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Introductory notes for the Acta IMEKO thematic issue on the 2023 SBM Metrology Conference – part 1

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Dear Readers,

This special issue presents a diverse collection of research papers demonstrating metrology's fundamental role in advancing scientific knowledge and technological innovation. The contributions span multiple disciplines, showcasing how precision measurement techniques continue to evolve and find new applications across various fields. From fundamental constants to practical instrumentation, these studies highlight the importance of accurate measurement in supporting basic research and practical applications that benefit society.

The development of the Kibble balance represents one of the most significant achievements in modern metrology, enabling the redefinition of the kilogram based on fundamental physical constants rather than a material artifact. The study presented in [1] describes an innovative approach to constructing a Kibble balance using 3D-printed components at Inmetro's Laboratory of Ultrasound. This prototype demonstrates the feasibility of building gram-level measurement instruments using accessible manufacturing techniques, achieving reasonable measurement uncertainty (maximum 14 %) despite being constructed primarily from plastic components. The balance operates on the principle of relating electrical power to mechanical power through both velocity and force modes, successfully measuring masses in the range of 100-600 mg. Beyond its technical achievements, this work highlights the potential for democratizing precision metrology by making sophisticated measurement principles accessible through simplified, cost-effective implementations. The prototype serves not only as a functional instrument but also as an educational tool that can help students and researchers understand the fundamental physics underlying mass measurement based on the Planck constant.

The study presented in [2] addresses a critical aspect of electrical metrology by investigating measurement uncertainty improvement in electric current source calibration through the use of precision shunts. This research compares direct current measurement using precision ammeters with an indirect method employing precision shunts and voltmeters, demonstrating that the indirect approach can significantly reduce measurement uncertainty despite involving more uncertainty sources. The authors provide a comprehensive analysis of uncertainty sources inherent to precision shunts, including calibration drift, temperature variations, self-heating effects, AC-DC differences, and loading influences. Particular attention is given to the AC-DC difference, which often dominates the uncertainty budget at high frequencies, and the loading effect that becomes more significant as shunt resistance increases. Through practical examples using a Fluke 5720A multifunction calibrator with a Fluke A40B-10A precision shunt, the study demonstrates the effectiveness of this approach for both DC and AC current source calibration, providing valuable insights for National Metrology Institutes and calibration laboratories seeking to enhance measurement accuracy.

The research presented in [3] investigates the evolution of the 25th solar cycle through ionospheric delay measurements using the GPS P3 method in southeastern Brazil, contributing to our understanding of space weather effects on precision timing systems. This study leverages Brazil's National Institute of Metrology's UTC(INXE) time scale facility located in a region affected by the South Atlantic Magnetic Anomaly (SAMA), where reduced magnetic field intensity creates conditions similar to equatorial latitudes despite the mid-latitude geographic position. The authors employ the GPS P3 ionosphere-free code technique to measure Total Electron Content (TEC) variations, demonstrating clear correlations between Vertical TEC (VTEC) amplitude and solar sunspot numbers throughout the current solar cycle. The research reveals distinct daily, seasonal, and annual patterns, with higher VTEC values observed during summer months (10-30 TECU) compared to winter (5-15 TECU), and peak ionospheric activity occurring between 12-24 hours during summer periods. Significantly, the study confirms that the 25th solar cycle is exhibiting higher than predicted sunspot activity, with peak activity expected in mid-2025, suggesting increased ionospheric effects on Global Navigation Satellite Systems in the near future. This work provides valuable insights for time and frequency transfer applications and highlights the importance of monitoring ionospheric conditions for maintaining precision in satellite-based timing systems.

Reference [4] introduces an innovative computer vision-based methodology for calibrating line scales that eliminates the need for traditional displacement measurement systems while maintaining metrological traceability. This study addresses significant limitations in conventional calibration methods, which rely on time-consuming visual comparisons between scales using graduated magnifying glasses, by proposing an automated system that reconstructs complete scale images through advanced image processing techniques. The methodology employs Harris corner detection algorithms to identify corresponding points across sequential images, followed by correlation analysis and linear transformation to create a unified composite image of the entire scale. The authors demonstrate the system's effectiveness using a Basler scA1000-30gm camera with LED illumination, achieving pixel-level precision measurements through Otsu binarization methods for mark centre determination. Validation tests conducted on a calibrated 600 mm scale showed excellent compatibility with reference standards, with normalized errors below 0.7 for all measurements and achieving uncertainties as low as 0.02 mm (95.45 % confidence) when using high-magnification configurations. The research successfully demonstrates that reliable and traceable calibration results can be obtained without direct physical displacement measurement systems, offering a more accessible and cost-effective approach to scale calibration while maintaining the precision required for metrological applications. This advancement represents a significant step toward democratizing precision measurement tools through the integration of computer vision technologies with traditional metrology practices.

