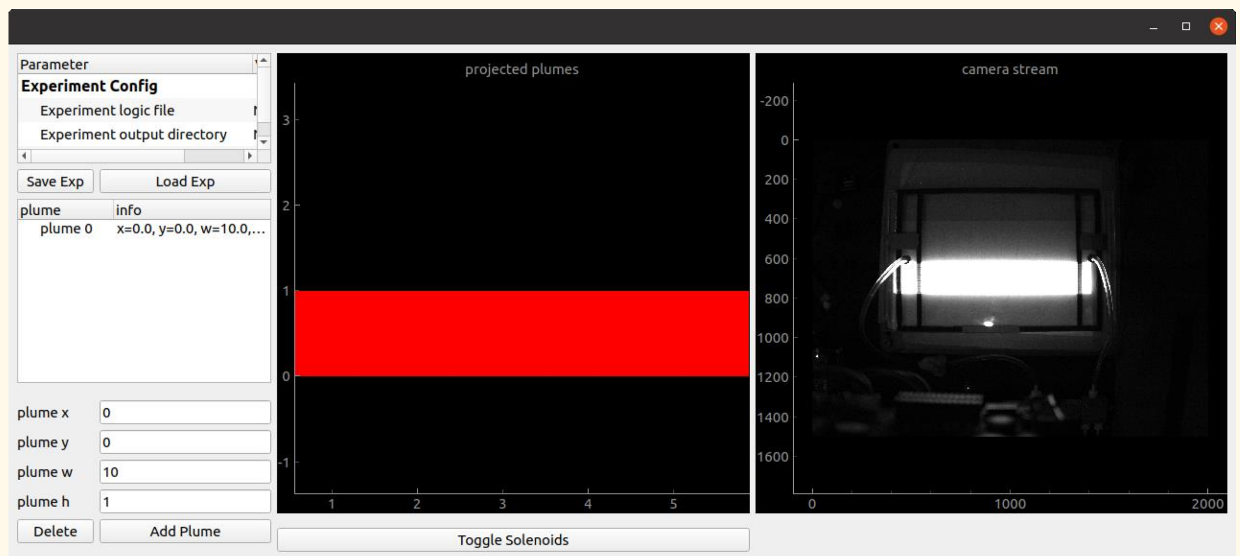
Using ROS2, I have integrated cameras, motors, machine-vision algorithms, Arduino boards, and mass-flow controllers into our virtual reality systems.



Closed-loop visual courtship assay

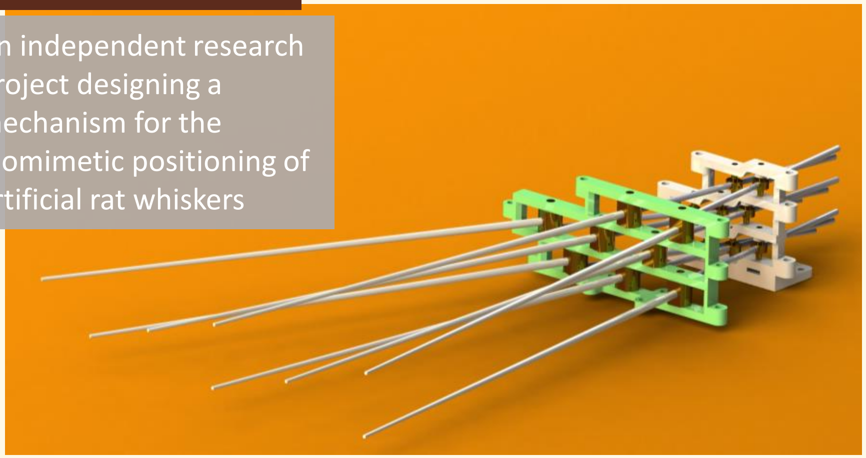
Designing GUIs for scientists

Using PyQt, I wrote custom interfaces to give access to complex systems for scientists that don't have a background in programming. I created modular widgets that connect to ROS2 communication, leveling out an otherwise steep learning curve.



