

DYNAMIC MODELING OF A REHABILITATION EQUIPMENT

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Abstract. In this article it has been studied a rehabilitation equipment behavior, by means of dynamic modeling. The software used is Matlab R2008b, with SimMechanics module. The SimMechanics dynamic model is composed of a mechanical system, driven by a linear actuator and controlled by a PID controller. The equipment simulation in real time is observed in Virtual Reality environment. For designing the mechanical structure model first is established the mass and moment of inertia of each element of the mechanism. After that are established the degrees of freedom and constraints, and attached coordinate systems to each item. Then are introduced the actuators, sensors for measuring movements are set, and the final step is starting the simulation. The SimMechanics dynamic model of the knee and hip rehabilitation equipment provides a real functioning and accurate graphs of the angle amplitude.

Keywords: dynamic modelling, rehabilitation equipment, Matlab R2008b

1. Introduction

The paper presents dynamic modeling of a knee and hip rehabilitation equipment. The equipment designed for the rehabilitation of the affections of the knee and hip uses continuous passive motion as kinetic therapy, being actuated by a pneumatic muscle.

The dynamic model realized in Matlab R2008b, SimMechanics module, simulates the functioning of the equipment, the software permits plotting graphs of the knee and hip angle amplitude.

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2. Rehabilitation equipment

The equipment presented in figure 1 is capable of achieving continuous passive motion of the knee and hip joints, being actuated by a pneumatic muscle [1]. In this configuration, the device allows making recovery exercises for knee and hip.

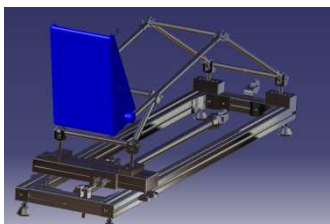


Figure 1 3D-CAD model of the rehabilitation equipment

To make the rehabilitation movement, the slider device is connected to an articulated bar mechanism, on which sits the ill leg. The limit positions which the patient foot touches during the exercise rehabilitation can be traced in Figure 2.

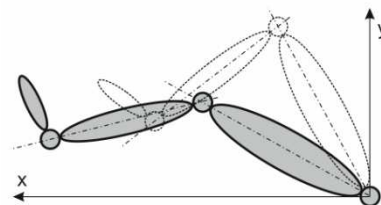


Figure 2 Moving limits of the hip and knee joints

For the construction of the equipment was used Festo pneumatic muscle with interior diameter of 20 mm and an initial length of 750 mm.

Because the maximum stroke of the free end of the muscle is about 20% of its length in relaxed state (150 mm) between the muscles and slide is located a mobile pulley mechanism, designed to amplify the size of the slider displacement up to the required value [2].

3. SimMechanics dynamic modeling

A SimMechanics multibody model is a block diagram containing one or more schemes, each representing a system composed of a set of interconnected blocks.

The basic components of any system are rigid *bodies*. In SimMechanics, the body means any point or extended spatial object, characterized by mass and a coordinate system attached, and which has no

degrees of freedom. Bodies are interconnected by joints.

Joints are the degrees of freedom (DoFs) of an element called the follower to another which is the basis [3]. *The base* may be another body or the whole system (ground). In SimMechanics, the system (ground) refers to a body of infinite mass and size that works both as a frame of reference for the entire system, but also as a fixed base of clamping the system components.

Sensors measure the joints and bodies forces and movements, which are displayed as a graph, through the Scope blocks. Scope blocks are taken from Simulink Sink library and not from SimMechanics.

Actuators are mechanical devices that move or control an element or a mechanism, by transforming the source of energy in motion.

Sensors and actuators blocks are the only elements that can connect SimMechanics blocks with other blocks outside this environment.

Controllers are devices that act as control over the entire system behavior. A PID controller has a proportional component, an integrative one and a derivative one.

The steps in projecting the model of the mechanical structure are: establishing the mass and moment of inertia of each element of the mechanism, establishing the degrees of freedom and constraints, attaching coordinate systems to each element, introducing the actuators, the sensors and starting the simulation.

4. Dynamic modeling of the knee and hip rehabilitation equipment

Dynamic modeling of the rehabilitation equipment is realized with Matlab R2008b software, with SimMechanics module.

The SimMechanics model of the equipment contains kinematic structure of the system and the dimensional parameters of its components. This is presented in figure 3.

