72-157

BRICKNER, Thomas Samuel, 1940-
CORTICAL AND CEREBELLAR CONTROL OF MOTOR FUNCTIONS, AN OPTIMAL ADAPTIVE LEARNING CONTROL SYSTEM.

The University of Nebraska, Ph.D., 1971
Engineering, biomedical

University Microfilms, A XEROX Company, Ann Arbor, Michigan

CORTICAL AND CEREBELLAR CONTROL OF MOTOR FUNCTIONS, AN OPTIMAL ADAPTIVE LEARNING CONTROL SYSTEM

by

Thomas S. Brickner

A DISSERTATION

Presented to the Faculty of

The Graduate College in the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Department of Electrical Engineering

Under the Supervision of Professor William L. Brogan

Lincoln, Nebraska

July, 1971

TITLE

CORTICAL AND CEREBELLAR CONTROL OF MOTOR FUNCTIONS, AN

OPTIMAL ADAPTIVE LEARNING CONTROL SYSTEM

BY

Thomas S. Brickner

APPROVED	DATE
Luh Tao	July 9, 1971
Allen Edison	July 9, 1971
Edwin Lowenberg	July 9, 1971
William Brogan	July 9, 1971

SUPERVISORY COMMITTEE

GRADUATE COLLEGE **UNIVERSITY OF NEBRASKA**

GRAD 52002 300 5-66(T)

PLEASE NOTE:

Some Pages have indistinct print. Filmed as received.

UNIVERSITY MICROFILMS

Dedicated to Katie, Jeannette
and little Anna, three very
special girls in my life.

ACKNOWLEDGEMENT

I would like to thank Dr. Russel Meints, Dr. Gerald Tharp and Chuck Olander for the aid rendered in the area of Physiology. Special thanks to Dr. William L. Brogan for the unselfish sharing of his time, which was considerable. Appreciation is given to Dr. John Davis for his encouragement at a very crucial point in my program. Thanks to Dr. Allen Edison, Dr. Edwin Lowenberg, and Dr. Luh Tao for the help provided and encouragement offered. Last but not least, I would like to show my appreciation to Marge Alles for typing this dissertation and to B. J. Holden for help offered in the home stretch.

TABLE OF CONTENTS

Page

CORTICAL AND CEREBELLAR CONTROL OF MOTOR FUNCTIONS,

AN OPTIMAL ADAPTIVE LEARNING CONTROL SYSTEM

Thomas S. Brickner, Ph.D.

University of Nebraska, 1971

Adviser: William L. Brogan

The human organism contains many advanced control systems. The autonomic control system regulates unconscious body functions such as breathing, pulse-rate and temperature. Other bio-control systems regulate conscious functions such as thought and motion. The cortical and cerebellar control of motor functions, an example of the latter category, is discussed here.

Analogies between muscular control and error nulling servo-mechanisms have often been made. A broader view is presented here because three distinct types of error can be conceived. An error can exist in the knowledge of the system input-output dynamics. This presents a problem of real time system identification. Another error can exist in the input used to realize a desired sequence of motions. This is analogous to the optimal regulator or optimal tracking problem. The final error can arise during the translation of a general act into the sequence of motions required to perform that act. The latter error is reduced by stepwise adjustments between repeated trials. The adjustments depend upon comparison of the goals with the performance as perceived via the sensory system.

Interactions of various areas of the brain, the muscle units, nerve tracts and proprioceptors are discussed in relation to this bio-control system. Physiological observations are cited to justify the proposed model. Obvious implications also exist for the design of high level electromechanical control systems.

CHAPTER 1

PREVIEW OF THE DISSERTATION

Investigation of biological systems starts by looking at some functions of interest. Examples of these functions could be the (1) response of the Erythropoietic (blood production) system, (2) dynamics of the Krek's Cycle, (3) regulation of a hormone system. In each example there are functional blocks that have been analyzed by extensive experimentation. The experiments performed have indicated the dynamics of the functional blocks. In addition to the functional relationships of the individual units the total response of the system is determined by the interaction of these blocks upon each other.

In the area of life science the large majority of the investigations consist of elaborate experiments designed to expose the dynamics of the individual blocks. In many cases the total response of the system will still be left unspecified since the exact interaction of the functional parts are not specified. In physiology and biochemistry studies systems are presented with vague lines or shadowed arrows from one block to another, indicating that the system's response is some composite interaction of all the functional groups acting together.

To more fully understand biological systems it is mandatory that the units of interest be tied together. This requires specifying or hypothesizing the interaction among the functional groups. The process of doing this very essential work necessitates the understanding of the biological system one is trying to model. Additionally, a certain ability in the area of system theory is beneficial. This type of work is being done and a better understanding of biological systems is

becoming available in many areas. The book by Guyton, Textbook of Medical Physiology, uses many of the notions of control system theory in the presentation of various biological systems. A much better understanding of the systems is achieved using system theory as compared with the ad hoc methods for suggesting interactions.

In this work a system representation for the control of voluntary motor functions is proposed. The model is presented conceptually in Chapter 2 and analyzed in the following chapters. The system to be analyzed is a specific biological system but the concept of representing these functions in a systematic mathematical fashion can be applied to other biological systems. A valid modeling of the biological system provides an important mechanism for obtaining a better understanding of the specific system under investigation. Experiments can then be performed on the mathematical model, saving untold hours of laboratory experimentations. The mathematical model can be used as a guide line to suggest experiments that should be performed and control points for altering the biological response.

