Multi-objective Trajectory Optimization to Improve Ergonomics in Human Motion

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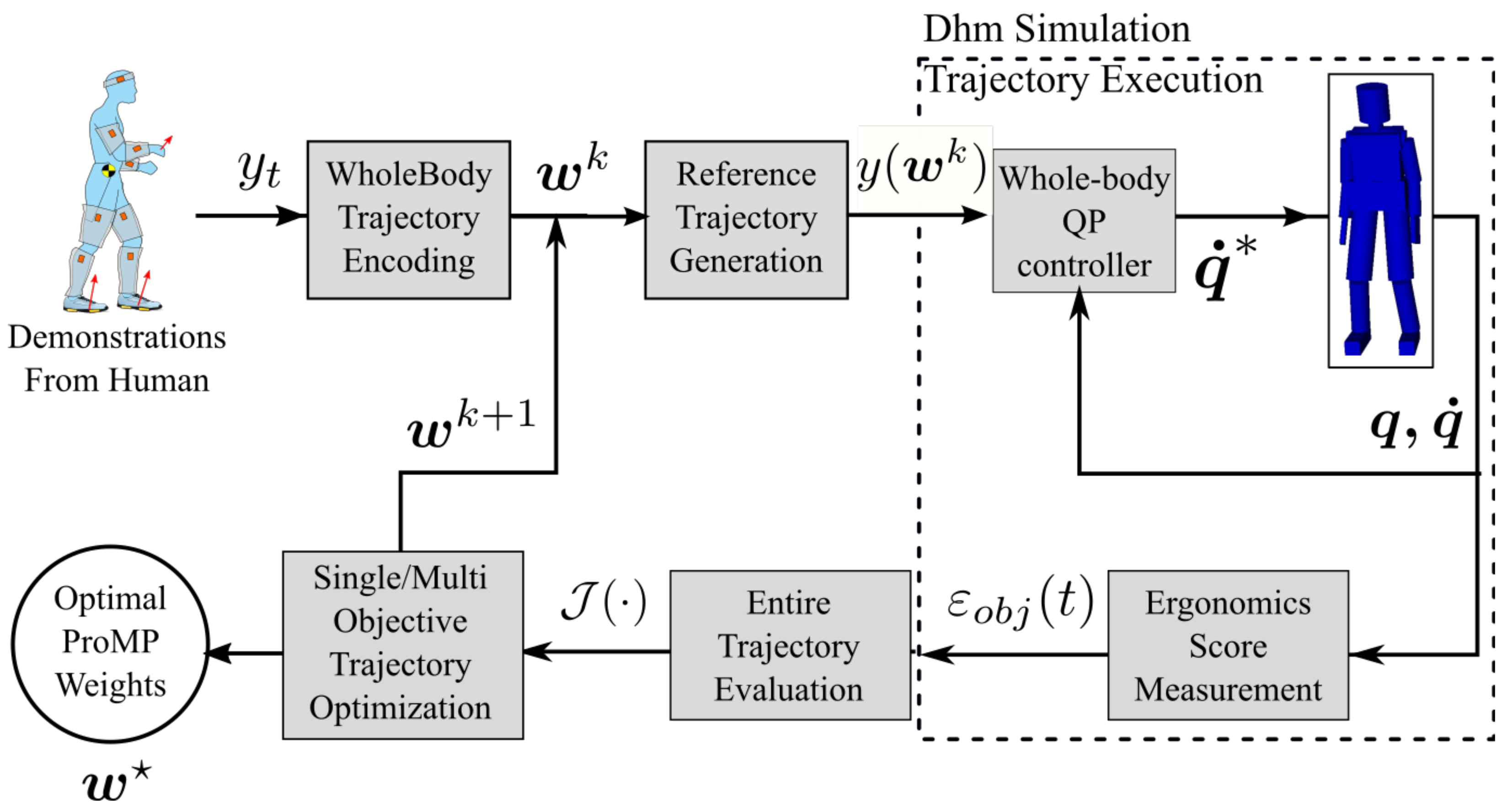
Introduction

- **Work-related Musculoskeletal disorders** are a major health issue often caused by awkward, **non-ergonomic body postures**
- We can identify and recommend more ergonomic body postures using:
  - Digital Human Models (DHMs)
  - Digital Ergonomics Evaluation Scores
  - **Parameterized Trajectory Optimization**

