biotechnology:
concepts and applications

LAWRENCE J. FOGEL

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Theoretical aspects and techniques to improve present systems and to conceive, design and produce future systems in the most safe, efficient and effective manner

BIOTECHNOLOGY:

CONCEPTS AND APPLICATIONS

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PREFACE

The practicing engineer is often called upon to design equipment for direct use by man. Not so long ago this requirement was met with an offhand nod and some reasonable and workable design usually resulted. In the more recent past, however, increasing equipment complexity and environmental requirements have made it necessary for the designer to reach for the handbook to determine relevant data so that the human operator will "fit" the designed machine. Today the designer is faced with machines which require that the human component be utilized to the fullest capability. No longer can the designer's intuition satisfy the needs nor can handbook data determine optimal design. We are presently faced with problems which require considerable understanding of the man and the machine so that both of these may be "married" in such a way that each one's attributes compensate for the other's deficiencies. There results a new embodiment: the man-machine system which can and will outperform previous expectations.

The field of biotechnology has emerged in recent years. This interdisciplinary subject utilizes mathematical tools to describe the functioning human operator. Within such a frame of reference it is possible to utilize and evaluate human characteristics objectively. Application of these techniques in present engineering and research efforts would be of distinct value; yet quantitative knowledge concerning the human operator is not widely known. Man-machine design concepts are rarely used.

This book attempts to bring some of the required information to the attention of a wide diversity of scientific personnel, ranging from the "practical" design engineer to the "theoretical" researcher. The text attempts to clarify man-machine relationships through the use of quantitative description and, wherever possible, this is done with a minimal dependence upon the particular terminology of the specialty under con-

sideration. Since some sophistication in mathematical concepts is required, several of the unique concepts are reviewed for the sake of ready reference. Somewhat detailed illustrations are indicated throughout the text at points where these are felt to be most useful. Most important, considerable discussion is devoted to an analysis of the scientific method since it is this technique which provides the foundation upon which biotechnology, and indeed, all of science is built.

In the last few years a number of schools have instituted courses in this field. These have variously been called Biotechnology, Human Engineering, Industrial Psychology, Systems Engineering, Experimental Psychology, Industrial Design, Cybernetics, and so on. These courses cover a wide range of material and from widely different points of view; yet, the common ingredient remains the man-machine relationship. It is hoped that the text which follows will serve a useful purpose with respect to each of these specialized interests and, through a well rounded approach, draw them together to the benefit of our rapidly growing technology.

ACKNOWLEDGMENTS

Biotechnology has been created by many men working in what were considered to be separate disciplines. To all of these I owe a debt of gratitude. In particular, I am indebted to those investigators whose work is referenced in this volume. Their contributions form the body of our current knowledge.

I am also grateful to a number of friends who provided both encouragement and constructive criticism. These include John Lyman, Jeff Sutton, Warren McCulloch, Heinz von Foerster, Richard Bolt, David Jagerman, Marvin Adelson, and Harry Malin. A large amount of secretarial and reference work went into the preparation of the manuscript of this book. Credit for outstanding effort is due to Viola Peregoy, Joyce Thompson Bernhard, Shirley West, and Richard Benedict.

Finally I want to acknowledge the love and understanding of my family who made it possible for me to devote so many hours to study and writing.

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INTRODUCTION

Biotechnology is an interdisciplinary science born of the increasing dependence of man on machines. The man-machine relation appears within almost every context, ranging from close control of massive high-speed mechanisms and vehicles to long range control through the planning and organization of large traffic, computation, or communication systems which are yet to be.

The modern trend toward automation and push-button weapons does *not* decrease the need for proper man-machine designs in any way, In fact, it serves to emphasize the importance of effective design since human control of such automatic systems has a more direct effect upon a much larger array of equipment. The greater the degree of automation, the more important becomes each human action. They *must* be correct and executed only at the proper time. The display, controls, and imposed environment can make or break the entire system. The human is found at some point in every system since technology is created by man for his own benefit.

