Musculo-Skeletal Modeling Software (MSMS) for Biomechanics and Virtual Rehabilitation

Mehdi Khachani, Rahman Davoodi, and Gerald E. Loeb

Alfred Mann Institute and Department of Biomedical Engineering
University of Southern California, Los Angeles, CA, USA
E-mail: khachani@usc.edu, Web: http://ami.usc.edu

INTRODUCTION

We have developed a new software for modeling human and prosthetic limbs and simulating them to analyze prosthetic, FES, and natural movement control systems. It provides tools to assemble and customize multi-body systems, actuators and sensors, and controllers and to simulate their dynamics. We have also developed a virtual reality environment (VRE) where these models can be simulated with the subject in the loop to evaluate the feasibility of prosthetic control systems and train the patients to operate them.

METHODS

MSMS mainly consists of graphic user interface (GUI), modeling, simulation, and database units [1]. MSMS is implemented using the Java programming language. Dynamic simulations are implemented in Simulink and C programming languages. Standard libraries such as Open-GL are used whenever possible. The basic components and tools have been built, tested and are in use but we anticipate incremental enhancements to both, so we have established an iterative rather than top-down development process.

RESULTS

At the current stage of development, MSMS provides a GUI for building and editing models. The user can edit component properties while visualizing the 3D model from different points of view. The animation feature in MSMS allows animating the model using either live simulation data sent via UDP or using motion files. In addition to animating the joints, the user can change the attributes of objects in the model such as their size and color in run-time. A new feature supports various technologies for 3D displays such as goggles and shutter glasses.

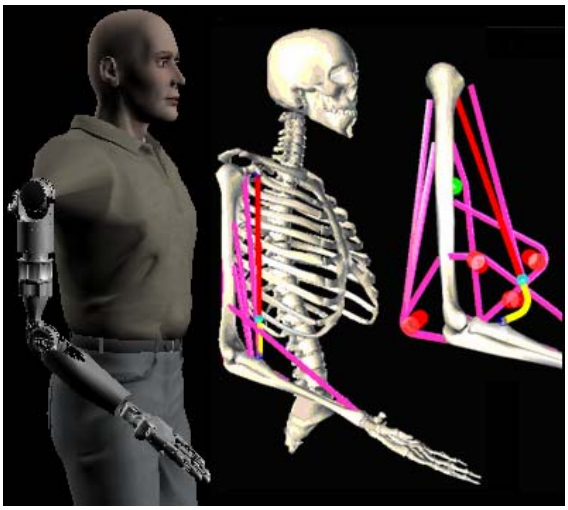

Figure 1: Prosthetic and musculoskeletal limb models in MSMS.

Building an accurate musculoskeletal plant relies on the fidelity of its elementary components. The complex mechanical properties of muscles and tendons are implemented using the 'Virtual Muscle' mathematical model [2]. Wrapping algorithms are used to calculate the path of the muscle from its origin to its insertion constrained by bony surfaces (spherical and cylindrical). The components of mechatronic prosthetic limbs are also

available. In addition to modeling biological and prosthetic limbs, MSMS includes models of the environment that consist of objects, external forces and torques, lights and cameras that are essential for simulations of complete rehabilitation tasks.

Models built in MSMS use the eXtensible Markup Language (XML) as a standard format to define musculoskeletal and prosthetic limb models. The database structure is flexible enough to allow for the possibility of establishing a modeling standard. To take advantage of existing models, MSMS can import models developed in popular modeling software including SIMM (Musculographics Inc., USA), and SolidWorks (SolidWorks Corp., USA).

An MSMS model can automatically be exported to dynamics engines such as SimMechanics, which is currently used by MSMS. The C-code representing its mechanical properties is wrapped in a Simulink block where it can be interfaced with controllers built from Simulink and Matlab toolkits. For real-time simulations, models of complete systems are compiled in C and downloaded to a target PC. Real time execution allows for patient-in-the-loop simulations. The subject generates voluntary commands (e.g. EMG or cortical signals) to control the simulated limb while using a stereoscopic display of the virtual arm from his point of view as visual feedback [3]. The patient's central nervous system learns to correct movement based on vision, as it would with the real prosthetic system. This VRE is an efficient and safe platform for testing designs for prosthetic systems. It can also be used to train patients with disabilities. We have developed models of real rehabilitation tasks in the VRE such as grasping and moving objects.

APPLICATIONS

MSMS is currently been used in several laboratories to study prototypes of neural prosthetic systems. In our laboratory, we are using MSMS and VRE to develop FES controllers for quadriplegic patients. These controllers use the residual voluntary movements of the upper arm to drive the synergistic movement of the paralyzed lower arm. Different control strategies are tested in VRE to determine their feasibility before clinical deployment.

Recent work at Caltech consists of testing cortical control of prosthetic limbs by nonhuman primates. Cortical signals are used to control in real time a virtual prosthetic arm that is modeled and visualized in MSMS. At the Rehabilitation Institute of Chicago, EMG signals from re-innervated chest muscles are used to provide motor commands to control the virtual prosthetic limb.

SUMMARY/CONCLUSIONS

MSMS and VRE provide a comprehensive framework for virtual prototyping of neural prosthetic systems for paralyzed and amputee patients. Tools to simulate contact and mechanical interaction with objects are still under development. These are computationally demanding tasks and in some complex applications we may have to trade off accuracy for execution speed while waiting for faster processors.

REFERENCES

[1] Davoodi, R. et al. (2007). *IEEE Trans. Biomedical Eng.*, in press.
[2] Cheng, E et al. (2000). *J. Neuroscience Methods*, **101**, 117-130.
[3]Hauschild, M. et al. (2007). *IEEE Trans. Neural Systems and Rehabilitation Engineering*, **15**,9-5.