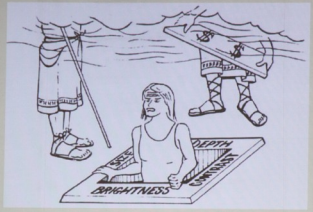

A new corner of Dante's visit to the Inferno
A holographer trapped in a box of technical constraints

S.A. Benton,
Display Holography An SPIE Critical Review of Technology,
Proc. SPIE **532** Holography (1985)

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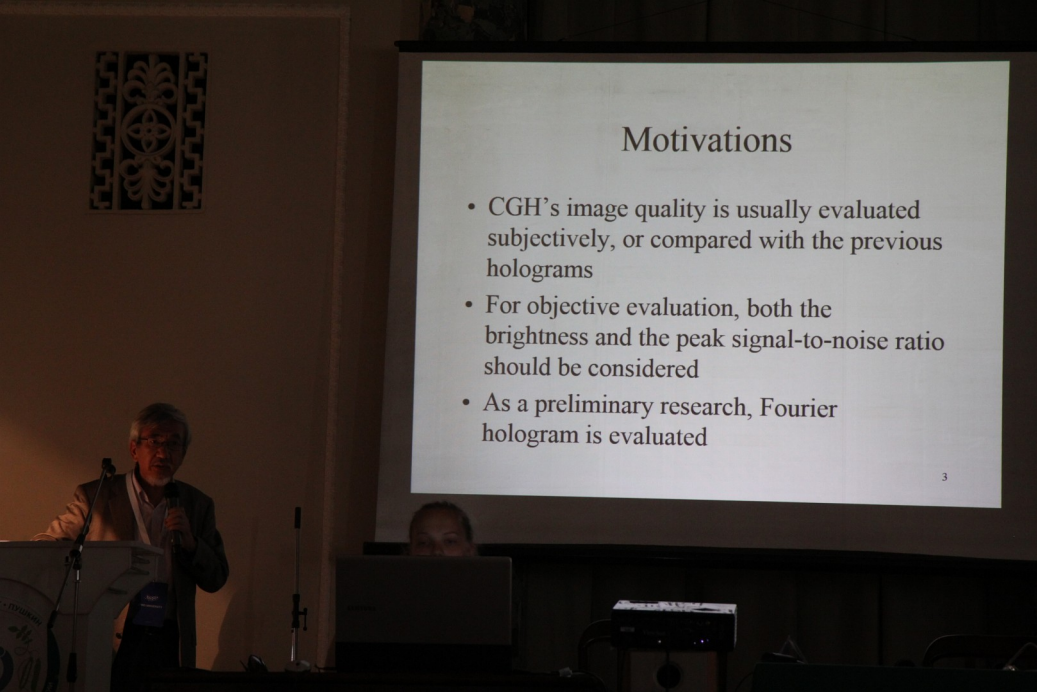

Motivations
• CGH's image quality is usually evaluated subjectively, or compared with the previous holograms
• For objective evaluation, both the brightness and the peak signal-to-noise ratio should be considered
• As a preliminary research, Fourier hologram is evaluated
3

