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Introductory notes for the Acta IMEKO first issue 2023, Special issue on metrology and digital transformation

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Dear Readers,

The transition of metrology into the emerging digital era has grown to become one of the key challenges in the 21st century for metrologists worldwide. We already know that its highly cross-functional and interdisciplinary nature will lead to many major changes in the field, where not only expertise in measurement science but also skills for digital data, digital infrastructures, and machine-driven processes will play an important role.

IMEKO accompanied by Acta IMEKO is playing an important role in interconnecting experts around the world to share knowledge to foster the transition into the digital future. As a result, IMEKO TC6 was started in 2021 [1]. The aim of TC6 is to develop, organise and disseminate fundamental concepts of measurement science that relate to digitalization and digital transformation in science, industry, and society. The TC promotes the accumulation and curation of knowledge in various forms relating to the digitalization of measurement methodologies and measurement outcomes. Its purpose is to provide a robust body of knowledge to support digital transformation whenever measurement is involved.

Digitalization's multidisciplinary nature is expected to overlap with other IMEKO groups' interests, therefore TC6 encourages collaborations and joint activities with other TCs and partner organizations around the globe.

On 19 – 21 September 2022 TC6 organized the first international conference on metrology and digital transformation – the M4Dconf 2022. With over 50 presentations and more than 200 participants from around the world the conference received great attention. Highlights were the sessions by patron organisations: a session organized by the International Committee on Weights and Measures (CIPM) on the digital transformation of the International System of Units, a session organized by the International Organization in Legal Metrology (OIML), a session on metrological traceability in digital applications by IMEKO TC8, as well as sessions supported by EURAMET and EUROLAB. With further support by APMP, GULFMET and SIM, many more high levels sessions were held providing a broad spectrum of hands-on contributions. Topics included: pathways to digital transformation for small and emerging organizations, representation and use of FAIR (findable, accessible, interoperable, reusable) metrological information, digital infrastructures and technologies, metrology for advanced and sustainable manufacturing, and applications of artificial intelligence methods. In almost 50 % of all presentations, the development and use of machine-readable digital certificates in metrology was presented as an important technology.

On behalf of IMEKO TC6 and the editors, it is a delight that this special issue of Acta IMEKO is dedicated to the 16 best contributions on digitalization in metrology from M4Dconf2022. It wouldn't have been possible without the dedication of the authors, reviewers, conference committee members, editors and the exceptional support of the Acta IMEKO team (Francesco Lamonaco, Dirk Röske and the copy-editors).

The usability and interoperability of conventional quantity-unit system builds the basis for reliable metrological data representation and exchange between both humans and machines. While today's analogue systems are suitable for human users a direct translation into digital formats is posing difficulties to digitalization. The metrology-information layer (M-Layer) is a new approach from research to overcome the limitations by providing profound metadata describing quantity kinds (aspects), units and scales to disambiguate transition between unit systems.

Blair Hall and Mark Kuster have a major contribution to the development of the M-Layer concept. The paper by Mark Kuster [2] reports work toward developing the M-Layer's current abstract conceptualization into a concrete model, working prototype, and demonstration software, with the eventual goal to create a FAIR resource.

Sensor Networks (SN) are becoming an inherent part of many upcoming technologies, including smart cities, smart grids, complex processes monitoring in many industries, autonomous driving, healthcare and many other applications. Martin Koval et al. [3] describe the general approach for SNs in their paper and deal with the principle components of SN architecture, plus the opportunities for the implementation of current and new technologies. Together with other technologies such as AI and utilization of Big Data, the SN is becoming an important tool for optimization of many processes. The SN can help to push the limits in metrology with new effective algorithms in the AI or helping to solve challenges in uncertainty evaluation.

However, SNs as measuring systems underpin many developments in digital transformation, with applications ranging from regulated utility networks to low-cost Internet of Things (IoT). The metrological assessment of sensor networks necessitates a fundamental revision of calibration, uncertainty propagation and performance assessment and new approaches for information and data handling regarding the individual sensors and their interactions in the network to allow a systems metrology approach to be established. The contribution by Sascha Eichstädt et al. [4] introduces some initial findings from recent research and gives an outlook into future developments.

Early in 2022 the National Institute of Standards and Technology embarked on a pilot project to produce digital calibration reports and digital certificates of analysis for reference materials. William Dinis Camara et al. [5] present a paper reporting on the progress of the effort for Reference Material Certificates and discuss some of the challenges and solutions in creating digital certificates. Challenges include the diverse and complex information presently contained in certificates, conversion of values to non-SI units of measurement to match the needs of stakeholders, format updates necessary for machine generation, and the wide variety of reference materials offered.

