The Mechanics and Dynamics of Single-Manifold Structures

Abstract

There are many systems such beams, pipelines, drone swarm paths, DNA, rails, etc., where the configuration may be described by a framed space curve parametrized by a single parameter. To generically capture the behavior of these systems, we utilize the application of differential geometry of framed space curves and mechanics to define the configuration of such "single-manifold" systems. Most importantly, this work leads to the development of numerous dynamic problems like advanced non-linear beam theory, shape reconstruction of slender structures, path-estimation, and computational graphics.

Using the beam example, the assumption of a rigid Euler-Bernoulli cross-section in the Cosserat beam theory suggests room for further development of a more general theory that consists of deformable cross-sections. A comprehensive kinematic treatment of geometrically exact and nonlinear Cosserat beams subjected to large deformation and finite strain is obtained. Among other deformation effects, the proposed kinematics also captures a fully coupled Poisson's and warping deformation. The developed kinematics is ultimately used to establish a measurement model of discrete and finite length strain gauges attached to the surface of the beam (or embedded into the beam). This measurement model of strain gauge is finally used to obtain an improved shape reconstruction algorithm (estimating position from limited strain measurements). Owing to the similarity in the mathematical construction of the state space of moving bodies and Cosserat beams with a Euler-Bernoulli rigid cross-section, the methodology of shape sensing of slender structures may be successfully applied to path-estimation of moving bodies. The finite element formulation of such comprehensive beams is complicated because the formulation involves higher order derivatives of the curvature and angular velocity tensors. We are currently addressing issues arising due to advanced kinematical models in such beams, such as calculating higher order derivatives of curvature and angular velocity and the configuration dependence on the mass matrix.

Biographical Sketch

Michael Todd received his B.S.E. (1992), M.S. (1993), and Ph.D. (1996) from Duke University's Department of Mechanical Engineering and Materials Science, where he was an NSF Graduate Research Fellow. In 1996, he began as an A.S.E.E. post-doctoral fellow, then a staff research engineer (1998), and finally Section Head (2000) at the United States Naval Research Laboratory (NRL) in the Fiber Optic Smart Structures Section. In 2003, he joined the Structural Engineering Department at the University of California San Diego, where he currently serves as Professor of Structural Engineering. He has published over 350 papers and proceedings in his research areas, which are in applying nonlinear time series techniques to structural health monitoring (SHM) applications, adapting Bayesian inference frames for optimal decision-making in SHM, developing novel ultrasonic interrogation strategies for aerospace structural assessment, optimizing sensor networks for various SHM-rooted performance measures, developing RF-based sensing systems for structural assessment, creating real-time shape reconstruction strategies for highly flexible aerospace and naval structural systems based on limited data sets, creating rapid assessment checks for validation of satellite systems, designing and testing fiber optic measurement systems for many structural applications, and modeling noise propagation in fiber optic measurement systems. Prof. Todd won the 1999 Alan Berman NRL Publication Award, the 2003 and 2004 NRL Patent Award, was a 2004-2005 UC San Diego Hellman Fellow, was an invited speaker at the 2003 National Academy of Engineering Japan-America Frontiers of Engineering Symposium, won the 2005 Structural Health Monitoring Person-of-the-Year Award, presented at Stanford University in September 2005, was named a 2009 Benjamin F. Meaker Fellow at the University of Bristol (UK), and won the 2016 Society of Experimental Mechanics D. J. DeMichele Award for contributions to research and education in experimental mechanics. He serves as the Managing Editor of *Structural Health Monitoring: An International Journal*.