True-3D = physical duplication of light distribution in a volume of interest

“True-3D”, in which none of the restrictions on the viewer exists due to physical duplication of light distribution, is more desirable and superior compared to stereoscopy; however such display systems are much more complicated.

Holography is a sophisticated true-3D method.
**Holography**

Greek: holos – whole (entire)

grapho – write (record)

The two step method for lensless recording of 3D information about an object in the form of a complex amplitude

\[ A(x,y) = A_o(x,y) \exp(\Phi(x,y)) \]

Optical holography requires:
- coherent (laser) light, high resolution recording material

Digital holography requires:
- Coherent light, high resolution and big aperture CCD/CMOS

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**Fundamental challenge in holographic video**

Goal:
- achieving a high enough space-bandwidth product of capture and display system to meet the image size and view angle requirements for the viewer.

- a large view angle is possible only with very small interference fringes (and thus small pixels),
- a large image translates to a large aperture of CCD and light modulator

Therefore what’s necessary is
- a massive number of very small pixels.
**MIT holographic systems: Mark-I, II, III**

**Mark I**: 1D light modulation by AOM + mechanical scanning

**Mark II**: 18 channel AOM+ bank of scanning mirrors
Controlled by custom based computer Cheops
150x75x150 mm³, 30 deg view angle

**Mark III**: based on surface acoustic wave (scanning replaced by HOE)
- 440 scan lines, 30 Hz
- 80 x 60 x 80 mm³, 24 deg view angle

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**See Real (2007)**

Approach: reconstruct only that part of the object wavefront that hits the eye pupil of observer. Vertical paralax only.
Separate observer window for each eye generated by spatial or temporal multiplexing

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QinetiQ: Active Tiling System

Features:
- For store and display CG holograms
- High frame rate of medium complexity
- Electr. address EASLMs –image generator
- Holograms written at high res. OASLM
- Parallel approach
- Monochromatic or frame –sequential-colour

1x4 channel AT unit

Spatial multiplex
3x8 billion-pixel
Full-paralax
Full-colour
3D image


Dynamic holographic stereogram

LCOSes display holograms calculated from 2D images

Achieved viewing angle 22.8 deg  (2008, Korea)

The existing holographic systems are based on CG holograms but **holograms of real objects**

Digital holography for 3D and 4D real-world objects’ capture, processing, and display

**OU LU, Bilkent, WUT, EPFEL, BIAS, CNR, Holoeye, LynceeTech, NUIM,**

### Real 3D Holographic video

**Registration**
- Numerical CGH
- Optical Digital Holograms

**Reconstruction**
- Numerical Optical

**Data processing**
- Cal. Complex amplitude
- Reduction of information
- Quality improvement
- Manipulation of 3D object

**A/D: CCD/CMOS**

**Digital holograms**

3D static & dynamic scenes

**Aim of EU project**
- Real 3D
Data displayed: Computer generated holograms

- Model of Object/scene 3D/4D
- Complex amplitude distribution of the object wavefront
- Determination $\Gamma(x,y,z)$
  - Fourier Hol., Fresnel Hol., Stereogram, ............
- Cloud of points
- Triangle mesh
- 2D images
- Photometric representation

Multi GPU systems (HORN6)
- Coding, Processing Registration Konwersja C/A
- 3D scene visualization
- SLM
- Eye tracking module

Real3D holographic video system

- Application of inline Fresnel holograms
- Capture of different perspectives of an object by multiple high resolution CCD/CMOS cameras in circular configuration
- Display of holograms by multiple phase-only SLMs in circular configuration
- Matching the parameters of capture and display systems
- Coding and compression of DHs for high quality data transfer
- Data processing of DHs into object phase data for display at SLMs
Capture system

- Multi CCD system (6)
- Circular configuration
- Normal of CCDs directed to object

Otherwise:
- Optical field might not fill detector
- Optical field might not be recorded due to high frequencies

Inline hologram registr.: PSDH (static)
Fresnel (dynamic)

- Best use of spatial bandwidth
- But need to remove DC and TI
- Good 3D perception

Capture system 6 CCDs

Source: Impulse laser 6ns

Problem low fill factor

Basler piA2400 -12gm (2456x2058, 3.45μm)
Capture system 6 CCDs

3D StereoMedia, December 2010

Removal of DC and twin image terms from inline holograms

Reconstruction of inline hologram

Phase shifting holography
Requires capture of at least 3 DH

Reconstruction of a single DH
Display system – Illumination along normal

Advantage: the captured optical field is directly reconstructed on SLMs

Disadvantage: complicated opto-mechanical realization

Multi LCOS SLMs

Liquid Crystal on Silicon SLM

Holoeyle 1080P

Pixel size 8µm

Reconstruction system – single illumination direction

Advantages:
Flexible system
Easy to adjust and calibrate

Problem:
the phase function at SLMs should include the tilt

LCoS display – HEO 1080P
Phase only
(res. 1080x1920, pp. 8µm)
Wide angle tilt processing algorithm

Tilt 0°  Tilt 10°  Tilt 20°  Tilt 30°  Tilt 40°

Without tilt procedure

With tilt procedure

Coupling the capture and display systems

Mismatch in geometrical and optical features of both systems

N1=N2

Wavelength  Size of pixels

Reconstruction distance

$z_{rec} = z_{reg} \frac{\lambda_{reg}}{\lambda_{rec}} \Delta^2_{rec}$

Transverse

$M_t = \frac{\Delta_{rec}}{\Delta_{reg}}$

Longitudinal

$M_l = \frac{\lambda_{reg}}{\lambda_{rec}} M_t^2$

Angular magnification

$M_a = \frac{\lambda_{rec}}{\lambda_{reg}} M_t$

- $z_{reg}$: distance between object and detector,
- $\lambda_{reg/rec}$: wavelength used during registration and reconstruction
- $\Delta_{reg/rec}$: pixel size of CCD and SLM respectively
Holographic display: Main modules

Multi SLMs Module

Control & Data Processing

Illumination

Nd:Yag: \( \lambda = 532\text{nm} \)

Observation

Naked eye observation
Directional diffuser
Through eyepiece

Display

Real images

SLMs & electronics

Colimator

Laser & electronics

Mirrors

SLMs

Configuration for FF=0.6

➢ hologram reconstruction
distance: 400 – 700 mm,
➢ observation of real
(but imaginary) image
Reconstruction of static object

3 different perspectives as seen by camera from combined image

6 views of different object perspectives as reconstructed by single SLMs

Simulations for newest JVC SLM

JVC SLM (simulation parameters)
Resolution: 8000 x 4000 pixels, pixel size 4.8 µm
Distance between eyes \( db = 65 \) [mm],
FF (for both capture and display) = 1
6 SLMs
Reconstruction distance: 1000 [mm],

Output:
VFOV = 111 [mm]
No gaps
Allowed a certain
Observer’s movement
Whish list

- Increase aperture (capture/display devices) and decrease the size of pixels
- CCD/CMOS at flexible substrate (circular configuration)
- Solutions (optical + numerical) for gaps problem
- Increase the quality of visualization the wavefront in space
- Efficient solutions for video capture and data transfer

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