

ACTIVE-PASSIVE THERAPY REHABILITATION SYSTEM

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Abstract— Increasing in traumas and stroke cases for accidents boosts researcher to develop new technologies aiming at to comfort enhancement, time and cost reduction in rehabilitation. In this work, it is presented the simulations of a robotic device able to perform several kinds of physical exercises; having isokinetic, isotonic, isometric and passive activities. Based on these operating concepts, a mechatronic system is designed based on commercial devices able to perform these types of tasks. This system allows patient or therapist to choose from diverse forces and velocity ranges. Additionally, the system is simulated to visualized and avoid eventual disturbances, caused by involuntary patient contractions or spasms caused by muscular atrophy. Through this robotic device, it is possible to incentive games or competitions among patients, increasing its mood and autonomy level during therapy sessions.

Keywords— Robotic rehabilitation, Force training, Active and passive movements

Resumo— O aumento de traumas e acidentes vasculares cerebrais por acidentes estimula o pesquisador a desenvolver novas tecnologias visando a melhoria do conforto, tempo e redução de custos na reabilitação. Neste trabalho, são apresentadas as simulações de um dispositivo robótico capaz de realizar diversos tipos de exercícios físicos, como treinos de força passivas, isocinéticas, isotônicas e isométricas. Com base nesses conceitos operacionais, um sistema mecatrônico é projetado com base em dispositivos comerciais capazes de realizar esses tipos de tarefas. Este sistema permite que o paciente ou terapeuta escolha entre diversas faixas de força e velocidade. Também, é possível modificar a posição do membro para diferentes comprimentos. Além disso, o sistema é simulado para visualizar e evitar eventuais distúrbios, causados por contrações involuntárias do paciente ou espasmos causados por atrofia muscular. Através deste dispositivo robótico, é possível incentivar jogos ou competições entre pacientes, aumentando seu humor e nível de autonomia durante as sessões de terapia.

Palavras-chave— Reabilitação robótica, Treinamento da força, Movimentos ativos e passivos.

1 Introduction

Nowadays, the increase in traumas and strokes case represents a great part of the hospital internment in the world (Bonita et al., 2004; Pendlebury, 2007). Thus, Alias et al. (2017) remark the importance to increase the patient independence during the rehabilitation process. This fact improve the therapist productivity, being able to serve more patients without jeopardizing the patient integrity.

The rehabilitation through robotic devices arose in the principle from exoskeleton systems towards the 60's with the introduction of General Electric enterprise to the automated exoskeleton market (Makinson, 1971; Vukobratovic et al., 1974). Recently, the BLEEX Zoss et al. (2006) and HAL Sankai (2006) are projects applied to neuroscience and bio-systems, aiming to replicate the human motion. This idea led to the researchers to analyze the advantages that would get these systems in a rehabilitation process.

Based on above, different robots models for rehabilitation emerged, some of them are organized by kinds and degrees of freedom. Monaco et al. (2009) presents NeuroBike like a robotic system for lower limb rehabilitation therapy, this device simulates and analyze the natural walking. Ochi et al. (2015) build a robotic platform that simulates the natural walking. On the other hand, Ochi et al. (2015), Bradley et al. (2009), Akdoğan and Adli (2011), Chisholm et al. (2014), and Guo et al. (2016) developed a portable mechatronic system for that the patients can use in its home, this device has several user modes for full independence of patient and the physiotherapist. All these variations have allowed increased the versatility and independence, decreasing the cost and the recuperation time in the patients with some motor difficulty.

On the other hand, control strategies have become in a field of interest in the development of rehabilitation robots, due to that a good control allowing increase the improvements percent-

age during the therapy sections. In recent works, is used modern control systems, Jiang et al. (2015) and Wang et al. (2017) used Fuzzy control and Neural Networks control in its research respectively. The use of these control strategies throws better results than classic control strategies. However, the classical control strategies also allow to obtain optimal results, this is widely used in systems with a single control variable, this system type is shown in Wu et al. (2016) to follow the desired trajectory of a robot through the current control in the motor with a proportional-integral (PI) controller.

