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Reconstruction of ultrashort laser pulses by convolutional neural networks

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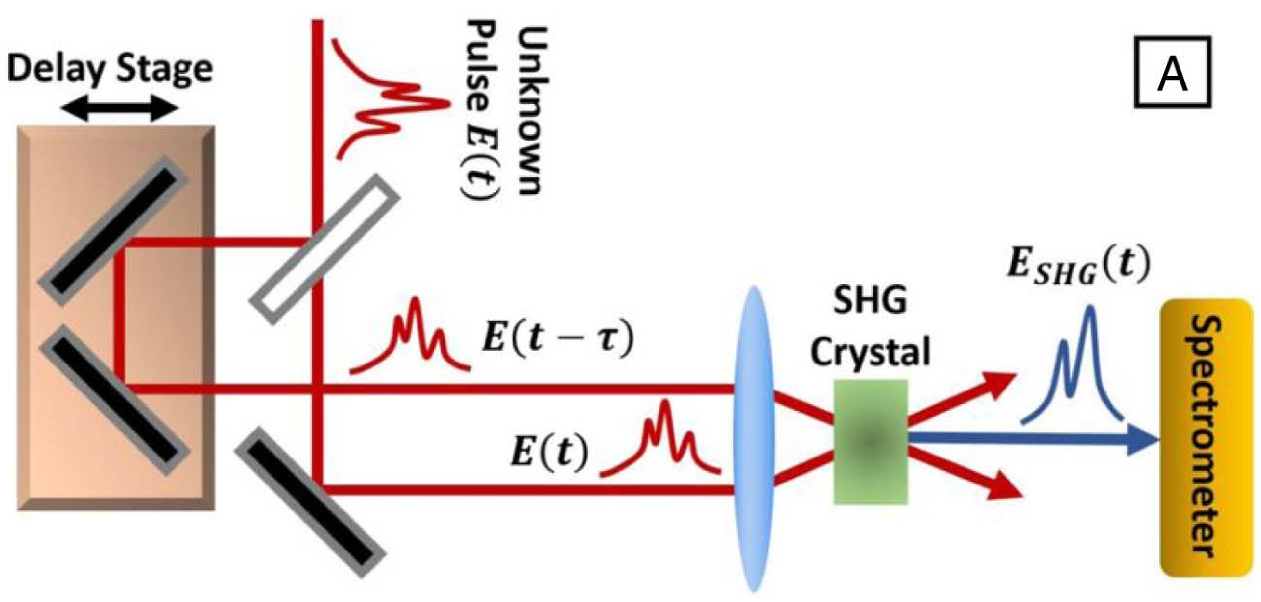
Abstract. The creation and reconstruction of ultrashort (femtosecond or attosecond) laser pulses is an important field of basic research. However, a large range of applications also use such pulses (femtochemistry or ultrafast imaging for example), but all are based on physical processes, which cannot be resolved in space or time using other means of investigation. Since these pulses cannot be measured by conventional electronics, their characterization involves a special technique, called FROG (frequency resolved optical gating), which uses the pulse and a delayed copy of itself to create a spectrogram. The reconstruction method means the recovery of the amplitude and phase of the pulse from the FROG spectrogram. Here, inspired by recent studies, we propose employing a CNN (convolutional neural network) to recover the amplitude and phase of ultrashort pulses. The input to the CNN is a set of FROG traces (computer simulated or experimental), which is trained by comparing the recovered pulses to known pulses. The method will provide a faster way to recover ultrashort pulses, and to avoid using conventional recovery algorithms like PCGPA (principal component general projections algorithm) for example. Here we present preliminary result of our model for the reconstructed amplitudes of the pulses, while results for the phase will be presented at a later stage of our work

Main goal

To reconstruct the amplitude and phase of ultrashort laser pulses from FROG traces, defined as:

$$I(\omega,\tau) = |F\{E(t)E(t-\tau)\}|^2$$

FROG in experiments



Schematic experimental SHG (second harmonic generation) FROG setup. The picture is from [1].