In automated digital systems and environments such as Industry 4.0 measurement data, including the calibration information, will need to flow through the whole process chain in digital format. The study presented by Juho Nummiluikki et al. [6] demonstrates a fully digitalized environment for calibration data generation, transfer, and usage in a Proof of Concept (PoC) project. It is an outcome from a collaborative approach showing an exchange of calibration information by DCCs from a National Metrology Institute through an accredited laboratory to end-users of calibrated measuring instruments.

Digital technologies have been providing their usefulness in instrumentation and measurements for many years. The ability to use software in measuring instruments became a common practice, bringing the advantage of signal and information processing and interfacing. Instruments can be calibrated and verified in an automated calibration system which can perform all the process without the operator interference. The paper by Cristian Zet et al. [7] presents the possibility of joining an automated calibration system and the creation of DCCs with the Blockchain technology for storing and validating data. Demonstrated benefits are digital traceability of DCC content by preservation of the full history of calibration information in a digital wallet and mechanisms to protect data from change.

Degradation of temperature sensors in harsh environments such as high temperature, contamination, vibration, and ionising radiation causes a progressive loss of accuracy that is not apparent. New developments to overcome the problem of 'calibration drift', include self-validating thermocouples and embedded phase-change cells which self-calibrate in situ by means of a built-in temperature reference and practical primary thermometers, such as the Johnson noise thermometer, which measure temperature directly and do not suffer from calibration drift. All these developments provide measurement assurance which is an essential part of digitalization to ensure that sensor output is always 'right', as well as providing essential 'points of truth' in a sensor network. Jonathan Pearce et al. [8] present in an overview to some state-of-the art developments giving an excellent insight on how data quality can benefit from combining new measurement concepts with digital technologies.

Sensor networks could provide useful new tools for laboratories to increase the understanding of other measurements, to validate assumptions on and optimize existing measurements. A practical application for more accurate determination of the measurement uncertainty of an interferometric long-distance measurement is presented in the work by Gertjan Kok at al. [9]. A network with five temperature sensors was installed in a laboratory to measure a more detailed profile of the ambient temperature. It aims for more accurate determination of values for the refractive index on the path travelled by the laser light. During the measurement campaign an offset in the mean temperature of 0.2 °C was found, which was equal to the maximum allowed bias in view of the claimed uncertainty for the long-distance measurement.

In the framework of EMPIR project ComTraForce, a Digital Twin (DT) concept of force measurement device was developed. DT aims to cover static, continuous, as well as dynamic calibration processes, preserving data quality and collecting calibration data for improved decision-making. To illustrate the DT concept, a prototype realization for static and continuous force calibration processes was developed, involving a simulation with ANSYS engineering software. Oksana Baer et al. [10] report on the current progress of the work in their paper. It is focused on data connection between a physical device and the DT. The DT model is validated using traceable measurements.

In recent years, the need for better data science and data engineering have raised many challenges for metrology concerning the increasing amount of data that needs to be made available in 'appropriate' ways. To ensure findability, accessibility, interoperability, and reusability (FAIR) of digital resources, digital objects as a synthesis of data and metadata with persistent and unique identifiers should be used. In this context, the FAIR data principles formulate requirements that research data and, ideally, also industrial data should fulfil to make full use of them, particularly when Machine Learning or other data-driven methods are under consideration. In the contribution by Tanja Dorst et al. [11], the process of providing scientific data of an industrial testbed in a traceable and FAIR manner is documented as a descriptive example.

'Data metrology', i.e., the evaluation of data quality and its fitness-for-purpose, is an inherent part of many disciplines including physics and engineering. In other domains such as life sciences, health, and pharmaceutical manufacturing these tools are often added as an afterthought, if considered at all. The use of data-driven decision-making and the advent of machine learning in these industries has created an urgent demand for harmonized, high-quality, and instantly available datasets across domains. FAIR principles alone do not guarantee that data is fit-for-purpose. Issues such as missing data and metadata, insufficient knowledge of measurement conditions or data provenance are well known and can be aided by applying metrological concepts to data preparation to increase confidence. A showcase for life science and health care projects where data metrology has been used to improve data quality is presented by Paul M. Duncan et al. [12].

Digitalization will also affect the ways metrologists will handle data in their everyday work. An example of a modern approach to ease annotating, archiving, retrieving, and searching measurement data from a large-scale data archival system is described by Frederic Brochu et al. [13]. Their tool extends and simplifies the interaction with their database and is implemented in popular scientific applications used for data analysis, namely MATLAB and Python. It allows scientists to execute complex interactions with the database for data curation and retrieval tasks in a few simple lines of accessible templated code.

