25.2: Eye-Tracking Solutions for Real-Time Holographic 3-D Display

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Abstract
The SeeReal electro-holographic display approach - using an observer window - has for the first time made possible large volume holographic reconstruction with real-time calculation. The observer tracking solution as implemented in the first SeeReal prototype is compared to new concepts providing for a larger tracking angle.

1. Introduction
Research for development of 3-D displays has grown in recent years. Most of this development still focuses on stereoscopic solutions. In a stereoscopic display a separate image is generated for each eye of the observer in order to emulate the convergence effect of a real world 3-D scene. Both images are still flat. This leads to a mismatch between accommodation of the eye lens to the screen and convergence. The result is a limit to the useful depth range of a scene shown on a stereoscopic display.

Holography is widely accepted as the technology coming closest to a real world 3-D perception. Until recently the development of large scale holographic 3-D displays was hindered by some severe obstacles.

The most severe problem for creation of a large size video hologram was the so called space-bandwidth product, directly related to the number of display pixels, leading to the requirement of a huge amount of pixels.

The second problem was the calculation time resulting from that pixel number. Previous electro-holographic displays were limited to small reconstruction volumes.

The company SeeReal Technologies has developed a new approach to electro-holography [1],[2] which was published and also demonstrated by means of a 20 inch prototype at SID 2007.

This approach overcomes previous limitations. A holographic reconstruction of the wave field that would be generated by a real existing object is obtained at - but only at - the observers eye position - and nowhere else.

This so called observer window limited to approximately the size of an eye pupil, largely reduces the required pixel number on the display. Separated holograms for the right eye and left eye of the observer are generated.

The calculation time is further reduced by using the concept of the sub-hologram, with simple locally confined lens functions for each object point and summing the up, eliminating the need for Fourier transform in hologram computation. This allows for real time calculation of holograms.

In contrast to traditional holographic reconstruction the SeeReal approach is directly related to eye tracking. In case of a movement of the observer's eyes, the observer window has to be tracked to the new eye position.

Observer tracking has been already known from some more advanced types of stereoscopic displays before, but holography with its need for coherent illumination leads to some special requirements for the tracking system. And even for the known stereoscopic tracking solutions there are limitations in the tracking range that are desired to overcome.

This work will discuss the tracking approach chosen for the first SeeReal real-time holographic prototype with its advantages but also limitations and will then explain new tracking concepts which aim at a large tracking range.

2. Tracking System
Tracking is based on two components: first a detection of the current eye position and second a means for shifting the observer window to this position.

2.1 Eye Finder
The holographic display is equipped with an eye position detector. Camera pictures of the observer are taken. An image processing software in a two step process is first detecting the face of the observer and then looking for the eye position inside the face.

In order to do a real time tracking this image processing has to be fast. In the current implementation total time for detecting the eye position of an observer is only approx. 10 milliseconds.

Also the eye finder is capable of detect and distinguish several users in front of a display simultaneously, which is important in a multi-user version of the holographic display.

2.2 Principle of Light Source Tracking
The holographic display is in the simplest case made up of a light source, a focusing means and a spatial light modulator (SLM). The light source is imaged via the focusing means to the observer plane. In the absence of the SLM there would only be this light source image – point like in case of a small light source. The light source image can be shifted by shifting the light source itself, the magnification of this shift depending on the imaging optics.

The observer window is the Fourier transform of the hologram coded into the SLM or at least part of it - depending on the actual coding. So, in the presence of the SLM this observer window replaces the light source image. Now, by moving the light source, the whole observer window can be shifted.

Light source tracking could in principle be realized by one single light source and a large lens, having the size of the display. Due to the requirement of coherent illumination of the SLM an ordinary Fresnel lens is not suitable for the task and a solid lens amongst other things would be too bulky.
2.3 Implementation of Light Source Tracking with Lens Array and Shutter Panel

A lens array in combination with a light source array was chosen as feasible solution.

Lens pitch needs to be large compared to pixel pitch of the SLM such as to still have a certain number of pixels with coherent illumination.

In principle light source tracking can be performed by mechanical shift of the light sources, but this is not a feasible solution especially if having a large number of light sources.

Another possibility would be an array with a very large number of light sources only part of them switched on at the same time. Tracking would then be performed by switching between several light sources. A solution similar to this has been implemented but with additional use of a shutter.

Shutter pixel act as secondary light sources. By switching on different shutter pixel the light source position can be changed. An LED array (primary light sources) is used for illuminating the shutter.

Figure 1 shows this implementation, which is was used in the 20 inch prototype.

2.4 Limitations of Light Source Tracking

Light source tracking has been proven to be a reliable solution. On the other hand it has also some disadvantages. For example the use of secondary light sources is not optimal in terms of light efficiency of the system.

Also there may be illumination crosstalk by light from secondary sources passing the wrong lens of the lens array. This does not cause any problem in a single-user system but may be disadvantageous for a multi-user display.

The most important drawback of light source tracking is the limitation of the tracking angle by aberrations. Large tracking angles put the need for an oblique optical path from the light source through the lens array. Aberrations may not necessarily degrade the reconstruction of single points, but somewhat corrupt the observer window leading to vignetting effects in the reconstruction.

While light source tracking may be well suited for a single user display – or a display with up to two users - with a tracking range of about +/- 15 degree, it is less useful for multi-user displays and large tracking ranges, like needed for example for TV applications.

2.5 Principle of E-Wetting Prism Tracking

The search for solutions capable of a larger tracking range lead to the conclusion that it may be advantageous to use a fixed optical path from the light source to the SLM and do any deflection of the light after it has passed the SLM.
This may be done with a prism array. Flexible prisms can be realized for example by liquid crystals but the aim was to find a solution that is also fast enough for real time tracking. Therefore a concept based on electro-wetting was developed.

The principle of electro-wetting [3] is based on a system of liquids in contact to each other having different refractive index. The angle between the liquids and therefore the deflection angle of the prism can be varied by applying a voltage. This principle is illustrated in figure 2.

It is advantageous to minimize the size of the prisms to get faster response. Therefore the intended prism size was adapted to the pixel pitch of the SLM. Simulations have shown that it is possible to get a response time in the range of 100 µs then. This enables time sequential tracking of several users. Tracking with a prism array will allow for a tracking range of more than ± 30 °. These results have lead to the development of test samples of prism arrays in order to do experimental verifications.

Figure 3 shows the setup for the holographic display with prism tracking.

3. Conclusions
Light source tracking has been proven to be a reliable solution for the SeeReal holographic display approach. It has some limitations but may be well suited for a system with a limited number of users and tracking range up to approximately ± 15 °.

The new concept of electro-wetting prism array tracking overcomes the limitations of light source tracking. It allows for tracking angles of more than ± 30 °. This fact together with its fast response makes it an ideal solution for a multi-user holographic display.

4. Acknowledgements
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5. References

Fig. 3: Concept of holographic display with E-Wetting solution, fixed light sources, lens array, SLM, Variable E-wetting prism array in front of the SLM.