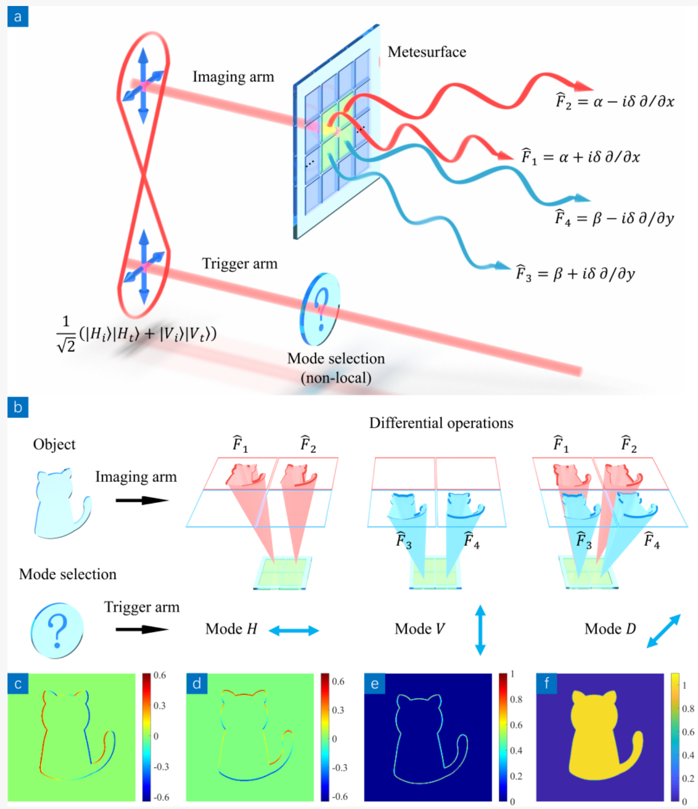
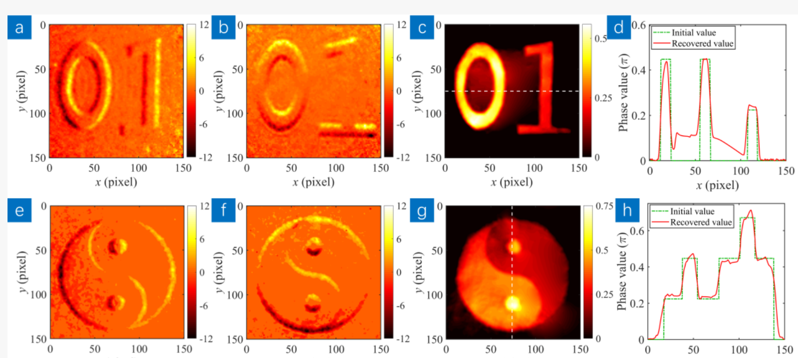
Integrated Metasurface for Quantum Analog Computation: A New Scheme to Phase Reconstruction

In complex light field environments, the accuracy and stability of phase reconstruction may be affected by noise interference and algorithm convergence issues.



Phase reconstruction via metasurface-integrated quantum analog operation.



Quantitative phase reconstruction results.

CHENGDU, SICHUAN, CHINA, May 30, 2025 /EINPresswire.com/ -- Phase reconstruction, as a key technology in the field of optics, aims to recover phase information from the intensity information of light waves. The phase of light waves contains crucial information such as the shape, thickness, and refractive index distribution of transparent objects, which is indispensable for many fields, including holographic imaging, optical microscopy, laser interferometry measurement, and even adaptive optical systems. However, since most detectors can only capture light intensity data, directly measuring the phase of light waves has always been technically challenging and remains unachievable. There are various traditional phase reconstruction methods, including interference-based measurement techniques, Fourier transform-based phase recovery techniques, and iterative phase recovery techniques. Although phase reconstruction technology has shown great application potential in many fields, it still faces a series of technical difficulties. In complex light field environments, the accuracy and stability of phase reconstruction may be affected by noise interference and algorithm convergence issues.

