Preface to the Second Edition

The present edition continues with the approach to bond graph modelling used in the first edition. There are also some improvements that are mostly the result of developments of BondSim program taking place over the last more than ten years. Its appearance is now quite different, and we hope more user-friendly. There were some other important changes as well. One is the use of .NET technology for efficient model solving during the simulation phase.

Also there is a range of new modelling components, in particular for digital signal processing, which enable modelling and simulation of mechatronics systems in its entity including the embedded digital signal processing. This was illustrated on an example of Coriolis mass flowmeter in Chap. 10. There is also support for 3D visualization and inter-process communications. It is now possible to visualize motion of complex mechanical system in space and their interactions with its surrounding.

The version of the modelling and simulation program environment that was used in the book is BondSim 2014. It is freely available to the readers. We recommend the readers to download it and use while reading the book. We also encourage the reads to try to solve their own problems using the approaches described in this book.

We would also like to thank Dr. Christoph Baumann of Springer-Verlag, Heidelberg, for his help, kindness, and patience during the preparation of the manuscript. We are also grateful to Ms. Petra Jantzen and Ms. Carmen Wolf for their help.

Dubrovnik
June 2015

Vjekoslav Damić
John Montgomery

Preface to the First Edition

A short history of this book

This book had its origins in the authors' common interest in modelling and simulating dynamic engineering systems, especially those related to *mechatronics*. These interests date from the early 1970s.

We well remember—even somewhat nostalgically—our experiences with one of the first digital computer simulation tools that became available: IBM's Continuous System Simulation Program (CMSP) for IBM 1130 computers. C.W. Gear's famous DIFSUB code for solving stiff differential equations—the forerunner of modern differential-algebraic equation solvers—also appeared around the same time. Then, in 1975, Karnopp and Rosenberg's classic book, *System Dynamics: A Unified Approach*, was published. It introduced a system analysis methodology based on bond graphs. We loved it from the start for it laid a solid foundation for the development of a systematic approach to modelling complex mechatronics systems. We were also aware of developments in the field of electronic circuit modelling that led to the famous Berkley's SPICE program.

The difficulties posed by solving real-world design problems motivated the first author to begin development of a methodology for computer-aided modelling and simulation of engineering—particularly mechatronics—systems. It was targeted to developing a methodology that supports systematic model development by decomposition. Bond graphs were taken as modelling formalism, because they are well suited to modelling different physical processes taking place in a typical mechatronic system. It was expanded, however, by developing the concept of bond graph word models into complete component models. More attention was given to component ports as interfaces of the components. The ports are treated as objects in themselves that enable representation of the complex interconnections inside the components. This way, a model of a system can be built as a complex multilevel structure, in a form that mimics how a real system is built. The component can be reused as well to build the models.

Another departure from classical bond graphs and the Continuous System Simulation Language (CSSL) philosophy was made by putting aside the causality issues. Strict input–output relationships in the models are not supported. Thus, instead of mathematical models in state-space equation form, differential-algebraic equation models are used. This enables separation of modelling and model solving tasks. We believe that, taken together, this extends the applicability of methods to solving real engineering problems.

The first implementation of this methodology was made in the beginning of the 1980s with the release of *Simulex*. This program was implemented using FORTRAN and run on Digital VAX-750 computers. *Simulex* models were described with SPICE-like scripts. The resulting equations were solved with a version of Gear's DIFSUB. *Simulex* was applied successfully to a range of practical problems in servo-systems and robotics.

The revolutionary appearance of PCs in the mid-1980s, followed by development of operating systems that supported user-friendly visual interfaces in the 1990s, spurred the next phase of development. This was also influenced by the paradigm shift in programming languages: The truly object-oriented languages were replacing the procedural languages—such as FORTRAN and C—that we had all been using. Another important technological development became available around the same time—symbolic computational algebra.

In the beginning of the 1990s, the shift to object-oriented modelling paradigm was made. Class hierarchies were developed that enabled representing component models as objects. Also, computational algebra methods were developed that, as explained in the present book, simplified some important user interface problems and the solution of model equations. Methods for solving differential-algebraic equations were further developed to support model solving during simulation. These all were implemented in a visual modelling and simulation program, *BondSim*, the first version of which appeared in the mid-1990s. It fully automated many important operations. Thus, there was no need for the developer to use any traditional programming; rather, models were developed and solved simply by mouse clicks.

In 1995, the authors met at The Nottingham Trent University and started collaborative work on *Dynamic System Simulations Using Bond Graphs*, a project funded partially through an ALIS (Academic Links and Interchange Scheme) award (1995–1998), sponsored jointly by the Croatian Ministry of Science and Technology and the British Council. This cooperation continued *via* e-mail and reciprocal visits to Nottingham (England) and Dubrovnik (Croatia). One result of this fruitful joint work is this book that we here offer to the reader.

What is this book about?

The title suggests that this book is about mechatronics; this is, indeed, one of its central themes. It is not, however, another book on what mechatronics *is*; rather, it is about how mechatronic problems can be solved by a systematic approach employing bond graphs. *Why bond graphs?* Because they offer an efficient means of modelling interdisciplinary problems, such as those commonly found in mechatronics. (The book, by the way, assumes no previous experience with bond graphs, though it certainly would be useful.)

The book shows, in step-by-step fashion, how models are developed systematically and then simulated in a way that permits thorough analysis of the problem under study. Every chapter that deals with an engineering application starts with the exposition and solution of a simple problem relevant to that chapter. Then, the solution of related—though much more difficult—problems is explained.

The book is divided into two parts: *Fundamentals* and *Applications*.

Part I, Fundamentals, consists of five chapters on bond graph modelling. It starts with an introduction to the subject and then proceeds with describing a systematic object-oriented approach to modelling; implementation of object-oriented modelling in a visual environment; and the numerical and symbolic solution of the underlying model equations.

Part II, Applications, consists of five chapters that apply bond graphs and component model techniques to mechanical systems, electrical systems, control systems, multibody dynamics, and continuous systems. Great attention is given to modelling electrical components and systems, including semiconductors. The same holds for multibody systems, both rigid and deformable, such as found in various mechanisms and robots.

What readers can gain from the book?

There are several ways in which this book can be used, depending mainly upon the background and interests of the reader.

Researchers in mechatronics and micro-mechanics design, for example, can use it to find out how difficult problems in their disciplines can be solved using a combination of bond graphs and component model techniques.

For the reader interested in simulation technology, the book provides an introductory description of the object-oriented visual approach to modelling and simulation.

The reader whose background is in one of the applied disciplines covered herein can gain valuable insight into how bond graphs may be used to solve problems particular to his area of interest.

We also think that the book can be useful as a textbook, or as a supplementary text, in courses on physical modelling of engineering systems in general. We believe that it can help students learn the system way of solving a problem in electrical and mechanical engineering, as well as coupled problems that span disciplines.

Finally, it is our sincere wish that the text and software will aid the reader in his work. We invite, and will appreciate, all constructive feedback.

BondSim Research Pack

A special version of BondSim—*BondSim Research Pack* (beta version)—is bundled with this book. It provides a visual development environment for the modelling and simulation of engineering and mechatronics systems based on bond graphs. The problems presented in the book are solved using the *BondSim Research Pack.*

It runs on the Windows 2000 Professional operating system, but can be used on other Windows platforms, too. The reader can use this version of *BondSim* to analyse all of the problems presented in the book. (These are found in *BondSim*'s program library.) The projects that a reader might develop on his or her own are somewhat more restricted. The interested reader can order the complete version of *BondSim* from the first author. (*See* Appendix for details.)

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Vjekoslav Damić
John Montgomery

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