PORTFOLIO

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MS in Aerospace Engineering, University of Illinois

BS in Mechanical Engineering, Mahindra University, India

Specialization in Controls and Dynamical Systems

Extensive hands-on experience through lab work

Robotics and mechatronics experience

PROJECTS

- Master's thesis
- Kalman filtering for orbit determination
- Structural design optimization
- UIUC Hopper
- Chaotic fluid mixing in micro-channels

I. MASTER'S THESIS

- Synthesized a novel position tracking controller for a quadrotor that minimized feedback data-rates from motion capture.

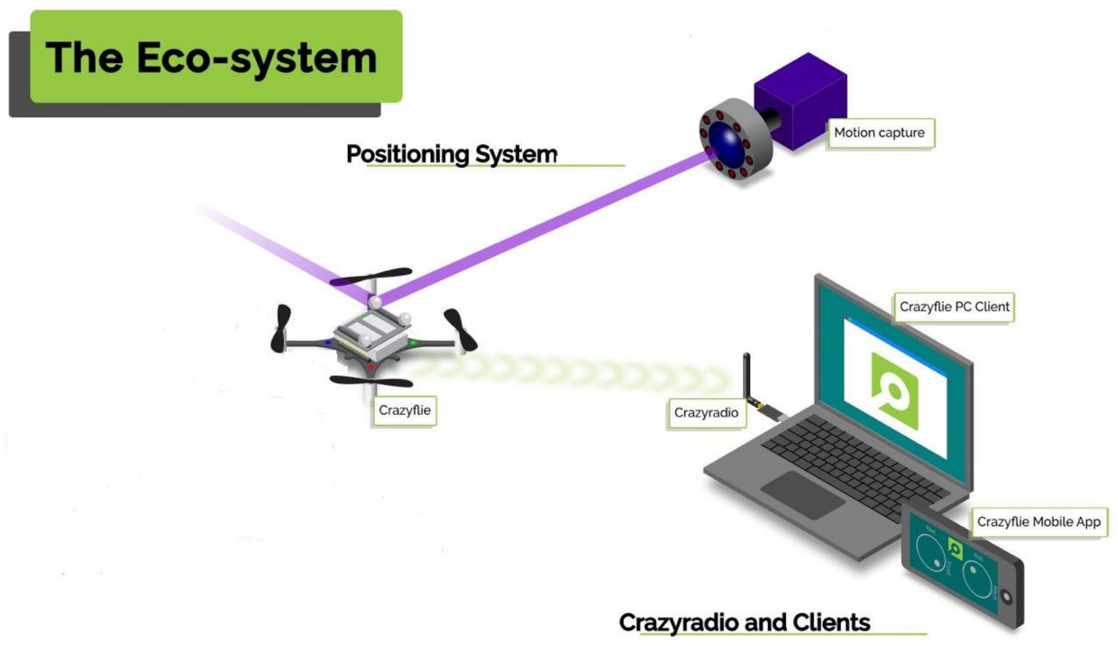
- Stages involved: (1) System/Parameter identification, (2) Model-in-Loop and Software-in-Loop simulations and (3) Hardware testing

- Implemented on open-source STM32 based project.

Industry Impact

- First of its kind study to implement results in literature on data-constrained control system on a practical system.

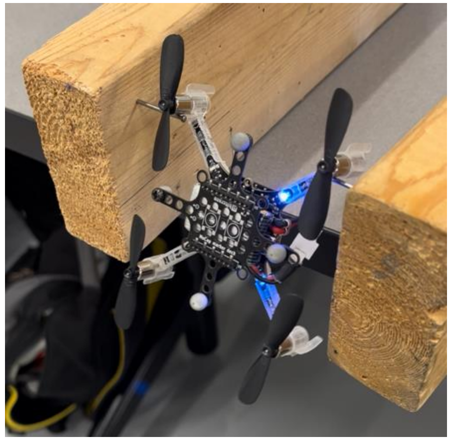
- Demonstrated a significant reduction in data-rates, allowing simultaneous control of a large swarm of robots.

