Figuring out joints and coordinates in OpenSim

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Note: This document is based on data culled from multiple sources cited in the OpenSim literature/the OpenSim users forum and my own experience. However, *none of the explanations presented here have been verified by any of the* OpenSim *maestros* so take everything with a grain of salt (and let me know if you find any errors so I won't keep disseminating false information). :)

1 Joints

Joints are used to define the motion of one body with respect to another. In order to do this, one has to define a location_in_parent as well as a location.

The location_in_parent defines the *location of the joint body in the parent body*, i.e. the location of the IAR with respect to the parent body, or, the point about which the child body rotates about.
The location, on the other hand, defines the position of the joint relative to the body it is in. Fig. 1 shows how OpenSim defines a child body relative to its parent body, and about which point the transformation occurs.[1]

Note that the center of mass and inertia of each body are defined with respect to the body fixed frame located on the body itself which is coincident with the origin of the geometry file of the rigid body. Hence, the location of the center of mass of a child body in terms of the body fixed frame located on the parent body $\bar{\mathbf{x}}_{C,P}$ is given by

$$\bar{\mathbf{x}}_{C,P} = \mathbf{r}_{LiP} - \mathbf{r}_L + \bar{\mathbf{x}}_C. \tag{1}$$

where $\mathbf{r}_{LiP}$, $\mathbf{r}_L$ and $\bar{\mathbf{x}}_C$ are defined in Fig. 1.

2 Coordinates

2.1 Center of Masses

To determine the center of mass positions of the individual bodies in the model in terms of global coordinates, use the BodyKinematics analysis option under the Analyze toolbox. More specifically, go to Tools → Analyze → Analysis tab → add tab → Select BodyKinematics. The output files contain the kinematics (positions and orientations, velocities and angular velocities, or accelerations and angular accelerations) of the centers of mass of the body segments in the model analyzed. The body segment positions, velocities and accelerations are given with respect to the origin of the inertial frame (i.e. ground) while the orientations are described using body-fixed X-Y-Z Euler angles with the angular velocities and acceleration given about the body-local axes.

[1] A somewhat similar figure can be found in the following OpenSim wiki page and [Christophy, 2010].

