Interacting with a torque-controlled virtual human in virtual reality for ergonomics studies

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Interacting with a Torque-Controlled Virtual Human in Virtual Reality for Ergonomics Studies

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Abstract

This paper presents a new tool to help ergonomists conduct studies on digital human models (DHM) in a more intuitive and physically consistent way. To do so, a virtual reality setup was combined with a DHM in a real-time physics simulation. Therefore, the user is able to directly manipulate the DHM within the virtual workplace and quickly experiment with a variety of scenarios.

Index Terms: Virtual human, virtual reality, physics simulation, ergonomics.

1 Introduction

In industry, ergonomics evaluation is a major means of preventing work related musculoskeletal disorders (MSD). However, ergonomics evaluation is traditionally a tedious process. In this regard, digital tools can help ergonomists measure a variety of ergonomics indicators more quickly and accurately. A common approach consists in using digital human models (DHM) which are numerical counterparts of workers simulated in virtual workspaces. In simulation, biomechanical and work related quantities needed for ergonomics analysis can easily be estimated, assuming a low gap between simulation and reality. Two main types of DHM software exist. Firstly, ergonomics-oriented DHM softwares such as [5] implement various analysis tools directly interpretable in terms of ergonomics. Secondly, biomechanical DHM softwares such as [1] dynamically simulate musculoskeletal models and give precise biomechanical measurements. However, those frameworks either has limited consideration in terms of dynamics or require expert knowledge to use.

In this work, we adopted a mixed approach introduced in [3] with a torque based DHM simulated in a real-time physics engine, thus enabling *physically consistent interactions* with the virtual workplace. Combined with this, a virtual reality (VR) interface is proposed to bring *more intuitiveness and interactivity* into the process of virtual ergonomics evaluation.

2 Methods

2.1 Physics-based DHM

The DHM (Fig. 2a) is composed of 21 rigid bodies linked by 18 compound joints, for a total of 47 torque-actuated degrees of freedom (DoF) plus 6 DoFs from the free floating base. The model can be scaled in terms of height and weight to model different morphologies. The DHM is implemented in the XDE (eXtended Dynamics Engine) physics simulation framework [4] which provides a client-server architecture (Fig. 1). The server runs the physics engine while a Unity based client renders the simulation while taking care of user inputs. Through the Unity interface, the user can rapidly configure the DHM or any workplace design before starting the simulation.

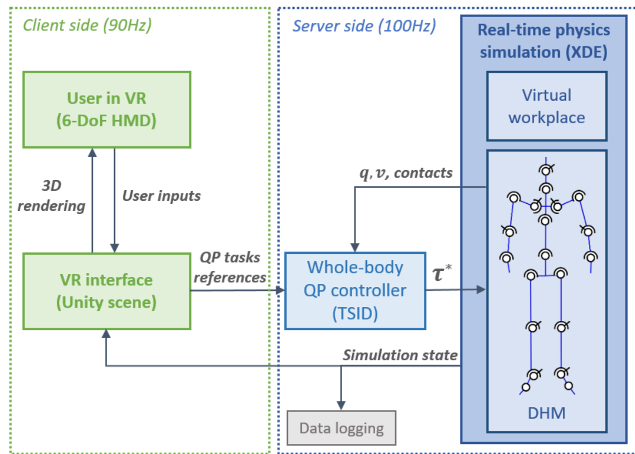

Figure 1: **Workflow of the proposed tool**, with q, v the positions and velocities of the DoFs of the DHM, τ^* the optimized joint torques computed by the QP controller.

As in [3], a controller based on quadratic programming (QP) computes at each simulation step the joint torques that enable the DHM to balance itself while satisfying multiple objectives in a physics simulation. Control objectives are defined by the programmer and formulated in terms of constraints (equations of motions, maximum joint torques, etc.) and tasks with weighted priorities (the tracking of a reference posture, segment pose or center of mass position). The controller is implemented using the TSID library [2]. In practice, the implementation details of the controller is abstracted away from the user thanks to the VR interaction interface.

2.2 VR interaction interface

The VR setup consists of a 6-DoF head mounted device (Oculus Quest 2) with two hand controllers.

Puppeteering. In the virtual workplace, the user can grab visual markers located at the specified effectors (both feet and hands by default) and move them around in order to change the Cartesian reference pose tracked by the QP controller (Fig. 2b). As in [6], different postures can be quickly configured but here with a physics-based manikin.

Contact handling. A contact task is automatically created if a planar contact is detected between a hand and a *pushable* object or between a foot and a *ground* object. These *pushable* or *ground* properties can be assigned to any object in the physics scene. If the user moves a foot marker above ground level, the corresponding

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foot-*ground* contact needs to break without making the DHM lose its balance. To do so, the center of mass (CoM) tracked by the QP controller is gradually shifted towards the position of the next stance foot, before breaking the contact. For a hand-*pushable* contact, the user can grab the tip of a 3D arrow representing the desired contact force, to change the reference force value tracked by the QP controller.