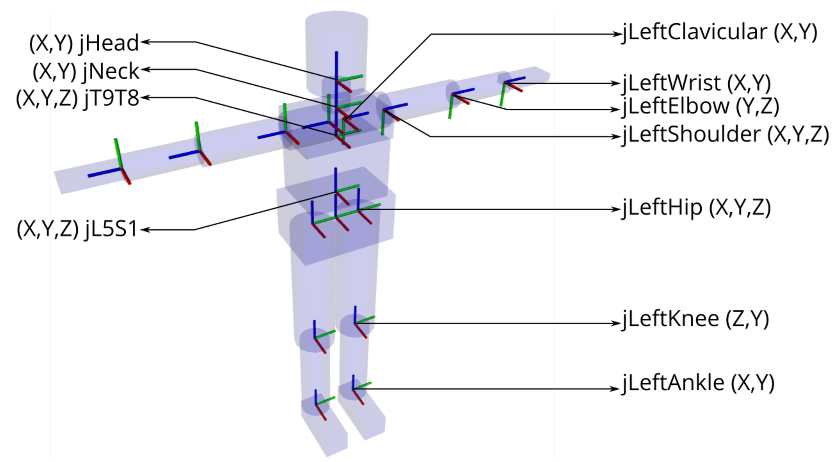
- However, **different ergonomics scores** often emphasize **different ergonomics risks**!
- Single-Objective Trajectory Optimization may lead to trajectories that are still non-ergonomic
- **We propose** to optimize whole-body trajectories w.r.t. to many ergonomics scores using a **multi-objective approach**.

Method's Overview



- Whole-body demonstrations are parameterized into a single-vector w_k
- The initial trajectory parameters are used to bootstrap a Multi-Objective Trajectory Optimization using the **NSGA-II optimizer** [1]
- At each rollout, the optimizer runs a **DHM simulation** controlled by **a velocity-based QP Controller** [2] that executes and evaluates the cost $\mathcal{J}$ of the whole-body trajectory

DHM Simulation, QP Controller, and ProMPs



$$\dot{q}^* = \arg\min_{\dot{q}} \|A_n \dot{q} - b_n\|_W$$
$$\text{s.t.} \quad \mathbf{C_{1,n}} \dot{\mathbf{q}} \leq \mathbf{b_{1,n}}$$
$$\mathbf{C_{2,n}} \mathbf{q} \leq \mathbf{b_{2,n}}$$

- The DHM has 43 DoF, and its inertia is defined according to anthropometric tables
- The QP controller generates whole-body motions that respect the **DHM's constraints**, such as its joint limits
- Each **reference Cartesian trajectory (** $y_t \in \mathbb{R}$ **)** is encoded in the **weights from a Probabilistic Movement Primitive (ProMP) distribution** [3], that are later stacked into the single-vector w_k at every rollout.

$$y_t(v) = \phi_t^\top v + \epsilon_y$$

$$w = [v^1 \dots v^{n_{trajs}}]$$

Ergonomics Scores Evaluation

- The cost for each whole-body trajectory is accumulated at each time-step of the Dhm simulation

- We also include **penalties in case the trajectory does not execute the desired task**