Researchers have proposed an metasurface-integrated quantum analog computing system. This system ingeniously combines multi-channel metasurfaces with quantum entanglement sources, enabling quantitative phase reconstruction with high signal-to-noise ratio at low signal photon levels. Traditional phase reconstruction often involves complex operation steps, while this technology effectively simplifies the complexity of traditional phase reconstruction. It shows application potential in multiple important fields. For example, in the field of optical chips, it helps improve the performance and functionality of analog computing chips; in wave function reconstruction, it can provide more accurate and effective methods; in label-free biological imaging, it can achieve label-free, high signal-to-noise ratio and high contrast imaging of transparent cells at low photon levels. This work, titled "Phase reconstruction via metasurface-integrated quantum analog operation", was published in Opto-Electronic Advances in 2025, Issue x.

Metasurfaces, as a type of ultra-thin planar optical devices carefully constructed from sub-wavelength structures, possess the extraordinary ability to precisely control the phase, amplitude, and polarization of light waves. In this study, researchers successfully achieved four key differential operations by means of the innovative multi-channel metasurface technology. It is worth emphasizing that these differential operations play a crucial role in obtaining the phase gradient and are indispensable links in the whole process. In the research and application practice of traditional phase reconstruction techniques, multiple measurements are often required to complete the entire phase reconstruction process. However, the innovative integrated design proposed in this study cleverly overcomes this difficulty. Through this unique design, the relevant system can efficiently measure all the information required for phase reconstruction at one time on a single device. This new technological approach not only greatly improves the operating efficiency of the system but also significantly enhances its compactness, bringing broader development space for research and application in related fields.

Application of Quantum Entanglement Sources: Quantum entanglement sources play an important role in specific application scenarios, especially showing significant advantages in achieving high signal-to-noise ratio imaging at low signal photon levels. To achieve this goal, the research team innovatively introduced quantum entanglement sources. Quantum entanglement sources have unique quantum characteristics and can stably generate entangled photon pairs. In the imaging process, one photon is dedicated to the imaging operation, while the other photon plays the important role of an external trigger signal to precisely control the opening and closing of the detector's shutter. This carefully designed mechanism has a strong noise filtering ability. Specifically, in the imaging process, only events closely related to the trigger photon are recorded. In this way, environmental noise is effectively suppressed and filtered out, thereby significantly improving the signal-to-noise ratio of the final image. In addition, the system fully utilizes the unique polarization correlation property of entangled photon pairs. Based on this, the system can not only realize the multi-channel function of mode selection but also complete non-local switching operations. The introduction of this characteristic further enhances the flexibility and functionality of the system, providing broader space for research and application in related fields.

Experimental Results
The experimental results show that during this experiment, the researchers achieved non-local manipulation of optical analog computation on the metasurface by precisely controlling the polarization state of the trigger. Consequently, they successfully obtained the four differential operations required for phase reconstruction. On this basis, the researchers accurately converted the phase gradient information of the optical field into phase distribution information by using the integral operation, thus realizing quantitative phase reconstruction. This complete experimental process not only fully demonstrates the crucial role of optical analog computation in the field of phase reconstruction but also provides a novel approach for the precise measurement of complex light fields. It is worth mentioning that the phase reconstruction method proposed in this study shows extremely broad application potential. Especially in key fields such as optical chips, wave function reconstruction, and label-free biological imaging, this method is expected to bring about important technological breakthroughs and application values. In addition, the successful application of quantum entanglement sources in this experiment provides a new path and direction for the technological development of fields such as quantum communication and quantum computing, with important scientific significance and potential application prospects.
Introduction to the Research Team

Hailu Luo is a professor in the School of Physics and electronics at Hunan University. He founded the Laboratory for Spin Photonics in 2009 and has conducted systematic and in-depth research in this field. Professor Hailu Luo has developed precision measurement techniques and differential imaging techniques based on the photonic spin Hall effect. His research interests include spin photonics, differential optics, quantum precision measurement, and quantum imaging. Professor Hailu Luo led his research team to publish more than 100 journal papers such as Physical Review Letters, PNAS, Science Advances, Opto-Electronic Advances, and Opto-Electronic Science. These papers have been cited more than 10,000 times. His H-index is 52 (Google Scholar). He has been selected as a highly cited Chinese researcher by Elsevier for four consecutive years (2020 - 2022) and won the second prize of the Ministry of Education Natural Science Award in 2021.

Andrew Smith
Charlesworth
marketing@charlesworth-group.com
Visit us on social media:
LinkedIn
YouTube
