

a manipulator with six degrees of freedom, the computation time required by this method is found to be too large to be implemented on a single Intel 8086/8087 microprocessor.

In summary, this book focuses on the computer-aided generation of the closed form dynamical equations for a robot manipulator with rigid links. Both the theoretical and the practical aspects of the method have been thoroughly discussed. However, the methods of incorporating parallel computation schemes which would be particularly useful for the construction of the dynamic model of a robot manipulator with six degrees of freedom have not been examined. Nevertheless, this book would be extremely valuable to both researchers and practicing engineers in the area of robot control. The reviewer also recommends this book for a graduate level course.

About the reviewer

Professor Alok Sinha obtained his B. Tech. degree in mechanical engineering from the Indian Institute of Technology, New Delhi. In 1980 he obtained his M.S. degree in mechanical engineering from the university of Kentucky, Lexington. His M.S. thesis involved computer simulations, costing and optimization of advanced power plants. In 1983 he received his Ph.D. degree in mechanical engineering from Carnegie-Mellon University, Pittsburgh. His research dealt with system identification and nonlinear dynamics. He joined the Pennsylvania State University in August 1983 as Assistant Professor of Mechanical Engineering. The areas of his teaching and research include robotics, control systems and vibration.

## Application of Optimal Control Theory in Biomedicine\*

George W. Swan

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CONTROL ENGINEERING lies, together with electronic and electrical engineering and computer science, at the heart of the new technological revolution concerned with industrial automation, signal processing, information technology and robotics. The concept of "control" can be briefly described as the problem of obtaining desired behavioural characteristics from a system by on-line collection of data and the systematic (computer-aided) processing of the data as an aid in decision making.

These basic problems occur in almost all branches of engineering, economic decision-making, biotechnology and some branches of medicine. The field is, therefore, inevitably interdisciplinary, with an importance that is rapidly increasing as process plants increase in complexity and demands grow to increase efficiency, reliability and safety and to minimize usage of natural resources.

Optimal control is a distinct and self-sufficient branch of control engineering that is concerned with, in rough terms, obtaining the "best" performance from a system. For example, it may be necessary to operate the plant to minimize energy consumption and hence cost. In general, the notion of "best" is formulated mathematically by requiring the decision making procedure to minimize or maximize a performance index devised to represent quality of control.

George W. Swan has written a book whose purpose is to present the reader with a variety of applications of engineering optimal control theory to biomedicine. The approach is theoretical and does not consider the implementation of these "optimal" therapies to patients. Each chapter, except two introductory ones on mathematical theories and system concepts, considers the modelling of a biomedical problem and then discusses the approach taken to apply optimal control.

During the past 20 years, satisfactory mathematical models have been developed for a large variety of physiological systems. From the different systems treated here the state equations are developed and different types of performance criteria constructed which are model dependent. Obviously as better models of the biomedical engineering problems become available, an up-dated solution becomes desirable, this being a point noted by the author. The control of biomedical systems is not naturally an optimal control problem, but an attempt has been made to use

the theory in a number of applications and then investigate where the techniques might be useful. Often in biomedicine it is not readily apparent what constitutes a suitable performance criterion, i.e. it is straightforward to state that the improvement in the health of an individual is a desirable objective though the problem remains of how to express this in quantitative terms. For example, numerous therapies depend on giving drugs so as to "minimize toxicity to the patient"; how does one quantify toxicity in a mathematical sense? This is the most important consideration because the ultimate success of any scheme will depend on the choices made at this point. In the book this is considered in depth for each system.

Each chapter is basically self-contained including its own set of references. Chapter 1 attempts to collect in one place a number of the concepts and results of engineering optimal control theory. These include brief descriptions of discrete and continuous-time-optimal control, Pontryagin's minimum principle, the linear-quadratic-regulator problem and singular optimal control problems. Later developments and applications in the book depend on the material in this first chapter. The book is aimed primarily at applied mathematicians. This is very evident in this chapter (and also in Chapter 2), as a familiarity with optimal control theory has been assumed.

Chapter 2 gives an over-review of systems concepts reviewing state equations, mathematical models, controllability, observability, reachability, identifiability, performance criteria in biomedical optimal control problems and finally the self-tuning regulator. Yet again the descriptions are concise. In some cases this will lead invariably to confusion, though each section has a large number of references for more in-depth study. The theory throughout the book is based upon state-space representations except for the self-tuning regulator which is a polynomial-based control algorithm. A short discussion on polynomial system representations would have clarified the presentation; also, calling the self-tuning regulator a mathematic model may be correct, but is misleading.

Chapters 3-6 deal with applications of optimal control theory in the improvement of patients therapies for certain disease states. Of these chapters, 3 and 4 consider the two major diseases in clinical endocrinology, namely diabetes mellitus, a disease of the pancreas and disorders of the thyroid. Chapter 5 considers the optimal administration of drugs via oral ingestion or via injection into a vein. Chapter 6 considers the use of chemotherapy or radiotherapy for the optimal control of cancer.

In all of these chapters the approach is similar. The current state of model development for each system is reviewed and one

\* Application of Optimal Control Theory in Biomedicine by G. W. Swan, Dekker, New York (1984), 304 pp. U.S. \$55.

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