EE367 Project Proposal: Reconstruction of attosecond X-ray temporal fields with machine learning

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1 Motivation and Background

X-ray Free Electron Lasers (XFELs) are extending their capabilities to the attosecond regime. At the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Lab, the XLEAP project has recently developed several attosecond soft x-ray modes. These sub-femtosecond modes are too short to be resolved using standard beamline measurements at LCLS, and instead are experimentally characterized using an angular streaking technique [1].

The angular streaking measurement uses a coaxial velocity map imaging spectrometer (cVMI) to measure the time-profile of attosecond XFEL pulses. The cVMI spectrometer encodes temporal information of the electric field of an X-ray pulse into a 2D photoelectron momentum distribution. The X-ray pulse time-profile must be extracted from this 2D image via a reconstruction method.

This project's goal is to take an experimental angular streaking image and retrieve the temporal profile of the X-ray pulse.

2 Related Work

This angular streaking measurement is regularly used at XFELs to characterize the X-ray temporal pulse profiles [1, 2, 3]. At LCLS, X-ray pulses are reconstructed from angular streaking images by first decomposing the momentum distribution into a set of basis functions, and then using a non-linear fitting algorithm to express each angular streaking image as a linear combination of these basis functions.

This method is shown in Fig. 1 and described in detail in [1]. This nonlinear fitting method has been used successfully; however, it is computationally slow and requires background and noise removal to be applied to the experimental images prior to fitting.

I also note that I have previously attempted to replace the nonlinear fitting method with a fully connected Neural Network. This NN was made to take an angular streaking image as input and return a temporal profile, and was trained using a data set simulated from the set of basis functions. However, while the model performed well on the simulated training and validation data, it did not generalize well to experimental images. The NN accurately determined the arrival time of the X-ray pulse, but consistently underestimated the pulse duration.

3 Project Overview and Milestones

The goal of this project is to develop a (machine learning based) method for efficiently and accurately reconstructing X-ray temporal fields from single-shot angular streaking images. Notable challenges include:

- The measured data is single-shot data and cannot be averaged.
- The measured data has a large (signal dependent?) background.
- The machine learning algorithm must be trained on simulated data, and generalization to real data may not work due to mismatch between the training set and the real data.

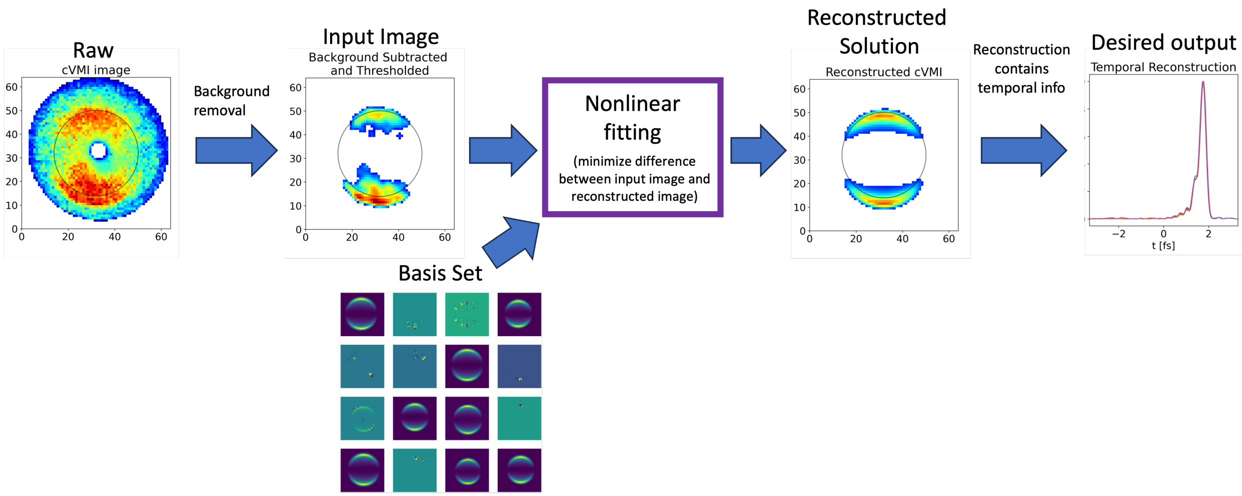

Figure 1: Process of the current reconstruction method via non-linear fitting.

3.1 Milestones

(1) Determine model structure for this problem. I want to use a CNN as opposed to a NN as I used previously. Also, this dataset has synchronous angular streaking images and X-ray spectra measurements; I would like to incorporate the extra frequency information into the model. I also want to brainstorm a way to make the model more robust to noise found in the experimental data but not in the simulated training set. [Week 1]

(2) Implement the model in pytorch. Simulate a training/validation set according to what inputs the determined structure needs, and train and evaluate the model on it. [Week 2-3]

(3) Use the trained model with experimental data and compare to the nonlinear fitting method. [Week 3]

(4) (If there is time) Perform ablation tests/hyperparameter scans. What is the necessary resolution of the basis set? Is it better to train the model on a data set that is continuously simulated, rather than simulated from the basis set?

(5) Evaluate robustness of model to noise and background.

References

[1] S. Li et al., "Characterizing isolated attosecond pulses with angular streaking," Optics Express (2018).

[2] J. Duris et al., "Tunable isolated attosecond X-ray pulses with gigawatt peak power from a free-electron laser," Nat. Photonics, vol. 14, no. 1, pp. 30–36, (2020).

[3] Hartmann, N. et al. "Attosecond time–energy structure of x-ray free-electron laser pulses," Nat. Photonic, vol. 12, 215–220 (2018)