Professional Experience

ASML work:

Several threads :
(1) **Are setup failures a results of how “warm” the system is?** (since primary controller is extremum seeking, the optimization landscape must be stationary).
(2) **Can we identify the cause of failure if warmup is not the problem?**

> a) *Frequency domain*: Spectogram of data for failure inference
> b) *Time domain*: Large parameter dataset ~ 12 signals, 300 trial sets: PCA, Covariance visualization plots, t-SNE, UMAP of various scalar mappings for the time series data

Conclusion was that the system warmup was overly conservative based on signal convergence. Proposed experiment for reduction in warmup time to evaluate hypothesis.

Extracurricular Projects

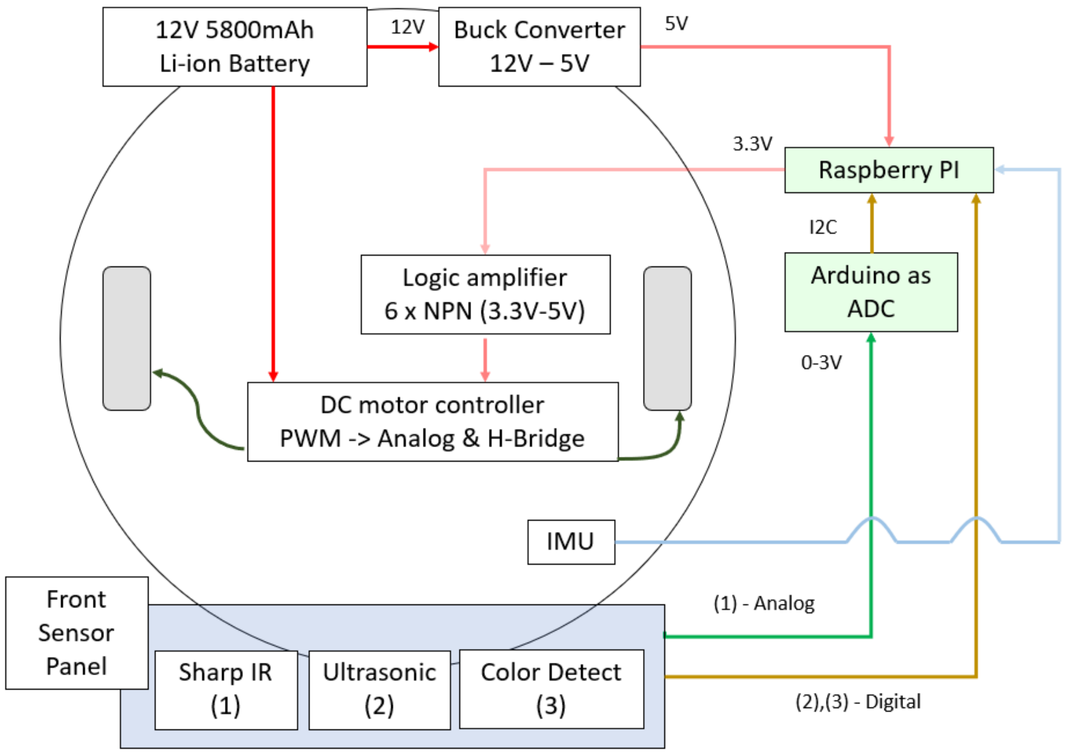
Hacked Roomba + Probabalistic robotics (Udacity) – (Video Link)

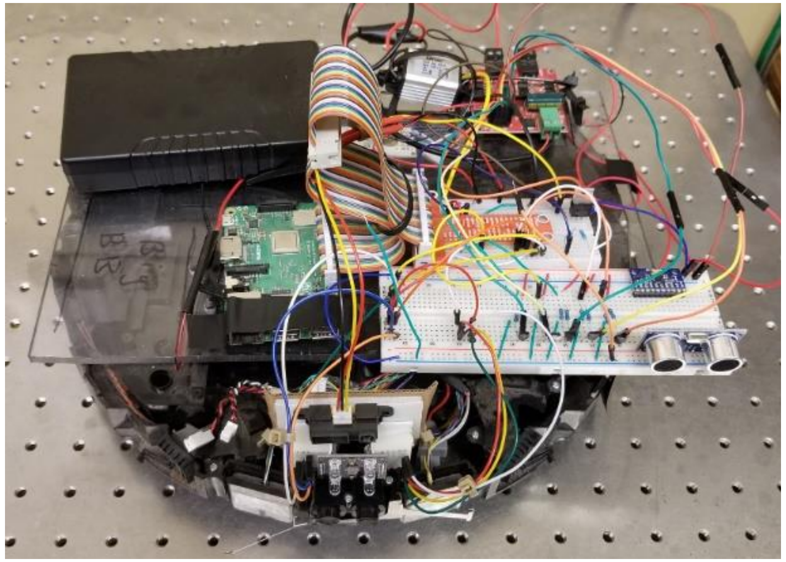
I worked with another PhD student to learn probabilistic robotics from Sebatian Thrun. I hacked a broken Roomba and we applied the concepts we learned.

- Used Python for Kalman filtering and sensor fusion of 1D range measurements (SharpIR, ultrasonic)
- (in progress) ROSberry Pi install
- (in progress) localization using particle filter
- (goal) execute dance moves to music*

Me+Friend

Me





*Project includes first designing "on-line" dance strategy to develop neural network. Then, deploy network for "on-the-fly" dance execution.

Controls Project overview – 4 mass spring damper (file available on LinkedIn)

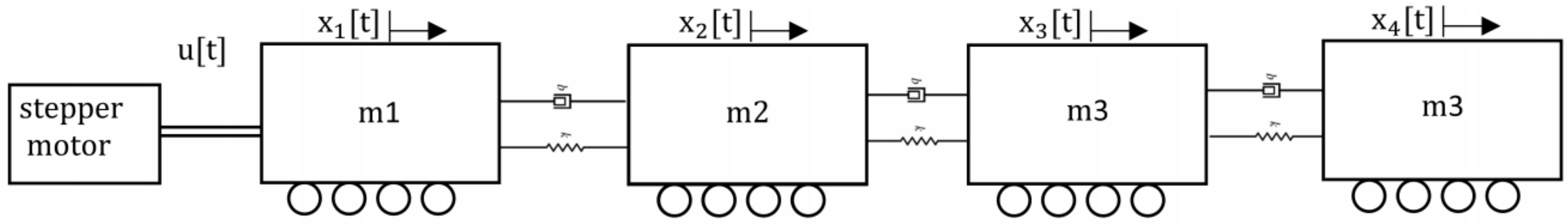
I wanted to apply the advanced controls theory to a simple (yet very challenging) problem of controlling a non-collocated non-square MIMO system. I settled on comparing LQG to MPC for a 4-cart dynamical system

The equations of motion are simple to obtain using conservation of momentum,

$$\begin{bmatrix} \dot{x}_1 \\ x_2 \\ \dot{x}_2 \\ x_3 \\ \dot{x}_3 \\ x_4 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ \frac{k1}{m2} & \frac{-(k1+k2)}{m2} & \frac{-(c1+c2)}{m2} & \frac{k2}{m2} & \frac{c2}{m2} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & \frac{k2}{m3} & \frac{c2}{m3} & \frac{-(k2+k3)}{m3} & \frac{-(c2+c3)}{m3} & \frac{k3}{m3} & \frac{c3}{m3} \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & \frac{k3}{m4} & \frac{c3}{m4} & \frac{-k3}{m4} & \frac{-c3}{m4} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \dot{x}_2 \\ x_3 \\ \dot{x}_3 \\ x_4 \\ \dot{x}_4 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ c1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \dot{x}_1$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \mathbf{x} + [0]\, \dot{x}_1$$

I chose to use an intuitive system that is MIMO (or single input for this case - SIMO) with fundamental performance limitations even with a feedback controller, i.e. finite bandwidth. This provides a challenge and an opportunity to dive deep into the performance/robustness tradeoff dilemma. Furthermore, this system can be easily constructed with simple materials (stepper motor drive, carts on bearings), so that an experimental study can follow. The system is a 4 mass-spring-damper assembly, with a schematic shown in fig. 1. For implementation, I would prescribe the velocity $u[t]$ with a stepper motor. Therefore, a feasible controller must consider rate limits.



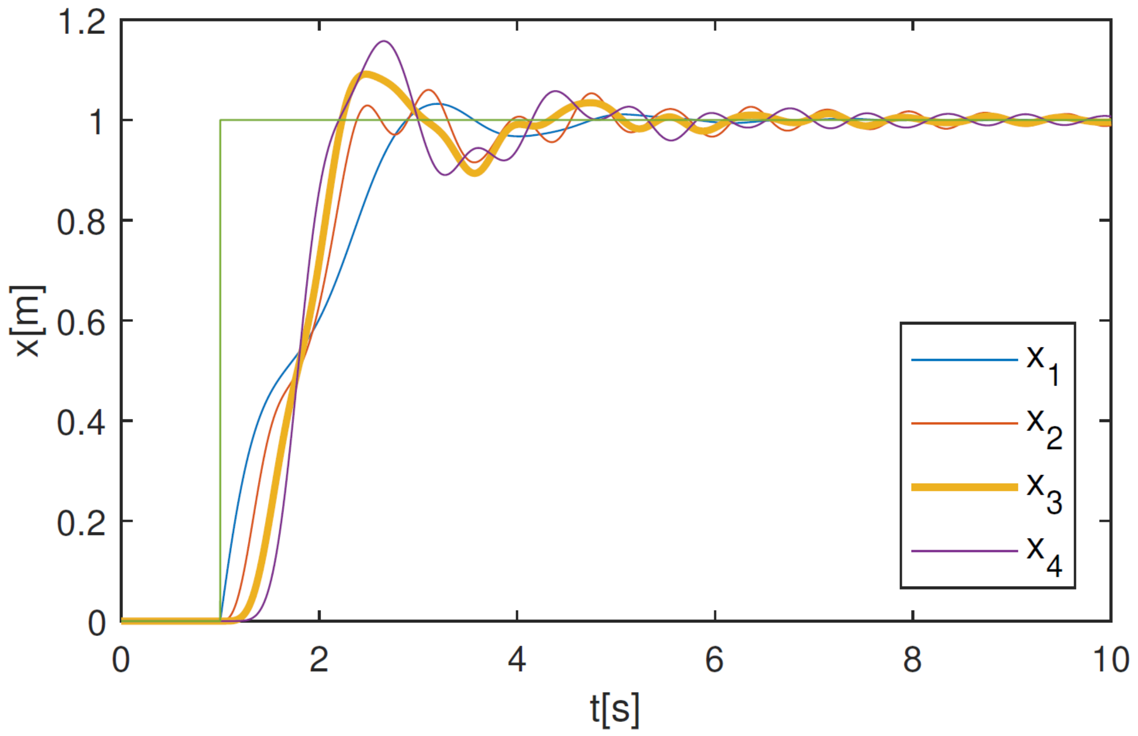
Controls Project overview – sample of results

Here, I am showing the step responses of the systems (controller design can be found in the pdf on linkedin). I found that for a well-tuned MPC controller, the performance is approximately equivalent to LQG. This is unsurprising given MPC is a finite-horizon LQR, and this is a deterministic simulation.

