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Introductory notes for the Acta IMEKO first issue in 2026

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Dear Readers,

the present issue of Acta IMEKO collects a set of contributions that clearly illustrate the evolving role of measurement science as a cornerstone of technological progress and societal development. The published works span a wide spectrum of applications, including biomedical diagnostics, industrial metrology, energy systems, environmental monitoring, advanced instrumentation, and digital infrastructures. Such diversity reflects the intrinsic interdisciplinarity of modern metrology and its increasing integration with computational intelligence, digital technologies, and emerging paradigms such as Industry 4.0 and Metrology 4.0.

A common thread across many contributions is the adoption of advanced data processing techniques, ranging from artificial intelligence and machine learning to stochastic modelling and optimization algorithms, to enhance measurement accuracy, robustness, and efficiency. At the same time, several studies emphasise the fundamental importance of uncertainty evaluation, traceability, and standardisation, reaffirming their central role in ensuring the reliability and comparability of measurement results across different domains and applications.

Furthermore, this issue highlights the growing contribution of metrology to sustainability-related challenges. From renewable energy production and greenhouse gases monitoring to resource-efficient digital infrastructures and sustainable education models, the presented works demonstrate how measurement science can actively support the transition toward more sustainable and resilient systems.

In this context, the contributions included in this issue can be directly associated with specific United Nations Sustainable Development Goals (SDGs), underlining the strategic relevance of metrology as an enabling discipline for achieving global sustainability targets. As EiC it is my pleasure to briefly introduce this issue papers.

Nowadays, breast cancer is a common cancer among people. Fortunately, early detection of the tumour can save many lives. Thermography uses infrared cameras to measure temperature changes on the skin's surface. In breast cancer, tumours cause increased blood flow and higher temperatures in the affected area. These temperature changes appear as hot spots in the thermographic image. Thermography can assist in early detection of cancer, but it is not sufficient for a definitive diagnosis on its own and should be used in conjunction with other methods like mammography. The article in [1] proposes and assesses an effective approach to enhance the performance of computer aided detection (CAD) systems that employ the ant colony-based swarm intelligence algorithm for breast cancer detection. The article focuses on using the Segmentation Fractal Texture Analysis (SFTA) technique for feature extraction, applying the ant colony algorithm, and the hybrid of ant colony and firefly algorithms to the extracted features to identify the most relevant ones, and classification of the selected feature groups using DTree, k-Nearest Neighbors (kNN), and Support Vector Machine (SVM) algorithms. The results indicate that the obtained accuracy, specificity, and sensitivity are 98 %, 97 %, and 99 %, respectively. The experimental results using 200 images from the Database for Mastodology Research (DMR) indicate that applying an ant colony-based feature selection algorithm can considerably enhance breast cancer detection using thermography images. This paper clearly fits with SDG 3 – Good Health and Well-being. Indeed, the proposed CAD system enhances early detection of breast cancer through improved feature selection and classification accuracy. By increasing diagnostic reliability, the work supports preventive healthcare and contributes to reducing mortality associated with non-communicable diseases.

In the last two decades, the interest in digital image correlation (DIC) has grown steadily in various industrial and scientific fields, thanks to its contactless nature, capability to provide full field measurements, and ease of implementation. The possibility to carry out measurements in the presence of significant relative motion between the camera and the target has been thoroughly investigated. In dynamic conditions, the main additional source of uncertainty is represented by the motion blur effect, which is

experienced whenever the relative displacement between the camera and the target during the exposure time is not negligible. Motion blur is a source of uncertainty, since it decreases the contrast in the image and the definition of the speckles in the acquired pattern. In [2], a complete procedure for motion blur estimation and compensation is considered. It was found that the uncertainty in the estimation of the blur intensity and orientation plays a crucial role in motion blur compensation. The Author propose a technique for the optimisation of the blur estimation and compensation phases based on fitting the motion optical transfer function to a motion model. Compensation with a Wiener filter is then performed, studying different approaches to image noise estimation. Results show that the optimized procedure has a positive effect on DIC performances, being able to reduce the effect of motion blur on uncertainty, in particular for motion blur levels larger than about 1–2 px. The entire work has been validated by considering the procedure performances on DIC analysis performed on different kinds of speckle image with various amounts of motion blur applied. This paper clearly fits with SDG 9 – Industry, Innovation and Infrastructure. The optimization of motion blur compensation improves the accuracy of full-field optical measurements under dynamic conditions, enabling more reliable structural analysis and supporting advanced industrial monitoring systems.