To cope with the diverse problems which are encountered, it is necessary to draw upon three of the pure sciences, Psychology, Biology, and Mathematics and to integrate this knowledge to create useful techniques for design and evaluation. Unfortunately these fields are widely different. Through the years of their development, they have become increasingly specialized in language and techniques and thus have placed a difficult burden upon those who would attempt to unify the results. Indeed the widely separate paths which these pure sciences have taken further emphasizes the wide unchartered domain which is essentially left untouched. Cybernetics is a term which has been adopted to cover the more theoretical aspects which are concerned with man-machine systems. Human Engineering is the term used to describe the application of specific data concerned with the actual linking of men and machines. Biotechnology is

the entire field which is concerned with the man-machine relations encompassing both the theoretical aspects and practical applications as they pertain to setting the stage for future system design.

This book is divided into six major sections placing the field of Biotechnology within a logical framework so as to facilitate application. Section A describes the scientific method, providing a foundation upon which technology is based. Only through a detailed understanding of the scientific method is it possible to survey the diverse materials which form the background and literature of Biotechnology. The essential ingredient of the scientific method is the use of mathematical models. Chapter 1 describes these models in some detail, and Chapter 2 presents certain particular models which may be found especially useful in both research and practical applications.

Section B concerns the human information input channels. The human operator can be used in a useful manner only if he is provided information concerning his environment and the purpose he is to fulfill. Chapters 3 through 8 specifically discuss particular sensory information input channels together with relevant limiting factors forming a background for the discussion of design which follows.

Section C concerns aspects of decision-making, the fundamental capability of the human operator. Chapter 9, the first of three chapters in this section, is devoted to manual tracking, wherein the human operator repeatedly attempts to minimize the perceived error through his control of the system. Chapter 10 takes a more general view of decision-making by considering decisions made by automata. The discussion relates to artificial intelligence and decision-making by automata, thus providing a frame of reference for Chapter 11 which concerns the empirical findings related to human decision-making.

Section D discusses extraction of information from the human operator. This can be accomplished through the individual's overt cooperative effort as discussed in Chapter 12, and through his use of provided controls. On the other hand, it is also possible to extract information from the human operator without his conscious effort. Chapter 13 describes techniques for sensing and interpreting extracted information that can be used to assay the efficiency of the man-machine system from its effect upon the internal functioning of the human operator.

Section E is concerned with specific applications and designs of machines and systems to accomplish the most effective use of the human operator. This section is constructed to gradually increase the scope of the system under consideration. For example, Chapter 14 concerns the design of personal equipment: those mechanisms and garb which directly protect the human body. Chapter 15 discusses environmental designs, including

living quarters. It is of special interest in this regard to consider closed ecological systems as they might relate to future space travel. Chapter 16 discusses problems in the design of consoles and cockpits for widely different systems in which the human operator is in direct control of the system under his purview. A number of the most pressing aircraft cockpit problems are discussed so as to introduce Chapter 17 which offers a proposed cockpit design for future aerospace craft. Chapter 18 views systems of even larger extent and offers a guide to man-versus-machine task allocation. The systems considered include communication and traffic control. System design must be accompanied by evaluation in order to assure that the intended purpose will be fulfilled. Chapter 19 describes techniques for system evaluation with respect to performance reliability. Aspects of simulation are reviewed as this pertains to the evaluation of proposed or existing equipment systems.

Section F is concerned with an overview of Biotechnology. More specifically, Chapter 20 describes the structure of Biotechnology in terms of the relationships among the many and various individual topics which all relate to man-machine system design. This chapter is intended to provide a bird's-eye view for those just entering the field who desire to know the direction in which their own efforts may best be placed in order that they may achieve a well rounded capability. Continual reference to the over-all structure of the field permits the active participant to remain aware of the many different viewpoints which may be used to approach the same problem area. In this way it is possible to maintain cross-fertilization of ideas.

