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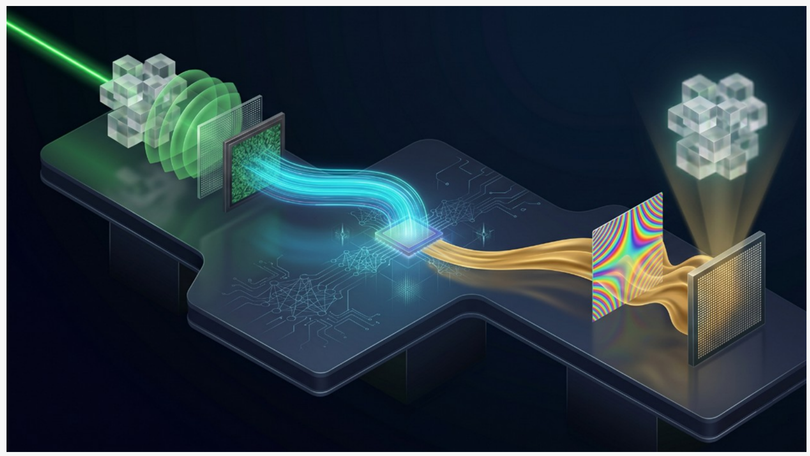
Breakthrough Holographic Telepresence Technology Captures and Replays 3D Wavefronts in Real Time

A reference-free optical system brings physically faithful three-dimensional remote presence closer to practical communication



Schematic of the measurement-driven holographic telepresence system, showing single-shot reference-free wavefront capture, computational wavefront reconstruction, and physical three-dimensional holographic replay.

Professor YongKeun Park's research group at KAIST develops advanced optical imaging and computational microscopy technologies for visualizing three-dimensional (3D) structures. Its research spans quantitative phase imaging, holotomography, label-free 3D m

CHINA, August 6, 2026 /EINPresswire.com/ -- Researchers at KAIST have developed a new holographic telepresence framework that captures and replays the physical light wavefront from a three-dimensional (3D) scene in real time. Unlike conventional 3D systems that reconstruct objects from depth maps, point clouds, or computer-generated models, the new approach directly measures optical wavefronts using a single camera image. This may help future communication systems reproduce depth, focus, and spatial presence more naturally.

Three-dimensional (3D) communication has long been a dream of science fiction and modern display technology. Video calls allow people to see each other across distances, and virtual or augmented reality systems can create immersive visual experiences. However, most current systems do not reproduce the actual light field from a real object or person. Instead, they estimate shapes, surfaces, or depth maps and then render a 3D-looking image using computational models. This can create convincing visual effects, but it does not fully preserve the physical behavior of light, such as diffraction, phase, and natural depth-dependent focusing.

The research team led by Professor YongKeun Park at Korea Advanced Institute of Science and Technology (KAIST), South Korea, developed a different approach. Rather than first turning a real scene into a geometric model, the system directly captures the complex optical wavefront of the scene. A wavefront contains both amplitude and phase information of light. This information is important because it determines how light propagates through space and how a viewer perceives depth and focus. In principle, if the wavefront is captured and replayed correctly, a 3D scene can be reproduced in a physically faithful way.

The key challenge is that ordinary cameras measure only intensity, not phase. Conventional holography often solves this problem using a reference beam, but such interferometric setups can be sensitive to vibration and alignment, making them difficult to scale for practical telepresence. The KAIST team instead used a pre-characterized geometric phase diffuser. This diffuser converts the incoming optical wavefront into a deterministic speckle pattern. Although the speckle image may look random, it carries encoded information about the original wavefront. By using a calibrated physical model and computational reconstruction algorithms, the system can recover the complex wavefront from a single intensity image.

After reconstruction, the recovered wavefront is displayed using a spatial light modulator, allowing the 3D wavefront to be replayed optically. The team demonstrated volumetric refocusing, dynamic reconstruction, and video-rate operation at approximately 28 frames per second, with a median end-to-end latency of about 50 milliseconds. This result suggests a route toward real-time holographic communication systems that transmit measured optical fields rather than computer-generated approximations.

The research group of Prof. Park introduced a measurement-driven holographic telepresence system that directly captures and replays the physical wavefront of a 3D scene. The broader importance of this work lies in its shift in philosophy. Many existing 3D communication technologies begin by estimating what an object looks like geometrically. They may use depth cameras, multiple cameras, light-field sampling, or computer-generated holography to produce images that appear 3D. The new method instead asks whether the optical wave itself can be measured and transmitted.

This distinction matters because real visual perception depends not only on object shape but also on how light propagates. A physically measured wavefront naturally contains information related to depth, diffraction, and focusing. This could be valuable for future telepresence, holographic display, remote collaboration, scientific visualization, education, medical communication, and industrial inspection. For example, a future system based on this principle could allow a remote user to observe a real object with more natural depth cues than those provided by ordinary flat screens or stereoscopic displays.

The work may also influence the future of immersive communication. Today's video conferencing systems transmit two-dimensional images. Virtual reality and augmented reality systems can create immersion, but they often rely on synthetic or reconstructed scenes. Holographic telepresence aims to make remote visual communication feel closer to "being there." By reducing dependence on interferometric reference beams and multi-frame acquisition, the KAIST system addresses some of the practical barriers that have limited wavefront-based communication.

Important challenges remain. The current prototype uses monochromatic green laser illumination, and image quality is limited by speckle noise. Further improvements are needed in display quality, color reproduction, miniaturization, and speed. However, the study suggests these limitations mainly reflect prototype hardware and could be overcome through improved sensor sampling, greater optical bandwidth, and temporal averaging.

In the long term, future holographic communication systems may combine direct wavefront measurement with artificial intelligence, optical engineering, high-speed cameras, advanced spatial light modulators, and data compression. Such systems could transform remote communication from image transmission into physical light-field transmission, opening a path toward more natural and realistic 3D presence.

Reference
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