Manipulation with Multiples drones for soft Bodies

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## WP 1: Mechanical Design of Soft Bodies and State Estimation

Objective

Mechanical Design of Soft Bodies and State Estimation

- 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

Methodology

Figure 1. Cosserat brother's description of a flexible slender body.
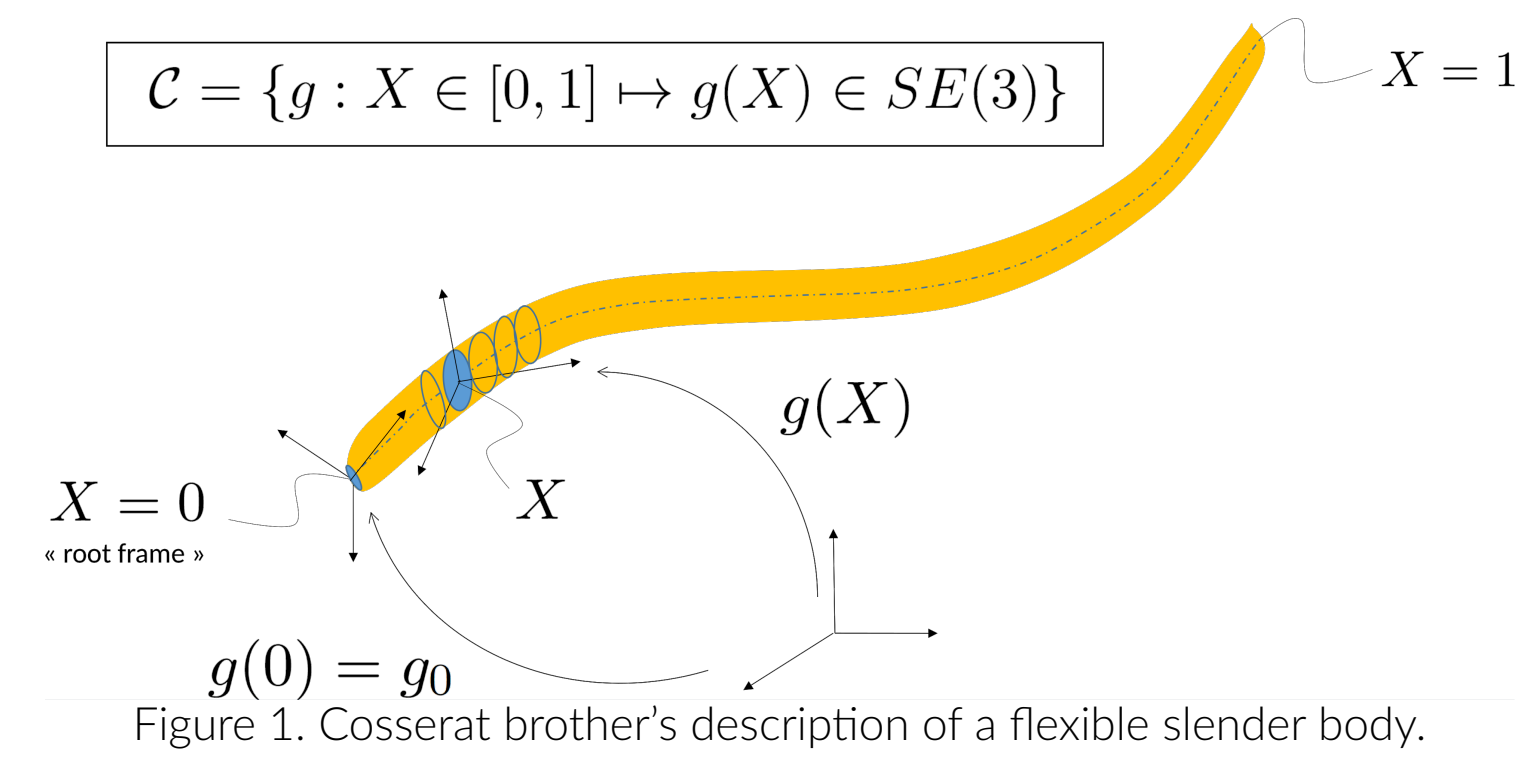
- Consider soft body a sequence of rigid cross-sections connected through active spherical joints
- Using Boyer et al. strain-based parametrization approach, we obtain a low-dimensional model

$$\begin{bmatrix} 0 \\ Q_{ad} \end{bmatrix} = \begin{bmatrix} \mathcal{M}_{00} & M_{0\epsilon} \\ M_{\epsilon 0} & M_{\epsilon\epsilon} \end{bmatrix} \begin{bmatrix} \dot{\eta}_0 \\ \ddot{q}_\epsilon \end{bmatrix} + \begin{bmatrix} F_v(q_\epsilon, \dot{q}_\epsilon, \eta_0) \\ Q_v(q_\epsilon, \dot{q}_\epsilon, \eta_0) \end{bmatrix} + \ldots$$
$$+ \begin{bmatrix} F_c(q_\epsilon, g_0) \\ Q_c(q_\epsilon, g_0) \end{bmatrix} + \begin{bmatrix} 0 \\ K_{\epsilon\epsilon} q_\epsilon + D_{\epsilon\epsilon} \dot{q}_\epsilon \end{bmatrix}$$

of the same form as a free-floating serial manipulator kinematic chain
- Dynamics methods i.e., FDM and IDM can be used one-to-one for our soft body system
- Control strategies conventionally used on rigid-link manipulators are transferable to our soft body