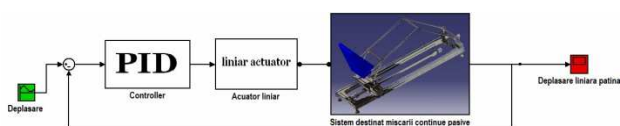

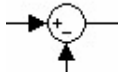

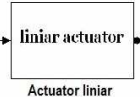
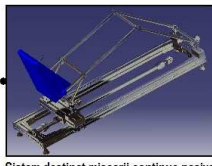
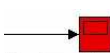


Figure 3 SimMechanics Model

In this figure it can be seen all components of the continuous passive motion equipment, each with a specific name and a corresponding block. For defining the mechanism simulation, the blocks are interconnected. Notations used are as follows:

Table.1 Notations used

Graphic element	Description
 Deplasare	Sine Wave block which specifies the relative movements of the elements
	Sum block which performs addition or subtraction of its inputs
 Controller	PID block which performs error correction in the system
 Actuator liniar	Liniar actuator
 Sistem destinat miscarii continue pasive	System for continuous passive motion
 Deplasare liniara patina	Scope block which displays output from the system

SimMechanics model consists of a mechanical system, driven by a linear actuator and controlled by a PID controller. Elements movements are set by Sine Wave block and the output, represented by the linear movement of the slide, is displayed by Scope block.

Mechanical system (figure 4) contains three articulated bars connected by three rotation joints and one translation joint.

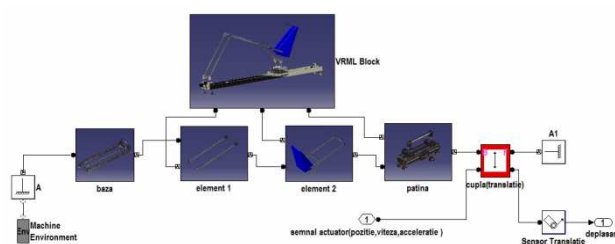


Figure 4 SimMechanics model of rehabilitation system

The base of the system is connected in one way to the rotation joint of the hip (*Element 1*) and is fixed on the other way, through A base to the environment (*Machine Environment*). The parameters of the mechanical simulation environment are defined through machine environment. Those parameters are: size and direction of gravitational acceleration, simulation mode (2D or 3D), analysis mode, constraints, linear

and angular tolerances of the assembly, linearization and visualization [4].

The element 1 is related to element 2, but also to VRML block.

Figure 5 presents the subsystem *Element 1*. Input 1 is the output of the subsystem Base of the base layer, a, and the output 3 will be the input for the subsystem *Element 2*. To the rotation joint 1 is attached a sensor to measure the angle of rotation performed by the hip. The value measured by the sensor is displayed through the *Scope block* (*phi1*) attached to it.

Element 1 is an articulated bar of 450 mm length and the attached sensor (*Body Sensor*) measures its movement and exports the value in the virtual environment (*VRML Block*).

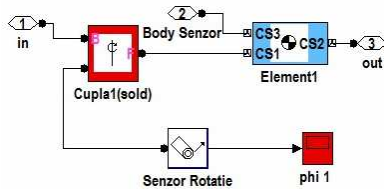


Figure 5 *Element1* Subsystem

The input for subsystem 2 (Figure 6) is the output of the previous subsystem. The rotation joint 2 has attached a rotation sensor that measures the amplitude of movement performed by the knee and a *Scope block* (*phi2*) which displays the measured values. Subsystem contains two articulated bars (2a and 2b) of length 400 mm and 168 mm, welded together at an angle of 150°. Output 2 of the subsystem leads to *VRML block*, and output 3 is the next layer input.

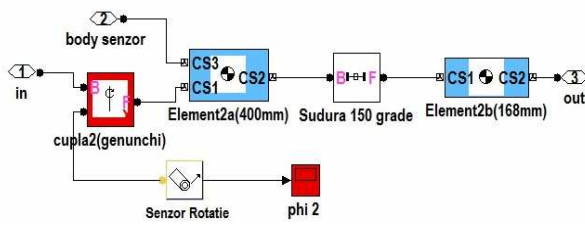


Figure 6 *Element 2* Subsystem

Slide subsystem (Figure 7) contains, in addition to inputs and outputs similar to those of other subsystems, a rotation joint for connecting the 2b element to the slide.

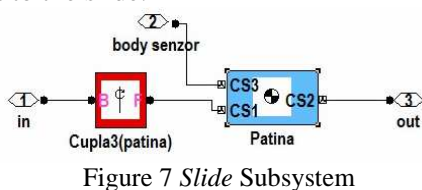


Figure 7 *Slide* Subsystem

Translation joint (Figure 8) is driven by an actuator which impose the sliding distance, velocity and acceleration to be achieved by slide.

As follower, the translation joint has a sensor which measures and displays the sliding distance and the point of fixing to the working environment.

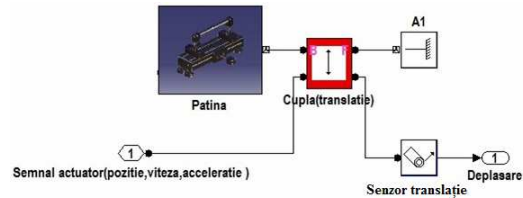


Figure 8 Translation joint

PID controller (Figure 9) has the role of adjusting the system behavior in order to achieve desired response.

