MuSkeMo: a cross-simulator compatible tool for constructing, analyzing, and visualizing subject-specific 3D musculoskeletal models in Blender

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Summary

MuSkeMo is a new software tool that consolidates common biomechanical workflows into a single package. The user can perform all the modeling steps to fully define 3D musculoskeletal models, and then export these to their simulator of choice. Simulated trajectories can be imported back into MuSkeMo to produce publication-ready visualizations. MuSkeMo is compatible with popular biomechanical simulators (OpenSim, MuJoCo, Gaitsym), and can perform common analyses (e.g., muscle moment arms) without requiring exports. MuSkeMo is free and open-source.

Introduction

Constructing musculoskeletal models from 3D scan data generally requires numerous processing steps in different software tools. Certain simulators have dedicated model-building workflows (e.g., OpenSim [1] has OpenSimCreator), but no cross-platform compatible solution exists, even though the physical parameters (e.g., inertial parameters) are not unique to any specific biomechanical simulator. MuSkeMo is intended to address this issue, by implementing numerous model construction workflows as an add-on for Blender (blender.org), an open-source 3D graphics program.

Methods

Model construction – MuSkeMo has a diverse set of features, including: computation of inertial properties from 3D meshes, composite body creation, muscle routing assignment, muscle wrapping, anatomical reference frames, geometric shape fitting of bony features, muscle path fitting, and landmarking. MuSkeMo provides a graphical user interface, and Blender's extensive 3D modeling tools can be used for model construction. 2D or 3D data (e.g., X-rays or segmented muscle volumes) can be imported for model personalization. MuSkeMo also implements empirical convex hull-based approaches, typically used for (fossil) animal models.

Model analysis – MuSkeMo provides analysis tools, including moment arm plots (which can be regenerated during muscle construction), and a real-time muscle length viewer, useful for visualizing muscle operating ranges of an imported trajectory.

Model and trajectory visualization – MuSkeMo is not a simulator, but simulated trajectories can be imported into MuSkeMo (e.g., from OpenSim .sto format) for high-quality animations and stills. MuSkeMo provides volume-accurate renderings of muscles (Fig. 1), and enables comparison of multiple simulation models with planned camera movements in the same scene.

Batch processing – MuSkeMo's feature set can be accessed via a Python API, enabling customization and automation.

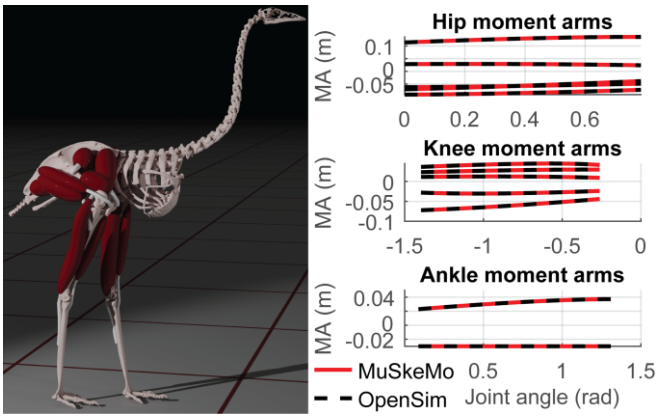

Fig. 1. Left: Emu model [2] constructed using MuSkeMo. Right: Moment arms (MA) comparison between MuSkeMo & OpenSim.

Results and Discussion

Predictive simulations from models constructed with MuSkeMo, and simulated with OpenSim, have been validated against empirical data [2,3], and have provided fundamental biomechanical insights. A model of the emu (a large bird related to the ostrich) was used to simulate gait transitions [2]. This provided a mechanical argument for why birds habitually use grounded running, even though superficially this appears to be a costly running style. Predictive simulations of a model of the horse adopted many of the gaits commonly seen in horses [3]. MuSkeMo was used to visually compare multiple Gaitsym simulations of human ancestor *Australopithecus* [4].

When plotting the moment arms from the emu model from [2], MuSkeMo gives the same outputs as those computed by OpenSim (Fig. 1), with an average root mean squared difference of 0.0052%. Further validation test results are presented in the user manual (see Github link below).

Conclusions and availability

MuSkeMo can be a useful tool for musculoskeletal modeling. Further example workflows and features are described in the preprint [5]. MuSkeMo is available from Github (https://github.com/PashavanBijlert/MuSkeMo), which also hosts the in-depth written user manual with tutorials, examples, and further validation tests. A video tutorial series is also available from the Github page.

References

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