

Simulating the Manipulation of Flexible Bodies Through Drones

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Figure 1: Jimenez-Cano *et al.*, “Control of an Aerial Robot with Multi-link Arm for Assembly Tasks” (2013).

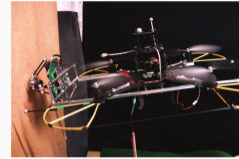


Figure 2: Fumagalli *et al.*, “Developing an Aerial Manipulator Prototype” (2014).

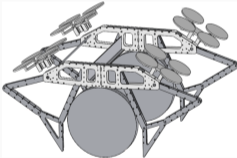


Figure 3: Saint-Sevin *et al.*, “Design and Optimization of a Multi-drone Robot for Grasping and Manipulation of Large Size Objects” (2018).

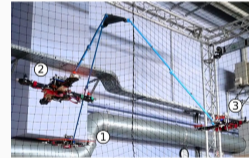
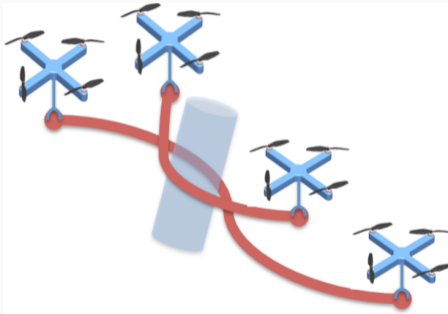


Figure 4: Saint-Sevin *et al.*, “Design and Optimization of a Multi-drone Robot for Grasping and Manipulation of Large Size Objects” (2018).

What we Imagine

A modular/adaptive aerial grasping device implemented as a soft gripper.



What we imagine

- Build “aerial fingers”: flexible bodies manipulated by drones
- Collaboratively controlling fingers: “aerial hand”
- Multi-scale problem
 1. Drone
 2. Flexible body
 3. Manipulation/Collaboration
 4. Path/trajectory planning

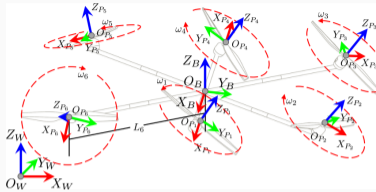


Figure 5: Kinematic model of a hexarotor used in the current preliminary studies.

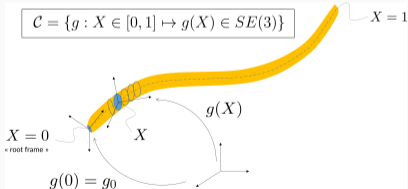



Figure 6: Model of a flexible body based on the Cosserat theory.

Challenges

- Rigid-flexible multibody system
 - Simple model of rigid-body for drones
 - What model for flexible body to describe rigid-body transformations and elastic-body deformations?
- Underactuated system
 - Drones may be underactuated (quadrotor vs. hexarotor)
 - Flexible body very underactuated
- Numerical efficiency
 - Conventional mass-spring-damper system for flexible body
 - Numerical evaluation of explicit dynamics very expensive
- Shape control of flexible body

Figure 7: Preliminary simulation results of manipulating a flexible body using arbitrary wrench generators on either ends

Figure 8: Preliminary simulation results of manipulating a flexible body using drones (hexarotors).




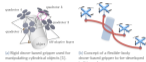
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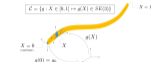
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1) Rigid dynamics program used for manipulating cylindrical objects (C)
2) Concept of a flexible body, whose based program for development in this work



$\mathcal{C} = \{X \in \mathbb{R}^3 \mid \exists \alpha(X) \in \mathbb{R}^{2 \times 2} \mid X = \alpha(X) \cdot X^0\}$

$X^0 = 0$
 $\alpha(X) = \mathbb{R}^2$

Dynamics

- Lagrange model of a drone
- Lagrange model of a flexible body
- Components obtained using the Inverse Dynamics Model (forward backward integration via column reordering)
- Full system dynamics read

Algorithms

Strain decomposition:

$$\begin{pmatrix} Q \\ \dot{Q} \end{pmatrix} = \begin{pmatrix} \frac{1}{2} \Omega Q + \frac{1}{2} Q \Omega \\ \frac{1}{2} \Omega \dot{Q} + \frac{1}{2} \dot{Q} \Omega \end{pmatrix}$$

Kinematics:

- Forward kin. $X \in \mathbb{R}^3$
- Backward kin. $\dot{X} \in \mathbb{R}^3$

Motivation

- Aerial robots with adaptive, mobile, and flexible arms have capabilities
- Control grasping aerial manipulators can be obtained by
- using model-free reinforcement learning (1), (2)
- using model-based reinforcement learning (3), (4)
- using model-based reinforcement learning (5), (6)
- "Flying hand" would be more adaptive and versatile
- including flexible bodies in these manipulators through dynamic models to design "flying gripper" parts of a "flying hand"

Concept

- Use thin drones to control and manipulate a flexible body as flexible body because of the grasping component
- Control the drone location of a floating base flexible manipulator
- Manipulate of three finger-like systems, then used to manipulate larger objects




Figure 2: Vision of the control loop of a flying base manipulation of three and one flexible base system, providing a controlling.

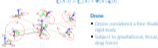


Figure 3: Kinematic modeling of a flexible body with three base fingers $F_{1,2,3}$ and a flexible body B .

Notation

\mathbb{R}^n : n -D Euclidean space
 \mathbb{S}^2 : 2-D sphere
 \mathbb{S}^1 : 1-D circle
 \mathbb{C} : complex number
 \mathbb{N} : natural numbers
 \mathbb{Z} : integers
 \mathbb{R} : real numbers
 \mathbb{C} : complex numbers
 \mathbb{H} : quaternion numbers
 \mathbb{Q} : rational numbers
 \mathbb{I} : imaginary numbers
 \mathbb{J} : jacobian matrix
 \mathbb{K} : gain matrix
 \mathbb{L} : Laplace transform
 \mathbb{M} : mass matrix
 \mathbb{N} : normal vector
 \mathbb{O} : origin
 \mathbb{P} : position vector
 \mathbb{Q} : quaternion
 \mathbb{R} : radius
 \mathbb{S} : shape matrix
 \mathbb{T} : transformation matrix
 \mathbb{U} : unitary matrix
 \mathbb{V} : velocity vector
 \mathbb{W} : weight matrix
 \mathbb{X} : position vector
 \mathbb{Y} : output vector
 \mathbb{Z} : impedance matrix

References

1. S. Briot, S. Bouffard, and S. Lefeuvre, "Robotic manipulation of rigid objects using a flying robot," in *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 1-6, 2019.
2. S. Briot, S. Bouffard, and S. Lefeuvre, "Robotic manipulation of rigid objects using a flying robot," in *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 1-6, 2019.
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5. S. Briot, S. Bouffard, and S. Lefeuvre, "Robotic manipulation of rigid objects using a flying robot," in *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 1-6, 2019.
6. S. Briot, S. Bouffard, and S. Lefeuvre, "Robotic manipulation of rigid objects using a flying robot," in *IEEE International Conference on Robotics and Automation (ICRA)*, pp. 1-6, 2019.

Results










Figure 4: Applied external forces on a flexible body and its position.

Figure 5: Total position and velocity of the flexible body.

Figure 6: Total position and velocity of the flexible body.

Figure 7: Total position and velocity of the flexible body.

Figure 8: Total position and velocity of the flexible body.



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Let's talk about:

- Manipulating flexible bodies
- Aerial manipulators
- Rigid-flexible multibody systems
- Model and algorithmic perspectives

