Study Of Effect Of Different Frequency And Amplitude Of FES On Lower Limb Musculoskeletal Model For SCI Patients

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***Abstract*— This paper shows the effect of different frequency and amplitude of functional electrical stimulator (FES) on the musculoskeletal model of the lower limb of human prepared in MSMS (Musculoskeletal Modelling Software). The proposed model was validated with respect to empirical data collected from Physiotherapy Centre. This study focuses on selection of accurate amplitude and frequency for achieving optimal angle (or gait phases) while walking. Concept, significance and factors of different frequency and amplitude on the lower limb musculoskeletal model prepared for spinal cord injury (SCI) patients have been detailed. The result generated by MSMS/MATLAB® for proposed model has been presented.**

***Keywords*— Biomechanics, Gait, Musculoskeletal System, Virtual muscles.**

I. Introduction

Disability is challenging especially for those who have been energized before spinal cord injury and are currently disabled. Spinal cord injury (SCI) can produce total or partial paralysis. The person who has one of these conditions may be not capable to move parts of his or her body. Paraplegia is usually the result of Spinal Cord Injury. The area of the spinal cord which is affected in paraplegia is either the thoracic, lumbar, or sacral regions. Paraplegia describes complete or incomplete paralysis affecting the legs but not the arms. A paraplegic is a person whose lower extremities are affected and has usually no control in his lower extremities. FES is a hopeful way to restore mobility to SCI by sending electrical signals to restore the function of paralyzed muscles. In this technique, low-level electrical current is applied to an individual with an SCI disability so as to enhance that person‘s ability to function and live independently. It is important to understand that FES is not a cure for SCI, but it is an assistive device [1].

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 [2], [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 neuroprosthersis, 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 [1], 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.

II. Methods For Lower Limb Musculoskeletal Modeling In MSMS

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 7 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 (A) illustrates proposed leg model in MSMS window. Left side of the window shows rigid segments, joints and 12 virtual muscles used in the model and right side of the window shows the complete right leg model.

Figure 1 (A): Proposed right leg model in MSMS with rigid body segments, joints and 12 virtual muscles.

In this model rigid body segments are used and coordinated that can be explored under "segments" block in "model explorer" (Figure 1 (A)). To model this rigid body segment 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, patella, and foot) as a child segment just before its respective parent segment.

In addition to this proposed leg model has three joints with respect to ground pelvis. This can be explored below the "joint" block in the "model explorer" (Figure 1 (A)). Proposed leg model contains the same joint type as the natural leg, e.g. hip joint in this model has a ball and socket joint with three degrees of freedom such as flexion/extension, adduction/abduction, and internal/external rotation which is same as the natural leg.

Proposed right leg model contains 12 leg virtual muscles which will help to achieve an equivalent response to a natural leg response in FES- aid walking. It can be explored below the "Actuators" block in the "model explorer".

III. Simulink Block For Lower Limb Musculoskeletal Model In MATLAB/SIMULINK®

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 1 (B) shows a simulation model with pulse generator 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.

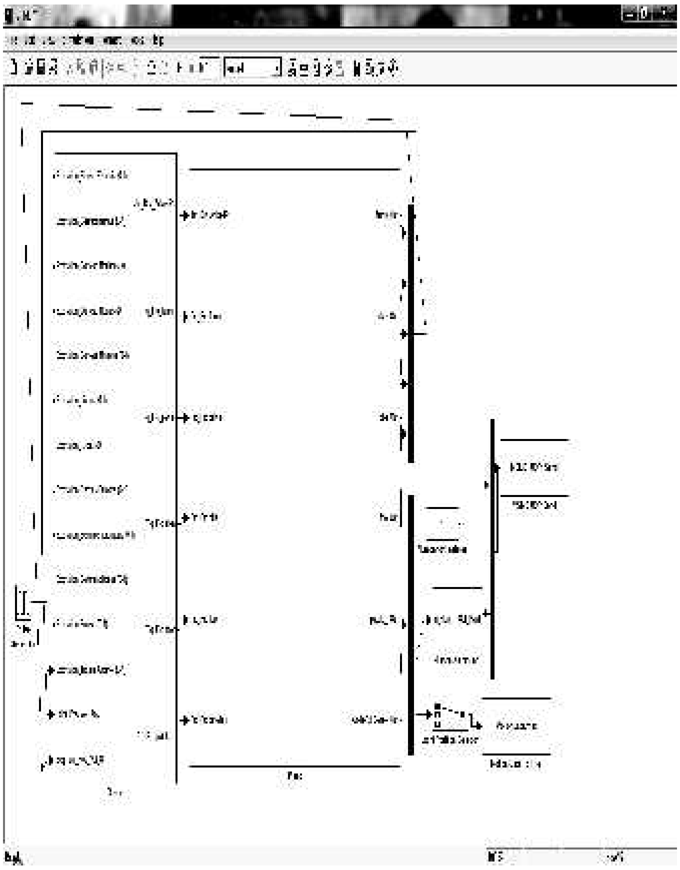

Figure 1 (B): Simulink model of proposed leg model in MATLAB/SIMULINK® with electrical stimulus (FES).

