Twist to Reshape, Shift to Transform: Bilayer Structure Enables Multifunctional Imaging

All-optical image processing has been viewed as a promising technique for its high computation speed and low power consumption.

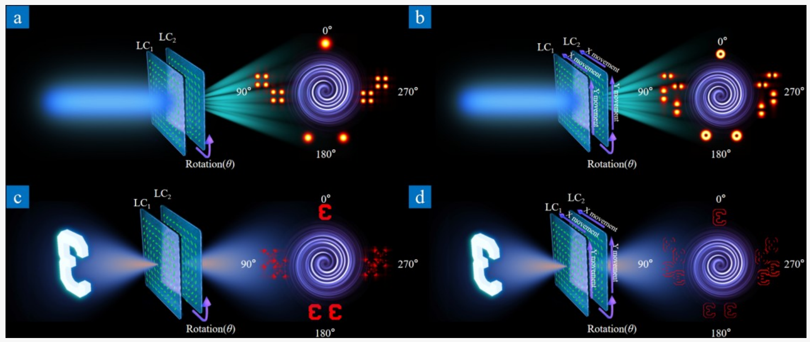

Fig 1: (a) Typical intensity distribution obtained by rotating the second liquid crystal layer (LC2) in the in-situ state. (b) Intensity distribution obtained by rotating LC2 in the ex-situ state.(c) Demonstration of bright-field imaging & vertex detection functions...

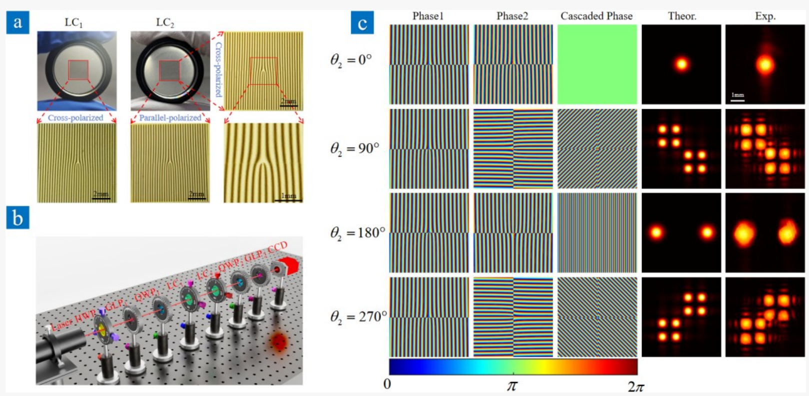

Fig 2: (a) Key characterization results of the double-layer liquid crystal device. (b) Schematic diagram of the experimental setup. (c) Measured light field distribution in the in-situ state.

CHENGDU, SICHUAN, CHINA, January 7, 2026 /EINPresswire.com/ -- Driven by the global wave of informatization, the real-time transmission, efficient processing, and intelligent analysis of massive data have become both the core engine propelling frontier technologies like artificial intelligence, autonomous driving, and augmented reality, and a critical bottleneck currently faced. As the most intuitive and information-rich carrier in communication, the processing efficiency of images directly determines the "comprehensibility" and ultimate "decision-making value" of visual information. However, traditional electronic computing architectures are gradually approaching their physical limits, encountering severe challenges in enhancing computing power and controlling energy consumption. The exploration of a groundbreaking new generation of computing paradigms is therefore urgent.

In this context, photonic computing, leveraging its inherent advantages of high speed, parallelism, and low energy consumption, is regarded as a strategic direction to break the "electronic bottleneck" and lead the future computing revolution. Photonic computing utilizes light (photons) for computation and information processing. A crucial branch, "optical analog computing," operates on the principle of processing light-carried information directly in real-time and in parallel using optical components and the physical laws of light propagation (such as interference and diffraction), rather than first converting images into digital signals. This approach enables tasks like edge enhancement and feature recognition, promising substantial gains in efficiency and reductions in power consumption.

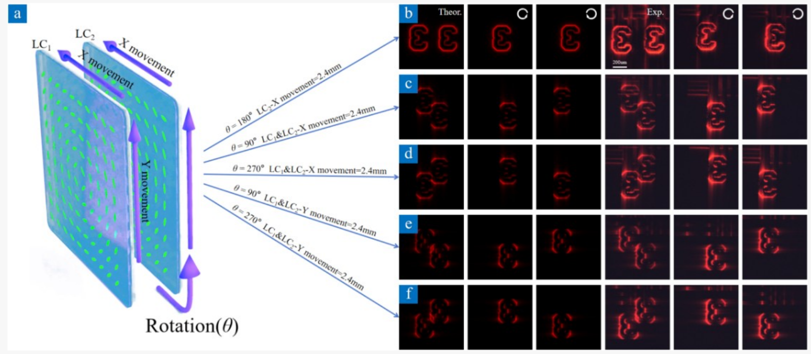

Fig 3: (a) Schematic diagram of the double-layer liquid crystal device under different rotation and displacement states. (b)-(f) Examples of various image processing results obtained using this platform.

