Multi-task Optimization to Evaluate Workstation Suitability over a Population of Virtual Humans

Jacques Zhong, Pauline Maurice, Vincent Weistroffer, Francis Colas

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Jacques ZHONG [1,2], Pauline MAURICE [1], Vincent WEISTROFFER [2], Jean-Baptiste MOURET [1], Francis COLAS [1]
[1] INRIA-LORIA, Larsen [2] CEA-LIST, LSI
Contact: jacques.zhong@cea.fr

Introduction

- **Musculoskeletal disorders** (MSD) in the industry are a major health issue with important productivity losses.
- **Virtual workstations** and **digital human models** (DHM) help **ergonomists** prototype safer workstations with lower risks of MSD.

Scientific problems

For a given virtual workstation and a population of workers:
1) How to study the **impact of the morphology** on the ergonomics?
2) How to generate **behaviors adapted to each morphology**?

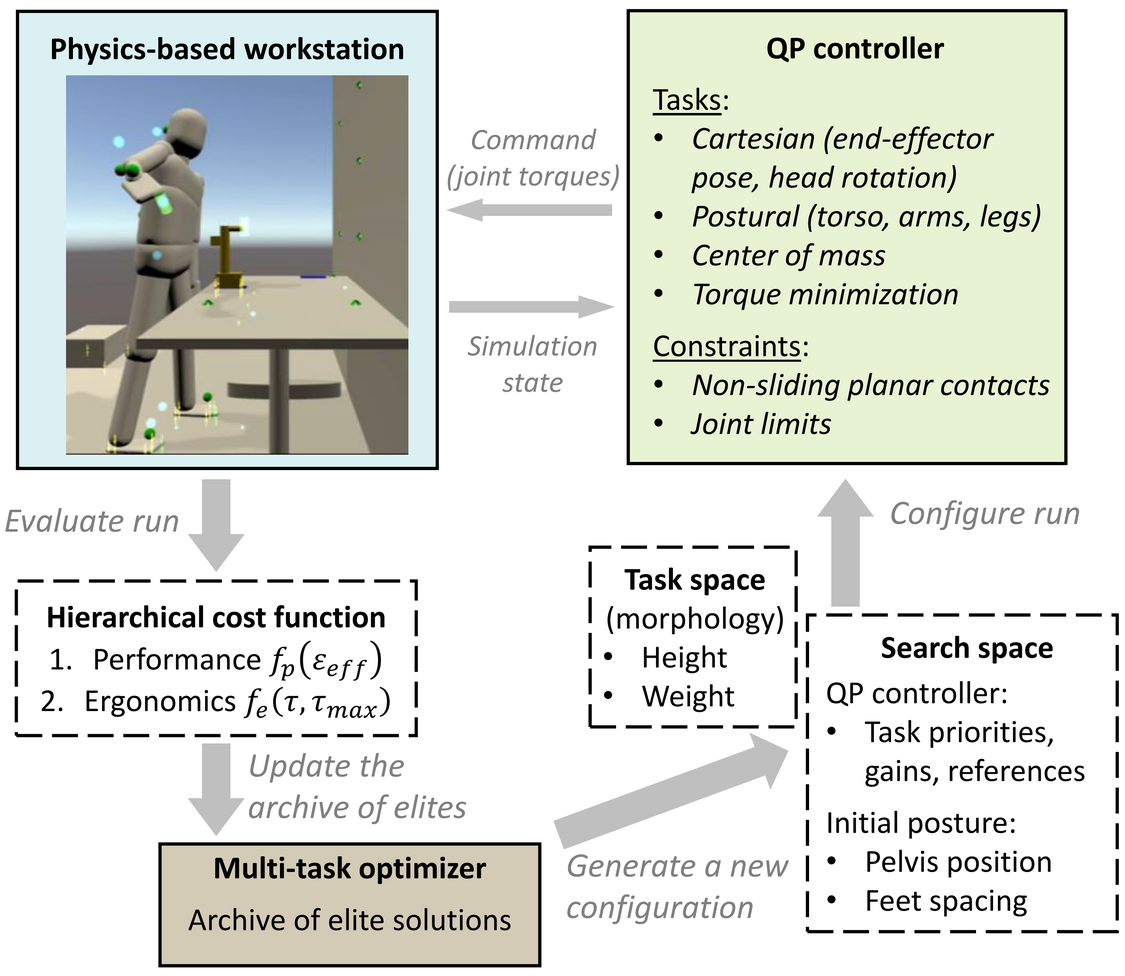
Main idea

Compute **workstation fitness maps** over large populations of virtual workers, by combining whole-body control and multi-task optimization.