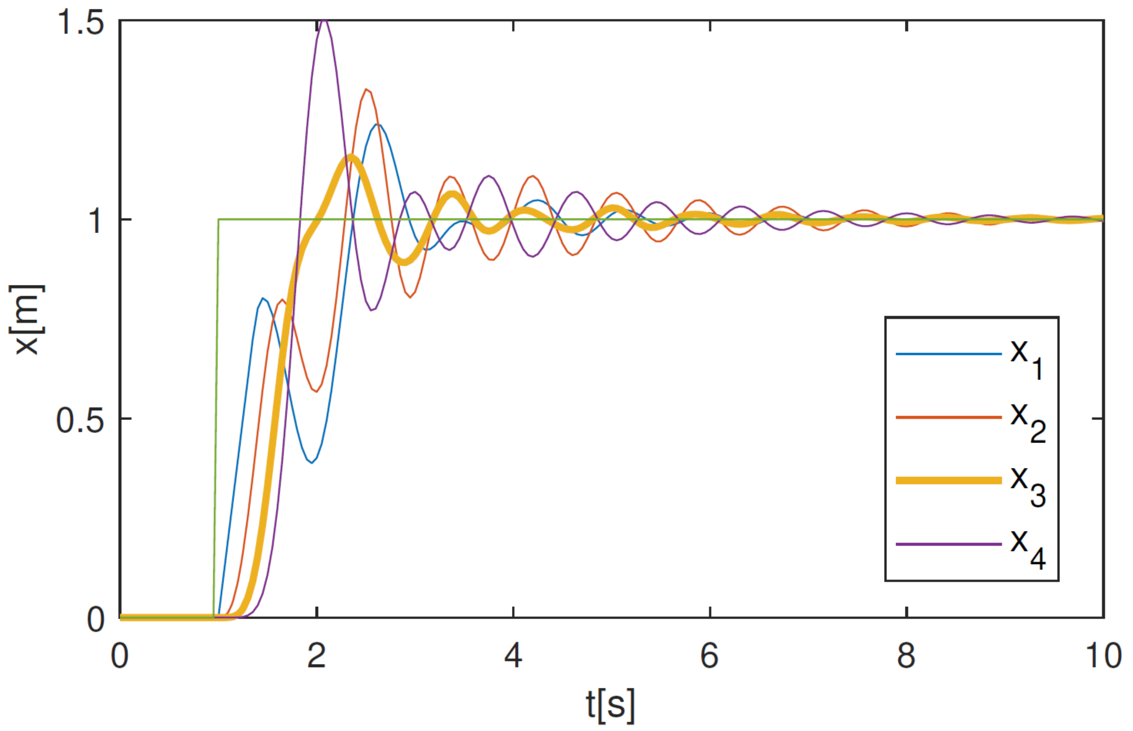
- The controllers were stable to disturbances and noise based on poles of sensitivity transfer functions

$$\begin{bmatrix} S_O(s)G(s) & T_O(s) \\ -T_I(s) & S_I(s)K(s) \end{bmatrix} \begin{bmatrix} v \\ r \end{bmatrix}$$

- The systems were also stable to moderate delay (10ms) based on phase margins
- Future work is to improve performance with addition of a feedforward block (non trivial due to non-square condition)



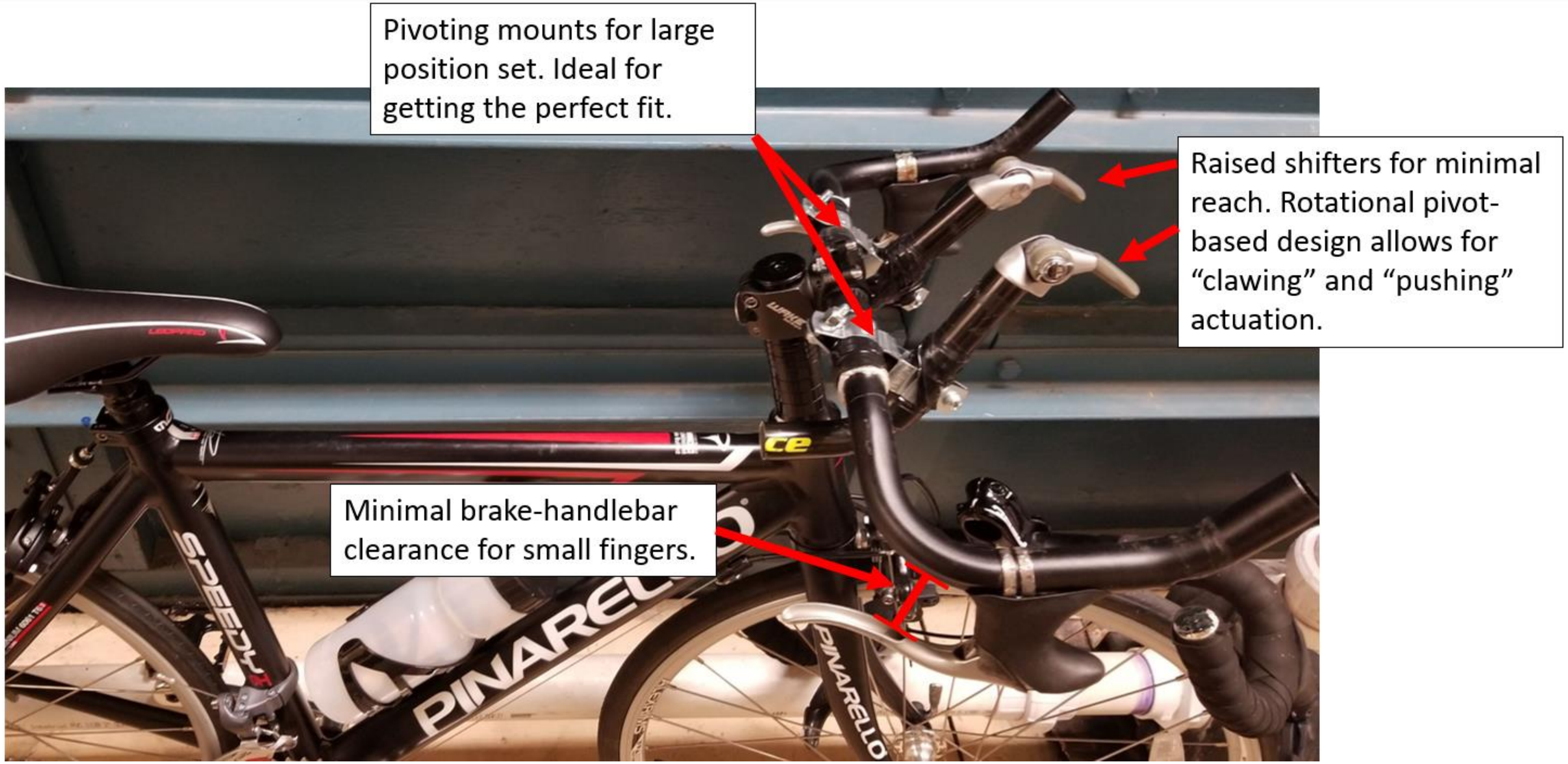
LQG step response



MPC step response

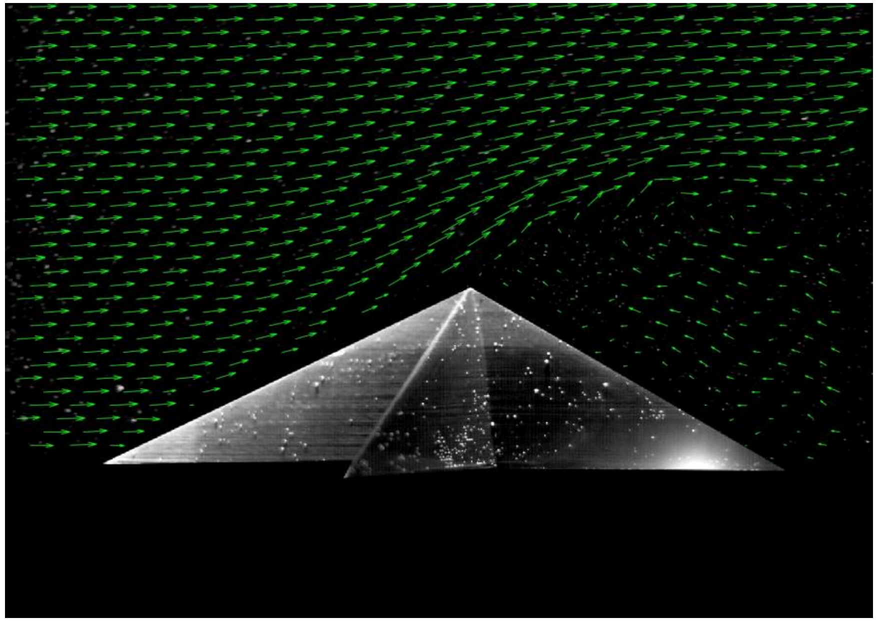
Bicycle mechanicking: Differently-abled bicycle augmentation

Description: During a team ride, I noticed that a member was having difficulty stopping and changing her gears. After a discussion and test session, I realized that she didn't have the ability to use the standard brake-shifters used for road bikes. I realized that no off-the-shelf products would solve her problems and decided to design a new "cockpit" so that she could safely and effectively ride her bike.



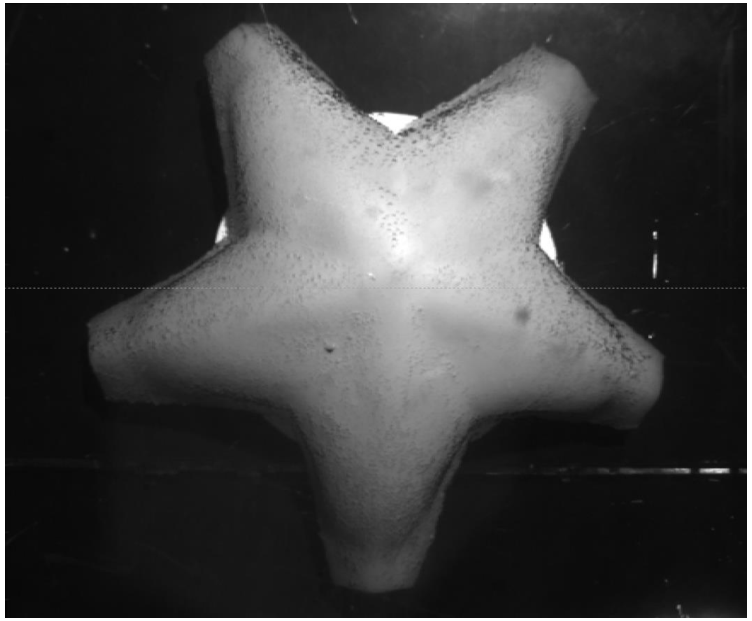
Academic Coursework

PhD work: 3 main projects: **Project overview**



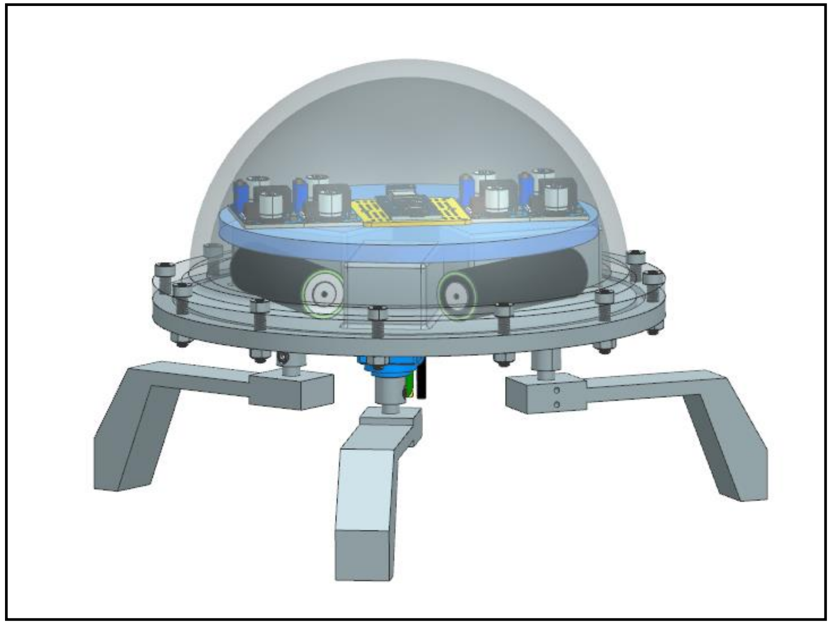
Rigid model study

- Designed multiple iterations of force sensor system
- Professional image acquisition (lighting, timing, etc.) processing/manipulation skills in MATLAB
- Simulated experimental system in Ansys Fluent to validate results
- Used simulation results for post-processing analysis to examine critically important flow features



Soft, morphing body

- Designed and coded Genetic Algorithm for global optimization of empirical black-box system
- Successfully designed and manufactured 2-actuator and 7-actuator robotic platform
- Used Arduino Mega dev board for control of 7 stepper motors
- Used UART to send instructions to embedded system from MATLAB



Crawling robot

- Designed and manufactured 3-arm radially symmetric sea star-inspired robot
- Designed a mathematical model and gait map for simulation studies
- Developed a controller for path-following using image feedback on neural network-based tracking camera (PIXYcam2) – 60Hz
- Manufactured waterproof electronics package for untethered system

