

Interferometric stabilisation of a fiber-based optical computer

Experimental study

Denis Verstraeten

ULB - Opera Photonics

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DE BRUXELLES

Outline

- 1 Introduction
- 2 Reservoir Computing
- 3 Photonics reservoir computer with frequency-multiplexed neurons
- 4 Interferometric stabilisation of RC optical resonator
- 5 Outlooks

Context

- The need for always faster data processing devices is ever increasing
- This motivates the study of a new physical computation paradigm, the **optical computer**
- This kind of computer relies on light to process information
- Different ways to implement computing logic
- In this work, focus on **Reservoir Computing (RC)**

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Reservoir Computing (RC) in a nutshell...

- Artificial Neural Network
- Real-time data processing scheme
- Can be implemented in physical systems
- State of the art performances in time series prediction

Mathematical model of a RC

Discrete time dynamics of a neuron [Jae01]:

$$x_i(t+1) = f_{NL} \left(W^{ij} x_j(t) + W_{in}^{ij} u_j(t) + W_{fb}^{ij} y_j(t) \right) \quad (1)$$

Discrete time output of the reservoir:

$$y_i(t) = W_{out}^{ij} x_j(t) \quad (2)$$

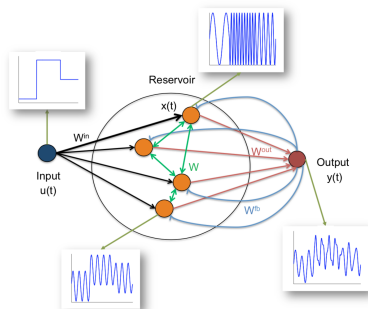
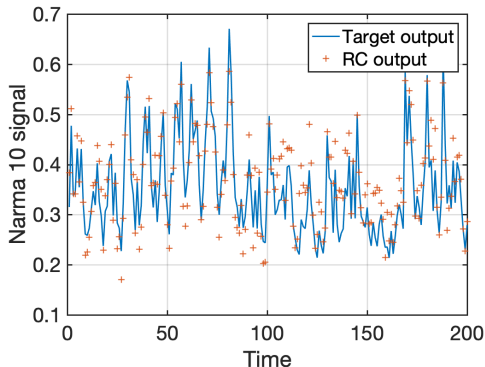


Figure: [BFP12]

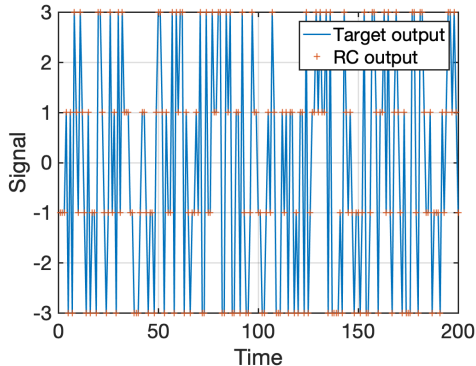
Simulation - NARMA 10

- Nonlinear
AutoRegressive
Moving Average
- 50 neurons
- Washout : 300
- Learning : 3000
- Testing : 6000
- NMSE = 0.1439



Simulation - Nonlinear Channel Equalisation

- 50 neurons
- SNR = 32 dB
- Washout : 300
- Learning : 3000
- Testing : 6000
- SER= $3.33 \cdot 10^{-4}$



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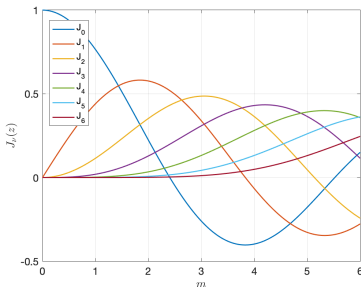
Motivations

- Blablabla
- Coupling of the different frequencies

Frequency coupling - phase modulator I

Effect of a *phase modulator* :

$$Ee^{-i\omega t} \xrightarrow{\Omega} Ee^{-i\omega t} e^{im \sin \Omega t} = \sum_{k=-\infty}^{\infty} EJ_k(m) e^{-i(\omega+k\Omega)t} \quad (3)$$



- Experimentally, $m \leq 2$
- $J_k(m)$ decrease fast with k
- Series can be truncated
- **Finite number of frequencies can be coupled ($2N + 1$)**

Frequency coupling - phase modulator II

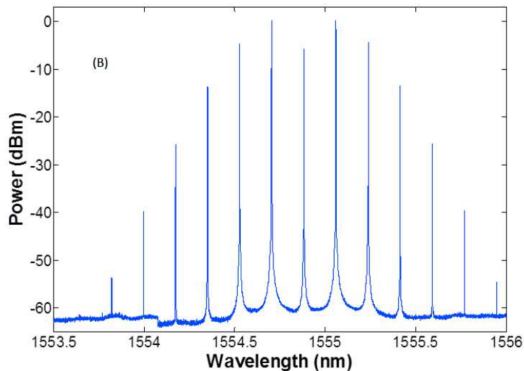


Figure: Spectrum inside the cavity. Only 13 frequencies are usable.
[Akr+16]

Mathematical Model

Definition of a neuron (complex electric field) :

$$x_k(t) = E_k e^{-i(\omega + k\Omega)t}, \quad k \in [-N, N] \quad (4)$$

Dynamics of a neuron :

$$x_k(n+1) = \alpha e^{i\phi_k} \sum_{j=0}^{2N} J_{-N+k+j}(m) x_{j-N}(n) + \beta u(n) \delta_{k,0} \quad (5)$$

RC Output :

$$y(n) = \sum_{i=-N}^N W_i |x_i(n)|^2 \quad (6)$$

Schematic principle

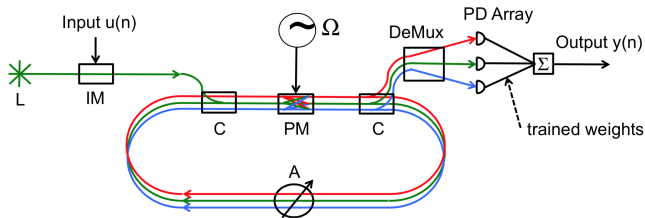


Figure:
[Akr+16]

- **One** input frequency
- Amplitude modulation :
input data $u(n)$
- Frequency coupling in PM Ω
- Nonlinearity in *Readout PD* :
 $|x_k(n)|^2$
- *Machine Learning* :
output weights W_i

Main issues I

- ϕ_k (in Eq. 5) should be a constant for each neuron
⇒ **Feedback loop regulation** of the optical cavity
- High losses induced by intra-cavity PM
- Intra-cavity amplification : EDFA

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- [Akr+16] A. AkROUT et al. "Parallel photonic reservoir computing using frequency multiplexing of neurons". In: (2016).
- [BFP12] A. Bernal, S. Fok, and R. Pidaparthi. "Financial Market Time Series Prediction with Recurrent Neural Networks". In: (2012). URL: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.278.3606&rep=rep1&type=pdf>.
- [Jae01] H. Jaeger. *The "echo state" approach to analysing and training recurrent neural networks*. 2001.