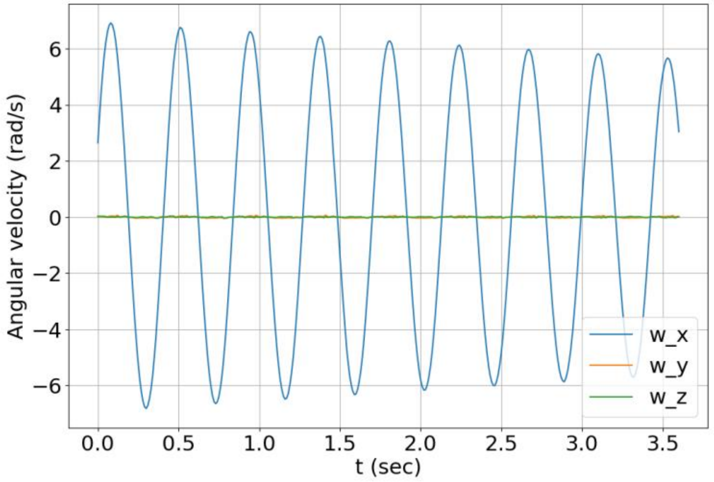


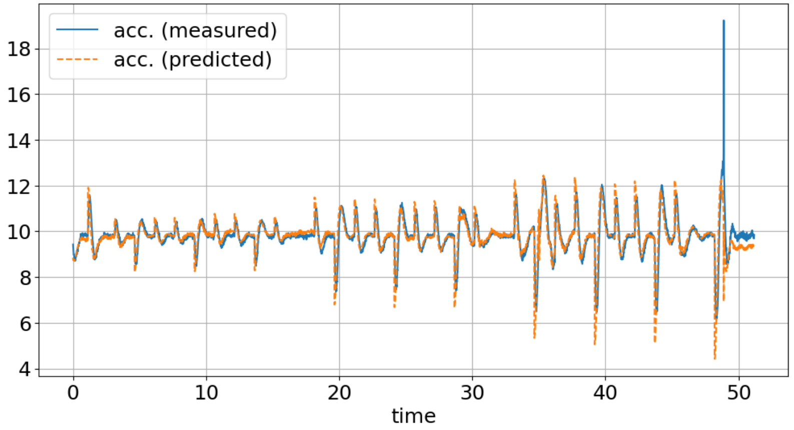
Picture credit: https://www.bitcraze.io/

System ID

1. Inertial parameters:
    - Made a makeshift rig to swing the drone about the 3 rotation axes.
    - Used the on-board gyroscopes to record angular velocities along different axes.
    - This allowed the estimation of the mean time period of oscillations and thereby the moments of inertia.
2. Force coefficients:
    - Ran a sequence of take-off and landing maneuvers and recorded data from onboard accelerometers and motor PWM signals.
    - Fit a linear relation between the commanded PWM signal duty cycle and the upward thrust on the drone.
    - The estimated force coefficients resulted in a close match between the measured and predicted z-acceleration.