Shifting from paper-based data archives to purely digital ones raises a need for proper tracing of changes in data records without accidentally deleting or overwriting content. Vashti Galpin et al [14] have developed a framework allowing traceable updates in relational databases. They present a prototype web application developed in the programming language Links for storing and displaying DCC using a relational database. Their work leverages the temporal database features that Links provides to capture different versions of a certificate and inspect differences between versions.

Modern programming language type systems help programmers write correct software, and furthermore help them write the software they intended to write. Such type systems could be a powerful tool in the digitalization of metrology. By exploiting advances in dependent type systems, it is possible to strengthen the ability of software to reason about dimensional correctness of metrology data and bridge the gap between human-readable semantic specifications of data, and the actual code representing it in a specific programming environment. Conor McBride et al. [15] show in their paper how expressive types can be used to encode dimension and units of measurement information, which can be used to avoid dimensional mistakes and guide software construction. An automatic creation of source code is considered to further help to eliminate a whole class of potential bugs in software.

Introducing new information systems in organisations is often disruptive for individual departments. Alexander Oppermann et al. [16] show how application of an Operation Layer concept can allow departments to maintain their existing process and infrastructures and still harmonise data through the use of uniform Representational State Transfer interfaces. The automatic data transfer implemented reduces the workload for employees, increases the productivity, integrity and availability of data and greatly reduces the susceptibility to errors.

We hope you will enjoy your reading.

Jon Bartholomew, Daniel Hutzschenreuter, Siniša Prugovečki and Cristian Zet

Guest Editors for the Special Issue on metrology and digital transformation

REFERENCES

[1] IMEKO, IMEKO TC6 homepage. Online [Accessed 24 March 2023] https://www.imeko.org/index.php/tc6-homepage
[2] Mark J. Kuster, Toward a metrology-information layer for digital systems, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-4. DOI: 10.21014/actaimeko.v12i1.1416
[3] Martin Koval et al., General Sensors Network application approach, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-5. DOI: 10.21014/actaimeko.v12i1.1409
[4] Sascha Eichstädt et al., Fundamental aspects in sensor network metrology, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-6. DOI: 10.21014/actaimeko.v12i1.1417
[5] William Dinis Camara et al., DIGITAL NIST: An examination of the obstacles and opportunities in the digital transformation of NIST's reference materials, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-4. DOI: 10.21014/actaimeko.v12i1.1403
[6] Juho Nummiluikki et al., Digital Calibration Certificate in an industrial application, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-6. DOI: 10.21014/actaimeko.v12i1.1402
[7] Cristian Zet et al., Automated calibration and DCC generation system with storage in private permissioned Blockchain network, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-7. DOI: 10.21014/actaimeko.v12i1.1414
[8] Jonathan Pearce et al., Progress towards in-situ traceability and digitalization of temperature measurements, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-6. DOI: 10.21014/actaimeko.v12i1.1386
[9] Gertjan Kok et al., Improved uncertainty evaluation for a long distance measurement by means of a temperature sensor network, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-6. DOI: 10.21014/actaimeko.v12i1.1411
[10] Oksana Baer at al., Digital Twin concept of a force measuring device based on the finite element method, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-5. DOI: 10.21014/actaimeko.v12i1.1404
[11] Tanja Dorst et al.: A Case Study on providing FAIR and metrologically traceable data sets, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-6. DOI: 10.21014/actaimeko.v12i1.1401
[12] Paul M. Duncan et al., Metrology for data in life sciences, healthcare and pharmaceutical manufacturing: Case studies from the National Physical Laboratory, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-5. DOI: 10.21014/actaimeko.v12i1.1406
[13] Frederic Brochu et al., A tool for curating and searching databases proving traceable analysis of data and workflows, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-6. DOI: 10.21014/actaimeko.v12i1.1408
[14] Vashti Galpin et al., Tracking and viewing modifications in digital calibration certificates, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-7. DOI: 10.21014/actaimeko.v12i1.1407
[15] Conor McBride et al., Measuring with confidence: leveraging expressive type systems for correct-by-construction software, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-5. DOI: 10.21014/actaimeko.v12i1.1412
[16] Alexander Oppermann et al., Digital transformation: Towards a cloud native architecture for highly automated and event driven processes, Acta IMEKO, vol. 12 (2023) no.1, pp. 1-6. DOI: 10.21014/actaimeko.v12i1.1410