

Kinematics-vis: A Visualization Tool for the Mathematics of Human Motion

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Summary

Kinematic analysis studies characterize human motion in healthy, pathologic, and rehabilitated subjects. These studies provide rich datasets which enable clinicians and researchers to understand disease progression, and the effects of surgical intervention and physical therapy. A variety of techniques – ranging from optical skin marker tracking to biplane fluoroscopy – are utilized to collect these datasets. The quantification and physical interpretation of these motion capture datasets (i.e. kinematic analysis) is predominantly conducted using Euler/Cardan angles, whose output – time series of 3 angles – is presented in peer-reviewed manuscripts in 2D graphs ([Ludewig et al., 2009](#)). This rudimentary presentation, however, obscures the physical meaning behind Euler/Cardan analysis. As other authors have noted, the visualization of these angles enables meaningful discussion between biomechanics researchers and clinicians ([Baker, 2011](#)). A ubiquitous open-source method to concurrently visualize recorded human motion and the results of kinematic analysis is presently lacking in the biomechanics community. ‘Kinematics-vis’ is a JavaScript web application that visualizes kinematic analysis output resulting from motion capture studies.

Statement of need

3D rotations are utilized to quantify human motion and in kinematic analysis. However, because 3D rotations belong to the $SO(3)$ mathematical group, they can be difficult to understand – especially for biomechanics researchers and clinicians with a limited mathematical background. Euler/Cardan angles are typically utilized to infuse physical meaning into kinematic analysis. However, they are described abstractly and attempts towards visualizing their physical underpinning is rarely made ([Baker, 2011](#)). Furthermore, 12 Euler/Cardan angle sequences exist for quantifying 3D orientations, and which sequence is most appropriate for quantifying human motion is debatable and varies by study ([Krishnan et al., 2019](#)). It has previously been shown that incorrect usage of Euler/Cardan sequences can significantly misrepresent human motion ([Aliaj et al., 2021](#)). Furthermore, studies rarely present multiple Euler/Cardan sequences in publications – which clouds data interpretation and limits the ability to compare results between laboratory groups and studies.

‘Kinematics-vis’ is a JavaScript web application that visualizes different methods of quantifying and decomposing human motion including, but not limited to, Euler/Cardan angles [Figure 1](#). The software enables researchers to visualize different kinematic analysis methods while outputting the 2D time-series graphs that are typically presented in peer-reviewed manuscripts ([Ludewig et al., 2009](#)). Presently, ‘kinematics-vis’ is specialized to study shoulder kinematic analysis. However, it is easily expandable to accommodate the decomposition sequences of

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40 other joints, including subject-specific 3D anatomic models. 'Kinematics-vis' is designed to
41 work from a central motion capture dataset, but also enables the visualization of singular
42 motion files. JavaScript and WebGL, the technologies which underlie 'kinematics-vis,' are
43 ubiquitous and a standard in modern web browsers – which facilitates collaboration between
44 researchers and clinicians.

45 Human motion analysis is a complex topic. Biomechanists, clinicians, and trainees typically
46 accept the results of research papers without having a consistent way to validate these results.
47 'Kinematics-vis' enables discussion amongst all parties interested in human motion analysis
48 and obviates the need for a significant mathematical background. 'Kinematics-vis' provides
49 a means for researchers to make their motion capture datasets visually explorable. This
50 provides insight which is missing in the 2D graphs accompanying peer-reviewed publications.
51 This software can be used as an adjunct to published manuscripts to allow readers to analyze
52 a motion of interest both visually and quantitatively.

53 Mathematics

54 The reader is referred to the following relevant references for the underlying mathematical
55 frameworks that underpin 'kinematics-vis':

- 56 ■ ISB recommendation on definitions of joint coordinate systems of various joints for the
57 reporting of human joint motion—part II: shoulder, elbow, wrist and hand (Wu et al.,
58 2005).
- 59 ■ Comparison of glenohumeral motion using different rotation sequences (Phadke et al.,
60 2011).
- 61 ■ Determination of axial rotation angles of limb segments — a new method (Cheng et
62 al., 2000).
- 63 ■ New mathematical definition and calculation of axial rotation of anatomical joints
64 (Miyazaki & Ishida, 1991).
- 65 ■ Beyond Euler/Cardan analysis: True glenohumeral axial rotation during arm elevation
66 and rotation (Aliaj et al., 2021).
- 67 ■ A survey of human shoulder kinematic representations (Krishnan et al., 2019).

Figures

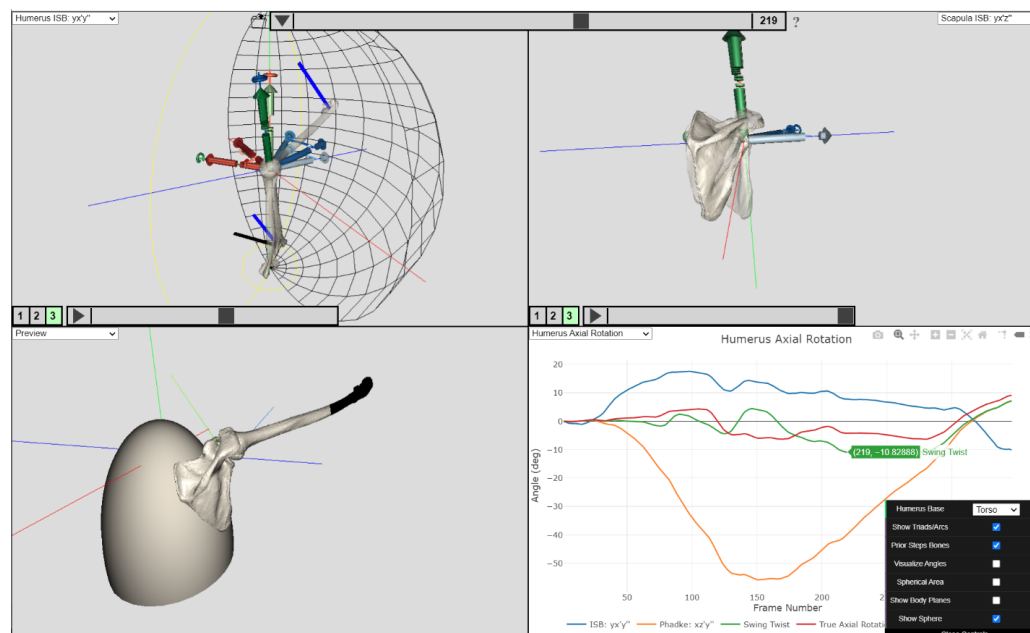


Figure 1: Example display of a shoulder motion analyzed using kinematics-vis. Arm elevation is shown with the humerus motion decomposed using the International Society of Biomechanics (ISB) $yx'y'$ sequence (top left) and scapular motion decomposed using the ISB $yx'z'$ sequence (top right). The 3D “Preview” view (bottom left) visualizes the simultaneous motion of the humerus and scapula. The 2D kinematic curves typically presented in peer-reviewed articles are also presented (bottom right).

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