Data generation and training of the CNN

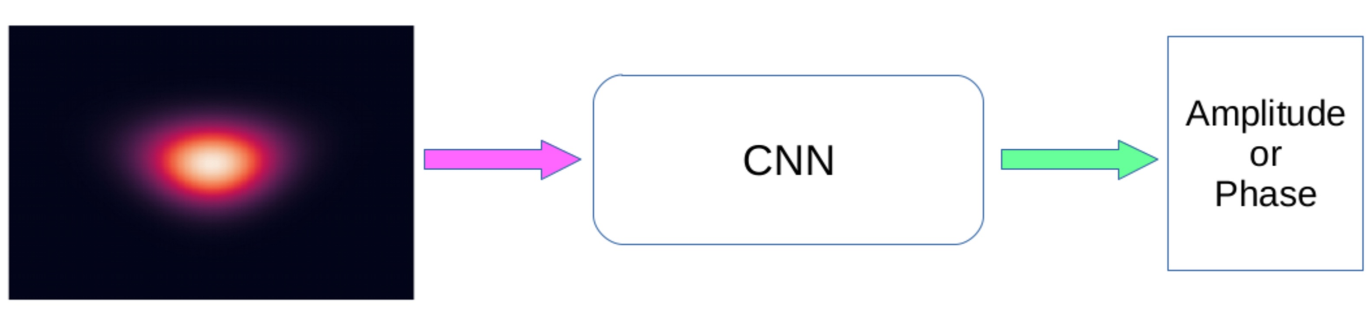
Experimentally it is time and resource consuming to generate a large set of FROG traces, therefore a computational model is used to generate simulated data sets. The algorithm incorporates some parameters of the chirped pulse amplification system at the ELI-RO facility, which are chosen to be in an experimentally viable range.

Specifically, for different grating distances and incidence angles of the compressor, the higher order terms in the Taylor expansion of the spectral phase are determined and consequently the phase itself. We also take into account the variation of a third parameter, the width of a glass piece introduced in the laser beam path. The spectral phase and the spectral amplitude (for a range betwen 20 and 50 nm) provide the pulse in frequency domain, while its Fourier transform gives the field in time domain, which is used to generate the FROG trace. The wavelength associated with the central frequency is 800 nm.

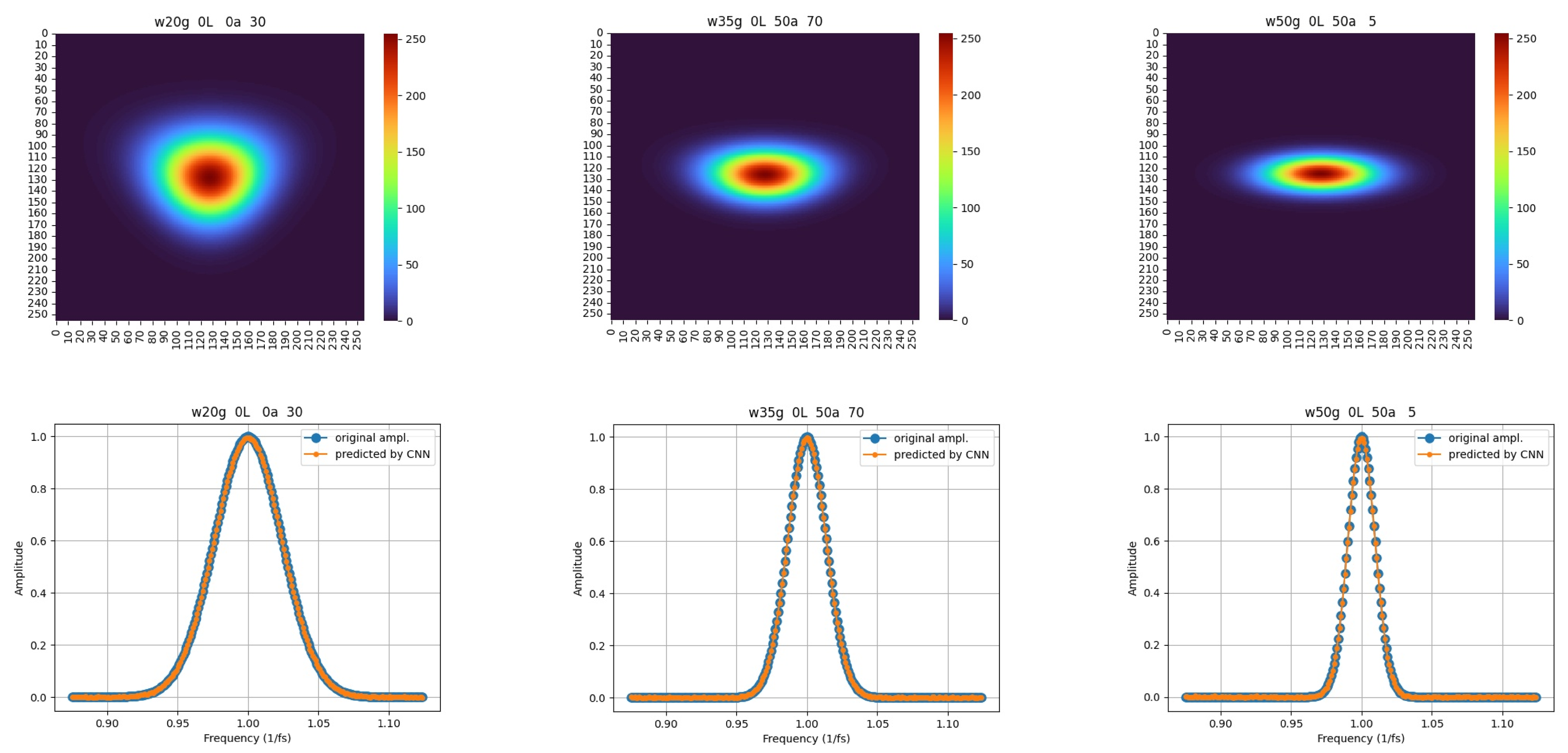
We generate a set of 10232 FROG traces and the spectral amplitude and phase associated with these traces. The amplitude or the phase are used as labels in the training of the CNN. The generated dataset is splitted into training, validation and test sets (70%, 15%, 15%).

