MAnipulation with Multiples drones for soft BOdies

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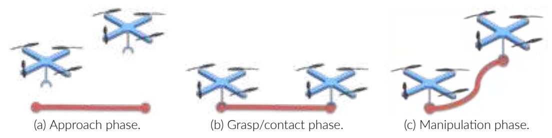
MAMBO main objective

Long term: Design universal aerial gripper composed of flexible bodies.
Short term: Manipulation of single soft body through combined action of two UAVs.



Challenges

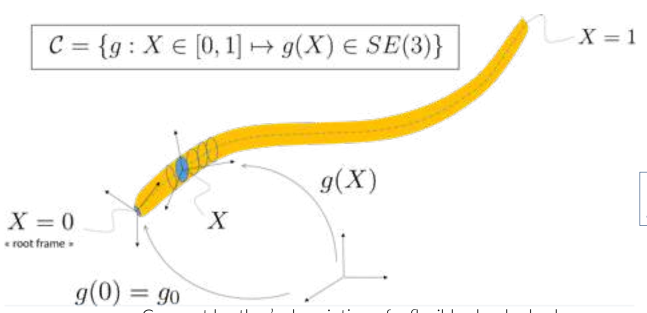
- Infinite number of DoFs in a soft body.
- Only 4 DoFs for a quadrotor.
- Underactuated system from the quadrotor perspective.
- Highly coupled and non-linear system due to interaction of quadrotors.

Publications

- L. Smolentsev, A. Krupa, F. Chaumette. Shape visual servoing of a tether cable from parabolic features. IEEE Int. Conf. on Robotics and Automation, ICRA'23, pp. 734-740, London, UK, May 2023.
- L. Smolentsev, A. Krupa, F. Chaumette. Shape visual servoing of a cable suspended between two drones. IEEE Robotics and Automation Letters (also presented at IEEE/RSJ Int. Conf. IROS 2025), To appear 2024.
- L. Smolentsev. Shape visual servoing of a suspended cable. PhD thesis, University of Rennes, March 2024.
- F. Boyer, A. Gotelli, P. Tempel, V. Lebastard, F. Renda, S. Briot. Implicit time integration simulation of robots with rigid bodies and Cosserat rods based on a Newton-Euler recursive algorithm. IEEE Transactions on Robotics, vol. 40, no. 1, pp. 677-696, 2024.

WP 1: Mechanical Design of Soft Bodies and State Estimation

Objectives:
- Create finite-dimensional model of infinite-dimensional physical soft body.
- Implement simulator of flexible body under action of two drones.
- Design control approach to manipulate body into shape and validate experimentally.



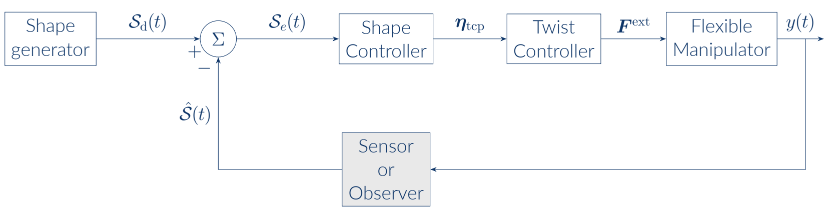
Cosserat brother's description of a flexible slender body.

Dynamics model of the Cosserat body (*strain-based parameterization*):

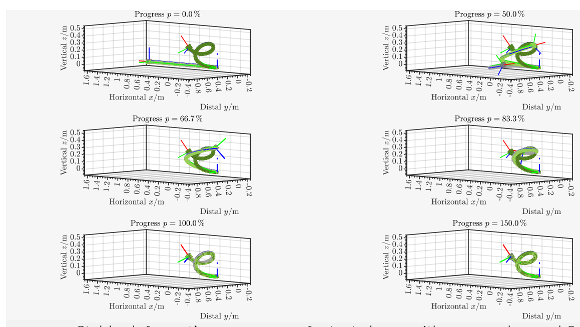
$$\begin{bmatrix}\mathbb{0}\\ \boldsymbol{Q}_{\mathrm{ad}}\end{bmatrix} = \begin{bmatrix}\mathcal{M}_{00} & \boldsymbol{M}_{0\epsilon}\\ \boldsymbol{M}_{\epsilon 0} & \boldsymbol{M}_{\epsilon\epsilon}\end{bmatrix}\begin{bmatrix}\dot{\boldsymbol{\eta}}_0\\ \ddot{\boldsymbol{q}}_\epsilon\end{bmatrix} + \begin{bmatrix}\boldsymbol{F}_v(\boldsymbol{q}_\epsilon, \dot{\boldsymbol{q}}_\epsilon, \boldsymbol{\eta}_0)\\ \boldsymbol{Q}_v(\boldsymbol{q}_\epsilon, \dot{\boldsymbol{q}}_\epsilon, \boldsymbol{\eta}_0)\end{bmatrix} + \dots + \begin{bmatrix}\boldsymbol{F}_c(\boldsymbol{q}_\epsilon, \boldsymbol{T}_0)\\ \boldsymbol{Q}_c(\boldsymbol{q}_\epsilon, \boldsymbol{T}_0)\end{bmatrix} + \begin{bmatrix}\mathbb{0}\\ \boldsymbol{K}_{\epsilon\epsilon}\boldsymbol{q}_\epsilon + \boldsymbol{D}_{\epsilon\epsilon}\dot{\boldsymbol{q}}_\epsilon\end{bmatrix}$$

