Optimization of dynamic motions for legged robots

I. Havoutis, J. Buchli, D. G. Caldwell and C. Semini

ISTITUTO ITALIANO DI TECNOLOGIA

Motivation

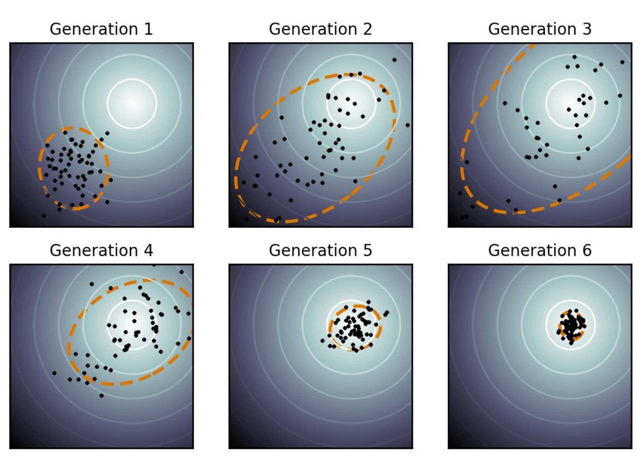
- Dynamic motions are useful in real-world applications
- They can be difficult to analytically define or author especially when dealing with systems acting in the real world (*noise, uncertainty, delays*)
- Instead, define high-level goals
- Use an optimization/learning method to arrive to the desired controller

The Hydraulic Quadruped robot

- Designed and built in the Dynamic Legged Systems Lab[1]
  - **12** hydraulically actuated joints
    - 4 rotational actuators
    - 8 linear actuators
  - Rugged hardware, impact tolerant
  - ***Fully torque controlled!***
- Actively compliant – no passive springs

Covariance Matrix Adaptation Evolution Strategy

- Algorithm for difficult non-linear non-convex **black-box** optimization problems in continuous domain[2]
  - Generate & evaluate population
  - Update evolution path
  - Adapt covariance matrix
  - Adapt step size
  - ..repeat



Example from http://en.wikipedia.org/wiki/CMA-ES

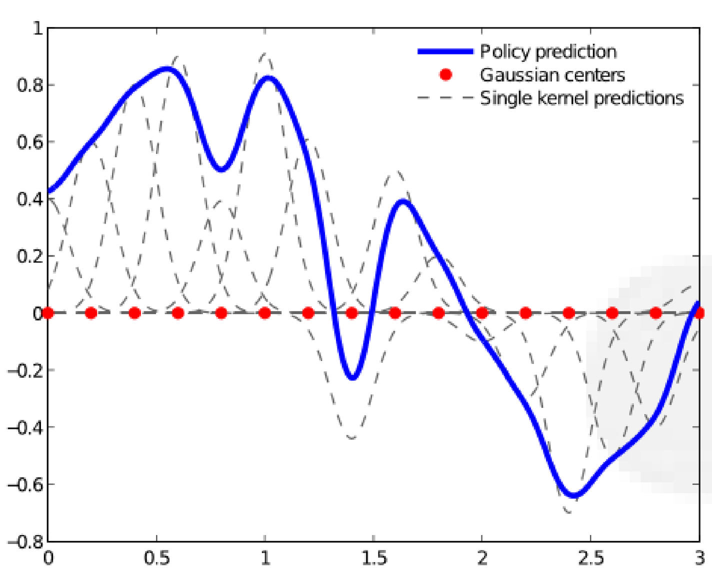
Setting up the policy

Weighted average of Gaussian kernels over a time lattice

- Regularly spaced kernels (μ's)
- Fixed kernel variance (σ^2)
- Varying weights (**w**)

