ME - PhD Thesis Defense

Design of Structures and Mechanisms using Topological Derivatives and Exploration of 4D-printed Shape-morphing Structures

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ABSTRACT

We employ topological derivatives to design supports for stiff structures and compliant mechanisms along with exploration of design features for 4D-printed shape-morphing structures. Topological derivative (TD) has been widely used as a powerful framework to obtain optimal topological designs. In this thesis, we use TD differently: not just to introduce the hole at a point but with specified displacement at that point. When the specified displacement is zero, it amounts to fixing that point. We show that TD with specified displacements, i.e., with Dirichlet boundary condition, opens new possibilities for locating the optimal support points for stiff structures and compliant mechanisms. The objective functional is strain energy for the former and mutual strain energy for the latter.

We begin with the derivation of TD with Dirichlet boundary condition (TD-Dbc) for the simplest case of a 1D bar. We derive separate analytical expressions for the TD of a bar for displacement and force loading cases because there is difference in sign of the TD as well as its magnitude. We consider 2D and 3D truss examples to illustrate the efficacy of the method for support design for both trusses and truss-based compliant mechanisms.

We also use TD with Neumann boundary condition (TD-Nbc) for the design of compliant mechanisms in 2D continuum domain. Topology-optimized compliant mechanism designs with mutual strain as the objective functional invariably lead to point flexures or hinges. We explore how these hinges are created inside the domain using TD expression of the mutual strain energy alone and also with strain energy as extra constraint.

To understand the sensitivity of the objective functional with Dirichlet boundary condition as in the case of TD expressions, we derive semi-analytical formulae for both displacement and force loads. These results apply to any domain, physics, and the discretization method. We show the examples and underlying interpretation of results for 1D, 2D and 3D domains.

Finally, we explore the design features for the desired deformations of the 4D-printed shape-morphing structures. 4D printing is an evolution of 3D-printed structure with time. We chose two processes: one uses hydrogel swelling, and another uses thermoplastics heating. We discuss the various features and speculate on how topological derivatives could be used to design topologies for optimally responsive structures.

Taken together, this thesis captures four inter-linked problems of designing structures and mechanisms using TD and exploration of design features in 4D printing.

ABOUT THE SPEAKER

Vageesh Singh Baghel is a PhD student in Department of Mechanical Engineering at IISc Bengaluru. He is working with Prof. G. K. Ananthasuresh in Multidisciplinary and Multiscale Design and Device (M2D2) laboratory. He completed BE from MITS Gwalior, Madhya Pradesh in 2014, and ME from BITS Pilani, Rajasthan, in 2017. His research interests include topology optimization, computational mechanics, compliant mechanism design, and 4D printing.