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Simulation of Permanent Magnet Elastomers Utilizing Discrete Elastic Rods

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Unlike bulky traditional actuators, permanent-magnetic elastomers (PMEs) offer untethered, programmable shape-morphing for soft robotics and haptics[1]. However, their non-linear magneto-mechanical coupling makes predicting spatial deflections computationally prohibitive, often forcing heuristic trial-and-error design. While Finite Element Method (FEM) analysis captures this coupling through a volumetrically discretized continuum [2], resolving these 3D volumetric field equations requires immense computational cost, rendering large-scale iterative optimization impractical.
Focusing on cilia-like actuators, a reduced-order model based on Discrete Elastic Rods (DER) is established as a highly efficient alternative [3]. The DER framework simplifies the actuator into a 1D spatial centerline curve discretized into segments. Solving a discrete energy minimization of the total potential energy, which comprises both elastic bending energy and magnetic energy.
When evaluating computational efficiency, the DER model solved the spatial equilibrium in seconds. Furthermore, the simulations demonstrated the capacity to capture extreme spatial deflections reaching 90° under medium-to-high field intensities (Figure 1).

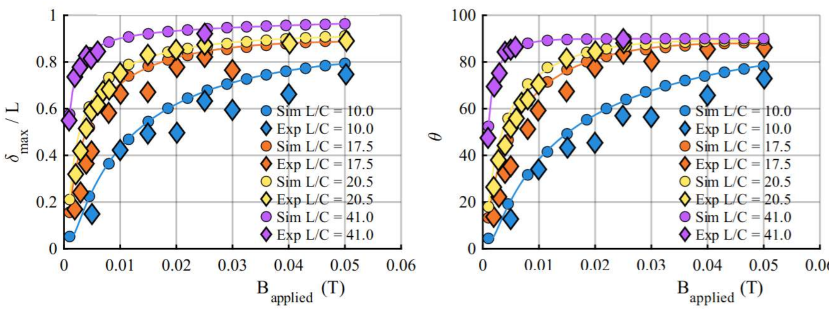

Figure 1: Superposition of the normalized maximum dis-placement and deflection angle generated by the DER model.

Ultimately, DER theory retains the geometric precision of continuous volumetric FEM modeling while drastically reducing computation time, successfully paving the way for future inverse design applications. For instance, this efficiency can optimize the evolution of complex projects such "Luminescent Tentacles" concept[1]. As a proposal, an evolved design could consist of dynamic magnetic fields that controls both shape and illumination; an XY pulley system precisely controls a magnet that deforms hollow PME pillars while simultaneously inducing current in embedded micro-coils to power wireless LEDs, eliminating the need for tethered wiring running through the tentacles.

References

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