Each of the sections within this book are separately introduced and are accompanied by a brief bibliography which indicates basic references to the chapters that follow. In addition, each chapter carries its own bibliography. The breadth of background of Biotechnology makes for voluminous reference material. Even though the individual bibliographies are considerable in extent, it is felt that these provide only the essential references to permit more detailed investigation. The wide range of subject material prohibits absolute consistency of notation throughout the text. Each symbol is defined as it is introduced, being chosen in a manner similar to that used in the current literature.

Biotechnology: Concepts and Applications is *not* a handbook. Rather, it is intended to provide a background of understanding from which present systems may be improved and future systems conceived, designed, and produced in a manner to make them most safe, efficient, and effective in their accomplishment of service to man.

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SECTION

A

THE SCIENTIFIC METHOD

This section is intended to provide a foundation upon which a frame of reference can be established for the subject of applied biotechnology. At first glance the contents may appear to be somewhat unrelated to this subject, but this is not the case. It is imperative that any new and interdisciplinary field be grounded upon the philosophy of science and furnished with the logical tools which permit the translation of empirical data into useful knowledge and worthwhile design techniques.

BIBLIOGRAPHY

BEVERIDGE, W. I., *The Art of Scientific Investigation*, originally published 1950, revised edition. New York: Random House, 1957.

BRIDGMAN, P. W., *The Logic of Modern Physics*, originally published 1927 (paperback edition). New York: The Macmillan Company, 1960.

HEISENBERG, W., *Physics and Philosophy*, copyright 1950. First Harper Torchbook Edition. New York: Harper and Brothers, 1962.

JEVONS, W. S., *The Principles of Science: a Treatise on Logic and Scientific Method*, originally published 1874, reprint. New York: Dover Publications, Inc., 1958.

JOHNSON, W., *People in Quandaries*. New York: Harper and Brothers, 1946.

KÖRNER, S. (ed.), *Observation and Interpretation*. London: Butterworth's Scientific Publications, 1957.

PEARSON, M. A., *The Grammar of Science*, original publication 1892, reprint. New York: Meridian Books, Inc., 1957.

POINCARÉ, H., *The Foundations of Science*, p. 553. Lancaster, Pa.: The Science Press, 1946.

———. *Science and Hypothesis*, translated 1905. New York: Dover Publications, Inc., 1952.

———. *The Value of Science*, unabridged republication of the First English Translation. New York: Dover Publications, Inc., 1958.

POPPER, K. R., *The Logic of Scientific Discovery*. New York: Scientific Editions, Inc., 1961.

SCHRÖDINGER, E., *Science and Humanism*. London: Cambridge University Press, 1951.

———. *Science Theory and Man*, first published as *Science and the Human Temperament*. New York: Dover Publications, Inc., 1957.

WHITEHEAD, A. N., *The Concept of Nature*. Ann Arbor, Mich.: University of Michigan Press, 1957.

WILSON, E. B., JR., *An Introduction to Scientific Research*. New York: McGraw-Hill Book Company, Inc., 1952.

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MATHEMATICAL MODELS AND THE SCIENTIFIC METHOD

1.1. FUNDAMENTAL CONSIDERATIONS

Scientific investigation begins with observation of the "real world."[1] As collected data accrue, it becomes possible to consider a number of different models in search of some rationale, some reason why the evidence is as it is. These models may be used to predict the next observation, and, as subsequent data are gathered, it soon becomes apparent that some models are more useful than others in this regard. In fact, it may be possible to select a particular model which achieves minimum error toward estimating any previously unobserved datum point. Obtaining such a model is the first step in understanding the observed data. It offers some knowledge of the behavior of the real world and, within its degree of precision, may be used to predict other observations for the purpose of analysis or synthesis. Obviously, proper selection of an appropriate model is of critical importance. The use of such conceptual models is fundamental to scientific thought.

Not all models are acceptable for consideration. The scientific method requires that the model be both self-consistent and "public information." The former constraint requires that the same set of fundamental assumptions cover all aspects of the same set of data. That is, the "ground rules" cannot change once the "game" has started. It is this constraint which eliminates

[1] This term includes any and all measurable entities and processes within the physical universe.