

Preface

With an-ever increasing complexity today's engineering systems are built of interacting components that exchange not only physical quantities such as energy but also exchange and process information. A lot of sensors and controllers are in use in all kinds of complex mechatronic systems. Being equipped with sensors and embedded computers mechatronic systems become able to perform some tasks autonomously and are sometimes called intelligent mechatronic systems. However, faulty sensors may cause controllers to output not the signals needed, while faulty actuators and faulty system components downgrade the effect of a healthy control. The increase in complexity makes engineering systems vulnerable to all kinds of faults and make humans dependent on their reliability and safety. As a result, there is a need for implementing mechanisms that allow complex intelligent systems to autonomously detect, isolate and accommodate faults in real-time. Once a fault has occurred, a controlled system is no longer the one that was designed to serve a certain purpose and to meet certain requirements. Depending on the severity of a fault a system may continue operating at downgraded performance and with restricted functionality, or may require immediate reaction. Incipient faults may lead to the future failure of a component which in turn may require a shutdown if possible at all. Accommodation of a fault can mean that a fault tolerant control was designed that can deal with faults, or that hardware redundancy is available that can replace faulty components.

In any case, fault detection and isolation is a prerequisite for real-time system supervision. In order to ensure reliability and safety it is important to take into account detection and diagnosis of possible abnormal system behaviour and means for automatic correction already during an integrated, concurrent design of complex intelligent mechatronic system by deliberately injecting faults into a system model and to study their effects on the system's dynamic behaviour.

Fault diagnosis has been a research subject since more than three decades and has received quite some attention. Besides data-driven methods various model-based approaches to fault detection and isolation have been reported in the literature. One of these methods is based on bond graphs. They were introduced by Prof. H. Paynter at Massachusetts Institute of Technology, Cambridge, USA back in

1959. As this modelling methodology starts from physical first principles, in particular from considering the exchange of energy between system components and the conversion from one kind of energy into another, bond graphs are particularly well suited for the development of models with continuous variables for multi-disciplinary systems in order to study their behaviour in time domain as well as in frequency domain.

In the course of the past 10 years, bond graphs have also been used for model-based approaches to fault detection and isolation of systems represented by a continuous time model. On the other side, modelling assumptions and the abstraction of state changes taking place virtually instantaneously lead to hybrid models that can appropriately and adequately accurately capture the dynamics of a complex system. Over the last decades, various approaches have been proposed on how to extend bond graph methodology so that systems represented by a hybrid model can also be covered. However, only recently, bond graphs have also been used for fault detection and isolation of such systems. The subject of this book is to demonstrate that bond graph methodology can well contribute to model-based fault detection and isolation for systems that are appropriately described by a hybrid model.

The book briefly recalls various bond graph representations of hybrid system models proposed in the literature. The development of hybrid models for the purpose of fault detection and isolation, in this book, makes use of conceptual non-ideal switches representing devices for which it is justified to abstract their fast state transitions into instantaneous discrete state switches and accounts for structural model changes by special sources that are switched on or off at the advent of a discrete event. As other possible approaches, this approach has its pros and cons. For illustration, the presented method is applied in a number of elaborated case studies that consider fault scenarios for switched power electronic systems that are commonly used in a variety of applications. Power electronic systems have been chosen because they may be appropriately described by a hybrid model and are well suited for application of the presented bond graph model-based approach to fault detection and isolation. The approach, however, is not limited to this kind of systems.

Beyond fault diagnosis, failure prognosis becomes more and more important with regard to maintenance. Taking actions only when a system component has run into a failure is not always an option. Periodical maintenance in certain time intervals is not cost efficient. A promising solution is to constantly monitor the health of a system in operation, to process and assess sensor measurements, and to estimate the so-called remaining useful life of component when an incipient fault has been detected. The book briefly shows that bond graphs can also support model-based failure prognosis.

Being active in the field of bond graph modelling for more than three decades, it has been a natural step for the author to use bond graphs also for model-based fault diagnosis of engineering systems and to show that bond graphs are not only useful for model development, model analysis, simulation and control of engineering systems but can also serve fault diagnosis of systems represented by hybrid models.

The book has arisen from the author's research and teaching experience and has been influenced by the work of other bond graph modellers and by the author's interactions with many leading personalities in this field. It addresses members of the world wide community of bond graph modellers, as well as students, researchers, and practicing engineers in industry concerned with fault diagnosis who might be interested to see how a graphical methodology such as bond graph modelling can support quantitative model-based fault diagnosis of engineering systems represented by a hybrid model. An appendix provides some fundamentals of bond graph methodology so that the use of bond graph modelling for FDI and prognosis in this book may be more easily followed. The book may be used in courses on fault diagnosis, as a supplementary text in modelling, simulation, and control and may also serve self-studies and as a reference.

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