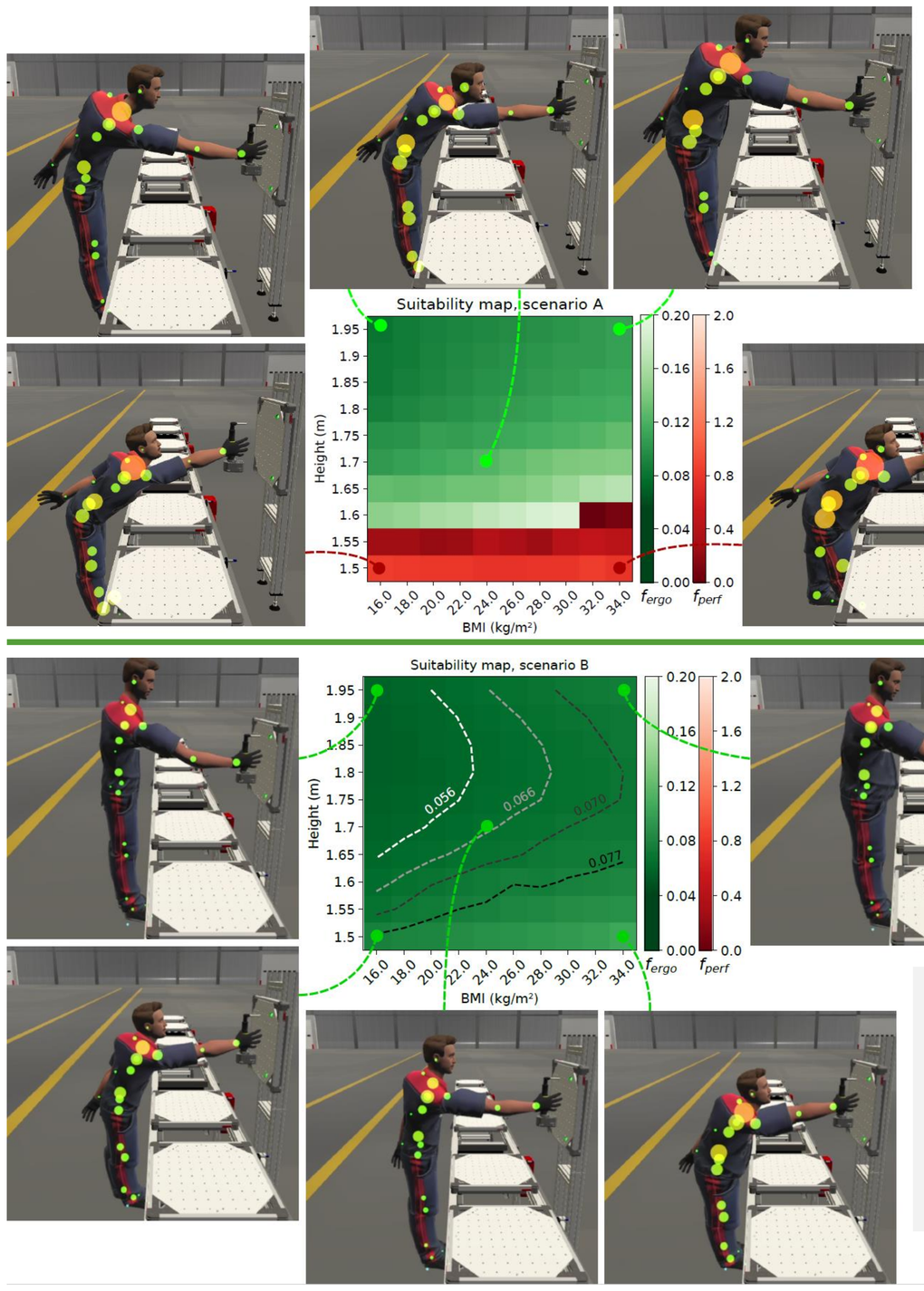
Method overview

Activity simulation with physics-based DHM:
- Virtual workstation created with the XDE/XSM framework [1]
- Configurable DHM (47 DoFs) performing the activity
- Quadratic-programming (QP) controller based on the TSID library [2]

Behavioral adaptation with Multi-Task optimization:
- Intuition: similar morphologies have similar solutions
- Simultaneously optimize all morphologies with Multi-task MAP-Elites [3]



