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Guest Editorial for Nondestructive Testing and Evaluation (NDT&E) Special Section

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Changing the World's Energy Future

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NONDESTRUCTIVE testing and evaluation (NDT&E) are interdisciplinary fields that require a significant amount of interconnection between fundamental physics, measurement techniques, data processing, decision making, and reporting to have a significant impact on industry. NDT&E practitioners are challenged to keep up with the fast-paced evolution of materials, structures, processing, and manufacturing technologies. The development of engineered materials, complex structures and composites, and novel forming techniques require NDT&E to rapidly evolve to meet the needs of industry.

This special section in the IEEE Open Journal of Instrumentation and Measurement (IEEE OJIM) highlights the recent developments in NDT&E techniques. The NDE&T techniques presented include the evolving classical NDT&E techniques, such as ultrasonic, acoustic emission (AE), and X-ray computed tomography (XCT) for characterization of complex materials and structures. Novel data interpretation methods using time–frequency, wavelets, machine learning (ML), and artificial intelligence (AI) are discussed. The often-overlooked infrastructure of integrating data acquisition and data management is addressed. The significance of the NDT&E special section in OJIM is that it provides a forum for a diverse audience to be introduced to a collection of methods and technologies that may be applicable to the readers' needs in unrelated applications.

Barzegar et al. [A1] discussed the criticality of damage imaging algorithms for evaluating the health of salient structures which may be composed of adhesively bonded joints. Baseline-free structural health monitoring (SHM) is essential, especially during service, for robust and real-time characterization. The authors evaluate the effect of shape on damage intensity distribution and damage index from imaging composite lap joints via a baseline-free SHM system. The system contains two parallel arrays of ultrasonic transducers that are placed on both sides of the lap joint in a pitch-catch configuration for inspection of the guided waves. Various shapes of damage intensity distribution have been investigated, including elliptical, diamond, rectangular, and quadrilateral. The effects of the damage on the total damage intensity distribution were evaluated for various ultrasonic parameters and damage shapes. A 2-D correlation coefficient has been used to compare the results obtained by the baseline-free SHM system with an image of the defects.

The article by Jolley et al. [A2] explores how to better characterize additively manufactured (AM) components. While XCT is a standard modality to detect and size internal porosity in AM parts, the resulting material characterization can be significantly influenced by frontend and backend measurement parameters. Somewhat surprisingly, XCT system configuration and post-processing methodologies can significantly affect the accuracy and precision of porosity characterization. Their study concentrates on understanding the influence of setup and analysis methods on porosity measurements by making measurements on different XCT systems and using different analysis techniques. A porosity benchmark consisting of mechanical polishing serial sections is created from the XCT-characterized samples to arbitrate the differences between the results formed by the interrogating test matrix. Their research ultimately aims to provide awareness into limitations and uncertainties in XCT-based porosity characterization.

Lesthaeghe and Holland [A3] presented a novel approach to addressing the need for flexibility in a modern nondestructive evaluation (NDE) laboratory. The authors present a reconfigurable, modular software architecture designed from the ground up to reconcile conflicting requirements for data management, automation, parallelism, geometry and robotics, and version control. The article describes a new pair of open-source tools, Dataguzzler-Python and SpatialNDE2, designed to streamline instrument control, data acquisition, and processing for the NDE lab.

The article by Jack et al. [A4] investigates the damages incurred during the drilling process on a carbon fiber reinforced polymer (CFRP) composite using nondestructive evaluation techniques, specifically full waveform ultrasonic testing (UT). The study compares the damage quantification obtained through UT with X-ray micro-computed tomography (μCT) scan data. A methodology to convert the captured waveform into a 3-D damage zone throughout the thickness of the laminate is presented. Tests were performed on three specimens, drilled with three different drill variations, and fabricated to demonstrate the methodology. The inspection results for each of the three samples are compared between the ultrasonic and X-ray CT inspection data sets, and the percentage error is presented.

Wilcox et al. [A5] presented their work on active microwave thermography (AMT). AMT uses an RF radiating antenna to generate heat by absorption within a specimen under test (SUT). The radiating RF power is not ideal and provides a nonuniform heat source within the SUT. The spatially nonuniform thermal gradients can reduce the effectiveness of AMT in correctly identifying material defects. To make AMT more effective despite the nonuniform heating, a novel image reconstruction technique, spatiotemporal variance reconstruction (STVR), is being developed. STVR exploits the spatial and temporal variance in the surface thermal profile, which provides significant advantages by eliminating the need for a reference measurement and manipulation of the interrogation signal. Illustrative AMT measurements were performed on a series of CFRP structures using both RF and halogen lamp heat sources. STVR was able to provide defect indications and effectively size the defect. All without the use of a reference measurement or signal manipulation.

Zonzini et al. [A6] used AE to listen to the initiation and growth of cracks. To characterize and locate the source of the resulting stress waves, the effective determination of the time of arrival (ToA) is imperative. A novel processing flow is discussed that transforms the ToF estimation from the time domain to the time–frequency domain using the wavelet transform (WT). Transient signatures can be recorded that can identify AE signals. Both continuous and discrete WTs are investigated to determine the most effective tradeoffs between time–frequency resolution and computational complexity. To further increase ToA determination, event-driven competences of neuromorphic architectures and especially spiking neural networks (SNNs) are used in processing spiky and sparse temporal information to retrieve ToA. This ToA determination is the most power-efficient algorithm that provides negligible loss of performance. The goal of the research is to combine the performance advantages of ToA in the determination of combining the WT operator with the spiking hardware and software. A metallic plate structure will be used to confirm that WT combined with SNN can achieve the necessary precision in ToA and AE source localization despite significant noise. The use of dedicated neuromorphic architectures will also be shown to significantly reduce the power expenditure per inference.