Simulator

- Commercially available robotics simulators support many different rigid joint types
- No support for custom, flexible joint types
- Necessity to create simulator for MAMBO combining techniques of rigid multibody simulators with our flexible joints
- Proof-of-concept implemented as object-oriented framework in MATLAB: https://gitlab.univ-nantes.fr/ls2n-armen/mambo/matlab-simulator
- Use of implicit Newmark-Beta time integration scheme, particular case of generalized α-scheme

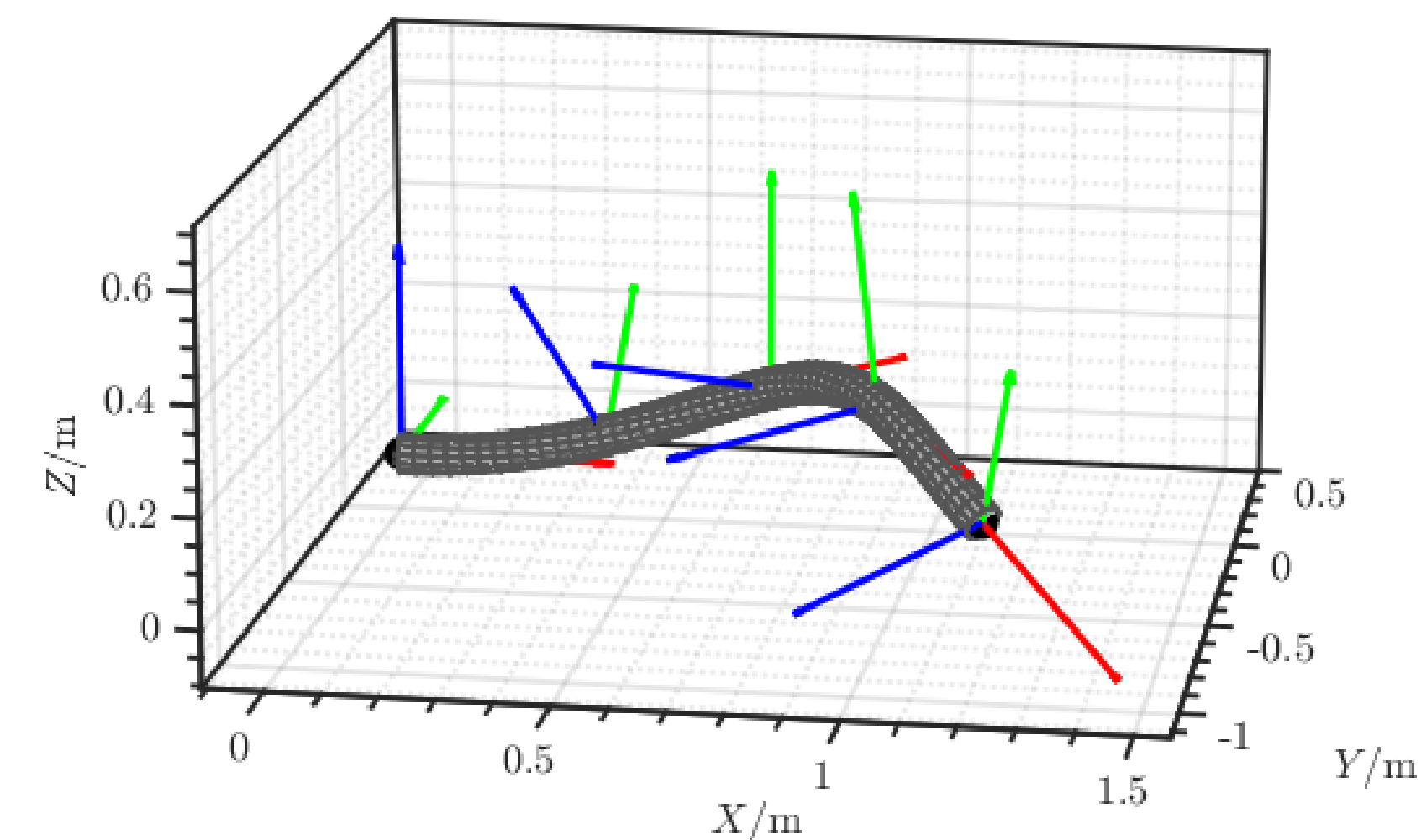### Shape Control of Soft Body

Figure 2. MATLAB visualization of a deformed soft bodies with 5 markers at equidistant positions.