The study presented in [5] addresses critical aspects of digital camera-based colorimetric measurements by systematically evaluating how acquisition parameters influence measurement accuracy in food quality assessment applications. This research tackles a significant gap in the literature where camera settings such as ISO sensitivity, aperture values, and exposure time have been largely overlooked despite their potential impact on colour measurement reliability. The authors developed a controlled measurement system using a Canon T3 digital camera, 24-ColorChecker colour plate, and D65 illumination within a stabilized environment, comparing results against a calibrated ColorFlex colourimeter as the reference standard. Through comprehensive testing across three aperture settings (f/1.8, f/5.6, and f/36) and seven ISO levels (100-6400), the study employed factorial experiment analysis and ANOVA techniques to quantify the statistical significance of parameter influences on Lab* colour space measurements. The research revealed that aperture settings significantly affect colour values regardless of the evaluation method used, while ISO sensitivity showed varying influences depending on whether luminance (L) values were included in the analysis. Specifically, ISO variations demonstrated minimal impact on ΔE calculations (which include luminance) but showed significant effects on ΔH measurements (which exclude luminance), indicating that ISO can effectively compensate for lighting deficiencies in ΔE-based applications without compromising results. This work provides essential guidance for implementing digital camera-based colorimetric systems in food industry applications, establishing the foundation for more reliable and standardized colour measurement protocols.

The research presented in [6] introduces an innovative double-faced optical-interferometric methodology for accurately estimating gauge block Fo/Fu dimensional variations, addressing fundamental limitations in conventional single-sided interferometric measurements. This study confronts the critical assumption that lower gauge surfaces and wringing plates are ideally planar, which can introduce significant errors in dimensional measurements when surface irregularities are present. The authors developed a comprehensive geometric modelling approach that classifies gauge block profiles into six generalized forms (Bi-Plane, Plane-Convex, Plane-Concave, Bi-Convex, Bi-Concave, and Convex-Concave) based on surface curvature characteristics determined through double interferometric measurements of opposite faces. The methodology employs sophisticated algorithms that utilize least-square routines to deduce surface tilt and curvature parameters from five-point measurements, subsequently applying appropriate corrections to account for "hidden" lengths at support points. Validation experiments using steel gauge blocks (1.01 mm and 1.005 mm nominal lengths) demonstrated the method's effectiveness, with measurement uncertainties achieving ±10 nm at 2σ confidence levels, comparable to double-ended interferometric systems. The study revealed substantial length variations caused by form deviations, particularly highlighting a significant centre length variation in a bi-concave gauge block configuration. This approach represents a significant advancement in dimensional metrology by enabling single-sided interferometers to achieve measurement accuracies previously only attainable with more complex double-sided systems, thereby improving the compatibility between optical and mechanical measurement methods while maintaining traceability to fundamental standards.

The study presented in [7] provides a comprehensive investigation of systematic effects in Mitutoyo's short gauge block interferometer (GBI), addressing critical aspects of measurement reliability and accuracy enhancement for Brazil's national dimensional metrology capabilities. This research tackles the challenge of maintaining measurement continuity and quality during planned instrument upgrades by systematically analysing wavefront curvature effects, imager defects, and phase determination accuracy through advanced processing algorithms. The authors developed sophisticated interferogram processing software that employs least-squares fitting techniques using all 16 phase-stepped data points, achieving superior stability and accuracy compared to conventional 4-point algorithms, with uncertainty improvements from 0.005 to 0.001 fringe fraction. Through comparative analysis using both GBI and Zygo interferometer measurements of calibration flats, the study demonstrated that the GBI possesses excellent wavefront quality, with residual uncertainty within 3 nm after flatness correction. The research revealed that systematic effects from saturation and imaging defects contribute uncertainties of approximately 5 nm (k = 2) for standard processing and 2 nm (k = 2) for the improved algorithm, while wavefront curvature effects remain within 6 nm (k = 2). Theoretical simulation studies using controlled interferogram stacks validated the processing algorithms' performance under various conditions, confirming the stability of both processors against pixel noise and saturation effects. This work establishes essential knowledge for maintaining Brazil's measurement capabilities in international comparisons and provides a foundation for future interferometer improvements while ensuring traceability and measurement quality are preserved during technological upgrades.

The research presented in [8] demonstrates an innovative step-down calibration method for evaluating the stability of 1 Ω and 10 kΩ standard resistors, addressing critical challenges in maintaining measurement traceability when transport-induced variations affect reference standards. This study confronts the well-documented problem of resistance value alterations in Thomas-type resistors due to mechanical stress from temperature fluctuations during transport to international calibration facilities, where changes as significant as 0.4 μΩ/Ω have been observed. The authors developed a comprehensive measurement strategy using Brazil's quantum Hall system (QHS) for validation, employing a step-down procedure that measures 1 Ω resistors through a stable 10 kΩ primary standard using a MIL 6010D commercial bridge. The methodology carefully addresses critical influencing factors including temperature stability in oil and air baths, leakage resistance effects, and power dissipation optimization to minimize systematic errors. Through systematic evaluation of temperature coefficients ranging from 0.5×10^{-6} to 8.0×10^{-6} Ω °C^{-1}, the study established optimal measurement conditions with power dissipation limited to 2.5 mW for most resistors and 1 mW for high-temperature-coefficient standards. Validation through comparison with QHS measurements demonstrated excellent agreement with normalized errors $|E_n| < 1$, confirming the method's reliability for stability assessment. The step-down approach offers significant advantages over traditional triangulation methods by enabling value-based rather than ratio-based evaluations, reducing the required number of measurement sets while extending capability to intermediate resistance ranges (10 Ω, 100 Ω, 1 kΩ), thereby providing a more efficient and reliable means of maintaining measurement traceability in electrical resistance standards.

We hope you will enjoy your reading.

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Section Editors

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