Enhanced Bi-LSTM for Modeling Nonlinear Amplification Dynamics of Ultra-short Optical Pulses

K. P. Saraeva and A. E. Bednyakova
Novosibirsk State University, Russia

Abstract— The fibre amplifier is a crucial component of a laser system. The main challenges to deal with in active fibres are managing high nonlinear phase shifts without wave breaking and generation of ultrashort sub-100 fs pulses, which are affected by strong gain shaping. As a result, there has been recent interest in a new regime for amplifying linearly chirped asymmetric pulses with gain-guiding nonlinearity (GGN) [1, 2].

Numerical modeling of the fibre amplifier is computationally intensive and time-consuming task that cannot be used in real-time experiments. One potential solution to this issue involves employing neural networks. Since the task of modeling pulse propagation through the fibre is entirely equivalent to forecasting time series it can be successively solved using recurrent neural networks (RNN) [3].

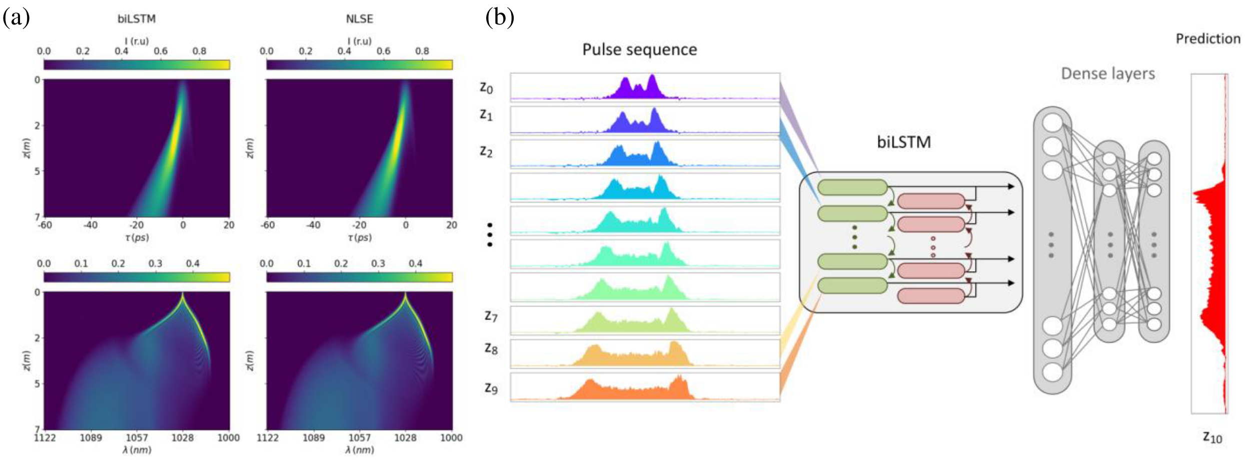

Figure 1: (a) A comparison of temporal and spectral pulse evolution predicted by RNN and obtained in full modeling. (b) A diagram of a neural network.

For modeling highly nonlinear propagation of ultrashort pulses inside the amplifier, a complex numerical model considering a dynamically changing amplification profile and Raman scattering is required. We have chosen the range of initial parameters that covers the change in relation between dispersion and nonlinear length from 0.25 to 250, resulting in a wide variety of propagation regimes, from smooth attractor-like modes to noise-like ones. The RNN trained with this range of parameters needs to generalize various propagation modes, which is a challenging task. We have significantly improved the original architecture, so that a single neural network can capture, diverse dynamic.

This study presents the results of applying a physically-informed RNN to predict the nonlinear evolution of spectral and temporal pulse intensities along an active fibre. We demonstrate that the RNN, trained on numerical simulation results, can accurately and rapidly reproduce the intricate dynamics of a GGN regime inside a fibre amplifier for a wide range of initial pulse parameters. We have constructed error maps in the parameter area and investigated the possibility of "cold" start predictions. We also consider practical applications of the obtained results and solving of the inverse problem.

ACKNOWLEDGMENT

This research was funded by the Ministry of Science and Higher Education of the Russian Federation (Project No. FSUS-2021-0015).

REFERENCES

1. Sidorenko, P., W. Fu, and F. Wise, "Nonlinear ultrafast fibre amplifiers beyond the gain-narrowing limit," *Optica*, Vol. 6, No. 10, 2019.
2. Turitsyn, S. K., A. E. Bednyakova, and E. V. Podivilov, "Nonlinear optical pulses in media with asymmetric gain," *Phys. Rev. Lett.*, Vol. 131, 153802, 2023.
3. Salmela, L., et al., "Predicting ultrafast nonlinear dynamics in fibre optics with a recurrent neural network," *Nature Machine Intelligence*, Vol. 3, No. 4, 344–354, 2021.