Rapid Gait Optimization in CasADi

Martin Fevre and James P. Schmiedeler
University of Notre Dame, Notre Dame, IN USA

Background

- Open-loop trajectories can be hard to stabilize in practice for high-dimensional spatial bipeds.
- Curse of dimensionality makes real-time gait optimization nearly impossible for complex bipeds.
- Template models simplify motion planning but unavoidably neglect important physical constraints and may yield impractical gaits.

Comparative Studies

- TROPIC was compared to FROST [2], another state-of-the-art HZD-based optimization package.
- Optimize 10-gait library for 7-DOF planar biped.
- TROPIC and FROST converged to nearly identical gaits, but TROPIC was on average 4 times faster [3].

Convergence Times on Spatial Bipeds

- 12-DOF biped model: <10 seconds
- 20-DOF humanoid model: <1 minute

→ TROPIC leverages CasADi's unprecedented efficiency into systematic gait design for complex biped robots.

Modeling Procedure

Hybrid Model of Walking

Constraints

- Gait characteristics e.g. walking speed
- Physical constraints e.g. friction
- Virtual constraints $y := y^d - y^d(\tau) \rightarrow 0$
  
  *User Inputs in MATLAB*

- TROPIC automatically transcribes NLP
- Hermite-Simpson or trapezoidal
- Algorithmic Differentiation
- CasADi generates sparse Jacobian and Hessian of constrained NLP’s Lagrangian.

Algorithmic Differentiation

- IPOPT + linear solver

Results

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TROPIC

- Open-source CasADi-based optimization package that enables systematic gait design for high-dimensional biped robots in MATLAB.
- Hybrid zero dynamics (HZD)-based optimization generates gaits and feedback controllers simultaneously.
- Trajectory optimization via direct collocation: large but sparse nonlinear program (NLP).

CasADi [1]

- Efficiently models optimal control problems.
- State-of-the-art implementation of algorithmic differentiation (AD) for computing derivatives.
- Symbolic expressions stored as directed graphs of symbolic primitives.
- Sparsity patterns are generated automatically.

References