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Ptychographic approach for FROG: beyond pulse reconstruction

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Frequency-resolved optical gating (FROG) is probably the most commonly used method for full characterization (i.e., amplitude and phase) of ultrashort optical pulses [1]. A FROG apparatus produces a two-dimensional (2D) FROG trace of an input pulse by interacting the pulse with its delayed replica in a nonlinear-optical medium, e.g., second harmonic generation (SHG) crystal. Current FROG reconstruction procedures are based on 2D projection-based phase retrieval algorithms. These algorithms require Fourier relation between the frequency and delay axes for the measured spectrogram resulting in reconstruction resolution limited by delay step. However, it is desirable to develop FROG algorithms that work well even if a significant part of the Fourier related spectrogram is missing or unmeasurable. Implementation of the ptychography– a powerful scanning coherent diffraction imaging method, to pulse diagnostic techniques in which the unknown pulse interacts with another pulse that is fully or partially known [2-3], demonstrated the superb robustness of the ptychographic reconstruction approach, both in terms of SNR and the use of only partial spectrograms. However, in these works, ptychographic reconstruction approach, have not been adapted to techniques like FROG, in which the unknown pulse interacts with its exact replica and therefore the reconstruction problem is more difficult.

In this talk, I will present our recent works in which we modified ptychographic reconstruction approach to FROG and utilized it for demonstrating new capabilities in FROG [4,6]. In our recent paper [4], we have shown that ptychgraphic-based algorithm for FROG trace inversion allows retrieving complex (i.e., amplitude and phase) pulses from FROG traces with under sampled delays and/or from spectrally filtered FROG traces. The ptychography-based pulse reconstruction algorithm for FROG does not require any prior information on the pulse, but if additional information about the pulse is known in advance, e.g., its power spectrum, then successful pulse recovery is possible even from a ridiculously small number of measurements. Moreover, we applied the ptychographic approach to a blind FROG and discovered that we could robustly recover two different pulses from a single blind FROG trace and the power spectrum of one of the pulses. Notably, the new algorithm can be applied to all FROG apparatuses, without any hardware modification, significantly extending the range of pulses that the devices can measure.

In our theoretical paper [5], we analyzed the uniqueness of bivariate and quartic phase retrieval problems. Particularly, we proposed a uniqueness result showing that given the signals power spectrum, blind FROG (and thus also FROG) trace determines almost all bandlimited signals up to trivial ambiguities.

Recently, we demonstrated characterization of several, non-identical, pulses from a single multiplexed FROG trace [6] by utilizing both the redundancy of the FROG trace and ptychgraphic-based inversion algorithm. We demonstrated full characterization of several pulses (that may be different) in repetitive or non-repetitive (e.g., isolated) pulse-bursts, including bursts with MHz-THz repetition rate. Our numerical simulations demonstrate that if additional information about the pulses is known in advance, e.g., their power spectra, then successful recovery of more different pulses is possible from a single noisy multiplexed FROG trace.

We believe that these new algorithmic capabilities will undoubtedly open many new opportunities in diagnostics of ultrashort laser pulses. The fact that our procedure can successfully recover pulses from significantly spectrally filtered spectrograms should allow us to measure ultrashort laser pulses with resolutions that are much higher than the corresponding bandwidth of the nonlinear process.

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