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Reconstruction of Ultrashort Pulses using Deep Neural Networks

Alex Dikopoltsev*[(1)], Tom Zahavy*[(2)], Ron Ziv[(2)], Ittai Rubinstein[(1)], Pavel Sidorenko[(1,3)], Shai Mannor[(2)], Oren Cohen[(1)], and Mordechai Segev [(1)]
(1) Department of Physics and Solid State Institute, Technion, Haifa 32000, Israel
(2) Department of EE, Technion, Haifa 32000, Israel
(3) School of Applied and Engineering Physics, Cornell University, Ithaca, New York 14853, USA
*equal contribution; alexdiko@technion.ac.il

Ultrashort pulses are used in numerous applications. Characterization of these pulses requires indirect schemes. A popular technique for characterizing ultrashort pulses is frequency-resolved optical gating (FROG) [1]. It is an established and recently mathematically proven [2] approach for full characterization of the amplitude and phase of ultrashort optical pulses. The reconstruction of pulses from these FROG measurements requires an algorithm that can solve a 4th order phase retrieval problem. Such common algorithms, the Principle Component General Projections Algorithm (PCGPA) [3] and recently proposed Ptychographic FROG [4] perform well at high SNR. However, while these algorithms perform well at low SNR after filtering the FROG trace, their performance drops at raw low SNR data.

Recovering the structure of ultrashort pulses through Neural Networks (NN) techniques were pioneered in 1996 [5]. This technique used a parametric model that was trained to reconstruct the pulse from its polarization-gated (PG) FROG measurements. The strategy of their technique was to manually engineer the features in the data (and then reconstruct only those features) instead of being fed with raw measurements because this was the only possible implementation available back then. The implementation limitations came from the low number of layer, small training sets, and old NN algorithms. However, today's Deep Neural Networks (DNNs) have enough layers to extract the structure of the data automatically by learning from many examples. The massive progress with DNN research has recently led to a superhuman performance in a plethora of applications. We note that deep learning techniques extract the structure of the data by learning from many examples, whereas classical algorithms reconstruct a single pulse from a single measurement. This fact endows our DNN with the advantage of filtering noise better than commonly used algorithms.

In this talk, I will present our recent work [6] in which, for the first time, theoretically and experimentally, we reconstruct ultrashort optical pulses by employing DNN. For this purpose, we train a Convolutional Neural Network (CNN) to learn the inverse mapping of the Second Harmonic Generation (SHG) FROG measurement function using techniques, where pulses and its FROG traces are provided during training (supervised training). The trained network outperforms state-of-the-art algorithms on simulated data. To further develop our methodology, we modify the training stage to combine, both, supervised (on simulated pulses only) and unsupervised learning (on the measured FROG trace) to successfully reconstruct pulses from low SNR measured FROG traces. For the implementation of the unsupervised procedure, it was necessary to devise an a-parametric (constant) DNN, which would represent the SHG-FROG measurement function, and hence, enable the computation of the derivatives of the FROG function using standard forward and back-propagation. Finally, I will discuss the application of DNN for reconstructing pulses without using (or even knowing in advance) the relations between the pulses and the measured signals.

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