Exploring the Dynamics of Octopod Manipulation

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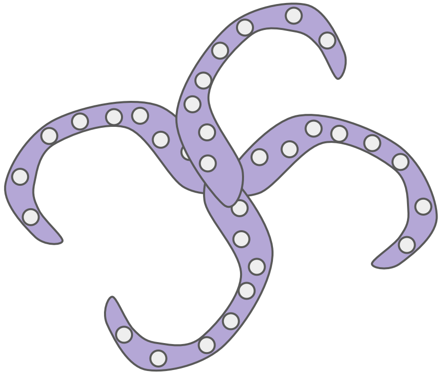


Content

Background

Octopods

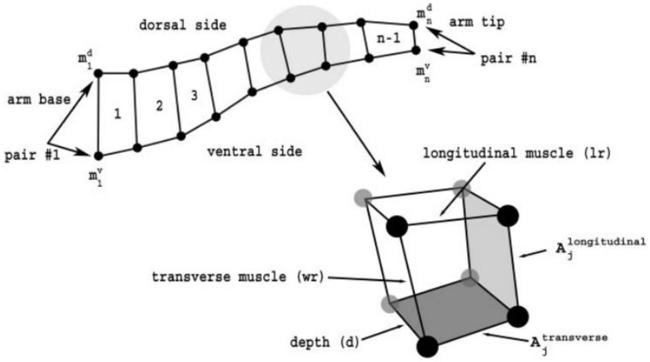
> Exceptionally flexible, virtually infinite DOF!

> Capable of stretching, contracting, folding over itself, rotating along its axis at any point, and following the contours of almost any object.

> Muscles generate forces + maintain the structural rigidity of the appendage.

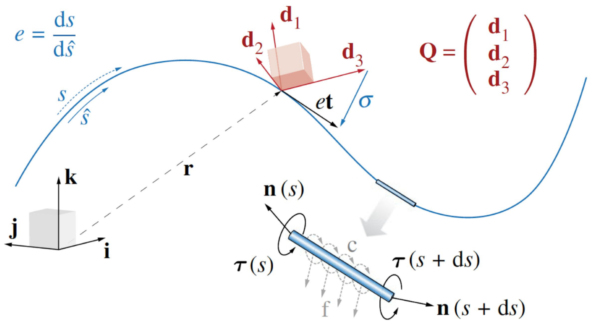
Different Models

> Planar



> Hydraulic-like

> Cosserat rods



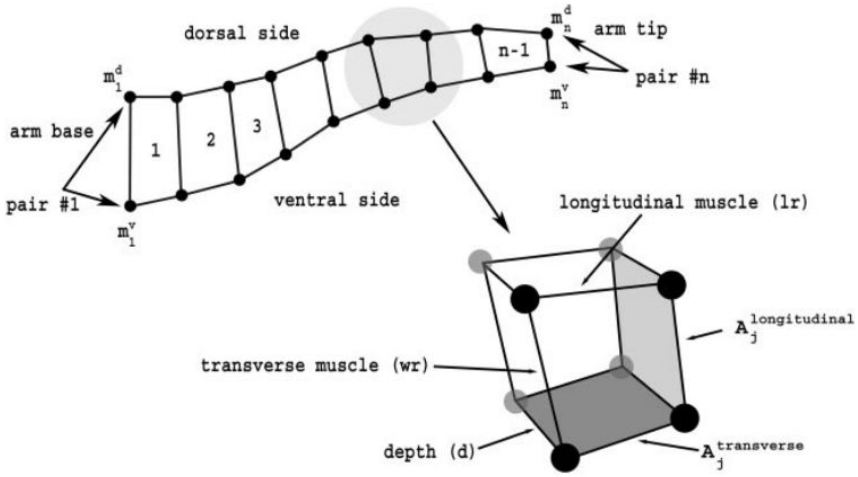
Diagram

Assumptions:

1> Simulated movements are free movements (e.g. do not interact with objects)

2> Discrete model (for simplicity). 20 segments (model /w 40 segments made little difference)

3> All forces confined to a single plane



Credits: [2,3]

Forces

1> Internal forces from arm muscles f^m

2> Vertical forces from gravity + arm buoyancy f^g

3> Drag forces (from water) f^w

4> Internal forces (constant volume constraints) f^c

$$M\ddot{q} = f^m + f^g + f^w + f^c$$

M : mass matrix

q : position vector

Forces

$$M\ddot{q} = f^m + f^g + f^w + f^c$$

M : mass matrix

q : position vector

Vertical forces from gravity + arm buoyancy

$$f^g = (\rho_{arm} - \rho_{water})V_{arm}\vec{g}$$

Archimedes Law

V : segment volumes

Drag forces (from water)

$$||\vec{d}_{per}|| = \frac{1}{2}\rho_{water}p_a c_{per}||\vec{v}_{per}||^2$$

$$||\vec{d}_{tan}|| = \frac{1}{2}\rho_{water}s_a c_{tan}||\vec{v}_{tan}||^2$$

\rho : density

p_a : projected area of segment

s_a : surface area of segment

v_per, v_tan : perpendicular, tangential directions of velocity

Forces

Internal forces (constant volume constraints)

