

# Design Optimization with respect to Ergonomic Properties

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Design optimization is founded on the ability to analyze the design's properties. Information technology has caused a drastic increase in the capability to analyze different properties, thereby enabling the solution of multidisciplinary design problems. This is one of the principal advances of design optimization in the past decade. This paper continues the development by targeting the design of artifacts that work in conjunction with the human body. Examples are footwear, vehicles of all sorts, workplaces, sports equipment, hand tools, and furniture. Optimization of such problems is only possible if the analysis model includes the human body and allows for determination of the consequences of prospective design changes on the body.

The human body can be perceived as a mechanical multibody system connected by joints and actuators in the form of muscles, as shown in Fig. 1. When the external forces and boundary conditions are known, the equations of equilibrium can in principle be solved to obtain the internal forces, i.e., the muscle and joint loads, and these in turn can provide information about mechanical work, efficiency, metabolic energy consumption, fatigue, and many other properties of the working human body. The solution of the equilibrium equations

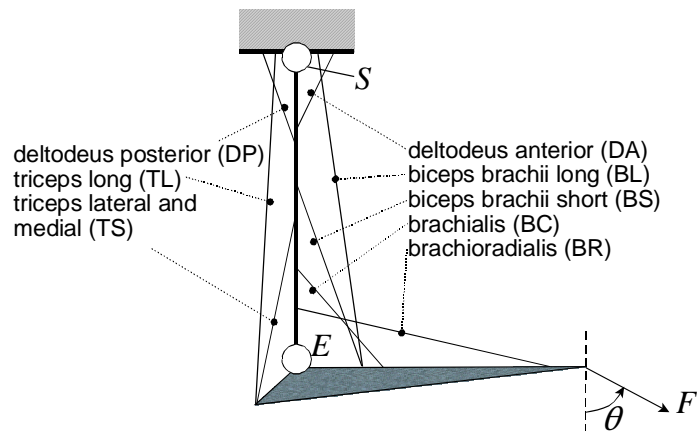


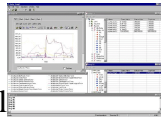
Fig. 1. Model comprising elbow (E) and shoulder (S) joint, and eight muscles. The model is subjected to a given external force (F).

is complicated by the human body being statically indeterminate, owing to the fact that there are more muscles available than necessary to drive most motions. Known solutions to this problem have involved either time consuming nonlinear optimization strategies or optimum control algorithms, both of which make the resulting analysis algorithm unsuitable for design optimization. Rasmussen et.al. (2000) have recently produced a solution to the redundancy problem based on min/max principles and linear programming. This new method possesses the numerical robustness and efficiency to form the basis of design optimization.

The working conditions of muscles depend on the position and movement of the body, because the effective moment arms and strengths of the muscles change with the joint rotations. Therefore, successful simulation of human movements also requires kinematic analysis taking such properties as bone geometry, tendon lengths, and muscle paths into consideration.

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## Implementation



The biomechanical analysis and design optimization capability is being implemented into software in the form of the AnyBody system (Rasmussen, 2000) coded in C++ using Microsoft Foundation Classes. AnyBody is a general body modeling system that allows the user to model smaller or larger segments of the body by definition of bones, joints, muscles, and tendons.

*Fig. 2. Example of muscle force analysis while bicycling, using the AnyBody system.*

The system will also comprise predefined models that suit common modeling purposes.

All properties of the models and boundary conditions in AnyBody are parametric, and any parameter can therefore be used as a design variable in the optimization problem. The design optimization problem is characterized by some degree of non-smoothness, and a robust feasible directions method with a relatively weak dependency on sensitivity analysis is therefore employed for the solution. The sensitivity analysis is based on finite difference.

The present study presents a few practical examples of design optimization including ergonomic improvement of a hand saw.

## Acknowledgments

This work was supported by the Danish Research Agency, Program on “Analysis and Optimization of Musculo-Skeletal Systems”.

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