Optical imaging and image processing (XI)

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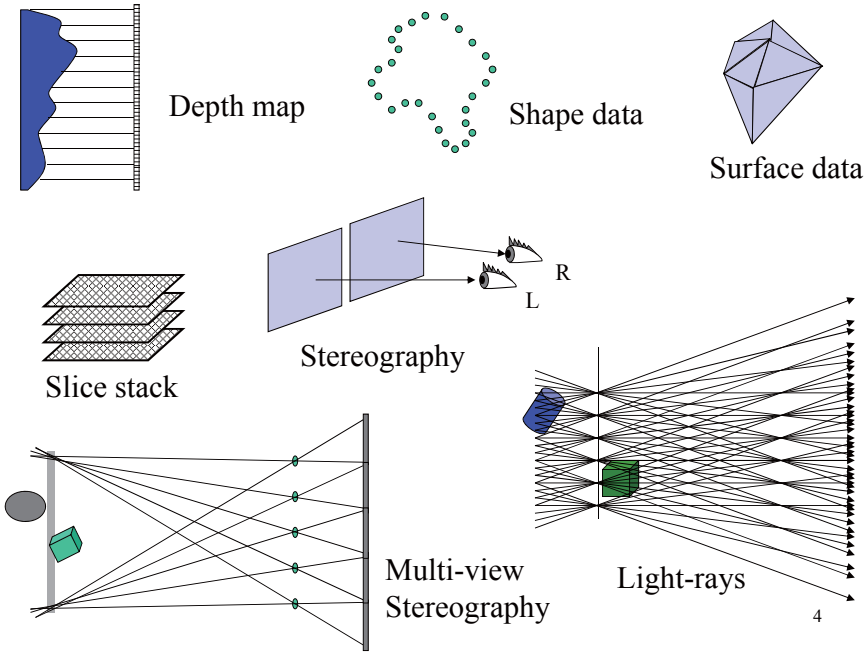
7. 三次元画像とホログラフィー
7. Three-dimensional imaging and holography
7.1 Variations of 3-D information

Type	Parameters	Amount of data
2D image	x, y, value	$N^2 \times L_b$
Depth map	x, y, depth	$N^2 \times L_d$
Shape data	x, y, z	$3P \times X$
Surface data	x, y, z, reflectivity x, y, z, color	$3P \times L_b \times X$
Slice stack	x, y, value, number	$N^2 \times L_b \times D$
Stereography	x, y, value, angle	$N^2 \times L_b \times M$
Volume data	x, y, z, value	$N^3 \times L_b$
Light-field	x, y, value, $angle_x$, $angle_y$	$N^2 \times L_b \times M^2$
Time-sequence	x, y, value, t	$N^2 \times T$

三次元画像工学、大越孝敬、朝倉書店 (1997)



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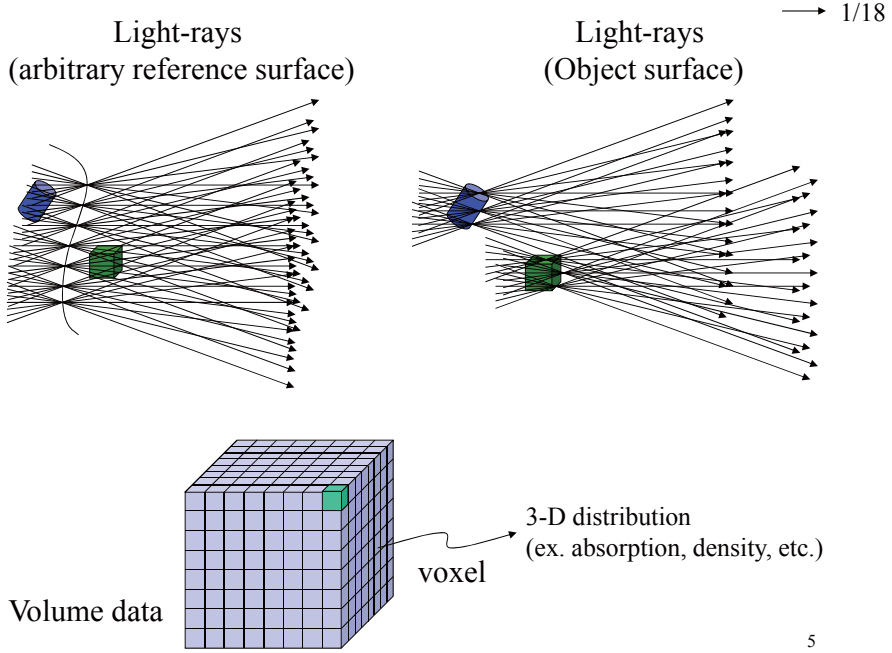
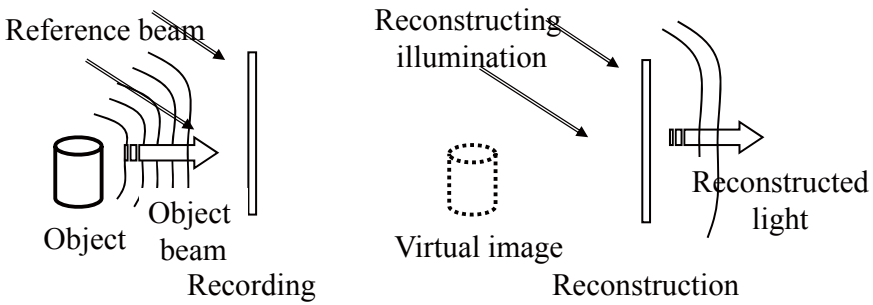


