Mark Galperin

engineering portfolio

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all sketches and renderings by Mark Galperin except where otherwise noted

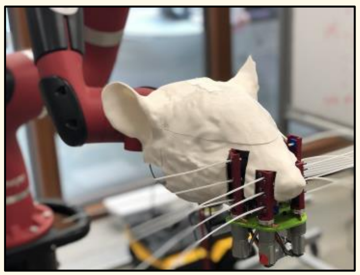
Overview

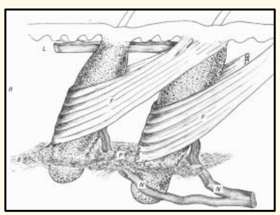
The SeNSE Lab of Dr. Mitra Hartmann aims to replicate the versatile active-sensing behavior of **whiskers** in rats and mice, designing artificial whiskers that **give robots a sense of touch.** An important component of rodent whisker sensing is the ability to move their whiskers, a process known as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

I was given a challenge in abstract: “Improve the way we move whiskers” . This led me to **design, simulate, build, and present** 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.

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.

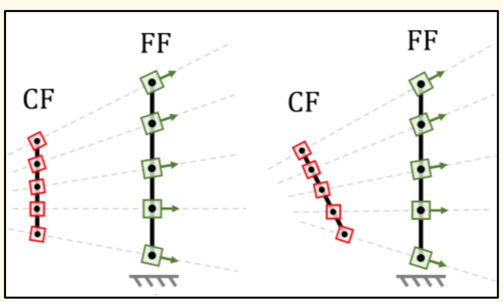




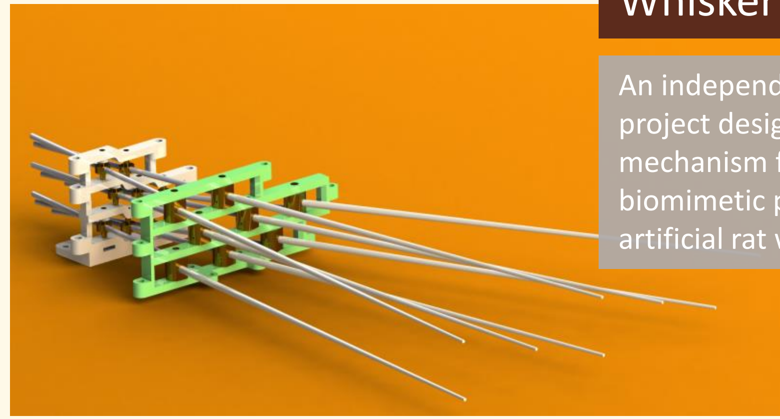
Dorfl 1983

I found inspiration in the parallel motions of multiple layers of tissue running through whisker follicles. Unlike our robot, whiskers are biologically actuated in **rows**.

Whisker Frames is a mechanism that controls the row-wise orientation and distribution of a whisker array by the free motion of a “control frame” (CF)



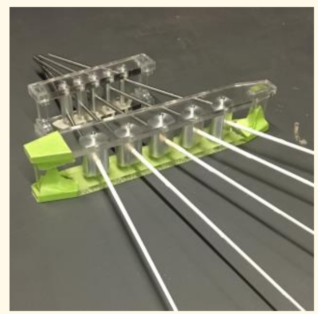
Whisker Frames

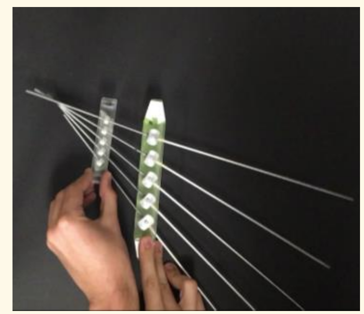


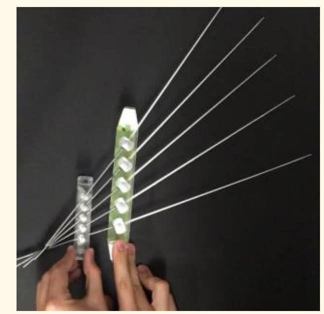
An independent research project designing a mechanism for the biomimetic positioning of artificial rat whiskers

