Rapid Gait Optimization in CasADi

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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.

TROPIC*

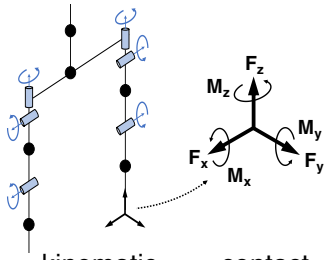
- Open-source CasADi-based optimization package that enables systematic gait design for high-dimensional biped robots in MATLAB.
- Hybrid zero dynamics (HZD)-based optimization generates gaits and feedback controllers simultaneously.
- Trajectory optimization via direct collocation: large but sparse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

Modeling Procedure

Hybrid Model of Walking



kinematic tree + contact model

Constraints

- Gait characteristics e.g. walking speed
- Physical constraints e.g. friction
- Virtual constraints
  $y := y^a - y^d(\tau) \to 0$
  y : controller output
  τ : step progression

User Inputs in MATLAB

Transcription

- TROPIC automatically transcribes NLP

direct collocation ⟶ $\min_z J(z)$

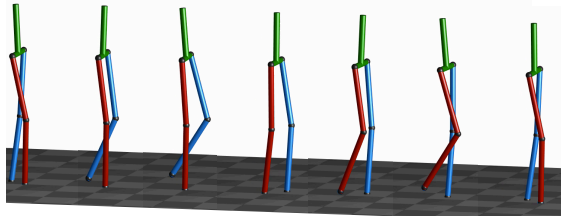
- Hermite-Simpson or trapezoidal

Algorithmic Differentiation

- CasADi generates sparse Jacobian and Hessian of constrained NLP's Lagrangian.

Solve NLP

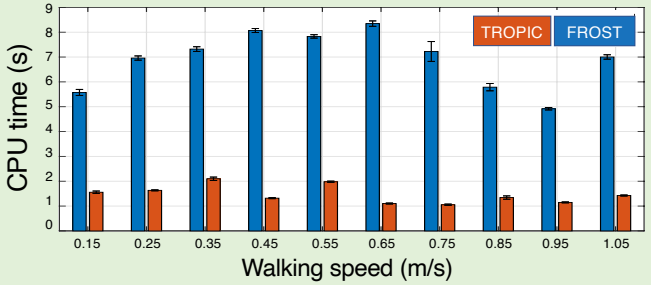
- IPOPT + linear solver



Results

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.**

References

[1] J. Andersson et al., "CasADi – A software framework for nonlinear optimization and optimal control," *Mathematical Programming Computation*, 11(1), pp. 1-36, 2019.

[2] A. Hereid and A. Ames, "FROST: Fast Robot Optimization and Simulation Toolkit," *Proc. IROS*, pp. 719-726, 2017.

[3] M. Fevre, P.M. Wensing, and J.P. Schmiedeler, "Rapid bipedal gait optimization in CasADi," *In review* (IROS 2020).

*TRajectory OPtimization In CasADi, https://github.com/fevrem/TROPIC