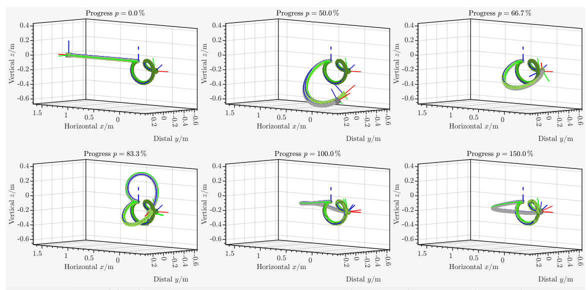
$\Rightarrow$ Model linear in acceleration

Propose a shape controller for modifying the body configuration



Results:


Stable deformation sequence of a test shape with one marker and 8 interpolation points.


Unstable deformation sequence of a test shape with one marker and 32 interpolation points.

WP 2: Control of Underactuated Systems with Soft Bodies and Vision-Based Control

Objective: Shape Control of a flexible cable using visual servoing embedded on the drone

Methodology:

- Parabola model for cable shape: $z = ax^2 + bx$
- Proposed visual features extracted from RGB-D image: $\mathbf{s} = (a, b, \alpha)$
- Visual error to minimize: $\mathbf{e} = \mathbf{s} - \mathbf{s}^*$
- Control law with a feed-forward and integral terms:

$$\mathbf{v}_f^* = \hat{\mathbf{v}}_l + \lambda \mathbf{R}(\phi)\mathbf{M}\mathbf{e} + \mu \mathbf{R}(\phi)\mathbf{M}\sum_i^N \mathbf{e}_i$$

$$\mathbf{M} = \begin{bmatrix} -k_1 \sin\alpha & -k_2 \sin\alpha & -D\cos\alpha \\ k_1\cos\alpha & k_2\cos\alpha & -D\sin\alpha \\ n_1 & n_2 & 0 \end{bmatrix}$$

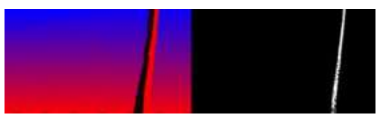
- Secondary task for maintaining cable visibility:

$$\dot{\psi}^*_{b_f} = -\lambda(\psi_{b_f} - \psi^*_{b_f}) - \mu\sum_i^N(\psi_{b_{f\,i}} - \psi^*_{b_f})$$

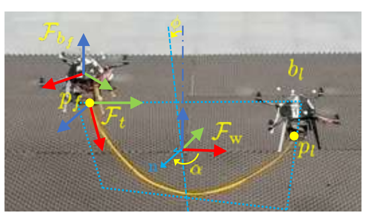
Features tracking from RGB-D camera:

- Estimation of the normal of the cable plane from observed point-cloud by RANSAC algorithm.
- Kalman filtering of the normal and estimation of the plane roll and yaw angles.
- Extraction of pointcloud intersecting the plane.
- Estimation of parabolic coefficients a, b by least squares.

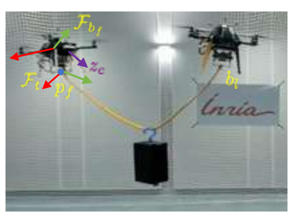
Experimental results:



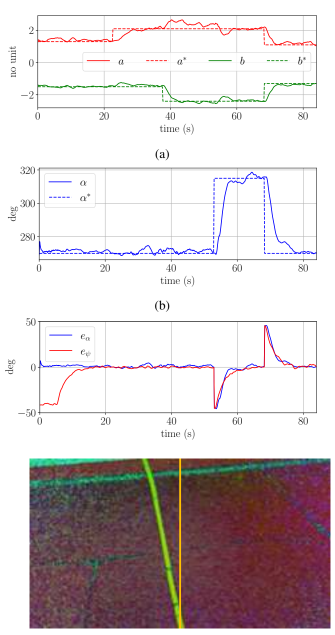
Scenario 1



Scenario 2



Scenario 1
Cable manipulation



Scenario 2
Leader following, box grasping and transportation