Internship research project (2025)

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"Synthesis of a AI-based GNLSE predictor for application to waveguide photonics"

Research project description:

Context:

The integration of various materials and the possibility of realising a wide range of optical functions on a chip through the advanced miniaturisation of guided optics in silicon photonics offer very broad opportunities for a continuum of studies ranging from fundamental physics to applications **[1]**. A recent trend of the field has been devoted to the investigation of third-order optical nonlinearities for the realization of integrated light optical sources, including frequency comb or supercontinuum sources needed to on-chip metrology/sensing and quantum communications **[2,3]**.

The problem to be solved:

The physics of **optical pulse propagation** in an optical waveguide is described by solving a highly **nonlinear partial differential equation** called the **Generalized Nonlinear Schrödinger Equation (GNLSE)**. This equation, that includes the dispersion and the effective nonlinearity of the constituent materials as well as the waveguide conditions responsible for a tight confinement of light in small cross-sections (~wavelength^2), provides **solutions that are dramatically sensitive to the input beam parameters and to any variation of the waveguide properties**. Both the propagation dynamics and the output spectral and temporal characteristics strongly depend on the injected optical pulse and to any variation of the waveguide cross-section along the propagation of light. On top of that, matching input beam conditions and/or modification of the waveguide profile along the light propagation path to achieve a given output pulse is a very complex nonlinear multivariate problem that can solved rigorously within the interaction picture framework **[4]**. **Fig. 1** shows a typical example devoted to optical pulse compression in an optical fibre based on the compression mechanism of high order solitons **[5]**.

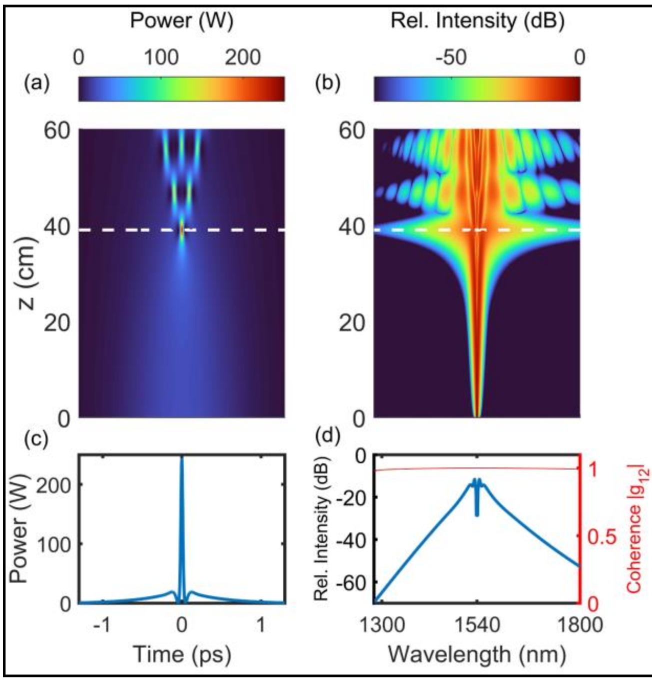

Fig.1: *(from [5])*

Simulation:

In (a) time and (b) frequency domains of an initial Gaussian optical pulse centred at 1540nm light wavelength, with a peak power of 21W and initial FWHM of 1.2ps, assuming 1.7dB/m of propagation loss and fiber dispersion parameters of β_2=-79ps^2/km, β_3=-0.079ps^3/km, β_4=0.0023ps^4/km. The dashed line represents the location of optimal compression.

(c) and (d) provide the simulated time trace and optical spectrum at the optimal compression point along light propagation, along with the light coherence statistical parameter $|g_{12}(\lambda)|$.

This approach is computationally demanding, creates a severe bottleneck in simulating various physical situations of interest, and precludes advanced optimization schemes to design experiments in real time or identify no intuitive input pulse conditions (time width, chirp, pulse shape) and optical waveguide profiles matching an **inverse optical problem** logic. In this context, **building a GNLSE efficient, fast, accurate predictor applicable to highly nonlinear and complex optical pulse propagation conditions is highly desirable for a large amount of applications**.

Recent works have been performed in this direction in the frame of pulse propagation in fibre optics. Different architectures of neural networks have been proposed to learning the complex input/output optical pulse properties characterizing a nonlinear optical fibre. In **[6]**, recurrent neural networks (RNN) were considered, as shown in **Fig. 2**. This work demonstrated the efficiency of RNN to learn the tested complex dynamics corresponding to different physical configurations including high-order soliton compression and supercontinuum generation, respectively. The same co-authors later implemented a simpler feed-forward neural network scheme to mimic the supercontinuum generation in a highly nonlinear optical fiber **[7]**.

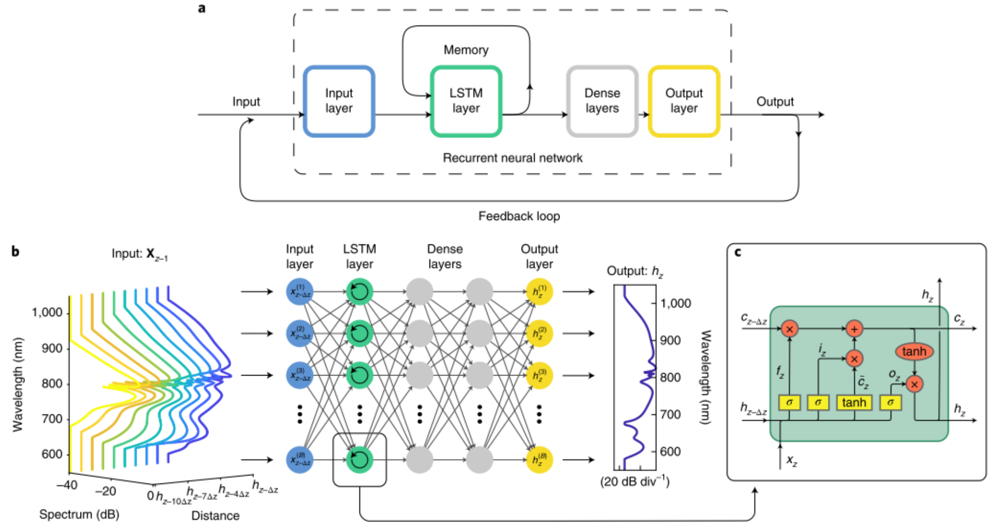

Fig.2: Recurrent neural network architecture proposed in **[6]**.

THE PURPOSE OF THE PROPOSED RESEARCH PROJECT IS TO:

1) Going farther than the published works that have been mostly devoted to low index contrast waveguides (fibres) in view to **investigating the optical pulse dynamics** in the much **strong**er **index contrast waveguides** of silicon photonics
2) **Propose** other **neural network architectures** (NNA), investigate their behaviours, and compare their characteristics
3) Demonstrate the efficiency of NNA to model light propagation **in optical waveguides with arbitrary chirped cross-sections along the light propagation (z-direction)**
4) **Solve the inverse problem in nonlinear optical waveguides** through the use of neural networks in various situations of physical interest, i.e. predict the waveguide cross-section profile along *z*, as well as the input optical pulse properties – time width, chirp, time envelop shape, chirp -, to match any desired output pulse characteristics after a given propagation distance

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For any question, you can send an email to eric.cassan@universite-paris-saclay.fr

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References:

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