

# CusToM: a Matlab toolbox for musculoskeletal simulation

Antoine Muller<sup>1</sup>, Charles Pontonnier<sup>1, 2</sup>, Pierre Puchaud<sup>1, 2, 3</sup>, and Georges Dumont<sup>1</sup>

<sup>1</sup> Univ Rennes, CNRS, Inria, IRISA - UMR 6074, F-35000 Rennes, France <sup>2</sup> Centre de Recherche des Ecoles de Saint-Cyr Coëtquidan, 56380 Guer, France <sup>3</sup> Univ Rennes, M2S - EA 1274, 35170 Bruz, France

DOI: [10.21105/joss.00927](https://doi.org/10.21105/joss.00927)

## Software

- [Review](#) ↗
- [Repository](#) ↗
- [Archive](#) ↗

Submitted: 04 July 2018

Published: 21 January 2019

## License

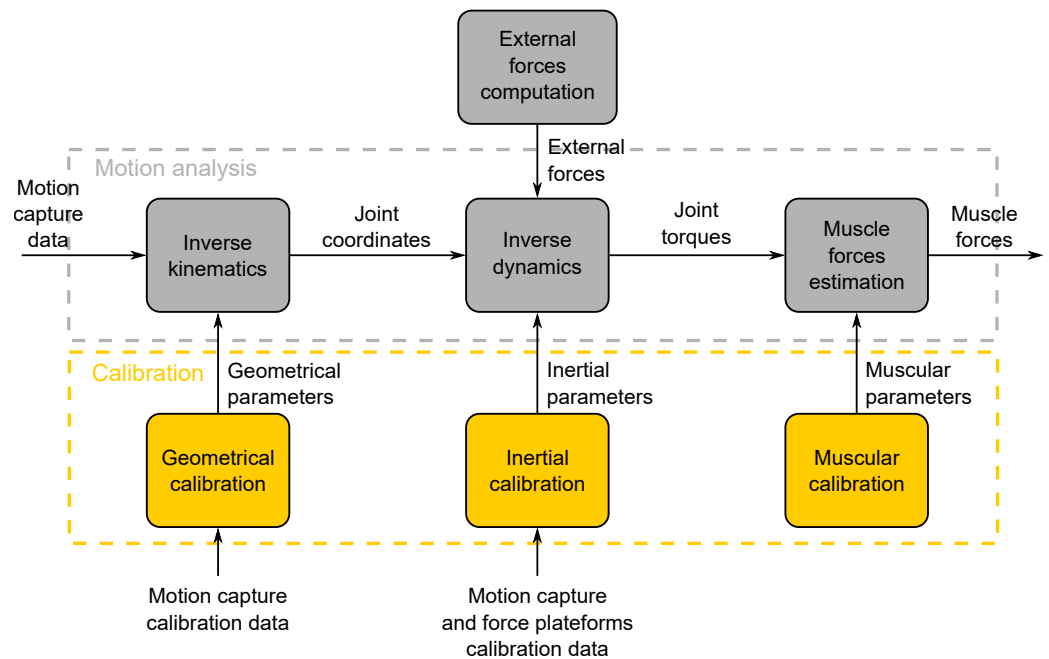
Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License (CC-BY).

## Summary

Customizable Toolbox for Musculoskeletal simulation (CusToM) is a MATLAB toolbox aimed at performing inverse-dynamics-based musculoskeletal analyses (Erdemir, McLean, Herzog, & Bogert, 2007). This type of analysis is essential to access mechanical quantities of human motion in different fields such as clinics, ergonomics and sports. CusToM exhibits several features. It can generate a personalized musculoskeletal model, and can solve from motion-capture data inverse kinematics, external forces estimation, inverse dynamics and muscle forces estimation problems as in various musculoskeletal simulation software (Damsgaard, Rasmussen, Christensen, Surma, & Zee, 2006; Delp et al., 2007) (Figure 1).

According to user choices, the musculoskeletal model generation is achieved by using libraries containing pre-registered models (Muller, Pontonnier, Germain, & Dumont, 2015). These models consist of body parts of osteoarticular models, set of markers or set of muscles to be combined together. From an anthropometric based model, the geometric, inertial and muscular parameters are calibrated to fit the size and mass of the subject to be analyzed (Muller, Germain, Pontonnier, & Dumont, 2016; Muller, Haering, Pontonnier, & Dumont, 2017; Muller, Pontonnier, & Dumont, 2017). The motion capture data (contained in a c3d file) are extracted with the Biomechanical ToolKit (BTK) (Barre & Armand, 2014). The inverse kinematics step computes joint coordinates trajectories against time (Lu & O'connor, 1999). Joint torques are computed in an inverse dynamics step (Featherstone, 2008). To this end, external forces applied to the subject have to be known. They may be directly extracted from experimental data (as platform forces) or be estimated from motion data by using the equations of motion in an optimization scheme (Fluit, Andersen, Kolk, Verdonschot, & Koopman, 2014). Lastly, muscle forces are estimated. It consists of finding a repartition of muscle forces respecting the joint torques and representing the central nervous system strategy (Crowninshield, 1978; Muller, Demore, Pontonnier, & Dumont, 2017; Muller, Pontonnier, & Dumont, 2018).