- Follow same methodology as in conventional IBVS method
- Control input determined from the relation of free-end velocity v_{drone} and marker error e_{marker}

$$v_{drone} = \lambda L_s^+ e_{marker},$$

where the residual error vector reads

$$e_{marker} = [e_1^\top, \ldots, e_m^\top]^\top$$

with the i-th marker's error defined through its positional error

$$e_i = r_i^* - r_i$$

over m equally distributed features (positions) along the soft body's length
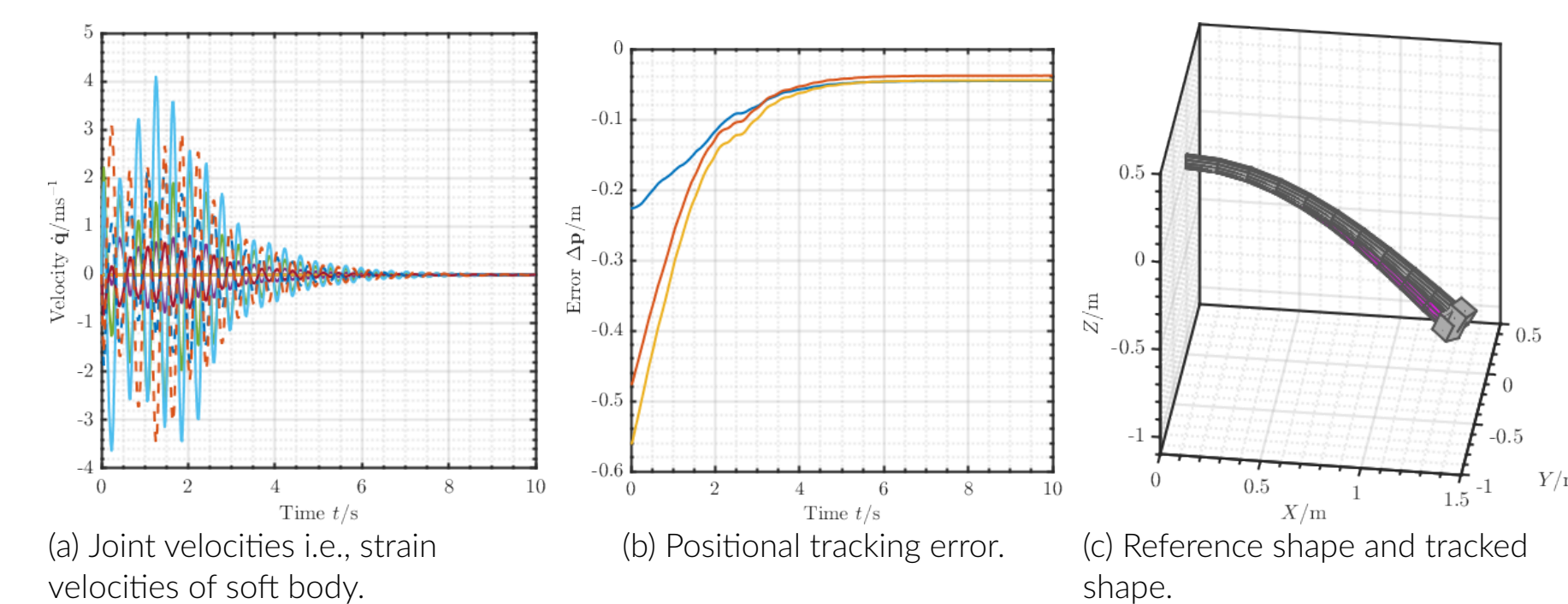

Figure 3. Results of IBVS-based shape deformation of a 1.6 m long soft body.