The FROG traces togheter with the corresponding labels are fed to the CNN, which is trained for several epochs using the Adam optimizer and the Mean Square Error as the loss function calculated for the input and the output of the CNN.

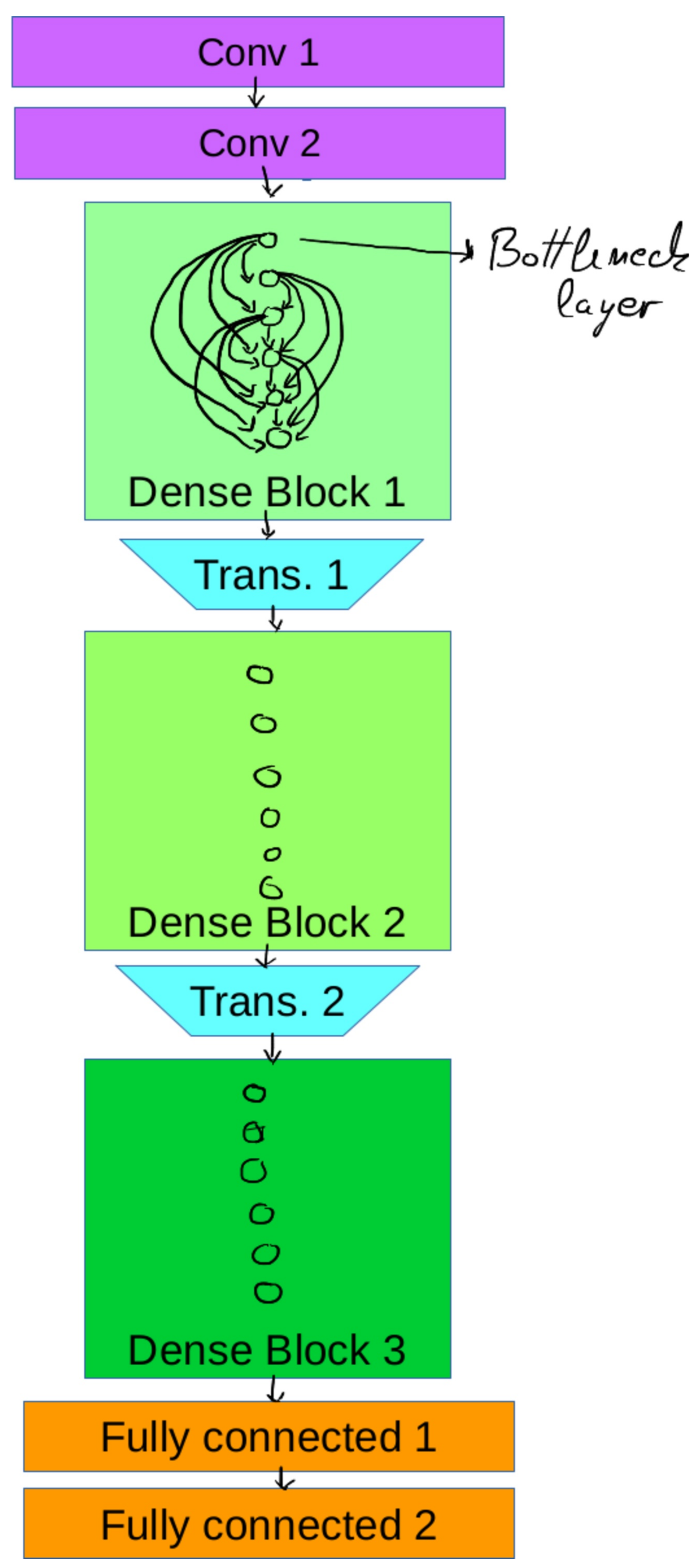
Schematic workflow



Preliminary results for amplitude (no glass)

