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Impact of low-pass filtering effect on a delay-based photonic reservoir computer

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Abstract We investigate the performance of a photonic reservoir computer based on a semiconductor laser with bandpass filtered optoelectronic feedback, focusing on how the change of the low-pass filtering alters the system's processing capabilities. We find a dependence of the computational ability and the memory capacity on the low-pass cut-off frequency. Additional analyses of the system's eigenvalue spectrum let us find the correlation between the distance from the imaginary axis to the nearest eigenvalue and the memory capacity of the reservoir computer. Furthermore, the maximum computational ability of the system shows no significant dependence on the bandwidth of the feedback loop.

Introduction

Reservoir computing (RC) is a relatively modern computational paradigm in the field of neural networks. Reservoir computing is based on a complex response of the dynamical system (called the reservoir) to the input signal perturbation and depends on the previous states of the reservoir. Thus, the RC system possesses fading memory similar to classical recurrent neural networks. The salient feature of RC is that only the output layer has to be trained and optimized, while the input and reservoir layers are fixed. This simplification in the network's architecture is suited for hardware implementation using different physical technologies. This work considers a photonic RC system based on a semiconductor laser with high- and low-pass filtered optoelectronic feedback. The system's architecture and operation principle are similar to that reported previously [1], with additional low-pass filtering in the feedback loop.

Results and discussions

Figure 1 shows the eigenvalue spectra of a steady-state calculated for the maxima of the memory capacity (MC) in each case. In the middle spectrum, corresponding to the maximum MC among the analyzed parameters, many eigenvalues can be characterized as having small damping. The overall spectral shape can also be considered as a relatively flat top. The 2D maps of the system's MC for the different values of the low-pass filter cut-off parameter along with the Hopf bifurcation borders are shown in Fig. 2. The 2D maps are asymmetric with respect to the feedback sign (as in [1]).

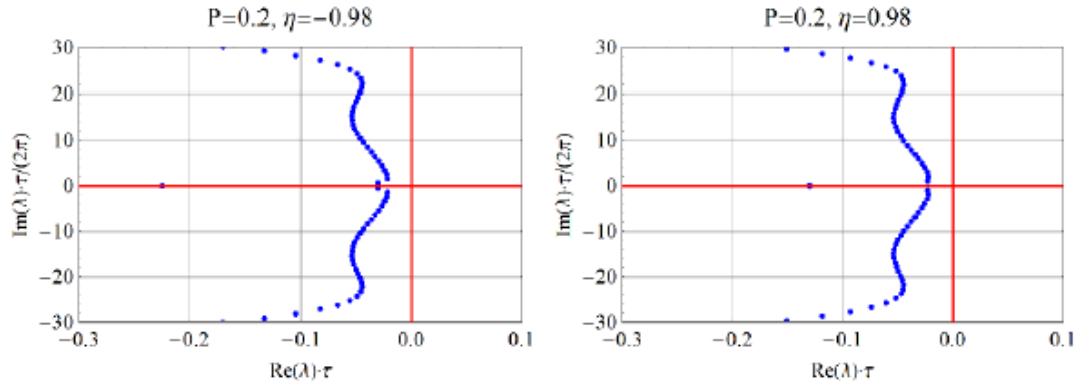


Figure 1: The spectrum of eigenvalues for the optimal value of the MC and different signs of the feedback.

As noticed in [3], the MC is maximized when many of the system's eigenvalues have real parts close to zero. To further investigate the correlation between the spectral properties of the reservoir and the MC, we performed the pseudo-continuous (PC) approximation of the eigenvalue spectrum. Using the approach described in [2], we introduce a measure that evaluates the average distance between the real parts of the pseudo-continuous (PC) spectrum and the imaginary axis:

$$D = \frac{1}{\lambda_0^- - \lambda_0^+} \int_{\lambda_0^-}^{\lambda_0^+} \lambda_1 d\lambda_0 \quad (4)$$

where λ_0 (λ_1) is the imaginary (real) part of the spectrum, $\lambda_0^- > 0$ and $\lambda_0^+ > 0$ are lower and upper bounds of the interval where $\lambda_1 \geq -1$.

The average distance D (Fig. 3) is well-correlated to the memory capacity. The area with the largest values of memory capacity for each τ_L corresponds to the area with the smallest values of the average distance.

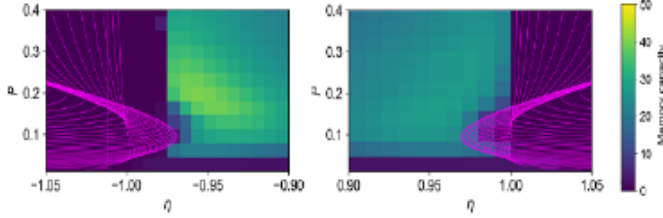


Figure 2: 2D maps of the system's memory capacity for the optimal value of the MC. The magenta lines are the Hopf bifurcation borders.

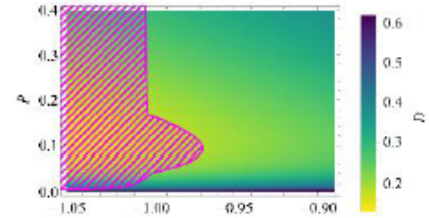


Figure 3: 2D maps of the average distance from the PC spectrum to the imaginary axis for the optimal value of the MC. The dashed region corresponds to the asymptotically unstable spectrum.

Figure 4 shows the 2D maps of the system's computational ability (CA). Despite the significant decrease in the system's bandwidth, the maximal CA remains unchanged with variations in the low-pass cut-off frequency. However, while MC is maximized when the average distance D is minimal, the CA decreases and vanishes in the vicinity of the Hopf bifurcation borders. It can be attributed to the interference of the previous inputs kept in the reservoir's memory.

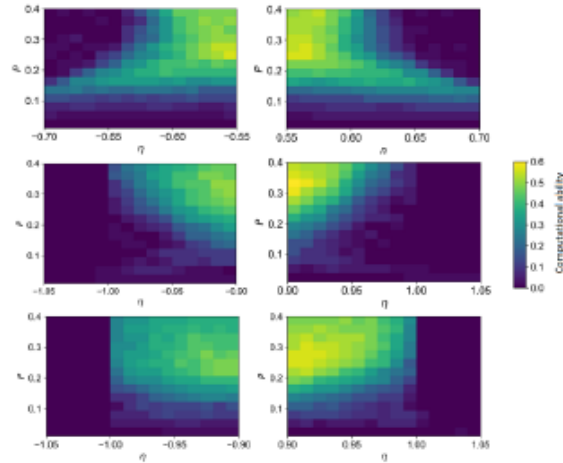


Figure 4: 2D maps of the system's computational ability with the decrease of the cut-off frequency from the top row to the bottom.

Conclusion

Changing the low-pass cut-off frequency changes both the memory capacity and the computational ability of an optoelectronic feedback RC. Reducing the distance between the real parts of the pseudo-continuous spectrum and the imaginary axis correlates with an increase in the memory capacity of an optoelectronic feedback RC and a decrease in its computational ability.

References

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