HOLOGRAPHIC SEE-THROUGH HEAD-MOUNTED DISPLAY (HMD)

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# Wearable HMD

<table>
<thead>
<tr>
<th>Optical System</th>
<th>Sony WGH Stereo Glasses</th>
<th>Lumus Optical Engine Module OE-32</th>
<th>Fraunhofer IOF</th>
<th>Google Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>WGH based planar system</td>
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<td>Planar waveguides with see-through elements</td>
<td>Free-form prism</td>
<td>Polarizing optics</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Image Type</th>
<th>Sony</th>
<th>Lumus</th>
<th>Fraunhofer</th>
<th>Google Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereo, 2D</td>
<td>Stereo, 2D</td>
<td>2D</td>
<td>2D</td>
<td></td>
</tr>
</tbody>
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<tr>
<th>Display Type</th>
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<tbody>
<tr>
<td>See-through</td>
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</tr>
</tbody>
</table>

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Eye accommodation inside Holographic image

Observing holographic image with accommodation at 450mm

Observing holographic image with accommodation at 750mm
Image formation by SLM

Virtual Object  SLM-Digital Hologram
Nondiffracted beam

Diffracted beams
Reading beam

\[ \sin(\theta_{\text{max}}) = \frac{\lambda}{2 \cdot P} \]

- \( P \) - SLM pixel size

8 μm pix - ±1.9° - Current Technology Level
8 μm pix - ±1.9° - Required Level

6X pixel size decrease is required

Holoeye HE0-1080P phase-only LCoS SLM:
typical pixel pitch 8μm and therefore, for green light (\( \lambda = 532\text{nm} \)), maximum diffraction angle, \( \theta_{\text{max}} \) is approximately ±1.9°.

HOLOGRAPHIC DISPLAY is future technology due to SLM pixel size

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Calculation of Viewing Angle

Phase SLM from HoloEye: LCoS PLUTO

Pixel pitch $p = 8 \, \mu m$
Wave-length $\lambda = 0.532 \, \mu m$
Illumination angle $\delta = \lambda = 60^\circ$, $\phi = 0^\circ$
Diffracted angle $\delta_x$, $\delta_y$

\[ d = 2p \]
\[ d(\sin \theta + \sin \delta) = \lambda \] (1)
\[ 2\theta = \delta + \lambda \] (2)

(1) $\Rightarrow \delta = \arcsin \left( \frac{\lambda}{d} - \sin \theta \right)$ (3)

(2,3) $\Rightarrow \theta = 0.5(\delta - \lambda) = 0.5\left\{ \arcsin \left( \frac{\lambda}{d} - \sin \theta \right) + \lambda \right\}$

\[ 2\theta_x = 0.5\left\{ \arcsin \left( \frac{0.532 \mu m}{2 \cdot 8 \mu m} - \sin 60^\circ \right) + 60^\circ \right\} = 3.6^\circ \]
\[ 2\theta_y = 0.5\left\{ \arcsin \left( \frac{0.532 \mu m}{2 \cdot 8 \mu m} - \sin 0^\circ \right) + 0^\circ \right\} = 1.9^\circ \]

$2\theta_x = 3.6^\circ$
$2\theta_y = 1.9^\circ$
$2\theta_{diag} = 4.0^\circ$
Principal optical system

\[
\tan(\omega) = \frac{y}{250}
\]

\[
\Gamma = \frac{\tan(\omega')}{\tan(\omega)} = \frac{250}{f'}.
\]
Setup for image quality estimation

Angular Image Definition

\[ \text{def} = 0.75 \cdot \text{FoV} \div \frac{n}{200} \]
## Setup for image quality estimation

