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Simulation of Electromechanical Sensors and Systems

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Abstract

The article gives a short overview of challenges facing the simulation of electromechanical sensors and the different approaches to model sensor systems. Furthermore, important prerequisites for an efficient simulation are discussed.

Key words: System simulation, electromechanical systems, co-simulation, combined simulation

Introduction

Electromechanical sensors are used in a lot of different measurement applications. Examples are accelerometers and gyroscopes in smartphones or pressure and level sensors in factory automation. The most modern electromechanical sensors are complex mechatronic systems which use the combination of the primary electromechanical transducer with electronics, system theory and information technology to achieve the wanted specifications.

For the development of new sensors with improved specifications at comparable or lower costs an efficient simulation is crucial. Typically, the first challenge is, that the complete electromechanical sensor cannot be modelled within one simulation method. The main reasons for that are different physical domains which often lead to very different simulation requirements in terms of time scales, geometric abstraction, linearity or whether to model in time or frequency domain. Fig. 1 shows as example important system components for an ultrasonic flowmeter. Different approaches for an efficient simulation of electromechanical sensors are presented in section 2.

A second and equally important issue is to choose the right abstraction level simulation method for a given development task. The efficiency of a simulation in the development process can be defined as the ability to give the necessary answers at the right time with a reasonable effort. Thus, an efficient simulation does not only depend on the physical problem and the available simulation methods, but also on clear objectives for the simulation and on the appropriate abstraction level for the current questions in a development process.

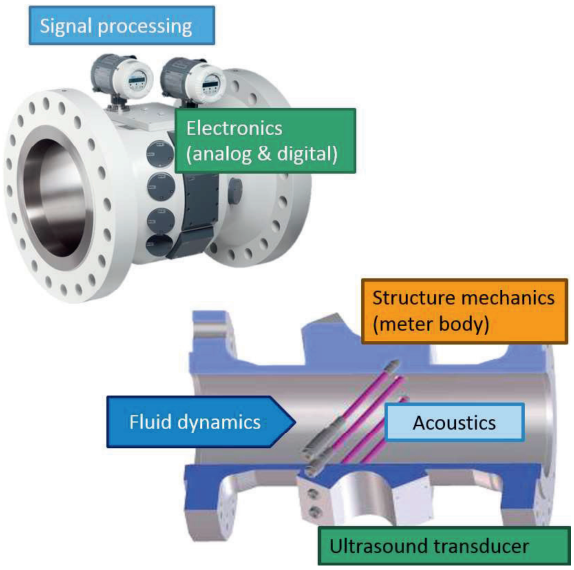

Fig. 1. Examples for important physical domains and system components for an ultrasonic flowmeter

Efficient Simulation of Electromechanical Sensor Systems

Different methods are common practice for the efficient simulation of electromechanical systems (see Schneider [1]). Distinguished methods by its efficiency are circuit models (see Lenk et al. [2]) and block diagrams (see Janschek [3]). In addition to these methods, hardware description languages (HDL) and finite element methods (FEM) have become established in recent years.

As mentioned above, the use of a single simulation method for modeling the complete electromechanical sensor is typically not possible or leads to unsatisfactory results regarding computing time or accuracy. To avoid these issues methods or programs are used which comprise a combination of different simulation methods. In the last years, there are mainly two approaches.

The first approach is the Co-Simulation, where the programs of different simulation methods are coupled via an additional coupling program (see e.g. Schroth et al. [4] and Eccardt et al. [5]). For this purpose, an exchange of data between two simulation programs is realized with an additional coupling program. However, since these coupling programs are custom-made programs adapted to a few simulation tasks, this is not a universal and easily accessible solution.

A second approach is the Combined Simulation which links several simulation methods at the user level (see Starke et al. [6] and Ziske & Neubert [7]). The user generates virtual objects using one method, which are installed in the user interface of another different method. In the data fields are not intervened thereby, i.e. the user does not create coupling programs. This approach is advantageous for understanding of phenomena and relations of a complex system by the engineer. A limiting factor for the practical use is that expert knowledge is required to set up the simulation of a complex electromechanical system.