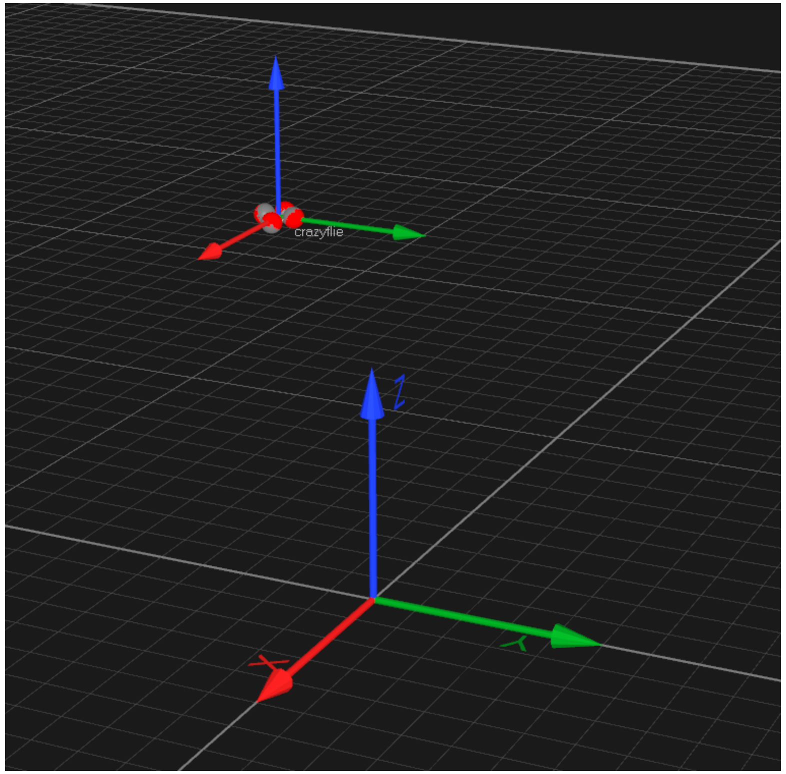






Qualisys motion capture system

- Established standard operating procedure for the AE dept for calibration and usage.
- Carried out extensive flight testing to develop suitable passive marker configurations.
- Quantified the uncertainty in 6DOF data computed by motion capture system.
- The motion capture stream was identified as the bottleneck in the overall state estimation process.
- As Lead Teaching Assistant for Autonomous Systems Lab, perform fine-tuning of motion capture cameras to ensure high-quality 6DoF streams.



Results

- Software-in-loop simulation show that proposed controller can closely track the true position of the drone.
- Proposed method consumes 6 bytes/sec compared to 12bytes/sec consumed by the stock controller.
- This allows packing more data in a single radio packet, allowing simultaneous control of multiple drones.

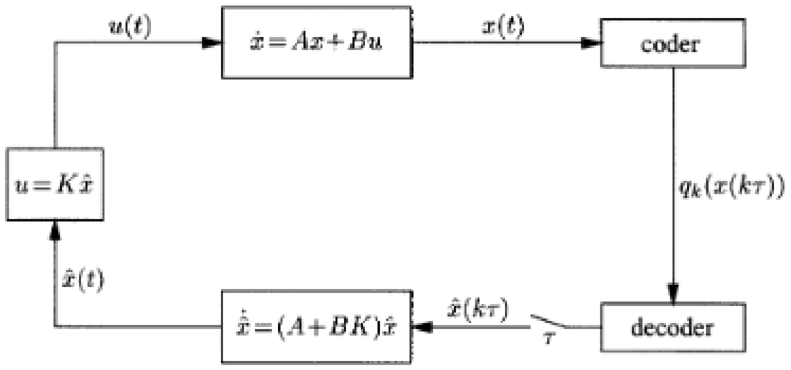
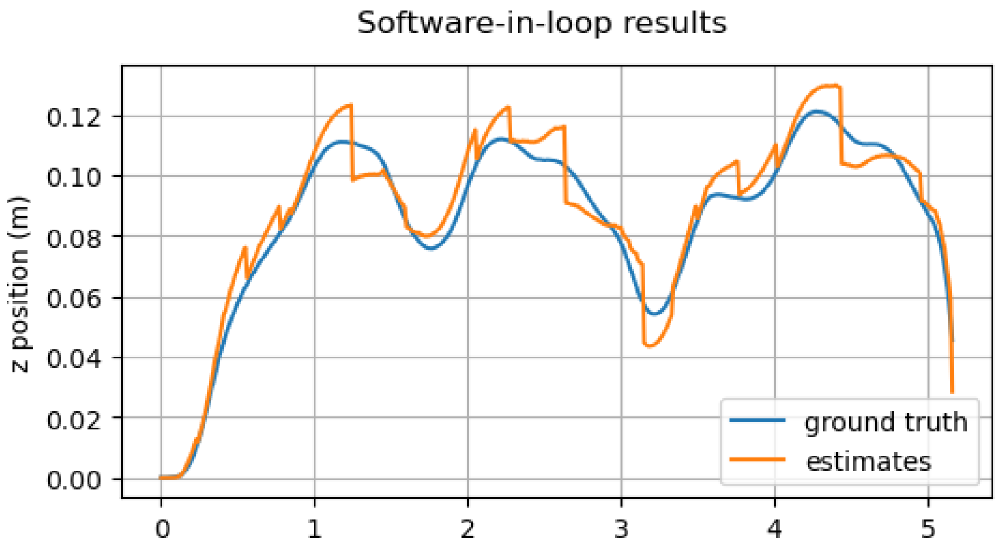


Fig. 1. Closed-loop system.