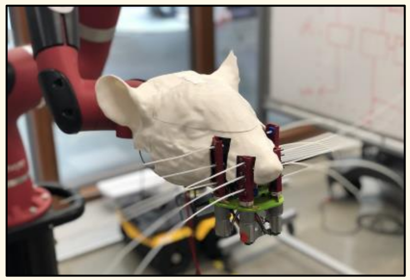
Whisker Frames

An independent research project designing a mechanism for the biomimetic positioning of artificial rat whiskers

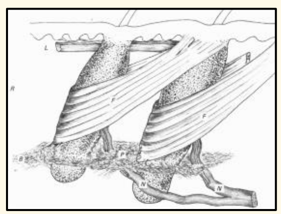


Inspiration and Concept

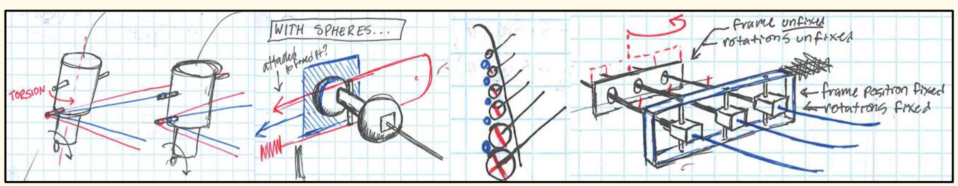
The lab's previous method of robotic whisking involved **columns** of whiskers, each actuated by its own motor. This was costly and space-inefficient. I started by generating design alternatives to fulfill desired motion characteristics.



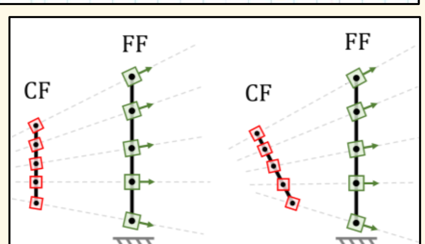
I then consulted anatomical papers to gain more inspiration and conceived a geometric concept based on the parallel motions of planar tissues that move **rows** of whiskers. I applied this concept to a rigid-body system to give the system kinematic stability.



Dorfl 1983



The result was Whisker Frames, a mechanism that controls the row-wise orientation and distribution of a whisker array by the free motion of a "control frame" (CF)



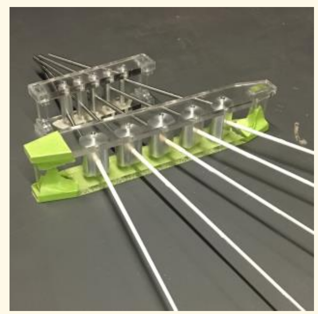
Overview

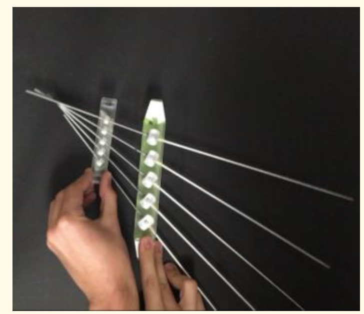
The SeNSE Lab of Dr. Mitra Hartmann aims to replicate the versatile active-sensing behavior of **whiskers** in rats and mice, designing artificial whiskers that **give robots a sense of touch.** An important component of rodent whisker sensing is the ability to move their whiskers, a process known as **"whisking".**

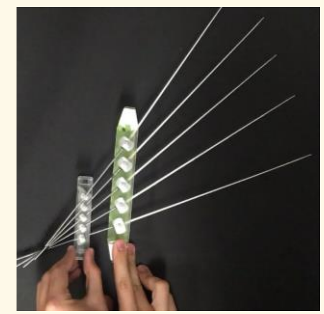
I was given a challenge in abstract: "Improve the way we move whiskers" . This led me to **design, simulate, and build** a biomimetic mechanism that not only replicates real biology, but proposes a new perspective on the study of neural control in rodents. **This work was the topic of my MS thesis, and I'm currently adapting the work for publication.**

