

Optical Engineering

SPIDigitalLibrary.org/oe

Laser Sensing and Imaging

Chunqing Gao
Dingyuan Tang

Laser Sensing and Imaging

Chunqing Gao

Beijing Institute of Technology
School of Opto-Electronics
Beijing 100081, China
E-mail: gao@bit.edu.cn

Dingyuan Tang

Nanyang Technological University
School of Electrical & Electronic Engineering
Singapore 639798
E-mail: edytang@ntu.edu.sg

Laser sensing and imaging now have growing importance in various fields ranging but not limited to atmospheric chemistry, industrial process surveillance, agriculture, and medical diagnostics. More and more special conferences and symposia have appeared, devoted to certain aspects of sensing and imaging. LIDAR is popularly used as a technology to make high-resolution maps, with applications in archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing, atmospheric physics, etc. Novel laser sources, spectroscopic approaches and imaging techniques play an increasing role as they enable noncontact sensing without or with only minimal sample pretreatment and/or sample preparation. Furthermore, the appearance of mid-infrared fiber laser sources is changing the application landscape of such techniques. In this special section, we present a collection of selective papers that represents to a certain extent the recent advances in laser sensing and imaging and the related technologies.

The first paper titled "Optical methods for monitoring harmful gas in animal facilities," by S. R. Zhang et al., summarizes the various optical detection methods, including nondispersive infrared gas analyzer, ultraviolet differential optical absorption spectroscopy, Fourier transform infrared spectroscopy, and tunable diode laser absorption spectroscopy, for the monitoring of harmful gases in animal housing. Daily detection of harmful gases emitted from animal factories is expected in the near future, subject to cost reduction and device miniaturization.

L. Wang et al., in the paper titled "Single-frequency and dual-wavelength Ho:YAG nonplanar ring oscillator resonantly pumped by a Tm:YLF laser," report a resonantly pumped monolithic Ho:YAG nonplanar ring oscillator with either single-frequency or dual-wavelength laser outputs. Single-frequency operation with slope efficiency of 61%, and output power of 3.09 W, was demonstrated at around 2 μm . The dual-wavelength outputs at 2091 and 2097 nm can be used to generate THz waves.

The paper titled "High-repetition-rate tunable mid-infrared optical parametric oscillator based on MgO: periodically poled lithium niobate," authored by Y. J. Yu et al., describes a mid-infrared optical parametric oscillator (OPO) with an idler wavelength of 3.85 μm at a repetition rate of 200 kHz. A mid-infrared tunability from 3.7 to 3.9 μm can be achieved by adjusting the temperature of MgO:PPLN crystal from 210 to 35°C.

In the paper "Laser-phased-array beam steering controlled by lithium niobate waveguides," D. C. Yang et al. present a

laser steering system based on the Ti-diffusion lithium niobate (LiNbO₃) waveguides. The waveguide can provide a continuous phase shift for laser-phased-array (LPA) by changing the voltage loaded on it. More array elements and smaller space between adjacent elements are necessary for a better LPA performance.

Focusing properties of an elliptical mirror with an aperture angle greater than π are studied by J. Liu et al. in their paper. Simulation results indicate that a bone-shaped focal spot is formed under linearly polarized illumination, and a tight-circularly symmetric spot is generated under radially polarized illumination. The change in eccentricity causes such a change in the focusing pattern under radially polarized illumination that a greater eccentricity causes a spot tighter in transverse direction but wider in axial direction. Under radially polarized illumination, the transverse and axial full-width-at-half-maximum will be 0.382λ and 0.757λ , respectively, and the conversion efficiency of the longitudinal component can go beyond 99%, when the semiaperture angle is $2\pi/3$ and the eccentricity is 0.6.

The paper titled "Analysis on wind retrieval methods for Rayleigh Doppler LIDAR" by Y. L. Han et al. reports a modification method for Rayleigh Doppler LIDAR wind retrieval. The signal-to-noise ratio of the energy monitor channel is involved in error estimation. When the splitting ratio of the two signal channels is 1.2, it could improve the measurement accuracy by about 1% at 30 km altitude for a Doppler shift of 250 MHz (44 m/s). Stabilities of retrieval methods, i.e., errors caused by the spectrum width deviation including laser pulse, Rayleigh backscatter, and filter transmission curve are discussed. The proposed method could increase the resultant precision by about 15% at 30-km altitude assuming an 8-MHz deviation in full width at half maximum of the Fabry-Perot interferometer.

A pulsed laser underwater imaging model based on pulse spatial and temporal broadening is proposed in the paper titled "Underwater pulsed laser range-gated imaging model and its effect on image degradation and restoration" by Y. W. Huang et al. Experiments based on a self-assembled laser range-gated imaging system were implemented. Furthermore, experiments on underwater image blur and restoration were also implemented and good image recovery results were demonstrated. The modulation transfer function-based restoration mechanism also implies a way to eliminate the blur effect caused by light forward scattering.