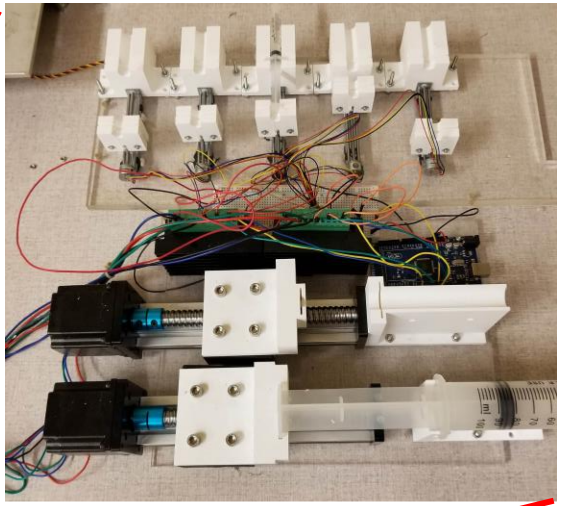
Publications

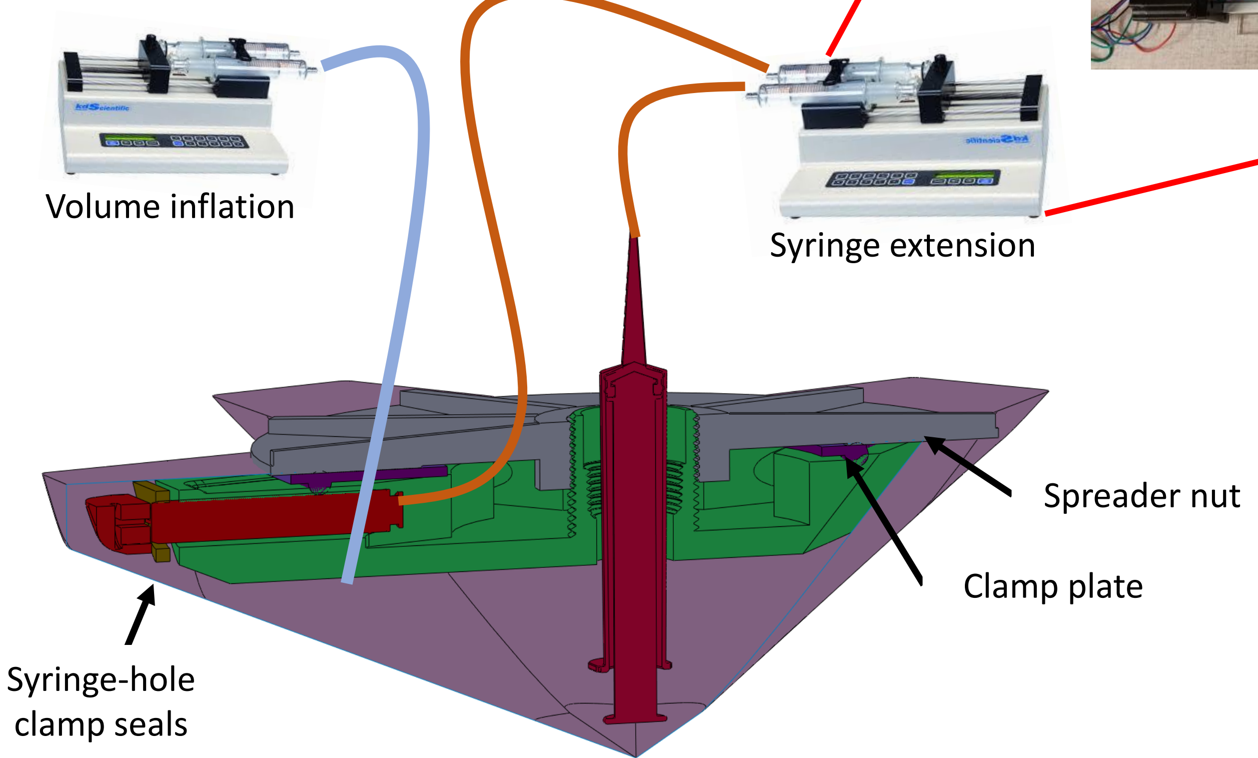
1. **Hermes, M.,** Luhar, M. (2021) Frictional locomotion of a tripedal radially symmetric robot. Submitted: Journal of Nonlinear Dynamics
2. **Hermes, M.**, McLaughlin, T., Luhar, M., & Nguyen, Q. (2021). Locomotion and Control of a Friction-Driven Tripedal Robot. arXiv preprint arXiv:2011.07370. ICRA 2021.
3. **Hermes, M.,** Luhar, M. (2021) Sea stars generate downforce to stay attached to surfaces. Nature Scientific Reports 11, 4513. https://doi.org/10.1038/s41598-021-83961-z
4. **Hermes, M.**, Ishida, M., Luhar, M., & Tolley, M. T. (2021). Bioinspired Shape-Changing Soft Robots for Underwater Locomotion: Actuation and Optimization for Crawling and Swimming. Bioinspired Sensing, Actuation, and Control in Underwater Soft Robotic Systems, 7-39.
5. Ishida, M., Drotman, D., Shih, B., **Hermes, M.**, Luhar, M., & Tolley, M. T. (2019). Morphing Structure for Changing Hydrodynamic Characteristics of a Soft Underwater Walking Robot. *IEEE Robotics and Automation Letters*, *4*(4), 4163-4169.
6. Li, Y., Mao, H., Hu, P., **Hermes, M.,** Lim, H., Yoon, J., ... & Wu, W. (2019). Bioinspired Surfaces: Bioinspired Functional Surfaces Enabled by Multiscale Stereolithography (Adv. Mater. Technol. 5/2019). *Advanced Materials Technologies*, *4*(5), 1970030.
7. Shahriari, A., **Hermes, M.**, & Bahadur, V. (2016). Electrical control and enhancement of boiling heat transfer during quenching. *Applied Physics Letters*, *108*(9), 091607.
8. Shahriari, A., **Hermes, M.**, & Bahadur, V. (2016, November). Dynamic and Controlled Tuning of the Boiling Curve During Quenching. In *ASME 2016 International Mechanical Engineering Congress and Exposition* (pp. V008T10A016-V008T10A016). American Society of Mechanical Engineers.

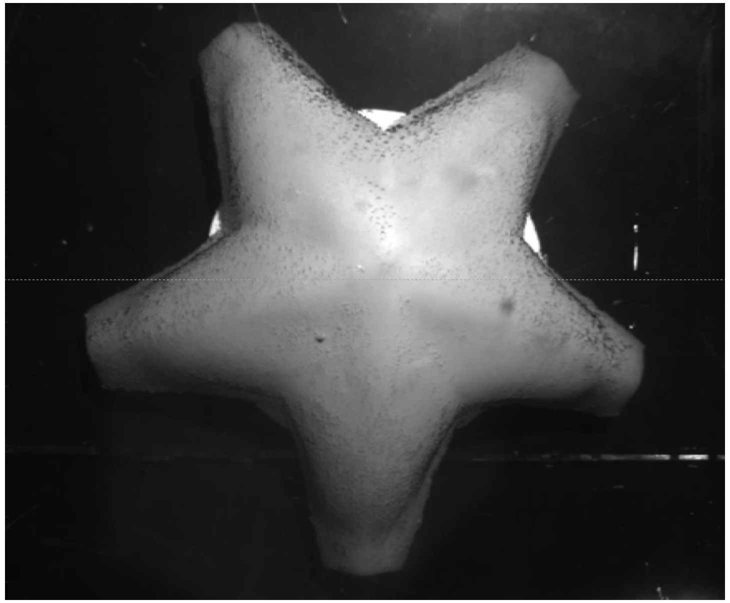
7-DOF morphing body – (In progress)

We developed a 7 syringe actuator shape changing robot to mimic how sea stars change their shape in response to wave activity (Hayne,2013)

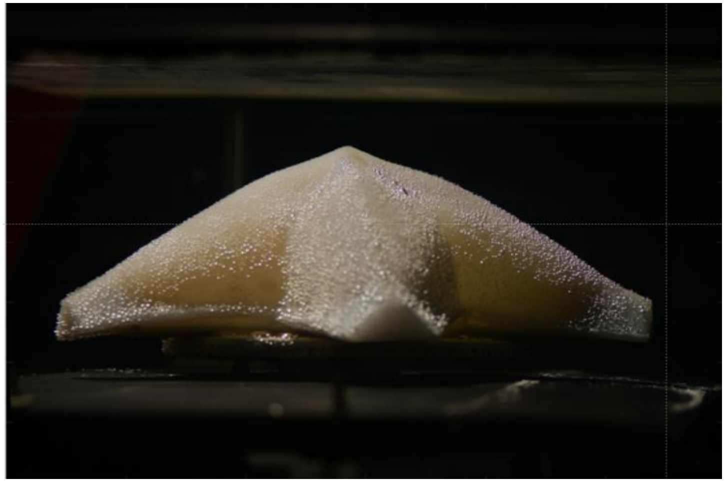
We applied a GA and are in the process of comparing GA to Bayesian Optimization, Stochastic Gradient Search, and Particle swarm algorithms







Top View

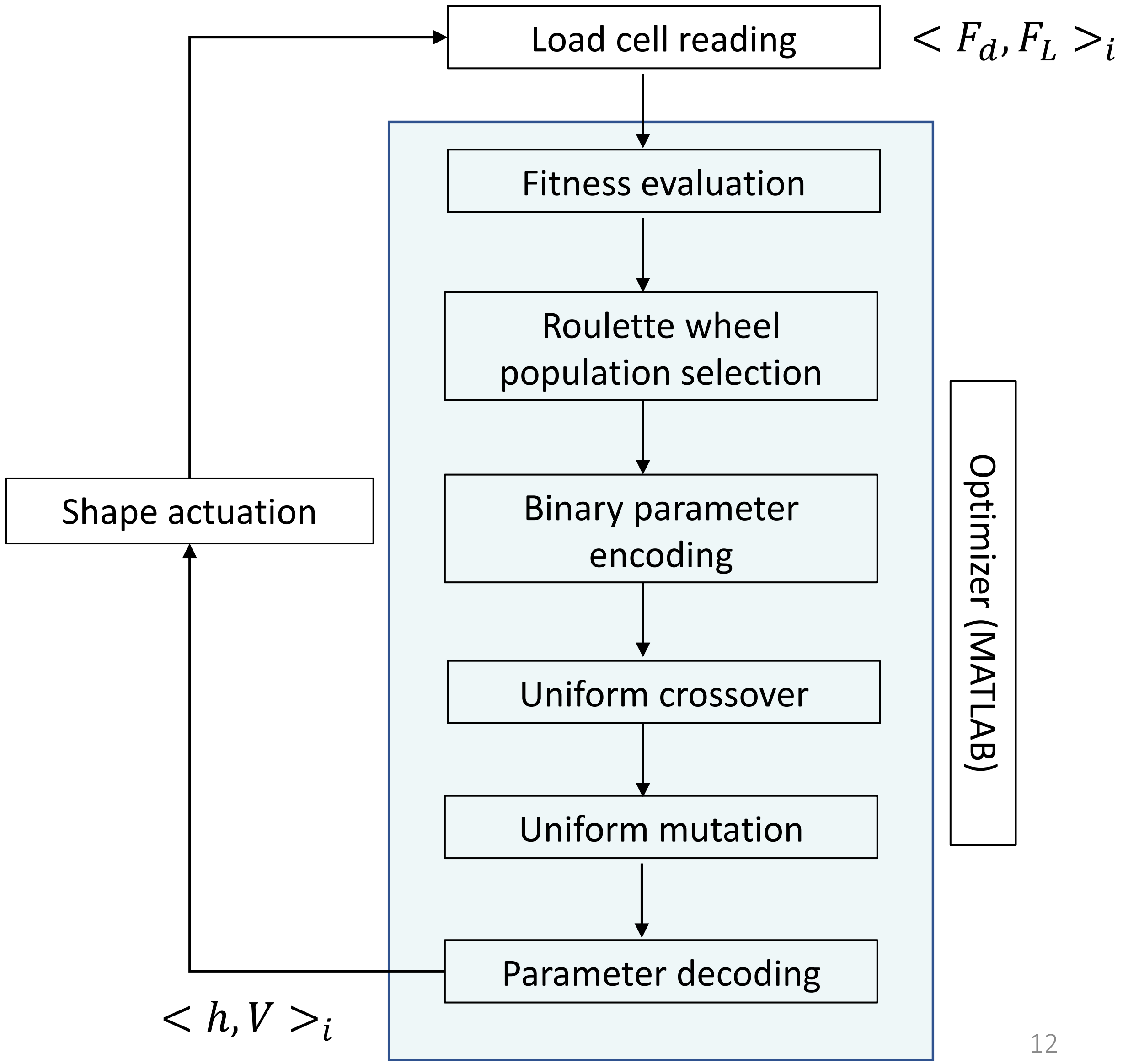


Side View

Optimization Algorithm (GA) – Publication (4)