Strength training is one of the biggest challenges for bedridden patients (International, 2010), because, the patient is unable to move the parts of its body on its own. The rehabilitation robots for the lower limbs (from now LLRR) are used to move the body limbs and increase its Range of Motion (from now ROM). Some papers that developed LLRR systems as (Wang et al., 2017; Sin et al., 2014; da Silva Rosa et al., 2013; Madoński et al., 2014; Yoon et al., 2006; Kikuchi et al., 2003), shown the importance to apply different training type. These exercises can be divided into active like isometric, isotonic, isokinetic exercise and passive movements. According to these authors, the biggest challenge is to simulate the isokinetic process. These improvements and additional functions aim to strengthen the force, stiffness, elasticity in the body muscles and bones to increase the ROM and bedridden patients health.

This paper present in section 2 the methods and materials that are used for development of paper. Section 3 provides the theory about exercises types for strength training and the proposed system for this task. In section 4 presents the results obtained in the robotic system simulation, the section 5 analyzed the main paper contributions and finally is presented the discussion about future works.

2 Methods

The overall scheme of this system (see figure 1), consists in to use a robotic device to perform the rehabilitation process on a patient. So, it is required to perform all types of exercise to train strength. This paper performs experiments on passive, isometric, isotonic, and isokinetic training modes. Also, is considered the use of this mechatronic system to move some body parts as legs, arms and neck. The device can be reconfigurable due to, the modularity and ergonomic with which it is projected. Aiming to give support to the physiotherapist, this system to provide independence to the user. The project has four components or subsystems: 1) mechanic system, 2) electric-electronic system, 3) control system and

4) human-machine interface system. The actuator uses a step motor with a ball screw to generate linear movement. This actuator also uses a torque sensor and an encoder for position and velocity measurements.

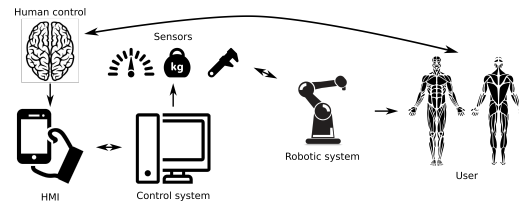


Figure 1: Overall scheme of process

A S load cell sensor and HX711 module are used to measure the force applied to the mobile plate of the actuator. The system modularity allows a wide range of exercise for different body parts. To simulate the system applied to these exercise type is used the CAD model of SMC actuator model LEFS32B800 with a mass in their mobile plate and a model of slider crank mechanism simulating the human leg, the previous parts were designed in a CAD software (SolidWorks). Then, the system was exported to dynamical software (Simulink) from numerical software using Simmechanics library. The results are obtained and validated applying different values and sources types and used the internal tools to add springs, dampers, and different slopes.

3 Set the Training modes

Based on the isotonic, isometric, isokinetic and passive exercises theory, is configured the robot for therapy sessions. Given the data in table 1, is possible to achieve a proper device setup. In all exercises are shown its different behaviors showing the position, velocity, acceleration, force, and torque. The exercises made in the day to day by a person can be expressed like some physical laws. The Newton's laws are widely used in this work, using too the Hooke's and Stoke's law. Then, the actuator uses the physical principles used in this work to perform the behavior analysis during the exercise sections.

Table 1: Training modes behavior.

Training type	Pos.	Vel.	Acc.	Force
Passive	V	C	N	V
Isometric	C	N	N	V
Isotonic	V	V	V	C
Isokinetic	V	C	N	V

V: Variable behavior, C: Constant behavior and N: Null behavior, adapted from (da Silva Rosa et al., 2013).

3.1 Passive exercise

In this exercise is presented a behavior where the user is dominated by the assistant with a constant velocity, variable position and force for limit magnitudes in rehabilitation (see table 1). Also, is setup the number of cycles required in a therapeutic section. The passive exercise allows to the therapist to understand best the patient status, assessing the user ROM to create a therapeutic sections planning.