In this dissertation the system for the control of voluntary motor functions is considered. The model developed for this system contains three functional loops. The first of these loops is a system identification loop. The presentation of this material will be covered in Chapter 3. The identification loop adjusts the parameters of a model system to the values of the physical system that is to be identified. The procedure used is Margolis Sensitivity Approach which is a gradient adjustment scheme.

The second loop is an optimal tracking loop. The analysis of this

loop is presented in Chapter 4. The use of Dynamic Programming is utilized to obtain the optimal tracking of a commanded or desired sequence of muscular movements. The reverse integration required to calculate the control law is very appropriate in representing the function of the control procedure as suggested by physiologists.

The third loop of the model provides a mechanism for explaining the trial and error process of striving to obtain maximum satisfaction of an overall system goal. This goal satisfaction loop is developed and discussed in Chapter 5. The satisfaction of most goals probably requires finding the proper trade-off between conflicting requirements. Constraints exist which limit performance to some feasible set of outputs. The third loop represents one possible way of systematically striving to maximize a goal satisfaction criterion while satisfying all constraint equations. Since there is no known analytical relationship between system outputs and goal satisfaction, such a relationship is hypothesized. The precise determination of this relationship in the human control system is left for future investigation by psychologists.

The purposes of this dissertation are (1) to develop a proposed model which is consistent with previous physiological experiments and currently accepted concepts regarding interactions of the basic units, (2) to analyze and perform simulation studies using this model, (3) to provide a more quantitative means of explaining some aspects of system operation in terms of the simulation results, (4) to demonstrate that optimal control techniques can provide a plausible explanation of the biological system and a useful approach to the design of man-made adaptive learning control systems.

The control model is not necessarily intended to suggest additional understanding of the physiological control system but is intended to model as closely as possible the actual control. The control model does contain parameters that can be adjusted to make the learning model (loop I) learn faster or slower. The optimal tracking loop, which also improves with repeated learning trials, contains parameters that can be adjusted to make the system track more or less precisely and obtain a certain level of accuracy in a variable length of time. In the outermost loop the constraints applied to the state variables can be adjusted for different maximum obtainable goals.

In all three loops the different combinations of parameters can represent individual differences in the functioning of the control system. Even though the individuals have different levels of performance, by virtue of parameter differences in their models, the same procedures of mathematical techniques still apply.

The last reason for pursuing this study is that the knowledge gained can very likely be applied to the design of other man-made systems. The biological control system could be used as a guide line for other electromechanical systems that could be controlled by the same type of methods. In many cases the control processes that regulate the biological system constitute an optimal design. The control of these systems have been continually updated and improved since the beginning of life. The better control gave more advantage to the improved system, and that alteration has been maintained by evolution.

Biological systems are extremely complicated and synergistic. A better understanding of these systems will not only elucidate the

particular system being modeled but will indicate procedures that can be applied to other problems.

CHAPTER 2

PRESENTATION OF THE MODEL

INTRODUCTION

The correct execution of a complicated muscular activity demands much thought and practice. Playing a difficult passage on the piano or mastering the game of golf are two examples. In the beginning, careful thought must be given to every detail of the action. A long period of learning, of developing habit and form, is required before proficiency and dexterity are attained. After a period of repetitious practice, the detailed movements that once were conscious actions can be executed almost unconsciously. The simplest explanation of this is that the cerebral cortex learns how to correlate all the required muscular movements into a coordinated form.[1, p 1691][2, pp 860-861]

These coordinated actions can be executed almost automatically, on demand, and as such become almost as easy to perform as conditioned reflexes. The degree of proficiency varies among different individuals.[1, p 1504, 1508-1509][3, p 380] Even for a given individual, performance is affected by psychological factors such as desire, self imposed limits on acceptable performance, and a general state of mind often described as being "up" for a given performance.[4]

The purpose of this chapter is to discuss physiological elements of the muscular control system in the language of the automatic control theorist. In particular, it is proposed that the muscular control system is an optimal adaptive learning control system. In this framework, the

terms such as desire, and being "up" for a performance can be interpreted as weighting factors in the various performance criteria to be discussed.

PHYSIOLOGICAL COMPONENTS IN THE MUSCULAR CONTROL SYSTEM

The major components of the muscular control system are the brain, the nerve tracts, the muscle units, and the various proprioceptors. In simple terms, the brain can be considered as the controller, the muscle units as the objects to be controlled, the proprioceptors as the sensors or measurement units, and the nerves as the wiring harness which connects these functional units.

THE BRAIN

In order to present a detailed theory of operation for the voluntary control of muscular activity it is necessary to divide the brain into several distinct functional parts.

Cerebrum

The cerebrum is the part of the brain which accomplishes conscious thoughts and initiates conscious actions.[2, p 652][1, p 1692] It is believed that the intention to carry out a given act arises in the gnostic[2, p 861] (conscious) area of the cerebrum. This "intention" is the basic input to the system under consideration.

Somatic Sensory

The somatic sensory cortex is the second major portion of the cerebrum of interest here. The sensory cortex receives information from various sensing elements, serves as a memory storage device and also actuates a third area of the cerebrum.