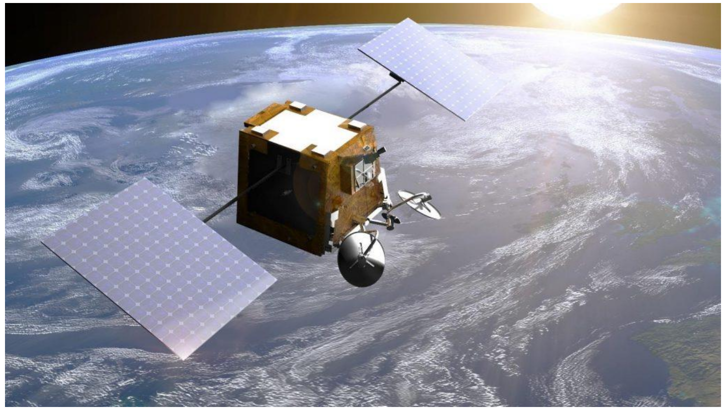
Liberzon D. On stabilization of linear systems with limited information, 2003



II. Kalman filtering for satellite orbit determination

- Performed statistical orbit determination of a OneWeb satellite.
- The analysis was based on topocentric observer measurements made at an observatory in Champaign, IL.
- Demonstrated the ability to identify Earth-orbiting objects from angle measurements only.

OneWeb

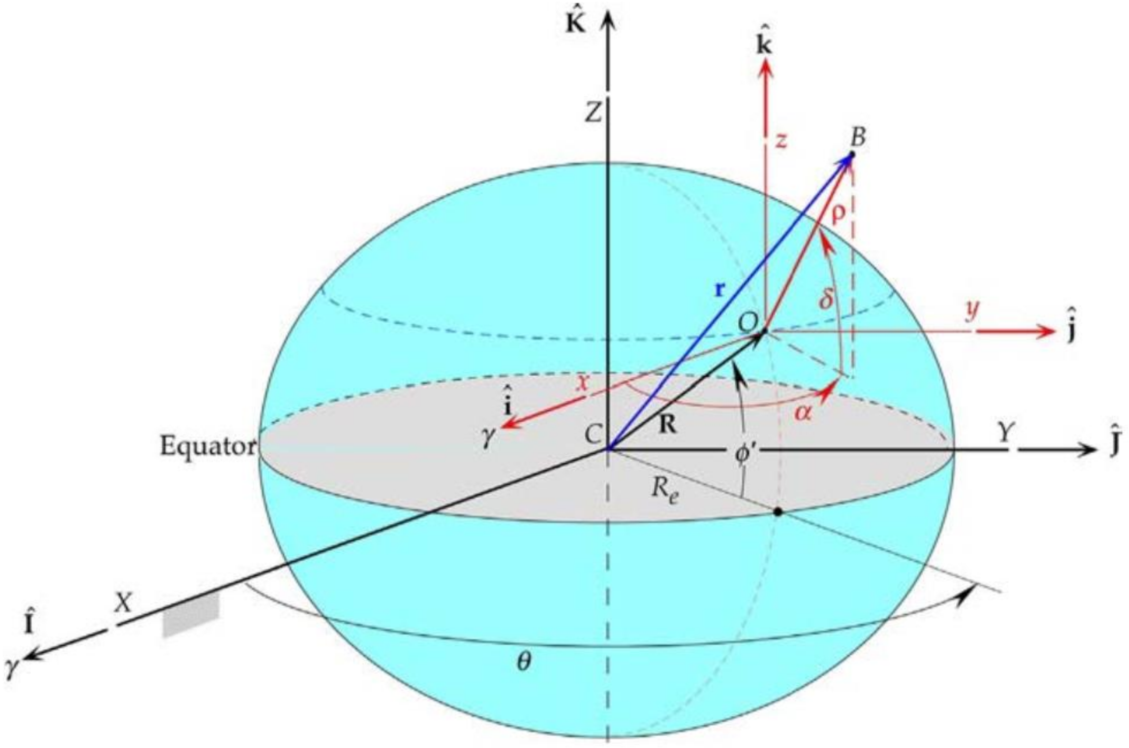


Picture credit: OneWeb

Topocentric angle measurements

- This project requires only widely available and cheap telescopes to roughly measure the Altitude/Azimuthal angles at any location on Earth.
- From only 3 sets of angle Alt-Azi recordings, fit an initial estimate of the satellite state vector.