7.2 3D display techniques

	Principle	Method	Depth-cues (Only important cues shown)
No parallax Single 2D image	Monocular depth-cue	Pictorial techniques	Overlapping, Linear Perspective Texture Gradient, Shades and Shadows, Aerial Perspective
		Large field of view Floating real-image	Display surface becomes unstable
No parallax Multiple 2D images		Motion picture Observer Tracking	Motion Parallax
Binocular stereogram Two 2-D images	Binocular parallax	Polarizing glasses, Anaglyph, Time-sequential, Goggle, Lenticular stereogram (binocular)	Binocular Parallax
Autostereoscopic 3D display (3D images)	Multi-view	Parallax panoramagram Lenticular sheet IP, Integral imaging	Binocular Parallax, Motion Parallax
	Depth sampling	Varifocal mirror LCD Stack	Binocular Parallax, Motion Parallax Accommodation, Convergence Difficult to reproduce overlapping effect
	light-ray or wavefront reconstruction	IP, Parallax barrier, High-density light-ray reproduction Holography	Binocular Parallax, Motion Parallax Accommodation, Convergence

Hologram



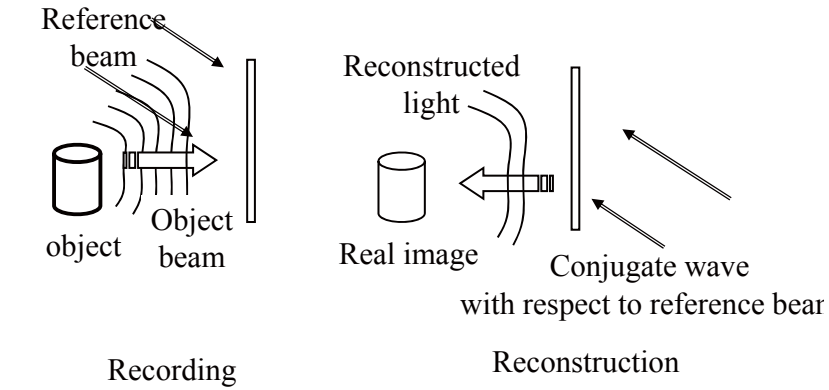
- Reconstructing wavefront of light wave

7.3 Holography

Wavefront recording and reconstruction
using the light interference and diffraction

- Recording and reconstruction of wavefront
  - Recording and display of 3D image
  - Optical measurement
- Modification of the light propagation or the beam shape
  - Diffractive optical element, Holographic optical element
  - Optical information processing
- Light dispersion, wavelength selectivity
  - Optical element, diffraction grating, filter
  - 3D display with white light reconstruction
- High-density information recording, redundancy
  - Optical memory
- Combination of above features
  - Security printing (anti-counterfeit printing)

Reconstruction of real image



Recording of hologram

- Interference of two wavefronts

  $I(\mathbf{r}) = < | U_{Sc}(\mathbf{r}, t) + U_{Re}(\mathbf{r}, t) |^2 >$

- Complex amplitude
  - Object wave $U_S(\mathbf{r}) = A(\mathbf{r}) \exp \{ j \phi(\mathbf{r}) \}$
  - Reference wave $U_R(\mathbf{r}) = B \exp \{ j k x \sin\theta \}$
- For coherent light

  $I(\mathbf{r}) = | U_S(\mathbf{r}) + U_R(\mathbf{r}) |^2$

  $= | U_S(\mathbf{r}) |^2 + | U_R(\mathbf{r}) |^2 + U_S(\mathbf{r}) U_R(\mathbf{r})^* + U_S(\mathbf{r})^* U_R(\mathbf{r})$

  $= A(\mathbf{r})^2 + B^2 + A(\mathbf{r}) B \exp \{ j (\phi(\mathbf{r}) - kx \sin \theta) \}$

  $+ A(\mathbf{r}) B \exp \{ -j (\phi(\mathbf{r}) - kx \sin \theta) \}$
- Amplitude transmittance of recording medium
  - When it is linear to exposed light energy

