

Book Review

Control of Movement for the Physically Disabled

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Springer-Verlag 2000.

ISBN 1-85233-279-4

It is an unfortunate paradox that the advances in medical therapy and care and the increased life expectancy results in an expanding population of physically disabled persons. Many physically disabled suffer from neuronal damage (e.g., stroke or spinal cord injury) that prohibits or disturbs the control of movements; others are amputees that lack a limb or part of a limb. The challenge to assist these patients with artificial motor control and artificial limbs is enormous; it requires a multidisciplinary expertise in medicine and engineering.

From a control engineer perspective, the biological motor control system is amazing. Even the very basic ability to produce a stable walking pattern in rough unknown terrain, which is naturally generated by the biological motor control system, is an extremely difficult engineering endeavor, as any student who tried to stabilize an inverted pendulum can testify (see, e.g., Raibert & Sutherland 1983 for an inspiring attempt to imitate biological locomotion in robots).

The authors, Popovic and Sinkjaer, are both trained as engineers and are well known for their research in this field. In this book they cover an extremely large portion of the state of the art technology and theories in the field of motor control for the physically disabled.

Other books contain more quantitative and qualitative examples about motor control (e.g., McMahon 1984, Rosenbaum 1991, and Latash 1993). However, these books do not thoroughly address the issues of rehabilitation technology.

My main criticism is aesthetic; this book uses a “wide survey” style, which includes rapid transitions from one model to another and from one result to the other. This style occasionally prevents full appreciation of each model and result. In addition there are a number of poor quality figures and several cumbersome sentences especially in the very first chapter. As a result, the book is rather difficult to read in certain sections.

In spite of these shortcomings, the book provides a comprehensive reference source, and it is certainly the definitive reference book in this field. I strongly recommend it for the biomedical engineering shelves of any medical and engineering library and for the researchers and students of this field.

In the rest of this review, I will briefly describe the field and the content of the book; and then compare it to other books, and comment about its potential use as a teaching text.

Motor Control and the Physically Disabled

In a very simplified manner one can describe the human motor control system as an interaction of three systems: Nervous, Muscular, and Skeletal. The nervous system integrates sensory information about the environment and about the state of the muscular and skeletal systems; it issues motor commands to the muscles that generate torques upon the skeletal system, which interact with gravity and external forces. A major difference between the biological and the artificial motor control system is the vast redundancy of the biological system (Bernstein 1967). For example, in a writing task, in order to generate a two dimensional movement of the “tip of the pen”, the nervous system has to generate a motor command that eventually specifies 26 angles of joints in the arm and fingers (7 degrees of freedom in the arm and 19 in the fingers); moreover, around each joint, there are typically multiple muscles, and each muscle is activated by many neurons. This redundancy suggests that there are many possible ways to perform any given task; it is occasionally referred to as the Bernstein problem. Another problem is the slow conduction of information by the nervous system, which introduces significant delays. These delays jeopardize simple feedback control strategies. Moreover the properties of the muscles and the nervous system are highly non-linear, their functions occasionally contains hysteresis and thresholds and the mechanical properties of the muscles such as

the instantaneous stiffness and viscosity, depend on the force, position and contraction velocity (Hill 1938). In addition, the system is time varying and has to cope with a noisy changeable and occasionally unknown environment. All together the biological system has to learn to control a time-varying non-linear many-to-one System (see Karniel and Inbar 2000 for a recent review). Beyond the basic problem of modeling the system, the combination of biological and artificial systems introduces many technological challenges.

In industrialized countries, stroke is the leading cause for disability in adults. A stroke occurs when the blood supply to part of the brain is stopped or when a blood vessel in the brain bursts. Spinal cord injuries or diseases are also frequent cause of disability, they typically occur in accidents where the spinal cord is simply cut (completely or partially) and the motor command is deprived from the muscles resulting in paralysis. Amputation of a limb or part of a limb as a result of an accident or disease is another cause for physical disability. Rehabilitation technology includes application of robotics devices and external control of muscles. Artificial limbs can assist the amputee in recovering part of the functionality of the lost limb both in terms of appearance and in terms of motor control. Actually, as suggested by the science fiction literature, artificial limbs could potentially allow even better performance than the original limbs. However, unfortunately with the current state of technology most amputees prefer a simple hook to sophisticated robotics artificial limbs and most paralyzed patients do not regularly take advantage of the existing products for external control of muscles. This situation emphasizes the need for further research and development of motor control rehabilitation technology.

Content of the book

This book contains five chapters; the first two describe the human motor control system, the third describes the various pathologies and the last two discuss different approaches for rehabilitation. It is impractical to fully cover the content of this book in a short review, especially since the authors comprehensively address many aspects of the field. Indeed, the references section contains more than a thousand sources. I will briefly

describe the main issues and raise some key concerns.

Chapter 1 describes the organs and tissues of the biological motor control system. Of special interest is the last part that describes the skeleto-muscular structure of the limbs. This description and the figures demonstrate the complexity of this system that includes many muscles around each joint and biarticular muscles (muscles crossing two joints).

Chapter 2 addresses mechanisms for neural control of movement. It concentrates on cyclic and goal directed movements, and although the authors start with an apologetic comment about the limitation of their description, they do provide a comprehensive survey of the research and theories that typify this field, starting with the inverted pendulum model for posture, through models of walking, to various theories and modeling approaches of reaching and grasping. The Chapter gives the reader a good idea about the available research, but it would be very difficult for the novice reader to fully comprehend these theories since many terms are first introduced without a definition (e.g., “endpoint control hypothesis”, “inverse model”) and the reader is frequently referred to the literature.