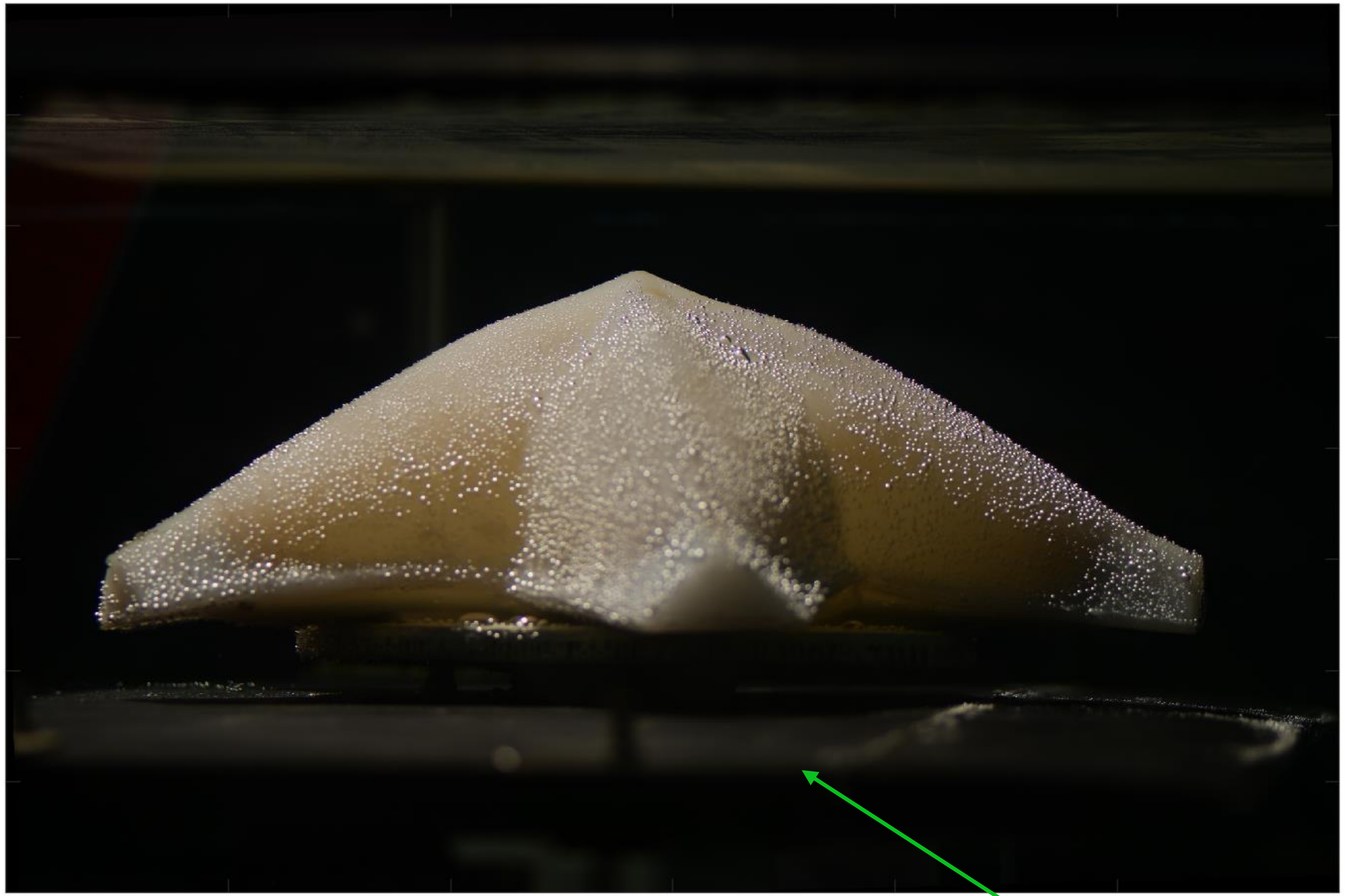
Genetic algorithm parameters:

- $\boldsymbol{x} = (\text{Volume } - V, \text{height} - h)$
- $P(\text{mutation}) = 0.1$
- $P(\text{crossover}) = 0.9$
- 8-bit binary encoding
- Population size: 10
- Stopping condition: 30 generations



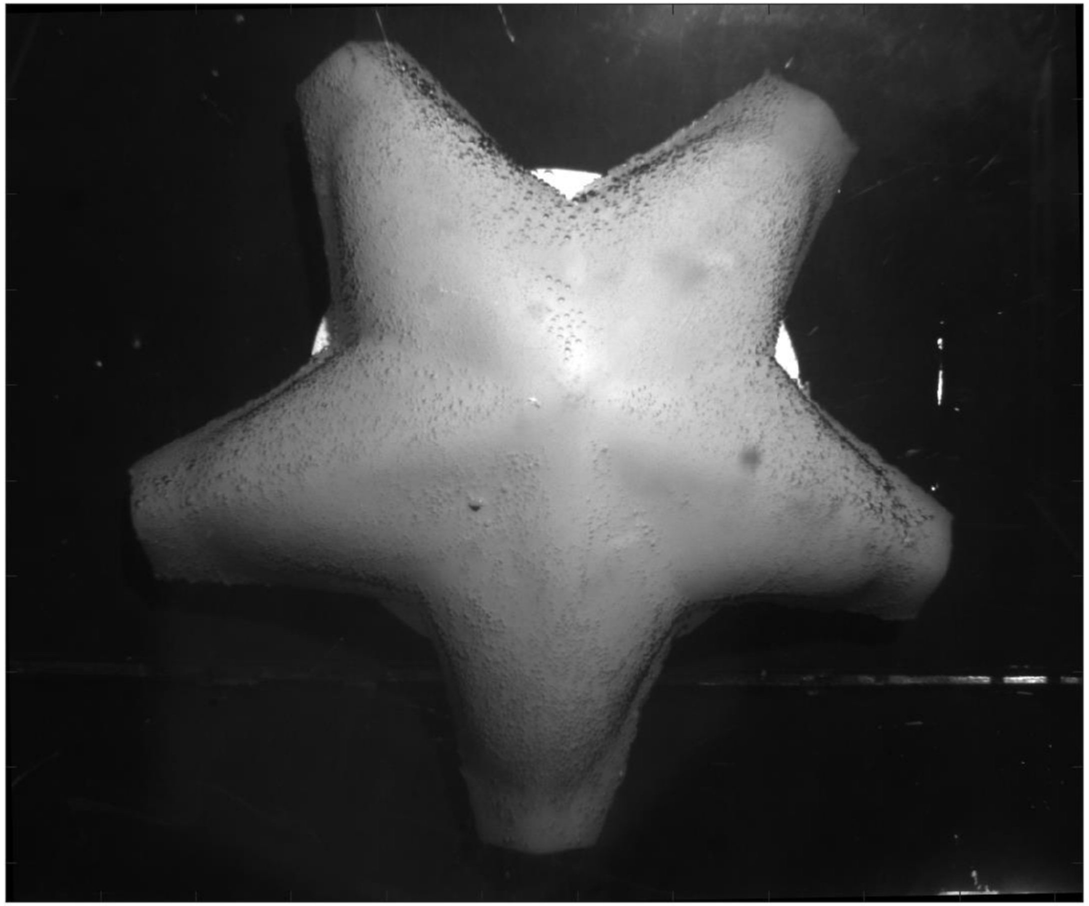
Demonstration of actuation abilities (VIDEO LINK)

Flow direction



Side view

Plate surface

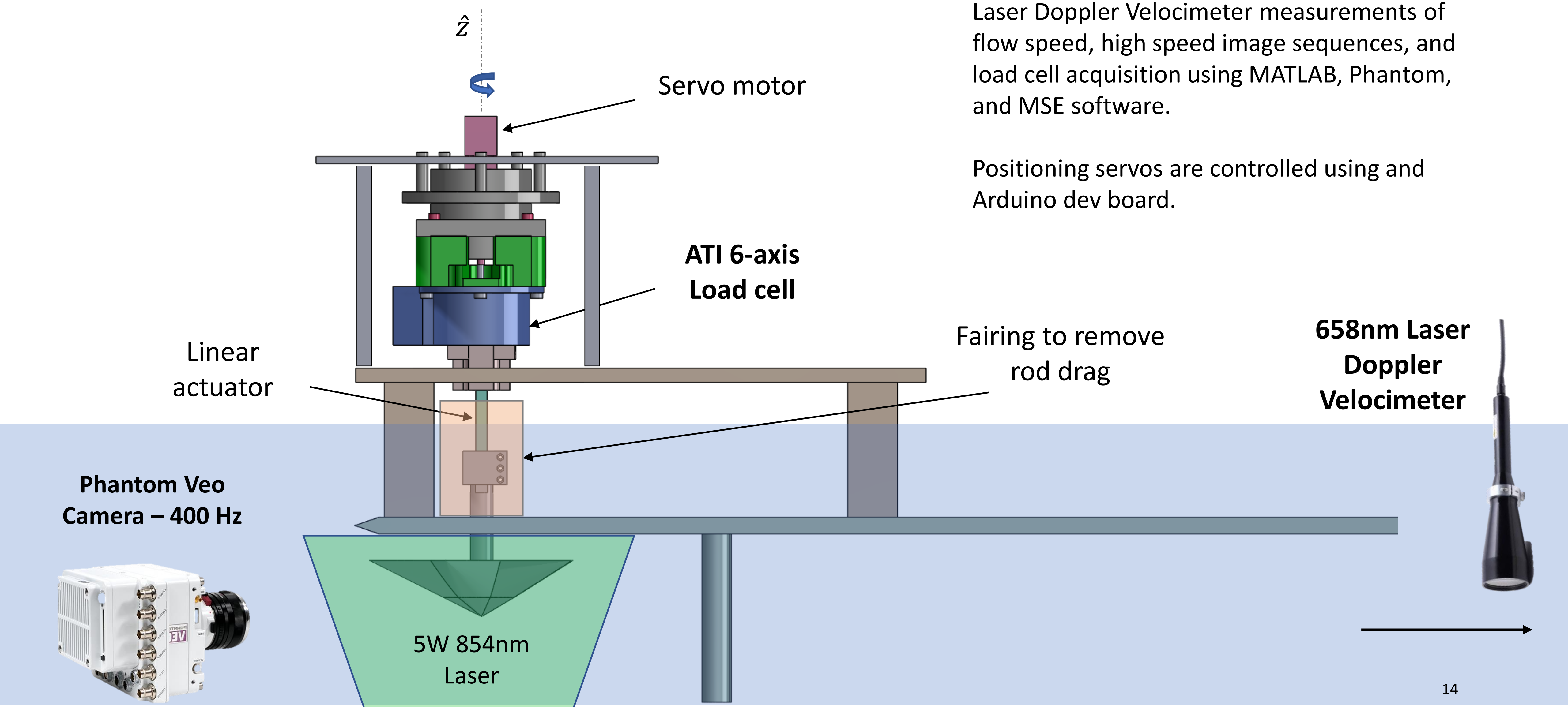


Top view

Force data acquisition - Publication (3)

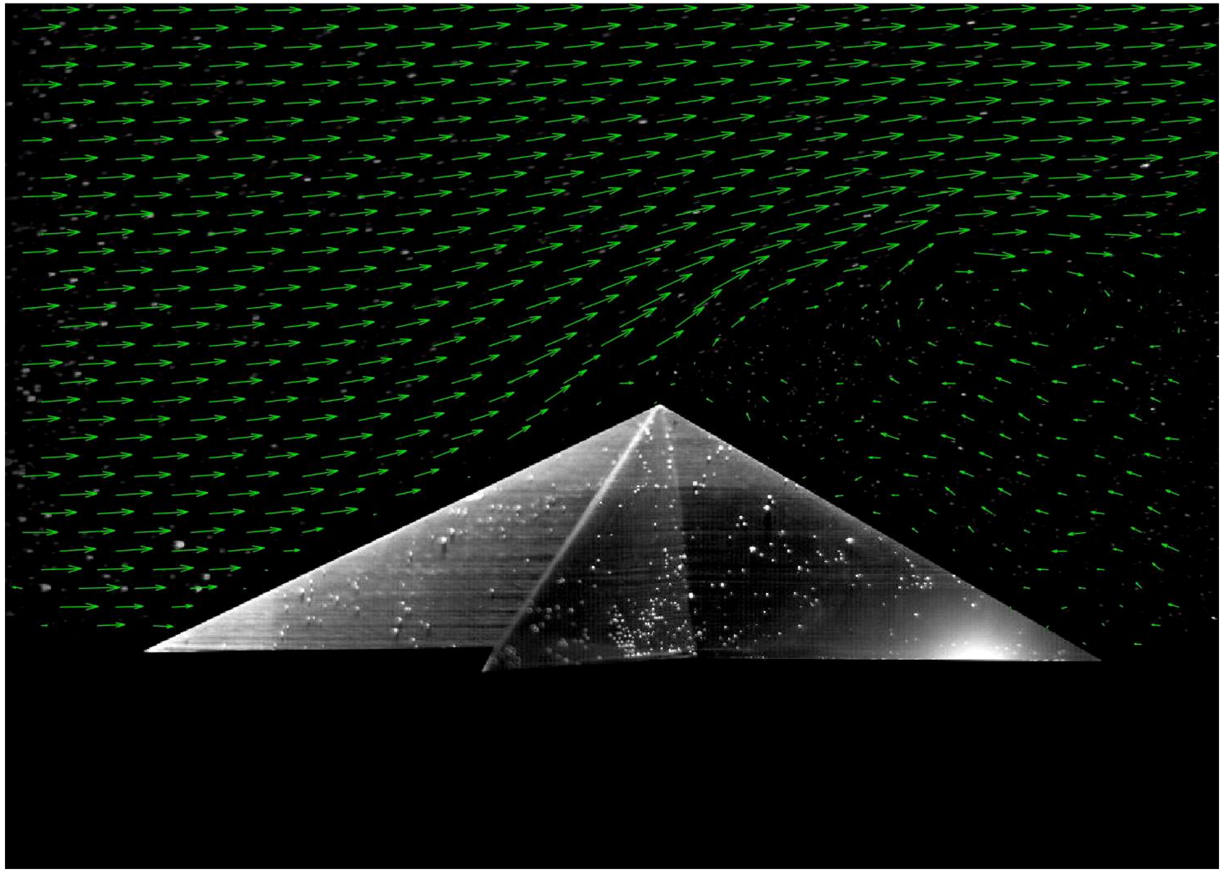
This is the final iteration of the force measurement system (see Appendix for details of prior systems). We simultaneously gather Laser Doppler Velocimeter measurements of flow speed, high speed image sequences, and load cell acquisition using MATLAB, Phantom, and MSE software.