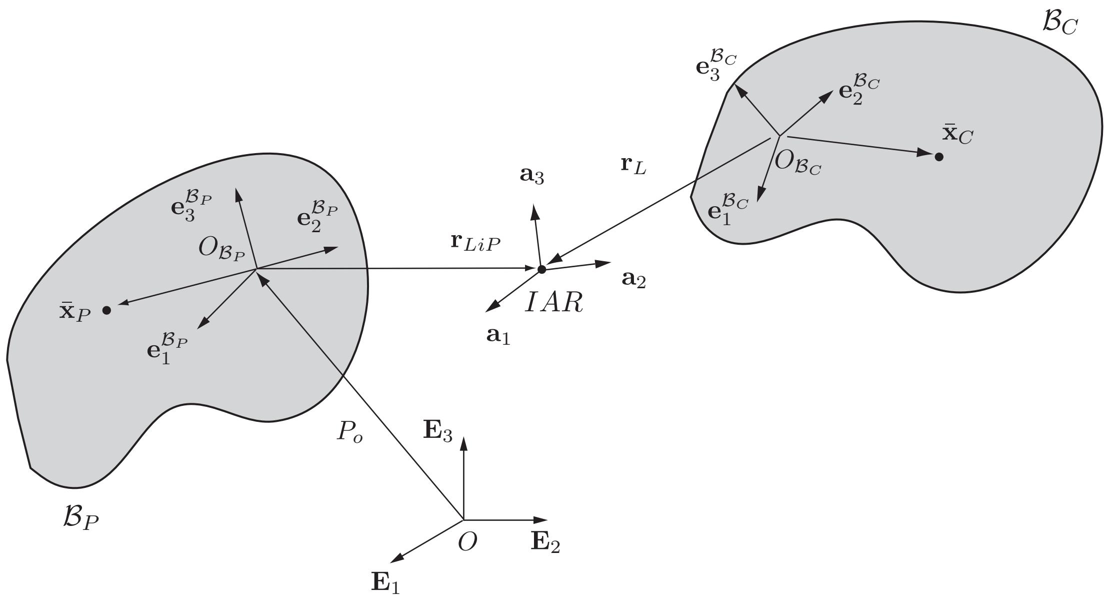

Figure 1: *A* parent body *(considered fixed for now) is located relative to the ground origin O by $\mathbf{P}_0$. The joint, located at the instantaneous axis of rotation, IAR, connects the* parent body *$\mathcal{B}_P$ and its* child body *$\mathcal{B}_P$ and is offset from the body fixed bases located on the* parent body *by the vector $\mathbf{r}_{LiP}$. The* child body *$\mathcal{B}_C$ is able to spatially transform about the axes of rotation, given by $\{\mathbf{a}_1, \mathbf{a}_2, \mathbf{a}_3\}$. The center of mass and inertia of each body are defined with respect to their body-fixed frames by the vectors $\bar{\mathbf{x}}_P$ and $\bar{\mathbf{x}}_C$, respectively. This figure also displays the corotational basis vectors $\left\{\mathbf{e}_1^{\mathcal{B}_P}, \mathbf{e}_2^{\mathcal{B}_P}, \mathbf{e}_3^{\mathcal{B}_P}\right\}$ and $\left\{\mathbf{e}_1^{\mathcal{B}_C}, \mathbf{e}_2^{\mathcal{B}_C}, \mathbf{e}_3^{\mathcal{B}_C}\right\}$ located at the origins of $\mathcal{B}_P$ and $\mathcal{B}_C$ respectively. $\left\{\mathbf{e}_1^{\mathcal{B}_P}, \mathbf{e}_2^{\mathcal{B}_P}, \mathbf{e}_3^{\mathcal{B}_P}\right\}$ is offset from the $\{\mathbf{a}_1, \mathbf{a}_2, \mathbf{a}_3\}$ axes of rotation by the vector $\mathbf{r}_{LiP}$ (defined as* location_in_parent*) while $\mathbf{r}_L$ (defined as* location *in the* .osim *file) specifies the position of the origin of $\mathcal{B}_C$ with respect to the instantaneous axis of rotation. That is, $\mathbf{r}_{LiP} \equiv$*location_in_parent*, and $\mathbf{r}_L \equiv$*location*.*

Remark 1: The _X,_Y,_Z and _0x,_0y,_0z subscripts denote the translational and rotational coordinates/velocities/acceleration respectively of the centers of masses of the bodies in the model.

Remark 2: The coordinates of the center of mass determined using the Analyze toolbox is not coincident with the center of mass of the same body defined in the .osim file since the former is defined with respect to the ground while the latter is defined relative to the body fixed frame attached to the body itself. Note that the center of mass of the body in the .osim file is coincident with the origin of the body's geometry file.[2]

That is, if $\bar{\mathbf{x}}_{C,i}$ represents the location of the CM of body i in the .osim file, $\mathbf{r}_{LiP,i}$ gives the location of the joint connecting body i to its parent body in the osim file, and $\mathsf{x}_{BK,i}$ is the coordinates of the center of mass as determined using the BodyKinematics Analysis, then,

$$\bar{\mathbf{x}}_{BK,i} = (\mathbf{r}_{LiP,i} - \mathbf{r}_{L,i} + \bar{\mathbf{x}}_{C,i}) + (\mathbf{r}_{LiP,i-1} - \mathbf{r}_{L,i-1}) + \ldots + (\mathbf{r}_{LiP,1} - \mathbf{r}_{L,1})\,. \tag{2}$$

The case where we have only 2 bodies: a parent body and a child body is depicted in Fig. 1 with $\bar{\mathbf{x}}_{BK,\text{child body}} = \bar{\mathbf{x}}_{C,P}$ of equation (1) since the body $\mathcal{B}_P$ is fixed.

[2] A good way to visualize where the center of mass of the body in the .osim file is, is to attach a marker to it. To the best of my knowledge, if you want to get the CM of the body in the .osim file to coincide with the CM of the body relative to the origin (or, even, to locate it in the geometric center of the body so it's more intuitive), you have to modify the bone geometry file itself.

