Learning Stable and Energetically Economical Walking with RAMone

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Introduction

Previously, we found that for RAMone (Fig. 1) walking was more economical at low speeds, and running at high speeds [2]. ***Do these simulated results extend to RAMone in hardware?***

This work is one step towards answering this for walking. Our walking controller uses different parameter values at different speeds. Hand-tuning these is time consuming and may not be successful.

Goal*: Automatically learn control parameters for RAMone that produce stable walking and minimize energy consumption*

RAMone

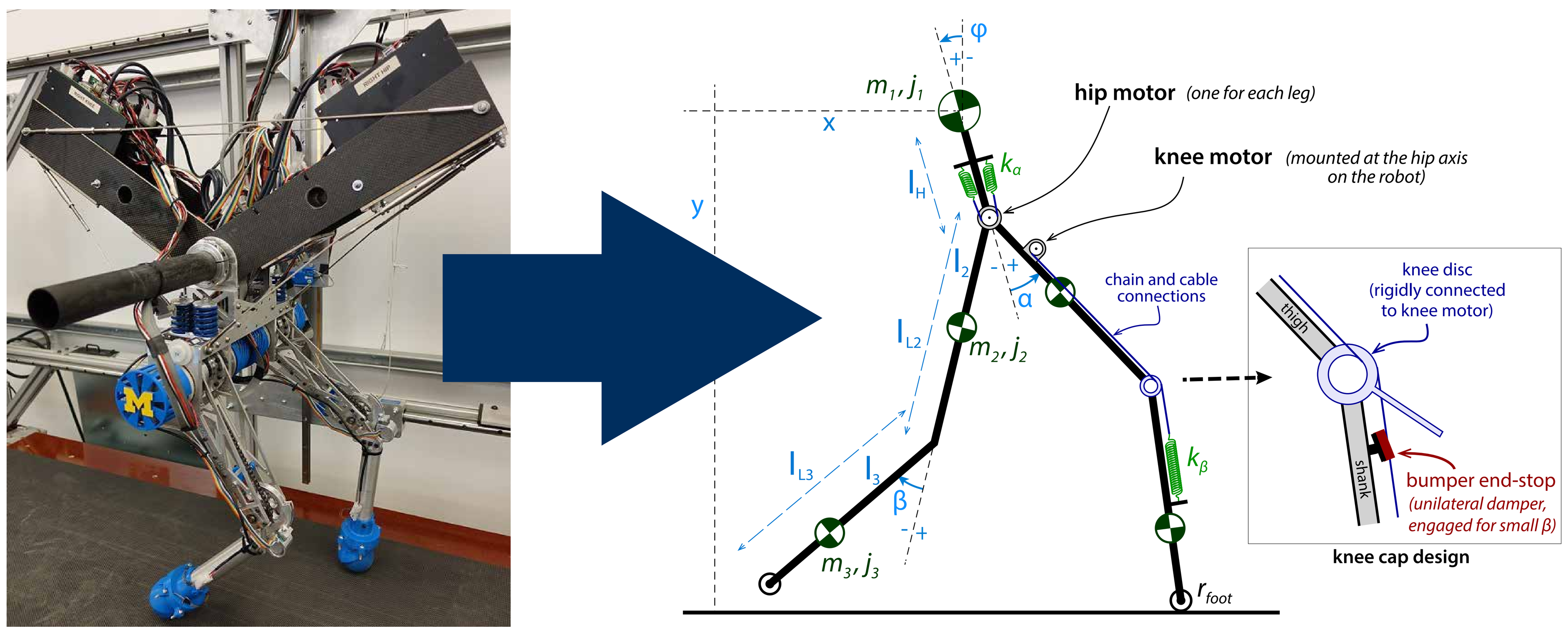


Fig. 1: The robot RAMone (left) is a five-link biped with series-elastic actuation at the knees and hips, and rolling contacts at the feet. In simulation, we use a detailed model of RAMone (right), which encodes the actuator dynamics with non-linear springs and accounts for dry friction and viscous damping in the joints.

Method

Overall approach

- Use optimal trajectories from [2];
- Stabilize trajectories with Hybrid-Zero-Dynamics style controller [3];
- Optimize HZD control parameters using Covariance Matrix Adaptation [1].

Optimization problem

Control parameters to optimize

$k_{\text{foot clearance}}$	modifies swing leg's knee angle
$k_{\text{foot placement}}$	modifies stance leg's hip angle
k_{hip}	hip proportional error tracking
k_{knee}	knee proportional error tracking

Cost Function to Minimize

For each trial set of parameters, we simulate RAMone for 6 s. Performance is evaluated with this cost:

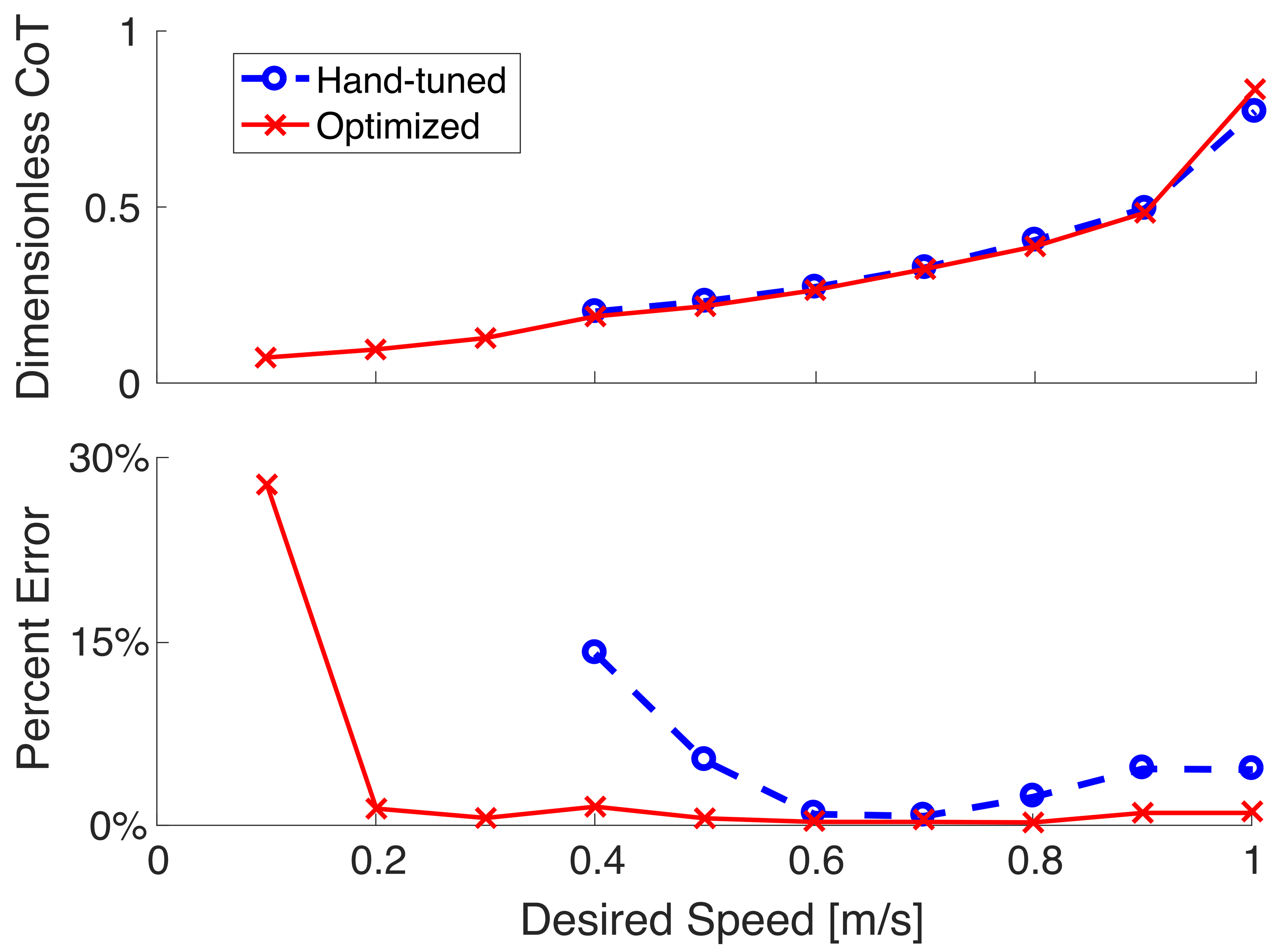
$$Cost = \begin{cases} 100 + 20 \cdot \Delta t_{\text{remaining}}, & \text{if robot falls} \\ 30 \cdot CoT + 1000 \cdot (\Delta \dot{x}_{\text{des}})^2, & \text{otherwise} \end{cases}$$

- $\Delta t_{\text{remaining}} = 6 - t_{\text{fall}}$ is the time between RAMone falling and a fixed end-time of the simulation (6 s);
- *CoT* is the cost-of-transport (based on electrical work, [2]), *a measure of energetic economy*;
- $\Delta \dot{x}_{\text{des}}$ is the difference between desired and actual speed of RAMone (average horizontal velocity of the main body).

Optimization Protocol

- Initial control parameters for the first speed (0.4 m/s) were found through hand-tuning.
- Subsequent speeds were initialized using optimal parameters at adjacent speeds.

Results



Compared to hand-tuned controls, optimized control parameters achieve

- Stable walking at a larger range of speeds;
- Similar cost-of-transport;
- Better tracking of desired speed.

Discussion

Possible reasons for little improvement in cost-of-transport:

1. The cost-of-transport does not depend strongly on the considered parameters;
2. Many local minima prevent finding the global optimum.

Future Direction

- Optimize additional control parameters or the trajectories.
- Modify the described method to optimize parameters on hardware.
- Stabilize *running* controller at various speeds in simulation and on hardware.
- Optimize parameters for robustness.

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References

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