$$f(t)=\sum_{i=1}^{m} w_i \varphi_i(t) / \sum_{i=1}^{m} \varphi_i(t),$$

$$\varphi_i(t)=\exp\left(\frac{-1}{2\sigma_i^2}(t-\mu_i)\right)$$



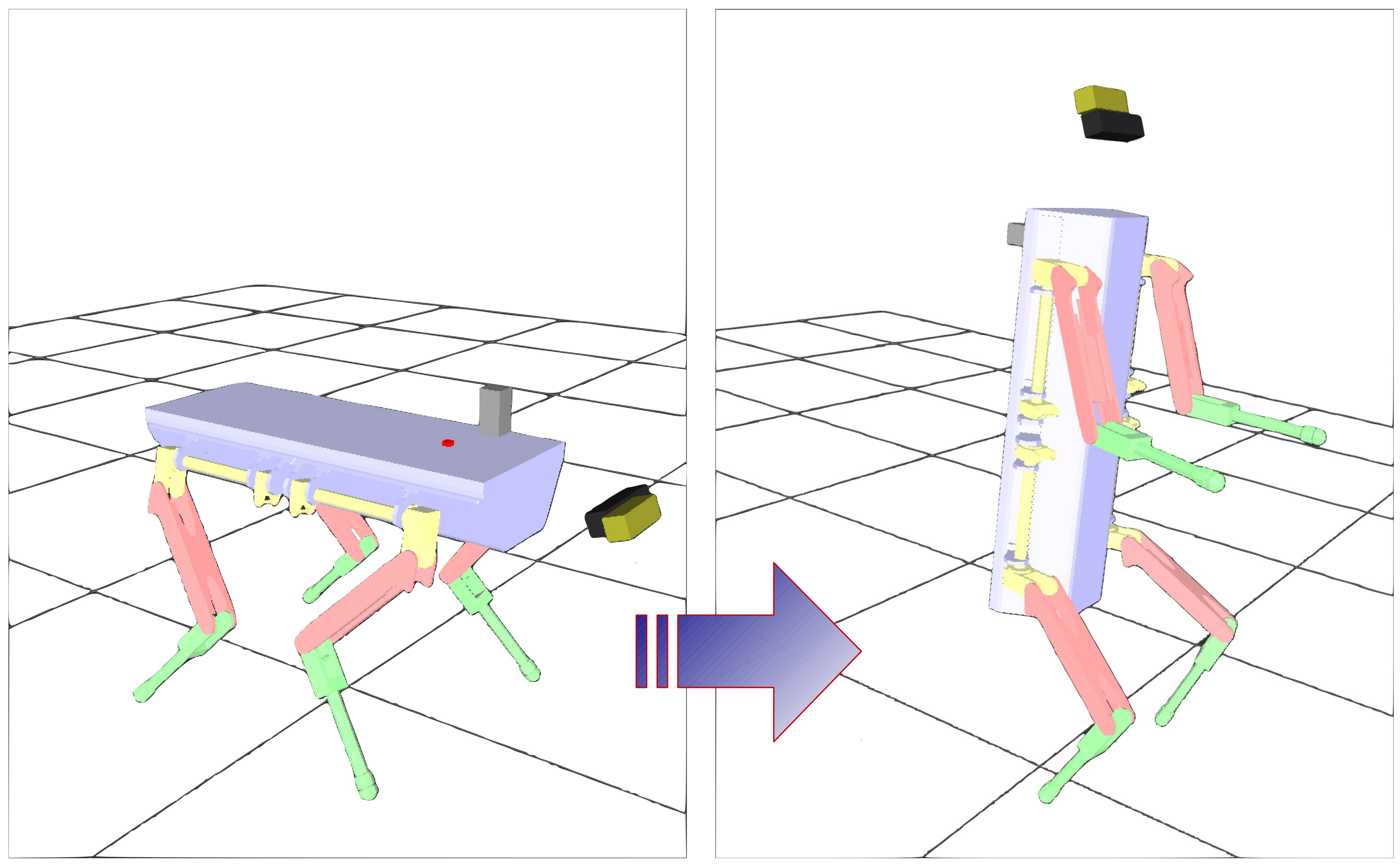
Cost function

$$C(\mathbf{w})=c_f+\int_{t_s}^{t_f} c_r(t)\,dt$$

Final cost:
- distance from *upright pose*
- magnitude of *linear velocity*
- magnitude of *angular velocity*

