Intelligent Nanophotonics: When Machine Learning Sheds Light

FAYETTEVILLE, GA, UNITED STATES, April 16, 2025 /EINPresswire.com/ -- Intelligent nanophotonics, combining nanophotonics and machine learning, is transforming optical information processing. This review highlights cutting-edge nanophotonic devices and the challenges to overcome for impactful technological advancements. It also explores opportunities in computational imaging, sensing, and machine vision, with significant implications for fields like the internet of things and smart health. Finally, it emphasizes the critical challenges and opportunities for interdisciplinary collaboration to advance intelligent photonics.

The intersection of artificial intelligence (AI) with nanophotonics has received tremendous interests because of its potential to solve the most challenging

Overview and trends of intelligent photonics in emerging technologies.

problems in both areas. In photonics, machine learning has been supporting numerous innovations as a powerful tool for inverse design and optical signal processing, with unprecedented speed and versatility. Fueled by metasurfaces and integrated photonics, optical neural networks provide a new computing paradigm that reshapes how neural networks can be implemented in hardware, paving the way for the realization of fast, energy efficient machine learning models. To translate into real-world technology, however, intelligent photonics still faces severe challenges in its theoretical framework, fabrication, and operation, which must be tackled to ensure their versatility and reliability while reducing manufacturing cost. Solution to these problems requires combining expertise from diverse areas, including machine learning, materials science, and optics engineering.

In this context, a team of researchers from Harbin Institute of Technology, Shenzhen, led by
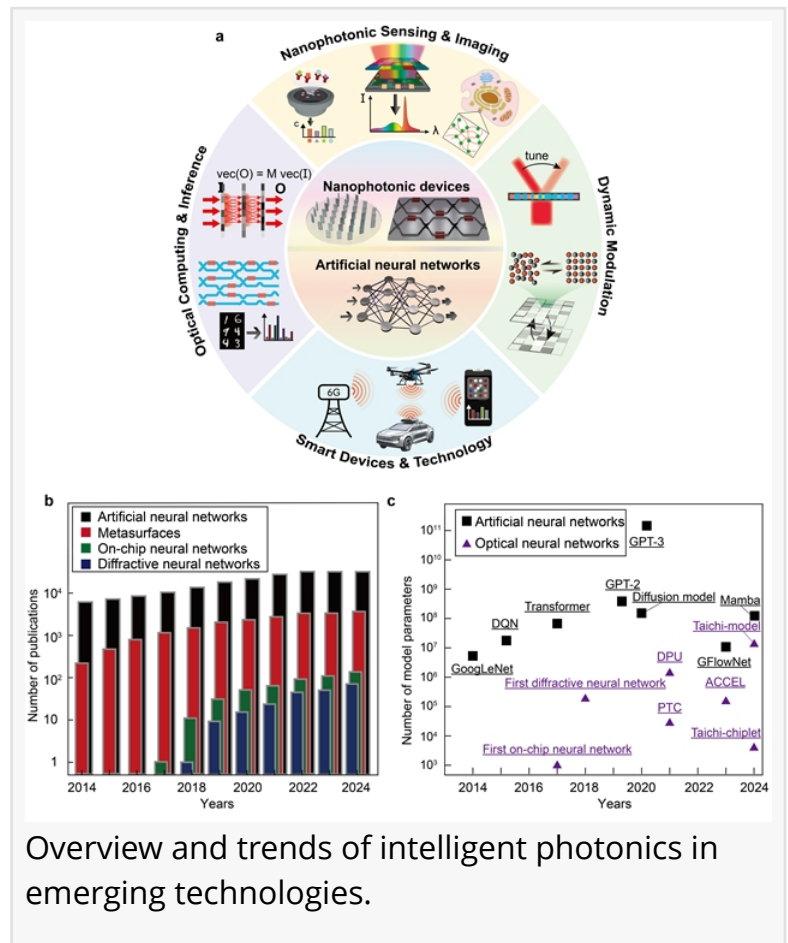
Professors Jingtian Hu, Shumin Xiao, and Qinghai Song provide a comprehensive, in-depth analysis for the current state of intelligent photonics, which emerges from the intersection of deep learning and nanophotonics, including: (1) progresses and opportunities of machine-learning-enabled photonics in computing, imaging & sensing, and dynamic devices, (2) grand challenges that must be tackled for intelligent photonics to be used in real world applications, and (3) their transformative impact on the futuristic technological landscape from metaverse and augmented and virtual reality to internet of things and smart health. Several highlights of this review include:
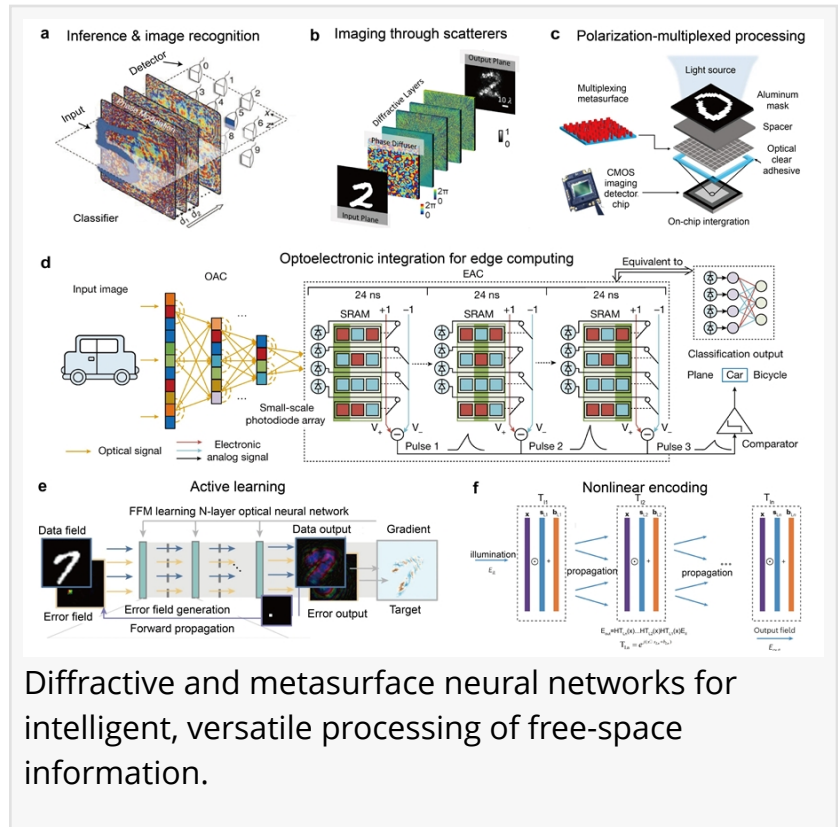
Diffractive and metasurface neural networks for intelligent, versatile processing of free-space information.