<table>
<thead>
<tr>
<th>FoV</th>
<th>0°</th>
<th>45°</th>
<th>50°</th>
<th>60°</th>
<th>70°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theoretical FoV 3.81°</td>
<td>Theoretical FoV 5.16°</td>
<td>Theoretical FoV 5.61°</td>
<td>Theoretical FoV 6.91°</td>
<td>Theoretical FoV 9.16°</td>
</tr>
<tr>
<td></td>
<td>Experimental FoV 1.8°±0.2°</td>
<td>Experimental FoV 5.0°±0.2°</td>
<td>Experimental FoV 5.5°±0.2°</td>
<td>Experimental FoV 7.1°±0.2°</td>
<td>Experimental FoV 9.1°±0.2°</td>
</tr>
</tbody>
</table>

**Image Quality, Angular Definition**

- 1°
- 1.3°
- 1.5°
- 5°

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Operation Principles of Holographic optical Elements (HOE)

Object wave: \( O = a_O \exp \left( -\frac{ik r^2}{2f} \right) \)
Reference wave: \( R = a_R \exp (-ik \sin(\theta)r) \)

The interference of two waves is declare as:
\[
I = (O + R)(O + R) = O \cdot O^* + R \cdot R^* + O \cdot R^* + O^* \cdot R
\]

Recorded Hologram:
\[
I_{\text{recording}} = a_O^2 + a_R^2 + a_O a_R \exp (-ik \frac{r^2}{2f}) + a_O^* a_R^* \exp (ik \frac{r^2}{2f}) - a_O a_R \exp (-ik \sin(\theta)r)
\]

Reconstructed Hologram:
\[
I_{\text{reconstructed}} = I_{\text{recording}} - \left( a_O^2 + a_R^2 \right) \frac{a_O a_R \exp (-ik \sin(\theta)r) + a_O^* a_R^* \exp (ik \frac{r^2}{2f}) - a_O a_R \exp (-ik \sin(\theta)r)}{a_O}
\]

Conventional Lens:
\[
A_{\text{in}} = a_0 \exp \left( i \theta - \frac{ik r^2}{2f} \right)
\]
\[
A_{\text{out}} = a_0 \exp \left( -i \theta - \frac{ik r^2}{2f} \right)
\]

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Mathematical Modeling of Volume Holograms

2 Plane Waves Tilt on Angle $\alpha$

<table>
<thead>
<tr>
<th>Transmissive Type</th>
<th>Reflective Type</th>
</tr>
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<tbody>
<tr>
<td><img src="image1" alt="Transmissive Type" /></td>
<td><img src="image2" alt="Reflective Type" /></td>
</tr>
</tbody>
</table>

Plane and Spherical Waves

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<tbody>
<tr>
<td><img src="image3" alt="Transmissive Type" /></td>
<td><img src="image4" alt="Reflective Type" /></td>
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</tbody>
</table>
Mathematical Modeling of Volume Holograms

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Setup for digital holograms generation

Hologram of 3D Object  Reconstructed 3D Image

3D Object

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Setup for digital holograms generation

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Setup with transparent HOE

FOW 2w' x 2w'' = 13° x 11.5°
DFOV 2w' = 17.3°

FoV = 17.3°
Setup with transparent HOE for observation by 2 eyes
Setup with hologram illumination by lightguide

Reconstructed holographic virtual image with accommodation at 1200 mm

Viewing angle of reconstructed virtual image is about 18°, linear field: 15" at 1200 mm
Setup with hologram illumination by lightguide
Prototype of See-through holographic imaging optical device

SAIT Russia Lab, Samsung R&D Institute Rus
Holographic imaging optical device, U. S. Patent 20140160543

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Reflection type spatial light modulator

1 - system for illumination of spatial light modulator
2 - spatial light modulator mounting on wave guiding plate
3 - viewing part with near to eye holographic optical element mounted on wave guiding plate
10 - wave guiding plate
11 - glass plate
20 - laser source of coherent radiation

Transmission type spatial light modulator

22 - eye
23 - viewing angle
24 - control block
31 - transmission type spatial light modulator
41 - transmission type holographic optical element
60 - transmission type holographic optical element
Thank you