    $T_A = T_0 + t_1 I(\mathbf{r})$

Reconstruction of hologram

- Reconstructing wave $U(\mathbf{r}) = U_R(\mathbf{r}) T_A$

  $= t_1 U_R(\mathbf{r}) T_0 + t_1 U_R(\mathbf{r}) \{ | U_S(\mathbf{r}) |^2 + | U_R(\mathbf{r}) |^2 \}$

  $+ t_1 U_S(\mathbf{r}) | U_R(\mathbf{r}) |^2 + t_1 U_S(\mathbf{r})^* U_R(\mathbf{r})^2$

  $= U_0'(\mathbf{r}) + U_D'(\mathbf{r}) + U_C'(\mathbf{r})$

  $U_D'(\mathbf{r}) = t_1 U_S(\mathbf{r}) | U_R(\mathbf{r}) |^2 = t_1 B^2 U_S(\mathbf{r})$

→ Object wave is reconstructed (Virtual image)

- Conjugate image reconstruction

  $U(\mathbf{r}) = U_R(\mathbf{r})^* T_A$

  $= U_0''(\mathbf{r}) + U_C''(\mathbf{r}) + U_D''(\mathbf{r})$

  $U_D''(\mathbf{r}) = t_1 U_S(\mathbf{r})^* | U_R(\mathbf{r}) |^2$

  $= t_1 B^2 U_S(\mathbf{r}) = t_1 B^2 A(\mathbf{r}) \exp \{ -j \phi(\mathbf{r}) \}$ (188)

→ Conjugate wave is reconstructed (Real image)

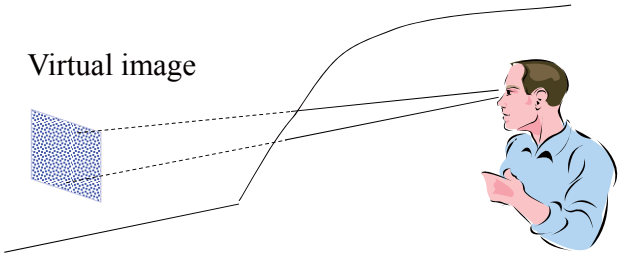
Applications of holography

- 3D display
  - Publishing, Security, Package, Interior, Advertisement, Education
  - Printing of 3D image data, Medical 3D displays
- Security Printing
  - Banknote (10k, 5k bills), Credit card, Package of digital media
- Optical measurement
  - Holographic interferometer
  - Shape, Motion, Vibration, Refractive index, birefrengence
  - Digital holography (using CCD cameras instead of photographic recording media)
- Optical information processing, Optical memory
  - Holographic matched filter, Holographic memory
- Holographic Optical Element (HOE)
  - Lens, Mirror, Diffuser, HUD, Projector, LCD
  - Screen, Dispersion element, Optical interconnection
  - Optical pickup, Scanner, Bar-code reader, Laser–beam printer, Beam shaping
- Imaging (Microscopy)
  - Electron holography, X-ray holography

Display holograms

- Laser reconstruction
  - Fresnel hologram
- White-light reconstruction
  - Image-type,
  - Rainbow hologram (1-step、2-step),
  - Volume reflection hologram (Denisyuk hologram, Lippmann hologram)
- Holographic stereogram
- Computer generated hologram
- Color holograms
  - Laser light reconstruction (RGB lasers)
  - White-light reconstruction
    - Rainbow-type, Volume-reflection type
  - Color holographic stereogram
    - Rainbow-type, Volume-reflection type

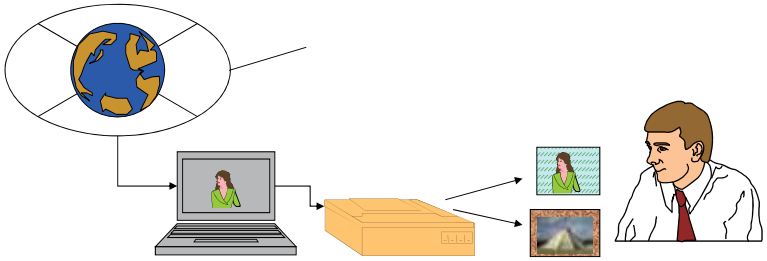
HUD(Head-up display)



- Features
  - Virtual image formation
  - Only the light of specific wavelength is reflected, others are transmitted. (High-transmittance)
  - Thin device (Sandwich between glasses)
- Substitution of concave half-mirror, Fresnel lens, and Dichroic mirror