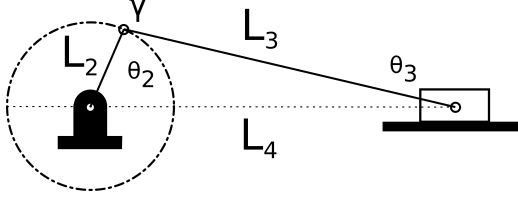


Figure 2: Slider-crank mechanism.

A slider-crank mechanism (see figure 2) is constituted by four links (base is fixed) and four joint. This mechanism is used widely in motors and pumps, due to that the mechanism allows to convert rotational movement in translational movement e vice versa (David, 2005). A typical analysis involves locating the position if the links, given its lengths (L_2 and L_3) like a thigh and a shank respectively, and the crank angle (θ_2). The slider position (L_4) and the interior joint angles (θ_3 and γ) must be determined. The equations used for this mechanism are:

$$\theta_3 = \sin^{-1} \left[\frac{L_2}{L_3} \sin \theta_2 \right] \quad (1)$$

$$L_4 = \sqrt{L_2^2 + L_3^2 - 2(L_2 L_3 \cos \gamma)} \quad (2)$$

$$\gamma = 180^\circ - (\theta_2 + \theta_3) \quad (3)$$

A human leg, for example, in a flexion and extension movement use the slider-crank mechanism as an analogy of a mechanic system. This is due to the similarity that presents both systems. Its movement can be established through displacement, velocity, and acceleration in the mechanism given the maximal ROM in the human joints. In the leg case, the maximal angles permitted in the ROM are shown in table 2.

3.2 Isometric exercise

This exercise is a type of strength training in which during the contraction, the joint angle and muscle length do not change. The force F applied to the system is opposite but with the same magnitude, making the body does not move.

3.3 Isotonic exercise

During the isotonic exercise, the muscle contraction exerted by the user is caused by a constant

Table 2: ROM maximal in the human leg joints.

Joint	Hip	Knee	Ankle
Medial rotation/ lateral rotation	-50°/ +40°	-	-
Adduction/ abduction	-20°/ +45°	-	-
Extension/ flexion	-30°/ +120°	0°/ +150°	-
Plantarflexion/ dorsiflexion	-	-	-40°/ +20°
Inversion/ eversion	-	-	-35°/ +20°

- It does not exist, adapted from (Pons, 2008)

force. The position, velocity, and acceleration are variable and dependent on the intensity with which the user performs the activity. An example is when lifting a weight. The physical representation is given by second Newton's law where m_1 it is mass body and g it is gravity such that:

$$F = ma - mg \quad (4)$$

3.4 Approximation of isokinetic exercise

This exercise consists in to generate a movement when is perform to a concentric or eccentric contraction at a set speed against a force of maximal resistance produced at all points in the range of motion (Teachpe, 2018; da Silva Rosa et al., 2013). In this approximation of the isokinetic exercise is simulated the spring and damper behaviors (see figure 3), when different resistances and viscosities are applied, the values aiming to produce the maximal force at all the ROM.

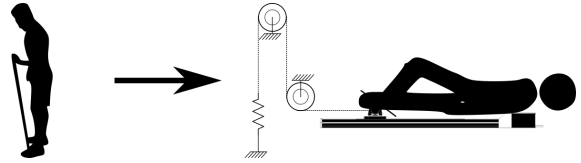


Figure 3: Analogy for isokinetic exercise with spring alone system.

For this system is used the equation based on Hooke's law:

$$F = -kx, \quad (5)$$

where F is a restitution force, k is a spring constant and x the displacement.

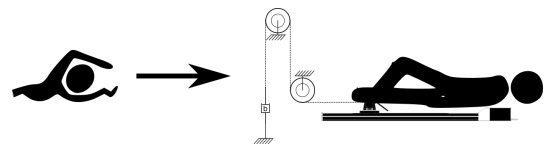


Figure 4: Analogy for isokinetic exercise.

Also, it is used the damper system to define the system of figure 4, this system approximate simulates the swimming movement in a pool water,

$$F = -c \frac{dx}{dt}, \quad (6)$$

where c is defined by Stokes's law (drag force) for different shape kinds, F is the damper force and $v = \frac{dx}{dt}$ is the velocity of the system.