To address the new metrological challenges brought about by the digital revolution, a series of projects has recently been developed worldwide with the primary aim of promoting a new infrastructure for digital legal metrology. These projects include the use of cloud technologies to support conformity assessment processes, the development of infrastructure for digital calibration certificates, research on the comparability of real and virtual measurements, and the development of assessment methods for machine learning and artificial intelligence. The objective of the paper in [3] is to present Pandora IRTech, a calibration and management software that utilises concepts and technologies from the Fourth Industrial Revolution. The software was built from a conceptual model based on state-of-the-art studies, process mapping, and risk assessment, identifying optimised structures and functionalities for its development. Finally, the applications created to optimise the calibration process and laboratory management in the current context of the digital revolution in metrology are presented and discussed. This paper clearly fits with SDG 9 – Industry, Innovation and Infrastructure. The development of a digital calibration and management platform aligned with Industry 4.0 enhances traceability, interoperability, and efficiency in metrological processes, fostering innovation in industrial measurement infrastructures.

Atomic frequency standards realise the measurement of the atomic transition frequency between two well-defined quantum energy levels. The study in [4] uses the Euler–Cromer method to numerically analyse the atomic transition probabilities for the caesium fountain clock, based on the Ramsey method of separate fields. Consequently, this examination successfully attains an optimal compromise correlation among the oscillating field (BO), static field (BZ), and detuning (δw). Thus, this work presents a new tool for time and frequency metrology standardization. This paper clearly fits with SDG 9 – Industry, Innovation and Infrastructure. Improved modelling and optimisation of atomic transitions contribute to the advancement of time and frequency standards, which are fundamental for telecommunications, navigation, and scientific research infrastructures.

Certified Reference Materials (CRMs) are indispensable for ensuring food safety, playing a fundamental role in method development, validation, and both internal and external quality assurance. Given the growing consumption of selenium-based dietary supplements and the associated health risks of improper dosage, the availability of specific CRMs is crucial for regulatory compliance and consumer protection. The study in [5] presents the production and certification process of a selenium-enriched yeast reference material. The certification of this CRM (CRM 8969.0001) was conducted by the Inorganic Analysis Laboratory (Labin) of the National Institute of Metrology, Quality and Technology (Inmetro). The work comprises the procedures for batch preparation, homogeneity assessment, stability studies, and material characterisation. This CRM provides a critical tool for Brazilian manufacturers and analytical laboratories to ensure the quality and safety of selenium supplements. This paper clearly fits with SDG 3 – Good Health and Well-being. Indeed, the development of a certified reference material ensures accurate quantification of selenium in dietary supplements, supporting food safety, regulatory compliance, and protection against health risks related to improper dosage.

As part of energy transition, many studies have considered biogas as a renewable energy source. To use it as a fuel, a purification process is necessary, so that it becomes biomethane, with a higher concentration of methane and calorific value. The quality control of biomethane from landfills intended for vehicle use is established by ANP Resolution No. 886 of 2022. To comply with this Resolution, it is necessary to correctly measure the composition of the components, using high-precision analytical methods. Therefore, the analytical methods were adapted so that they can determine the composition of the major components present in biomethane. The work in [6] sought to adapt and validate analytical methods to subsequently evaluate the composition of a biomethane sample, produced by the gas industry, containing methane, carbon dioxide, and oxygen, and to verify whether the results are in accordance with the parameters reported in the Resolution. Metrological tools were used to quantify biomethane, such as certified reference materials, calibrated instruments, and a validated method. Based on the results, it was possible to conclude that the methods are suitable for their intended use, and that the methane composition does not comply with the limit established in the resolution. This paper clearly fits with SDG 7 – Affordable and Clean Energy. Indeed, the validation of analytical methods for biomethane composition supports quality control in renewable fuels, contributing to the reliability and adoption of cleaner energy sources.

