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701 E. Chocolate Avenue, Suite 200, Hershey PA 17033-1240, USA
Tel: 717/533-8845; Fax 717/533-8661; URL-http://www.idea-group.com

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Chapter X

Evolutionary Methods for Analysis of Human Movement

Rahman Davoodi, University of Southern California, USA

Gerald E. Loeb, University of Southern California, USA

ABSTRACT

A movement rehabilitation therapist must first diagnose the cause of disability and then prescribe therapies that specifically target the dysfunctional unit of the movement system. Objective diagnosis and prescription are difficult, however, because human movement is the result of complicated interactions among complex and highly nonlinear elements. Treatment based on limited observations may target the wrong element of the movement system. Researchers in central nervous system (CNS) control of human movement and functional electrical stimulation (FES) restoration of movement to paralyzed limbs face similar challenges in objective analysis of the integrated movement system. In this chapter, we will present evolutionary methods as powerful new tools for analysis and rehabilitation of human movement. These methods have been modeled after the same biological processes that have been optimized for the control of human movement in the process of biological evolution. Therefore, it is logical to think that these methods, if applied properly, could help us understand the control of human movement and repair it when it is disabled. A case study demonstrates the potential of evolutionary methods in movement analysis and rehabilitation.

BACKGROUND

As long as the movement system in humans functions properly, its operation seems simple and effortless. After diseases or injuries impair human movement, however, we realize how difficult it is to rehabilitate or restore function. We often find it difficult even to understand the exact cause of the impairment. The difficulty arises from the fact that human movement is produced by complex interactions among complex elements such as muscles, skeletal linkage, sensors, and the many CNS circuits. Our limited understanding of these movement components and the interactions among them makes it difficult to properly diagnose and treat movement disabilities. Often clinicians have to make therapy decisions based on limited observations and examinations. Such decisions are usually subjective and may target the wrong parts of the movement system. Improvements in diagnosis and treatment therefore require more sophisticated tools for measurement and analysis. The need will only increase with the growing sophistication and complexity of the rehabilitative interventions. Consider, for example, the use of robots in movement rehabilitation (Jezernik, Colombo, Keller, Frueh, & Morari, 2003). Because the robot cannot exercise clinical judgment during the course of the interaction with the patient, the prescribing clinician must specify the details of the treatment and contingencies for unexpected outcomes. In FES control of movement, paralyzed muscles are contracted by applying electrical currents. Over the years, sophisticated hardware has been developed to interface safely with the biological tissue and stimulate individual muscles (Loeb, Peck, Moore, & Hood, 2001; Smith et al., 1998), but still missing is an equally sophisticated control system to coordinate the activation of the muscles. Development of such control systems is hampered by our limited understanding of the musculoskeletal systems and the way they interact with and adapt to each other.

Various methods have been used in the past to analyze and repair human motor behavior. Neurophysiologists have used electrophysiological recordings to study the role of elements such as the muscles, sensors, and the CNS circuits. But these measurements alone cannot elucidate the interactions between these elements and the mechanical system that actually creates the movements. Rehabilitation of movement deals with the movement in its entirety and, therefore, requires the analysis of these interactions. Clinical motion analysis focuses on the movements themselves and their underlying kinetics. Movement patterns of the patient can be compared with the norm to identify abnormalities and monitor the effect of rehabilitative interventions over time. More sophisticated inferential analyses (such as the estimation of individual muscle forces) may be used to identify the cause of a movement deficit. Motion analysis, however, is limited to analyzing existing movement in healthy and moderately disabled subjects. It provides little guidance when movement is entirely lost or severely limited. For example, an FES engineer is interested in novel movement patterns that are customized to the weaker muscles of the paralyzed patient and the proper strategy for the control of muscles to realize them. A therapist might be interested in novel movement trajectories that are customized to the capabilities of a disabled patient. Such customized trajectories then may be used to provide feedback to patients in physical therapy sessions (Colborne, Olney, & Griffin, 1993; Wu, 1997). But the answers to these questions are not unique because the musculoskeletal system is highly redundant and there are many ways to accomplish a movement task. The task of the therapist, therefore, is to find the best