A General Method for Scaling Musculo-Skeletal Models

Rasmussen, John; Zee, Mark de; Damsgaard, Michael; Christensen, Søren Tørholm; Marek, Clemens; Siebertz, Karl

Published in:
2005 International Symposium on Computer Simulation in Biomechanics

Publication date:
2005

Document Version
Accepted author manuscript, peer reviewed version

Link to publication from Aalborg University

Citation for published version (APA):
A General Method for Scaling Musculoskeletal Models

John Rasmussen, 1 2Mark de Zee, 3 Michael Damsgaard, 3 Søren T. Christensen, 4 Clemens Marek and 4 Karl Siebertz
1Ford of Europe, Cologne, Germany
2Ford Forschungszentrum, Aachen, Germany
3AnyBody Technology A/S, Aalborg, Denmark
4Department of Orthodontics, School of Dentistry, University of Aarhus, Denmark

1 Institute of Mechanical Engineering, Aalborg University, Denmark; email: jrime.aau.dk

Computer models of pure technical systems are fully established in automotive engineering, but several comfort and evaluation tools, employing human perception, are hardware and slow down the vehicle development process.

Musculoskeletal modeling is much more challenging than mere kinematics, because scaling parameters not only contact the visual appearance, but also to properties like muscle insertion points, muscle parameters and wrapping surfaces.

This paper presents a general method for scaling musculoskeletal models. The method has been implemented in the AnyBody Modeling System and its associated pubic domain repository of models.

The scaling procedure is implemented in a generic manner and allows the use of user-defined scaling laws.

Musculoskeletal scaling procedures are tested for geometrical and kinematic compatibility on the so-called AnyFamily.

The AnyFamily is a group of anthropometrically defined, individual models generated by Ramsis. The purpose of the AnyFamily is to provide a population 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 geometrical data generated by Ramsis, most prominently segment lengths and masses.

Examples

A typical application of scaleable 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 turn a steering wheel or pull a hand brake.

These pictures, three of the family members, Macy, Karl and John, who are respectively a 10th 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 bodies.

The postures of the three models adjust automatically to the package environment because of the system's ability to model the kinematics of the environment surrounding the body as well as the body itself, the body and environment form a single mechanism.

Pedaling example

In addition to mere kinematics, the method also scales the muscle strength and is able to compute muscle forces and activities for different working tasks for different sized models. So, for a similar task a small female will use more of her muscle strength than a large male. In the pedaling example below, the same three family members have been seated on bicycles 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.

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 such. The nodes of each segment are subjected to scaling of the form

\[ y = S x + t \]

where \( x \) is the position vector of the node in the local coordinate system, \( S \) is the scaling matrix, \( y \) is the original node location, and \( t \) 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 ratio of node, point, or body parts.

This transformation allows for non-uniform scaling rotation and translation depending on the \( x \) and \( y \), which are computed from the segment lengths and segment masses. The scaling factors for the corresponding bodies are computed from the segment lengths and segment masses, respectively. The ratio of the segment lengths is defined as

\[ \frac{S_1}{S_2} = \frac{l_1}{l_2} \]

and the scaling factor of the segment masses is defined as

\[ \frac{S_3}{S_4} = \frac{m_1}{m_2} \]

where \( S_1 \) and \( S_3 \) are the ratios for scaling the segment length and segment mass, respectively.

Method 1: Uniform Scaling

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

The scaling of muscle force is nonlinear with the power of 2/3. This comes from the notion that muscle strength depends on cross sectional area while muscle weight depends on volume, and it is a rule-of-thumb within biology for scaling between species from insects to dinosaurs.

While this method is an obvious choice, the uniform geometry scaling does not seem to capture the physics behind longitudinal segments. This is especially obvious when considering the friction in joints.

Method 2: Non-uniform Scaling

This is a non-uniform scaling taking into account the fact that body segments tend to be organized with soft tissues arranged in layers around a longituinal bone, here corresponding to the y-axis. This leads to a scaling in the perpendicular directions which is square rooted and dependent on the mass as well as the length.

\[ S_1 = S_3 = \frac{1}{\sqrt{S_2}} \quad \frac{1}{\sqrt{S_4}} \]

Experiments show that this method tends to estimate the strength better than Methods 1 and 2.

Conclusion

Anthropometric scaling based on segment data has been implemented and result in scaling of size as well as muscular strength. Three different scaling laws, of which the mass-fat scaling, the uniform and non-uniform scaling laws are implemented. The muscle strength scaling needs further validation.

Acknowledgement

This work was supported by the Ford Motor Company.