

Lower Limb Musculoskeletal Modeling for Standing and Sitting Event by using Musculoskeletal Modeling Software

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Abstract— This paper shows how the musculoskeletal modeling for standing and sitting event of lower limb of humans is possible using MSMS (Musculoskeletal Modeling Software). Concept, significance and factors of musculoskeletal modeling of lower limb have been detailed. It presents how the complexity of biomechanics related to lower limb can be modeled with MSMS and also represents how such model can be useful in generating MATLAB/SIMULINK® model that can be further used in the development of prototype neuroprosthesis model for paraplegic patients having lower extremity disorders. Proposed modeling includes 12 leg virtual muscles which shows its accuracy for event of standing to sitting event with due consideration of the coordinating position, Mass, Inertia used for rigid body segment, and Joint Type, Translational Axes, Rotational Axes used for lower limb joints. The result generated by MSMS for proposed modeling has been presented. Merits and demerits of proposed modeling have also been discussed.

I. INTRODUCTION

Models are used widely in all types of engineering, and especially in Biomechanics. The term model has many uses, but in the engineering context, it usually involves a representation of a physical system, a prototype, that may be used to predict the behavior of the system in some desired respect. These models can include physical models that appear physically similar to the prototype or mathematical models, which help to predict the behavior of the system, but do not have a similar physical embodiment. Many software develops procedures for designing models in a way to ensure that the model and prototype will behave similarly. A model is a representation of a physical system that may be used to predict the behavior of the system in some desired respect. Models of the lower extremity musculoskeletal system [1], [3] have made achievable a wide range of biomechanical investigation especially for paraplegic patients with lower extremity disorders after spinal cord injury (SCI) or multiple sclerosis (MS). For example, Models of the musculoskeletal system facilitate individual to study neuroprosthesis, neuromuscular coordination, evaluate athletic performance, estimate musculoskeletal loads, simulate the effects of musculoskeletal surgeries such as joint replacements, investigate a possible cause of crouch gait and to study muscular coordination of walking, jumping, sitting [4], standing [5] and cycling [6]. MSMS (Musculoskeletal Modeling Software) [7] is open-source software that allows users to develop, analyze, and visualize models of the musculoskeletal system, and to create dynamic simulations of movement. In MSMS, a musculoskeletal model consists of rigid body segments

connected by joints. Muscles span these joints and generate forces and movement. Once a musculoskeletal model is created, MSMS facilitates users to study the effects of musculoskeletal geometry, joint kinematics, and muscle-tendon properties of the forces and joint moments that the muscles can generate. In additions MSMS solves an inverse kinematics problem and an inverse dynamics problem using experimental data [2].

II. METHODS FOR LOWER LIMB MUSCULOSKELETAL MODELING FOR STANDING AND SITTING EVENT IN MSMS

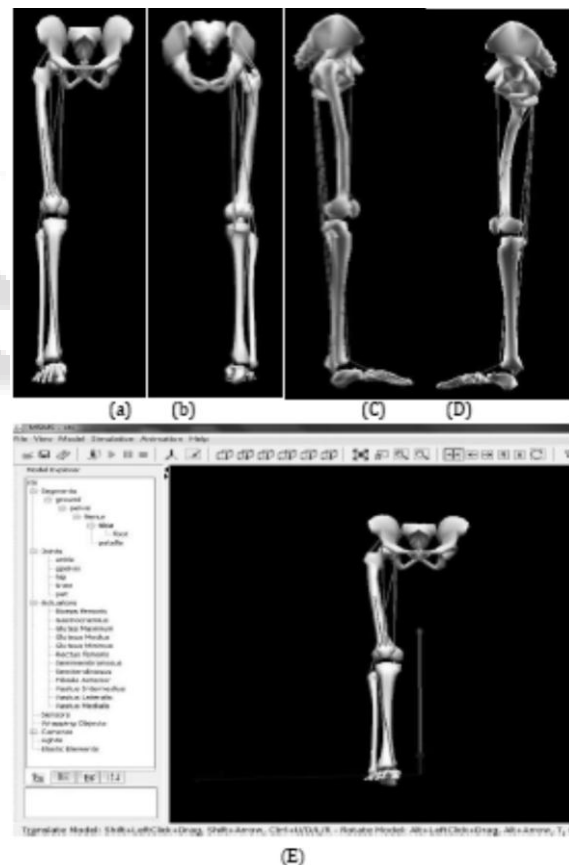


Figure 1: Proposed right leg model in MSMS; (A) front view, (B) back view, (C) right view, (D) left view and (E) with the coordinate system of each joint.

