Comparative Study of two Biomechanics Frameworks for Upper Limb Exoskeleton Simulations

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EXTENDED ABSTRACT

1 Introduction

The design and optimization of exoskeletons present significant challenges. Predictive numerical simulations of musculoskeletal systems provide valuable information including kinematics, muscle excitation levels or control inputs of actuators, and help reduce the need for expensive experimental testing campaigns when designing assistive devices.

OpenSim is widely used within the biomechanics community for these kinds of simulations due to its well-validated biomechanical models and numerous readily available features, such as scaling tools. Moreover, OpenSim offers various simulation capabilities, including forward dynamics and optimal control via MOCO [1]. It is particularly well-suited for simulating models with an open-tree kinematic topology, such as human limbs. However, modelling biomechanical systems with complex kinematic topologies, such as closed kinematic loops, can present challenges when using software with a recursive description, as is the case with OpenSim [2]. Upper-limb exoskeletons are a typical example that introduce a kinematic closed loop into the biomechanical system. Other studies such as [3] have addressed this challenge using a simplified upper limb model without musculature and using symbolic approaches. These limitations motivate the exploration of more general, state-of-the-art multibody software like Odin (https://doi.org/10.5281/zenodo.7468114), which can support detailed biomechanical models for realistic simulations.

Odin is a research code for multibody systems that is structured as a finite element (FEM) code. It uses geometric methods for spatial discretization, the time integration and motion description, where finite motions are represented as Lie group elements of $SE(3)$. Additionally, Odin incorporates features not available in OpenSim, such as flexible elements and non-smooth contact handling that can be beneficial for modelling the compliance of an exoskeleton or studying other biomechanical systems.

In this work, we compare the resolution of a numerical simulation for a shoulder flexion with an upper-limb exoskeleton using both OpenSim and Odin. This comparison aims to highlight the strengths and limitations of each tool for simulating biomechanical systems with complex kinematic topologies.

2 Methodology

The shoulder exoskeleton modelled in this study is directly adapted from the passive exoskeleton described in [4] and shown in Figure 1. It consists of six articulated bodies and does not introduce any additional net degree of freedom to the system, nor does it restrict shoulder mobility. A motor was incorporated in the fourth revolute joint to replace the passive actuation, enabling active control of the exoskeleton. The musculoskeletal model chosen for the simulation is MoBL-ARMS, a model available in OpenSim [5]. This model was simplified by excluding the degrees of freedom and muscles of the wrist to focus on the shoulder and elbow dynamics. This resulted in a model with four degrees of freedom for the arm and 24 muscles. The complete model, including the exoskeleton that is attached to the back of the skeleton and to the humerus, is shown in Figure 2.

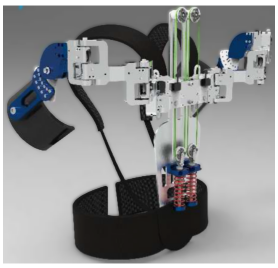


Figure 1: Passive exoskeleton used as the basis for the modelled exoskeleton [4].

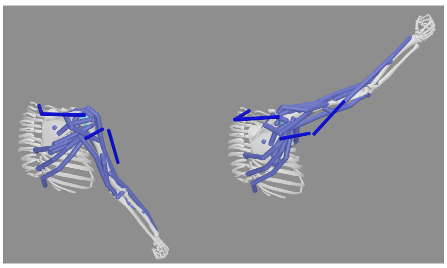


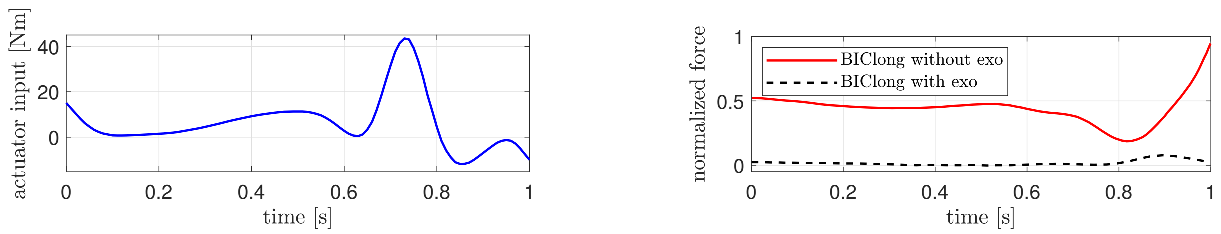
Figure 2: OpenSim model used for the simulation, showing the exoskeleton (dark blue) in both lower and upper poses.

The two software packages are compared for two types of simulations. The first type involves solving a forward dynamics problem for prescribed muscle excitations and motor torque inputs. The second simulation consists in solving an optimal control problem to determine the optimal muscle excitations and motor torque inputs required to move from an initial lower arm position (Figure 2 on the left) to a prescribed upper pose (Figure 2 on the right). For each simulation framework, the ease of creating a musculoskeletal model with an exoskeleton, numerical accuracy, and computational efficiency are compared.

Simulations in OpenSim were performed using its built-in forward dynamics tools and the optimization capabilities of MOCO for solving the optimal control problem. Finding a good initial guess for the optimal control problem was challenging and required several steps, including solving a simplified model without the exoskeleton. To leverage OpenSim's existing biomechanics functionalities and enable the simulations, several biomechanical features were added into Odin. These include a muscle model adapted from [6] that is consistent with the equivalent muscle model in OpenSim and importing the musculoskeletal model. Finally an optimal control solver based on the multiple shooting method was implemented [7].

3 Results and Discussions

The introduction of the kinematic closed loop caused by the exoskeleton is difficult to model with OpenSim's recursive formalism. Nevertheless, the optimal muscle forces and torque profiles of the active exoskeleton could be successfully determined by following a specific workflow to achieve a suitable initial guess. Results to the optimal control problem obtained for a one-second shoulder flexion are represented in Figure 3. The optimal motor torque input of the exoskeleton is depicted in Figure 3(a) and a comparison of the normalized force of the long head of the biceps (BIClong), a muscle with significant involvement in shoulder flexion, for simulations with and without the exoskeleton is shown in Figure 3(b).



(a) (b)

Figure 3: Optimal motor torque input of the exoskeleton(a) and comparison of the muscle forces of the BIClong with and without exoskeleton (b), computed with OpenSim for the solution of the optimal control problem of a shoulder flexion.

The computational framework in Odin is still under development, but the initial results for forward dynamics simulations are promising. In particular, modelling kinematic loops, such as the exoskeleton, is more straightforward in Odin, because of its systematic approach for defining geometries and constraints. This study highlights Odin's potential as a framework for advancing musculoskeletal modelling and simulation in applications involving exoskeletons.

4 Conclusion

This comparative study highlights the challenges and opportunities in simulating musculoskeletal systems with exoskeletons. While OpenSim provided reliable results, Odin's evolving framework shows potential for simplifying the modelling process and improving simulation efficiency.

Acknowledgement

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