Interferometric stabilisation of a fiber-based optical computer

Experimental study

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Outline

Context

- TODO

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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]:

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

Discrete time output of the reservoir:

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

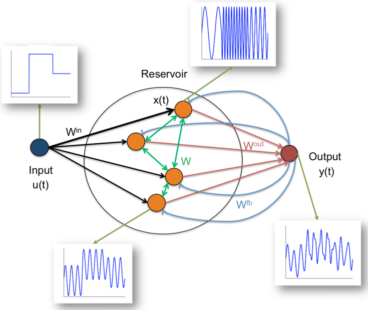
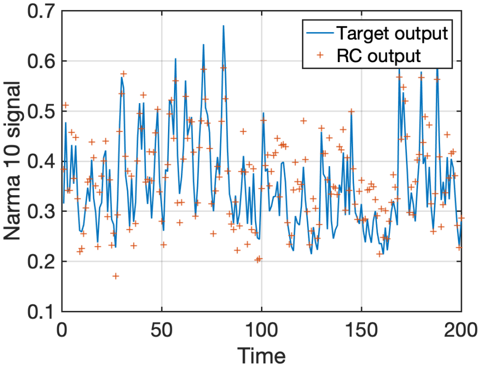


Figure: [BFP12]

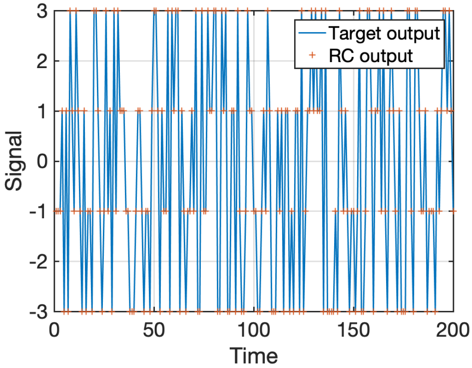
Simulation - NARMA 10

- 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= $3.33 \cdot 10^{-4}$



Outline

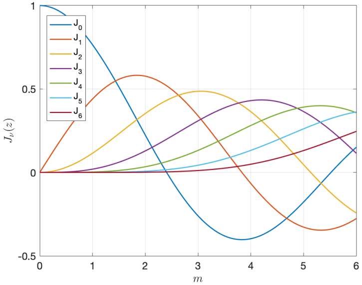
Motivations

- TODO
- Coupling of the different frequencies

Frequency coupling - phase modulator I

Effect of a *phase modulator* :

$$Ee^{-i\omega t} \underset{\Omega}{\rightarrow} Ee^{-i\omega t} e^{im \sin \Omega t} = \sum_{k=-\infty}^{\infty} E J_k(m) e^{-i(\omega + k\Omega)t} \qquad (3)$$



- 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

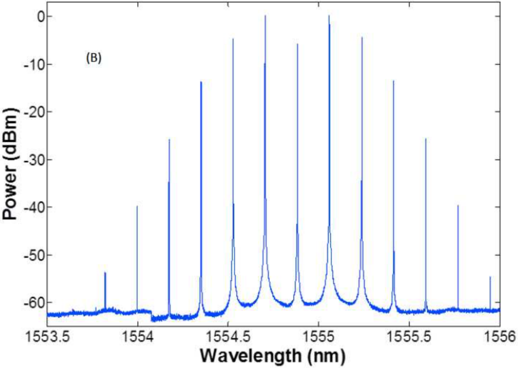


Figure: Spectrum inside the cavity. Only 13 frequencies are usable. [Akr+16]

Mathematical Model

Definition of a neuron (complex electric field) :

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

Dynamics of a neuron :

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

RC Output :

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

Schematic principle

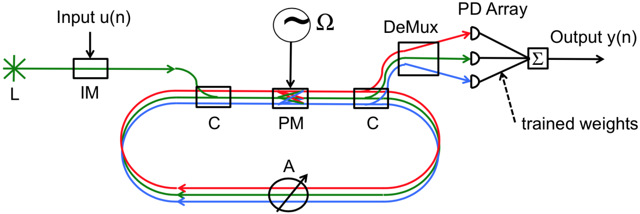


Figure: [Akr+16]

- **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
  $\Longrightarrow$ Feedback loop regulation of the optical cavity
- TODO

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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.