- Due to the very low cost of measuring equipment, anyone can use the developed starter MATLAB code to determine orbits of earth-orbiting objects.
- Resulting estimation for the state is valid for two weeks before perturbations are too large to ignore.



Reference coordinate frame to measure Altitude/Azimuthal angles of observation ‘B’.
Picture credit: Curtis [2021]

Kalman filtering Vs Least squares

- Collect a time-series of additional angle measurements.
- There exist two methods for determining a best-fit orbit:
    - Global least squares
    - Sequential Kalman filtering

- This project weighs the merits/demerits of both methods.
- Wrote MATLAB code implementing both methods.

- Demonstrated that :
    - Least squares, while simple, yields a larger residual.
    - Kalman Filtering, while complex to program results in a better-fit for the intial state vector of satellite.

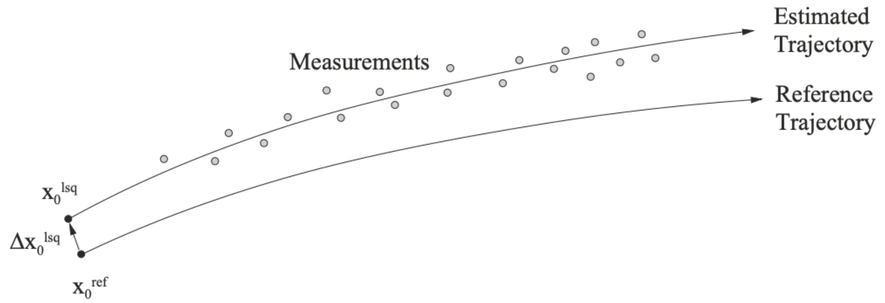


Fig. 8.1. Least-squares orbit determination: the parameters of a reference trajectory are corrected to find the trajectory which best fits the observations in a least-squares of the residuals sense.

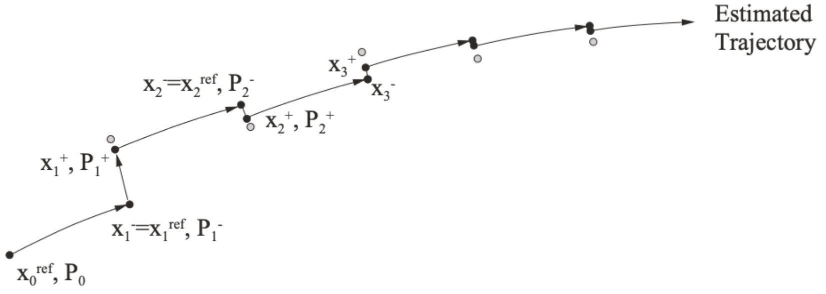
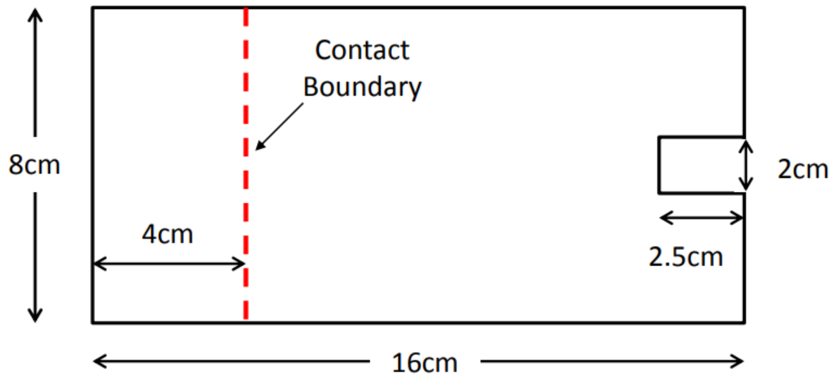


Fig. 8.8. The extended Kalman filter (EKF) makes use of the latest estimate to propagate the state vector and the state transition matrix. This makes the EKF less sensitive to non-linearities than the linearized Kalman filter.

