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AI-driven real-time optics control system to achieve aberration-free coherent wavefronts at 4th-generation synchrotron radiation and free electron laser beamlines

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When dealing with experiments conducted at 4th-generation synchrotron radiation and free electron laser beamlines, the primary challenge for X-ray optical elements lies in achieving and maintaining focused X-ray beams of high intensity, possessing near-perfect wavefront quality and exceptional stability. Optical elements necessitate more stringent specifications compared to other applications due to the shorter wavelength and ultra-small emittance of the radiation generated by these sources. In the case of diffraction-limited light sources producing coherent photons, it is crucial to preserve well-controlled wavefronts. The degradation of the wavefront proves detrimental to phase-sensitive imaging techniques such as Tomography. For coherent X-ray scattering experiments employing techniques like X-ray Photon Correlation Spectroscopy, Coherent Surface Scattering Imaging, and Coherent X-ray Diffraction Imaging, wavefront uniformity holds particular significance. X-ray optics must be manufactured with a near-perfect shape, and automatically and consistently align and focus the beam according to experimental requirements. Furthermore, they should be capable of providing real-time correction in response to wavefront deformations. At the APS, we have successfully demonstrated the practical application of two methods: i) utilizing a Neural Network (NN) model to autonomously control deformable mirrors with remarkable precision and control. The NN is trained to establish a time-dependent relationship between the hardware setup and the wavefront properties during experiments. ii) Employing Bayesian optimization with Gaussian processes to automatically align and stabilize the focusing optical systems of hard X-ray synchrotron radiation beamlines. This approach utilizes ultra-realistic digital twins constructed using the OASYS simulation framework and enables effective steering of the optical assembly.

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no

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