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Modelling in Measurement
- From classical analytical approaches to cognitive data-driven solutions –

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Summary:

Models are an inseparable part of Metrology. They make it possible to derive measurement results, including measurement uncertainties, from measurement data or output signals and knowledge about the measurement process. Models establish a functional relationship between the measurand and all relevant quantities on which the measurand depends. Models do not necessarily have to be derived from analytical-functional relationships; they are increasingly data-driven with cognitive capabilities. In general, they are used to design measurement systems, analyze measurement data, make inferences and predictions, and form the basis for evaluating measurement uncertainties.

In industrial measurement and sensor technology as well as in metrology, we have recently seen quite significant, almost revolutionary developments, primarily promoted by the digital transformation process. Probably the most important influence on measurement and sensor technology has been the rapid development of information and communication technology towards systems with cognitive capabilities for context understanding and explainability, interaction, adaptation and learning.

Significant new technological and metrological approaches in measurement and sensor technology are:

Classical modelling approaches. They are based on physical principles and are typically referred to as analytical parametric. However, with the increasing use of digital technologies, large sensor networks, and powerful computers, classical approaches are increasingly being replaced or complemented by data-driven modelling approaches. This is especially true where large, complex and flexible networked sensor systems are used and little expert knowledge of real-world and often changing contexts is available.

Due to the digital transformation, processes in industry are changing with increasing speed. Complex sensor networks are used in fully digitized production processes. Due to the increasing availability of low-cost *Industrial Internet of Things* (*IIoT*)-enabled measurement devices, sensor networks are much larger, more complex and flexible networked than in traditional measurement applications. As a result, and due to incomplete expert knowledge about the systems and their potential changes, data analysis is typically data-driven. Probably the most important influence on measurement and sensor technology has been the rapid development of information and communication technology towards systems with cognitive capabilities for context understanding, interaction, adaptation and learning. In addition, the use of digital twins, where a model of a physical object is updated based on an evolving data set, intentionally increases the flexibility of networking. With this paradigm shift in the treatment and analysis of measurement data, traditional approaches to modelling in metrology need to evolve and be complemented.

Keywords: analytical parametric modelling, data-driven modelling, digital twins, cognitive sensors

The following topics will be discussed in the paper:

- Cause-effect principle in measurement
- Forward and inverse modelling in measurement
- Classical analytical modelling
- Virtual representations in measurement
- Data-driven modelling of cognitive sensors and flexible measurement systems
- Quality and explainability of cognitive systems and abilities in measurement

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