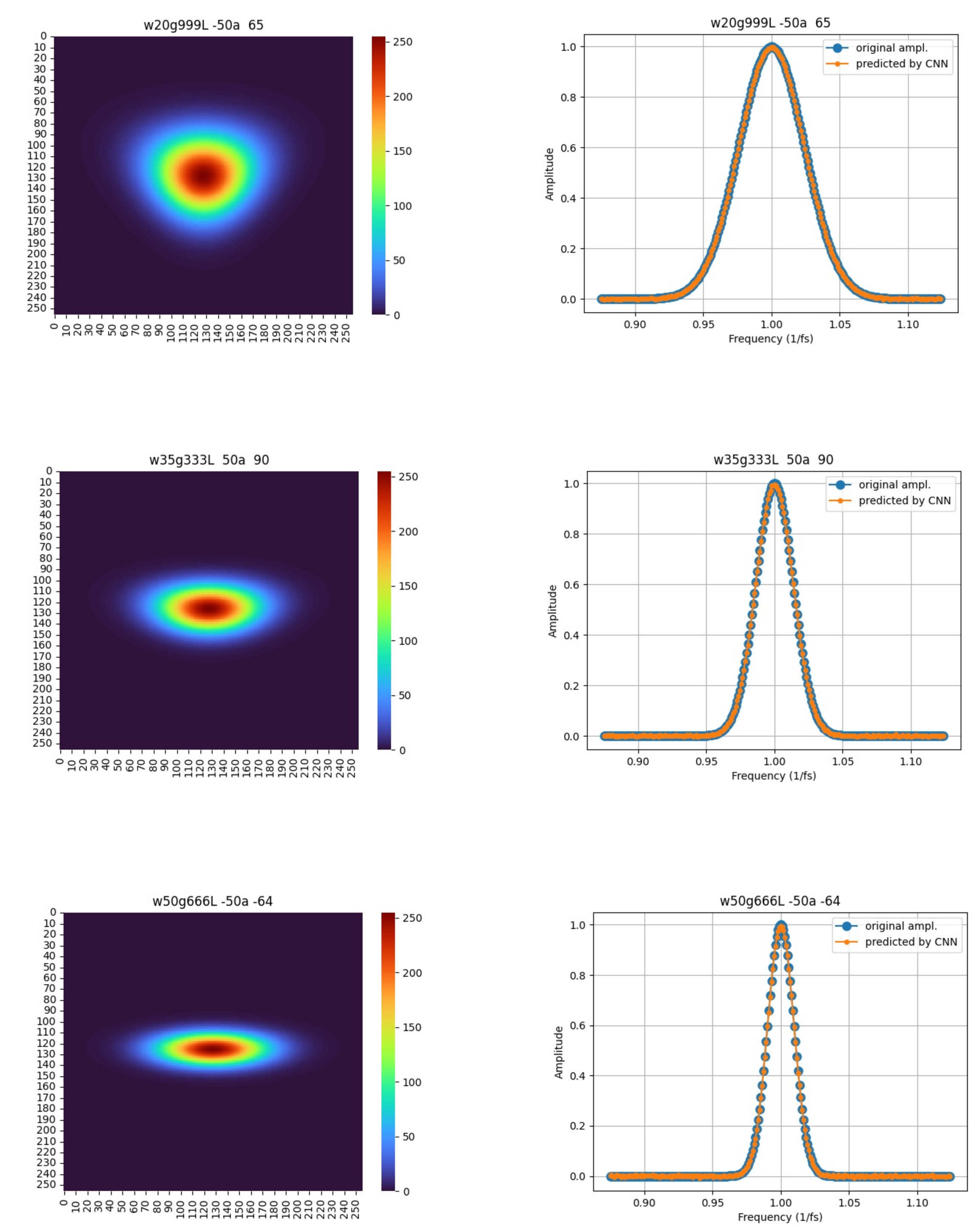


CNN model



The CNN is a variant of the DenseNet-BC model [2], modified for the purposes of the current work. Above the schematic architecture of the model is presented.

Preliminary results for amplitude (glass)



Acknowledgement

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Bibliography

[1] T. Zahavy et al, Optica 5, 5, 666-673 (2018)
[2] G. Huang et al, arXiv:1608.06993 (2017)