4 Preliminary experiments

Initial experiments performed in the virtual model of mechatronic system have allowed knowing its behavior to anticipate possible failures in the real model. For this prototype were simulated the proposed models in section 3 through use of a dynamical software library (Simmechanics). A computer-aided design software (CAD) is used to project the linear actuator model. The model is compound by a linear actuator, a weight placed in the mobile part and slider crank mechanism simulating the human leg (see figure 5). The parameter assumed during the simulations are shown in table 3

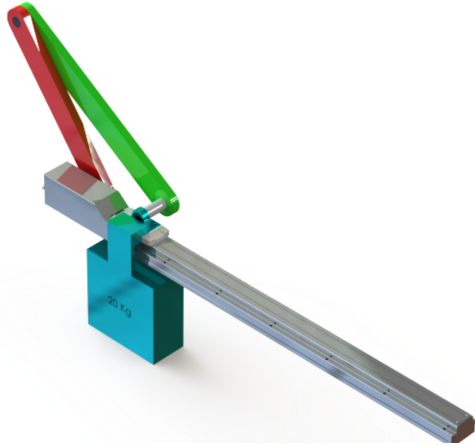


Figure 5: System planned to perform passive and active rehabilitation.

4.1 Passive exercise

Figure 6 represents the angle achieved (dotted line) by the thigh when is perform a passive movement. This simulation uses the leg extension and flexion movement. The minimal and maximal values for the range of motion in the joints are exposed in table 2. The input signal is established as trapezoidal function, that is shown in figure 6 in bold line.

4.2 Isometric exercise

Based on the isometric exercises theory, the reaction forces about a body is bigger than action force exerted on its. This is seen in figure 7 when

Table 3: Summarized of parameters in the experiment.

Parameter	Value	
	Passive	Isometric-Isotonic-Isokinetic
Shank		500[mm]
Thigh		400[mm]
Slope		45°
Gravity		9.81[$\frac{m}{s^2}$]
Mass		20[Kg]
Source signal	Displacement (trapezoidal)	Torque (sinusoidal)

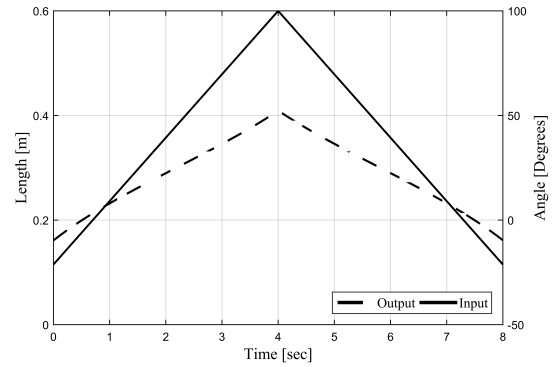


Figure 6: Angular position of thigh.

is applied a force with magnitude 200 N and sinusoidal signal. So, any force performs for the user will have an opposite force with the same magnitude.

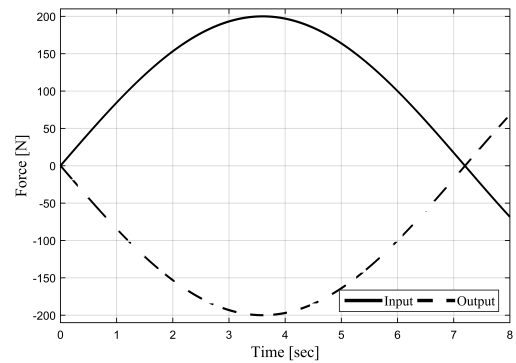


Figure 7: Input signal vs output signal during the isometric exercise in the actuator.

4.3 Isotonic exercise

Figure 8 represents the reaction forces (dotted line) acting about the prismatic joint of robot when is applied a torque signal in the thigh. Then, it is calculated the force required to move the mass give 138 N approximately using the equation 4.