MSMS is used to build a standard model of a lower limb musculoskeletal modeling. Skeletal geometry integrates rigid models of the pelvis, femur, tibia, fibula, patella, talus, calcaneus, metatarsals, and phalanges that were shaped by digitizing a set of bones from a male adult subject with an approximate height of 1.8 m and an approximate mass of 75 kg. The model consists of 5 rigid body segments and

includes the lines of action of 12 virtual muscles. For slanting the coordinate systems of each bone segment so that in the anatomical position the X-axis points anteriorly, the Y-axis points superiorly, and the Z-axis points to the right. Figure 1 illustrates different views of the proposed model with a proposed leg model in MSMS window. Left side of the window shows rigid segments and joints used in the model and right side of the window shows complete right leg model with the coordinate system of each joint.

In this model five rigid body segments are used and coordinated that can be explored under “segments” block in “model explorer” (Figure 1 (E)). To model this rigid body segment we have considered the mass, Inertia etc. as shown in table. 1. Where, we have considered pelvis as a ground segment. Subsequently we have constructed femur under pelvis by taking into consideration pelvis as a parent segment. Similarly by putting together a new rigid body segment (namely tibia, talus, patella, foot) as a child segment just before its respective parent segment.

Sr.No.	Rigid Body Segment	Mass (in kg)	Center of Mass (in m)	Inertia(in kg*m ²)= $\begin{bmatrix} I_{XX} & I_{XY} & I_{XZ} \\ I_{YX} & I_{YY} & I_{YZ} \\ I_{ZX} & I_{ZY} & I_{ZZ} \end{bmatrix}$
1.	Pelvis	11.777	X=-.0707, Y=0.0, Z=0.0	$I_{XX} = 0.1028, I_{YY} = 0.0871,$ $I_{ZZ} = 0.0579,$ $I_{XY}, I_{XZ}, I_{YX}, I_{YZ}, I_{ZX}, I_{ZY} = 0.0$
2.	Femur	9.3014	X=0.0, Y=-0.17, Z=0.0	$I_{XX} = 0.1339, I_{YY} = 0.0351,$ $I_{ZZ} = 0.1412,$ $I_{XY}, I_{XZ}, I_{YX}, I_{YZ}, I_{ZX}, I_{ZY} = 0.0$
3.	Tibia	3.7075	X=0.0, Y=0.1867, Z=0.0	$I_{XX} = 0.0504, I_{YY} = 0.0051,$ $I_{ZZ} = 0.0511,$ $I_{XY}, I_{XZ}, I_{YX}, I_{YZ}, I_{ZX}, I_{ZY} = 0.0$
4.	Patella	0.0919	X,Y,Z=0.0	$I_{XX} = 0.0011, I_{YY} = 0.0011,$ $I_{ZZ} = 0.0011,$ $I_{XY}, I_{XZ}, I_{YX}, I_{YZ}, I_{ZX}, I_{ZY} = 0.0$
5.	Foot	1.75	X=0.10, Y=0.03, Z=0.0	$I_{XX} = 0.0014, I_{YY} = 0.0039,$ $I_{ZZ} = 0.0041,$ $I_{XY}, I_{XZ}, I_{YX}, I_{YZ}, I_{ZX}, I_{ZY} = 0.0$

Table. 1: Data Used While Coordinating Rigid Body Segment.

In addition to this our proposed leg model has five joints with respect to ground pelvis. This can be explored below the “joint” block in the “model explorer” (Figure 1 (E)). Out of these five joints, four joints are movable joints (namely hip, knee, ankle, and pelvis) and residual are fixed joints (namely patella). Our proposed leg model contains the same joint type as the natural leg. Table. 2 shows the data for the model of joints such as its type, proximal and distal segment, and its rotational axes.

Proposed right leg model contains 12 leg virtual muscles [8] which will help to achieve an equivalent response to natural leg response such as standing, and sitting. Proposed leg virtual muscles are based on hill muscle model [9]. It

can be explored below the “Actuators” block in the “model explorer”. Data used in a proposed model for virtual muscle is given in the Table. 3 and DOF of different joint are given in the Table. 4.

