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# Reservoir computing based on laser subject to optoelectronic feedback

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**Abstract**— We study delay-based photonic reservoir computing using a semiconductor laser with an optoelectronic feedback. Multiple Hopf bifurcation branches possess the parity asymmetry with relation to the feedback sign. We observe the corresponding difference in the normalized means square error (NMSE) values corresponding to the prediction of the  $n+2$  and  $n+3$  points based on the  $n$  samples in the chaotic timeseries prediction task.

**Keywords**— Reservoir computing; optoelectronic feedback; bifurcation analysis.

## I. INTRODUCTION

Photonic reservoir computing (RC) is a promising paradigm combining the computational capabilities of recurrent neural networks with the high processing speed and energy efficiency of photonics. The principle of operation of photonic RC systems lies on mapping an input signal onto a high-dimensional space using a nonlinearity of a photonic system. The mapping allows for the utilization of simple regression methods to solve complex time-series prediction and classification tasks. Generally, a recurrent network is used as a reservoir due to its fading memory. A single nonlinear system subject to a time-delayed feedback can be considered as a virtual network, and the internal states of virtual nodes are assigned by sampling the temporal waveform of the dynamical output within the feedback loop. This allows for easy hardware implementation of the virtual network exploiting a single nonlinear dynamical system with a time-delayed feedback loop. Numerous studies have been reported on the implementation of delay-based reservoir computing using optical and photonic systems [1]. To enrich the distinctive properties of the reservoir, the laser system is expected to operate close to a bifurcation point.

## II. RESULTS

We study delay-based photonic reservoir computing using a semiconductor laser with an optoelectronic feedback. A rate equation model for a laser with an optoelectronic filtered feedback is used. The delay-differential equation model consists of the three equations for the normalized electric field intensity  $I(t)$ , the carrier density  $N(t)$ ;

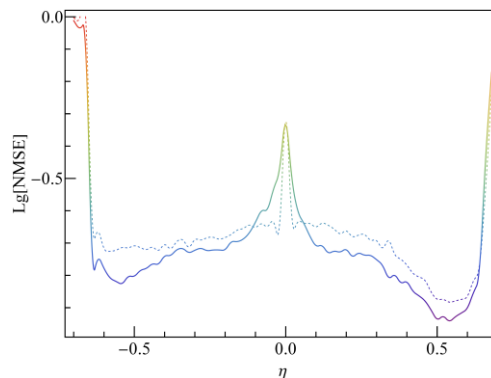


Fig. 1.  $\lg(\text{NMSE})$  with respect to the feedback strength. Dotted and solid lines are cases of 32 and 48 nodes correspondingly.

and the high-pass filtered intensity signal  $I_F(t)$ . The stability boundaries which correspond to the Hopf bifurcation condition are determined analytically. We use the Santa Fe time-series prediction task [Ref] to evaluate the performance of reservoir computing. Our objective is to determine the location of the optimal operating point defined as a point with minimal normalized means square error (NMSE) and relate it to the stability properties of the system. We use 3000 points for training and 1000 for testing; the number of virtual nodes is chosen in regard to the relaxation oscillation frequency. Single-point prediction of the chaotic data is performed. Input signal applied to the pumping current is determined by the chaotic waveform having  $n$  sampling points, and three cases are investigated: prediction of  $n+1$ ,  $n+2$  or  $n+3$  sampling point. The best NMSE value in the order of  $10^{-7}$ , for  $n+1$  point prediction task,

is obtained in the absence of feedback and a rapid increase in NMSE is observed in the vicinity of Hopf bifurcation without regard to the feedback sign. On the contrary, the minimum values of NMSE for  $n+2$  and  $n+3$  point prediction task correspond to Hopf bifurcation points resulting from positive feedback. We discuss whether the parity asymmetry can explain strongly asymmetric reservoir computing performance.

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#### REFERENCES

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