IV. Effect Of Different Frequency And Amplitude Of FES On Lower Limb Model And Results

After validating the lower limb model with respect to empirical data collected from physiotherapy center, a study of the effect of different frequency and amplitude of FES is carried out in MSMS and MATLAB/SIMULINK® environment. Technical specifications of available FES have a frequency range from 20 to 60 Hz and amplitude range from 10 to 100mA. In this study, a different combination of frequency and amplitude are applied to proposed lower limb model to achieve an optimal angle while walking. A study divided in two parts, in the first part of study possible results is collected by keeping frequency constant and varying amplitude as per amplitude range specify by technical specification of FES. In the second part of the study possible results are collected by keeping the amplitude constant and variable frequency as per frequency range specify by technical specification of FES.

The first part of the study carried out by keeping frequency constant at 40Hz and varying amplitude in 10, 30, 40, 50, 60, 80, 100mA manner. In the second part of study by keeping the amplitude constant at 60mA and varying frequency in 20, 30, 40, 50 ,60 Hz manner. Figure 1 (C) shows the result of achieving knee joint angle in degree by applying electrical stimulus having frequency of 40Hz and amplitude of 60mA. Figure 1 (D) shows the result of achieving ankle joint angle in degree by applying electrical stimulus having frequency of 40Hz and amplitude of 60mA.

V. CONCLUSION

In this study, we formed a lower limb musculoskeletal model for SCI patients and validate it with empirical data collected from physiotherapy center. A different frequency and amplitude are applied from its minimum to the maximum available range to the proposed model. In case of different frequency and constant amplitude, it shows that, at low frequency we obtain optimal angle slowly and jerkily, while at a high frequency optimal angle is obtained very fast. In case of different amplitude and constant frequency, it shows that, at low amplitude optimal angle is obtain jerkily, while at high amplitude optimal angle is obtain very fast. So, in conclusion it is preferable to choose intermediate frequency (~ 40Hz) and amplitude (~ 60mA) to achieve optimal angle of respective joint.

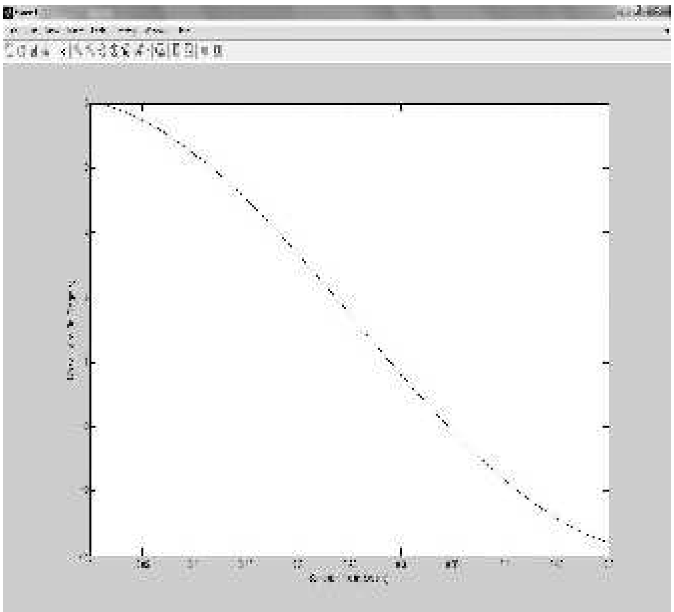

Figure 1(C): Result of knee angle (in degree) achieve after applying stimulus having frequency of 40Hz and amplitude of 60mA to knee muscle of lower limb.

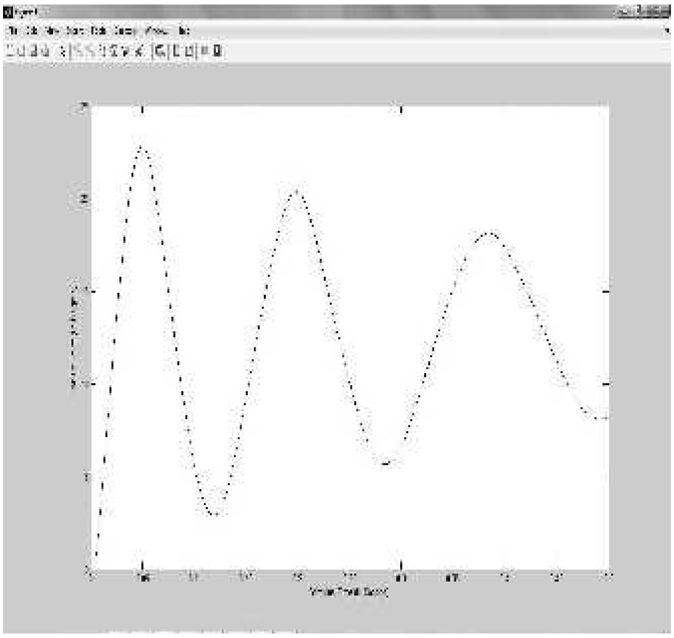

Figure 1(D): Result of ankle angle (in degree) achieve after applying stimulus having frequency of 40Hz and amplitude of 60mA to ankle muscle of lower limb.

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