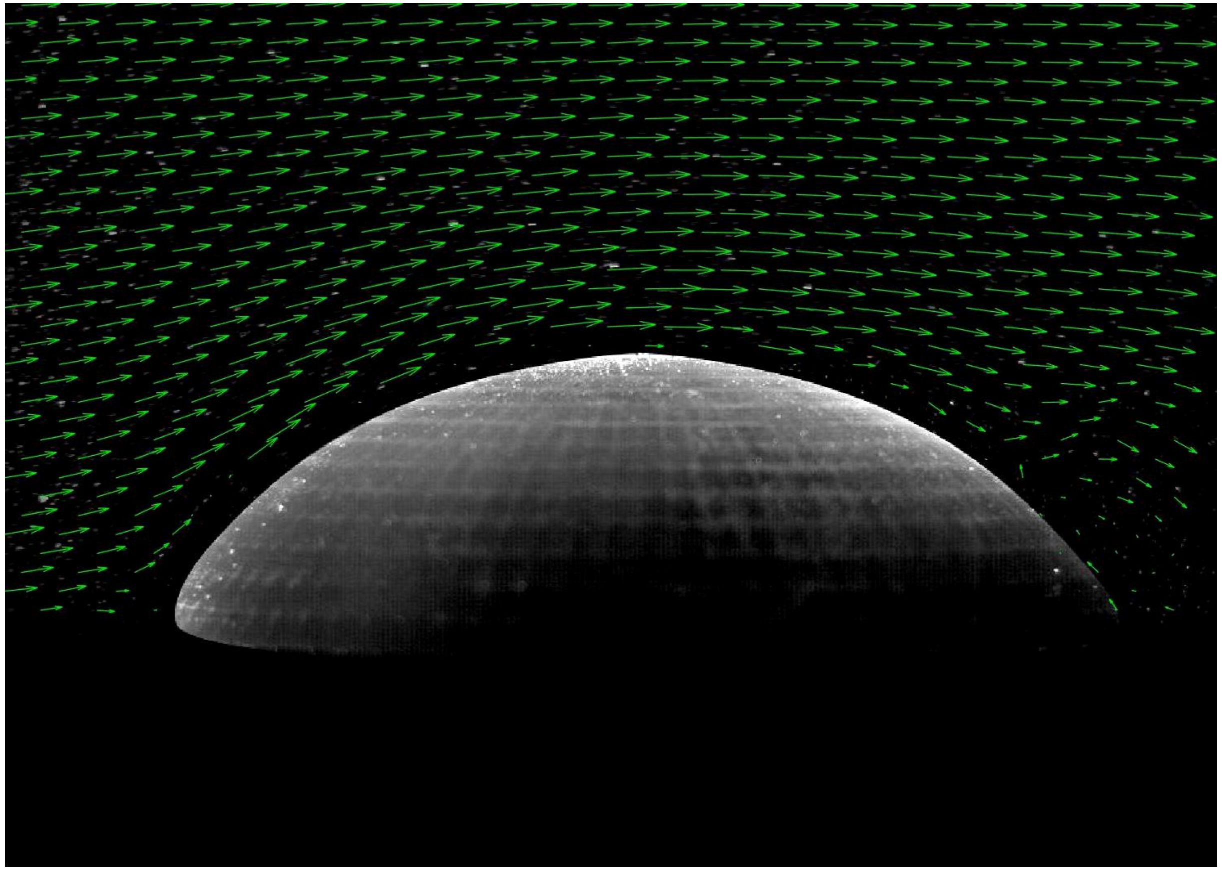
Positioning servos are controlled using and Arduino dev board.



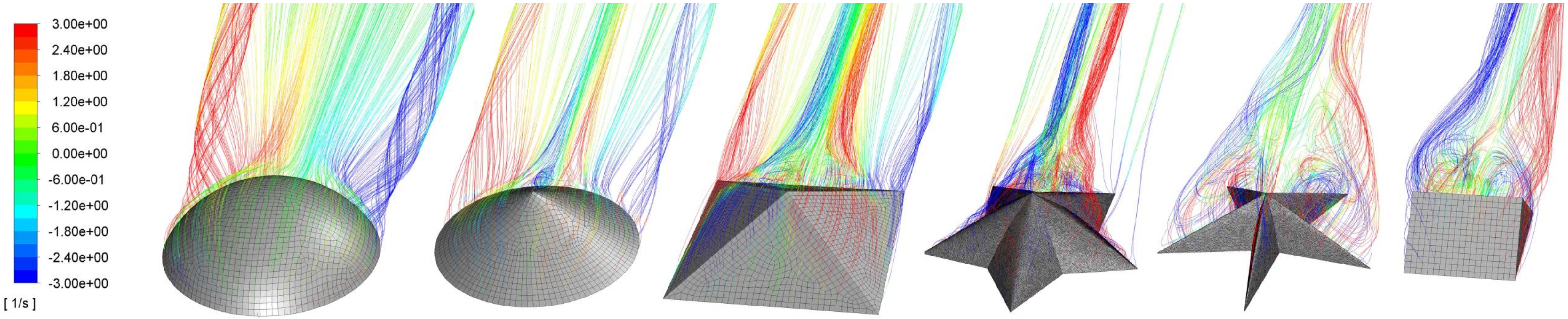
High speed vector field - Publication (3) – (VIDEO LINK)

Slowed 20x

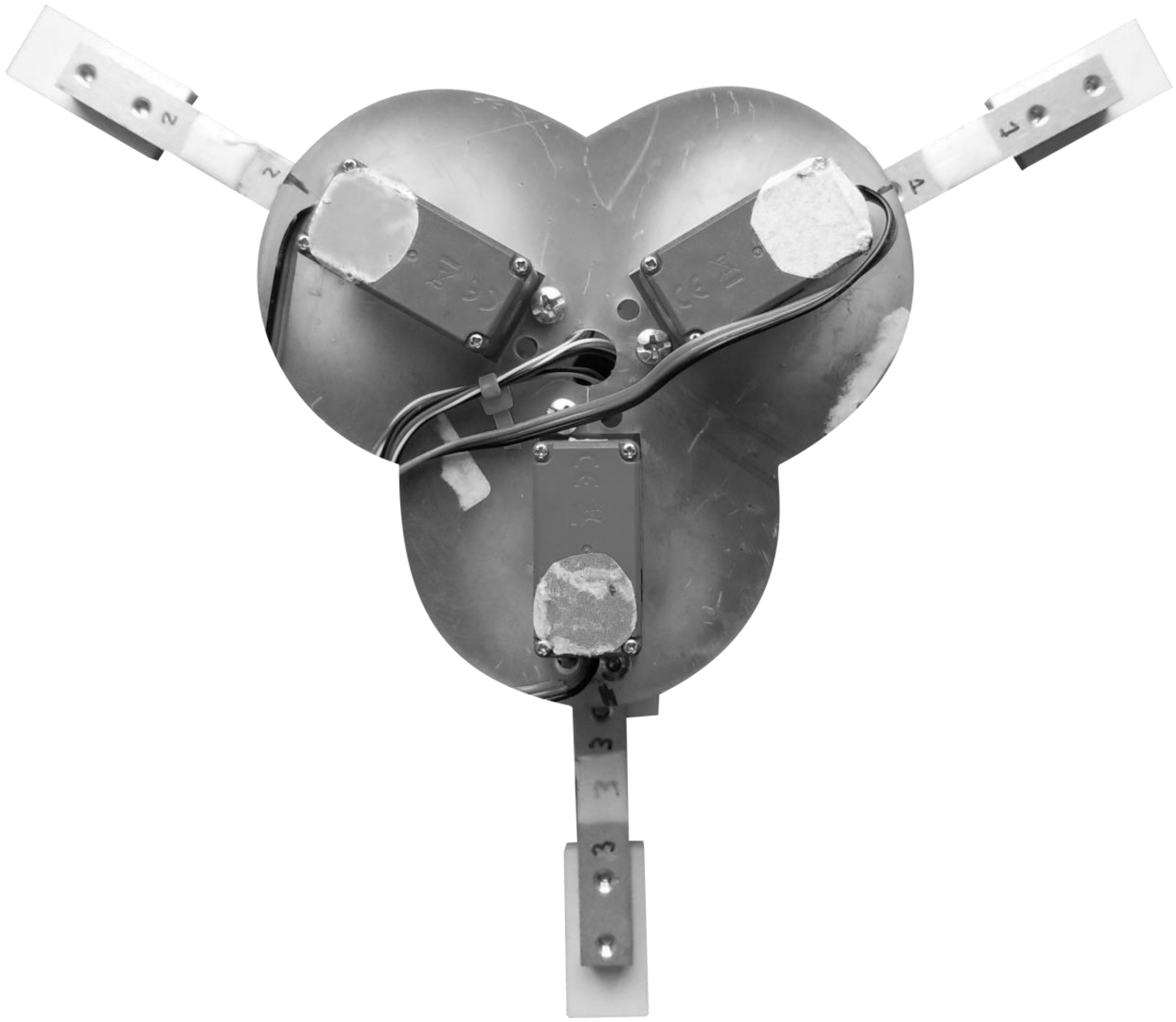




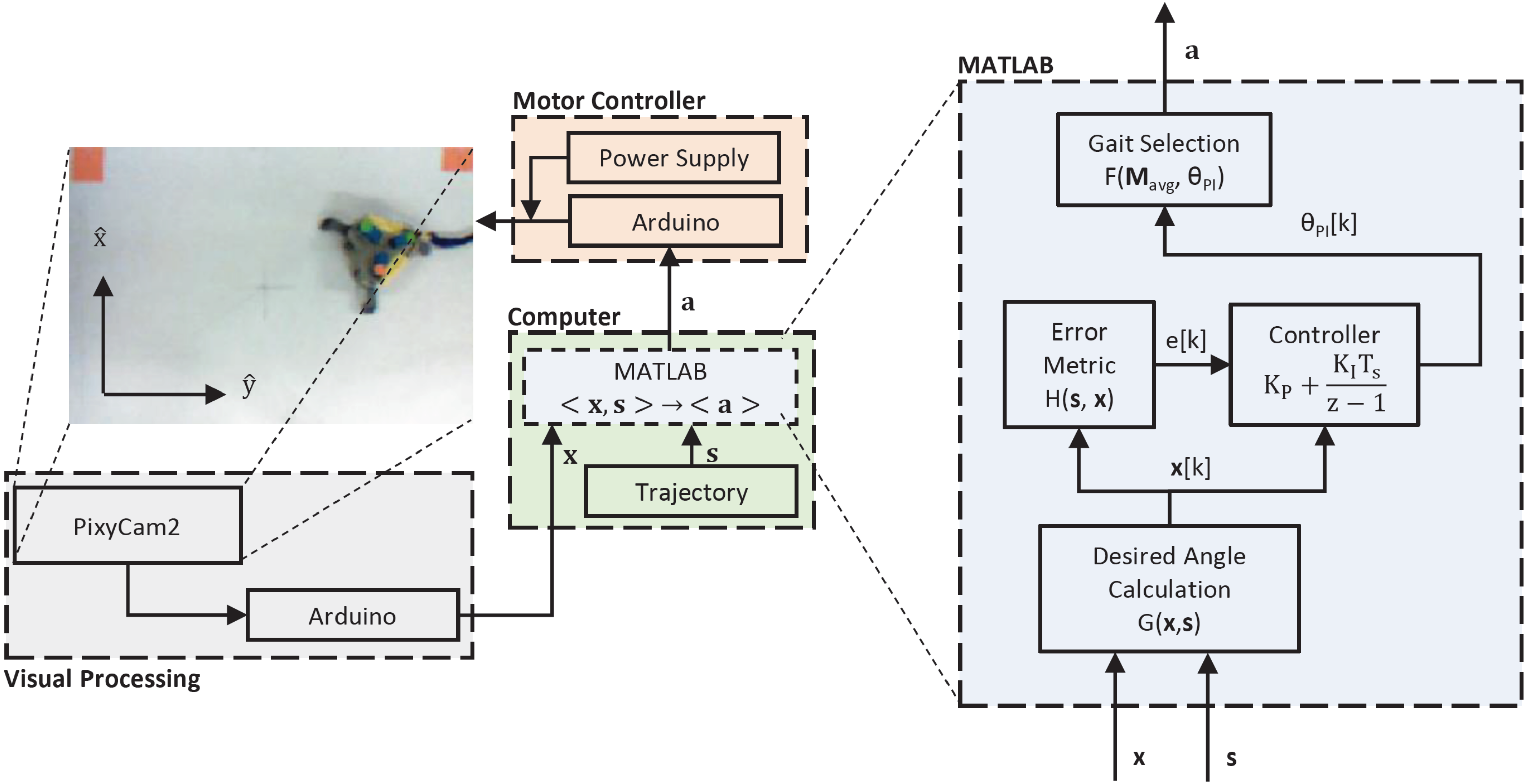
Fluent simulations (RANS $k - \epsilon$) - Publication (3)



