Accelerating Optical Edge Sensing with Photonic Deep Learning

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Category: Information

Abstract: Existing optical sensing networks rely on sensors deployed at the internet's edge and processing in the cloud. Data acquisition, transmission, and processing lead to large energy consumption, data traffic, and long latency that are unacceptable in the era of the Internet of Things (a self-driving car would require decision-making within <1 ms). Optical neural networks (ONNs) are emerging to process machine learning tasks with great potential to elevate the electronic bottleneck for both general-purpose computing (Z. Chen, et al, VCSEL-ONN, ***Nat. Photonics*** 2023) and decentralized photonic edge computing (Sludds, et al, ***Science*** 378, (2022)). In particular, incorporating ONN processors with optical sensing would lead to the development of *"smart optical sensors"* that can detect and process optical signals without the need of converting the signal to the electronic domain, thus reducing energy consumption, latency, data traffic, and sensor footprint by orders of magnitude.

Intended outcomes: 1. **first smart optical sensors** incorporating both sensing and processing in a single photonic integrated circuit. 2. **System integration** with laser frequency combs, electro-optic modulators, photonic memories, and long optical waveguides. 3. **state-of-the-art computing performance**: low-energy (10 fJ/MAC), low latency processing (<1 ns), high-density processing chip area 1 cm^2; 4. **On-chip optical sensing** with an optical neural network to retrieve sample information (sample existence, concentration, etc). 5. **Reduced data traffic** with in-sensor processing.

Capability and Impact:

As the global emergence of IoT will continue to explore optical sensing for real-time, high-sensitivity detection, pushing the demands on lower latency, lower energy consumption and footprint, smart optical sensors will play an essential role in addressing the response time, energy cost and data traffic issues, such as in autonomous driving.

For optical sensing, the implementation of neural network hardware (with custom-designed kernels) could enhance the sensitivity of a specific feature that might have been buried in a regular spectral measurement, which would lead to new breakthroughs in biosensing and disease monitoring.

Toward photonic integration, the success of the project will have a profound impact on miniaturized and low-power optoelectronic circuits (frequency combs, photonic memories, coherent detectors) for neuromorphic photonics.

For computing, the architecture allows MAC operations on both amplitude and phase information encoded with hundreds of comb modes in parallel, which might lead to the development of next-generation **ultralow-power optical tensor processors** with high throughput and low computing power in the post-Moore's age.