Experimental Validation

- Ongoing close cooperation between LS2N-ARMEN and Inria-RAINBOW
  - MAMBO simulator by LS2N-ARMEN deployed in Rennes
  - Ongoing simulation of slack cables in the MAMBO simulator without a controller
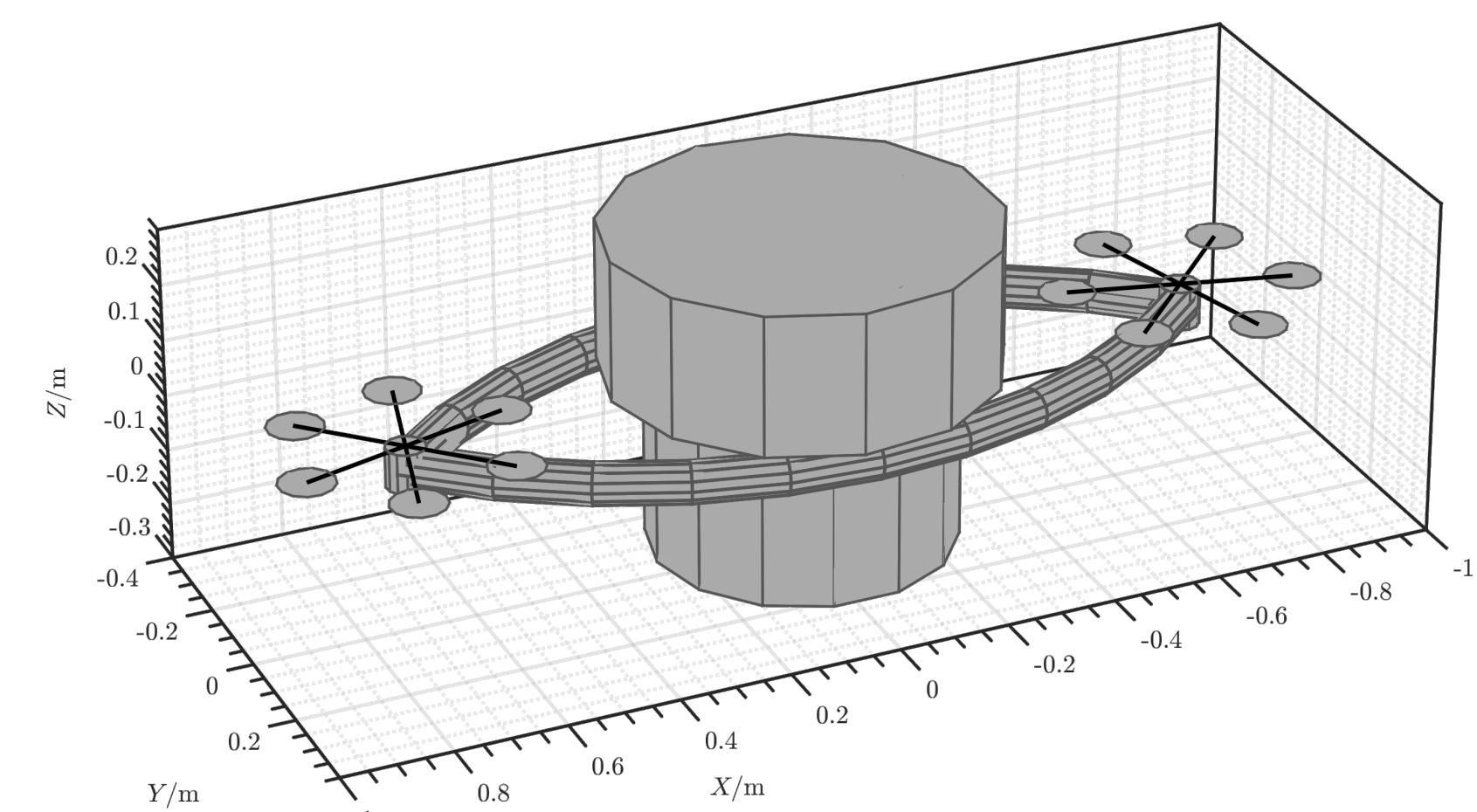- Preparation for experiments of deformation of clamped-free soft body ongoing

Figure 4. MATLAB mock-up of experimental setup envisioned for experimental validation in Q[2,3]/2023.

Project: MAMBO

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

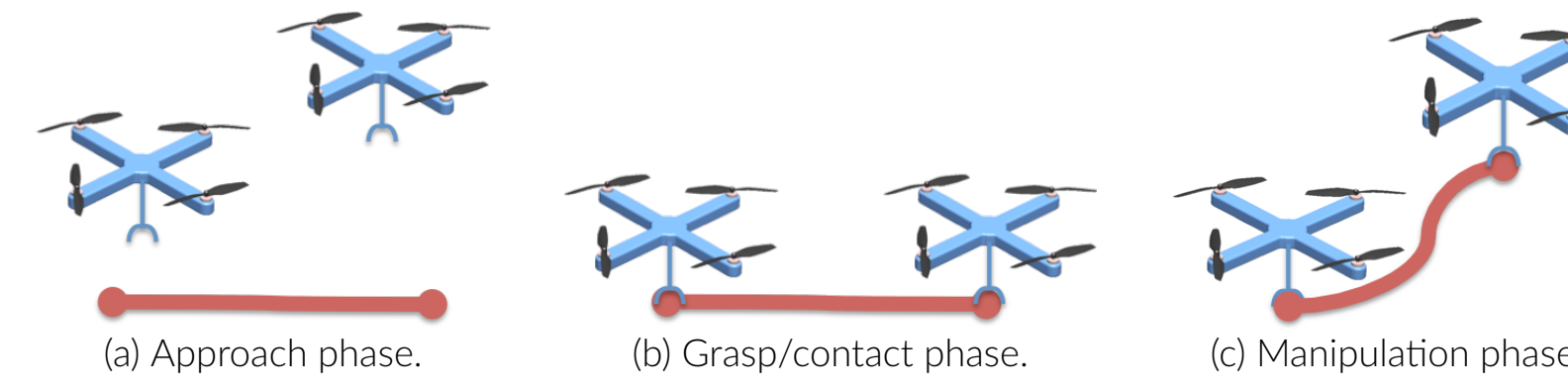(a) Approach phase. (b) Grasp/contact phase. (c) Manipulation phase.