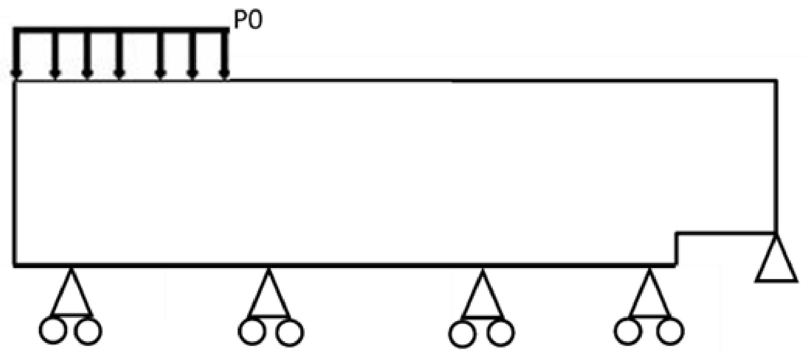
Picture credit: Montenbruck 2000

III. STRUCTURAL DESIGN OPTIMIZATION

- Devised a compliant mechanism that generates a gripping force with no relative motion between its parts.
- Design challenge: Maximize gripping weight while minimizing material requirements.
- The problem involved constraints on the design space where an operator could apply input force only to the left of a contact boundary.
- This problem was solved using Topology optimization which iteratively solves for the material density distribution.
- Developed FEM solver in MATLAB to use in the topology optimization problem.

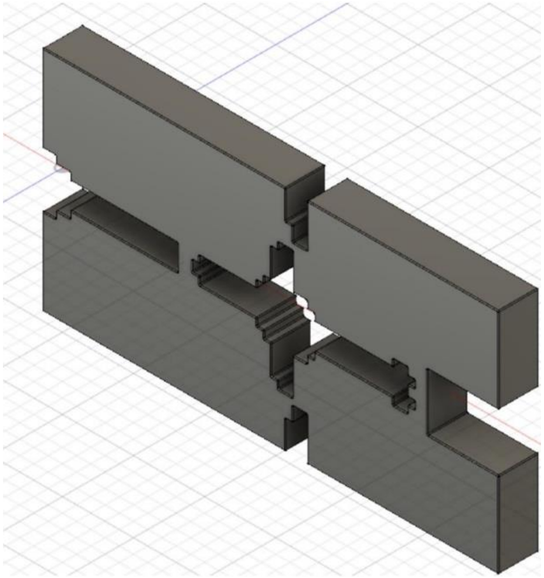


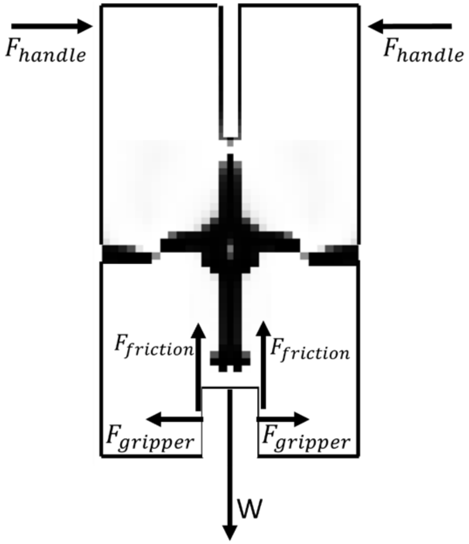
Problem statement depicting the permissible design space



