3D capture, processing, display, and perception with digital holography: results from a European-funded project

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Abstract: "Digital holography for 3D and 4D real-world objects' capture, processing, and display" (acronym "Real 3D") is a research project funded under the Information and Communication Technologies theme of the European Commission's Seventh Framework Programme, and brings together nine participants from academia and industry (see www.digitalholography.eu). This three-year project contributes to a long-term effort to facilitate the greater presence of digital holography in the three-dimensional capture and display markets. At the end of its third year, the aims and results of the project are summarized.

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1. Introduction

Current and newly-developed 3D displays have the disadvantage of requiring special eyewear, limit the number of simultaneous viewers, discard completely certain depth cues (such as blurring) thus causing fatigue, or else encode only a small number of distinct different views. It can be argued that there is only one known technology that can capture a full 3D scene in a single shot, including phase information, and re-project that light field perfectly thus overcoming all of the above disadvantages: the broad class of holographic techniques. All other techniques are 3D only under a whole host of conditions. Unfortunately, conventional holograms are not dynamic.

The project "Digital holography for 3D and 4D real-world objects' capture, processing, and display" is funded under the Information and Communication Technologies theme of the European Commission's Seventh Framework Programme, and brings together nine participants from academia and industry. This three-year project contributes to a long-term effort to facilitate the greater presence of digital holography in the three-dimensional capture and display markets. Specifically, it is charged with eliminating current obstacles to achieving fully functional 3D video capture and display with digital holography for unrestricted viewing of real-world objects that employs all real 3D principles, hence our acronym "Real 3D."

2. Outputs

The primary outputs of the project are:

Output 1. A 3D holographic acquisition system based on digital camera technology, arranged nonuniformly in a circular configuration around a space of diameter 10 cm that will be capable of holding a dynamic real-world 3D scene. The acquisition system will be capable of recording holographic video of the 3D scene.

Output 2. A 3D holographic display system based on liquid crystal on silicon (LCOS) technology, arranged nonuniformly in a circular configuration of diameter of at least 10 cm. The reconstruction system will be capable of displaying holographic video of the 3D scene.

Output 3. The signal/image/information processing theories, techniques, and tools required for the processing, analysis, and synthesis of the data from capture to display, including adapting the data captured for display on alternative configurations and on conventional 3D displays. This includes holographic data of both microscopic and macroscopic 3D scenes.

Output 4. Reports containing the hard scientific data, in terms of functionality, performance, resolution, restrictions, data quality, and visual perception, that would be required by a company to take our proof-of-concept outputs and develop the next stage in the commercialisation of this 3D technology. In addition, reports on the theories, techniques, and tools that enable this technology.

3. Demonstrators

To demonstrate the outputs in action, and to demonstrate robust implementations of some of the project results [1–31], we have developed functional models of four digital holographic 3D capture, processing, and display scenarios, encompassing (i) a model for the full 360° range of perspectives of reflective dynamic macroscopic 3D scenes, (ii) microscopic reflective 3D scenes, (iii) transmissive or partially transmissive microscopic 3D scenes, and (iv) capture of 3D scenes at infra-red wavelengths.

(i) A compact multi-camera hologram capture device has been developed, hologram requirements have been specified to maximise viewer impact, an integrated framework of hologram processing (dc, twin, noise removal) and hologram video compression has been developed, a circular optoelectronic display-side configuration has been fully specified and implemented, and a suite of appropriate visual perception tests has been designed.

(ii) Holograms of microscopic objects have been captured with dual wavelengths to allow phase unwrapping of larger discontinuities, the data has been processed to admit extended focus images and reconstructions on tilted planes, and the data has been conditioned for conventional stereo displays.

(iii) A two-axis rotation setup for microscopic objects has been implemented and data has been captured of transmissive biological specimens. On the processing side, a tomographic reconstruction algorithm has been finalised to accurately obtain volumetric data. For display, multi-color holographic reconstructions from phase-only SLMs have been obtained using LED illumination.

(iv) Holograms have been acquired in the infrared and promising applications have been demonstrated at different scales. The advantages of a long wavelength and wide range of transparent materials have been demonstrated with the capture of person sized objects and with the imaging of otherwise invisible defects in silicon, respectively. Procedures have been developed to optoelectronically reconstruct the resulting data on versatile relatively-compact setups and on wider-viewing-angle setups using multiple displays.

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