# Using traditional glass plate holograms to study visual perception of future digital holographic displays

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**Abstract:** We study observers looking at a 3D scene captured in a traditional glass plate hologram using eye-tracking. We compare this with stereoscopic and 2D images. Our results can guide development of future digital holographic displays.
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## 1. Introduction

Digital holography [1, 2, 3] has always sought higher resolution devices. Recent advances in three-dimensional (3D) digital holographic displays attempt to combine multiple display devices to improve the field of view, stereo parallax, and motion parallax [4, 5]. However, digital cameras and digital display devices still do not match the resolution and physical size of traditional glass plate holograms from many decades ago. This implies that one must make compromises when designing such a system. In digital holographic video transmission and optical display, the technical choices, compromises, and optimizations should be driven by our understanding of visual perception [6]. Our long-term aim is to contribute to the understanding what requirements the human visual system, eye movement behavior, and the visual perception process demand of the next generation of 3D holographic displays. For the reasons we will describe below, the current generation of digital holographic displays are not suitable. Instead, we propose to using high quality traditional glass-plate holograms. Our results can guide development of future holographic displays by measuring key 3D cues that observers instinctively look for when perceiving a convincing 3D scene. Also, our quantitative comparisons with stereo displays can form the basis of a technology roadmap for digital holographic displays.

The purpose of this particular study is to analyze how people look at a 3D scene reconstructed by a holographic display. We wish to measure how people move their eyes when viewing holograms and how the binocular eye movement patterns differ from viewing two-dimensional (2D) and stereo stimuli. We also wish to investigate how the two eyes work together when viewing particular details at different depths and what differences and similarities there are when viewing stereo images and holograms. Finally, we wish to measure how well are people able to estimate the actual depth of the scene from these three different types of stimuli.

Numerous studies have been undertaken of how people perceive 2D images and stereo images. There has been special interest in the issues of visual discomfort of the stereoscopic displays [7, 8]. There have also been perceptual studies on how people view digital holographic data displayed on conventional 2D [9], mobile [10], and stereoscopic displays [11, 12, 13, 14, 15, 16], and the effects of motion in numerically reconstructed digital holographic video [17, 18]. Comparisons on visual performance and depth-range capabilities of stereoscopic and holographic displays show that holographic displays have a potential to show natural 3D scenes with unlimited depth and natural perception experience [19]. However, visual perception studies with optical holographic displays have been mostly concerned with subjective analysis [6, 20] or mathematical analysis of their capabilities [21, 22]. One reason for this is the small object reconstruction lateral size with current holographic displays causing a small field of view, reduced stereo parallax, and reduced motion parallax. This arises from a small hologram capture sensor (~2 $cm^2$) with relatively large pixels (side length 1 μm – 9 μm), and a small active holographic display plane (~2 $cm^2$) using relatively large pixels (> 10 μm). Speckle is an issue due to a laser being used on capture side. A laser on the display side brings with it additional speckle and eye safety challenges, while less spatially coherent options such as LEDs can cause blurring in the reconstructed 3D scene.

We wish to bridge this gap by studying visual perception of traditional glass plate holograms which fulfill all the properties of a holographic display for still images. By using glass plate holograms we can have a visually rich scene at a size which gives possibilities to study binocular parallax and measure eye movements.

The fixation location in 3D space can be determined from the eye position in the calibration plane collected during each fixation. From this, it is possible to compute the fixation distance, i.e. the point where the lines of sight of the left and right eyes cross in space. We hypothesize that the correlation between the fixation distance and the subjectively estimated depths improves with increasing amount of depth information available to the viewer. That is, we predict that in stereoscopic viewing this correlation is better than in non-stereo viewing, and that in hologram viewing it is even better.

## 2. Eye tracking experiment

The experiment was performed with 5 subjects with normal or corrected-to-normal 2D and stereo vision. 2D and stereo stimuli were presented on a stereoscopic display (24 in. Hyundai W240S), which was viewed with circular polarizing glasses when used in stereo mode. For 2D mode, polarizing glasses were not used.

In order to collect the eye movement data, a binocular Eye Link II eye tracker (SR Research Ltd., Ottawa, Canada) was used. This video-based eye tracking system tracks the fixation location of pupils at a 250 Hz sampling rate when corneal reflection mode is used. It is tolerant of small head movements, and can be used with any type of 2D display or 3D scene. The EyeLink II system consists of three miniature cameras mounted on a headband. Two eye cameras are used for binocular eye tracking and the third camera tracks the orientation of the head with respect to four infrared markers surrounding the display or scene. For evaluating the glass plate holograms, the set up shown in Fig. 1 was constructed. The angle of illumination of the hologram is crucial for ensuring an appropriate viewing experience so the distances and illumination angle were carefully configured for optimal viewing for our particular holograms. For illumination, a narrow beam (10 deg.) 50 W halogen light bulb was used.

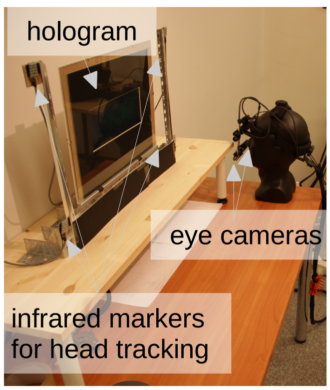


Fig. 1. Eye tracking set-up

Fig. 2. Example stimulus showing four interest areas in different depths

Seven different holograms were used as hologram stimuli. An example is shown in Fig. 2. 2D and stereo image stimuli were created by taking photographs of the holograms from two different viewing angles, using a Canon EOS 7D camera under the same illumination conditions that the hologram was viewed during the experiments. The left and right images from each stereo pair were taken with a lateral separation of 6.5 cm and along parallel optical axes, which corresponds to an average distance between the two eyes for an adult. The images were taken at the distance of 90 cm from the hologram which is the same as the viewing distance for the experiment set-up.

The experiment consisted three parts according to the different type of stimuli: (1) first the participant evaluated 2D images, then (2) the stereo images, and finally (3) the holograms. This order rather than randomized order was chosen so that the amount of 3D information exposed to the participant increases monotonically. This avoids the perception of the 2D and stereo stimuli being influenced by memory of the more complex holographic scene.

## 3. Results and discussion

We found that the convergence variation between eyes was greater when viewing the hologram stimuli than equivalent stereo or 2D stimuli. The subjectively evaluated perceived depth variation was also greater for hologram stimuli than stereo or 2D stimuli.

Our long term aim is to contribute to the understanding of what are the visual perception requirements for the new generation of 3D holographic displays. Technology has not advanced sufficiently yet to allow a high quality holographic display for unrestricted viewing of dynamic real world scenes with a wide viewing angle. By studying the human visual system's response to glass plate holograms, we can determine what technical compromises have the least impact on unrestricted viewing on future digital holographic displays.

Our conclusion is that for holographic displays, we should not neglect the inherent properties of multiple accommodation, monocular parallax, and monocular cues such as blur, perspective, and occlusion.

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