Build and Physical Design Iteration

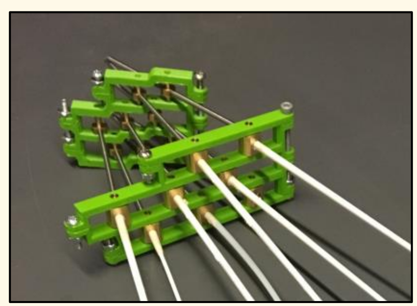
As soon as I could, I started building physical mock-ups to generate a proof-of-concept. My second iteration (below) combined laser-cut acrylic frames with machined aluminum joints and steel rods to control a single row of whiskers.

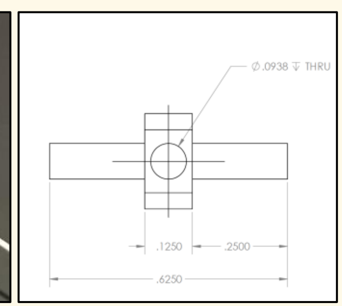


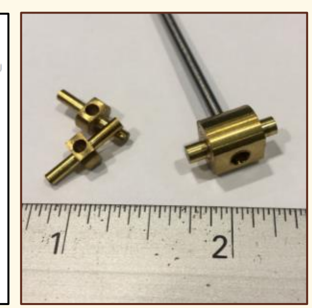




The third iteration aimed to **miniaturize** the system to match the experimental scale (5x-rat). This forced me to impose tight projective tolerances, machine brass to 0.003" accuracy, and design multi-row, 3D-printed frames to hold delicately machined parts.

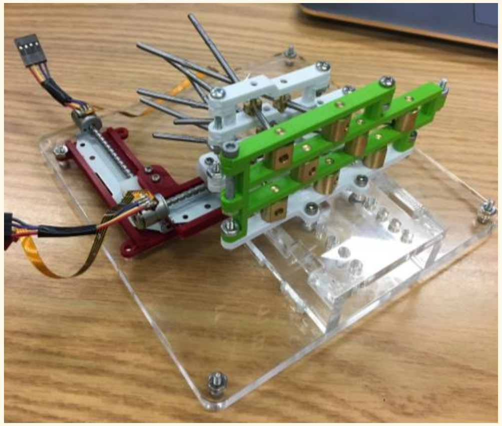


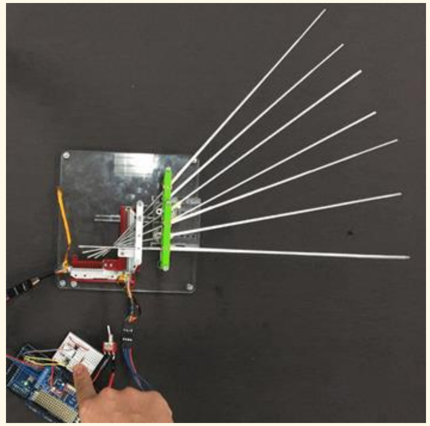




Whisker Frames – contd.

