Two Degree of Freedom Design for Robust Nonlinear Control of Mechanical Systems

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Project Overview

- Computational methods for real-time trajectory generation for nonlinear mechanical systems
- Theoretical and computational methods for analyzing robustness to perturbations which preserve the mechanical nature of the system
- Theoretical and experimental studies to explore the tradeoffs between aggressiveness in trajectory generation and robust performance
- Implementation of proposed techniques in industrial applications
Configuration Controllability for Mechanical Systems

Motivating Problems

• For mechanical systems, often interested in moving between equilibrium points (or relative equilibria), not general states
• Requires more geometric understanding of controllability, tuned to mechanical systems

Objectives

• Give computable tests for controllability between equilibrium points rather than arbitrary states (configuration + velocity)
• Understand underlying geometry to exploit controllability structure in stabilization, trajectory generation, trajectory tracking

Techniques

• Use Riemannian structure associated with kinetic energy metric (Levi-Cevita connection)
• Make use of symmetric product to encode geometry of geodesically invariant sets (complements Lie bracket)

Results to date

• Complete characterization of configuration accessibility (weak notion of controllability)
• Sufficient conditions for equilibrium controllability in terms of smallest “totally geodesic” distribution generated by external force fields

Significance

• Describes underlying geometry of nonlinear control of mechanical systems, exploit inherent structure (Lagrangian)
• Extensions to mechanical systems on Lie groups (e.g., satellites, aircraft, underwater vehicles) gives even sharper results (more structure)
Trajectory Generation and Tracking Using Differential Flatness

Approach: Two Degree of Freedom Design

- Use online trajectory generation to construct feasible trajectories
- Use (scheduled) linear control for local performance
- For many mechanical systems, system is differentially flat => reduce dynamic system to algebraic equivalent and generate feasible trajectories in real time

Results

- Aggressive tracking for fully actuated mechanical systems by exploiting mechanical structure (Bullo & Murray, 1997)
- Real-time algorithms developed and tested on ducted fan (Van Nieuwstadt and Murray, 1996)
- Necessary and sufficient conditions for flatness for a class of mechanical systems (Rathinam and Murray, 1996)
Summary of Accomplishments

Major Milestones

- General framework for control of mechanical systems, exploiting geometric structure [5]
- Necessary and sufficient conditions for differential flatness of mechanical systems with one fewer input than control [4]
- Application of flatness based control laws for tracking of aggressive trajectories to Caltech ducted fan [3]
- Algorithms for constructive controllability for underactuated mechanical systems on Lie groups [1]

Honors and Awards (1997)

- Plenary speaker, SIAM Conference on Applications of Dynamical Systems (May 97)
- Donald P. Eckman Award (AACC, June 97)
- Plenary speaker, SIAM Conference on Control and Its Applications (May 98)

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