Running cost:
- exceeding *joint limits*
- magnitude of *joint torques*

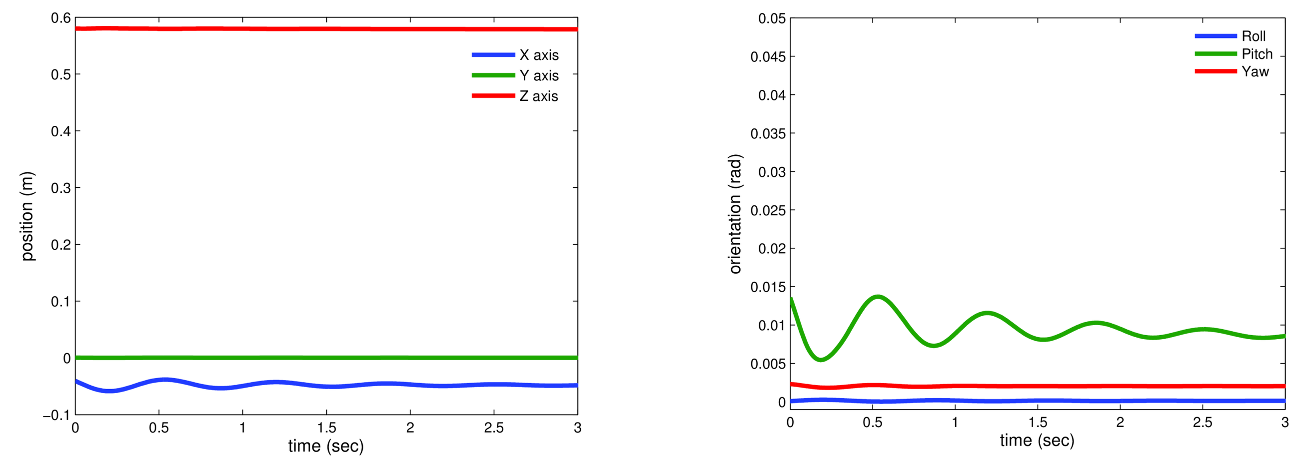
Dynamic Rearing Motion



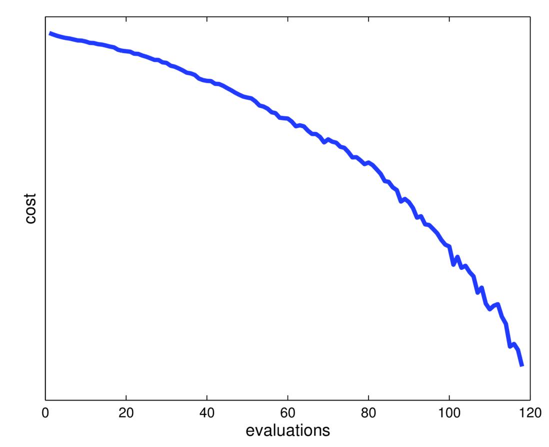
Simulation results

Rigid body dynamics simulation using a CAD based robot model with kinematic and dynamic constraints, and a realistic contact model.

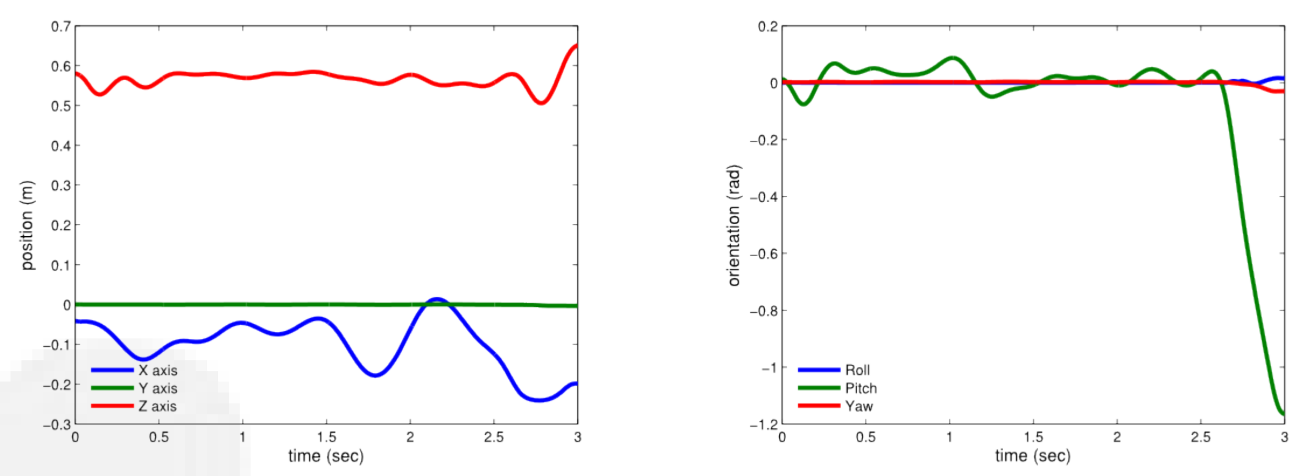
- Initial policy roll-out
  - Robot stands in place



- Policy optimization
  - Minimal parameter set
    - Standard deviation
    - Population size



- Optimized policy roll-out (~3k trials)
  - Robot *wiggles* back and forth
  - then pushes-off with its front legs while pulling-in the hind legs (…*see clip*!)



Currently

- Optimization/learning on the real quadruped robot
  - Starting from the policy optimized in simulation
- More dynamic motion examples
  - Jumping in place and over an obstacle/gap
  - Optimizing sequences of dynamic motions

[1] C. Semini, N. G. Tsagarakis, E. Guglielmino, M. Focchi, F. Cannella, and D. G. Caldwell, "Design of HyQ - a hydraulically and electrically actuated quadruped robot," Journal of Systems and Control Engineering, 2011.
[2] N. Hansen, S. Kern, "Evaluating the CMA Evolution Strategy on Multimodal Test Functions", Lecture Notes in Computer Science, Springer Berlin Heidelberg, 2004.

Dynamic Legged Systems Lab
Advanced Robotics Department
Istituto Italiano di Tecnologia

ioannis.havoutis@iit.it
buchlij@ethz.ch
darwin.caldwell@iit.it
claudio.semini@iit.it

Agile & Dexterous Robotics Lab
Institute of Robotics and Intelligent Systems
Eidgenössische Technische Hochschule Zürich