In radiopharmaceutical production centres and nuclear medicine services, the use of short-lived radionuclides as radiotracers is essential, with growing applications and attracting the interest of national metrology laboratories. These laboratories are responsible for ensuring the traceability of radioactive standards, which is crucial for the precise determination of the activity of used radiopharmaceuticals. However, the short half-life of radionuclides complicates direct traceability for nuclear medicine services (NMS). To overcome this limitation, the National Laboratory for Ionizing Radiation Metrology (LNMRI) is developing a mobile system based on an NaI(Tl) scintillation detector. The study in [7] aims to present the schematic arrangement of the proposed system for calibrating dose calibrators, as well as to conduct characterisation tests of its main parameters and determine calibration factors for specific radionuclides. This development seeks to ensure traceability for

key radiopharmaceuticals used in nuclear medicine services, providing greater accuracy and reliability in diagnosis and treatment. This paper clearly fits with SDG 3 – Good Health and Well-being. The development of a mobile calibration system ensures traceability of radionuclide measurements, improving the accuracy and safety of radiopharmaceutical applications in medical diagnostics and treatment.

Ultrasound techniques are widely used for monitoring chemical reactions and characterising liquids. While the speed of sound in pure fatty acid esters (methyl and ethyl) is reasonably well established, the influence of molar ratio and alcohol type on the speed of sound in biodiesel across different frequencies remains unexplored. The study in [8] investigates the ultrasonic characterisation of soybean biodiesel produced using different alcohols and molar ratios at frequencies of 1 MHz, 5 MHz, 7.5 MHz, and 10 MHz. The speed of sound in biodiesel samples was measured using the pulse–echo technique, with the expanded uncertainty determined at a 95 % confidence level. The results show that biodiesel samples produced with different alcohols at the same molar ratio exhibit distinct speed of sound values. Additionally, biodiesel synthesised at a 6:1 molar ratio demonstrated the lowest speed of sound. The findings confirm that ultrasound effectively differentiates biodiesel samples based on speed-of-sound measurements. This study highlights ultrasound as a promising technique for identifying biodiesel production pathways, offering a non-invasive and efficient analytical tool for quality assessment. This paper clearly fits with SDG 7 – Affordable and Clean Energy. The use of ultrasonic techniques for biodiesel characterisation provides a non-invasive method for quality assessment, supporting the optimization and standardization of biofuel production processes.

Ultrasonic testing is widely used in industrial non-destructive evaluation; however, the influence of transducer contact force on signal stability during conventional contact measurements is still insufficiently documented for metallic specimens. The study in [9] investigates the effect of applied contact force on ultrasonic wave velocity and signal amplitude in SAE 1020 carbon steel, using a 5 MHz contact transducer and a controlled loading device. Three cylindrical specimens were tested under increasing, decreasing, and cyclic force protocols within a range from 2 to 20 kgf. The results showed negligible variation in ultrasonic velocity throughout the investigated force range, whereas signal amplitude increased markedly at low forces and reached a plateau near 10 kgf. These findings indicate that contact force primarily affects coupling efficiency and signal amplitude, rather than bulk wave velocity, under the present experimental conditions. The proposed procedure contributes to improved repeatability and supports more reliable contact-based ultrasonic measurements in industrial practice. This paper clearly fits with SDG 9 – Industry, Innovation and Infrastructure. Indeed, by improving the repeatability and reliability of non-destructive testing procedures, the study contributes to safer and more durable industrial components and infrastructures.

Liquefied Petroleum Gas (LPG) is a versatile fuel with high energy content, easy storage, and a lower environmental impact if compared to other fossil fuels. It is widely used in industry, commerce, and agriculture, making accurate systems for measuring LPG mass—the product's trading unit—essential. The study in [10] evaluates the main factors influencing mass measurements in dynamic systems, considering regulatory standards and calculation algorithms. The measurement function and associated uncertainty calculation are presented, along with the key contributors to expanded uncertainty: corrections for pressure, density, and temperature. These account for approximately 45 %, 43 %, and 9 %, respectively, of the total uncertainty, based on experimental averages. Results show that the uncertainty limits established for secondary quantities by the Brazilian Institute of Metrology, Quality, and Technology have limited practical relevance. Although individual uncertainties exceed prescribed limits, the maximum uncertainty of LPG mass—the primary variable—remains compliant, underscoring the importance of output-focused criteria. Finally, the study recommends future research to refine acceptance criteria for individual calibration, aiming to ensure more efficient and reliable LPG mass measurements. This paper clearly fits with SDG 7 – Affordable and Clean Energy. The evaluation of uncertainty sources in LPG measurement systems enhances accuracy in fuel quantification, which is essential for fair trade, efficient distribution, and energy management.