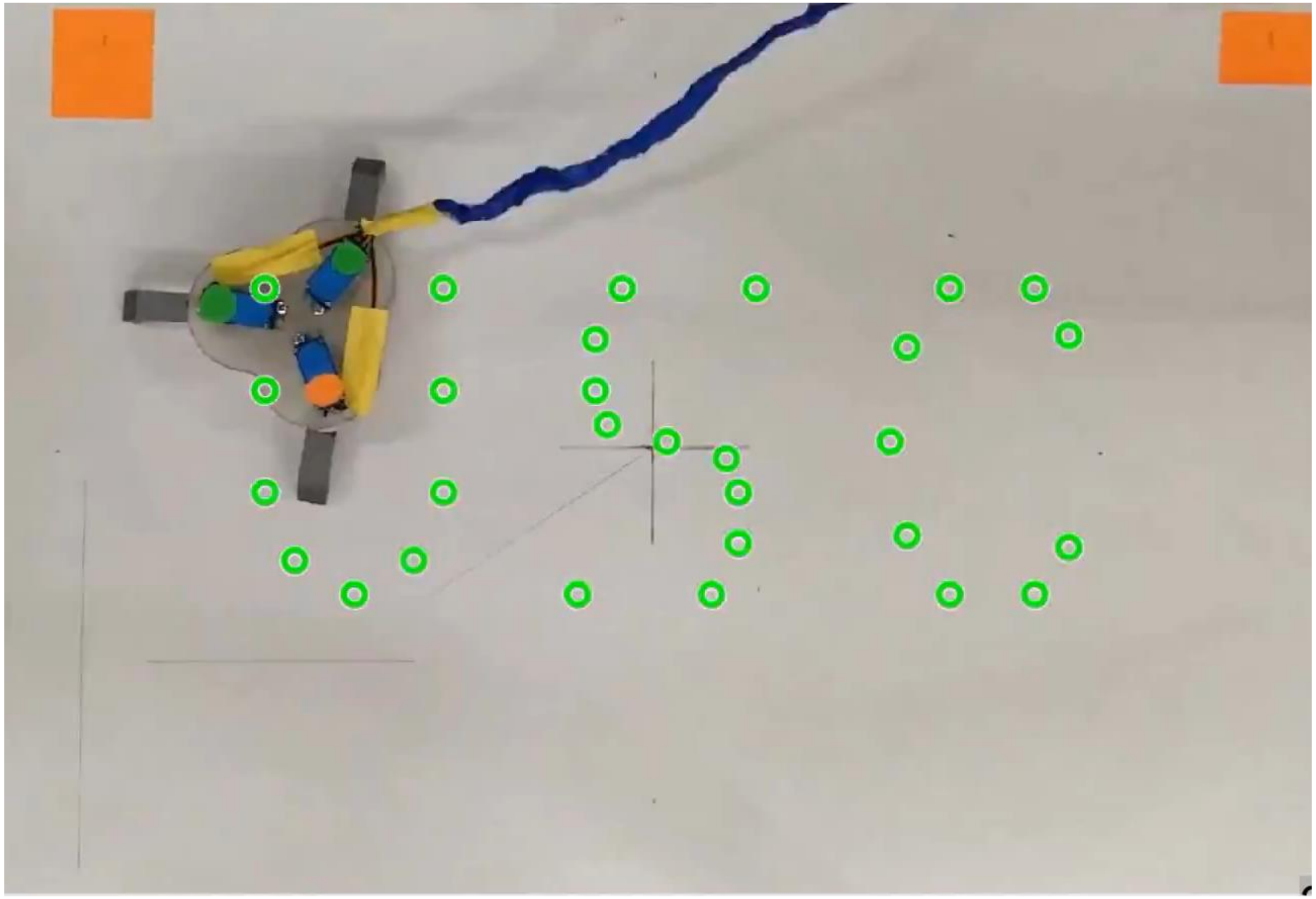
Robot with force sensors - Publication (1,3)



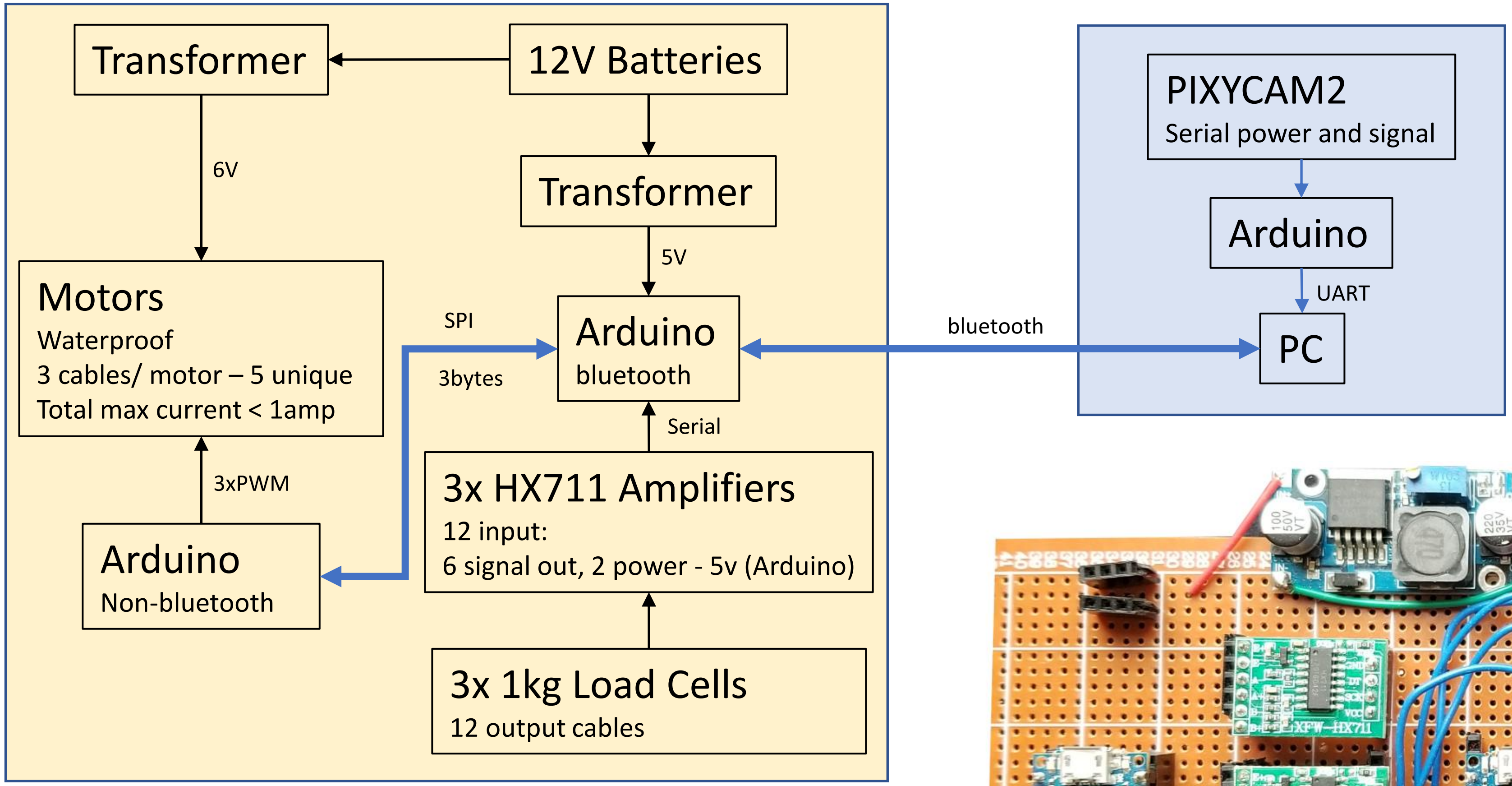
Robot control schematic- Publication (1,3)

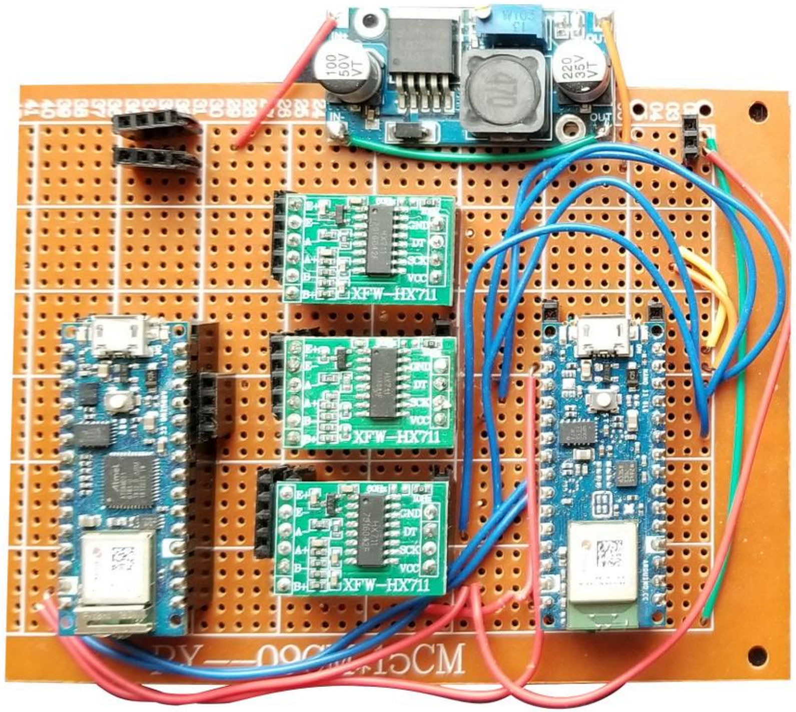


Robot path following- Publication (3)- (VIDEO LINK)



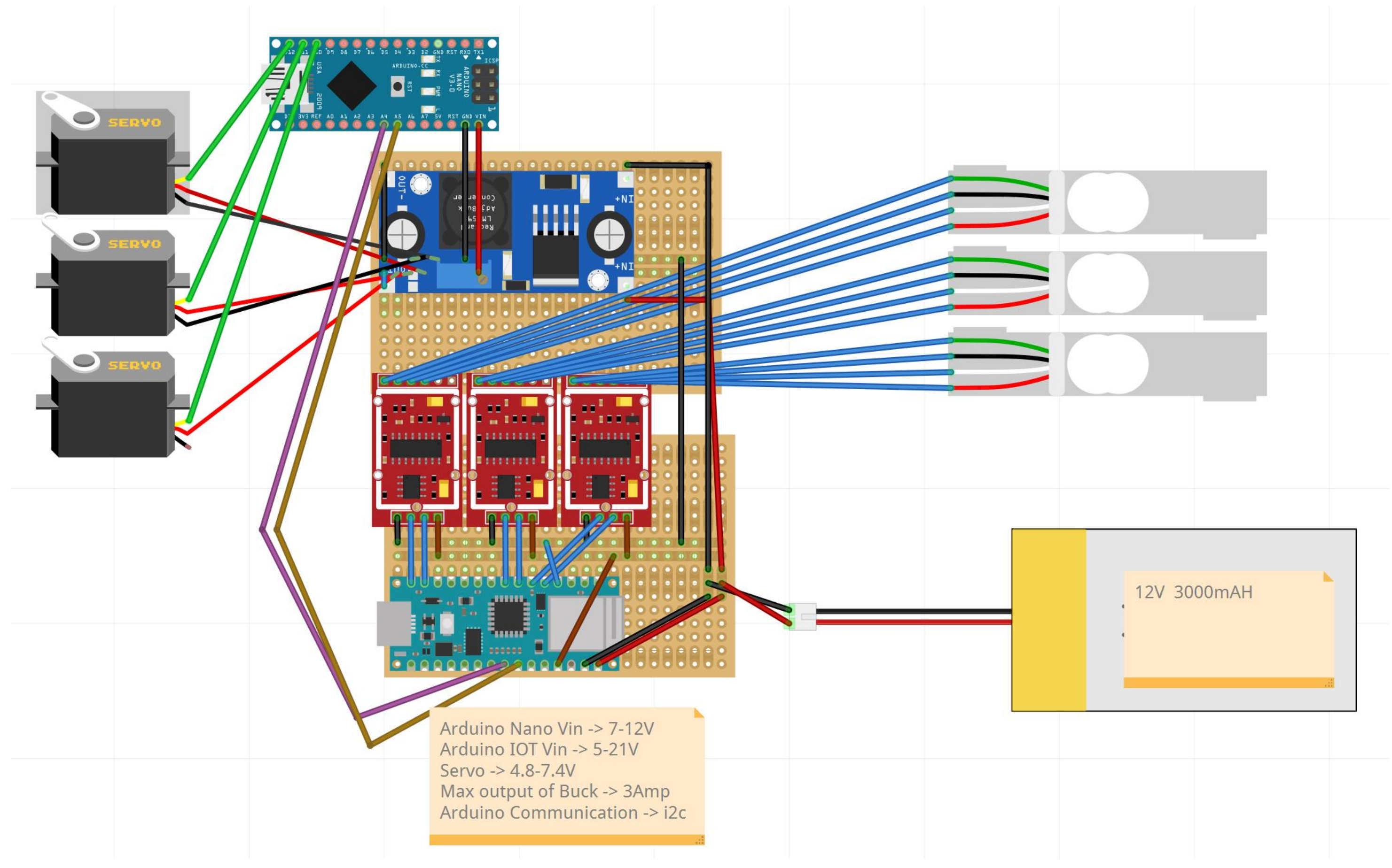
Untethered robot: electronics design schematic – in progress (manufacturing complete)