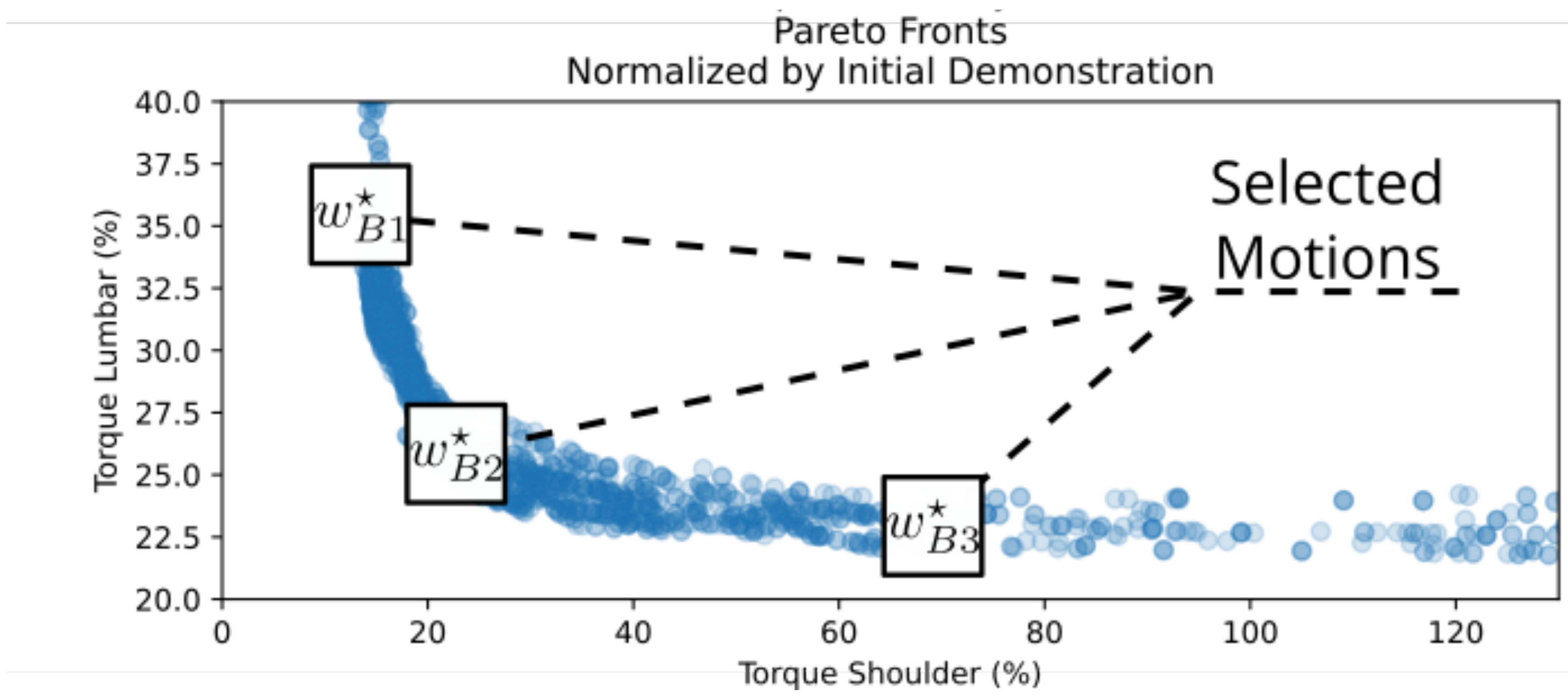
$$\mathcal{J}_{obj} = T_{fall}\mathcal{P}_{obj}^{fall} + \mathcal{P}_{obj}^{via} + \sum_{t \in [0 \dots T]} \varepsilon_{obj}^2(t)$$

Description	Score	$\varepsilon_{\text{obj}}(t)$
RULA-C	Regression of RULA	ε_{rc}
Normalized whole-body effort	$\frac{1}{n_{joints}} \sum_{i \in joints} \left(\frac{\tau_t^i}{\tau_{max}^i}\right)^2$	ε_{nwe}
Torques Shoulder	$\|\boldsymbol{\tau}_{shoulder}\|$	ε_{tsh}
Torques Lumbar	$\|\boldsymbol{\tau}_{lumbar}\|$	ε_{tlb}
Back Flexion	$\|\theta_{L5S1}^{Y}\|$	$\varepsilon_{\text{back}}$

Experiment

- 5 Box lifting demonstrations
- **Minimize efforts at the lumbar back, and at the shoulder**
- 20 Multi-Objective optimization replicates

Results and Conclusions



- Ergonomics scores can indeed be conflicting for ergonomics whole-body motion optimization
- **MO Optimization outputs a Pareto Front of solutions (a set of non-dominated solutions) that can be selected afterwards**
- An ergonomics expert may choose to favor one or more scores to favor when picking a trajectory from the Pareto Front

[1] Deb, K., Pratap, A., Agarwal, S., & Meyarivan, T. A. M. T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II
[2] Rocchi, A., Hoffman, E. M., Caldwell, D. G., & Tsagarakis, N. G. (2015). Opensot: a whole-body control library for the compliant humanoid robot coman
[3] Paraschos, A., Daniel, C., Peters, J. R., & Neumann, G. (2013). Probabilistic movement primitives