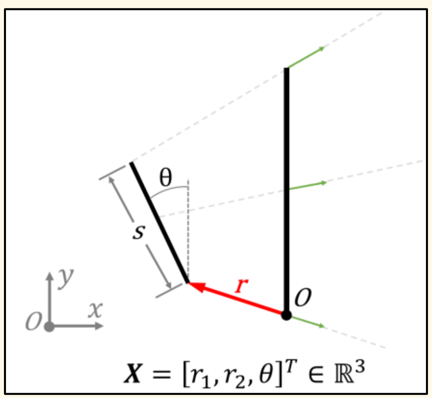
Motorized Build

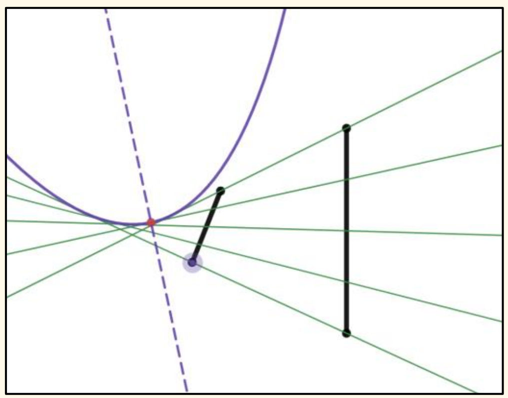




The final physical iteration to demonstrate Whisker Frames used two linear stepper motors to control the position of the control frame. With the help of an Arduino Mega and interface circuitry, I could control both the direction and distribution of whiskers.

Vector Modeling and MS Work





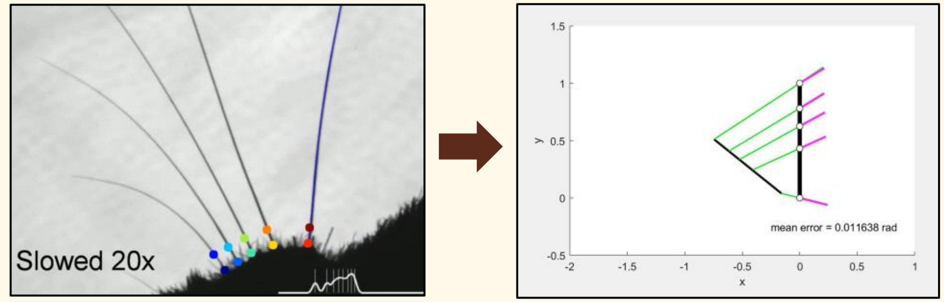
For my MS thesis, I studied this mechanism using the tools of algebraic geometry, defining a vector model (left) and visualizing my work using Desmos, an interactive graphing software (right).

In this simply-defined geometry, I found a property that would come to re-define the system: **all "whisker lines" (green) are tangent to a parabola.** This helped generalize my analysis and was an unexpectedly beautiful connection!

Biomimetic Trajectory Optimization

Using the vector model, I was able to compare the mechanism to real whisking angles observed on rats, as captured in slow-motion video.

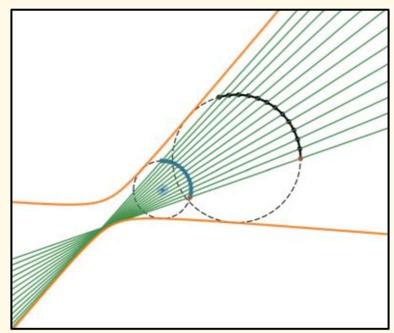
Using MATLAB, I analyzed the video data to calculate "virtual whisker frames" positioned such that they replicate biological whiskers in a smooth time trajectory. **Optimal trajectories matched the whiskers down to an average error of one degree (1°) over the entire time span.**

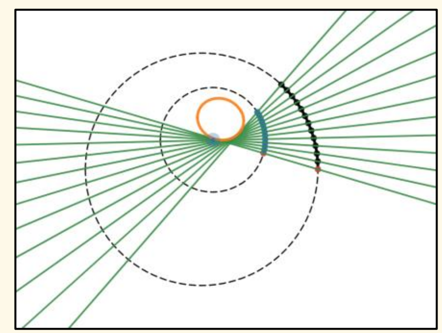


Dan O'Connor, Johns Hopkins University

Alternate Geometries (Future work)

By changing the straight lines to **circle arcs**, the curvature of the rat face can be better mimicked. **This geometry also produces whiskers tangent to a conic section!** (But instead of a parabola, its hyperbolas and ellipses)





