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AI/ML-Driven Alignement, Stabilization and Control of Beamline Optics at the Advanced Photon Source Upgrade

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In experiments conducted at 4th-generation synchrotron radiation and free electron laser (FEL) beamlines, the primary challenge for X-ray optical elements is to achieve and maintain focused X-ray beams with high intensity, near-perfect wavefront quality, and exceptional stability. Additionally, in diffraction-limited light sources that produce coherent photons, preserving well-controlled wavefronts is crucial, since the deterioration of the wavefront can adversely affect imaging [1] and coherent X-ray scattering experiments [2-3]. As a result, precision manufacturing of X-ray optics is essential, adhering closely to an ideal mathematical shape. These optics should possess the capability to align and focus the beam based on various sample and experiment requirements, automatically and consistently. Furthermore, they should be able to provide real-time correction in response to wavefront deformations [4].

In the last few years, extensive studies and experiments have been carried out at the Advanced Photon Source (APS) at Argonne National Laboratory with the purpose to engineer automatic optics control systems, supported by Artificial Intelligence (AI) technologies and advanced, real-time wavefront sensing techniques, to pursue near-perfect wavefront control at the future beamlines of the upgraded APS-U synchrotron. We developed and successfully tested at the 28-ID IDEA beamline of the APS a neural-network (NN) machine learning (ML) model to control a bimorph adaptive mirror to achieve and preserve aberration-free coherent X-ray wavefronts. The NN is trained to manage the time-dependent relation between the hardware setup and the wavefront properties at the experiments [5]. In parallel, we employed Bayesian optimization (BO) with Gaussian processes (GPs) to automatically align and stabilize the focusing optical systems of hard X-ray synchrotron radiation beamlines and experimentally tested at the 28-ID IDEA beamline, providing effective steering of the optical assembly [6]. These prototypical systems have been improved and engineered to manage the optics of the featured beamlines of the new APS-U synchrotron, through extensive studies of AI-driven technologies and the use of real-time, full-field, single-shot wavefront sensing downstream of the focus [7].

References

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I plan to submit also conference proceedings

Yes

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