Joint Misalignment in Robotic Rehabilitation Exoskeletons, Problem and Possible Solutions

Volker Bartenbach, Dario Wyss, Robert Riener
Sensory-Motor Systems Lab, ETH Zürich, Switzerland

Abstract

Joint misalignment is a potential problem in robotic rehabilitation exoskeletons that can cause undesired disturbing forces. These forces can reduce the usability of such systems by constraining joint movements and by imposing uncomfortable or even harmful forces on the human. Different technical solutions to reduce the effect of misalignment are possible and in this paper we present one mechanical solution to reduce the negative effects of misalignment in lower limb robotic rehabilitation exoskeletons. The problem of misalignment is discussed and a mechanism that integrates dedicated misalignment compensation joints is presented. Finally, to validate the presented mechanism, an experiment was conducted to determine if it is able to reduce undesired misalignment forces.

1 Introduction

Over the last years, robotic exoskeletons have become more common especially in the field of rehabilitation for example of stroke or spinal cord injured patients. They are used for training to regain lost capabilities [1] or as personal assistive devices that restore the walking capability of disabled people [2].

One problem that can occur in these devices is a misalignment between the human joints and the mechanical joints of the robotic exoskeleton. Misalignment can occur for multiple reasons: Either the exoskeleton is not well adjusted to the patient or forces that occur during operation cause shifting along the human limb. Another reason for misalignment can be an insufficient representation of the human kinematics in the mechanical design of the exoskeleton, for example a simple hinge joint does not reproduce the moving joint axis of the human knee joint over its range of motion.

The undesired misalignment of the rotational axis of the human joints and the exoskeleton induces deformation of the compliant parts of the exoskeleton and the human soft tissue, thus creating constraining forces that can disturb and limit the movement and cause discomfort or even injuries and pain. Solutions to reduce the effects of misalignment can be for example avoiding rigid connections between user and exoskeleton if not necessary [3], integrating redundant degrees of freedom in the exoskeleton to allow a certain “self-alignment” of the axis [4] or adding joints that allow for a defined relative movement between exoskeleton structure and the human [5].

In our research we explore the effects of joint misalignment in lower limb exoskeletons and investigate the feasibility and efficacy of mechanical solutions for misalignment compensation.

2 Methods

The goal of the presented work is to test one design of a misalignment compensation mechanism for a lower limb exoskeleton and investigate, if and how undesired constraining forces can be reduced by such a mechanism.

2.1 The experimental VLEXO exoskeleton

For the experiments we used our existing experimental lower limb exoskeleton VLEXO (Versatile Lower Limb Exoskeleton). This system was specifically designed to test and evaluate mechanical and kinematic concepts for future applications in rehabilitation exoskeletons.

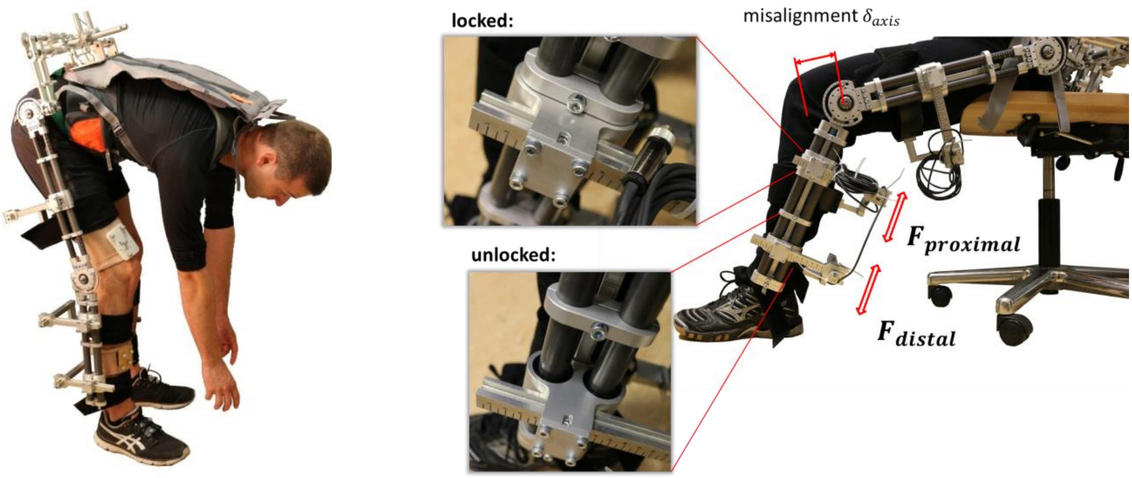

Figure 1: left: the VLEXO experimental platform, right: the experimental setup and a detailed view of the misalignment compensation mechanism in the two shank cuffs. If unlocked, the cuffs can slide with minimum resistance up and down the exoskeleton structure. The force sensors are integrated in the cuff attachment and measure the forces that are parallel to the structure of the exoskeleton ($F_{proximal}$ and F_{distal}) . The misalignment was not specifically adjusted and has to be considered random.

The system is a passive exoskeleton with 4 degrees of freedom (DOF) per leg (3 hip DOF and one knee DOF) and has integrated misalignment compensation joints in each cuff attachment at the legs (2 at the shank and one at the thigh). All the main joints, as well as the misalignment compensation joints, can be locked or unlocked individually to enable the investigation of the effects and potential benefits of an altered kinematic configuration (figure 1).