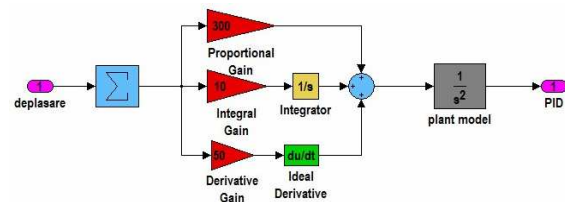


Figure 9 PID Subsystem

The signal from SineWave block enters in the PID subsystem to be processed and then transmitted to the transfer function. Each component, proportional, integrative and derivative will act on the input value to obtain a desired behavior. Chosen values of the components are: $K_P = 300$; $K_I = 10$; $K_D = 50$.

Linear actuator subsystem (Figure 10) takes information about position, velocity and acceleration from the controller and turns them into a signal applied to the translation joint which realizes the sliding movement of the slide.

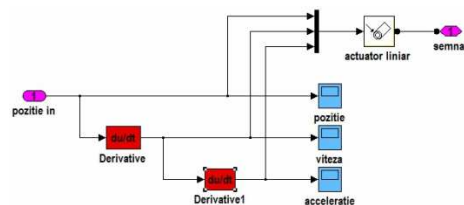


Figure 10 Linear actuator subsystem

After running the dynamic model can be viewed the sequence of movements performed by rehabilitation equipment (Figure 11).

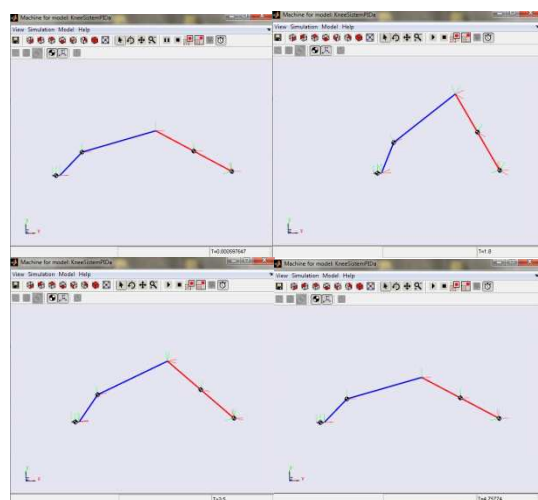


Figure 11 Successive positions of the rehabilitation equipment

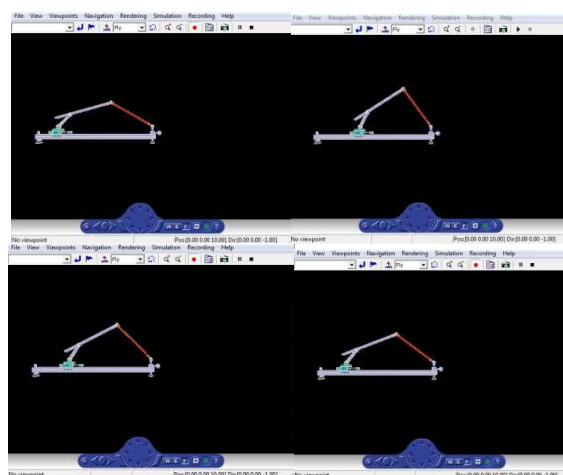


Figure 13 Successive positions of the SimMechanics model connected to the virtual scene

The optimum visualization of the dynamic behavior of the equipment is the one projected in Virtual Reality Toolbox module.

To connect SimMechanics model to the virtual reality are used body sensors which measure elements movement and then exports the value measured in the virtual world as follows:

- measured value for the translational movement is transmitted directly to VR Sink block;
- measured value for the rotation is transmitted to *RotationMatrix2VR* block to be transformed into an acceptable value for virtual space.

Sensors and matrix are connected to the *VR Sink* block, which writes data from SimMechanics into the virtual world (Figure 12) [5].

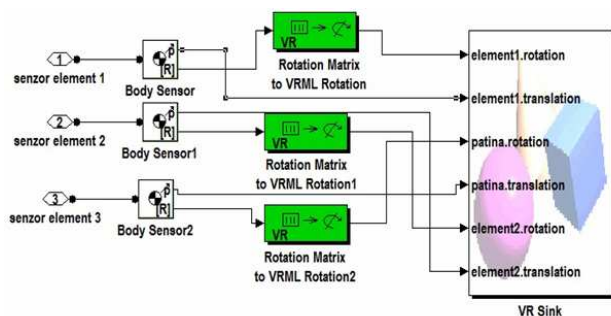


Figure 12 Transformation matrix and VR Sink block

By opening *VR Sink* block it is launched the virtual scene, where can be viewed the animation of the model (Figure 13).

4. Conclusions

The dynamic model presented in this paper provides the opportunity to simulate the functioning of the rehabilitation equipment. Simulation type used in the equipment behavior analysis is based on time. It is considered that the system works for 10 seconds, making a repetitive move of smooth oscillation between the ends of the race. The set values obtain a slider movement of 300mm.

Acknowledgements

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