The 8th European Congress on Computational Methods in Applied Sciences and Engineering
ECCOMAS Congress 2022
5-9 June 2022, Oslo, Norway

A finite element method for the Cosserat Rod to describe undulatory locomotion

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Keywords: *Cosserat Rod, Structural Deformation, Biomechanics, Resistive Force Theory, Undulatory Locomotion, Finite Element Methods*

Understanding how microswimmers use the interplay of their neural control system, proprioception and muscles to produce a variety of swimming gaits and locomotion manoeuvres has attracted a lot of interest in the past. Here, we present and analyse a numerical method to study the dynamics of an open viscoelastic Cosserat rod - a slender three-dimensional object - immersed in a low Reynolds number fluid environment approximated by resistive force theory. Our model allows for both elastic and viscous bending, twisting, shearing and stretching and is an extension of the work presented in [1]. It describes the time evolution of both the midline curve and an orthonormal local reference frame which determines the rod's three-dimensional geometry. Piecewise linear finite element functions are used to derive a fully-discretized version of the nonlinear model equations. We demonstrate that the solution to the nonlinear problem can be found by linearizing the equations of motion and then solving the linear problem iteratively during each time step.

We then use the model to simulate the undulatory locomotion of *Caenorhabditis elegans*, a one-millimetre long soil-dwelling slender nematode. *C. elegans* is commonly used as a model organism for comprehensive investigations spanning genetic, neural control, sensory transduction, behaviour, and locomotion studies. *C. elegans* generate undulatory locomotion by sending a wave of muscle contractions along their body which creates a bending moment resulting in a harmonic alteration of its midline curvature. In our model, the bending moment is generated by defining a spatio-temporal pattern of preferred curvatures which serves as an effective motor control.

Fitting the model to midline trajectories, reconstructed from experimental recordings of *C. elegans* in a 3D setting [2], we infer muscle activation patterns for novel locomotion manoeuvres. These patterns could serve as a benchmark for gaining a better understanding of *C. elegans* neuromuscular control.

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