Modeling and Analysis of Human Motor Control and Learning

Max Berniker & Steve G. Massaquoi

Artificial Intelligence Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

http://www.ai.mit.edu

The Problem: How does human neural circuitry control posture and voluntary movements? Humans are equipped with an amazing repertoire of motor skills. Despite being outfitted with what by many engineering criterion are noisy signals, slow computation times, devastating transmission delays and marginal actuators, the human system exhibits motor control and, more impressively, motor learning that far surpass our best engineering efforts. We seek a better understanding of how this is accomplished.

Motivation: With a clear understanding of human motor control circuitry the benefits afforded will be widespread. For instance, insight into human motor disorders and their possible treatment, as well as a basis for development of advanced neurological diagnostic techniques should become available. Similarly, this knowledge will provide a framework for implementing biomimetic control systems. In addition, control systems might be had that compliment the aptitudes of natural human motor control and learning with the resources of modern control theory.

Previous Work: Much of the work done can be grouped into "top-down" and "bottom-up" approaches. Top-down approaches have focused on macro-scale events such as limb dynamics and kinematics during movement and the possible control architectures that would suffice. The bottom-up approaches focus on micro-scale events such as neural firing patterns during movements and their possible correlations. While great gains have been made through both approaches, they are often both limited in their ability to illuminate a consistent and system-wide theory for motor control. The top-down view can be sufficiently abstracted from the real physical system as to hinder quantitative verifications, and the bottom-up view can have difficulty in extrapolating from such fine-scale details. Many have begun work to bridge the gap between these bodies of knowledge [1, 2] but we await a unifying cogent theory of human motor control.

Approach: Utilizing what has been found from the top-down and bottom-up examaniations, we seek to examine self-consistent models for human motor control. Neuroanatomy, biomechanics, engineering control theory, and neural networks, are all key in the development of a credible model. Not only should the models be capable of exhibiting the fidelity of motor control observed, they must also be consistent with known neurocircuitry. Therefore, not only should the models exhibit the motor behavior of normally functioning persons, they should also be capable of exhibiting the motor pathologies of persons with deficits when similar "injuries" are enforced on the model. When the models have progressed sufficiently they shall be physically embodied for further analysis with the anthropomorphic robots of the AI Leg Lab. Not only will this provide a realistic test-bed, it will offer a proving ground for biomimetic control.

Difficulty: Human motor control and motor learning is far more advanced than the current modern control techniques employed to control robotic manipulators and robots in general. This being the case, only aspects of human motor control shall be examined. Specifically, interaction tasks with inertial loads, balance and walking shall all be explored.

Impact: When the questions are properly posed, the models obtained through this research shall be able to offer support for or against relevant theories of human motor control. The consequences for biomimetic control and a clearer understanding of the functionality of the human motor system are far reaching.

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References:

[1] Steve Massaquoi and J.J. Slotine. The intermediate cerebellum may function as a wave-variable processor.

Neuroscience Letters, pages 60–64, 1966.

[2] Emanuel Todorov. Direct cortical control of muscle activation in voluntary arm movements: a model. *Nature Neuroscience*, (4):391–398, April 2000.