$$f^c = Cp$$

$$p = (GM^{-1}C)^{-1}[\gamma - GM^{-1}(f^m + f^g + f^w)]$$

$$\ddot{q} = M^{-1}(f^m + f^g + f^w + f^c)$$

C : encodes constant volume constraint

p : compartmental pressures

$$M\ddot{q} = f^m + f^g + f^w + f^c$$

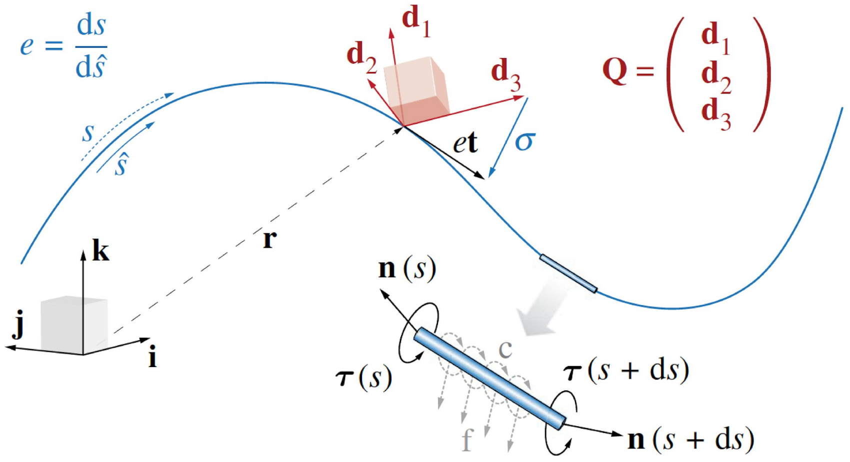
M : mass matrix

q : position vector

Diagram

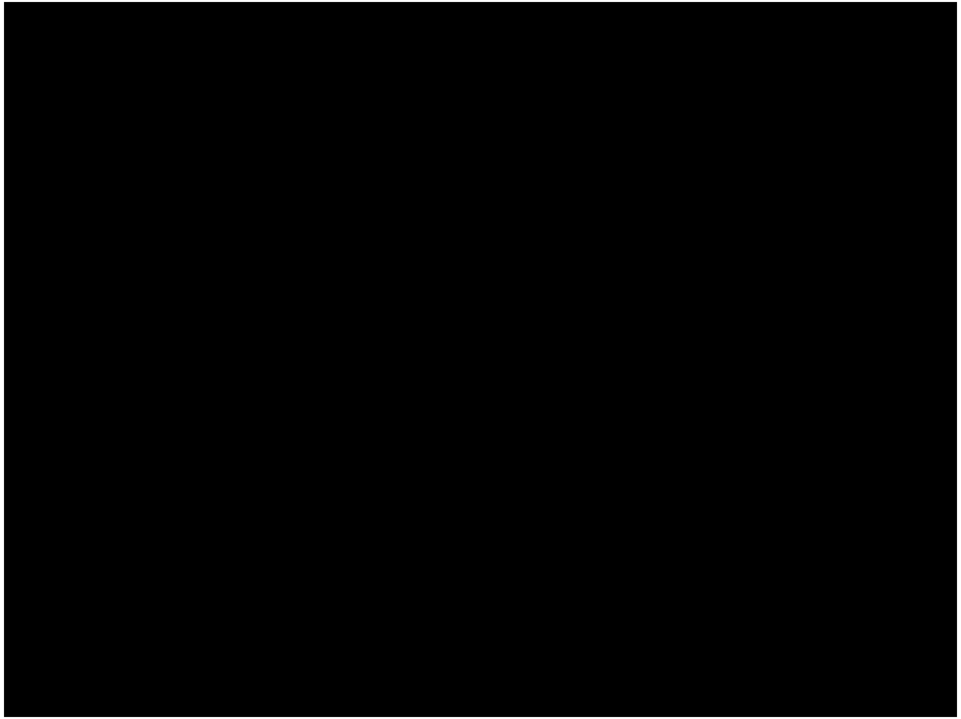
Kirchoff rods model 1-D bend + twist

Cosserat rods are a generalization to account for stretch + shear



Credits: [4,5]

Simulation



Code: https://github.com/bhaprayan/octopie

References

[1] Yaakov Engel, Peter Szabo, and Dmitry Volkinshtein. "Learning to Control an Octopus Arm with Gaussian Process Temporal Difference Methods". In:Advances in Neural Information Processing Systems 18(2005).

[2] Yoram Yekutieli et al. "Dynamic Model of the Octopus Arm. I. Biomechanics of the Octopus Reaching Movement". In: Journal of Neurophysiology 94 (Aug. 2005), pp. 1443–1458

[3] Yoram Yekutieli et al. "Dynamic Model of the Octopus Arm. II. Control of Reaching Movements". In: Journal of Neurophysiology 94 (Aug. 2005),pp. 1459–1468.

[4] Zhang, Chan, Parthasarathy, Gazzola, Modeling and simulation of complex dynamic musculoskeletal architectures, Nature Communications, 2019. doi: 10.1038/s41467-019-12759-5

[5] Gazzola, Dudte, McCormick, Mahadevan, Forward and inverse problems in the mechanics of soft filaments, Royal Society Open Science, 2018. doi: 10.1098/rsos.171628

Questions?

Thanks! :)