Experimental Investigation of Time-Stretch-Based Reservoir Computing with an Optical Input Mask

Yuanli Yue[1], *Shouju* Liu[1], *Weichao* Xu[2], *Chao* Wang[1,*]
[1]School of Engineering, University of Kent, Canterbury CT2 7NT, United Kingdom.
[2]School of Automation, Guangdong University of Technology, Guangzhou, China.

Abstract. In this paper, we experimentally demonstrated a novel all-optical reservoir computer with an all optical input mask. The combination of the binary random masks and the time-stretched ultrashort pulses has increased the system's classification performance. Compared with the traditional digital masks, this method shows superior classification performance in spoken-digit classification tasks and eliminates the need for high-speed modulation for digital masks.

1 Introduction

Reservoir computing (RC) is introduced as an Echo State Networks (ESNs) and Liquid State Machines (LSMs), and meets the requirements for processing large amounts of time-series data [1]. In recent years, Reservoir Computing research has obtained significant attention, and the powerful RC systems has been applied in processing complex task such as prediction, robot control, and speech recognition [2]. To further improve the data processing speed, optical Reservoir computing concept is proposed.

A typical RC system comprises an input layer, a reservoir layer, and an output layer. Typically, a temporal mask is multiplied with the input signal before the input signal enters to the reservoir layer. The mask can be regarded as the input weight between the input signal and the virtual nodes. In previous study, the mask of delay-based RC is adopted in different methods such as a binary random signal, a sinusoidal analog signal, a six-level signal, and so on [3, 4, 5]. Different masks are used to reduce the noise and improve the performance of RC. However, the existed method has its limitations. All the masks are modulated in digital field, and multiplied with the input signal before input signal added. This would sacrifice the modulation speed and introduce the new noise during the modulation. To solve this, we have proposed and numerically demonstrated a method to enhance the performance of photonics RC using all-optical input masks [6, 7]. The simulation results have shown that a RC with an optical mask has a better performance in waveform classification [8].

In this study, we experimentally investigated an all-optical reservoir computer based on photonic time stretch platform [9] with an optical mask. The classification performance with spoken-digit recognition is evaluated. An all-optical mask can overcome the existing electronic bottleneck. Experiment results show that it has a better performance than traditional RC with digital input masks.

2 Principle and Experimental setup

The proposed photonic time-stretch based RC structure is shown in Fig. 1. An all-optical masking process is added in the input layer. An ultrashort pulse emitted from a mode-locked laser (MLL) is stretched using a dispersion compensating fibre (DCF) and serves as the optical carrier. A one-to-one mapping relation exists between the wavelength and time domains. This unique feature enables an alternative way to implement temporal mask. Instead of direct implementation of temporal mask via a modulation process, an optical spectral filter with random binary response is used to shape the optical spectrum, which equivalently embeds the binary random mask in the temporal signal. The optical spectral filter is constructed using an optical diffraction grating to spread optical spectrum in space, and a spatial mask with random binary slots to shape the optical spectrum.

A binary random mask is adopted in this work. A Gaussian pulse multiplied with the mask on the optical link, and then the signal to be classified modulated by an Mach-Zehnder modulator (MZM). In the reservoir layer, the nonlinear wavelength node coupling is achieved by a semiconductor optical amplifier (SOA). Spectral comb lines are chosen as virtual nodes. The spectral mixing can interaction between different neurons.

The optical mask is utilized using a pair of diffraction gratings and a spatial mask, which has a minimum 0.3mm width, manufactured with high accuracy. The mask has 179 binary random values. After that, the signal to be classified is modulated via MZM. The nonlinear interaction is achieved within the SOA (Thorlabs SOA1117P). The SOA has a low noise figure and large

* Corresponding author: C.Wang@kent.ac.uk

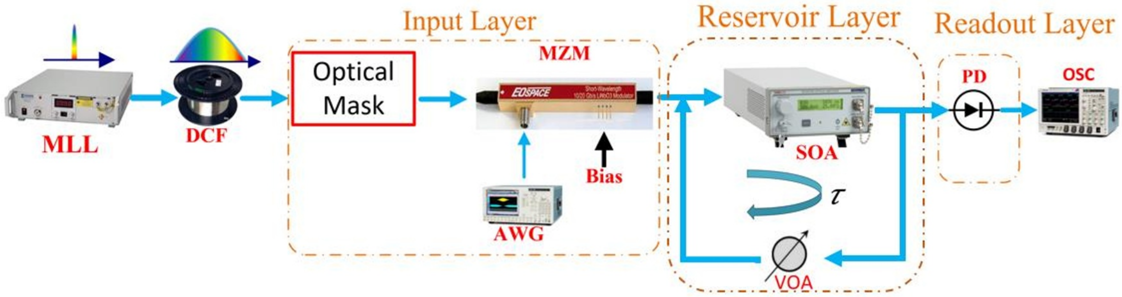

Fig. 1: The schematic of the proposed all-optical reservoir computer. MLL: Mode-Locked Laser, DCF: Dispersion Compensating Fibre, MZM: Mach-Zehnder modulator, AWG: Arbitrary Waveform Generator, VOA: Variable Optical Attenuator, SOA: Semiconductor Optical Amplifier, PD: Photodetector, OSC: Oscilloscope.