Symmetric boundary conditions for FEM problem

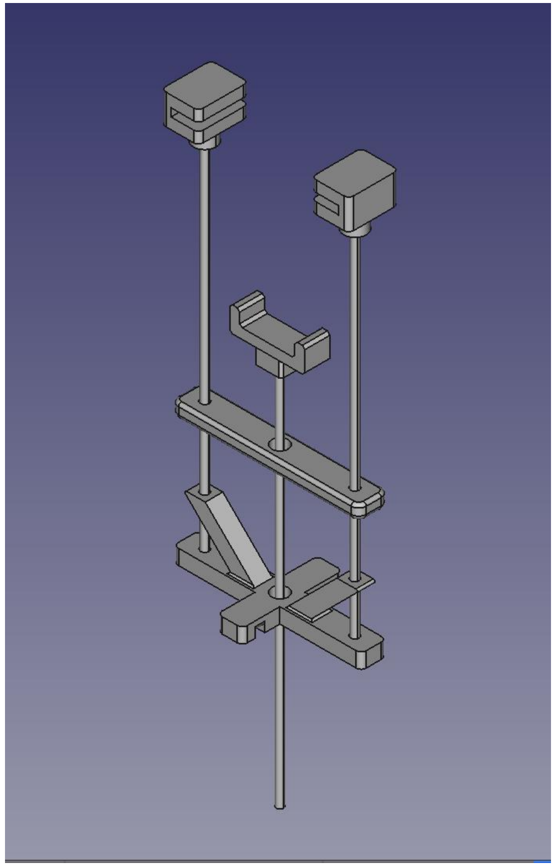
- Resulting design was 3D printed and weighed 0.5lbs.
- Based on nominal material properties, the design was projected to be able to lift 3.3lbs.
- The designed mechanism was capable of lifting upto 2.7 lbs; close to the idealized predictions.
- Design submission was among the top 4 out of 15 submissions.



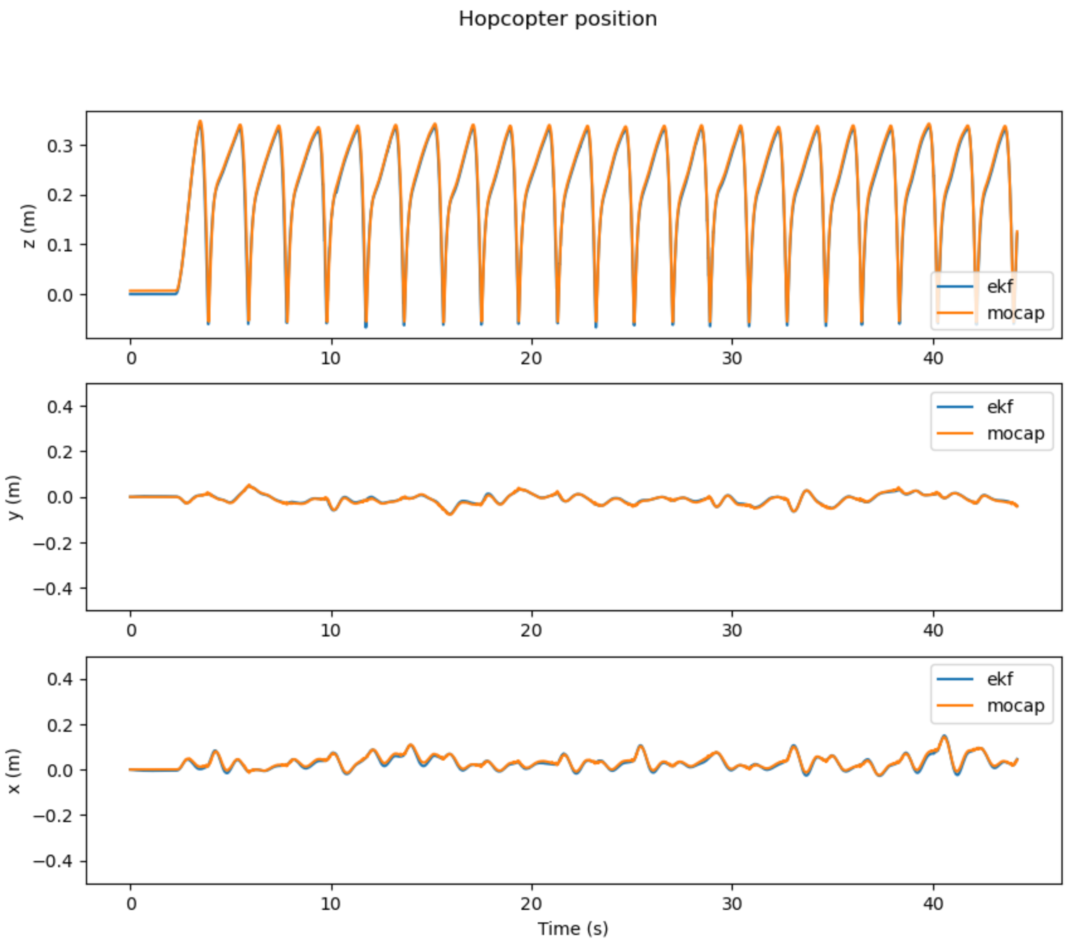


IV. UIUC Hopper

- Current project to use hopping quadrotors to manipulate objects on the floor
- Inspired by similar projects such as Salto-1P, PogoDrone and Hopcopter
- Developed CAD model for a lightweight(<3g) leg extension.