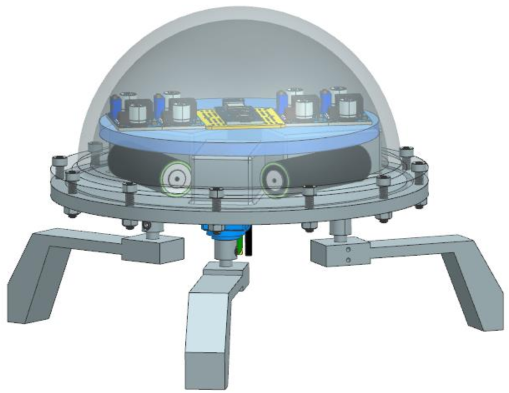


Untethered robot – in progress (manufacturing complete) – (VIDEO LINK)

4”



4”



Future plans

Academic Project Goals:

- 7DOF Silicone robot:
  - **Bayesian optimization** vs PSO vs GA for global optima
  - Consider optima drift in operation by constantly searching local gradients
- Tripedal robot:
  - Real time flow sensing from force sensors
  - Are there non-sinusoidal gaits that result in better performance?
    - **RL policy, geometric mechanics**

Personal Project Goals:

- **FreeRTOS**:
  - Implement metronome with BLE communication – send light pulses from MATLAB
    - This demonstrates performing a critical task (metronome) while accomplishing sub-priority tasks
- 4 mass-spring system
  - Improve performance with **feedforward control**
    - Currently pursuing **LSTM** network for model inversion
  - **iLQG and MPPI**
- Turtlebot
  - Implement dance procedure in simulation

Appendix

(Version 1)

Description: The first iteration of the hydrodynamic force measurement system was designed around an (inherited) submersible FUTEK 100g load cell. The sensor was mounted to a container underneath the test object, which was designed to allow lift and drag measurement by changing mounting pieces.

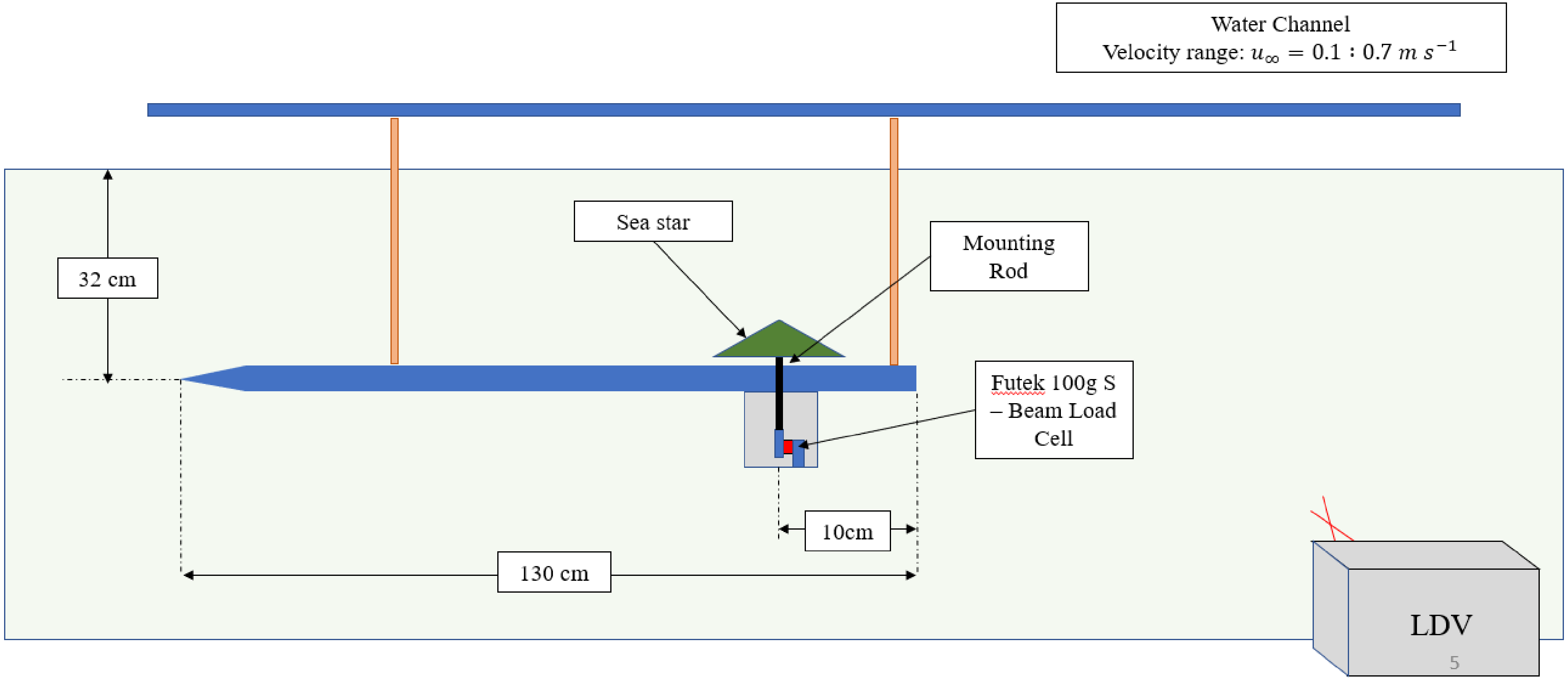


Figure: First iteration of underwater force measurement system. Futek submersible 1-Dimensional load cell was mounted to a rigid housing below the measurement region with a manually controlled lift/drag configuration.

Problems to resolve: We discovered that the 1-D S-beam load cell was too fragile to torque generated from the loads, and, after several testing trials, the load cell became damaged.

(Version 2)

Description: We wanted a robust (failure proof) method to test following the load cell damage, and thus designed a cantilever beam setup. Using a MAKO camera and MATLAB for image analysis, we measured deflection with ~ 0.01 mm resolution. Several beam thicknesses were tested for maximizing deflection and minimizing oscillation.

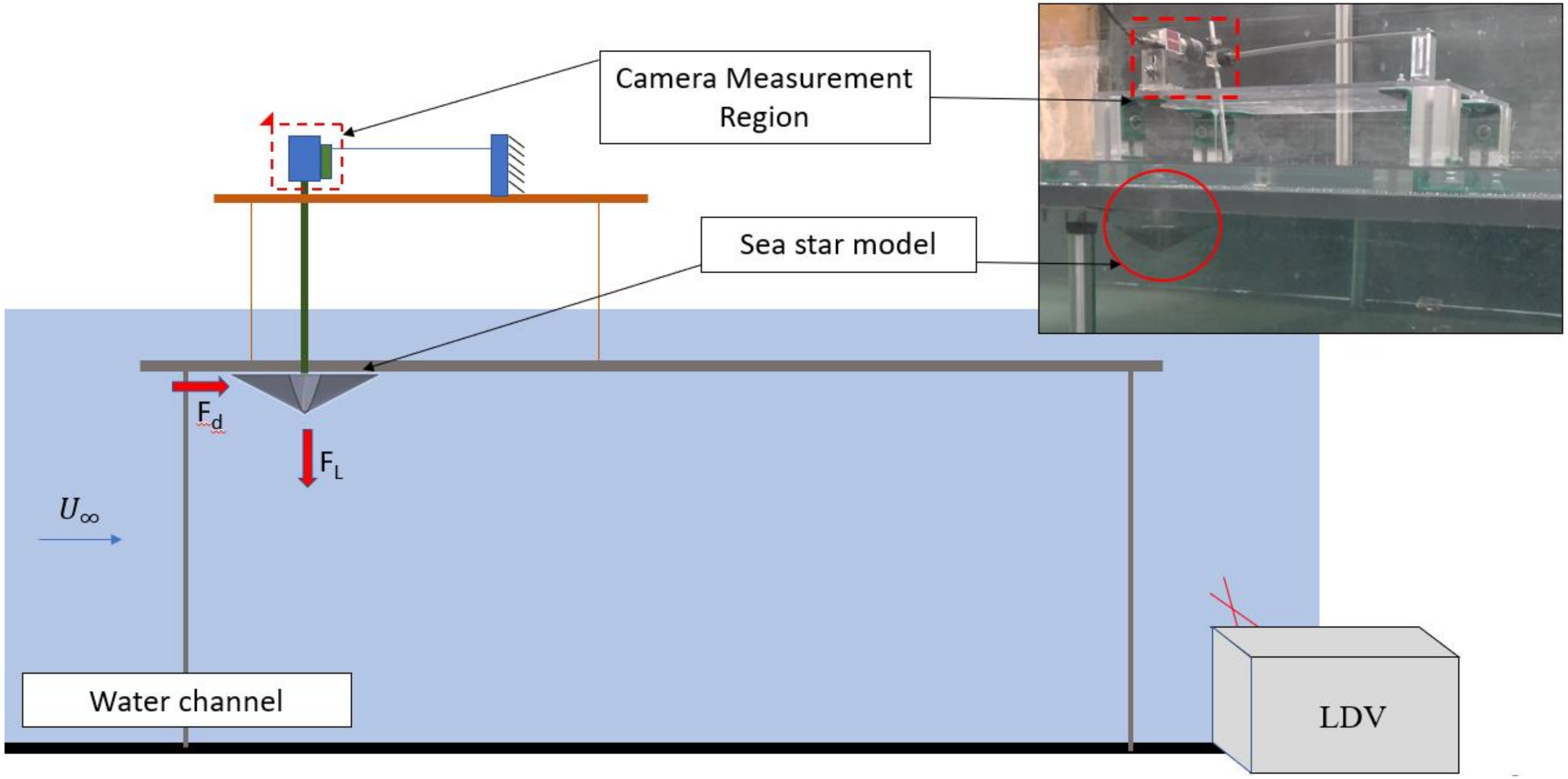
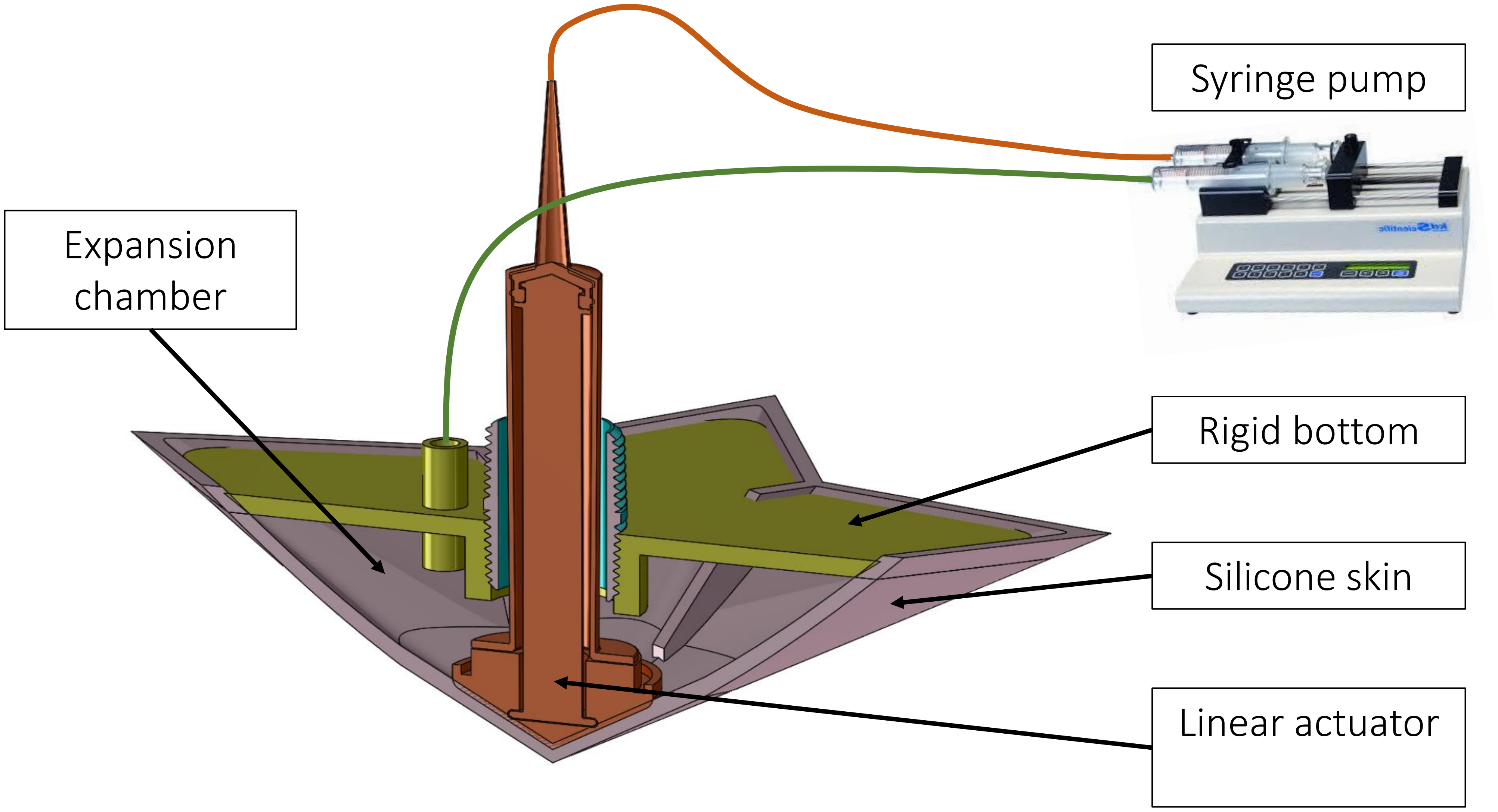


