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Data-Based Condition Monitoring and Disturbance Classification in Actively Controlled Laser Oscillators

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The successful operation of the laser-based synchronization system of the European X-Ray Free Electron Laser relies on the precise functioning of numerous dynamic components operating within closed loops with controllers. This study presents a comprehensive overview of the application of data-driven machine learning methods to detect and classify disturbances in these dynamic systems, leveraging the output signals from controllers. Four distinct feature extraction techniques are introduced, encompassing statistical analysis in both the time and frequency domains, characteristics of spectral peaks, and the use of autoencoder-generated latent space representations in the frequency domain. Remarkably, these methods do not necessitate system-specific knowledge and can be adapted for deployment in other dynamic systems. This research integrates feature extraction, fault detection, and fault classification into an automated and comprehensive condition monitoring framework. To achieve this, a systematic comparison is undertaken, evaluating the performance of 19 state-of-the-art fault detection algorithms and four classification algorithms. The objective is to identify the most suitable combination of feature extraction and fault detection or classification algorithms for effectively modeling the condition of an actively controlled phase-locked laser oscillator. Experimental evaluations show the effectiveness of clustering algorithms, highlighting their capacity to detect perturbed system conditions. Furthermore, our evaluation shows the support vector machine as the most suitable choice for classifying different types of disturbances in the laser-based synchronization system.

Primary Keyword

anomaly detection

Secondary Keyword

Tertiary Keyword

Primary author: GRÜNHAGEN, Arne (Hamburg University of Applied Sciences)

Co-authors: Prof. EICHLER, Annika (Deutschles Elektronen Synchrotron DESY); Prof. TROPMANN-FRICK, Marina (Hamburg University of Applied Sciences); Prof. FEY, Görschwin (Hamburg University of Technology)

Presenter: GRÜNHAGEN, Arne (Hamburg University of Applied Sciences)

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