Shape morphing untethered ferromagnetic soft robots

Abstract:

Cosserat rod theory is the popular approach to modeling ferromagnetic soft robots as 1-Dimensional (1D) slender structures in most applications, such as biomedical. However, recent soft robots designed for locomotion and manipulation often exhibit a large width-to-length ratio that categorizes them as 2D shells. For analysis and shape-morphing control purposes, we develop an efficient coordinate-free static and dynamic model of hard-magnetic shells found in soft magnetic grippers and walking soft robots. The approach is based on a novel formulation of the Cosserat shell theory on the special Euclidean group (SE3).

The shell is assumed to be a 2D manifold of material points with six degrees of freedom (position and rotation) suitable for capturing the behavior of a uniformly distributed array of spheroidal hard magnetic particles embedded in the rheological elastomer. The shell's configuration manifold is the space of all smooth embeddings $\mathbb{R}^2 \rightarrow \mathrm{SE3}$. According to a novel definition of local deformation gradient based on the Lie group structure of SE3, we derive the strong and weak forms of equilibrium equations, following the principle of virtual work. We extract the linearized version of the weak form for numerical implementations. The resulting finite element approach can avoid well-known challenges such as singularity and locking phenomenon in modeling shell structures.

The proposed model is analytically and experimentally validated through a series of examples that demonstrate its superior efficacy, particularly when the shell undergoes severe rotations and displacements.

Bio:

My main area of interest is geometric continuum mechanics and I started studying this field during my undergraduate degree at the University of Guilan. I then continued my education at MSc level (2014) in Applied Mechanics at Sharif University of Technology. Upon completion of my master's degree, I realized that continuum mechanics could be applied to many different fields such as biomechanics, aerospace engineering, electrical engineering, etc. However, my knowledge of continuum mechanics was still limited and therefore I started my PhD studies in Rational Mechanics at Sharif University of Technology where I worked with some of the top researchers in the field. During my doctorate studies, I had the great opportunity to work with an esteemed professor at the University of Calgary (UofC) as a visiting graduate student on a one-year sabbatical. My research at UofC focused on generalized continuum mechanics using differential geometric methods to model living tissue evolutions such as morphogenesis. I completed my PhD in 2020 with numerous published papers in the field of Solid Mechanics.

I moved to Canada in 2021 with the desire to continue my studies in a field where I could use the theoretical knowledge I have acquired and apply it to an area that would benefit humanity. Therefore, I joined the ASRoM-Lab as a PhD Student. My research is on novel shape-morphing soft robotic systems for space exploration. My goal is to develop model-based dynamic closed-loop strategies to control shape-morphing continuum robots experiencing large deformation to adapt to varying environments and to enable multitasking.