On the Effect of Attachment Position and Compliance of Wearable Robots on Human Joint and Interface Forces

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Abstract

A common kinematic structure for wearable lower extremity exoskeletons is kinematically equivalent to the human leg [1]. The unavoidable kinematic incompatibility between the robot and the human limb due to misalignments in the joints axes can cause several problems, such as unwanted reaction forces in the human joints or shear forces and additional pressure at the attachment points.

Several authors proposed dynamics models of exoskeletons attached to the human body. They combine a Multibody model of the wearable robot with a model of the musculoskeletal system, utilizing freely or commercially available software such as OpenSim [2] or AnyBody [3] or use extremely simplified models [4] to simulate the combined dynamics. The question arises, how the physical human machine interface is modeled. Some sources (see [5], [6] and [7]) suggest using kinematical constraints while in [8] a unilateral force element and in [4] a spring-damper is used for the strap-type attachments. In reality the forces are transmitted through soft tissue [1] and several approaches exist to approximate its viscoelastic properties.

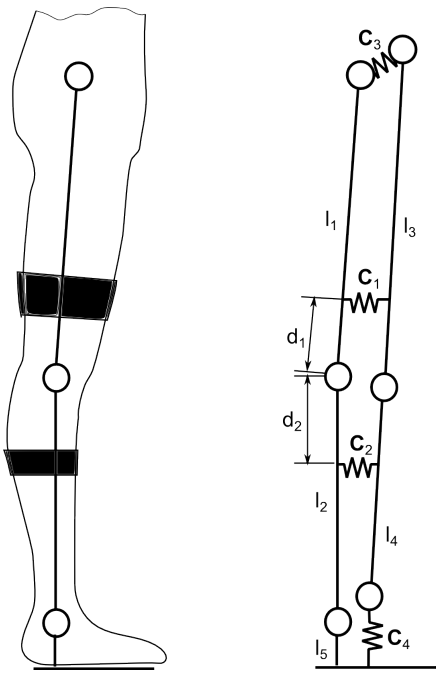

Figure 1: Lower extremity exoskeleton and structure of planar biomechanical model.

For our investigation we use models of different fidelity, the simplest is shown in Figure 1. It is composed of three rigid parts l_1, l_2 and l_5 connected by revolute joints representing the robotic device and two bodies l_3 and l_4 representing the human leg moving in the sagittal plane. The two models are connected by spring-elements at the interface locations. The resultant of the gravitational forces acting on the upper body is applied at the location of the human hip joint.

We investigate the effect of the attachment positions *d* and elastic properties, represented by the matrices **C** in Figure 1, on the quantities that are relevant for safety and comfort of a wearable robot during the execution of the squat task. These are in particular the reaction forces and torque values in the human joints and the forces that occur at the interface between human and device. The initial misalignment is controlled by varying the length of l_3 and l_4 and the attachment point of bushing 4 at l_5. Further dynamic simulations are conducted using more detailed models based on commercial software.

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