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Enhanced photonic time-stretch reservoir computing using all-optical input masks

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Abstract—Input masks are essential in reservoir computing to enhance its performance. Here we report a novel all-optical masking scheme for photonics time-stretch reservoir computing based on optical spectral filtering. This approach overcomes the electronic bottleneck in digital temporal masking and offers better performance in classification tasks.

Keywords—reservoir computing, input mask, photonic time stretch, classification

I. INTRODUCTION

Reservoir computing (RC) is a special variant of Recurrent Neural Network (RNN) [1], featuring much simplified training process as only the output weights are to be trained. RC provides a promising solution for sequential temporal data processing as it does not need more specific reservoir parameter settings. Recently, great research efforts have been made in physical implementation of RC systems [2]. In particular, photonic RC has attracted great research interest due to its advantages of low energy consumption, parallelism, and fast processing speed. For example, an all-optical RC based on photonic time-stretch and nonlinear spectral mixing has been demonstrated for high-throughput object classification [3].

In RC systems based on time delayed virtual nodes, a temporal input mask is usually introduced to enhance the complex transient response [4]. For high-speed input signals, temporal input masking requires large bandwidth in sequence generation and modulation, hence suffering from the electronic bottleneck. In this work, we propose and demonstrate a novel all-optical masking scheme in photonic time stretch RC based on optical spectral shaping. Due to one-to-one mapping relationship in a time stretch optical pulse, spectral encoding of designed mask enables equivalent high-speed temporal masking without using digital sequence generation and modulation, hence completely overcoming the existing electronic bottleneck. In addition, our results show that the presented RC offers better classification performance compared to traditional RC with digital input masking.

II. PRINCIPLE

As shown in Fig. 1, the proposed photonic time-stretch RC structure introduces an all-optical masking process in the input layer. An ultrashort pulse emitted from a mode-locked laser (MLL) is stretched using dispersion compensating fibre (DCF) and serves as the optical carrier. The all-optical masking process is achieved based on optical spectral filtering thanks to wavelength-to-time mapping in time stretched optical pulses. The input sequential information to be classified is modulated to stretched pulse using a

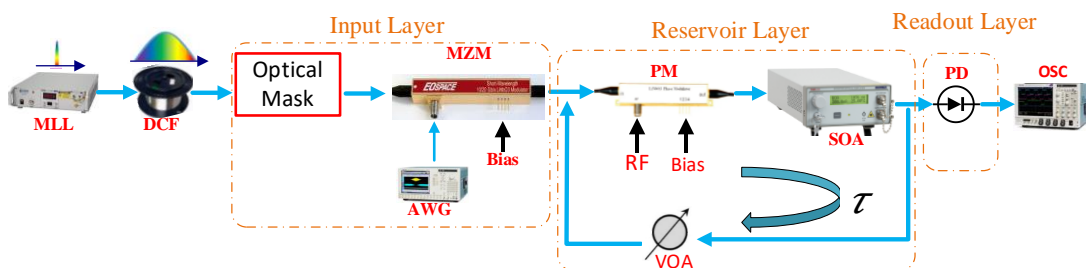


Fig. 1. Schematic of the photonic time stretch photonic reservoir computer with all-optical input masks.

modulator. The reservoir layer is implemented using a delayed optical loop. The delay time τ equals the sampling time T of the input signal. Nonlinear wavelength node coupling is achieved using a phase modulator and a semiconductor optical amplifier (SOA) [3].

III. SIMULATION RESULTS AND DISCUSSION

To evaluate the utility of the proposed photonic time stretch RC system with an all-optical mask, numerical simulations were carried out using VPIphotonics following the setup in Fig. 1. Waveform classification is chosen as the benchmark test. Two different waveforms, square wave and triangle wave, are involved. The whole sequential waveform is discretized into 99 input points. We have selected two different types of optical spectral filtering schemes for equivalent temporal masking. The first one is a binary optical mask achieved using a programmable optical spectral filter where 400 random binary values are selected. The second optical mask is based on a non-balanced MZI filter [5], where a tunable time-delay in one arm is used to control the equivalent temporal sampling frequency, and an extra dispersion element is introduced in another arm to produce an overall chirped spectral response, as shown in Fig. 2(b). Totally 400 uniformly spaced points are used to sample the chirped spectrum, producing an analog random input mask.

In the reservoir layer, a 20 GHz sinusoidal signal is used to drive the phase modulator. The optical feedback ratio is set to be 3 dB. The feedback strength can be controlled by an optical attenuator. In the readout layer, 400 updated statuses are collected using a photodetector (PD) and an oscilloscope. Linear regression is used to calculate the output weights. Normalized root mean square error (NRMSE) is used to quantify the classification performance of the reservoir computing with different input masking schemes, with the results shown in Fig. 2 (c). For comparison, a digital mask with 400 random binary values is produced using an arbitrary waveform generator (AWG) and implemented in the photonic time stretch RC using a separate modulator as in normal time-delayed RC systems.

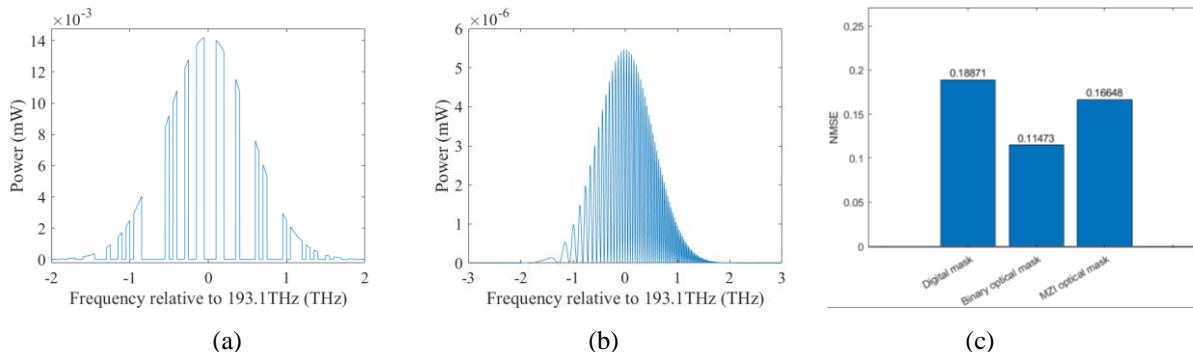


Fig. 2. All optical masking using (a) an optical binary mask, and (b) a non-balanced MZI structure. (c) NRMSE evaluation of the waveform classification tasks using a digital mask, and the proposed two optical masks.

We can see that the all-optical masks offered overall better performance than the binary digital mask, where the masking process could be distorted due to nonlinearity in modulation. The optical masks are directly implemented in the optical domain using fixed optical filters. Therefore, much higher equivalent sampling bandwidth can be achieved, and less noise is introduced. Among the two optical masks, the binary mask has a better performance than the MZI mask.

IV. CONCLUSION

In this paper, we propose and demonstrate a novel all-optical input masking scheme in photonic time stretch reservoir computing. Thanks to the duality between wavelength and time in a stretched optical pulse, high data-rate temporal masking can be equivalently implemented using optical spectral filtering, completely eliminating the electronic bottleneck in sequential mask generation and modulation in conventional delay-based photonic RC systems. Our results also show that the optical masks offer a better classification performance than the digital mask.

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