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Biology and Control Theory: Current Challenges

Springer

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Preface

Bio and Control: Introductory Ideas

Historically speaking, the connection between biology and control feedback theory goes back to the analogy suggested by NORBERT WIENER in the 40s for explaining some human behaviors by using *feedback* mechanisms: brain control of a standard arm mechanical movement. At the same period of time, ERWIN SCHRÖDINGER pointed out some similarities between physics principles and the laws governing alive organisms, and he suggested a physics-based approach for the modeling and the analysis of such organisms by using the *analogy* (electrical, mechanical, and chemical processes). Without being exhaustive on the corresponding methodologies, these simple ideas are at the origin of a large number of models that tried to reproduce the behavior of living organisms. Without any doubts, such models served and helped in defining the first inter- and trans-disciplinary programs between biology and other sciences and/or disciplines from Mathematics to Physics and Computer Sciences in the last decade.

In this context, the control feedback theory has its own place, and we hope that it is able to bring the beginning of answers in the understanding of biology dynamics. The mathematical description of signals and circuits is not only at the origin of the modern control feedback theory, but also contributed significantly at the emergence of *Systems Biology*, as mentioned by P. WELLSTEAD in his essay *Schrödinger's Legacy: Systems and Life* (ETS Walton Lecture, 2005), and this example is far to be an isolated case.

Formalism, Potential Interactions and Some Expectations...

Taking into account the current competences in the field of the classical control feedback theory, namely, analysis, observation and control of dynamical systems (linear or nonlinear, finite-dimensional or not), the *main objective* for the edition of this book is to propose a (potential) "progressive transfer" of some of the "competences" issued from control feedback theory towards the domains of the life sciences, and especially towards all the domains of life sciences in which a *dynamic behavior* can be pointed out (see also some discussions in the report of the panel on future directions in control, dynamics and systems: *Control in an information rich world*, edited by R.M. MURRAY).

In this sense, take an extremely simple example: a same molecule has different meanings and various interests of study for the specialists in the life sciences domain, depending on the type of action considered:

- Action on isolated enzymatic systems (biochemical);
- Action on a dynamical chain of reaction in the alive cell (biology);
- Action on the human organic functions (pharmacology, physiology);
- Human therapeutic actions (medicine),

and each of these actions can be translated by some particular quantitative and qualitative properties of the corresponding dynamical system modeling the considered action.

Roughly speaking, any behavior of a biological system with respect to one (or several) time scaling can be interpreted in a dynamical system framework or context by using appropriate (analysis and control) tools. Indeed, we think that some knowledge in control feedback theory could deserve to have a *better understanding* of different kinds of dynamic evolution provided that some variables of the system are measurable (or observable), even if one cannot control the object under consideration. Furthermore, several tools and methods for a *qualitative and quantitative analysis* of such evolutions hold.

Next, it is worst to note that, in biology, the notion of *structure* has a larger sense than in automatic control theory. More precisely, the structure defines the set of relations existing between the different elements that constitute the object or the set of objects under consideration. Behind each structure, there is some *complexity* (any alive organism is strongly complex) with its *own hierarchy* (any alive organism is highly organized). Thus, the notion of *closed-loop* exists (and is recognized like that since more than an half century) in the context of biological systems, and as emphasized by HENRI LABORIT *"every life evolution from and after the photosynthesis has been regulated by feedback between more ordered and less ordered structures of the environmental device"*.

In summary, in our opinion, the fact to create some links between control theory community and that one of the life sciences could allow addressing the following problems (see also the challenges from biology briefly presented in *New issues in the Mathematics of Control* by R. BROCKET in *Mathematics Unlimited - 2001 and beyond* for some insights in neurobiology, cell biology and psychology):

- To model, observe and have a perception of the alive structures;
- To analyze the dynamic interconnections between biological systems and structures.

Finally, we also believe that this interaction between specialists in biology and control feedback theory will be useful in both directions. More precisely, biology systems need appropriate analysis tools due to their structure and hierarchy, complexity and environment interference, and we believe that these aspects may generate interesting research topics in control area. Indeed, several works, raising the potential impact of control developments to bring some beginning of answers in the context of biological systems, have been published in the recent years (special sessions or workshops at the interface between these communities, see, for instance, the proceedings of CDC 2005 and 2006). The idea of this book was conceived in the context mentioned above.

How to Read the Book?

This book is organized as follows.

- Part 1 is devoted to model selection and consists of chapters 1 through 4: modeling perspective in chronic myelogenous leukemia (first chapter), an aid for an early diagnosis of HIV/AIDS infection (Chapter 2), a multi-scale control oriented model in ovulatory processes (Chapter 3) and finally some robotics insights in modeling visually guided hand movements (Chapter 4).
- Part 2 is devoted to models for system analysis and consists of chapters 5 through 10, as follows: analysis of monotone and near-monotone biochemical network structures (Chapter 5), system and control in understanding the biological signal transduction (Chapter 6), analysis of some piecewise-linear models of genetic regulatory networks (Chapter 7), the modeling and the analysis of cell death signalling (Chapter 8), a Petri Net approach to persistence analysis in chemical reaction networks (Chapter 9), and finally some geometric ideas in stability analysis of various delay models in bioscience (Chapter 10).
- Part 3 is devoted to analysis and control aspects and consists of chapters 11 through 13: modeling and control of anesthetic pharmacodynamics (Chapter 11), a direct adaptive control of some non-negative and compartmental systems with delays (Chapter 12), and finally the analysis and control of dynamics in biological systems in presence of limitations (Chapter 13).

Note that this partition is somewhat arbitrary as most of the chapters are interconnected, and it mainly reflects the editors' biases and interests.

We hope that this volume will help in claiming many of the problems for control researchers, starting discussions and opening interactive debates between the control and biology communities, and, finally, to alert graduate students to the many interesting ideas at the frontier between control feedback theory and biology. There are, of course, many areas which are not represented through a chapter, and therefore we would like to apologize to those whose areas are not profiled.

Acknowledgements

The idea of this edited book inherits from the organization of an International Workshop on the subject in April, 24-25th, 2006, at LAAS-CNRS, Toulouse, France, co-organized with HeuDiaSyC (UMR CNRS 6599), Compiègne, France. Such a meeting was the third one of a series initiated with the 1st CNRS-NSF Workshop on *"Advances on time-delay systems"* (Paris, La Défense, France, January 2003) and continued by the International Workshop on *"Applications of time-delay systems"* (Nantes, France, September 2004).

Foremost, we would like to thank all the contributors of the book. Without their encouragement, enthusiasm, and patience, this book would have not been possible. A list of contributors is provided at the end of the book.

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