2.3 Ergonomics evaluation

In the virtual scene, the joint torques are represented by colored spheres (Fig. 2b) to enable a quick estimation of the strain experienced by the DHM. For now, quantitative ergonomic indicators are computed offline using data logged during the simulation.

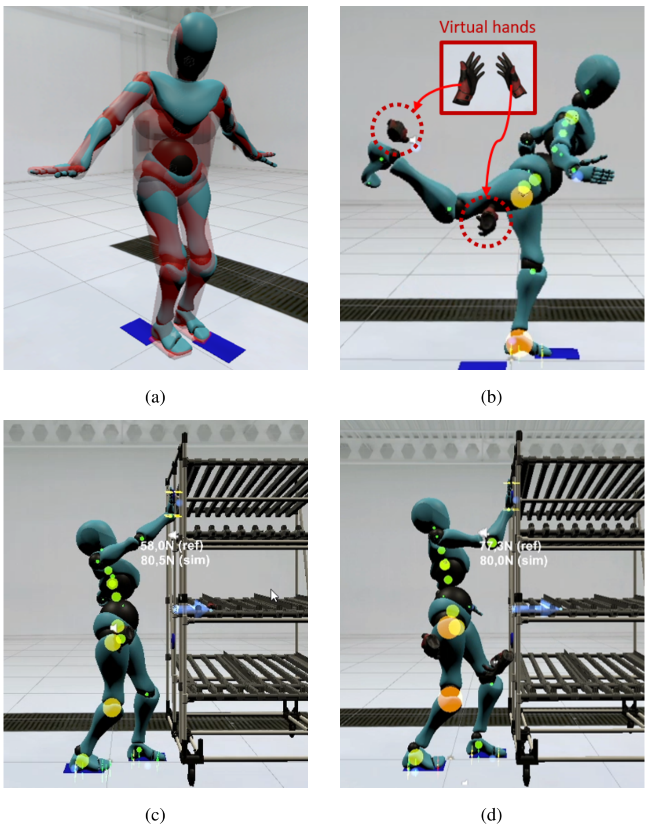

Figure 2: **(a)** The DHM in its reference posture, with its collision mesh in transparent red. **(b)** The DHM being puppeteered, in a single-leg stance. **(c)** Small DHM pushing the low target. **(d)** Tall DHM pushing the low target.

3 Experiment

The tool is demonstrated on a scenario (Fig. 2c, Fig. 2d) where the user puppeteers the manikin into a pushing stance (one leg in front of the other), then guides the right hand of the manikin to apply a force of 80 N on a target plate in front of it.

The scenario was repeated for each combination of three DHM morphologies (Small = {160 cm, 55 kg}, Average = {170 cm, 65 kg} and Tall = {180 cm, 75 kg}) and two target heights (80 cm and 170 cm). In this experiment, we expect that it is easier for a small person to push a lower target and conversely for a tall person to push a higher target. In order to compare the different configurations, a joint torque indicator $I_{\tau_{group}}$ from [3] is computed for each group of

Target	Low			High		
Morphology	Small	Average	Tall	Small	Average	Tall
Torso	0.353	0.468	0.899	0.905	0.914	0.701
Right arm	1.506	2.203	2.434	0.990	0.826	0.430
Right hand	0.103	0.242	0.259	0.549	0.303	0.493
Left leg	1.413	1.166	1.747	0.362	0.842	2.185
Right leg	1.422	1.391	1.722	3.502	4.577	5.693
Left arm	0.006	0.009	0.012	0.007	0.012	0.018
Left hand	0.198	0.259	0.258	0.231	0.310	0.346

Table 1: Joint torque ergonomic scores for each pushing configuration.

joints (torso, legs, arms and wrists):

$$I_{\tau_{group}} = \frac{1}{N} \sum_{i=1}^{N_{joint}} \left(\frac{\tau_i}{0.15 * \tau_i^{max}} \right)^2 \tag{1}$$

Here, the maximum torques τ_i^{max} are scaled by 0.15 to account for the endurance limit [7].

The main result (Table 1) is that for the torso and the right arm, *the score is lower when the morphology is more suited to the target height* — when the small DHM pushes the low target or the tall DHM pushes the high target. Moreover, regardless of the morphology, a higher target means more torques on the back leg (right leg): the reaction force of the high target generates more momentum around the CoM, which is better countered by the back leg.

4 Conclusion

This paper presented a new tool for ergonomics studies that leverages both physics-based DHM and virtual reality. With the proposed intuitive VR interface, the ergonomist can quickly conduct a variety of experiments in real-time where the DHM physically interacts with its workplace. A use case involving different morphologies and target heights shows coherent results in terms of joint torques.

For future work, it is possible to add more VR interactions with the DHM (object pulling, load handling, etc.), display other indicators through the VR display and perform a user study to evaluate the usability of the tool. Moreover, the QP controller uses a simple balancing strategy; a more advanced CoM trajectory planning that takes into account the non co-planar contacts created by the hands might be needed.

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