The study in [11] focuses on the uncertainty analysis of pressure transducers, which are widely used in industrial applications. Pressure transducers convert mechanical pressure into electrical signals for measurement and monitoring across diverse sectors, like aerospace, automotive, and medical fields. The paper proposes a novel method for performing calibration uncertainty analysis through relativization, allowing the normalisation of uncertainty contributions to various measurement parameters. By applying this approach, the study offers a standardised method to understand and quantify the impact of different sources of error on the overall measurement uncertainty. Furthermore, the techniques discussed in the study are applicable not only to pressure sensors but also to other measurement systems with multiple output units, contributing to the accuracy and reliability of measurement processes across various industries. This paper clearly fits with SDG 9 – Industry, Innovation and Infrastructure. Indeed, the proposed normalization-based uncertainty framework improves calibration practices and can be generalised to multiple measurement systems, supporting industrial measurement reliability.

In [12] it is presented a gate-time-resolved evaluation of frequency-measurement uncertainty using the GUM analytical framework and large-scale Monte Carlo simulations. The experiment employed a time-interval counter (TIC) disciplined by a 10 MHz reference from a Cesium (Cs) clock to measure phase differences against a Rubidium (Rb) oscillator. Phase data were collected continuously over two days to analyse oscillator stability, and additional frequency datasets at 1 ms, 100 ms, and 1 s gate times, each spanning ten minutes, were examined to assess the effect of averaging time on measurement uncertainty. Uncertainty was evaluated using the GUM model and a Python-based parametric Monte Carlo simulation with one million iterations. A moving-block bootstrap (MBB) method was additionally applied to the same data to assess the influence of time-correlated noise. The results show that GUM slightly overestimated expanded uncertainty at short gate times (−8.38% at 1 ms, −3.37 % at 100 ms, 0 % at 1 s). Kurtosis analysis revealed non-Gaussian behaviour at shorter averaging times, while Allan-variance analysis identified transitions between white, flicker, and drift noise regimes. These findings demonstrate that simulation-based approaches can capture temporal correlations more effectively, enabling realistic and automated uncertainty evaluation in time-and-frequency metrology under the Metrology 4.0 framework. This paper clearly fits with SDG 9 – Industry, Innovation and Infrastructure. Indeed, the integration of Monte Carlo simulations and statistical analysis enables more realistic

uncertainty evaluation in time and frequency metrology, particularly under non-Gaussian and time-correlated noise conditions.

In [13], Authors present the experimental evaluation of an optimal control solution for the Quanser gyroscope system. To address the challenge of manually tuning the $\boldsymbol{Q}$ and $\boldsymbol{R}$ weighting matrices of the traditional Linear–Quadratic Regulator (LQR) controllers, which perform poorly when system parameters vary, they developed an optimal controller based on a Genetic Algorithm. This method automatically searches for optimal $\boldsymbol{Q}$ and $\boldsymbol{R}$ values based on the Integral of Absolute Error (IAE) criterion, ensuring precise trajectory tracking and fast response. Experimental results demonstrate that the proposed optimal controller exhibits superior performance, with a settling time of 1.98 s, zero overshoot, and a steady-state error of only 0.21 degrees. The most significant contribution of this study, however, is the rigorous experimental implementation and validation of the actual Quanser hardware. Data from the hardware demonstrates the controller's superior, stable operation, enhanced accuracy, and robust dynamic response compared to standard LQR in a real-world environment. These results affirm the potential of the developed method, even when the system is subjected to noise, delays, and nonlinearities. The paper highlights the crucial role of hardware validation in translating theoretical advancements into reliable and effective practical control solutions. This paper clearly fits with SDG 9 – Industry, Innovation and Infrastructure. Indeed, the development of adaptive control strategies improves system performance and robustness, contributing to advancements in automation and control engineering applications.

