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Objective and Motivation

1.1 Introduction

The objective of this work was to support the design of mechatronic systems by the use of simulations. This raises the question of what exactly is mechatronics. Current definitions describe mechatronics as an interaction between electronics, mechanics and information technology, see Isermann [164] or Wallaschek [421]. It makes no difference here whether we are talking about macromechanics or micromechanics. In the former case we speak of mechatronics, in the latter of micromechatronics or microelectromechanical systems (MEMS). As was discovered during the course of this project, although the dimensions of the mechanics in the systems under investigation may vary, the methods used for modelling and simulation are largely the same, which makes the joint consideration of macromechanics and micromechanics an obvious approach.

Why is the modelling and simulation of mechatronic systems difficult? First of all, the field of mechatronics incorporates very different domains and similarly varied methods of description. The field of electronics includes analogue and digital, as well as continuous and event-oriented, processes. The same is true of mechanics, although often for totally different reasons. In the field of mechanics, events may, for example, be triggered by the transition from static to sliding friction. In electronics, on the other hand, an event is brought about by the flicking of a switch, triggering a connection to the entire digital world. In mechanics we also have to deal with geometric aspects in three spatial dimensions. Furthermore, multibody and continuum mechanics of different representational forms also have to be taken into account. Finally, software can be considered as information in bistable circuits and thus classified as electronics. However, this is not sufficient to achieve an efficient and transparent consideration, which means that we have to develop our own models for the software.

The development of models is thus a difficult process at the best of times and one which is prone to errors. However, a systematic verification and validation of the model is not in sight. As in other fields of simulation, models containing errors can produce arbitrary results. Recognising such errors is often not a simple matter.

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This is particularly true if the simulation relates to the design of a technical system and its task is to make predictions about the system's functionality. In this case the system in question does not exist at all in the real world, which means that no measurements are available for checking the model. Rather, the design has yet to be investigated and completed. So proving the correctness of a model is a matter of importance. If we now interpret — as did Butterfield in [55] — a model as a scientific theory, then the validation of the model must be placed within narrow boundaries. According to Popper [338] the following is true for the validation of a theory:

> *In order to be scientific, a theory must be falsifiable. It must be empirically testable, at least in principle, and there must be a test that disproves the theory in the event of a negative outcome.*
>
> *There can never be a rigorous validation of a scientific theory. The best that we can do is to develop empirical tests for the theory—fair tests, but the stricter the better—and to hold onto the theory only as long as it has passed all tests.*

The same applies for the validation of models. We can develop as many tests for a model as we like, but this does not prove the validity of the model. At best, trust in a model increases with the number of tests.

Depending upon the problem to be solved, we can differentiate between two fundamental starting points in the simulation of mechatronic systems. If the mechanical part of a mechatronic system is to be developed, then the mechanics should be developed taking into account the electronics. In this case electronics and software are commonly considered as a regulatory function and dealt with along with the mechanics in the form of suitable equations. The purpose of this work is to investigate the opposite case — the development of electronics and software taking into account the mechanical component. This type of design should be supported by simulations.

Hardware description languages, which have been widespread in the field of electronics for some time, and for which various commercial simulators are already available, represent the tools for achieving this end. Anything that can be modelled using a hardware description language can also be simulated.

Thus the task is primarily a modelling problem. Furthermore, standards exist for hardware description languages, which means that models can be exchanged between simulators. One example is the IEEE standard VHDL 1076.1 (VHDL-AMS) [160], which permits the description of digital and analogue systems. The aim of this work is to cover the entire breadth of modelling for mechatronic and micromechatronic systems using hardware description languages and to thereby take a direct route to the corresponding simulations.

This structure of this work is as follows: After the introduction, the second chapter deals with the principles of modelling and simulation for electronics and mechanics. Particular importance is attributed to the verification and validation of models. The third chapter describes state of the art techniques for the simulation of mechatronics and micromechatronics. Chapter 4 supplies the most important constructs of digital and analogue hardware description languages. Chapters 5 and 6 deal comprehensively with the methods for the consideration of software and mechanics in hardware description languages. This creates a compendium of basic methods that can be combined at will according to the system under consideration. This is illustrated in Chapters 7 and 8 on the basis of six demonstrators for mechatronics and micromechatronics. The ninth chapter finally summarises the work and highlights its most important conclusions. At the end of the book there is a bibliography, the appendix containing lists of symbols, trademarks, and abbreviations used, plus the index.