2019
Iberdiscap

X Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad

Buenos Aires 20, 21 y 22 de noviembre

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PRESENTACIÓN

Según la Organización Mundial de la salud (OMS, 2018) más de mil millones de personas, es decir, un 15% de la población mundial, padece alguna forma de discapacidad. La misma fuente señala que entre 110 y 190 millones de adultos tienen algún tipo de limitación funcional. Las tasas de discapacidad están aumentando a causa del envejecimiento de la población y el aumento de las enfermedades crónicas, entre otras causas. Las personas con discapacidad tienen menos acceso a los servicios de asistencia sanitaria y, por lo tanto, necesidades básicas insatisfechas.

Las personas con discapacidad se enfrentan a una gran variedad de obstáculos cuando buscan asistencia sanitaria, entre ellos: costos prohibitivos, oferta limitada de servicios, obstáculos físicos, aptitudes y conocimientos inadecuados del personal sanitario

Los gobiernos para mejorar la salud de las personas con discapacidad deben facilitar el acceso a servicios de asistencia sanitaria de buena calidad, que sean asequibles y que utilicen de manera óptima los recursos públicos, procurar que las personas con discapacidad se beneficien de los programas de salud pública en pie de igualdad, aplicar incentivos para estimular a los proveedores de asistencia sanitaria, hacer accesibles los servicios y proporcionar exámenes, tratamientos y seguimiento integrales, considerar opciones para reducir o eliminar los pagos directos por parte de las personas con discapacidad que no tienen otros medios de costearse los servicios de asistencia sanitaria, incluir a las personas con discapacidad en la vigilancia de la asistencia sanitaria, realizar investigaciones en torno a las necesidades, las barreras y los resultados sanitarios de las personas con discapacidad y adoptar las medidas para que éstas resulten útiles a las personas.

El uso de tecnologías complejas y avanzadas se extendió a todos los campos y la rehabilitación médica no fue ajena a este fenómeno. En su desarrollo participan equipos de varias disciplinas, articulando de manera novedosa la acción de los médicos, ingenieros y técnicos.

En nuestro país, se ha tomado conciencia de que el desarrollo y la evolución de la Tecnología de la Rehabilitación debe hacerse en el seno de los centros y servicios hospitalarios de rehabilitación; como así mismo se puede generar en centros universitarios, pero siempre deben ser verificados y valorados en ámbito de la salud.

En nuestro país la acción desarrollada por la Asociación Iberoamericana de Tecnologías de Apoyo a la Discapacidad (AITADIS) y la Red REASISTE han favorecido que el Instituto Nacional de Tecnología Industrial (INTI) y el Hospital Lencinas, a través de la participación institucional de médicos fisiatras, protesistas y ortesistas, kinesiologos, y otros profesionales de la salud y organismos públicos

Feasibility study of human-exoskeleton computer model to simulate interaction controls for robotic assisted rehabilitation

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Abstract
The objective of this work is to propose and verify the feasibility of a computational interaction model between user and exoskeleton of lower limbs. It should be able to reproduce and test the interaction controls developed for rehabilitation. This is expected to reduce the need for physical contact between human and robot as well as the time spent during the tuning and tests of the controllers, as well as promoting agility and flexibility. The initial tests of the model proved that it is feasible and capable of reproducing the interaction controls, proving to be a powerful tool for the development of interaction controls in robotic rehabilitation.

Keywords: Human-exoskeleton interaction model, OpenSim, robotic neurorehabilitation

1. Introduction
Robotic has emerged as a promising resource for rehabilitation therapy offering significant benefits to therapists such as data storage about the treatment, repeatability of the movements and more intensive therapy sessions (Androwis et al, 2018; Huang and Krakauner, 2009).

The prerequisites of the human-robot interaction are the assurance of patient safety, treatment efficacy and attendance to the *assist-as-needed paradigm*, so an effort has been made by rehabilitation engineers to design patient-robot interaction controls in order to meet these prerequisites (Ibarra and Siqueira, 2014).

However, testing and validating these interaction controls often require physical interaction between an user and a robot during the experimental trials, putting the user at risk, and often requiring reasonable time and resources in the testing preparation.

The objective of this work was to develop a computational patient-exoskeleton interaction model and a simulation algorithm able to be used for reproduction, validation and testing of interaction controls, applied in robotic rehabilitation of lower-limbs. We seek to reduce the need for physical contact between human and robot and to promote agility and flexibility during the tuning and tests of the controllers.

2. Methodology
This section presents the development of the proposed interaction model, the simulation algorithm and the description of the tests performed.

2.1. Interaction Model
The proposed interaction model is based on a computational neuromusculoskeletal (NMS) model of the lower limbs coupled to an exoskeleton computational model (Fig. 1a). The NMS model is a three-dimensional, 23 degree-of-freedom, computer model of the human lower-limbs biomechanical system called Gait2392 (Delp et al, 1990) and provided by the OpenSim[2]. This model, in its default version, corresponds to an individual that is approximately 1.8 m tall and has a mass of 75.16 kg. The anthropometry of the model can be fitted to a specific subject, through the Scale Tool from OpenSim. In this work the default version was used.

