Dynamic Metrology for the Factory of the Future

Development of measurement capabilities and mathematical tools

Sascha Eichstädt, Physikalisch-Technische Bundesanstalt (PTB), Germany
Trevor J. Esward, National Physical Laboratory (NPL), United Kingdom
Nicolas Fischer, Laboratoire National de Métrologie et d’Essais (LNE), France

The state of the art

Modern industrial production and assembly lines increasingly rely on aggregated measurement information from sensor networks, automated system control and decision-making. This requires reliable information about the manufacturing processes, which is to be derived from measurement data. Data analysis and machine learning tools for large data sets, sometimes also called “big data analysis” are often applied to the sensor network data with the aim of compensating for potential measurement deficiencies of the individual sensors.

Such intensive utilization of interconnected measurement devices is often identified as “Industry 4.0” or the “Factory of the Future” (FoF):

*The technological foundation is provided by intelligent, digitally networked systems that will make largely self-managing production processes possible. In the world of Industry 4.0, people, machines, equipment, logistics systems and products communicate and cooperate with each other directly. Production and logistics processes are integrated intelligently across company boundaries to make manufacturing more efficient and flexible.*


A huge number of research activities and medium to large scale research projects have been devoted to the development of improved manufacturing, communication and efficiency. For instance, the European Factories of the Future Research Association (http://www.effra.eu) currently lists over 200 different European research projects addressing topics ranging from advanced materials to robotics.

Many approaches towards instrumenting the factory of the future focus on the visualisation and appropriate aggregation of measurement data. Data analysis tools, such as neural networks and other machine learning methods, aim at compensating the limitations of individual data points by aggregating huge data sets. Many regulations and guidelines addressing secure data communication and data protocols have been published in the last decade. However, to date a sound metrological treatment of sensor networks as envisioned for the factory of the future is missing.

From a metrological perspective, typical limitations of sensors in FoF scenarios are

- Poor precision of the underlying time axis;
- Low accuracy owing to quantization;
- Lack of traceability due to internal digitization;
- Systematic effects in dynamic real-world environments;
- Limited or non-existent provision of measurement uncertainty information;
- Data loss and data corruption owing to communication issues.

The metrological situation at the FoF differs from the usual NMI laboratory calibration environment:

- Measurement systems providing only digital output of pre-processed data;
- Calibration information is sparse or only available on a sensor-type basis;
- Measurements are required for decision-making and conformance testing, unlike an NMI calibration process, where the aim is simply to describe the measuring system;
- Data analysis has to be carried out in real time or close to real time;
- Measurement environments are complex and usually dynamic;
- Synchronization of measurements is poor.

Previous work

Measurement scenarios for the FoF are highly dynamic and real-time data analysis is required. The metrology of dynamic measurements has made good progress in the last decade, including the establishment of primary dynamic calibration for several types of high-precision sensors and the development of mathematical and statistical tools for the analysis of dynamic measurements and the evaluation of dynamic uncertainties [IND09, BAR]. For instance, PTB and NPL have developed mathematical tools for the estimation of dynamic measurands [DEC] and the propagation of uncertainties through the application of digital filters [PTB1, PTB2, PTB3]. Moreover, for over a decade NMIs have been developing primary calibration for accelerometers [PTB4], force transducers, torque sensors and bridge amplifiers [BAR2].

Regarding the reliability of sensor networks from a metrological perspective, NPL has carried out a measurement and data analysis study [NPL1], proposed data aggregation methods [NPL2] and investigated the influence of errors in the sensors’ internal clocks [NPL3]. Recently, NPL has also published a software simulation tool for the investigation of distributed measurement networks [NPL4].

Metrological data analysis and evaluation of measurement uncertainties for distributed sensor networks is currently being developed at several European NMIs as part of the EMRP project GridSens. Software tools for the analysis of dynamic measurements with single sensors are being developed as part of an EMPIR project [14SIP08] and already available publicly as software repository PyDynamic.

Future developments

For the development of a metrological infrastructure for the factory of the future it is necessary to combine recent advances in the analysis of big data sets, time series analysis, system and control theory and recently developed metrological foundation for dynamic measurements. The aim is to enable reliable decisions based on sensor network data in the context of the economic constraints and sustainability requirements of the FoF manufacturing environment. Therefore, the following research activities will be pursued:

- Development of reliable calibration methods for sensors with digital outputs and internal digital signal processing;
- Development of real-time capable data analysis methods that allow the incorporation of the above mentioned limitations of individual sensors in a metrologically acceptable way;
- Establishment of a data structure that allows the reporting of measured values together with statements of their quality.

The data analysis methods to be developed will scale with the number of sensors, providing performance and reliability statements for single sensors as well as for large sensor networks. NMI-level investigations of the measurement capabilities of typical sensors used in modern industrial environments will be carried out, and mathematical and statistical methods for the compensation of their limitations will be developed. As a result of the proposed research activities, guidelines, best-practice guides and software tools will be available to improve the design and implementation of sensor networks and the development of the factory of the future. Furthermore, input and guidance for international standardization bodies will be provided in order to establish metrology for the factory.
of the future. For improved impact, research activities for the development of mathematical and statistical methods for dynamic measurements are coordinated on a European level at MATHMET - The European Centre for Mathematics and Statistics in Metrology.

References


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