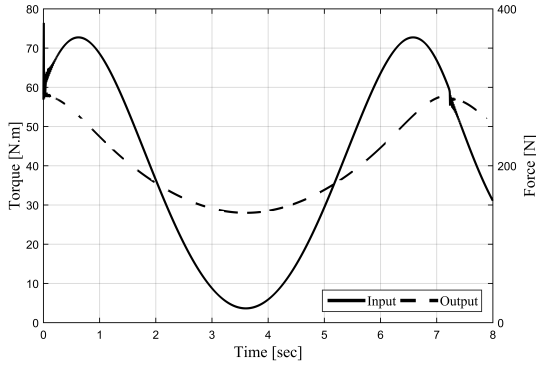


Figure 8: Torque required (bold line) to move the mass in the actuator during isotonic exercise.

4.4 Approximate isokinetic exercise

Figures 9 and 10 show the behavior of the an approximate isokinetic exercises exposed in the section 3.4. These graphics showed the reaction forces during the performed movement. For both figures is presented the weight force exerted on the mobile plate of the linear actuator. Based on this, it added up the weight force with the restitution force of a spring that have a constant $k = 200[\frac{Kg}{s^2}]$ like is shown in figure 9. Also, it added up the weight force with the viscous force of a damper with constant $b = 120[\frac{Kg}{s}]$, the results are shown in figure 9.

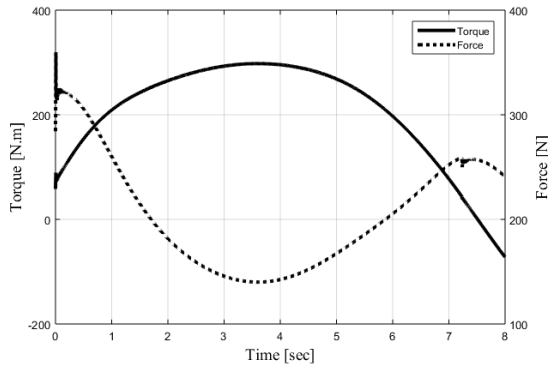


Figure 9: Torque performed by the hip joint vs reaction force in the mobile plate of actuator when is used a spring-mass system.

In the graphs is possible to see the similarity between the dynamical laws that govern these systems and its respective behaviors. So, it is possible to see that the spring is dependent on the displacement and on the other hand, the damper is dependent on the velocity. Due to this, the graphs 9 and 10 show the force on the spring and damper respectively with a behavior similar to displacement and velocity profiles.

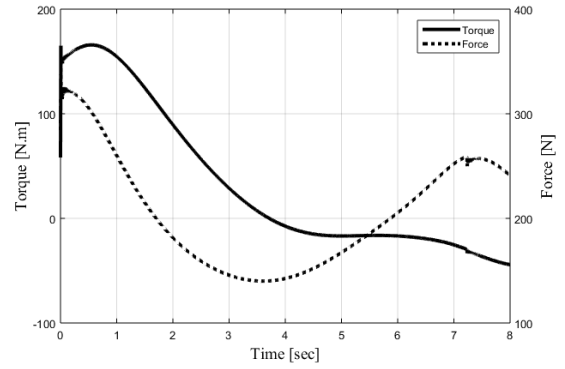


Figure 10: Torque performed by the hip joint vs reaction force in the mobile plate of actuator when is used a damper-mass system.

5 Conclusions

The system simulations allowed to analyze its behavior for several positions, velocities, and forces. This is an important fact, due to the possibility to can predict the movements without to produce damage to the user.

In this experiment is used a mass of 20 Kg, but in the simulation and the real system is allowed to modify the spring and damper parameters. Aiming to convert this device into an assistant to perform a variety of strength training.

For the therapist and the patient, this device generates independence, because it can adjust and teach the patient its duties in the sessions. Then, the therapist can review the results and its can to decide if the patient has some improvement or not, adjusting the parameters newly.

6 Discussions

In this paper is presented the results achieved from simulations of a mechanical system and comparing this with the behavior of the physics laws that govern its kinematic and dynamic. Following works will include the hospital crane kinematic model to determine the actuator orientation. Also, will be presented the methodology used, its planning, building and results of real model when is performing an exercise aforementioned.

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