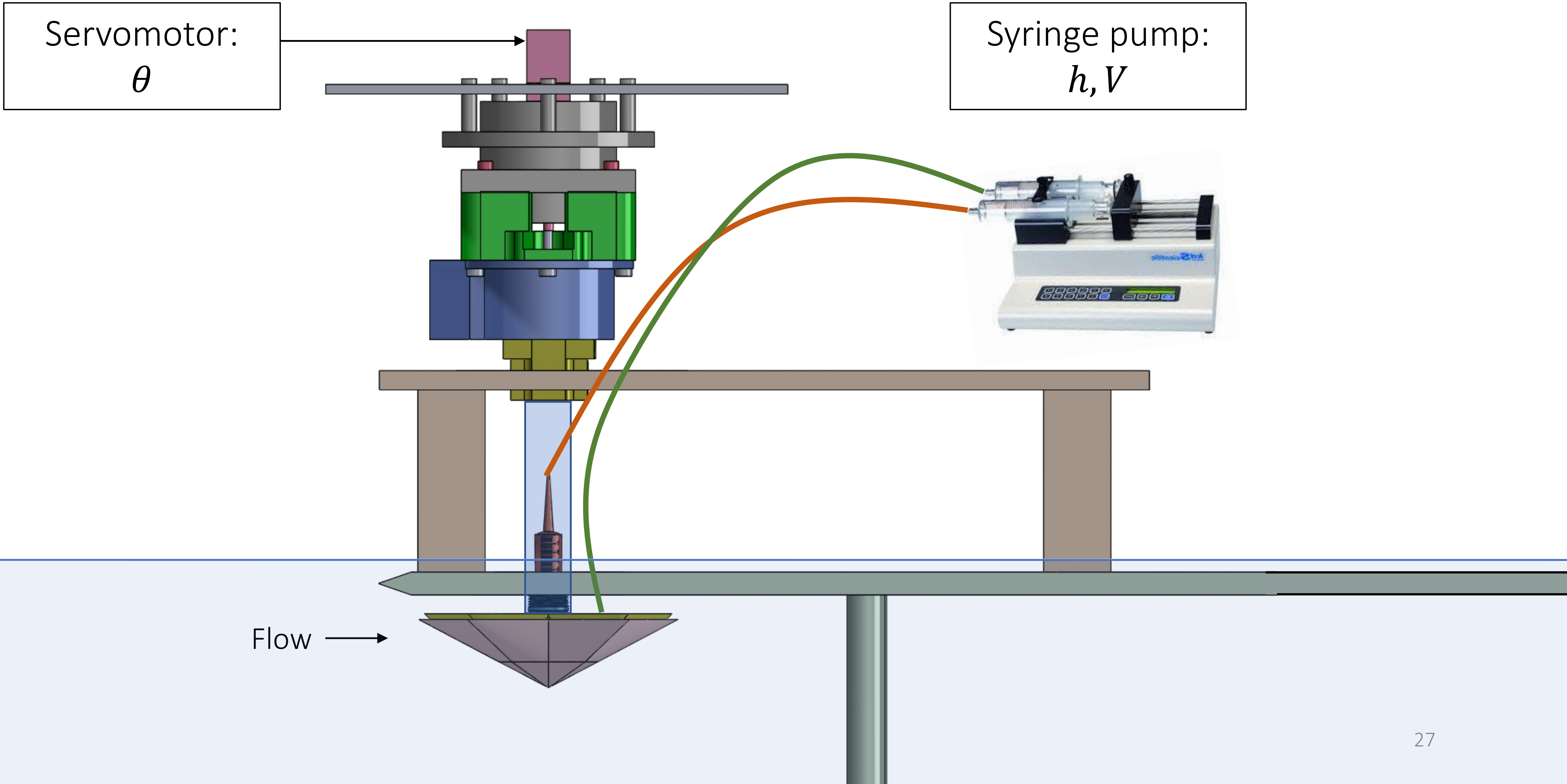
Figure: A linear beam of varying thicknesses (*116″,18″ ,14″*) was clamped to an aluminum mount with the free end attached to test rod assembly. Deflection was measured using a MATLAB controlled MAKO camera at 80 frames per second. Forces were decoupled using linear beam theory with the small angle assumption.

Problems to resolve: For this iteration we encountered several critical problems. First, all beams were significantly oscillatory. Even in steady flow, the broadband noise sensitivity gain was large. In addition, for measurable differences, we required a thin beam for more deflection. However, the angle of attack, which was proportional to deflection, was too variable for reliable data.

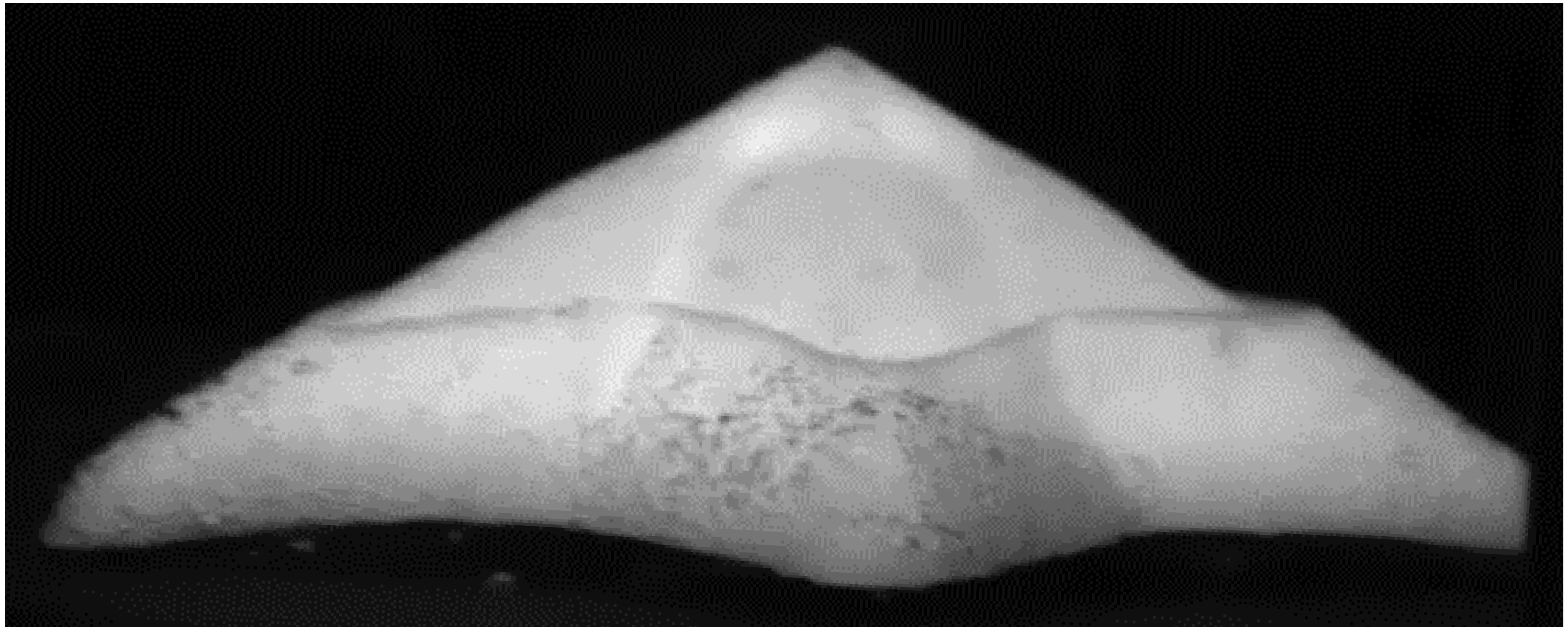
2-DOF morphing body



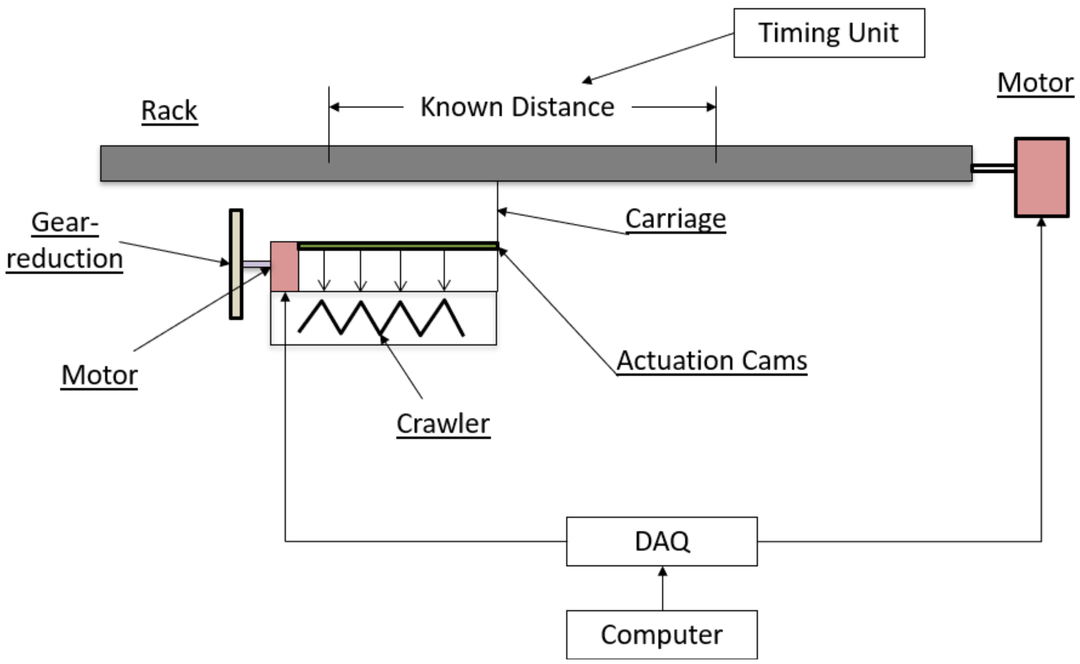
Experimental Setup



Shape Optimization in Action



Description: I built a traveling cam structure mounted to a traverse to study sinusoidal actuation of a simple segmented crawling structure. Phase and frequency were systematically varied and mapped to linear translation of the object. The empirical results were used to validate a mathematical model, which was used to extrapolate beyond the configuration space of the physical system.



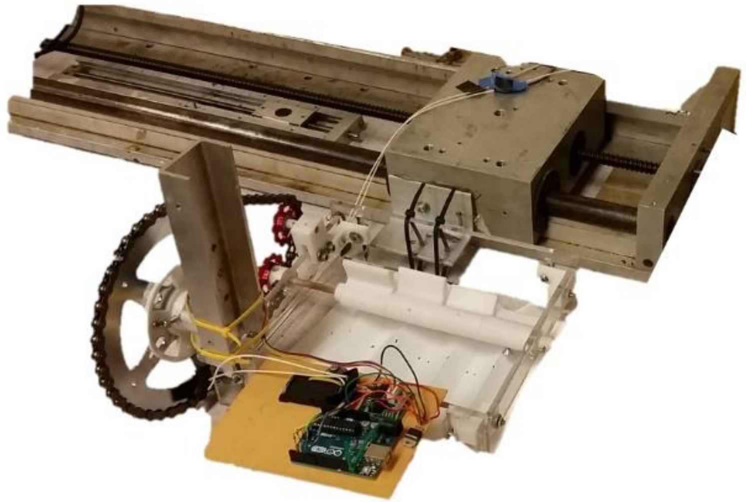


Figure: (a) Process diagram of the segment crawler, which was initially made of paper. (b) Two stepper motors are driving both the camshaft and translational carriage. Linear velocity from the crawling body is matched by the translation stage.