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3D Visualization and Display Technology for Immersive Shared Spatial Communication

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요 약

This work presents a display-based 3D visualization system that enables immersive spatial experiences without the need for head-mounted devices. Using lens-array-based integral imaging, the system reconstructs volumetric scenes in real time and supports natural depth perception from multiple viewing angles. A field demonstration using a large-scale projection setup confirms its applicability in public and collaborative settings. The proposed approach offers a practical and inclusive alternative for shared spatial communication in next-generation media environments.

Ⅰ. Introduction

Communication technology is shifting from throughput-oriented paradigms to experience-centric models that prioritize spatial perception and real-time immersion. In this context, immersive communication—the delivery of depth-rich, lifelike visual experiences across users—has emerged as a key direction in system design. Rather than relying on individualized hardware, future immersive platforms must support co-located, multi-user engagement through shared spatial environments. As 6G approaches, enabling such collective visual interaction is becoming as vital as conventional metrics like latency and reliability [1].

Conventional systems, such as virtual or augmented reality headsets, offer immersion but limit accessibility and group scalability. Their dependence on head-mounted displays restricts natural interaction and creates a disconnect between users and physical space [2]. To overcome these limitations, we propose a display-centered framework based on integral imaging. By reconstructing volumetric scenes through a lens-array display, our system enables real-time 3D perception on a large screen—without the need for personal gear. The architecture offers a practical and socially inclusive alternative for multi-user immersive visualization.

Ⅱ. System Architecture and Field Deployment

The proposed system enables immersive, multi-user 3D visualization through a gear-free integral imaging architecture. It is composed of two main modules: (1) a spatial content acquisition process, and (2) a lens-array-based display for volumetric reconstruction.

The acquisition of multi-perspective elemental images can be achieved through various approaches. In our prior work, we demonstrated a single-pixel scanning method using custom photonic devices for spatial light acquisition [3, 4], as illustrated in **Figure 1a**. However, the present study focuses on the visualization and display side of the system, assuming that the required elemental images are already obtained via either sensor-based or pre-rendered content.

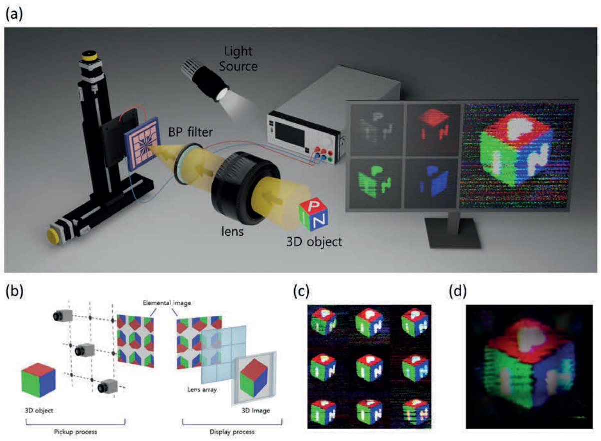

Figure 1. System overview of the proposed gear-free integral imaging display. (a) Acquisition setup using a photonic sensor, lens, and band-pass filter. (b) Principle of integral imaging with pickup and display processes. (c) Captured elemental images. (d) Reconstructed volumetric image.

The display module employs a commercial tablet display combined with a custom-designed lens array to reconstruct volumetric images from elemental views (**Figure 1b-c**). These images are optically projected into space to generate a continuous range of viewpoints, allowing users to perceive depth and spatial structure from different angles without wearing head-mounted devices. The system ensures appropriate focal alignment and consistent image quality across angles. A representative volumetric reconstruction is shown in **Figure 1d**.

As a proof of concept, the system was demonstrated during PSY's Summer Swag 2023 concert, where preprocessed visual data was projected onto a 40-meter-wide water screen (**Figure 2**). While the demonstration employed 2D imagery, it validated the feasibility of deploying the platform in large-scale, dynamic environments, highlighting its potential for public exhibitions and shared immersive experiences.

Ⅲ. Discussion and Conclusion

The experimental demonstration supports our core hypothesis that gear-free volumetric visualization enables intuitive spatial perception and co-located immersion without requiring head-mounted displays or complex sensing infrastructure. By reconstructing depth-rich imagery through integral imaging, the system allows multiple users to share a consistent 3D experience, supporting natural and collective engagement.

This finding highlights the potential of display-centered communication platforms as a foundation for future immersive applications in education, exhibitions, and collaborative environments. Unlike conventional immersive systems, which rely on individualized hardware, the proposed approach lowers the barrier to access and enhances inclusivity in group settings.

Future work will focus on extending the system to support larger-scale deployment, dynamic content adaptation, and potential integration with AI-driven scene understanding or 6G communication protocols. These directions aim to transform immersive displays into a socially and semantically expressive medium for next-generation human communication.

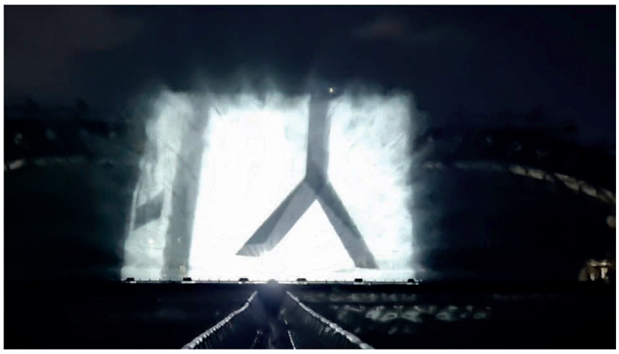

Figure 2. Water screen performance from a K-pop concert, illustrating a real-world interface for quantum-based semantic visualization.

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