Advances in optical metrology and instrumentation: introduction

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Optical measurement and characterization are two of the pillars of metrology. The ability to measure precisely with high dynamic range and accuracy better our understanding of nature and the universe. In this feature issue, we present a collection of articles that delves into the fundamental techniques used to advance the field. © 2020 Optical Society of America

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Optical techniques allow the measurement of features on the atomic scale, for fields such as lithography, to the cosmic scale, where gravitational waves can be detected. While the uses of optical metrology are numerous, the fundamental techniques are relatively limited, and it is only when supported by specific instrumentation that truly novel science is enabled. Young [1] showed us the power of optical interference, and Michelson and Morley [2] demonstrated its application for dimensional metrology. But it was Maiman's invention of the laser [3] that unlocked the potential for coherent optical measurement over vast distances. This enabled advances in technology that led to the Laser Interferometer Gravitational-Wave Observatory (LIGO), which observed gravitational waves and confirmed a critical part of relativity theory [4]. This is but one example where fundamental principles for optical measurement and advances in instrumentation led to significant advances in our understanding of nature. The same can be said of advances in image sensors, detection, and signal processing.

The first paper in this feature issue is a tutorial [5] that provides a broad overview of currently implemented optical measurement techniques and expands on the rapidly evolving intersection between structured light and time of flight. Marrugo *et al.* detail some of the challenges associated with these techniques, providing potential avenues for future investigations.

Five articles presented in this issue cover optical measurement techniques and instrumentation for the small scale. de Groot and Colonna de Lega [6] propose a practical theoretical model for interference microscopes, including imaging properties when using partially coherence light. Their work elucidates

that simplified models using coherent light and a linear, locally shift-invariant transfer function are valid within certain slope limitations and assuming optical aberrations are considered. Dickins *et al.* [7] seek to improve the development of additive manufacturing processes, such as metal powder bed fusion, by providing in-process measurement methods. In their work, the merits of single-view and multi-view fringe projection are compared and contrasted on additively manufactured components. Zorin *et al.* [8] propose an optical coherence tomography system that shifts the measurement spectrum to the mid-infrared range. Not only does this reduce scattering in three-dimensional imaging, but their implementation also enables morphological and chemical information to be obtained. Liu *et al.* [9] discuss the intersection between metrology and machine learning, which is a budding field of interest. Here, deep learning is used to mine information from light scattering patterns generated by surface defects. Fuerst *et al.* [10] demonstrate the use of the chromatic properties of light for simple point-to-point metrology. Their work shows the surface slope limitations of certain techniques.

Five further articles look to techniques on the meso- and macro-scale. Kim *et al.* [11] present work on absolute laser range finding using ultra-short pulses. Here, they demonstrate the power of frequency comb lasers, where both distance and refractive index information can be obtained from multiple objects simultaneously. Wisniewski *et al.* [12] present an integration of lasers and resonators for inertial sensing, demonstrating high accuracy frequency measurements and validating them through ancillary optical measurement techniques. Joo *et al.* [13] demonstrate displacement interferometer topologies with spatially separated beams and robust common paths to reduce

influences from thermal effects, all the while not introducing periodic errors. Dubey and Kumar [14] present an intersection between classical measurement techniques and more modern techniques, where holographic shearing and Talbot shearing are explored. Furukawa *et al.* [15] explore interference and signal processing, demonstrating an extension of the measurement range beyond $\lambda/2$ by analyzing the peak direction of the interference signal.

This feature issue demonstrates the innovative progresses in optical metrology and instrumentation. Looking to future challenges, with emerging technologies, e.g., nanophotonics, plasmonics, and metamaterials [16,17], data science, and machine learning with artificial intelligence, a new revolution in optical metrology will happen, after the previous revolutions brought about by the laser, advances in digital computing, and advances in detection technology. We hope this issue can inspire the next generation of researchers to take up these future and other currently unknown challenges.

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