Figure 5. Three main stages of manipulating a single soft body with drones.

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

Work Packages

1. Mechanical design of soft bodies and state estimation
2. Control of underactuated systems with soft bodies and vision-based control
3. Experimental validation

IAC recommendations

- Given the delays and deviation from the original project plan, we recommend that the team revisit the project goals and update the plan including the tasks in the WPs
- The overall system perspective, that combines the flexible body(ies) and one or two pairs of drones and the object to be lifted, should be given more attention linking the different parts of the project creating more synergies between the two participating groups
- The purpose and use of the simulation environment should be clarified since it requires substantial resource
- Develop a scientific dissemination plan

Future Work

- Experimental validation of the tether cable control with two quadrotors on both experimental drone-platforms of Rainbow and Armen teams
- Experiments using quadrotors on board vision system
- Model the eccentricity of the cable attachment point in order to avoid perturbations from quadrotor motion

Acknowledgements

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

Objective

Shape Control of a Tether Cable Using Visual Servoing

- Derivation of a geometric model for the control task
- Determination of relevant visual features and related interaction matrix
- Tracking of visual features from RGB-D vision

Methodology
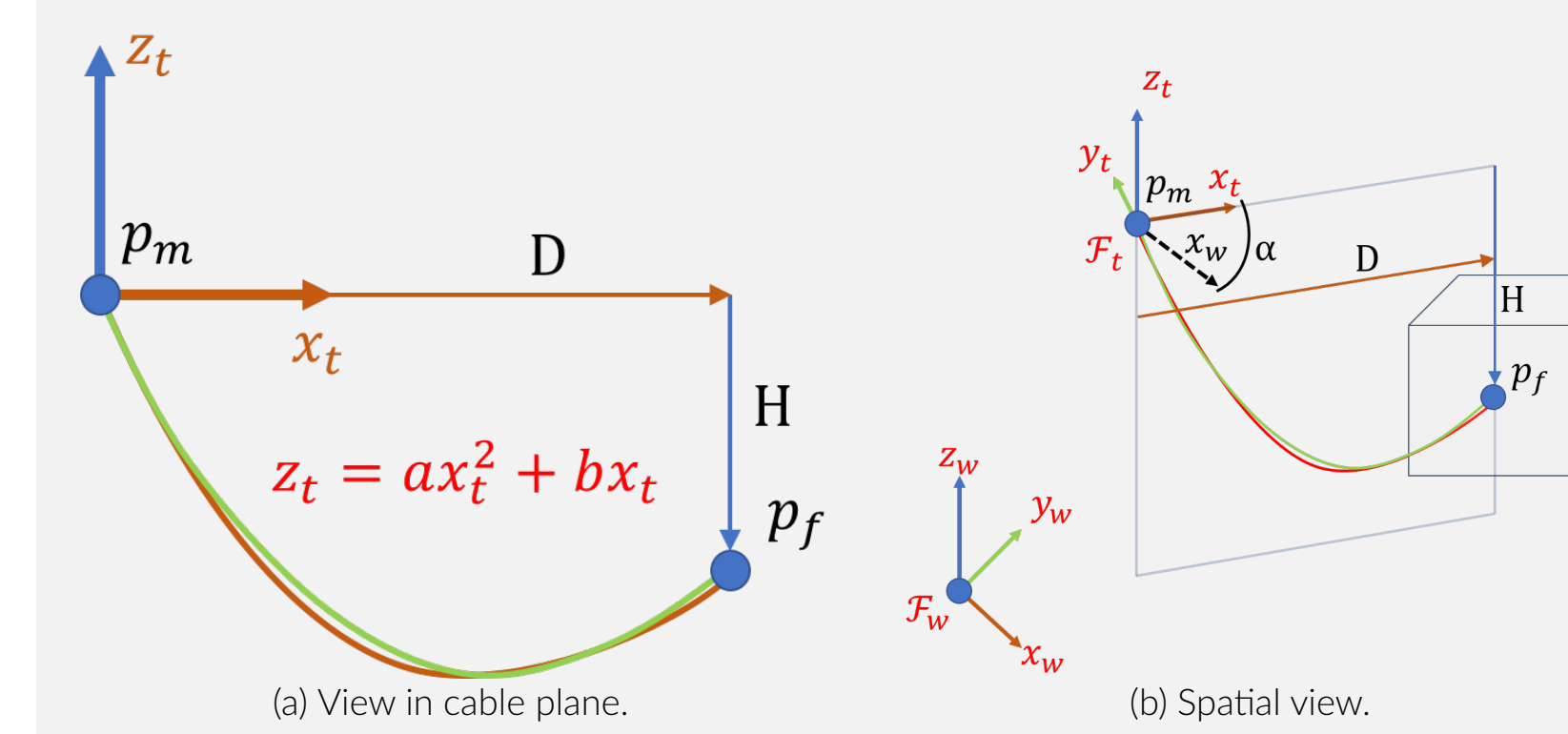

(a) View in cable plane.   (b) Spatial view.

Figure 6. Tether (green curve) and its parabola model (red curve): $D > 0, H < 0$ in this configuration.

- Choice of parabola curve to model the suspended tether cable shape subject to gravity deformation
- Proposed visual features extracted from RGB-D image: $s = (a, b, \alpha)$
- Visual error to minimize: $e = s - s^*$
- Control law with exponential decrease of the visual error over time: $v_m = -\lambda L_s e$ with control gain $\lambda > 0$ and interaction matrix L_s relating the velocities of the cable attachment points with the velocities of the visual features
- Secondary control task of the quadrotor yaw ψ for observing the tether with an onboard RGB-D sensor while performing the cable shaping task
- Quadrotor tilt motion and secondary control task are not deteriorating shape control task while the cable is attached in quadrotor center of thrust otherwise both are considered as an external perturbation for the shape controller (actually)

Interaction Matrix

- When controlling both attachment points of the cable: $L_s = [-M^{-1}, M^{-1}]$
- When controlling only one point, the other is static: $L_s = -M^{-1}$
- $M = \begin{bmatrix} k_1 c_\alpha & k_2 c_\alpha & -D s_\alpha \\ k_1 s_\alpha & k_2 s_\alpha & D c_\alpha \\ D^2 + t_2 k_1 & D + t_2 k_2 & 0 \end{bmatrix}$ with $k_i = f(s, D, L)$
where L is the cable length needed as the only *a priori* knowledge about the cable
- Necessary condition to do the task is rank $L_s \equiv 3$ and rank $M \equiv 3$
- The rank is less than 3 if and only if the cable is taut horizontally or vertically (2 configurations that are not specified as desired target)

Features tracking from RGB-D data

- Estimation of the normal to the plane containing the tether in the world frame from observed point-cloud
- Rejection of the noise on the estimate of α by considering the plane vertical due to gravity
- New set of cable points obtained by projecting this plane into the camera frame for better depth estimation for each image points $p_m = (x, y, 1)$: $z_i = -\frac{{}^c d}{{}^c n^\top p_m}$
where ${}^c n$ is the projected normal and ${}^c d$ is the distance to the plane from the camera

Experimental Results

(a) Initial configuration. (b) First target: stretching task. (c) Second target: bending task.

Figure 7. Cable shape control using serial manipulator.