Fadhil et al. [A7] investigated the effect of low temperatures on the acoustic properties between the coupling fluid and the rail steel. Low-temperature conditions on ultrasonic attenuation and velocity can significantly affect the transmission of ultrasound in metal rails. Useful considerations for improving the value of cold weather UT are discussed. Common coupling fluids used in rail detection vehicles with liquid-filled tyres containing the ultrasonic transducers are investigated. The tests consisted of measurements of the velocity of longitudinal waves propagating in the fluid and reflected from a steel disc. The properties of the rail steel were evaluated by using the head and web of different rail sections to form two test specimens. The evaluation of longitudinal and mode-converted shear waves was carried out by measuring the longitudinal and mode-converted shear wave velocities together with attenuation measurements. These measurements were carried out on rail specimens with side holes. The tests were carried out at temperatures ranging from -50 °C to $+20$ °C. The coupling fluid tests showed a linear increase in velocity with decreasing temperature at different rates for different fluids. The rail steel also showed increased velocities for both longitudinal and shear waves with decreasing temperature. The experimental results show that temperature-dependent velocities must be taken into account to obtain the required angle of refraction and the appropriate amplitude thresholds for acceptance criteria.

Torenvliet and Zelek [A8] have developed an innovative generative AI-based technique for time-series anomaly detection and data attribution in data with outliers called diffusion partition consensus (DPC). DPC is demonstrated by using well-structured time-series datasets from a single ultrasonic probe. The DPC method exploits crosstalk between a conditional score-based diffusion model and two specific Savitzky–Golay filters. Verification and validation are performed on sequences of increasingly information-rich synthetic datasets, and on NDE datasets from a nuclear reactor pressure tube and a calibration fixture. The AI technique is an iterative technique using a combination of stochastic and deterministic methods based on confidence and consensus of specified parameter estimates, which update multiple data classification partitions over the dataset, recursively allowing a new set of estimates and confidence measures to be determined. The fault diagnosis algorithms allow human involvement in the decision-making process, making DPC suitable for safety-critical applications such as nuclear reactors. A key feature of DPC is that it is unsupervised. The unsupervised nature of DPC allows the use of unlabeled data sets, no reliance on out-of-distribution generalization, independent fault diagnosis, and robust convergence.

The Guest Editors would like to thank all the authors who contributed their papers to this NDT&E Special Section. We also thank the reviewers for taking time out of their busy schedules to provide constructive feedback, which significantly improved the quality of this Special Section. We are grateful to the Editor-in-Chief, Prof. Reza Zoughi of Iowa State University, for organizing this Special Section, and to the OJIM administrators, LeeAnn Pannebaker and Laura Roach, for their support in making this Special Section publishable.

APPENDIX: RELATED ARTICLES

[A1] M. Barzegar, D. J. Pasadas, A. L. Ribeiro, and H. G. Ramos, “Baseline-free damage imaging for structural health monitoring of composite lap joint using ultrasonic-guided waves,” *IEEE Open J. Instrum. Meas.*, vol. 3, pp. 1–8, 2024, Art. no. 6000308, doi: 10.1109/OJIM.2024.3487239.

[A2] B. Jolley, C. Knott, D. Sparkman, and M. Uchic, “Comparative analysis of internal porosity in AM Ti64 using X-ray computed tomography and mechanical polishing serial sectioning,” *IEEE Open J. Instrum. Meas.*, vol. 3, pp. 1–11, 2024, Art. no. 6000411, doi: 10.1109/OJIM.2024.3477569.

[A3] T. J. Lesthaeghe and S. D. Holland, “Dataguzzler-Python and SpatialNDE2: Crucial software infrastructure for reconfigurable NDE data acquisition with spatial context,” *IEEE Open J. Instrum. Meas.*, vol. 3, pp. 1–9, 2024, Art. no. 6000209, doi: 10.1109/OJIM.2024.3459989.

[A4] D. A. Jack, P. K. Ravindranath, K. Matalgah, and T. Fleck, “Quantification of drill hole damages in CFRP laminates using high-resolution ultrasonic testing,” *IEEE Open J. Instrum. Meas.*, early access, Oct. 28, 2024, doi: 10.1109/OJIM.2024.3487238.

[A5] L. M. Wilcox, E. M. Johnson, E. T. Bohannon, C. E. Johnson, and K. M. Donnell, “Spatiotemporal variance image reconstruction for thermographic inspections,” *IEEE Open J. Instrum. Meas.*, vol. 3, pp. 1–11, 2024, Art. no. 8000111, doi: 10.1109/OJIM.2024.3493891.

[A6] F. Zonzini, W. Xiang, and L. de Marchi, “Spiking neural networks for energy-efficient acoustic emission-based monitoring,” *IEEE Open J. Instrum. Meas.*, vol. 3, pp. 1–13, 2024, Art. no. 3500313, doi: 10.1109/OJIM.2024.3485618.

[A7] A. T. Fadhil, G. Washer, A. Poudel, K. Yadav, and S. Shrestha, “Ultrasonic testing of railroad rails: Cold temperature effects and considerations,” *IEEE Open J. Instrum. Meas.*, vol. 3, pp. 1–11, 2024, Art. no. 3500211, doi: 10.1109/OJIM.2024.3477571.

[A8] N. Torenvliet and J. S. Zelek, “Diffusion partition consensus: Diffusion-aided time-of-flight estimates, anomaly detection, and localization for ultrasonic nondestructive evaluation data,” *IEEE Open J. Instrum. Meas.*, vol. 3, pp. 1–11, 2024, Art. no. 2500311, doi: 10.1109/OJIM.2024.3485711.

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