In recent years, the rise of nanophotonics and metasurface technology has enabled the design of various ingenious two-dimensional planar optical devices to flexibly manipulate light propagation, offering possibilities for creating ultra-compact, multifunctional optical processors. However, a key challenge persists: once fabricated, the functionalities of many such optical devices become fixed, making it difficult to adapt to the complex and variable real-world image processing tasks. This stands as a major obstacle to the widespread application of optical computing.

To address this challenge, a collaborative team led by Yougang Ke and Linzhou Zeng from Hunan Institute of Science and Technology and Professor Xinxing Zhou from Hunan Normal University has innovatively proposed and developed a reconfigurable optical computing platform based on a double-layer liquid crystal structure. The core breakthrough of this platform lies in the introduction of mechanical degrees of freedom. By precisely controlling the rotation and lateral displacement of the two liquid crystal layers, the team has successfully achieved multifunctional, switchable all-optical image processing, opening new possibilities for developing high-performance, highly adaptable integrated optical systems. The basic concept and functional examples are illustrated in Figure 1.

The operating principle of the platform relies on the exquisite control of the relative rotation angle and spatial displacement between the two liquid crystal layers, thereby introducing reconfigurable synthetic phase modulation. This dynamically shapes and outputs a rich variety of light field patterns, as shown in Figure 2. Through the coordinated manipulation of rotation and displacement, the system can flexibly switch between various physical configurations, such as in-situ/ex-situ and twisted/non-twisted states. Based on this physical control mechanism, the platform integrates eight types of image processing functions in one go. These include single/dual-channel bright-field imaging, vortex filtering, one-dimensional edge enhancement, vertex recognition, and resolution-tunable edge extraction based on the photonic spin Hall effect. The processing results of these functions can be clearly obtained under different device states, as exemplified in Figure 3.

This innovative platform combines the advantages of high integration, low energy consumption, strong adaptability, and low cost, laying a solid foundation for translating optical analog computing from theory to practice. In autonomous driving, it could serve as a front-end preprocessing unit for vision systems, highlighting road edges or identifying key obstacle features in real-time, significantly reducing the load on backend digital processors and improving response speed and safety. In biomedical imaging, it could directly enhance the microscopic contrast of cellular structures without complex algorithms, aiding in medical diagnosis. In augmented reality (AR), it could rapidly process real-world environmental information, enabling smoother and more intelligent virtual-real interaction.

This achievement is published in Opto-Electronic Advances (OEA) 2025, Issue Vol. 8, No. 12, under the title "In-situ and ex-situ twisted bilayer liquid crystal computing platform for reconfigurable image processing." The research was supported by the Natural Science Foundation of China, theHunan Provincial Major Sci-Tech Program, and the Natural Science Foundation of Hunan Province. The research teams are from the Laboratory of Intelligent Photonic-Electronic Technology at Hunan Institute of Science and Technology and the College of Physics and Electronic Science at Hunan Normal University.

About the Research Group:

The Laboratory of Intelligent Photonic-Electronic Technology at Hunan Institute of Science and Technology is affiliated with the School of Information Science and Engineering. It was founded in 2021 by Associate Professor Yougang Ke and Lecturer Linzhou Zeng. The laboratory focuses on the core scientific question of "how to utilize light waves/electromagnetic waves for information interaction more efficiently." It is dedicated to fundamental research on electromagnetic wave manipulation and propagation mechanisms, striving to promote the intelligent design of metasurfaces and liquid crystal devices. The lab actively explores their innovative applications in imaging, communications, display, and information encryption. Since its establishment, faculty and students from the laboratory have published over 10 papers in high-level journals including Opto-Electronic Advances, Laser & Photonics Reviews, ACS Photonics, Nanophotonics, and various IEEE Transactions/Journal/Letters.

Xinxing Zhou is a professor and doctoral supervisor at Hunan Normal University, recognized as a Young Scholar under the "Furong Scholars Award Program" of Hunan Province. His main research areas are spin photonics, optical precision measurement, and sensing. He has published over 100 papers in journals such as Opto-Electronic Advances and Laser & Photonics Reviews, with more than 5,200 citations (Web of Science) and an H-index of 37. He has presided over projects including the NSFC General Program and Youth Program, and the Changsha Outstanding Youth Project. As a key member, he has participated in the NSFC Innovative Research Group Project. He received the 2021 Second Prize of Natural Science from the Ministry of Education (third contributor) and has been consecutively listed in Stanford University's "World's Top 2% Scientists" from 2020 to 2025. He was selected as a LaserLink 2024 Annual Figure by the Chinese Laser Press. He serves as an Associate Editor or Youth Editorial Board

Member for journals including IEEE Photonics Journal and as Deputy Director of the Changsha Branch of the Chinese Laser Press.

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