(a) Task error stretching. (b) Control velocities stretching.
(c) Task error bending. (d) Control svelocities bending.
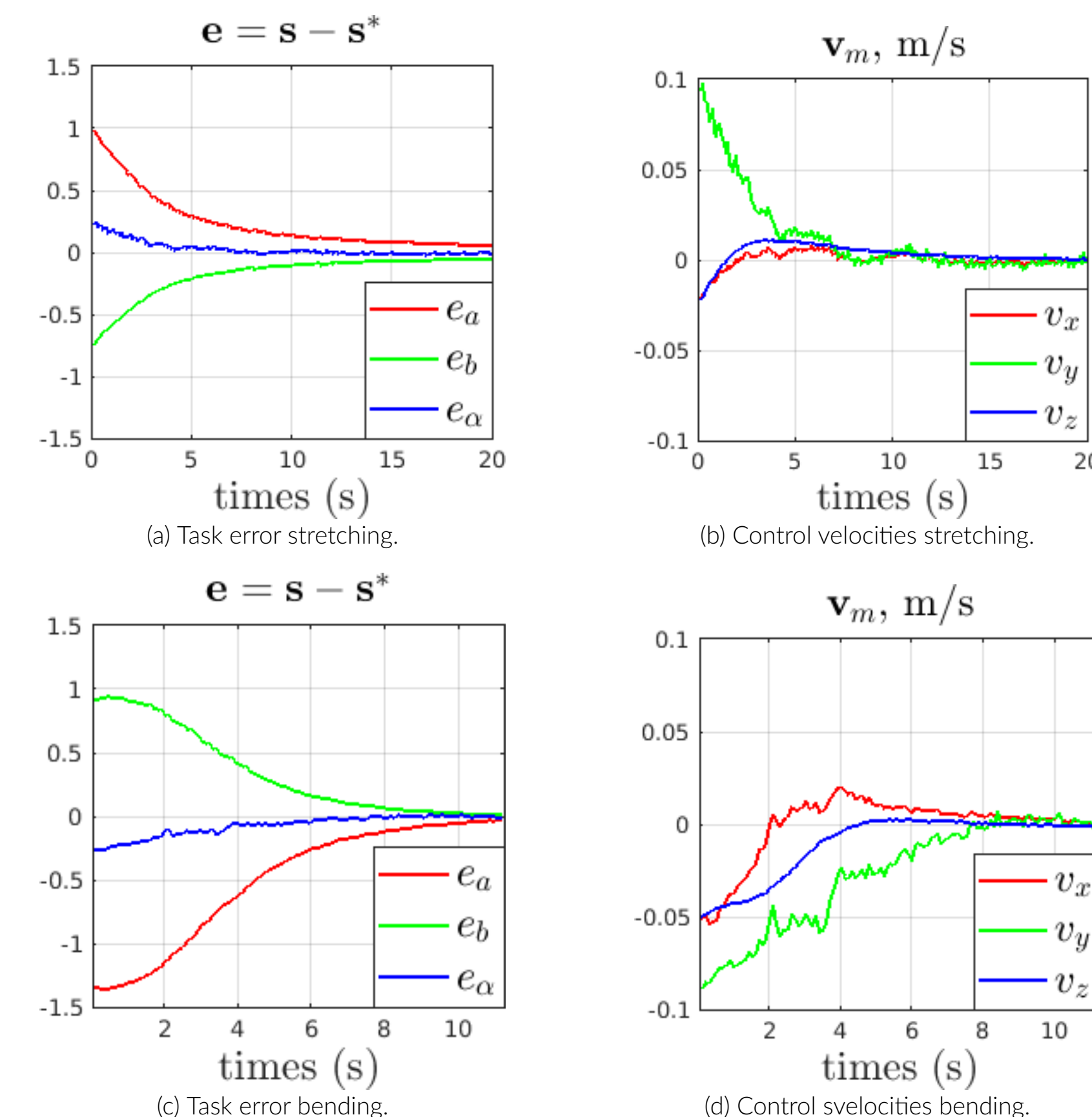
Figure 8. Features error and velocities for manipulator visual servoing experiment.

