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Terahertz Optical-Digital Neural Network Imaging

Shang-Hua Yang[1,2]

[1]*Department of Electrical Engineering, National Tsing Hua University, Hsinchu, Taiwan*
[2]*THz Optics & Photonics Center, National Tsing Hua University, Hsinchu, Taiwan*
Email: shanghua@ee.nthu.edu.tw

Terahertz (THz) band has recently had significant attention due to its exceptional capabilities in non-invasive, non-destructive sensing and imaging applications [1-3]. However, current THz imaging systems face substantial challenges due to hardware limitations, leading to information loss and reduced imaging throughput during data digitization and information extraction. To overcome these challenges, we propose a hybrid compressive optical–digital neural network that enables both real-time THz imaging and precise object information extraction. This approach utilizes a physical encoder, an optical neural network (ONN), to transform and reduce the dimensionality of physical signals, effectively compressing them to fit the physical constraints of THz sensor arrays. After the compressed signals are captured and digitized by the THz sensor array, a jointly trained digital neural network (DNN) reconstructs the signals into their desired or original form. Our proposed THz ONN–DNN computational imaging system demonstrates enhanced imaging quality, an expanded field of view with a lens-free system, diffraction-free imaging, and real-time THz video capture at 2 frames per second without requiring a graphics processing unit. Furthermore, the end-to-end optimization of the hybrid architecture allows the system to maintain high fidelity even under low signal-to-noise ratio (SNR) conditions, a common bottleneck in THz sensing. By offloading the primary computational burden to the passive optical layer, we achieve a significant reduction in digital post-processing latency and power consumption. Experimental results confirm that the system successfully identifies complex spatial features across a variety of material substrates, providing a scalable solution for high-throughput security screening and industrial quality control. This work establishes a new paradigm for THz wave modulation, demonstrating that the synergy of wavefront engineering and deep learning can circumvent traditional hardware boundaries, paving the way for compact, edge-deployable THz intelligent vision systems.

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