High-Force Low-Impedance Actuation for Therapeutic Robotics

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Applying robots to provide sensory-motor therapy is a flagship example of *contact robotics* and provides an instructive perspective on the engineering challenges unique to this emerging area. The ultimate goal is to promote, enhance and accelerate recovery after any injury that affects motor behavior, such as stroke (Volpe et al., 2009) or cerebral palsy (Krebs et al., 2009). The process of recovery resembles motor learning (Hogan et al., 2006) and providing a high "dosage" of movement experience (many repetitions) is one way robotic tools may augment conventional therapy. However, repetition alone is not enough: voluntary participation is essential (Volpe et al., 2004) and to ensure it, the machine must assist only as needed. Even more important, the machine must not suppress any productive movements a patient can make. It must "get out of the way" of appropriate movements while gently resisting inappropriate movements; guidance is more important than assistance (Krebs et al., 2003).

Providing *permissive guidance*—encouraging "good" movements while discouraging "bad" movements—presents conflicting design requirements. The robots are required to exchange significant forces (and/or power) with a human, often up to large fractions of body weight. At the same time, they must also be backdrivable or feel "gentle", i.e. present a low and variable mechanical endpoint impedance. Meeting these conflicting requirements is a formidable engineering challenge that is limited by existing actuator and control technologies.

I propose briefly to survey our experience with the engineering of therapeutic robotics; provide an overview of the tools available to address the performance and stability of high-force low-impedance actuators; discuss the utility of available actuator and interaction control technologies; and present a novel actuator architecture (with preliminary experimental validation) that may provide a superior solution for therapeutic robotics.

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