(a) Initial configuration. (b) First target: bending task. (c) Second target: stretching task.
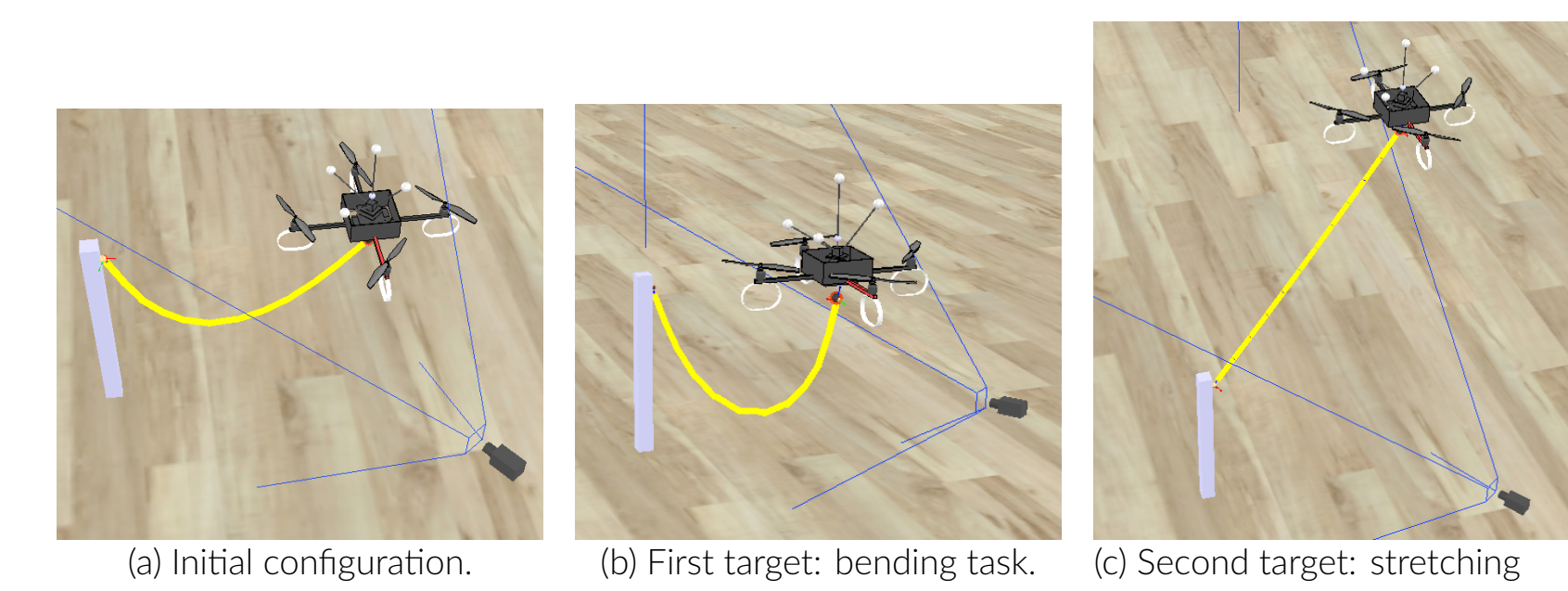
Figure 9. Cable shape control using quadrotor.