Build and Physical Design Iteration

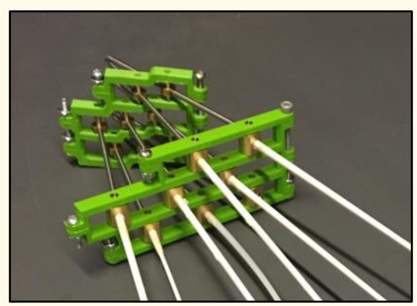
As soon as I could, I started building physical mock-ups to generate a proof-of-concept. My second iteration (below) combined laser-cut acrylic frames with machined aluminum joints and steel rods to control a single row of whiskers.

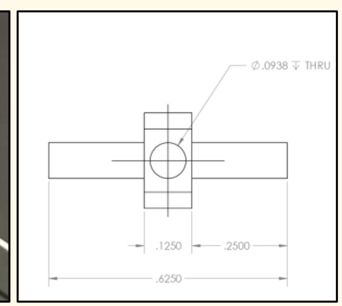


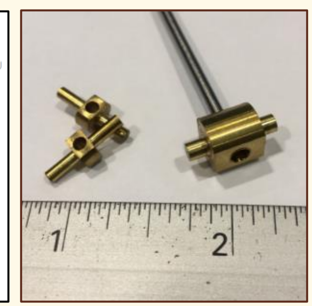




The third iteration aimed to **miniaturize** the system to match the experimental scale (5x-rat). This forced me to impose tight projective tolerances, machine brass to 0.003” accuracy, and design multi-row, 3D-printed frames to hold delicately machined parts.

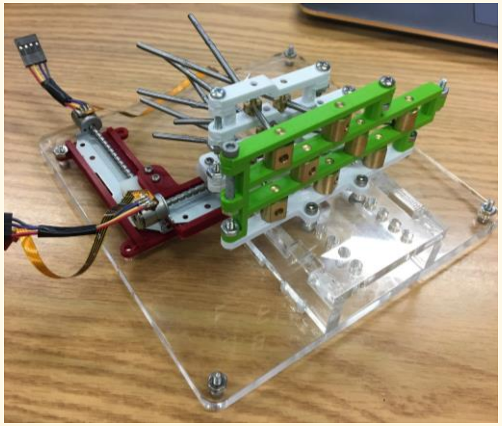


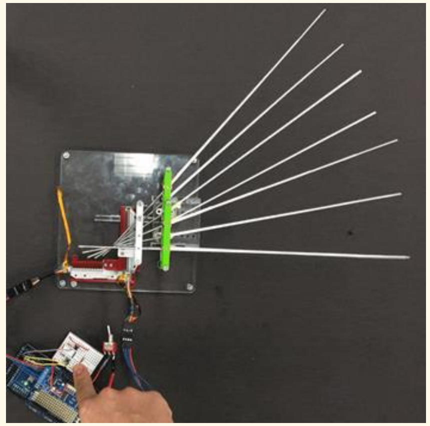




Whisker Frames – contd.