An additional trend is system simulation packages which are part of major Computer-Aided-Engineering (CAE) programs. For this purpose, a development to include and connect different simulation methods to enable the simulation of complex electromechanical and cyber-physical systems is ongoing. An example for a system simulation module is the Simplorer (ANSYS [8]) which offers the use of circuit models, block diagrams, hardware description language models and C/C++ programs in a model. Furthermore, FE-Models can be connected to the system model via a co-simulation or can be included as Reduce-Order-Model (ROM). Especially the ROM integration can speed-up the simulation drastically [10] but the quality of automatically created ROMs depends strongly on the physical domain and the geometry of the problem. The big advantage of system simulation packages for modeling electromechanical sensors is that virtually all parts of a modern sensor are modeled together. This includes hardware, i.e. the mechanical and electrical subsystems, as well as software, i.e. signal processing algorithms and system software. Nevertheless, there is still work to be done to improve functionality and usability.

A schematic overview of the different simulation approaches is shown in Fig. 2.

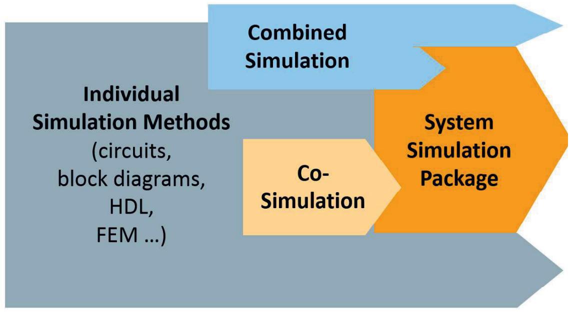

Fig. 2 Simulation approaches for modeling electromechanical sensors

Choosing an Efficient Simulation

An efficient simulation depends not only on the simulation task and the available simulation method, but also on objectives of the simulation, the level of abstraction and the person performing the simulation. Following steps are necessary:

1. define the objectives of the simulation
2. compile the known facts of the simulation task (geometry, material, boundary conditions etc.)
3. partition the electromechanical systems in subsystems which can be modeled independently
4. choose the level of abstraction for the subsystems
5. choose the simulation method(s)
6. validate the model(s)
7. perform simulation
8. interpretation of the results

Especially the first step is very important and often too little attention is paid to it. The model is not the reality and therefor the objectives of the simulation must first be defined in order to derive the necessary range of validity of the model from this. Furthermore, it makes a big difference, whether the model is intended for automated optimization or for understanding.

Based on the defined simulation objectives the model is build up by compiling the properties and boundary conditions of the system. At interfaces with no or with weak interaction the system should be partitioned when possible.

In the fourth step the level of abstraction has to be chosen. The level of abstraction of each subsystem should only be as detailed as necessary. This keeps the computational costs low and makes the model easier to handle and to understand. For subsystems that are not well known, it is very hard to decide which abstraction is sufficient. In such cases, it is often helpful to validate the submodel with test cases first. Afterwards the simulation method for the complete electromechanical system is chosen. For this, the background of the person performing the simulation must also be taken into account in order to ensure optimal use of the model. Prior to the simulation, the model should be validated with simple test cases. The last step is the interpretation of the results. Particularly for electromechanical systems with several physical domains, this is a prerequisite for drawing the correct conclusion

Summary

In the development of electromechanical sensors an efficient simulation is a simulation that gives the necessary answers for a simulation task at the right time in the development process with a reasonable effort. The efficiency depends not only on the physical problem and the available simulation methods, but also on clear objectives for the simulation and on the appropriate abstraction level.

There are several simulation methods with different advantages and disadvantages. For modeling a complete electromechanical sensor, it is typically necessary to combine two or more simulation methods, e.g. by Co-Simulation or Combined Simulation. The future trend is the use of system simulation packages, which are part of CAE programs, e.g. ANSYS Simplorer.

Nevertheless, the basic requirements of an efficient simulation are to set clear objectives, to choose an appropriate level of abstraction and to make an accurate interpretation of the results.

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