Sr.No.	Joint Name	Joint Type	Proximal Segment	Distal Segment	Rotational Axes
1.	ground _pelvis	Pin/revolute	Ground	Pelvis	pelvis_rz:- (X,Y,Z)=(0,0,1)
2.	Hip	Pin/revolute	pelvis	Femur	hip_rz:- (X,Y,Z)=(0,0,1)
3.	Knee	Pin/revolute	Femur	Tibia	knee_rz:- (X,Y,Z)=(0,0,1)
4.	Ankle	Pin/revolute	Tibia	Foot	ankle_rz:- (X,Y,Z)=(0,0,1)
5.	Patella	Weld	Femur	Patella	None

Table. 2: Data Used In A Proposed Model For Joints.

Sr.No.	Muscle Name	Optimal Fiber Length (in cm)	Optimal Tendon Length (in cm)	Physiological Cross-Sectional Areas (PCSA) (in cm)
01	Biceps femoris	09.80	32.20	11.60
02	Gastrocnemius	05.90	38.20	09.90
03	Gluteus maximus	15.70	07.30	30.40
04	Gluteus medius	07.30	06.60	36.10
05	Gluteus minimus	05.60	02.60	36.10
06	Rectus femoris	07.60	34.60	13.90
07	Semimembranosus	06.90	37.80	19.10
08	Semitendinosus	19.30	24.50	04.90
09	Tibialis anterior	06.80	24.10	11.00
10	Vastus intermedius	09.90	10.60	16.80
11	Vastus lateralis	09.90	13.00	37.00
12	Vastus medialis	09.70	11.20	23.70

Table. 3: Virtual muscle data used in a lower limb modeling. [3]

Joint Names	DOF
Pelvis	0° to 30°
Hip	0° to 60°
Knee	-60° to 0°

Table. 4: proposed lower limb model’s joints dof

III. MATLAB/SIMULINK® MODEL OF LOWER LIMB

One of the major advantages of MSMS is that, it can generate a simulink model (.mdl) by using command “Save Simulation”. This simulink model represents the algorithms that can simulate the movement of the MSMS model in response to control excitations and external forces, This Simulink model can be opened and run in Matlab’s Simulink environment which helps for further Biomechanics investigation. Here Figure. 2 shows a simulation model of a proposed leg model of MSMS. This Simulink model can be

used in generating and simulating the complete lower extremity model having external electrical stimulus such as the one used in neuroprosthesis models. Such neuroprosthesis model can be helpful for designing the prototype programmable functional electrical stimulator (FES) that can be helpful to the paraplegic patients with lower extremity disorders.

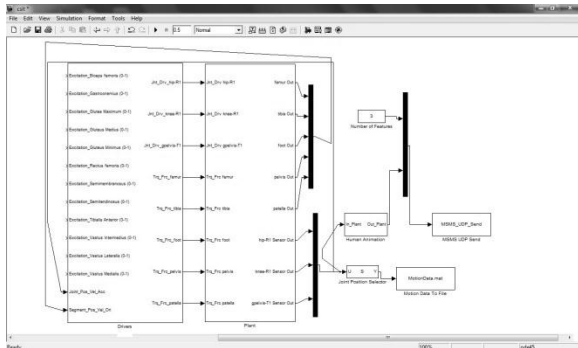


Figure. 2: Simulink model of proposed leg model in MATLAB®

IV. RESULTS AND CONCLUSION

In this study, we formed a model that calculates the fiber lengths and forces of the muscles based on a vigorous data set of experimentally considered structural design. The model can be used to study the relationship between moments at different joint with respect to muscles responsible to produce respective joint movement. Figure 2 shows the result of movement at the hip joint and Figure 3 shows the result of movement of the knee joint versus muscle at the knee joint. The accuracy of the muscle paths was tested by qualitative evaluation of model expected to experimentally measured moment. Using this model further response of electrical stimulus to the lower limb model can be tested and if the open loop test results can be validated with the experimental setup data then closed loop control can also be implemented in future.

