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APPLICATIONS OF MACHINE LEARNING IN PHOTO-CATHODE INJECTORS

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Abstract

To configure a photoinjector to reproduce a given electron bunch with the desired characteristics, it is necessary to adjust the operating parameters with high precision. The fine tunability of the laser parameters are of extreme importance as we try to model further applications of the photoinjector. The laser pulse incident on the photocathode critically affects the electron bunch 3D phase space. Parameters such as the laser pulse transverse shape, total energy, and temporal profile must be controlled independently, any laser pulse variation over both short and long-time scales also requires correction. The ability to produce arbitrary laser intensity distributions enables better control of electron bunch transverse and longitudinal emittance by affecting the space-charge forces throughout the bunch. In an accelerator employing a photoinjector, electron optics in the beamline downstream are used to transport, manipulate, and characterize the electron bunch. The adjustment of the electron optics to achieve a desired electron bunch at the interaction point is a much better understood problem than laser adjustment, so this research emphasizes laser shaping.

INTRODUCTION

Delivering a laser pulse to the photocathode typically involves several optical elements to transport the pulse from the remote laser area to the electron gun. In addition, shaping optics are usually placed close to the photocathode, and diagnostic elements are also as close to the photo-emission gun as possible to provide accurate measurements of laser parameters on the photocathode. Copper photocathodes are very robust and long-lived in operation, and therefore are attractive for facilities requiring high availability. Work functions for most practical metals are 3-4 eV, and so UV laser pulses are used to generate photoemission, with typical wavelengths between 250-300 nm. This places stringent requirements on optical fabrication tolerances that are rarely achieved in practice. Moreover, at high current photoinjector beam photocathode and its uniformity is disturbed through ion bombardment [1] and increases vacuum pressure which thereby changes and alters the electron density from a giver laser shape. More specifically, wavefront distortion at each optical surface of even 1/20th wave, corresponding to less than 15 nm, can lead to laser intensity modulation of 10% or more through diffraction, which then degrades electron bunch emittance. Partial mitigation of this and other detrimental effects is achieved using Fourier relay imaging throughout the laser system and transport optics. This optical configuration as shown in Fig. 1, consists of a series of image planes transferred through the system by lens pairs in a 4f arrangement. An initial object plane is repeatedly imaged to critical elements such as amplifiers and harmonic generation crystals in the laser system, and finally to the photocathode. This will also enable the use of a spatial light modulator (SLM) between the two harmonic generation crystals for intensity control of the second harmonic of the ATF Nd:YAG laser at 532 nm. Subsequent fourth harmonic generation and image relaying will allow the profile at the photocathode to be controlled and optimized.

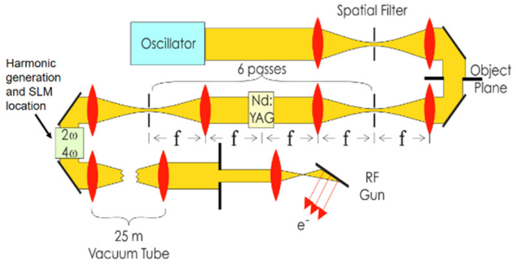

Figure 1: Facility configuration.

Li *et al.* demonstrated that ultraviolet laser transverse profile shaping could be utilized to improve X-ray free electron laser performance [1]. The authors employed a digital micromirror device to control the shape of a 253 nm drive laser at the linear coherent light source. However, due to the low damage threshold of the digital micromirror in the UV, the work is limited in its applications. On the other hand, Maxson *et al.* [2] used a SLM for shaping the drive laser of a dc photoemission gun. The authors created a simple shaping algorithm which results in a detailed transverse laser shaping with very high fidelity. An active feedback system was put in place which would take the unshaped electron beam image, and then create accurate detailed laser shaping further contributing to better efficiency. In this project we aim to use a liquid crystal based SLMs to control the transverse shape of the second harmonic of a Nd:YAG laser at 532 nm.

In order to enable optimization of laser profile for a specific photoinjector and electron beam parameters, a learning phase is required to train the neural network. Two methods may be used for the training process. First, an image of the photocurrent can be formed downstream with the magnetic optics that reproduces the emission profile at the photocathode. This profile can then be recorded by a phosphor screen and a camera. Image analysis will then permit the quality of fit between the ideal and measured emission profiles to be calculated and used as a fitness function to train the neural network [3, 4]. Second, at each iteration of the neural network-controlled laser profile, an emittance scan can be performed with the magnetic optics and beam profile monitors, and the beam emittance calculated for use as a fitness function. These two methods can be compared for efficiency and may prove to be complimentary.

We aim to link to the objective that the CBB have presented in their strategic plan. Neural Network based controllers help in Beam Dynamics and Control Optimal Outcomes. Additionally, better control of beams in electron microscopes can be implemented using our neural networks. What we apply and learn from here can be applied to MeV-class ultrafast electron diffraction systems and microscopes.

RESEARCH FOCUS

Our goals are better routine control of the emittance of the electron beam through use of machine learning and laser manipulation using a spatial light modulator (SLM).

Refine the electron gun model in VSIM for the Brookhaven system, together with Argonne Leadership Computing Facility for these simulations. During experimental runs, we will connect the main ATF at BNL with ALCF resources [5]. This allows us to rapidly build the model as illustrated in Fig. 2. SLM will modulate phasefronts and cause beam reshaping through diffraction. Inserting SLM between second and fourth harmonic generation crystals allows device to operate at optimum efficiency and damage threshold. Modulated green beam profile is transferred to UV and imaged to photocathode. Higher-order energy diffracted out of central beam is filtered by aperture or limited acceptance angle of fourth harmonic crystal (~few milliradian). Detailed study of a photoinjector to configure and study the parameters so as to result in efficient and robust laser shaping with high fidelity. Facilitate the study of efficient delivery of laser pulse to photocathode. Provide a high efficiency architecture of shaping optics. Further study of the proposed architecture, along with its optimization with the help of machine learning techniques and algorithms is the main objective to be achieved. Machine learning based model of the system correlating inputs and outputs. Optimized set of inputs which are the photoinjector and electron beam parameters, and feature engineering them to produce an optimized output in terms of laser shaping profile. Neural network for its ability to handle a high number of variables and to give a consistent prediction of the output is considered for the architecture. Neural network is optimized with the help of data obtained through Trained Neural Network architecture that can be used as a more reliable and efficient laser control and shaping optics design for the photoinjector and electron beam parameters as compared to the conventional laser shaping algorithms. One or two research articles in proceedings of a relevant conference or any well reputed journal.

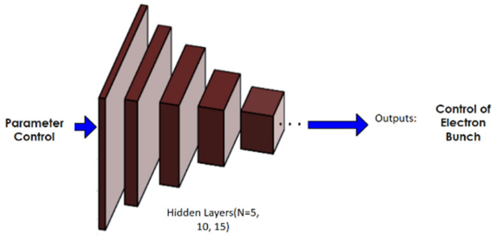

Figure 2: Surrogate model.

FUTURE SCOPE

We are looking forward to training our model further so that it can predict the best input parameters for the photoinjector and an electron beam to get an optimal result.

ACKNOWLEDGEMENT

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