

A SOFTWARE TOOL FOR FASTER DEVELOPMENT OF COMPLEX MUSCULOSKELETAL MODELS IN SIMULINK™

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INTRODUCTION

Computer models of musculoskeletal systems are useful in the study of various aspects of movement and control in humans and animals. Unfortunately, developing such models is usually a challenging task by itself.

SIMM™ (Musculographics Inc., USA) is the only commercial software for developing anatomically realistic musculoskeletal models (Delp and Loan 2000). The user generates a set of input files describing bone surfaces, articulations, and muscle-tendon parameters, and uses SIMM to assemble these graphically into an anatomically realistic model (Fig. 1). With the help of SD/Fast (Symbolic Dynamic Inc., USA) SIMM generates a set of files in the programming language “C” containing the equations of motion for the musculoskeletal model. This process requires the user to understand the structure of the SIMM-generated C-programs and to write additional programs for any other components required by the system under study (e.g. sensors, controllers). SIMM also has substantial limitations on its ability to incorporate run-time changes of muscle excitation, external forces, prescribed motion, and initial conditions, which handicap its use to study control algorithms. For example, the muscles can only be excited in an open-loop manner while many applications involve closed-loop control of muscles.

Our main objective is to build reusable I/O blocks for different components of the neuromusculoskeletal systems. We have chosen to do this in Simulink (Mathworks Inc., USA), an attractive, easy to use, and popular software package for simulation of complex systems. One particularly relevant source of such component blocks is the Virtual Muscle™ package developed by Cheng et al. (2000), which generates Simulink blocks representing the force-generating properties of realistic muscle models with user-specifiable parameters.

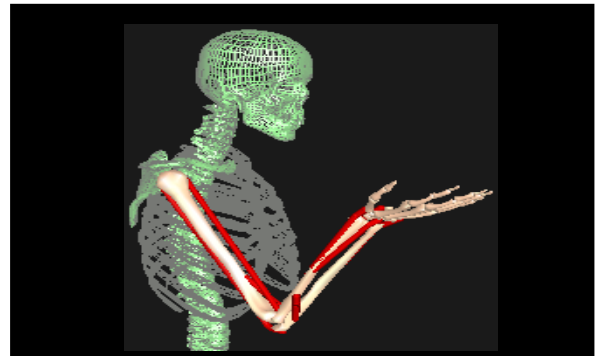


Figure 1. Example arm model with 5 segments, 10 DOF, and 12 muscles in SIMM window.

MUSCULOSKELETAL MODELING IN SIMULINK (MMS)

MMS is a set of Matlab scripts and C-files that are added to the normal model-building process in SIMM to generate Simulink models, and to add additional functionality without the user having to write any C-code

at all. MMS generates compiled C-code that calls the SIMM code and files as required. This compiled C-code is wrapped in a Simulink S-function, which permits it to be connected to other Simulink blocks and called during simulations. Within Simulink, the MMS output appears graphically as a large block with intuitively labeled input and output connectors for all of its state variables (Fig. 2). MMS also provides three major enhancements to the capabilities of SIMM to allow simulations of closed-loop sensorimotor control systems.

1. It allows the use of any non-SIMM model of muscle force production such as Virtual Muscle (Cheng et al. 2000).
2. It allows the user to change the initial configuration of the musculoskeletal model in each simulation run without recompilation. This includes restricting DOFs in the model, as long as the basic topology is preserved.
3. It allows the interactive configuration and run-time modification of the external forces, external torques, and prescribed motions. The prescribed motions can be modified in run-time, including locking/unlocking the joints.

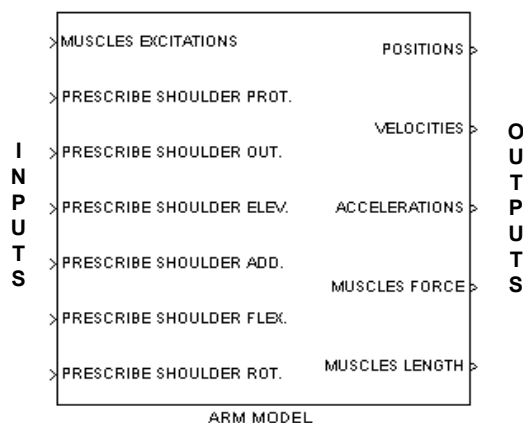


Figure 2. Generic representation of the MMS-generated Simulink block for the example arm model. Shoulder motion is prescribed by the user and the rest of the DOF are controlled by the muscles.

Once the Simulink block is generated, the user only needs to connect the inputs (e.g. muscle excitations) and outputs (e.g. joint angles) of the block to appropriate sources and destinations and run the simulation. More advanced applications can take advantage of the utilities, toolboxes and easy programming environment in Matlab and Simulink for design and optimization of controllers.

SUMMARY

SIMM is currently the most popular software for graphic and dynamic simulation of movement in musculoskeletal systems. Building dynamic models with SIMM requires substantial C programming, thereby limiting its use. We have developed MMS software to convert the SIMM musculoskeletal and kinetics models to Simulink blocks. In addition, MMS removes some runtime constraints so that the resulting blocks can be used in simulations of closed-loop sensorimotor control systems. Researchers, clinicians and educators in the fields of motor control and biomechanics are among the potential users who may benefit from using MMS. SIMM licensees can obtain a free copy of MMS by contacting the authors.

REFERENCES

- Delp, S. L., Loan, J. P. (2000). *Computing in Science & Engineering*, **2**, 46-55.
 Cheng, E. J. et al. (2000). *J. Neuroscience Methods*, **101**, 117-130.

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