2- μm fiber lasers have become a research topic with an increased emphasis due to a variety of applications, including eye-safe LIDAR, spectroscopy, remote sensing, and mid-infrared (MIR) frequency generation. Q. Wang et al., in the paper “2- μm fiber laser sources for sensing,” review their latest development on various 2- μm fiber laser sources, including single-frequency fiber lasers, Q-switched fiber lasers, mode-locked fiber lasers, and MIR supercontinuum fiber sources. All these fiber laser sources are based on thulium and holmium ions using a proprietary glass fiber technology.

Laser range-gated imaging systems can obtain images of targets hidden around the corner, with an intermediary reflective surface with certain specular reflection characteristics. The paper titled “Image contrast model of non-line-of-sight imaging based on laser range-gated imaging” authored by K. D. Xu et al. describes a simulation of the target signal illumination and disturbance radiation on the photosensitive surface of a non-line-of-sight imaging system based on modeling of an intermediary reflective surface. Meanwhile, an image contrast model of a non-line-of-sight imaging system is constructed. Simulation of the image contrast for a laser range-gated imaging system as non-line-of-sight imaging equipment was carried out by analyzing the effects of varying the target signal illumination and intermediary reflective surface reflection. The simulation results show that the reflection characteristics of the intermediary reflective surface have a significant effect on the non-line-of-sight imaging. The image contrast model of non-line-of-sight imaging constructed in this paper provides insights into the theoretical analysis and system design, as well as practical application of non-line-of-sight imaging.

In the paper titled “Detection and discrimination of microorganisms on various substrates with quantum cascade laser spectroscopy” authored by A. C. Padilla-Jiménez et al., infrared spectroscopy detection based on quantum cascade lasers was used to obtain the MIR spectral signatures of *Bacillus thuringiensis*, *Escherichia coli*, and *Staphylococcus epidermidis*. These bacteria were used as microorganisms that simulate biothreats (biosimulants) very truthfully. The experiments were conducted in reflection mode with biosimulants deposited on various substrates, including cardboard, glass, travel bags, wood, and stainless steel. Chemo-metrics multivariate statistical routines such as principal component analysis regression and partial least squares coupled to discriminant analysis, were used to analyze the MIR spectra. The investigated infrared vibrational techniques were useful for detecting target microorganisms on the studied substrates.

X. J. Ning et al., in the paper titled “Hierarchical model generation for architecture reconstruction using laser-scanned point clouds,” introduce an automatic hierarchical architecture generation framework to produce full geometry of architecture based on a combination of facade structures detection, detailed windows propagation, and hierarchical model

consolidation. The method highlights the generation of geometric models automatically fitting the design information of the architecture from sparse, incomplete, and noisy point clouds. Experiments on modeling the scanned real-life buildings demonstrate the advantages of the method, in which the reconstructed models not only correspond to the information of architectural design accurately, but also satisfy the requirements for visualization and analysis.

An optical parametric oscillator is an attractive way of generating tunable MIR light in the spectral range where lasers simply do not exist—for the needs of spectroscopy, medical applications, remote sensing, etc. J. H. Peng introduces the fundamentals of the optical parametric oscillator and the related new phase-matching, cavity design, and spectroscopic techniques in the paper titled “Developments of mid-infrared optical parametric oscillators for spectroscopic sensing: a review.”

The final paper in the special section is authored by P. Rieger, titled “Range ambiguity resolution technique applying pulse-position modulation in time-of-flight scanning LIDAR applications.” It reports a new method for resolving range ambiguities fully automatically in scanning LIDAR, enabling measurements exceeding the maximum unambiguous measurement range. A specific model of the LIDAR transmission path (i.e., emitter–target–receiver) accounting for the time-variability of consecutive measurements is set up as the theoretical foundation. Based on the model the influence of intentional variation of the intervals between pulse emissions on the intervals of successively received echoes is discussed and an algorithm for automated, definitive association of pulse emissions and their resulting echoes is delineated. Simulation results indicate a probability of incorrect associations of $< 10^{-5}$, which is positively proved by applying this technique to the real-world scan data.

Chunqing Gao has been a full professor in the School of Opto-Electronics, Beijing Institute of Technology (BIT), China, since 2001. He received his BS and MS degrees from BIT, and a PhD degree from Technical University, Berlin, Germany. His technical interests include solid-state lasers and applications. He has published about 130 scientific papers and has 13 authorized patents in fields of optics and lasers. He is a fellow of the Chinese Optical Society (COS) and a member of the Optical Society of America (OSA) and SPIE.

Dingyuan Tang has been an associate professor in the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore, since July 2000. He received his bachelor's degree in physics from Wuhan University, China, in 1983, a master's degree in optics from the Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Science, China, in 1986, and PhD degrees from Hannover University, Germany, in 1993, respectively. His research interests include laser physics and engineering, nonlinear optics and dynamics, ultrafast optics, and laser materials. He is a member of the Optical Society of America (OSA).