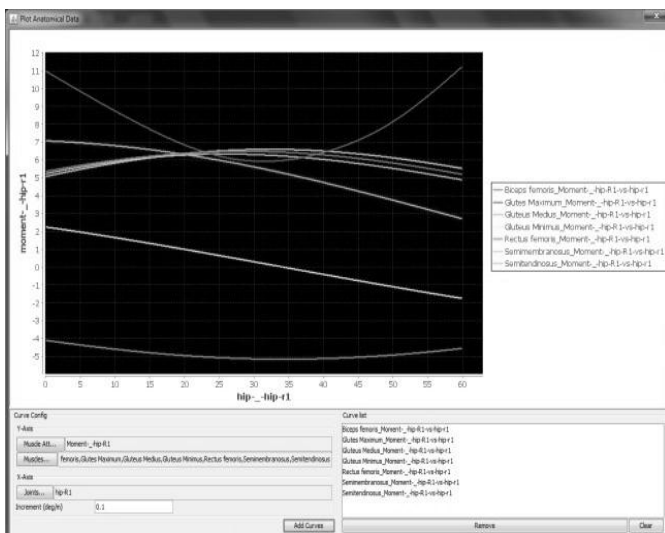


Figure.3 shows the result of movement at the hip joint versus muscle at the hip joint.

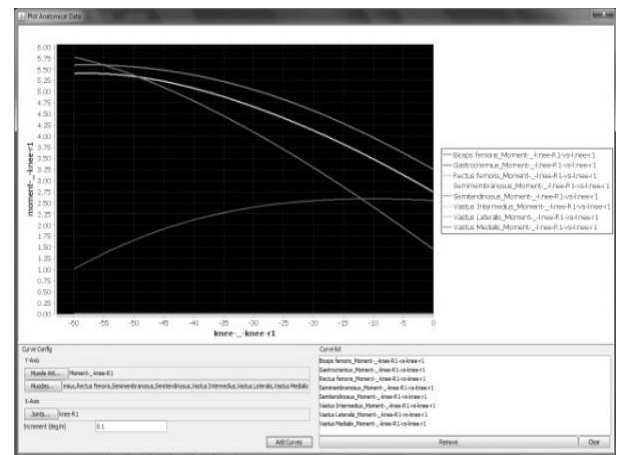


Figure. 4 shows the result of movement at the knee joint versus muscle at the knee joint.

There are some limitations of this model that should be considered. Here only 12 muscles are considered and remaining muscles were ignored. However, these muscles make small contributions to the overall joint moment and are not likely to alter simulation results of joint function.

REFERENCES

- [1] Scott Delp, Allison Arnold, Samuel Hamner, "Introduction to Musculoskeletal Modeling", Neuromuscular Biomechanics Laboratory, Stanford University.
- [2] Samuel Hamner, Clay Anderson, Eran Guendelman, Chand John, Jeff Reinbolt, Scott Delp, "Scaling, Inverse Kinematics, and Inverse Dynamics", Neuromuscular Biomechanics Laboratory, Stanford University
- [3] Edith M. Arnold, Samuel R. Ward, Richard L. Lieber, And Scott L. Delp, "A Model Of The Lower Limb For Analysis Of Human Movement", Biomedical Engineering Society, November 2009.
- [4] Colleen Louise Mchenry, "A Biomechanical Model Of Femoral Forces During Functional Electrical Stimulation After Spinal Cord Injury In Supine And Seated Positions", University Of Iowa, 2010.
- [5] Gustavo P. Braz, Michael Russold, Glen M. Davis, Facsm, "Functional Electrical Stimulation Control Of Standing And Stepping After Spinal Cord Injury: A Review Of Technical Characteristics", Neuromodulation: Technology At The Neural Interface, 2009.
- [6] Margit Gföhler, Thomas Angeli, And Peter Lugner, "Modeling Of Artificially Activated Muscle And Application To Fes Cycling", 12th International Conference On Mechanics In Medicine And Biology, September, 2002.
- [7] R. Davoodi, I.E. Brown, G.E. Loeb, "Advanced Modeling Environment For Developing And Testing FES Control Systems", Medical Engineering & Physics 25 (2003) 3–9, Elsevier, April 2002.
- [8] Ernest J. Cheng, Ian E. Brown, Gerald E. Loeb, "Virtual Muscle: A Computational Approach To Understanding The Effects Of Muscle Properties On

Motor Control”, *Journal Of Neuroscience Methods*
101 (2000) 117–130, June 2000.

- [9] Jeffrey W. Holmes,” Teaching From Classic Papers: Hill’s Model Of Muscle Contraction”, *Advances In Physiology Education*, August , 2012.