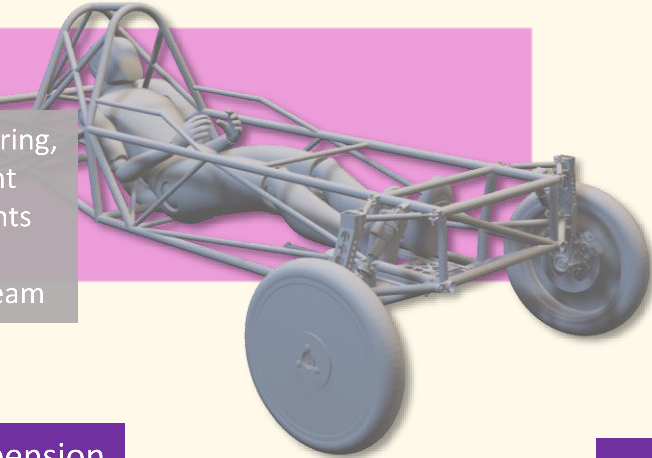
I'm also currently writing this for publication! I am aiming to submit to the journal Bioinspiration and Biomimetics by the end of 2023.

Check out my thesis: **markgalperin.github.io/MSThesis.pdf**

Play with the Desmos demo: **tinyurl.com/WhiskerFrames**

NU Solar Car

Designing, manufacturing, and documenting front suspension components for the Northwestern University Solar Car team



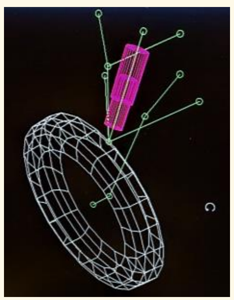
Project Statement

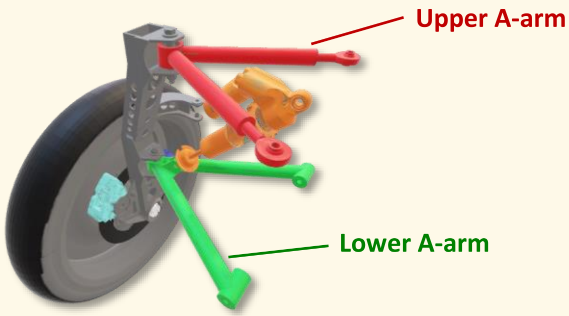
To design and build a rolling chassis (frame, suspension, brakes) for the NUsolar team to qualify for the American Solar Challenge 2020. We aimed to design a rolling chassis that was **lighter, more efficient, and more rules-compliant** than the previous year's car, while still being compatible with the existing aerodynamic shell.

As part of my senior capstone project**, I designed, manufactured, and validated suspension components**, working with a team of experienced peers. Despite being the only member on the team without prior car team experience, **I worked outside my comfort zone to confidently deliver a successful design.**

Designing the Suspension

As one of my first tasks, I defined the front suspension points using SHARK, a suspension analysis tool by Lotus Engineering (left). We then used that geometry to each design components for the assembly (right). **I focused on designing the A-arms.**

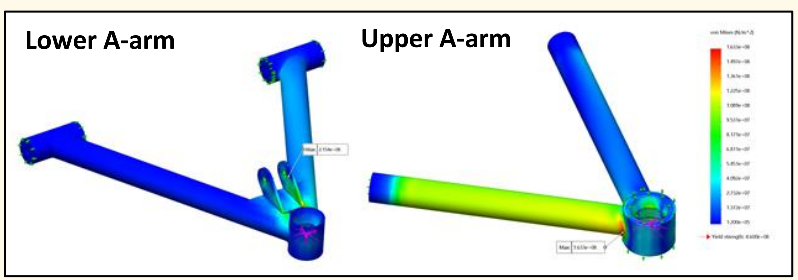




A-Arm Design

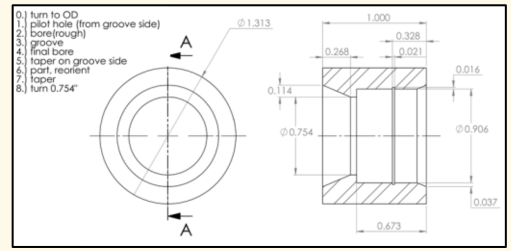
Using SOLIDWORKS, I modeled the upper and lower A-arms, as well as spacers, bushings, and fixturing parts for proper assembly.

