

Kinematics

Steps to Obtaining Valid Kinematics:

1. Film scaling factors, origin and vertical or horizontal references or calibrate volume (statically and dynamically) for 3D studies.
2. Place reflective markers on the body and record body mass, height and segment lengths and girths, as necessary for modelling.
3. If planning to use Visual3D or similar programs, film a brief period with the subject standing motionless. Afterwards some markers may be removed depending on the model chosen (e.g., medial markers).
4. Film the motion trials. Record what experimental condition was recorded on paper or into a database for future reference.
5. Convert the video images to obtain trajectories of the markers, sometimes called digitization. For automatic systems, such as, Vicon and MAC, this step “reconstructs” 3D trajectories from the various 2D camera views.
6. Refine (scale) the digitized coordinates to metric units (x, y) with respect to a Newtonian (laboratory) frame of reference. This process can be realized with a Fractional Linear Transform (FLT) for 2D studies. For 3D systems this step is part of the reconstruction step (above) and uses a Direct Linear Transform (DLT) or similar algorithm.
7. Examine data for “gaps” or erroneous data, then fill the gaps or eliminate the erroneous data using interpolation. Extrapolation (at the beginning and end) should be avoided.
8. Smooth the coordinates to remove high frequency noise. One method uses low-pass digital filtering (see next page), other methods include quintic splines and Fourier reconstruction.
9. Compute time derivatives using finite difference calculus (see next page).
10. Optionally, compute additional coordinates such as segment centres of gravity or joint centres of rotation and/or compute angular kinematics such as segmental angles and joint angles.

Equations for a Fractional Linear Transform

$$x = \frac{c_1 u + c_2 v + c_3}{1 + c_7 u + c_8 v}$$
$$y = \frac{c_4 u + c_5 v + c_6}{1 + c_7 u + c_8 v}$$

where c_1 to c_8 are the FLT coefficients, (u, v) are the digitized coordinates and (x, y) are the transformed (refined) coordinates

Equations for a Low-pass, Second-order, Recursive Filter

$$x'_i = a_0 x_i + a_1 x_{i-1} + a_2 x_{i-2} + b_1 x'_{i-1} + b_2 x'_{i-2}$$
$$a_0 = a_2 = \frac{1}{2} a_1$$
$$a_0 + a_1 + a_2 + b_1 + b_2 = 1.0$$

Note, that the filter needs two data points (x_i, x_{i-1}) before the first datum (x'_3) can be computed. Points x'_1 and x'_2 must therefore be estimated. Repeat for the Y and Z directions.

Kinematics Equations

$$v_{x_i} = \frac{(x'_{i+1} - x'_{i-1})}{2\Delta t}$$
$$a_{x_i} = \frac{(v_{x_{i+1}} - v_{x_{i-1}})}{2\Delta t}$$
$$a_{x_i} = (x'_{i-1} - 2x'_i + x'_{i+1}) / \Delta t^2$$

Use similar equations for Y- and Z-coordinates and segment or joint angles. Note, that velocities and accelerations cannot be computed for the first and last positions ($i=1$ and n).

Kinematic Computer Software

Step	Program
Video capture	APAS: DOS: Grab Windows: Capture Alternate: VideoWave & APAS: Trim SIMI: Motion Vicon: Workstation
Digitizing	APAS: (DOS) Digitizer, (Windows) Digi4 SIMI: Motion Vicon: Workstation or Nexus
Refine	APAS: Transform Biomech [†] : Cinedata SIMI, Vicon or Visual3D
Smoothing	APAS: Smooth Biomech [†] : Kinematics SIMI, Vicon Polygon or Visual3D
Differentiation	APAS: Smooth Biomech [†] : Kinematics SIMI, Vicon Polygon or Visual3D
Animation	APAS: Imager Biomech [†] : Imager SIMI, Vicon Polygon or Visual3D

[†]Note, Biomech software only processes 2D data.