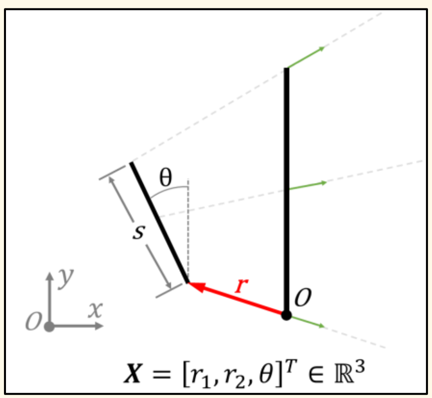
Final Motorized Build

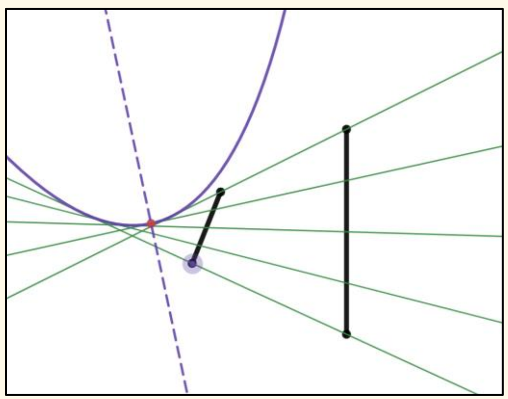




The final physical iteration of Whisker Frames was mounted to two linear stepper motors to control the position of the control frame. With the help of an Arduino Mega and interface circuitry, I could control both the direction and distribution of whiskers.

Vector Modeling and MS Work





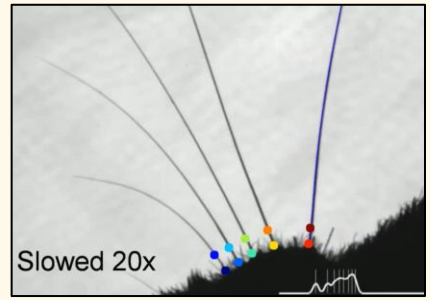
For my MS thesis, I studied this mechanism through the lens of algebraic geometry, defining a vector model (left) and visualizing my work using Desmos, an interactive graphing software (right).

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!

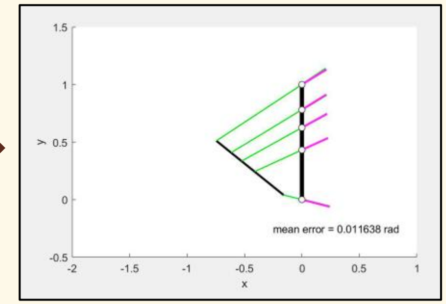
Biomimetic Trajectory Optimization

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.**

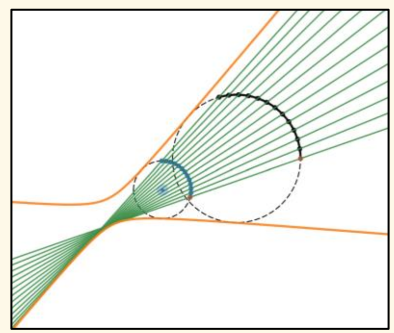


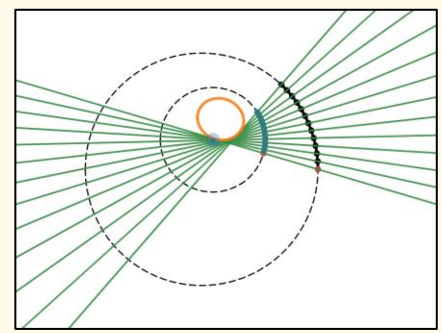
Dan O'Connor, Johns Hopkins University



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)





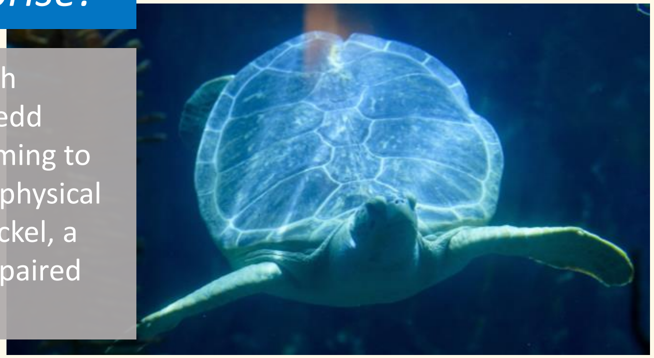
I'm also currently writing this for publication! I am aiming to submit to the journal Bioinspiration and Biomimetics by the end of Summer 2021.