University laboratories are essential for engineering education, but they often require significant resources in terms of energy, equipment, and space. The paper in [14] presents a comparative Life Cycle Assessment of two models: a traditional measurement laboratory with 20 physical workstations and an immersive digital twin-based laboratory (*IM-MetaLAB*) supported by one high-performance workstation and 20 virtual reality headsets. The study extends the Life Cycle Assessment framework to the triple bottom line, jointly addressing environmental, economic, and social dimensions. Results highlight substantial advantages of the immersive model. Energy demand decreases from 18,000 to 7,000 kWh/year, with associated emissions reduced by more than 60 %. Over a seven-year horizon, electronic waste is reduced from 500–600 kg to about 200 kg. Economically, capital expenditures drop from approximately 100,000 € to 25,000 €, while annual operating costs fall from 17,000 € to 5,000 €, yielding a per-student exercise cost four times lower. Socially, immersive access enables remote 24/7 participation, improves completion rates (70 % vs 56 %) and average grades (27.4/30 vs. 25/30), and eliminates commuting emissions (≈ 24 tCO2/year for 40 students). The immersive laboratory thus proves to be a sustainable, cost-effective, and pedagogically effective alternative to the traditional activities, showing how digital twin and virtual reality technologies can support both innovation in teaching and institutional sustainability goals. This paper clearly fits with SDG 12 – Responsible Consumption and Production. Indeed, the life cycle assessment demonstrates significant reductions in energy consumption, emissions, and resource use through virtual laboratories, supporting sustainable education and resource efficiency.

Dilution of precious goat milk with cheaper cow milk represents one of the most common types of food fraud in the dairy industry. Existing methods for detecting the presence of cow milk mainly rely on chemical tests or spectroscopic analyses, which require dedicated laboratory facilities, expensive instrumentation, complex sample preparation, and long waiting times for results. In [15], the Authors propose an innovative method based on the combination of speckle pattern imaging and artificial intelligence models to detect the adulteration of goat milk with cow milk. The instrumental setup Authors developed is based on a low-cost semiconductor laser and an industrial CMOS camera. In the paper, the Authors have analysed five milk samples and applied well-established machine learning models, achieving an accuracy of 96.9 % on the test set. These results are very promising and pave the way for the development of new opto-electronic systems to fight milk adulteration. This paper clearly fits with SDG 2 – Zero Hunger. The proposed method enhances food authenticity verification, contributing to food safety, quality assurance, and consumer protection within the agri-food sector.

Networked measurements are essential for the design and implementation of cooperative cyber-physical systems in the Industry 4.0/5.0 era. Indeed, the need for accurate models of real-time communication systems and, especially, of their latency is paramount for enabling technologies such as advanced manufacturing solutions, simulation, and industrial internet. The paper in [16] presents a novel approach to measuring latency in wireless communication networks, focusing on the metrological characterization of individual subsystem contributions. By leveraging Time-Sensitive Networking (TSN) for synchronisation, and employing cost-effective hardware solutions, Authors aim to provide a structured assessment of the measurement system's capability to isolate and quantify latency contributions of individual communication modules, from the protocol stack to the Wireless Network Interface Controller (WNIC). The proposed approach is practical, flexible, and adaptable to various environments and deployment scenarios, representing a significant advancement in latency measurement techniques for modern network environments. This paper clearly fits with SDG 9 – Industry, Innovation and Infrastructure. Accurate latency characterization supports reliable real-time communication systems, which are essential for industrial automation and cyber-physical systems.

The study in [17] presents and validates two simplified methods to estimate the frontal area of swimmers during active motion, based on video recordings from frontal and lateral views. The aim is to provide low-complexity and practical tools suitable for use in some everyday sport training environments, such as swimming pools. The frontal view enables a direct measurement of the true projected area but is affected by factors such as the water transparency and the variable swimmer-camera distance. Although providing only a 2D projection, the lateral view benefits from a short working distance and good stability, improving the analysis of posture-related features such as body alignment and angle of incidence. By tracking and analysing the evolution of the frontal area over the stroke cycle, the proposed methods allow the separation of propulsive and resistive contributions, revealing stroke-specific technical patterns. The results show that this approach can detect changes in technique, posture, and performance across different swimming styles and for the same athlete under varying conditions. Despite limitations in absolute accuracy due to simplified calibration and environmental variability, the system demonstrates sufficient repeatability and sensitivity for comparative analysis. The methods support biomechanical evaluation and feedback,

contributing to technique refinement and improved swimmer performance. This paper clearly fits with SDG 3 – Good Health and Well-being. The proposed methods support performance analysis and training optimization in sports science, promoting physical health and well-being.