- Implemented a finite-state machine to alternate between (1) Aerial, and (2) Stance Phases.
- Time from design to hopping: 1 month ☺



Link to YouTube video!

V. CHAOTIC FLUID MIXING IN MICRO-CHANNELS

- The problem of mixing is of central interest in many industries. Its applications range from chemical synthesis to internal combustion engines.
- In micro-channels, viscous forces dominate, and the flow is laminar.
- Effective mixing seeks to homogenize a pair of immiscible fluids.
- This study draws on ideas in literature that make use of secondary flows generated from curvature in these micro-channels.
- The resulting laminar flow is superimposed with vortices orthogonal to the main flow.
- Therefore, a sequence of bends and twists in pipes can be leveraged for effective mixing.
- Performed numerical particle tracking simulations to identify Lagrangian Coherent Structure (LCS) ridges.
- These are barriers across which fluid tracers don’t cross.
- Carried out extensive numerical simulations to find useful microchannel configurations.
- Resulting designs are spec’d out in terms of positions, amplitude and duty cycle of point vortices.
- These are in turn translated into requirements on radii of curvature of the microchannels.

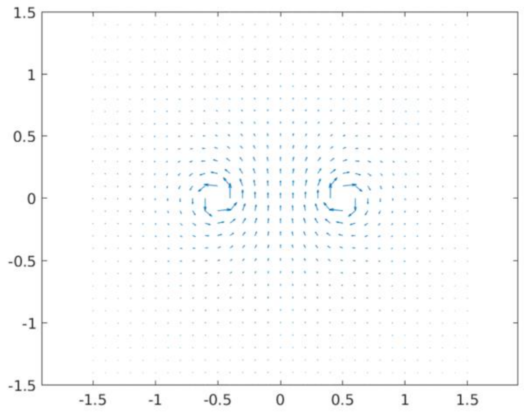
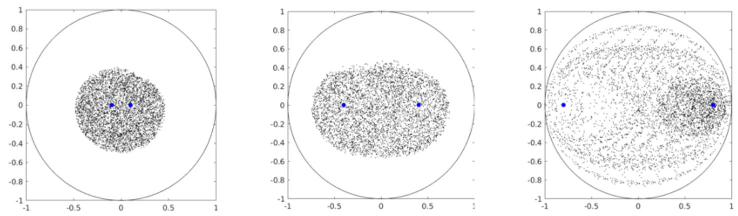
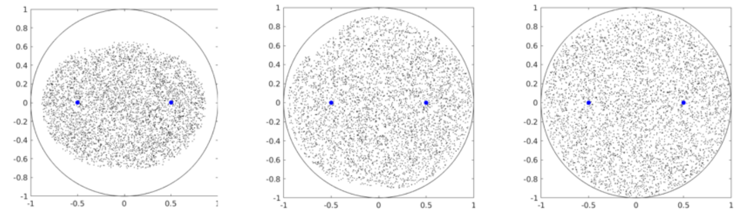


Figure 3.3: Velocity field for 2 point vortices



(a) $(x_i, y_i) = (\pm 0.1, 0)$ (b) $(x_i, y_i) = (\pm 0.4, 0)$ (c) $(x_i, y_i) = (\pm 0.8, 0)$

Figure 5.1: Varying positions, $A_1 = A_2 > 0$, $T_d = 2s$



(a) $A_2/A_1 = 1$ (b) $A_2/A_1 = 3$ (c) $A_2/A_1 = 5$

Figure 5.2: Varying strengths $(x_i, y_i) = (\pm 0.5, 0)$, $T_d = 3s$

THANK YOU