Introduction

Concurrent advances in robotics, haptics, biology and medicine are poised to enable a revolution in healthcare, in which people interact directly with robotic technology to improve their quality of life. In this proposal we describe two examples of this confluence of technology with applications in human motion analysis and training and in human-interactive robotics for home healthcare. Both projects are the subjects of new multi-disciplinary collaborations at Stanford to address growing societal needs.

Robotic Analysis Applied to Human Movement

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Robots have proven to be an effective rehabilitation tool for persons with sensori-motor deficits, however the concept of adapting robotic sensing, control and display technology to wearable devices for improving or restoring human performance has received less attention. Fig. 1 illustrates an approach in which motion tracking, dynamic modeling and control, and display are applied to motion training.

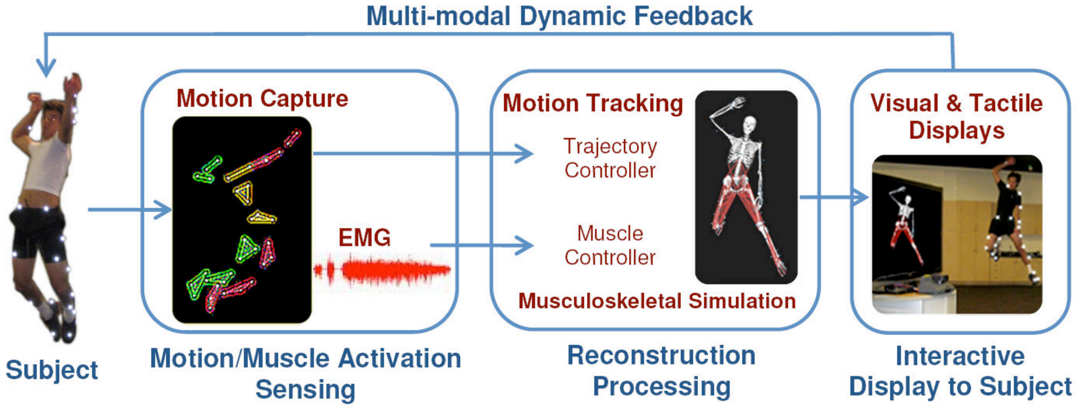

Figure 1 - Interactive Multi-Modal Feedback Mechanism

Advances in biomechanics, dynamic reconstruction algorithms and wearable devices will soon make it possible to provide real-time feedback of biomechanical information to patients undergoing rehabilitation. The sequence in Fig. 1 begins with dynamic reconstruction of human motion. Building upon algorithms and models developed in the context of humanoid robotics (Khatib et al., 2004) we have developed and implemented a novel muscle effort criterion for predicting physiologically accurate upper limb motion (Khatib et al., 2004, De Sapio et al., 2006). More recently, we proposed and implemented a new algorithm to reconstruct human motion from motion capture data through direct control of captured marker trajectories (Khatib et al., 2008). The approach projects marker points onto a simulated human model and tracks the trajectory in marker space without costly inverse kinematics computations (Demircan et al., 2008).

The next stage in Fig. 1 is dynamic simulation of muscle activity. Simulations of movement allow one to study neuromuscular coordination, analyze athletic performance, and estimate internal loading of the musculoskeletal system. Simulations can also be used to identify the sources of pathological movement and establish a scientific basis for treatment planning (Delp et al., 2007).

The third stage in Fig. 1 involves interactive display of results to the subject. Wearable haptic feedback has been proposed as a way to augment or even replace visual or audio feedback for motion training. Vibration is the most common feedback mechanism, but is imprecise at providing a sense of the magnitudes or velocities of motions. Nonetheless, vibration has shown promise in improving balance and grasp force control in patients recovering from stroke and other pathologies that affect the neuromuscular system . Wearable vibration devices are also being tested as a means to help patients with dystonia to isolate the effects of particular muscle activations.

For applications involving motion training and rehabilitation, skin stretch is a useful complement to the cues provided by vibration. Skin stretch is a component of the human proprioceptive apparatus (Collins et al., 2005) and artificially stimulated skin stretch near the joints can provide subjects with useful information about joint movement and velocity (Bark et al., 2008). As with vibration, the inherently low power requirements of skin stretch lend themselves to the design of compact wearable displays.

In addition to providing subjects with information about the motion of their limbs (which can also be conveyed visually) we expect that conveying real-time information about muscle force will be more intuitive using tactile displays. The ability to convey multimodal information is also important. For example, for neurological rehabilitation after surgery or stroke, we expect that providing proportional proprioceptive feedback will be most useful as subjects relearn movements. In athletic applications, where movements are often fast and highly stereotyped, we expect that providing discrete event cues may be more useful (e.g. alerting the subject that a particular muscle group has been activated too early or late in a golf swing or if the force in a muscle becomes high such that injury is likely).

Bio-Inspired Human-Safe Robotics

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The growing proportion of elderly individuals in industrialized societies will soon constitute a crisis unless cost-effective ways can be found to help them maintain dignity and quality of life, as they become increasingly dependent on daily assistance and healthcare services. Robotic technology has the capacity to augment, and in some cases replace, the services that people provide.

To realize this goal, robotic platforms will be required to navigate the unpredictable and dynamic environment found in homes with greatly improved sensing, planning and reactivity compared to today's robots. Inadvertent collisions, although mitigated with sensing technology and intelligence, are inevitable. Consequently, there is a need for inherently safe designs that have sufficient power and precision to carry heavy loads while also exhibiting low inertia and soft exterior surfaces. Several research groups have investigated new actuation techniques to overcome the limitations of existing approaches. (e..g. Zinn, 2004). We have developed the distributed macro–mini (D2M) actuation approach to address the problem of a large reflected inertia by partitioning torque generation into low- and high-frequency domains, which are controlled by distributed pairs of McKibben (macro) and electromagnetic (mini) actuators. With this combination we were able to achieve a 10-fold reduction in effective inertia while maintaining high-frequency torque capability.

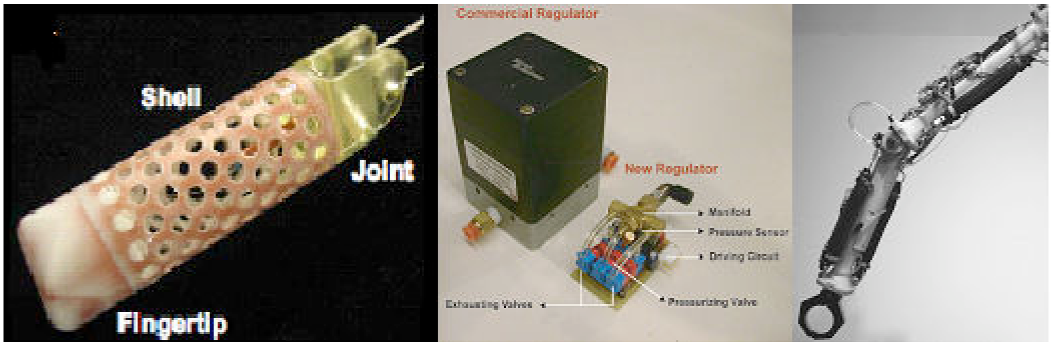

Fig. 2. (left) exoskeltal structure with embedded sensors, (center) integrated valve unit, (right) prototype S2r arm.

Further integration calls for use of Shape Deposition Manufacturing (SDM) techniques. SDM allows multiple materials, as well as sensors, actuators and other discrete parts, to be integrated in a single heterogeneous structure (Fig. 2). The ability of SDM to provide local variations in materials properties also permits structures with high specific strength and stiffness in selected areas while providing high impact energy absorption in other areas.

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