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A General Method for Scaling Musculoskeletal Models

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Musculoskeletal modeling is much more challenging than mere kinematics, because scaling portions not only to the visual appearance, but also to properties like muscle insertion points, muscle parameters and wrapping surfaces. This purpose generalizes a general method for scaling musculoskeletal models. The method has been implemented in the AnyBody Modeling System and its associated public domain repository of models.

Musculoskeletal anthropometric parameters. The scaling procedures are tested for geometrical and kinematical compatibility on the so-called AnyFamily. The AnyFamily is a group of anthropometrically defined models generated by Ramsis. The purpose of the AnyFamily is to provide a comparison representing some of the anthropometric variation of the population and thereby serve as a validation of the system's ability to scale models.

Each member of the AnyFamily is represented by a set of (anthropometric) data generated by Ramsis. The most prominent segment lengths and masses are:

<table>
<thead>
<tr>
<th>Placement</th>
<th>Segment Lengths</th>
<th>Segment Masses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>0.15 L</td>
<td>0.07 m</td>
</tr>
<tr>
<td>Torso</td>
<td>0.15 L</td>
<td>0.07 m</td>
</tr>
<tr>
<td>Arm</td>
<td>0.15 L</td>
<td>0.07 m</td>
</tr>
<tr>
<td>Hand</td>
<td>0.15 L</td>
<td>0.07 m</td>
</tr>
</tbody>
</table>

Scale factors

The definition of a segment in the human model requires mass properties and in addition a number of nodes defined in the segment's local coordinate system. The nodes are used for joint centers, muscle insertions, and so on. The nodes of each segment are subjected to scaling of the form:

\[ S = SP + \varepsilon \]

where \( S \) is the position vector of the node in the local (segment-fixed) coordinate system of the scaled segment, \( P \) is the original node location, \( \varepsilon \) is a 3x1 scaling matrix, and \( \varepsilon \) is a translation vector. The translation plays the role of moving the local coordinate system relative to the actual geometry of the segment. The scaling matrix \( S \), takes care of the real scaling factors, node posture.

This transformation allows for non-uniform scaling rotation and translation depending on the \( x \) and \( y \), which are computed from the segment lengths. Classic strategies for this computation have been attempted. They all rely on two different scaling factors:

\[ k_1 = \frac{x_1}{x_0}, \quad k_2 = \frac{y_1}{y_0}, \quad k_3 = \frac{z_1}{z_0} \]

which represent the scaling of segment length and segment mass, respectively relative to a reference configuration.

Method 1: Uniform Scaling

This method is a uniform scaling using a diagonal matrix with the same scaling factor on all diagonal positions and an assumed relationship between muscle strength and mass based on the idea that muscle strength depends on a functional area while body mass depends on volume. In other words, it presumes that the segment is scaled in all directions as it is in the length direction.

\[ S = \begin{bmatrix} k_1 & 0 & 0 \\ 0 & k_2 & 0 \\ 0 & 0 & k_3 \end{bmatrix} P \]

The scaling of the muscle force is nonlinear with the power of 2/3.

Experiments show that the muscle strength can then be estimated as:

\[ F = \frac{M}{R_{\text{max}}} \]

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\[ F = \frac{M}{R_{\text{max}}} \]

Conclusion

Antropometric scaling based on segment data has been implemented and results in scaling of size as well as muscualr strength. Three different scaling laws, of which the mass law is the most common, are implemented. The muscle strength scaling needs further validation.

Acknowledgement

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Examples

A typical application of scaleline musculoskeletal models is for investigation of compatibility between human bodies of different sizes and car package dimensions. Traditional manikins cover the kinematic compatibility, but they do not predict the human's ability to tune a steering wheel or pull a hand brake. In these pictures, three of the family members, Macy, Karl and John, who are respectively a 5th percentile female, a 50th percentile male and a 95th percentile male, have been inserted into a vehicle package environment adjusted to normally accepted comfort positions for these percentile values.

Pedaling example

In addition to the kinematics, the method also scales the muscle strength and is able to compute muscle forces and activities for different working tasks for differently sized models. So, for a similar work task a small female will use more of her muscular strength than a large male. In the pedaling example below, the same three family members have been asked to pedal a bicycle adjusted to their respective dimensions. The three models are subsequently required to drive the pedals with a typical crank torque variation, all of them producing an average mechanical output of 170 W.