Chapter 3 presents the pathologies, i.e. the possible diseases, injuries, and malfunctions of the sensory-motor system and it describes the measurements that are used by physicians to assess and quantify the disability. These assessment methods include infrared camera, image processing and other technologies to track the kinematics and dynamics of the movement.

Chapter 4 is the heart of the book. It addresses the key problems faced in the field of rehabilitation and presents the state of the art technologies utilized in restoration of movement. One simple but ingenious idea is to transfer the force of a functional muscle in order to create movement in a nonfunctional joint. This could be done surgically by means of “tendon transfer” or externally by means of a harness and cable system, which is referred to as “body powered prosthesis”.

A large portion of this fourth chapter is dedicated to Neuroprosthesis and to artificial limbs. (Neuroprosthesis refers to any system that replaces the function that was lost due

to nervous system damage). The principal method presented is functional electrical stimulation (FES). The authors describe new technologies for the electrodes and the sensors (e.g., accelerometers, force sensors).

The section on artificial limbs presents a variety of cosmetic and robotics devices for amputees. Some of the figures captions contain the world wide web (WWW) address of the manufacturer, which is very useful for further information, especially for nice pictures and video clips of prosthesis in operation. This citation technique is indeed useful but it is inherently risky since the WWW isn't rigid and users tend to change their sites frequently. When I tried some of these sites, one was not available and another seemed to be wrong. One issue of interest is the importance of the mechanical properties of artificial legs that contain strong elastic elements to provide shock absorption and storing of energy. These features are naturally available in the tendon and muscles as well demonstrated in the kangaroo's hop that store energy in the landing for the next hop (see Raibert & Sutherland 1983). This example provides a good message for engineers to understand the impact of the plant mechanical properties and not to concentrate merely on the controller. (See also the studies of Full and colleagues that provide more examples for the important role of the muscles - Dickinson, Farley, Full, Koehl, Kram & Lehman 2000).

Chapter 5 specifically addresses issues of control system theory. In this chapter the biological motor control system is modeled in terms of desired trajectory, controller, plant, sensors and feedback loop. The plant dynamics are presented in forms of mechanical model, differential equations and frequency transforms. The system identification problem is presented and various control strategies are described. The main application in mind is FES, which involves external control of muscles. Many new concepts are introduced without detailed explanation (e.g., Fuzzy logic, Feedback error learning) and therefore a student will probably find it very difficult to follow all these possibilities. On the other hand, since at this point it is hard to predict which method would prevail, there is an advantage in unfolding a wide view of all the possibilities.

Related Books

I am not aware of any other book that comprehensively addresses the issues of motor control for rehabilitation, however a few books are available about the theory of motor control. A couple of relevant books are Wilson (1998) that is dedicated to the hand, and Latash & Turvey (1996) which contains a translation of a text by Bernstein that was written 50 years ago but is still highly relevant. Three good textbooks on motor control are McMahon (1984), Rosenbaum (1991), and Latash (1993). McMahon (1984) provides a good background on muscle properties and modeling with examples and exercises; it concentrates on issues of locomotion. Rosenbaum (1991) presents a comprehensive introduction to the field of motor control, and Latash (1993) describes the field from the point of view of the equilibrium point hypothesis, which is an important (and highly controversial) theory in the field of motor control. Other useful sources are the edited books of Winters and colleagues (Winters & Woo 1990 and Winters & Crago 2000), and some chapters in the neuroscience literature in Arbib (1995) and in Kandel Schwartz & Jessell (2000). One can also find books on specific treatments or rehabilitation techniques; for example, Graupe and Kohn (1994) describe a specific project for FES. Compared to these and other books, the advantage of the book reviewed here is in its up-to-date wide and comprehensive address of the theories and technologies available for rehabilitation of the physically disabled.

Potential use as a teaching textbook

This book covers most of the knowledge available in this field and therefore, it could definitely be used as the main reference for a class about control of movement for the physically disabled. However, in order to fully understand the content of this book - the reader will need to know the basics of system theory (e.g., Feedback control, inverse model, continuous and discrete transforms), robotics (e.g., dynamics equations) and many other engineering concepts that are mentioned briefly (e.g., Artificial neural networks, fuzzy logic). In addition the reader will need to know basic medical terminology of anatomy (e.g., Biceps Brachii m., lateral, dorsal, coronal view, transverse section). Although a student of biomedical engineering may have this background, to facilitate

wider use of this book for a broader audience I would recommend to add an appendix about system theory and a glossary of medical terminology. I would also suggest adding examples and exercises, solved and unsolved. The few examples in Chapter 5 are based on research studies and are too complex. They do demonstrate the complexity and the tools involved in building a model for the motor control system, but the student would find it extremely difficult to reproduce these results as an exercise. A simplified version of these projects could be introduced as exercises in order to provide the student with the feeling of the modeling work.

I hope that some of these suggestions would be incorporated in future editions of this book. Meanwhile, I would rather use it as a comprehensive reference material than as a course main teaching text.

Final Remark

This book provides a broad view of the basics and of the state of the art research and technology in this field from well-recognized authority.

In the foreword to this book the authors mentioned that the future of the field requires experts who are able to integrate novel advances in technology and neuroscience into innovative ideas and solutions. They express the wish that the book will provoke the reader to be one of the individuals who will make the difference in the future progress of this field, a laudable cause that this referee fully supports. Besides this truly noble cause of helping the physically disabled there is another bonus that awaits any engineer studying biological motor control: The promising well of possible new ideas that lie in the gap between the human intelligent motor control, and our current artificial control.

Acknowledgments

The author is grateful to Zev Rymer, Sandro Mussa-Ivaldi, and Karen Fleming for their helpful comments on the manuscript.

The author was supported by NIH grant 5 P50 MH48185

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