For a large set of musculoskeletal models and motion data, CusToM can easily perform all of the analyses described above. CusToM has been created as a modular tool to let the user be as free and autonomous as possible. The three model parts are defined as bricks customizable and adaptable with each other, namely the osteoarticular models, set of markers and set of muscles. The design or the modification of a musculoskeletal model is simplified with this modularity. Following the same idea, some methods are defined as adaptable bricks. Testing new cost functions in the optimization schemes, changing performance criteria or creating alternative motion analysis methods can be done in a relatively easy way.



**Figure 1:** CusToM pipeline

The development of a user interface facilitates the data management and the model definition during a given study.

## Acknowledgements

We acknowledge contributions from Diane Haering, Felix Demore, Marvin Chauwin, Claire Livet, Lancelot Barthe and Amaury Dalla Monta.

## References

- Barre, A., & Armand, S. (2014). Biomechanical toolkit: Open-source framework to visualize and process biomechanical data. *Computer Methods and Programs in Biomedicine*, *114*(1), 80–87. doi:[10.1016/j.cmpb.2014.01.012](https://doi.org/10.1016/j.cmpb.2014.01.012)
- Crowninshield, R. D. (1978). Use of optimization techniques to predict muscle forces. *Journal of Biomechanical Engineering*, *100*(2), 88–92. doi:[10.1115/1.3426197](https://doi.org/10.1115/1.3426197)
- Damsgaard, M., Rasmussen, J., Christensen, S. T., Surma, E., & Zee, M. de. (2006). Analysis of musculoskeletal systems in the AnyBody Modeling System. *Simulation Modelling Practice and Theory*, *14*(8), 1100–1111. doi:[10.1016/j.simpat.2006.09.001](https://doi.org/10.1016/j.simpat.2006.09.001)
- Delp, S. L., Anderson, F. C., Arnold, A. S., Loan, P., Habib, A., John, C. T., Guendelman, E., et al. (2007). OpenSim: Open source to create and analyze dynamic simulations of movement. *IEEE Transactions on Biomedical Engineering*, *54*(11), 1940–1950. doi:[10.1109/TBME.2007.901024](https://doi.org/10.1109/TBME.2007.901024)
- Erdemir, A., McLean, S., Herzog, W., & Bogert, A. J. van den. (2007). Model-based estimation of muscle forces exerted during movements. *Clinical Biomechanics*, *22*(2), 131–154. doi:[10.1016/j.clinbiomech.2006.09.005](https://doi.org/10.1016/j.clinbiomech.2006.09.005)

- Featherstone, R. (2008). *Rigid body dynamics algorithms* (p. 272). doi:[10.1007/978-1-4899-7560-7](https://doi.org/10.1007/978-1-4899-7560-7)
- Fluit, R., Andersen, M. S., Kolk, S., Verdonshot, N., & Koopman, H. F. J. M. (2014). Prediction of ground reaction forces and moments during various activities of daily living. *Journal of Biomechanics*, *47*(10), 2321–2329. doi:[10.1016/j.jbiomech.2014.04.030](https://doi.org/10.1016/j.jbiomech.2014.04.030)
- Lu, T. W., & O’connor, J. J. (1999). Bone position estimation from skin marker coordinates using global optimisation with joint constraints. *Journal of Biomechanics*, *32*(2), 129–134. doi:[10.1016/S0021-9290\(98\)00158-4](https://doi.org/10.1016/S0021-9290(98)00158-4)
- Muller, A., Demore, F., Pontonnier, C., & Dumont, G. (2017). MusIC makes the muscles work together. In *XVI International Symposium on Computer Simulation in Biomechanics* (p. 2).
- Muller, A., Germain, C., Pontonnier, C., & Dumont, G. (2016). A simple method to calibrate kinematical invariants: application to overhead throwing. In *Proceedings of the 33rd International Society of Biomechanics in Sports*.
- Muller, A., Haering, D., Pontonnier, C., & Dumont, G. (2017). Non-invasive techniques for musculoskeletal model calibration. In *Proceedings of the 23ème Congrès Français de Mécanique*.
- Muller, A., Pontonnier, C., & Dumont, G. (2017). Uncertainty propagation in multi-body human model dynamics. *Multibody System Dynamics*, *40*(2), 177–192. doi:[10.1007/s11044-017-9566-7](https://doi.org/10.1007/s11044-017-9566-7)
- Muller, A., Pontonnier, C., & Dumont, G. (2018). The music method: A fast and quasi-optimal solution to the muscle forces estimation problem. *Computer Methods in Biomechanics and Biomedical Engineering*, *21*(2), 149–160. doi:[10.1080/10255842.2018.1429596](https://doi.org/10.1080/10255842.2018.1429596)
- Muller, A., Pontonnier, C., Germain, C., & Dumont, G. (2015). Dealing with modularity of multibody models. In *Proceedings of the 40ème Congrès de la Société de Biomécanique, Computer Methods in Biomechanics and Biomedical Engineering* (Vol. 18, pp. 2008–2009). doi:[10.1080/10255842.2015.1069599](https://doi.org/10.1080/10255842.2015.1069599)