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Real-time comprehensive electron beam diagnostics through machine learning in ultrafast electron diffraction system

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Ultrafast electron diffraction (UED) is a powerful technique for observing atomic-scale structural dynamics in materials. Electron beam parameters—beam size, divergence, energy spread, and bunch length—determine spatio-temporal resolution. Traditional diagnostic methods require complex instrumentation that cannot be integrated into routine workflows, particularly for high-repetition-rate facilities. We present a machine learning approach enabling comprehensive, non-invasive extraction of electron beam parameters directly from diffraction patterns. Deep neural networks trained on physics-based simulations decode signatures that beam parameters imprint on diffraction images. The method exploits distinct physical mechanisms: geometric effects from beam size, angular distortions from divergence, chromatic aberrations from energy spread, and temporal convolution from bunch length. This enables bunch length measurement without dedicated temporal diagnostics—traditionally one of the most challenging parameters to access non-invasively. The trained models can be deployed across UED facilities using standard imaging detectors, democratizing access to advanced diagnostics. This approach eliminates expensive specialized equipment and enables real-time beam monitoring and optimization, enhancing experimental throughput and data quality for ultrafast materials characterization.

Footnotes

Funding Agency

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Yes

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