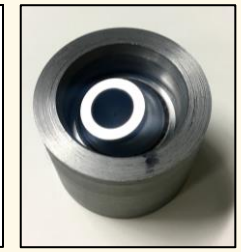
I validated the design using finite element analysis and reduced the previous car's excessive factor of safety (~4.1) to 2.18 and 2.3, with a net weight reduction of 27% and 8% for the lower and upper A-arms.

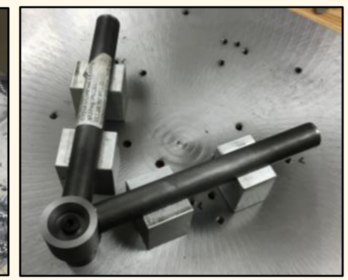


Manufacturing

Using the skills I learned as a shop trainer**, I manufactured all my own parts**: I turned bores and tapers with tight tolerances to hold spherical bearings in a transition fit, machined collets and spacers for weld fixturing (for both my parts and others) and **made sure to prepare drawings for all my parts**, manufacturing instructions included. I also helped others on the team manufacture their parts.







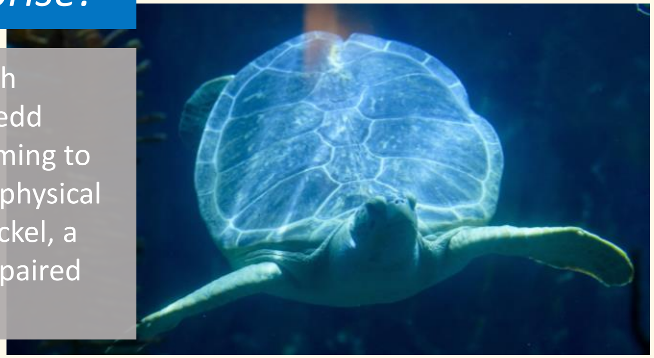
Assembly

With all parts manufactured, we were able to assemble the entire front suspension, as well as the rest of the rolling chassis just in time for the pandemic to cut our quarter short.

Suspension Assembly Model Coloration by Ieva Stakvileviciute

Nickel *Surprise!*

A project with Chicago's Shedd Aquarium aiming to improve the physical activity of Nickel, a physically impaired sea turtle



Nickel

Nickel, a green sea turtle at Chicago's Shedd Aquarium, was struggling with ***inactivity***, only moving around her tank at times she expected to be fed.

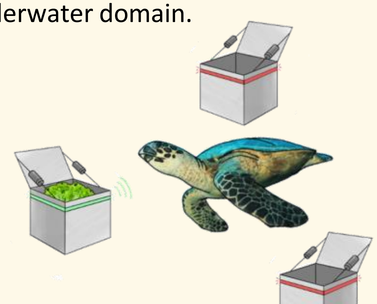
As part of a Segal Design Certificate capstone project, our team was tasked with improving Nickel's physical activity by engineering a non-corrosive, fish-friendly device for use in Shedd's Caribbean Reef exhibit.

Research and Concept

When researching for this project, we took the time to observe Nickel on her home turf. **Nickel has mobility issues** due to a spinal injury, giving her less control over her back flippers. Between feeding times, she would rest in corners of the tank, remaining stationary for hours at a time.

