Modelling, optimization, and simulation of a robotic assistive device for walking

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Introduction

Human movement disorders such as stroke can result in severe long-term motor disability affecting daily life. Walking difficulty is a key aspect of motor disorders and the most important deficit patients want to overcome ([1]). Rehabilitation technology has achieved great clinical efficacy for motor impaired patients. However, limited customization, low acceptability, technical complexity, and high cost are unresolved. Thus, further investigation is necessary. In this work, we propose a model-based framework to study the interaction dynamics between the user and a gait assistance robotic device. Model parameters were estimated from motion data of a healthy subject while wearing the device.

Materials and Methods

One healthy male subject of age 22 [yr], height 1.91 [m], and weight 78 [kg] participated in the study with no known neurological or sensorimotor impairment. Five conditions were tested: walking and squatting with and without the device, and flexing and extending the knee while seated with the device. Experimental data included 3D trajectories of reflective markers and ground reaction forces (all sampled at 100 Hz). Marker placement is shown in Figure 1.

Figure 1: *Markers (1-27) used during motion recordings.*

The human body was modelled as a multibody system of 12 rigid bodies connected by 12 joints (23 degrees of freedom (DOF)) and the device model of 2 bodies with 2 joints (7 DOF) was added by connecting it to the thigh. Inverse kinematics (IK), resulting in the model generalized coordinates, was performed in OpenSim [2]. A user-device contact model was developed including a 12-parameter bushing element for each connection to the user's leg: one for the thigh and one for the shank. The bushing element comprise 3 linear and 3 rotational springs, and 3 linear and 3 rotational dampers [3]. The estimation of the 24 parameters was performed by initially simplifying the 12D parameter space of each bushing element to a 1D space. Once a good fit was obtained, a fine parameter tuning was performed in each dimension. In this work, the refinement search was limited to a 20% change (see [4] for further details).

Results

A sample comparison of the angle between the human knee joint and the device joint is shown in Figure 2 for the walking experiment while wearing the device.

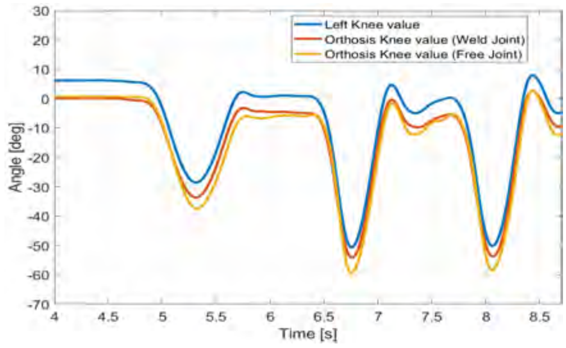

Figure 2: Knee angle over time during walking. Results from two versions of the assisted model are shown.

The best model parameters are reported in Table 1. Both the linear and rotational stiffness and damping are considered uniform across spatial directions.

Table 1: Parameters of the bushing elements in: N/m, N/(m/s), Nm/rad, and Nm/(rad/s)), respectively.

	Translational		Rotational	
	Stiffness	Damping	Stiffness	Damping
Thigh	840	56	840	56
Shank	48	3.2	48	3.2

Discussion

The proposed model-based framework allows for the investigation of the interaction forces between the body and an assistive device. A key feature of the proposed approach is the capacity of making predictive simulations from motion data without wearing the device. For example, potential design flaws could be investigated.

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