gain across a broad spectral bandwidth. In this experiment, the driven current was set to 250 mA.

3 Results and discussion

We experimentally demonstrated an isolated spoken-digit recognition task. The spoken-digit database is widely used in examining the capacity of RC systems. The datasets of ten spoken digits (0–9) are chosen from NIST TI-46 corpus [10]. There are 10 voices from 0 to 9, with the temporal waveforms shown in Fig 2. The spoken-digit signal was send to the reservoir and its states were generated in the output layer.

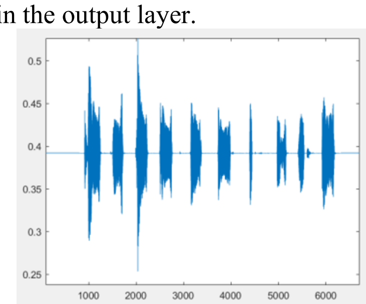

Fig. 2. Raw spoken-digit data representing 0 to 9.

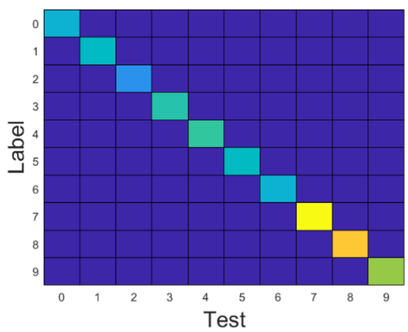

Fig. 3. Confusion matrix of spoken-digit classification.

In this study, we chose 'the winner-takes-all' decision strategy. This means that the classification result will select its biggest possible value among the different voice recognition. The classification result in shown in Fig 3. The signal to be classified can be recognized correctly. We have also calculated the Words Correct Rate (WRR) of the proposed RC scheme with an optical mask. The accuracy can be as high as 97.98%.

4 Conclusion

In this paper, we have proposed the all-optical RC scheme with an optical input mask. The optical mask is employed to the optical link before the modulation. The pre-added optical mask can overcome the bottleneck of the electronic limitation. It have a more faster calculation speed than the digital mask and it also have less requirement on electronic speed. The experimental result shows it can classify the spoken-digit tasks correctly. Compared with the digital mask, the RC system with an optical mask performs better.

This work was supported in part by the Engineering and Physical Sciences Research Council of the U.K. (EP/S005625/1, EP/T51732X/1), and in part by the National Natural Science Foundation of China (61975248).

References

1. H. Jaeger, and H. Haas. *science*, **304** (2004)
2. G. Tanaka, T. Yamane, J.B. Héroux, R. Nakane, N. Kanazawa, S. Takeda, H. Numata, D. Nakano, and A. Hirose. *Neural Networks* **115** (2019)
3. B. Schneider, D. Joni, and B. Peter. *IEEE transactions on neural networks and learning systems*. **12** (2015)
4. J. Nakayama, K. Kanno, and A. Uchida. *Optics express*, **24** (2016)
5. Y. Kuriki, J. Nakayama, K. Takano, and A. Uchida, *Optics express*, **26** (2018)
6. Y. Yue, S. Liu, Y. Feng and C. Wang, *2022 Conference on Lasers and Electro-Optics (CLEO), **1-2*** (2022)
7. Y. Yue, S. Liu, Y. Zhai, and C. Wang, *2022 IEEE International Topical Meeting on Microwave Photonics (MWP),* **1-3** (2022)
8. Y. Yue, S. Liu, Y. Zhai, and C. Wang. *2022 IEEE Photonics Conference (IPC),* **1-2** (2022)
9. A. Mahjoubfar, D. V. Churkin, S. Barland, N. Broderick, S. K. Turitsyn, and B. Jalali, *Nat Photon*, **11** (2017).
10. M. Liberman, R. Amsler, K. Church, E. Fox, C. Hafner, J. Klavans, et al., Ti 46-Word (Linguistic Data Consortium, Philadelphia, PA, 1993).