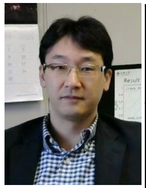
【Grant-in-Aid for Scientific Research (S)】

Highly Energy Efficient and Broadband Information Processing Platform based on Optical Functional Circuits



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Project Information	Project Number : 24H00072 Project Period (FY) : 2024-2028 Keywords : Optical Neural Network, Energy Efficient, AI Inference, Optical Transceiver, High-Order Modulation Format

Purpose and Background of the Research

●Outline of the Research

As the social application of machine learning and AI inference advances rapidly, the energy consumption for information processing has become the major issue. Although computational devices are often considered to be the main cause of energy consumption in information processing, communication devices also consume similar amount of energy. In data centers, a large number of computers are interconnected and data traffic between them is growing at an annual rate of more than 20%. This causes an increase of energy consumption in data centers. A device called an optical transceiver is responsible for transmitting and receiving data transferring between computers. As the needs for machine learning and AI inference increase, energy consumption in optical transceivers has become an urgent issue to be addressed.

In this research, we aim at reducing the energy consumption of optical transceivers using AI inference. Our approach will utilize a new AI inference technology called optical neural network (ONN in short). ONNs are optical circuits that can power-efficiently execute AI inference at a speed of light. It helps reduce the energy consumption of the optical transceiver by executing tasks such as encoding and distortion compensation that are typically done by electronic digital signal processors.

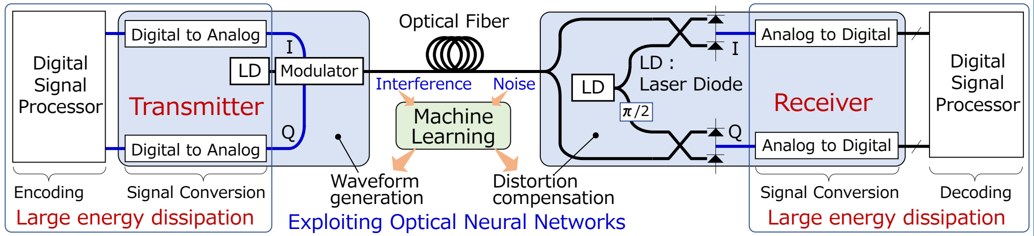

Figure 1. Overview of Optical Transceiver with Optical Neural Network

●ONNs Exploiting High-Speed and Low-Power Nature of Light

While electronic circuits use electric charges for computing, ONNs use light wave propagation to perform AI inference. Since the propagation speed of light is independent from signal power of light, high speed inference is possible even with weak light. With this property, it is possible to perform ultra-high speed and power efficient AI inference. Additionally, since optical signals of different wavelengths do not interfere with each other, optical neural networks can perform AI inference with a high degree of parallelism by multiplexing many optical signals having different wavelengths.

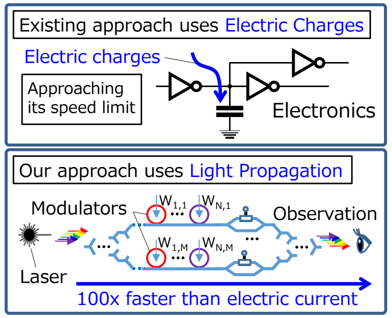

Figure 2. Electronics and ONN

●Inspiration based on Cross-Layer Considerations

The co-researchers have been engaged in research on a broadband communication technology called high-order modulation. It is a wideband communication technology that transmits information by carrying multiple bits of information in one signal pulse. Since the high-order modulation formats such as 16-QAM aim to increase only the number of bits per signal pulse to be transmitted, the energy consumption of signal transmission itself does not increase in principle. Therefore, the high-order modulation is an inherently energy-efficient information transmission method. However, it requires the receiver circuit to accurately decode the transmitted multi-bit information by a method called equalization. The equalization is currently performed using electronic digital signal processors, causing increased energy consumption in today's optical transceivers. In this research, we will achieve equalization through AI inference using an optical neural network. With this approach, we aim to significantly reduce the power consumption in data transfer by optical transceivers.

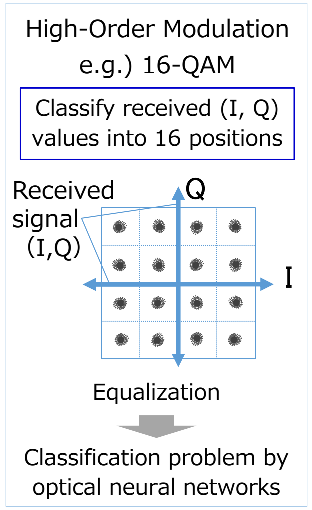

Figure 2. High-Order Modulation and Equalization

Expected Research Achievements

●Clarifying the Energy Lower Bound of Optical Computing (Academic Viewpoint)

Some research fields in computer engineering have pursued how to solve real-world problems in an energy-efficient way on the conventional computer model shown on the left in Figure 4. In this research, we pursue the question of how to perform energy-efficient broadband information processing using optical operations based on the light propagation, as shown on the right in Figure 4. This will reveal the optimal configuration of the optical computing circuit from the perspective of energy efficiency.

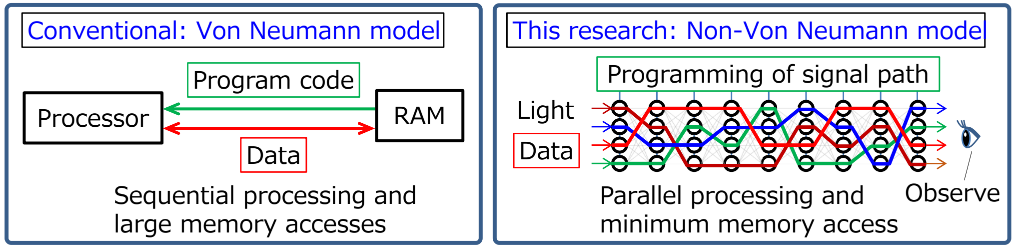

Figure 3. Clarification of the energy lower bound in optical computing model

●Silicon photonics ecosystem (Social Viewpoint)

Contrary to the growing global need for optoelectronic circuits based on silicon photonics, the environment for prototyping and design education is not sufficiently developed. Silicon photonics is a technology that combines optical circuits and electronic circuits on a silicon substrate to realize optoelectronic integrated circuits. In this research, we aim to build an ecosystem for optoelectronic circuit design in collaboration with the Silicon Photonics Consortium organized by the National Institute of Advanced Industrial Science and Technology.

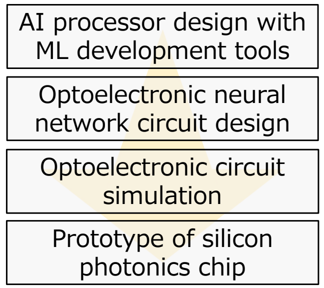

Figure 4. Prototyping flow

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