(1) Large-scale optical networks for fast, energy-efficient computing

Optical computing is a viable solution for the pressing problems of speed and energy efficiency in existing neural networks caused by their rapid growth in size. However, a framework that can integrate these optical neural networks in existing computing platforms is still missing but requires both algorithmic and hardware-level innovations. The authors provide a thorough analysis of the challenges and opportunities for optical neural networks to become a real-world technology for energy-efficient centralized computing, promoting sustainability in the AI industry.

(2) Sensing-computing integration in edge devices

Another key advantage of neural networks based on diffractive and metasurfaces is their direct access to all degrees of freedom in photon, including phase, polarization, and orbital angular momentum. This capability makes them extraordinarily efficient for sensing and imaging tasks while simultaneously performing necessary computing with the signals. The authors will discuss in detail how this sensing-computing integration can completely transform the design and operation principles for optoelectronic devices and its impact on applications such as sensing, machine vision, and telecommunication.

(3) Impacts and implications to technological landscape of AI-technology

From metaverse to internet of things, the authors expect intelligent photonics to become an essential component in these futuristic technologies with the unique ability to implement diverse functionalities in a compact design. By envisioning a technological landscape of

intelligent photonics, this review aims to bridge the knowledge gap between academia and industry to inspire collaborations that truly advance these transformative technologies.

In summary, this review provides a thorough exploration of the recent advancements in intelligent photonics, underscoring the transformative potential of this interdisciplinary field.

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