If unlocked, the misalignment compensation joints allow the cuffs to move up and down the exoskeleton on integrated linear ball bearings. By allowing this movement, the kinematic constraints that results out of a stiff connection between exoskeleton and human limb is resolved and the misalignment force that occurs mostly parallel to the human limb segments should be strongly reduced. A force sensor is integrated in the cuff attachment to measure this force. A linear position sensor is measuring the displacement of the unlocked misalignment compensation joint and angle sensors can measure all the other joint angles.

2.2 Experimental design and protocol

In the experiment, the subjects wearing the exoskeleton were sitting on a chair and conducted isolated knee movements, while the misalignment joints in the shank attachment were set to 3 different configurations. In the baseline condition both misalignment compensation joint were locked. In the condition “Proximal unlocked”, the proximal misalignment joint was unlocked and in the condition “Distal unlocked” only the lower, distal joint was unlocked. The protocol and the conditions are illustrated in figure 2. In each condition the subjects performed 15 repetitions of the knee flexion movement from 0° to 90° while the forces between cuffs and exoskeleton were recorded. The thigh segment of the exoskeleton was tightly fixed to reduce the overall translation of the exoskeleton to a minimum.

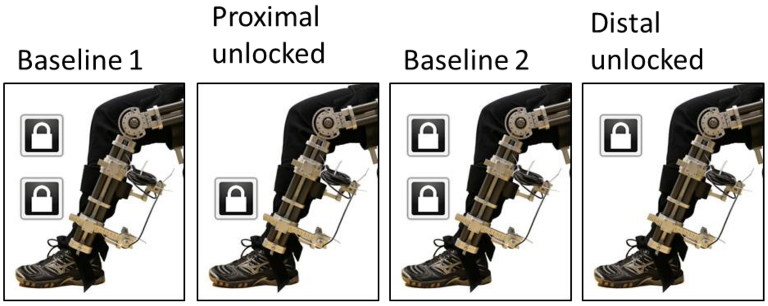

Figure 2: The experimental setup and protocol, the subjects were in a seated position and conducted 15 isolated knee movements from 0° to 90° flexion in each condition. The second baseline measurement was conducted to ensure that the setup was not altered. The forces were measured in the cuff attachment parallel to the shank exoskeleton structure.

3 Results

In total, 3 subjects were measured. The results for the recorded forces from one of the measurements are shown in figure 3. The plotted values show the amplitudes of the misalignment forces for the 15 flexion repetitions.

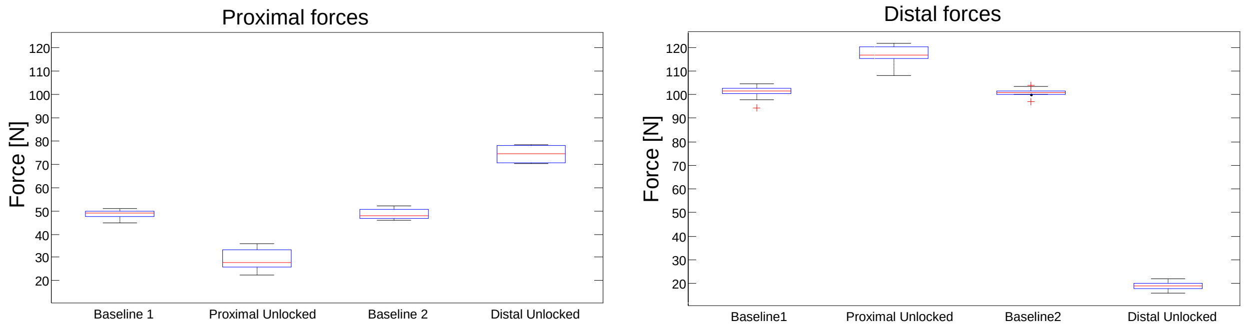

Figure 3: The force amplitudes of one subject measured in the human exoskeleton interface underneath the cuffs. The proximal forces were recorded underneath the proximal cuff, the corresponding distal forces underneath the distal cuff.

The results from all 3 subjects looked similar. They all showed a reduction of the forces in the unlocked cuff attachment as well as a corresponding but lower increase of the force in the other shank attachment that stayed locked. All subjects showed a stronger effect in the distal cuff. In the best cases, the measured forces were reduced to 20-30% by unlocking the misalignment compensation joints. Subjectively, all subjects reported a less constrained feeling while conducting the movement with the distal joint unlocked.

4 Conclusion

The results from the measurements show, that the integrated misalignment compensation joints can be used to reduce the forces in the interface resulting from misalignment. They also indicate that there is a difference in the amplitude of the force reduction depending on the cuff position, and effect that can be caused by the uneven distribution of soft tissue. The increase in the force of the second unlocked joint indicates that the kinematic coupling between the cuffs plays an important role and has to be considered when integrating this misalignment compensation mechanism.

These results indicate some potential benefits by the integration of misalignment compensation joints in rehabilitation exoskeletons. First: they can effectively reduce undesired disturbing forces that can hinder movements of the patient in the exoskeleton and therefore hamper the rehabilitation process. Second: by reducing such forces they can increase the comfort of the system, encouraging and enabling longer training sessions or a more frequent usage of such a system. Third: by reducing the effects of misalignment they have the potential to reduce the setup time to adjust a rehabilitation system to a new patient, thus increasing the time efficiency of the system.

Acknowledgments
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Contact: Volker Bartenbach, volker.bartenbach@hest.ethz.ch, +41 44 632 9918