Moment Arm Computation 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 Moment arm computation in OpenSim version 2.0.1 and below

The motion of bones about a joint is controlled by the action of the muscles spanning the bones as shown in Fig. (1). The tendency of a muscle to rotate a bone about a joint is described by the moment arm of the muscle, and is a useful parameter to study as it both defines the function of a muscle about a joint, and provides a straightforward metric for validating the accuracy of muscle paths used in a given muscoloskeletal model [Pandy, 1999].

Consider two rigid bodies A and B, which articulate at a joint (cf. Fig. 1). In general, six generalized coordinates: three translational and three rotational, are necessary to define the position and orientation of body B in body A. For the case of the model of the lumbar spine presented in our paper, the three rotational generalized coordinates are flexion-extension, axial rotation and lateral bending, while the three translational degrees of freedom are constrained to zero.

Classically, the moment arm of the muscle has been determined by measuring the distance between a muscle's line of action and the joint's instantaneous axis of rotation (IAR). as this is the value most easily determined via anatomical dissections of cadavers. However, this method is best suited for joints that have only a single degree of freedom, with the joint IAR remaining fixed with respect to both bones [Pandy, 1999]. A more general prescription features the partial velocity method,

$$\rho_i = \mathbf{v}_{rel} \cdot \hat{\mathbf{l}}, \tag{1}$$

where $\mathbf{v}_{rel}$ is the relative velocity of the muscle attachment point on the upper body (point R of Fig. 1), with respect to the lower body, $\hat{\mathbf{l}}$ is the unit vector along the muscle's line of action for the portion of the muscle spanning the joint of interest, and ρ_i is the moment arm of the muscle associated with the generalized coordinate q^i.

Equation (A.1) is equivalent to

$$\rho_i = -\frac{\partial \tilde{l}^{MT}}{\partial q^i}, \tag{2}$$

determined via the principle of virtual work. Here $\tilde{l}^{MT}$ is the *effective length* of the musculotendon actuator system, defined as the length of the portion of the muscle that spans the joint of interest. That is, if two bodies A and B of a given musculoskeletal model have attachment points P_1 through P_{m-1} on body A, and P_m through P_n on body B, with the line connecting point P_m to P_{m-1} spanning

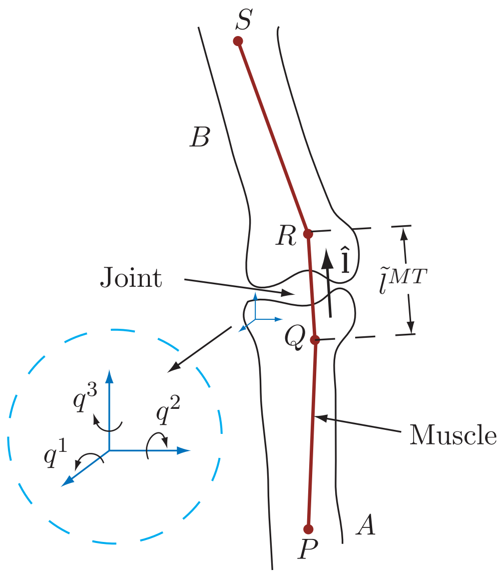

Figure 1: *The points P, Q, R, S define the muscle path of the muscle shown with points P and Q fixed in body A while points R and S are fixed in body B. The effective length of the muscle $\tilde{l}^{MT}$ is defined as the length of the portion of the muscle with attachment points spanning the joint with which it exerts a moment on, and is equal to the length of the line joining points Q and R in the diagram. The moment arm of the muscle with respect to the generalized coordinates q^i, $(i = 1, 2, 3)$ is given by $\rho_i = -\frac{\partial \tilde{l}^{MT}}{\partial q^i}$.*

the joint of interest, the moment arm of the muscle depends only on the change in the effective muscle length, $||\mathbf{r}_{Pm-1} - \mathbf{r}_{Pm}||$ (cf. Figure 1 for the case $n = 4$). Eqn. (A.2) corresponds to Eqn. (4) of Pandy [1999] and Eqn. (3) of Erdemir et al. [2007], and is the method utilized in OpenSim to determine the moment arms [Delp and Loan, 1995]

In order to determine $\frac{\partial \tilde{l}^{MT}}{\partial q^i}$ numerically in OpenSim, the length of the path at coordinates $(q^i - \delta q^i, q^i, q^i + \delta q^i)$ is computed. A quadratic is then fit to the three points, and the derivative of the value at the coordinate determined. This is set to the negative of the moment arm of the muscle with respect to the q^i coordinate.

2 OpenSim Version 2.1.0 b5 and later

The newer versions of of OpenSim (version 2.1.0 b5 and greater) compute the moment arm as the *moment applied by the muscle per unit of muscle force* (=Muscle Moment/Muscle Force)[Pandy, 1999].[1]

References

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Ahmet Erdemir, Scott McLean, Walter Herzog, and Antonie J. van den Bogert. Model-based estimation of muscle forces exerted during movements. *Clinical Biomechanics*, 22(2):131–154, 2007.

[1] Also, personal communication with Ayman Habib of the OpenSim research group.

Marcus G Pandy. Moment arm of a muscle force. *Exercise and Sport Sciences Reviews*, 27:79–118, 1999.