# OPENCAP FOR ANYBODY

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Musculoskeletal biomechanics for human movement aims to provide an understanding of the loads the human body is exposed to during both daily activities and more physically demanding activities. The human body is simplified and modeled as a musculoskeletal system by applying fundamental concepts in applied mechanics. To build the model, we need to capture, interpret and analyze kinematic and kinetic variables from human movement during physical activity. This provides us with the knowledge to be able to consider the human body and it's interaction with the environment, for example in product development or health care.

OpenCap is an open-source software that is freely available to anyone for estimating the three-dimensional kinematics and dynamics of human movement using two or more smartphones [1]. OpenCap is validated for kinematic and dynamic measures against traditional and gold standard measures computed with marker-based motion capture and force plates; e.g., OpenCap estimated joint angles with a mean absolute error (MAE) of $4.5°$ and ground reaction forces with an MAE of $6.2\%$ of bodyweight compared to gold standard. These results demonstrate that high-quality motion capture via OpenCap enables very affordable and flexible motion capture that does not need a specialized and expensive indoor laboratory. Today, the kinematics are estimated from video using AI tools, i.e. deep learning models, and inverse kinematics in OpenSim [2].

AnyBody is a general modeling software system for musculoskeletal biomechanics in which bones are modeled as rigid bodies constrained by joints and actuated by muscles [3]. The governing equations are given by the Newton–Euler equations, see Eq. (1),

$$\begin{bmatrix} \bar{M} & \bar{H}_g^T \\ \bar{H}_q & 0 \end{bmatrix} \begin{bmatrix} \ddot{\bar{q}} \\ \bar{\lambda} \end{bmatrix} = \begin{bmatrix} \bar{Q}^e \\ \bar{c} \end{bmatrix}, \qquad (1)$$

where $\bar{M}$ is the inertia matrix, $\bar{H}_q$ is the Jacobian of the constraint equations, $\ddot{\bar{q}}$ is the acceleration vector, $\bar{\lambda}$ is the joint reaction forces and torques vector, $\bar{Q}^e$ is the external load vector, and $\bar{c}$ is the right-hand side of the acceleration constraints. In musculoskeletal models, the unknown muscle forces are included in the vector $\bar{\lambda}$.

Load distribution between muscles is computed via optimization, see Eq. (2),

$$min\, G = \sum_i \left(\frac{f_i}{N_i}\right)^p, i \in \{1, ..., n\} \qquad (2)$$

subject to Eq. (1) and $f_i \geq 0$, i.e., muscles can only pull and not push. $f_i$ is the muscle force generated by the $i^{th}$ muscle, $N_i$ is the strength of the muscle $i$, and $p$ is the order of the polynomial. This integrated solution technique facilitates inclusion of bi-articular muscles in a direct way that is not possible in OpenSim. Moreover, AnyBody seems to be more robust in estimating muscle forces [4].

We aim to combine OpenCap's motion capture ability and musculoskeletal modeling in AnyBody.

An approximate workflow to integrate AnyBody modeling into the OpenCap's processing pipeline is:

- set up a TensorFlow and Python environment for GPU-based AI motion estimation;
- write new (Python) code that automatically converts OpenCap marker trajectories to C3D files compatible with AnyBody and adjusts the markers' names in the process;
- map the OpenCap augmented markers to a custom marker set adapted to the AnyBody musculoskeletal model;
- write new code that maps the collected data on a marker set for a three-dimensional AnyBody model;
- carry out experiments of daily motions to collect motion data and then compute joint reaction forces and muscle forces to test the workflow.

We will present a comparison of traditional gold standard marker-based motion capture and the combination of OpenCap, smartphones, and AnyBody for computing joint reaction forces and muscle forces.

## References

[1] Uhlrich, S.D., et al., OpenCap: Human movement dynamics from smartphone videos. PLOS Comput Biol, 19(10), e1011462, (2023)

[2] Delp S.L., et al., OpenSim: Open-source software to create and analyze dynamic simulations of movement. IEEE Trans Biomed Eng, 54(11), 1940–1950, (2007)

[3] Damsgaard, M., et al., Analysis of musculoskeletal systems in the AnyBody Modeling System. Simul Model Pract Theory, 14(8), 1100–1111, (2006)

[4] Gautam, K., et al., Comparison of OpenSim and AnyBody modeling system predictions in biomechanical modeling of upper extremities. Int J Res Orthop, 10(4), 717–724, (2024)

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