Environmental issues, including global warming, dependence on fossil fuels, deforestation, and rising CO_2 emissions, have become major challenges worldwide. In Türkiye, fossil fuel demand has continued to rise over the past two decades, despite policies promoting renewable energy. The effectiveness of these policies on transport-related greenhouse gas (GHG) emissions remains uncertain. To address this gap, the study in [18] analyses the long-term evolution of transport emissions over the last 33 years, integrating inventory-based estimates with experimental measurements to provide a metrologically validated dataset. Portable exhaust gas analysers (Horiba PG-350 and Testo 350XL) were used in conjunction with calibrated thermal mass flow meters and thermocouples to quantify CO_2, CH_4, and N_2O emissions across various vehicle types and load conditions. Calibration traceability and uncertainty estimation were performed in accordance with ISO/IEC 17025 and the GUM guidelines. Experimental results were compared with IPCC Tier 2 estimates, showing close agreement for CO_2 (± 3.8 %) and larger variability for CH_4 and N_2O. These findings highlight the essential role of metrology in improving the reliability of emission data and support the integration of measurement-based validation into national GHG inventory frameworks. This paper clearly fits with SDG 13 – Climate Action. The integration of metrological validation into emission inventories improves the reliability of greenhouse gas data, supporting evidence-based climate policies and mitigation strategies.

In [19], the Authors describe the realisation of a time-of-flight scanning LiDAR (Light Detection and Ranging) prototype, that leverages mirrors as micro-electromechanical systems (MEMS) for agile beam steering in a compact size, and a field-programmable gate array (FPGA)-based processing unit for real-time 3D image reconstruction. The proposed 3D LiDAR system is designed to operate within a range of up to 1 meter with a spatial resolution of 400 × 300 pixels at a frame rate of 30 Hz. The LiDAR prototype architecture consists of 3 main parts: an optomechanical system, a digital processing unit (FPGA-based), an analog front-end. Processed 3D depth maps are rendered in real time via a high-definition multimedia interface (HDMI), providing immediate visual feedback. The full system was deeply characterised and tested. The integration of MEMS mirrors, an FPGA-based time-to-digital converter, and an optimised analog front-end resulted in a highly efficient, compact, and real-time depth sensing platform, ready for a final engineering step. The results obtained represent a feasibility study for a potential commercial product, that is low-cost and small-size, with different consumer applications. This paper clearly fits with SDG 9 – Industry, Innovation and Infrastructure. The development of compact and real-time 3D sensing systems enables advanced applications in automation, robotics, and industrial inspection.

Underwater communication traditionally relies on acoustic systems, which suffer from high energy consumption, significant latency, and undesirable environmental impact. Optical wireless communication (OWC) technologies represent a promising alternative, yet they are strongly limited by light attenuation in water, especially under turbid conditions. In [20], an innovative low-cost underwater optical wireless communication (UOWC) system based on red LEDs (light-emitting diodes) and photodiodes was developed, allowing not only data transmission, but also experimental characterisation of signal degradation in turbid water. The system was tested by varying the concentration of suspended clay to evaluate the reduction in optical intensity and data transmission rate. Results show a maximum data rate of 1.5 Mbit/s in clear seawater, followed by an exponential decrease in performance as turbidity increases. The proposed approach provides a reproducible and low-cost method for studying the underwater optical channel and represents a foundation for future developments aimed at optimising UOWC systems in more complex and realistic scenarios. This paper clearly fits with SDG 14 – Life Below Water. Indeed, the study advances low-impact underwater communication technologies, supporting marine monitoring and reducing reliance on environmentally intrusive acoustic systems.

I hope you will enjoy your reading.

Francesco Lamonaca
Editor in Chief

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