The virtual model of the exoskeleton was developed based on the ExoTAO (Fig. 1b), which promotes movements in the sagittal plane (Santos et al, 2017). To this end, coordinate actuators, which produce generalized torques, proportional to an input control signal, were added to the hip, knee and ankle joints of the Gait2392.

$$\tau = u \, . \, \tau_{max} \tag{1}$$

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where τ is the generalized torque, u is the input control signal that varies between -1 and 1, and τ_{max} is the maximum torque that can be applied by the actuator.

Initially some simplifications were considered: the actuator is ideal (no mass, delay or losses), the axes of the joints of the robot and the user are collinear and the torque is applied directly to the joint in question.

Figure 1. (a) Interaction model. The yellow arrows represent the coordinate actuators and the red lines represent the muscles. (b) User wearing the ExoTAO.

2.2. *Simulation Algorithm*

To simulate the interaction controls using the interaction model, an algorithm based on Forward Dynamic was developed using MATLAB. The forward dynamics describes how the positions and velocities of the model changes when torques and forces are applied to it. The total torque applied to the interaction model is the sum of the user and exoskeleton torques (Fig. 2).

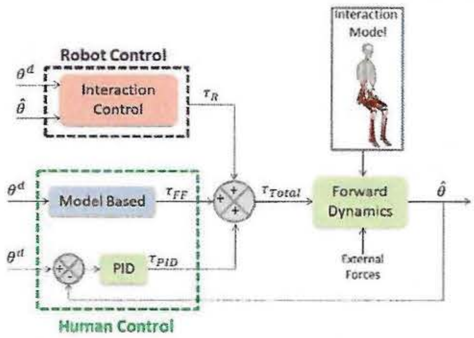


Figure 2. The interaction control determines the torques necessary to perform a desired movement (θ^d). The external forces are due to the contact with the environment (e.g. ground reaction forces). The $\hat{\theta}$ is the computed position that is expected to be equal to the reference one.

The human control consists of a feedforward loop, modeled utilizing the Inverse Dynamics Tool from the OpenSim, and a PID feedback loop. The feedforward loop provides a user-estimated torque to perform the movement. The feedback loop seeks to eliminate the effects of the disturbances that affect the good performance of the motion.

The robot control loop consists of the interaction control which in this work is an impedance control, whose the control law is given by:

$$\tau_{robot} = K_{robot}(\theta^d - \hat{\theta}) - B_{robot}\dot{\theta} \quad (2)$$

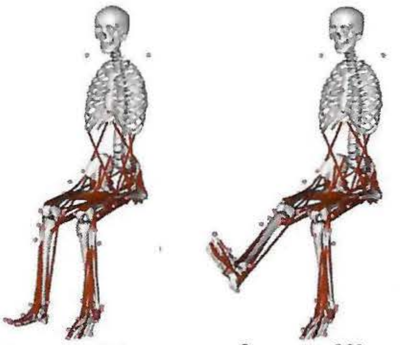
Where B_{robot} is the damp coefficient of the robot, constant and equal to 0.012 N.m.s/rad and K_{robot} is the stiffness of the robot, variable according to each test performed.

2.3. *Tests procedure*

Two simulation tests were performed and in each of them the stiffness and the operation mode (assistive/resistive) of the robot were variated. Only the right knee joint was used in the tests and the model remained in a seated position (i.e. without ground reaction forces involved) performing knee movements according to a sinusoidal desired trajectory with an amplitude of -70°, knee flexed to -20°, knee extended (Fig. 3). The features of the tests are given below.

Test 1: K_{robot} = 2.6 N.m/rad, robot is operating in the assistive mode, helping the patient to perform the movement, according to a desired trajectory. In this case, the patient was simulated as having some weakness, reflecting an inability to perform the desired movement by itself. Therefore, the torque produced by the patient was limited to a maximum value of 10 N.m.

Test 2: K_{robot} = 0.024 N.m/rad, robot is operating in the resistive mode, opposing to the patient's movement. For this, the desired trajectory of the robot was shifted in 180 degrees in relation to the patient's one. In this case, the user has no weakness, equaling a healthy individual.