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

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

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.

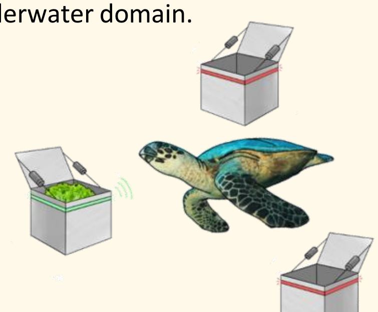
As part of a Segal Design Certificate capstone project, our team was tasked with improving Nickel's physical activity by engineering a non-corrosive, fish-friendly device for use in Shedd's Caribbean Reef exhibit.

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.**



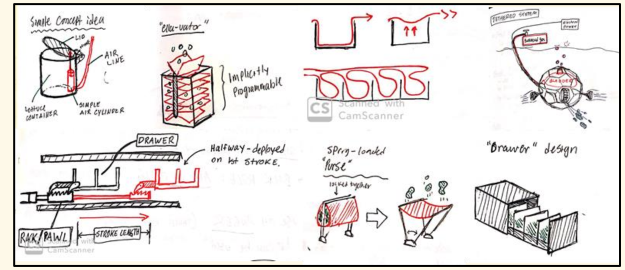
Drawing by Peter Hartman

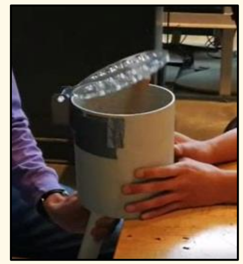
Ideation and Prototyping

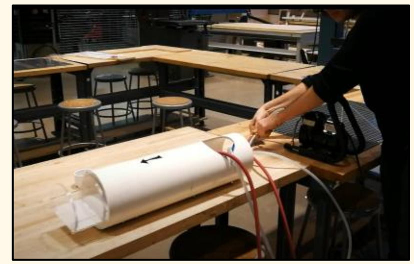
With the concept locked, our team worked quickly to produce alternatives and build mock-ups, working together and independently on a daily basis.

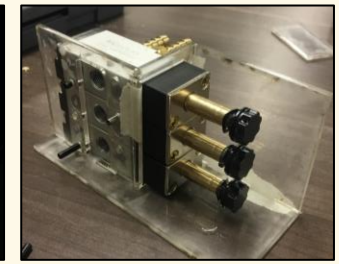
Frequent sketching for internal design reviews got us closer to conceptualizing how our mechanism could dispense food underwater

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

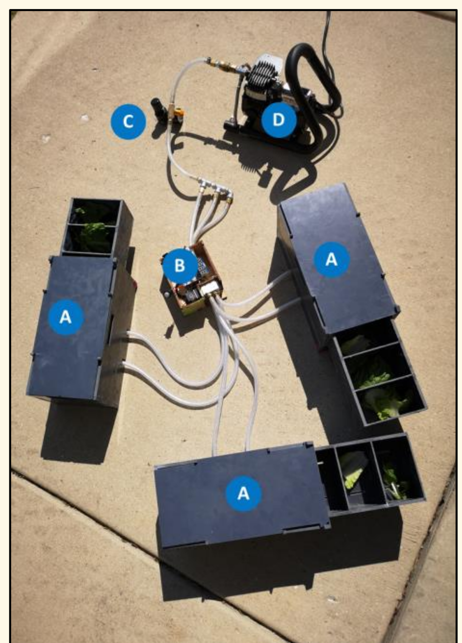








I took charge in directing our physical mock-ups, building pneumatic dispensers using tank-safe materials using multiple rapid prototyping techniques. (Left) Our first foray into using a pneumatic cylinder to open a lid. (Middle) a "drawer" design I hypothesized to incrementally release food. (Right)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