Suitability maps – Screwdriving activity

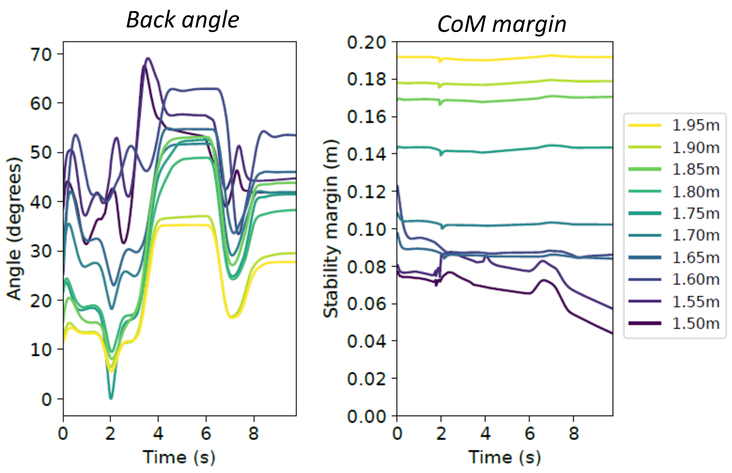


Scenario A
50k evaluations
Panel distance: 1 m
*
Fail rate = 22 %
Mean f_{ergo} = 0.116

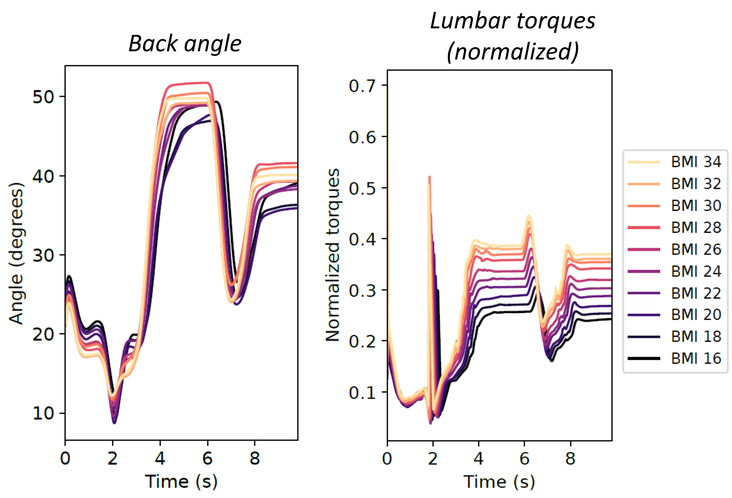
Scenario B
50k evaluations
Panel distance: 0.8 m
*
Fail rate = 0 %
Mean f_{ergo} = 0.070

Behavioral strategies

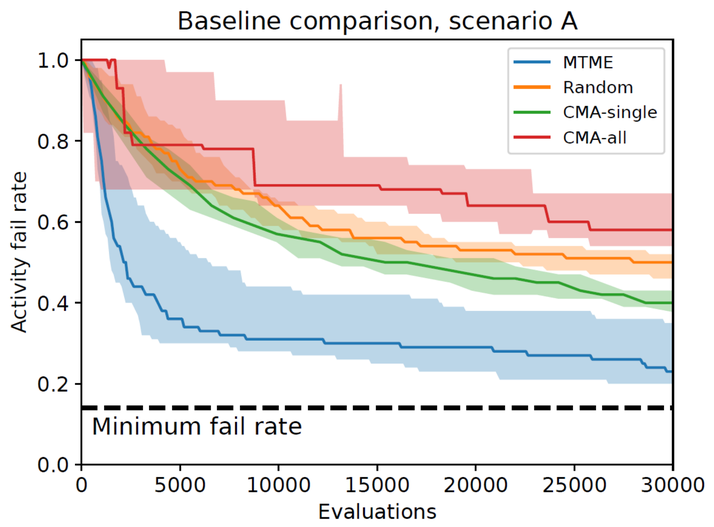
Effects of height
(scenario A, BMI = 24)
- Smaller DHM need to lean forward more
- Smaller DHM have less stable postures



Effects of BMI
(scenario A, H = 1.8m)
- Similar postures
- Higher BMI means higher torques on lumbar and lower body joints



Benchmarking



Baselines
MTME: Multi-task MAP-Elites
Random: Evaluate with random solutions and morphologies
CMA-single: Optimize each morphology separately with CMA-ES
CMA-all: Find one solution for all morphologies with CMA-ES

⇒ MTME outperforms all the other baselines.

Conclusion

With MTME, we were able to efficiently generate a large amount of morphology-adapted behaviors in order to assess workstation suitability.

Perspectives:
- Validate with an ergonomist on different scenarios
- Enrich the behaviors of the DHM: multi-contact, self-collision, …
- Reduce computational cost

References
[1] Merlhiot, X. (2012) 'The XDE mechanical kernel: Efficient and robust simulation of multibody dynamics with intermittent nonsmooth contacts'
[2] Del Prete, A. *et al.* (2016) 'Implementing Torque Control with High-Ratio Gear Boxes and Without Joint-Torque Sensors'
[3] Mouret, J.-B. and Maguire, G. (2020) 'Quality diversity for multi-task optimization'