Photonic VCSEL-neuron for spike-rate representation of digital image data

Matěj Hejda, Joshua Robertson, Julián Bueno, Juan Arturo Alanis and Antonio Hurtado
Institute of Photonics, SUPA Department of Physics, University of Strathclyde, Glasgow, United Kingdom

With the increasing importance and capabilities of artificial intelligence (AI) approaches across all the domains of our society, the focus is now also moving towards the hardware used for running these algorithms. Neuromorphic computers, inspired by the computational capabilities of the brain, offer a viable, high efficiency alternative to usual von Neumann-based electronic processors. Besides the conventional CMOS-based electronics, novel technologies are also being investigated for neuromorphic computing [1]. Optics and photonics are one these promising alternative technologies for such systems, offering desirable properties including high bandwidth and low power operation. Among the photonic technologies for neuromorphic hardware, vertical cavity surface emitting lasers (VCSELs) provide mature fabrication technology, suitability for integration and high-speed operation.

This work demonstrates a spiking photonic neuron based on a commercially available, off-the-shelf, telecom-wavelength VCSEL [2]. The spiking VCSEL-neuron enables encoding of analog signals into spikes directly in the optical domain, at multiple magnitudes higher speeds than the timescales of biological neurons. We utilize the inherent dynamical behaviour of a single VCSEL-neuron to perform conversion of digital numerical data (pixel values in images) into rate-coded optical spike trains [3], where the local spiking frequency represents the encoded data. Individual colour channels of a digital 32×32 RGB image were serialized (in randomized order) and turned into a modulation waveform of *return-to-zero* pulses (pulse length $t = 53.3$ ns), with the amplitude of each pulse linearly mapping each single pixel value. By modulating the external signal entering the VCSEL-neuron, the laser responds with continuous train of *sub*-ns (approximately 100 ps) long spikes with frequencies of up to 1 GHz while remaining quiescent for dark (zero value) pixels. A schematic of the encoding is shown in Fig. 1a. The output timetrace of the VCSEL-neuron, encoding individual pixel data from a selected colour channel (RGB-R, RGB-G, RGB-B), was post-processed and the local average spiking frequency was calculated. By directly assigning the normalized spiking frequencies to the image pixel matrix, we perform a reconstruction of each individual colour channel as well as the merged RGB composite with good match between input and processed images (Fig. 1b). These results demonstrate a hardware-friendly system based upon a VCSEL operating as a spiking optical neuron for reliable, high speed interfacing between digital and spike-rate represented image data in the optical domain. With the raising prospects of neuromorphic chips for efficient AI computing, this work introduces VCSEL-based spiking neurons as a viable solution for all-optical spike-based information encoders and input layers for event-based machine vision systems.

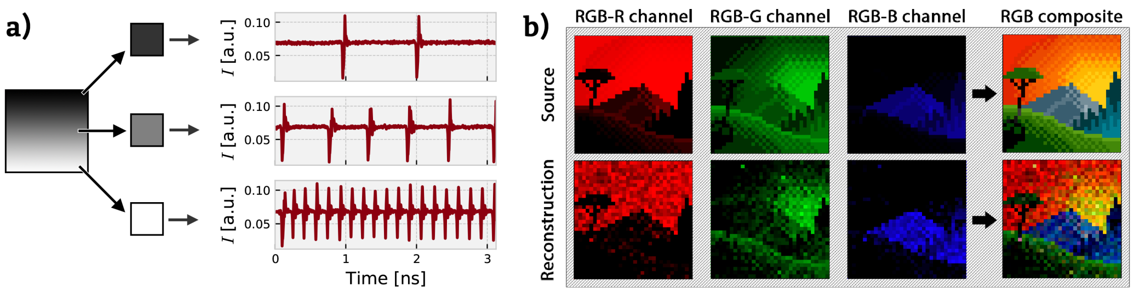

Fig. 1 a) Encoding schematic showing how different image (gradient) pixel intensities are translated into optical spike trains with varying frequency. b) Comparison between the source (top row) and reconstructed 32×32 pixel RGB image (bottom row) obtained from the VCSEL-neuron's rate-coded spiking response.

References

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