Hoping to learn how captive animals are encouraged to be active, we took a trip to the Brookfield Zoo to meet with their exhibit designers and caretakers. **We learned that animals in captivity have been shown to be more active when the source and timing of their feeding is irregular**. We ventured to extend this idea to the underwater domain.

***Nickel Surprise* is a device that disrupts the regularity of Nickel's feeding schedule, encouraging her to be search for her food by dispensing it *irregularly*, at different times and locations.**



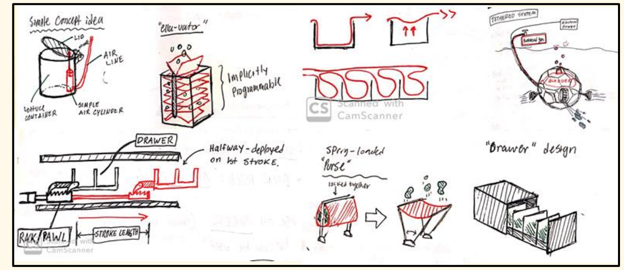
Drawing by Peter Hartman

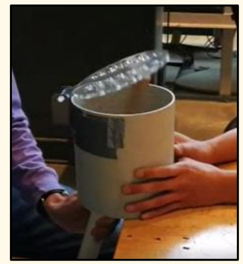
Ideation and Prototyping

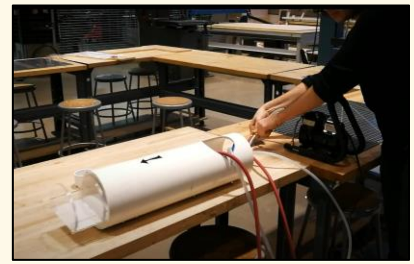
With the concept locked, our team worked quickly to produce alternatives and build mock-ups, working together and independently on a daily basis.

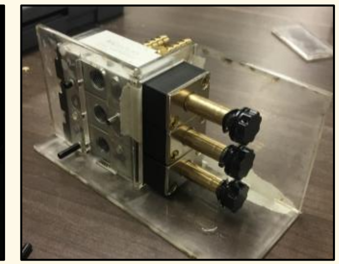
Frequent sketching for internal design reviews got us closer to conceptualizing how our mechanism could dispense food underwater

We settled on attempting a **pneumatic** system.

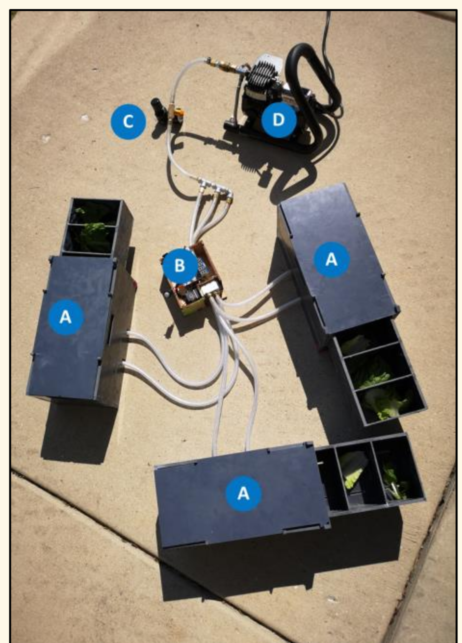








I took charge in directing our physical mock-ups, building pneumatic dispensers using tank-safe materials using multiple rapid prototyping techniques. (Left) Our first foray into using a pneumatic cylinder to open a lid. (Middle) a "drawer" design I hypothesized to incrementally release food. (Right) A mounting mock-up to control multiple solenoid air valves.



Final Design and Testing

Nickel Surprise! Consists of **(A)** Three pneumatic dispenser units controlled by **(B)** an electronics and valve control unit connected to **(C)** a needle valve controlling input airflow from **(D)** an input pressure source (at the Shedd, a scuba tank).

We were able to test this design at the Shedd with the help of the scuba diving team, **successfully releasing food at randomized time intervals**.