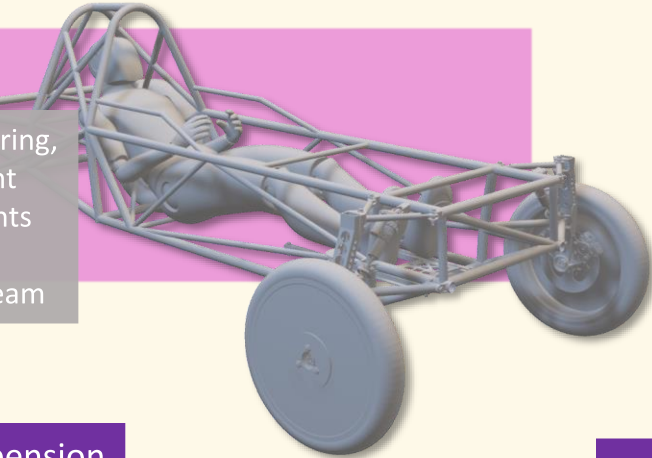
Final Design and Testing

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**.

NU Solar Car

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



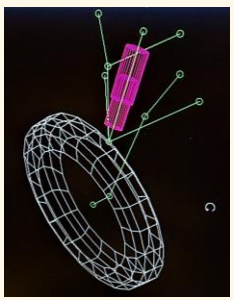
Project Statement

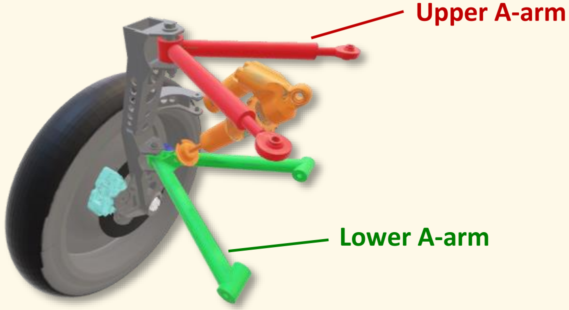
To design and build a rolling chassis (frame, suspension, brakes) for the NUsolar team to qualify for the American Solar Challenge 2020. We aimed to design a rolling chassis that was **lighter, more efficient, and more rules-compliant** than the previous year's car, while still being compatible with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

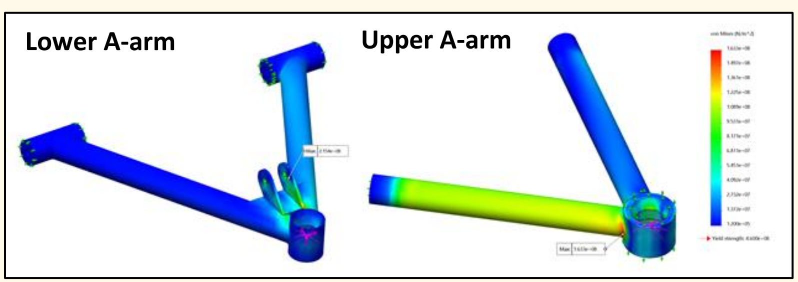




A-Arm Design

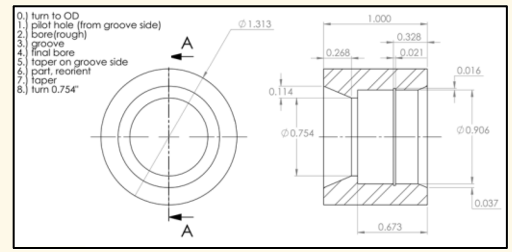
Using SOLIDWORKS, I modeled the upper and lower A-arms, as well as spacers, bushings, and fixturing parts for proper assembly.

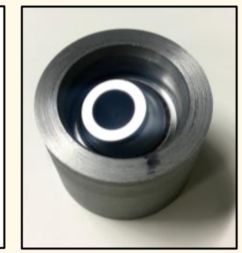
I validated the design using finite element analysis and reduced the previous car's excessive factor of safety (~4.1) to 2.18 and 2.3, with a net weight reduction of 27% and 8% for the lower and upper A-arms.



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