2.2 Arbitrary Points

The Analyze tool can also be used to determine the motion of a point Q on a body, for example, the trajectory of the tip of the transverse process on a vertebral body, or the attachment points of muscles. That is, go to Analyze → Analysis tab → add tab → Select PointKinematics → click on edit to be able to set the point you want to output. The parameters that you will need to enter to obtain the trajectory of your point of interest are:

1. body_name: This is the name of the body your point is defined relative to (e.g. $\mathcal{B}_A$).
2. relative_to_body_name: The PointKinematics analysis will output the coordinates of your point of interest relative to this body (e.g. $\mathcal{B}_B$).
3. point_name: Whatever name you decide to give your point. E.g. L5_TransverseProcessTip, MF_m1s_r_P1, etc.
4. location: The (x, y, z) coordinates of the point, taken relative to the origin of the body defined in body_name

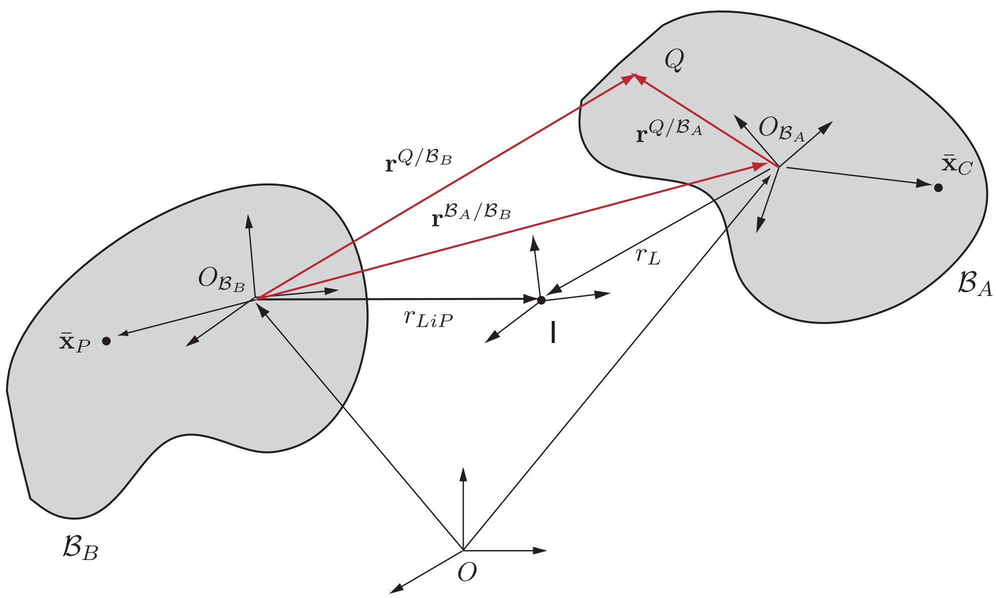

Figure 2: *The point Q is defined relative to $\mathcal{B}_A$ by the coordinate defined in* body_name*. The* PointKinematics *analysis can be used to determine the coordinates of point Q with respect to $\mathcal{B}_B$ by the appropriate definitions of the parameters necessary as mentioned in the text.*

A separate PointKinematics analysis has to be run for each point that we are interested in tracking. The (x, y, z) coordinates of the point (defined as state_0, state_1, and state_2 respectively in the output file) are precisely

$$\mathbf{r}^{Q,\mathcal{B}_B} = \mathbf{r}^{Q,\mathcal{B}_A} + \mathbf{r}^{\mathcal{B}_A/\mathcal{B}_B}, \tag{3}$$

where $\mathbf{r}^{Q,\mathcal{B}_A}$ denotes the vector going from the origin located on $\mathcal{B}_A$ to point Q, $\mathbf{r}^{Q,\mathcal{B}_B}$ is the vector going from the origin located on $\mathcal{B}_B$ to point Q, and $\mathbf{r}^{\mathcal{B}_A/\mathcal{B}_B}$ is the vector going from the origin of $\mathcal{B}_B$ (coincident with the location of the $\{\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3\}^{\mathcal{B}_B}$ body fixed basis vectors) to the origin of $\mathcal{B}_A$ (which is where $\{\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3\}^{\mathcal{B}_A}$ is situated as well). If we have N bodies and we want to find the position of a point on body $\mathcal{B}_N$ with respect to body $\mathcal{B}_1$, then the output produced from the PointKinematics analysis is.

$$\mathbf{r}^{\mathcal{B}_A/\mathcal{B}_B} = (\mathbf{r}_{LiP,A} - \mathbf{r}_{L,A}) + (\mathbf{r}_{LiP,A-1} - \mathbf{r}_{L,A-1}) + \ldots + (\mathbf{r}_{LiP,B+1} - \mathbf{r}_{L,B+1}), \tag{4}$$

as can be concluded from Fig. 2.

References

M. Christophy. A detailed open-source musculoskeletal model of the human lumbar spine. Master's thesis, University of California at Berkeley, 2010.