Bioinspired Adaptive Optical Imaging - Giving Machines 'Living' Eyes

Report on Reviews Published in Opto-Electronics Plus

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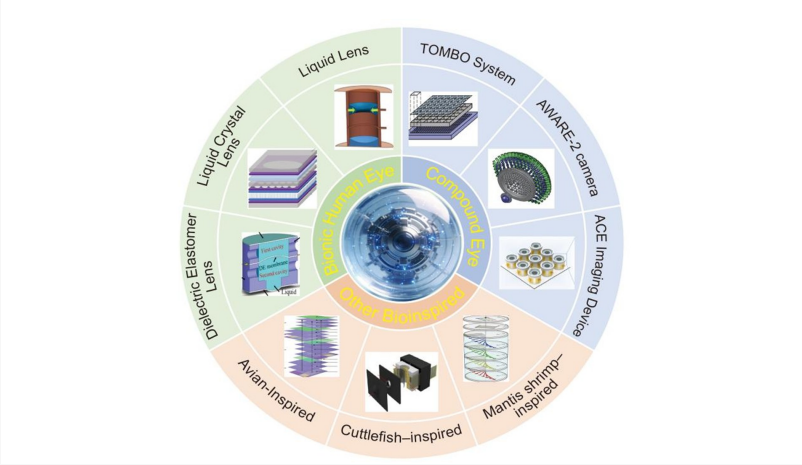
Imagine a smartphone camera that can instantly zoom in and out like the human eye, adjusting to an object's distance without any mechanical motor noise. Or consider a drone equipped with a camera possessing the compound eye of an insect, capable of simultaneously seeing in nearly 180 degrees in all directions and reacting with lightning speed to fast-moving obstacles. This is not science fiction; it is the future being realized by "bioinspired adaptive optical imaging technology."



The main research directions of bioinspired adaptive optical imaging technology include human eye-inspired adaptive imaging, compound eye-inspired adaptive imaging, and other bioinspired adaptive imaging technologies.

Researchers at the Display and Imaging Laboratory at Beihang University, China, where they focus on 3D display technology, liquid lens imaging technology, liquid crystal technology, and related fields.

Traditional optical imaging systems have lenses and sensors that act like rigid organs, with key parameters such as focal length and field of view fixed at the time of manufacture. When faced with the real world—characterized by fluctuating light, varying target distances, and complex environments-their performance often falls short. To overcome these limitations, scientists have turned to nature, the "ultimate optical laboratory" honed by billions of years of evolution.

From the precise focusing and pupil adjustment of the human eye, to the wide field of view of insect compound eyes, and the complex polarization vision of mantis shrimp, biological visual systems demonstrate unparalleled adaptability, efficiency, and robustness.

Part 2: Summary of the Review Article

Inspired by the sophisticated visual systems found in nature, bioinspired adaptive optical imaging technology is undergoing a profound transformation from static imitation to dynamic intelligence. A review article published online on March 30, 2026, in Volume 2 of Opto-Electronics Plus, titled "Bioinspired adaptive optical imaging technology," systematically outlines the landscape of this field. The review focuses on two core research directions and anticipates future trends. The study is led by Dr. Wang Qionghua, Professor and Doctoral Supervisor at Beihang University, China.

Prof. Wang Qionghua from Beihang University, China

The first direction is human eye-inspired adaptive imaging, which aims to mimic the "camera-type" vision of mammals by replicating the focusing function of the crystalline lens and the aperture control of the pupil. Key technical approaches include: liquid lenses, which achieve millisecond-level fast focusing by controlling the shape of a liquid droplet with voltage, featuring a simple structure and already finding applications in smartphone cameras; liquid crystal lenses, which use an electric field to control the alignment of liquid crystal molecules to alter the refractive index, offering no moving parts and ease of array integration, showing great potential in augmented reality displays; and dielectric elastomer lenses, which utilize high voltage to deform an elastic film, generating large deformation with an actuation mechanism more closely resembling biological muscles, promising for high-performance bioinspired zoom systems.

The second direction is compound eye-inspired adaptive imaging, dedicated to achieving extreme wide-angle and dynamic perception. Insect compound eyes consist of numerous individual ommatidia, naturally providing a wide field of view, high sensitivity, and keen motion detection capabilities. This field is evolving from fixed focal lengths towards adaptive focusing: early systems like TOMBO used planar microlens arrays for parallel imaging, followed by multi-scale architectures like the AWARE series cameras, which achieved billion-pixel ultra-wide field-of-view imaging using a "primary objective lens + micro-camera array" configuration. A recent breakthrough involves integrating tunable components, such as liquid lenses, into each

individual ommatidium. This enables compound eye systems to achieve both wide-area coverage and dynamic focusing based on target distance, as well as control aperture shape to adapt to complex lighting conditions.

Furthermore, the review explores inspirations from other biological models, including the foveal imaging of birds, the infrared thermal imaging of snakes, and the polarization and multispectral vision of mantis shrimp. Collectively, this research paints a grand picture of evolution from the imitation of single parameters towards the integration of multi-modal and multi-functional capabilities.

Part 3: Summary and Outlook

Although significant progress has been made in bioinspired adaptive optical imaging technology, challenges remain for practical applications, including issues related to integration density, reliability, and multi-parameter cooperative control. Future advancements in this field will rely on the deep integration of metasurfaces, novel optoelectronic materials, soft adaptive materials, and neuromorphic architectures combining sensing, storage, and computation. Through interdisciplinary collaboration, future vision systems will no longer be simple image recorders but will become intelligent units capable of environmental perception and information preprocessing, playing an indispensable role in areas such as autonomous driving, robotics, and precision medicine.

Part 4: Introduction to the Research Team

The Display and Imaging Laboratory was established in September 2018, led by Professor Wang Qionghua. As of September 2025, the laboratory comprises 56 members, including 6 faculty members, 3 postdoctoral researchers, 1 assistant, 27 doctoral students (including 1 international student), and 19 master's students. The laboratory's research focuses on 3D display technology, liquid lens imaging technology, liquid crystal technology, and related fields.

The laboratory is currently undertaking projects such as the National Key Research and Development Program of China, the Major National Scientific Research Instrument Development Project, and the Key International (Regional) Cooperative Research Project of the National Natural Science Foundation of China. Independently or in collaboration with Sichuan University, the laboratory has developed proprietary technologies including naked-eye integral imaging light field 3D displays, naked-eye grating 3D displays, 2D/3D compatible displays, 3D cameras, 3D image and video processing software, holographic 3D display systems, electrowetting liquid lenses, continuous optical zoom microscopes, and liquid crystal lens arrays. The team has also achieved innovative results in the areas of 2D liquid crystal materials, liquid crystal light field manipulation, and blue-phase liquid crystals.

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Reference
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About Professor Wang Qionghua from Beihang University, China
Dr. Wang Qionghua is aProfessor and Doctoral Supervisor at Beihang University, recipient of the National Science Fund for Distinguished Young Scholars, Changjiang Scholar Distinguished Professor of the Ministry of Education, National "Ten Thousand Talents Program" Leading Talent in Science and Technology Innovation, Fellow of the Society for Information Display (SID), Optica (formerly OSA), SPIE, the Chinese Optical Society (COS), and the Chinese Society for Optical Engineering (CSOE). She serves on the Editorial Board of PhotoniX and as an Associate Editor for the Journal of the Society for Information Display, among other journals.

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Xiaoqing Liu
Institute of Optics and Electronics
+86 19136186296
liuxiaoqing@xlll.cn
