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Technical note

Measuring human–robot interaction on wearable robots: A distributed approach

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ABSTRACT

This paper presents a novel, distributed approach to monitor physical interaction between a user and a wearable robot. We propose to apply a matrix of optoelectronic sensors embedded in a thin and compliant silicone bulk onto the user-robot contact surface. This distributed tactile sensor can measure the pressure distribution on the interaction area without affecting the comfort of the user, and does not require the robot to be specifically designed to house it. Besides the estimation of the interaction force/torque, the distributed approach allows to monitor the pressure on the user's skin. This information is fundamental to assess the comfort and safety of the users which determine the final acceptability of the robot-mediated rehabilitation. The proposed method is preliminary evaluated on an elbow active orthosis during a repetitive rehabilitation task. Experimental results prove the relevance of this approach for the detection of the user motion intention through a measurement of the interaction force distribution.

1. Introduction

Robot-mediated rehabilitation has been proposed as an effective way to provide extensive treatments for different kind of diseases [1–6]. Unlike conventional therapy with physiotherapist, robotic devices can deliver controlled, repeatable and interacting training at a much higher pace and intensity [7], which seems to be a key-factor for improving the clinical outcome [8]. By guaranteeing highly controllable movements and reliable measures, robots are an ideal research instrument to help neurologists and therapists to target open questions in the field of rehabilitation.

Research in rehabilitation robotics is a work-in-progress field [9]: besides clinical studies, lots of effort is currently spent for the technological development of new devices capable to selectively assist the many degrees of freedom of the human limbs, by means of wearable robots (i.e. powered exoskeletons) [10]. Powered exoskeletons are wearable robots with a one-to-one correspondence to the kinematics of the limb to be assisted, and can control each limb segment independently to the others (torque can be applied and measured independently at each joint [11]). The superior controllability of exoskeletons is a crucial factor for research, where the major goal is a thorough understanding of the recovery process, and a highly quantitative comparison of different rehabilitation strategies is needed. In addition, the independent control of user's joints may reduce compensatory movement patterns and possibly promote true recovery [12].

Exoskeletons interact with the user's limb by means of multiple connection points [11,13–15]. Usually, each limb segment is connected to the wearable robot using a wide physical interface such as a cuff or an orthosis to smoothly transmit the loads to the user [16–20]. The human–robot physical interface should be designed to provide a safe and comfortable interaction, while transmitting the torque/force to each joint/limb segment. A critical aspect of its design relates to sensorization, which should provide a measure of the interaction forces, which can be used to assess the performance of the patient in executing the task (e.g. the level of effort spent in completing the therapy). This information can then be exploited to adapt the level of assistance given by the robot, promoting the patient's active participation, in order to enhance the effectiveness of the therapy (the so-called "assist as needed" rehabilitation strategy [6,21]).

In this work we propose distributed direct measurements of the contact force on the whole human–robot interaction area, as a novel strategy to monitor the physical human–robot interaction (pHRI) on wearable robots.

A comprehensive measurement of pHRI is very difficult to obtain by means of traditional single-point force/torque sensors (e.g. load-cells). This is caused by the continuous and distributed nature of the human–robot interaction, which is a fundamental feature for wearable robots. A common way to measure interaction force/torque is to apply a sensor of this kind between the cuff and the exoskeleton link. While expensive, this solution is practical and can give accurate measurements. Nevertheless, it requires the distributed contact forces at the interface to be transferred to the robot through

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