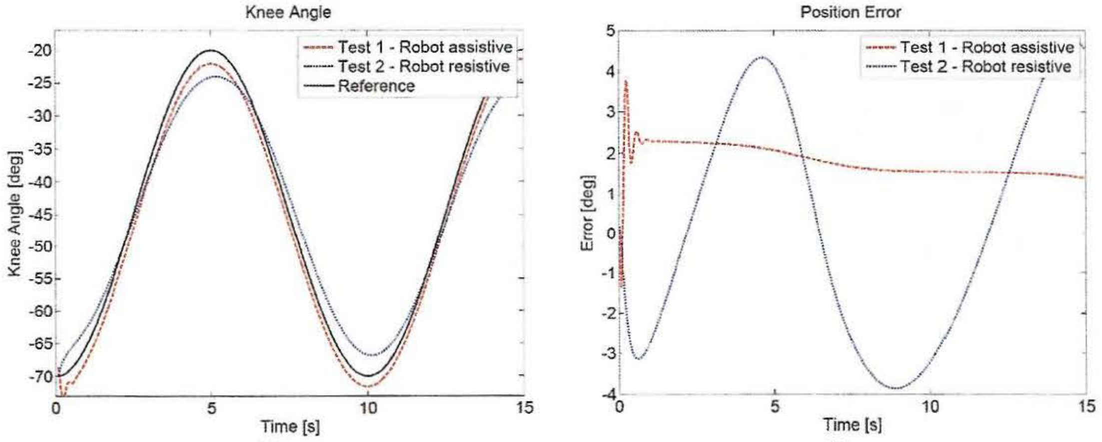
$\theta_{knee} = -70°$ $\theta_{knee} = -20°$

Figure 3. Knee positions according to the range ends of the executed movement.

The simulations were performed on a computer with Intel® Core™ i7-5500 2.40 GHz processor, 8,00 GB of RAM, 2,00 GB dedicated video card, Windows 10 Home Single Language 64 bits. The OpenSim version 3.3 and the MATLAB R2017b were the platforms where the simulations took place.

3. Results and Discussions

In the Test 1, the exoskeleton helps the patient to perform the desired movement, reducing the position error. The trajectory performed by the user in this test is close to the desired on and the tracking error has small values. In the Test 2, the exoskeleton opposes the movement produced by the user, however, in this test the trajectory performed is close to the desired one, indicating that the user was able to overcome the opposition torque imposed by the robot (Fig. 4).

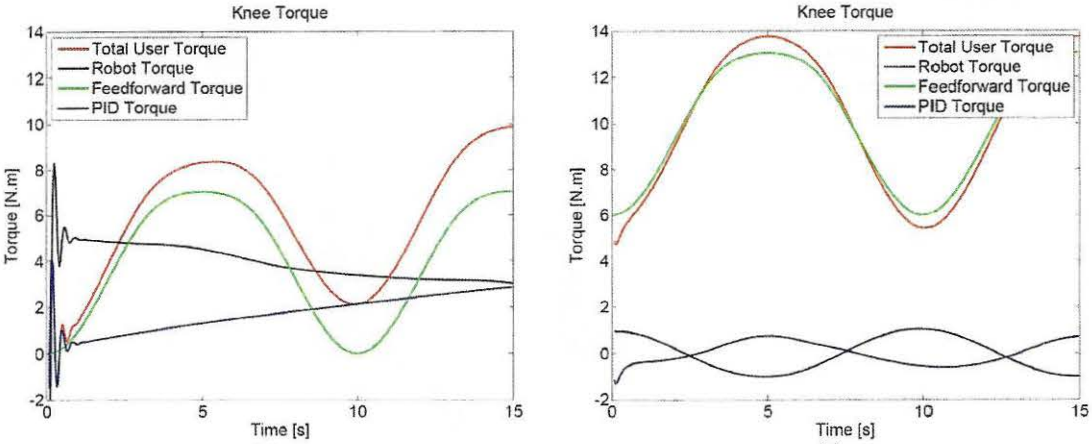


(a) (b)

Figure 4. (a) Trajectory of the knee obtained with the tests ($\hat{\theta}$), compared to the desired one (θ^d). (b) Position errors of each test. For the test 1, the RMS error is 1.85° and for the test 2, the RMS error is 2.91°.

When the robot is in the assistive mode, as the error overrides over time, the amount of assistance provided by the exoskeleton is reduced, remaining mainly the user torque, as occurred in the Test 1 (Fig 5a).

When the robot is in resistive mode, its torque is opposed to that of the user, as shown in Figure 5b. Tracking errors appear which the patient attempts to eliminate, by applying a feedback control torque based on afferent signals (e.g. touch, vision).



(a) (b)

Figure 5. (a) Torque of the Test 1 – exoskeleton in the assistive mode. (b) Torques of the Test 2 – exoskeleton in the resistive mode. The Feedforward The feedforward torque is the torque that the user assumed was necessary to perform the movement. Feedback torque is the torque that the user uses to correct errors caused by disturbances. The total torque developed by the user is the sum of the feedforward torque and the feedback one.

The Test 1 took 24 minutes to be simulated and the Test 2 took 18 minutes. The preparation time of each test was approximately 20 minutes for each. Other tests can be performed, changing the interaction control, the model or the simulation conditions (e.g. number of iterations of the algorithm). Such changes only take a few minutes to make and less than an hour to simulate, which is not possible in laboratory tests with actual exoskeleton and user.

About the interaction control tested, is possible to affirm that it attempts the assist-as-need paradigm and can be used to place the robot in either assistive or resistive mode.

4. Conclusions

Until this time, the proposed model and algorithm proved to be feasible. The next steps are to perform gait movements with the model using ground reaction forces, test other interaction controls in the literature, and model the actuator (which in this case was considered ideal) to approach a real one.

5. Acknowledgments

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