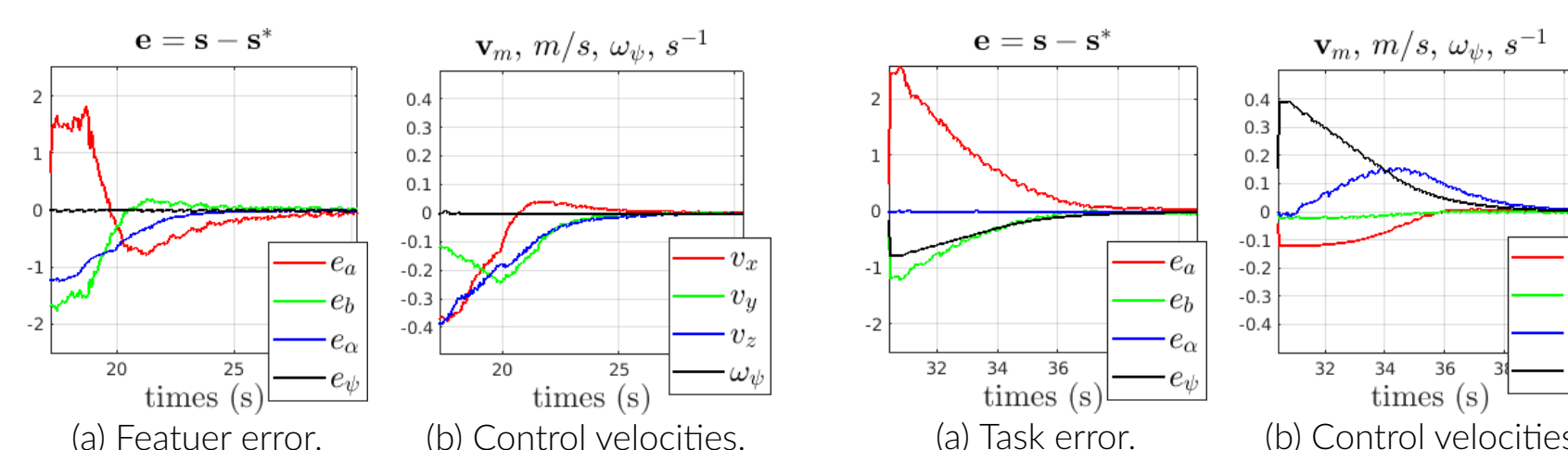(a) Featuer error. (b) Control velocities.

Figure 10. Feature error and control velocities for cable relaxing with a quadrotor in simulation.
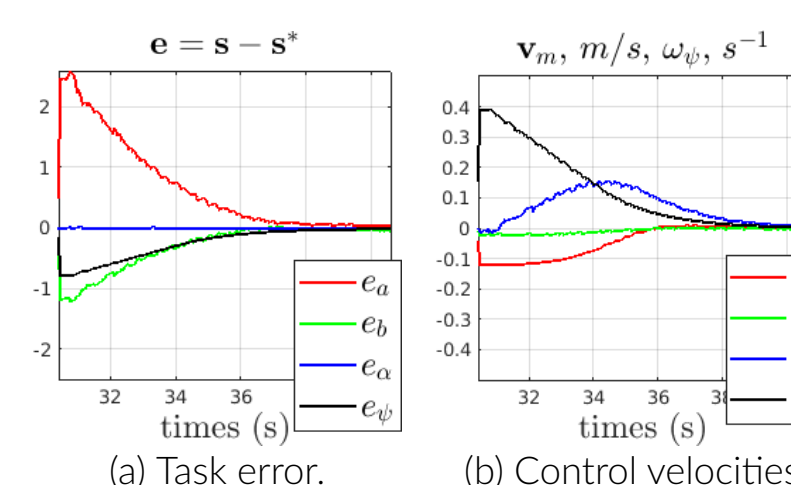

(a) Task error. (b) Control velocities.

Figure 11. Feature error and control velocities for cable stretching with a quadrotor in simulation.