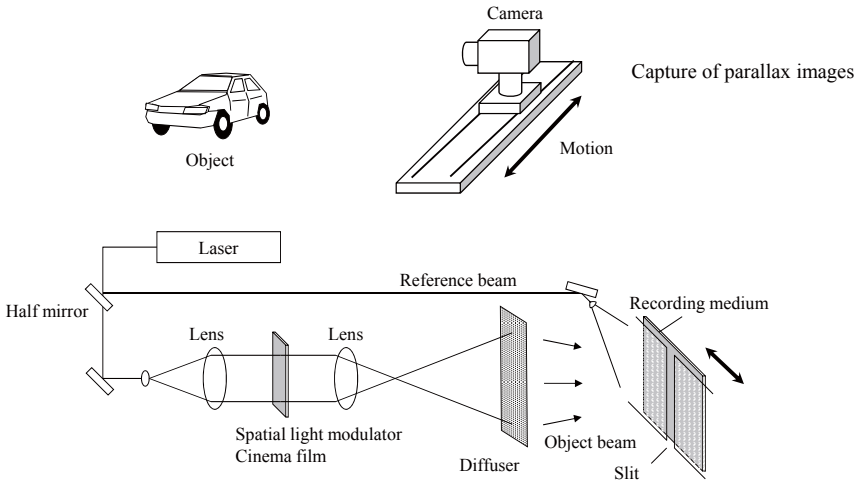
Holographic printer

- Holographic stereogram
- Computer Generated Hologram (HOE)



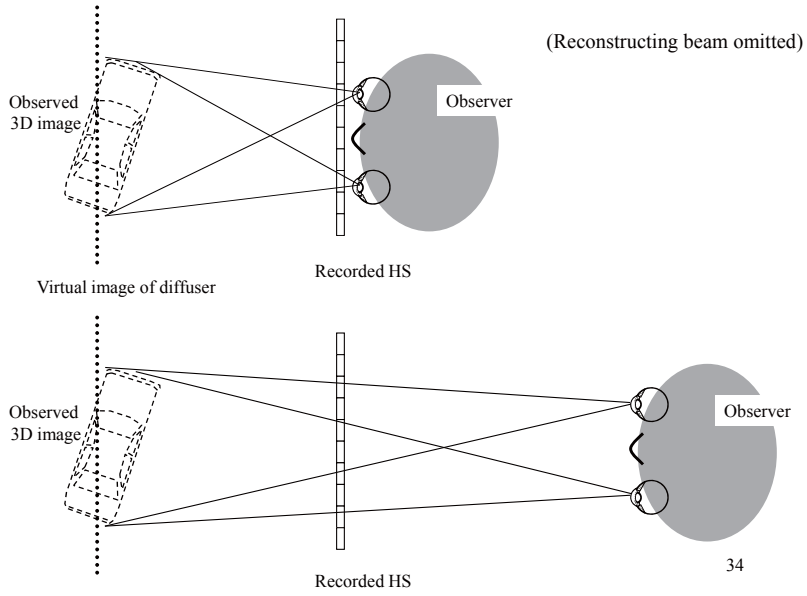
3D image printer　　3D display

Recording of holographic stereogram
Horizontal parallax only (HPO)

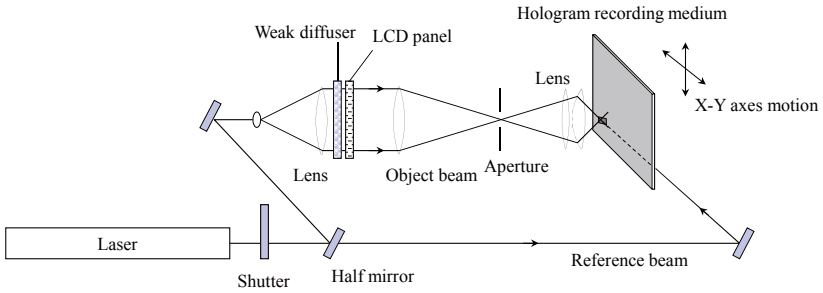


Recording of hologram

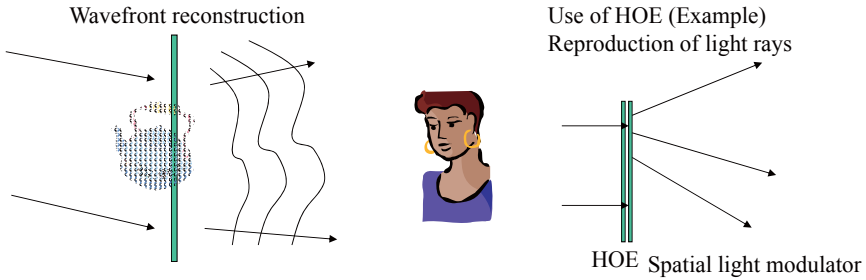
Observation of holographic stereogram



Recording of full-parallax holographic stereogram



Electro-holography, Holographic TV



High-resolution spatial light modulator

- 3D electronic display using holography
- Wavefront reconstruction (CGH)
- Use of holographic stereogram technique
- Use of holographic optical element
- High-resolution image with the large range of depth