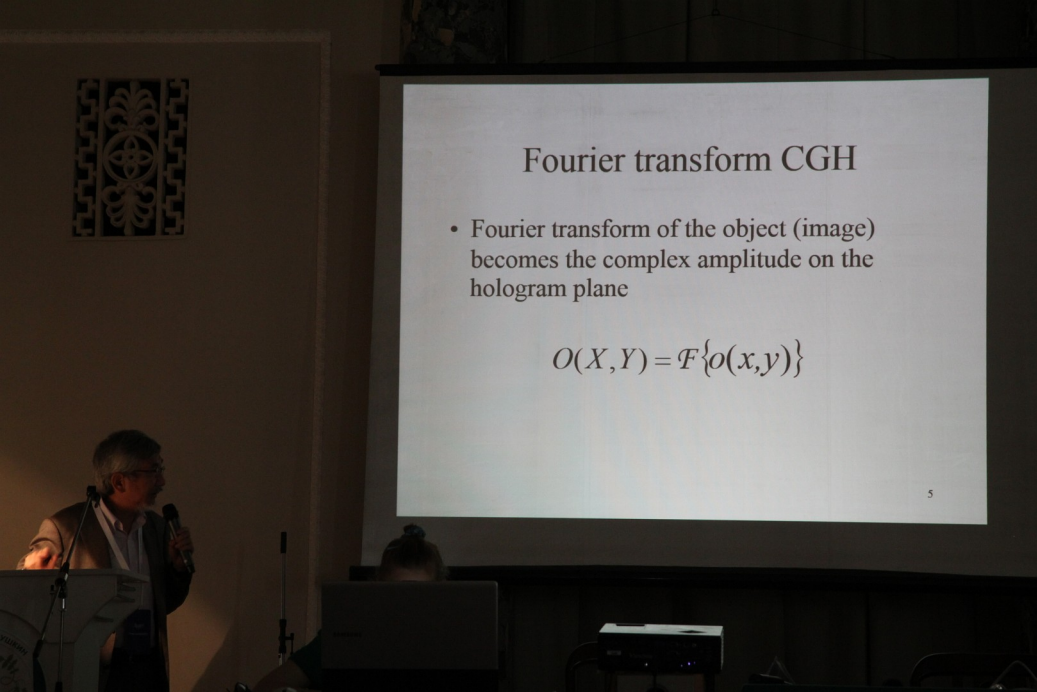
Fourier transform CGH

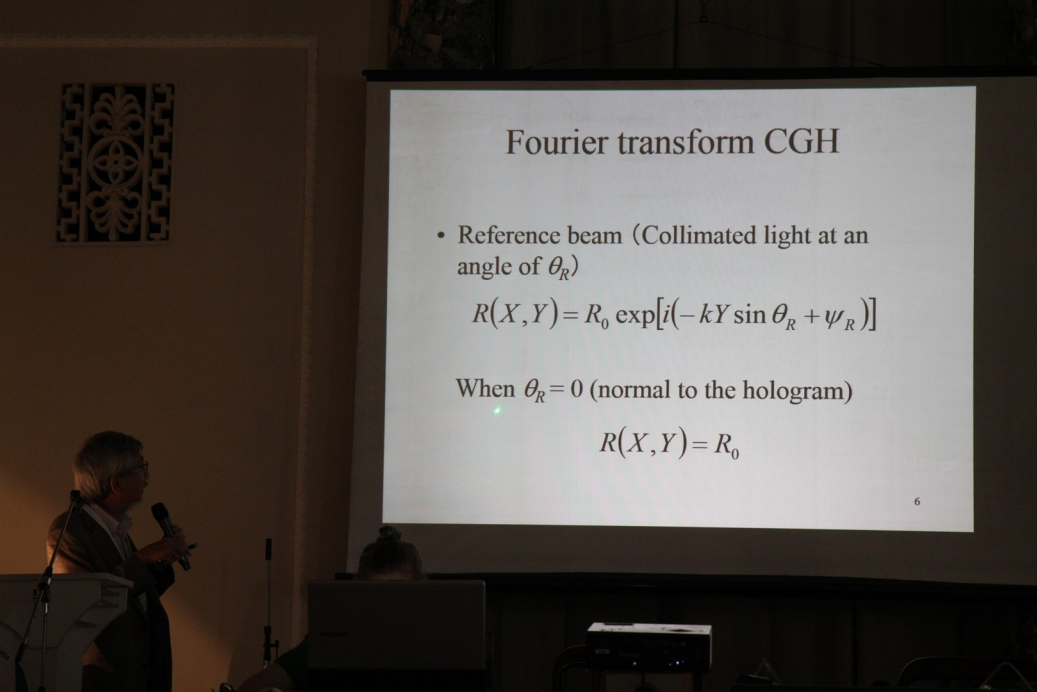
- Multiply a random phase factor before calculating the Fourier transform

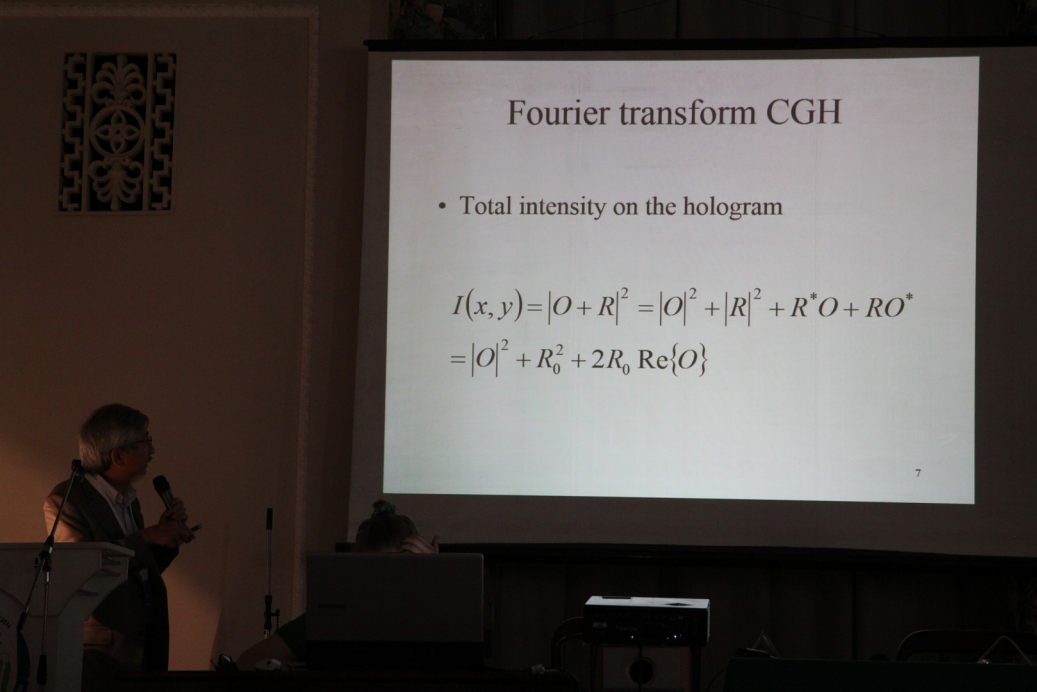
Original image in the input plane

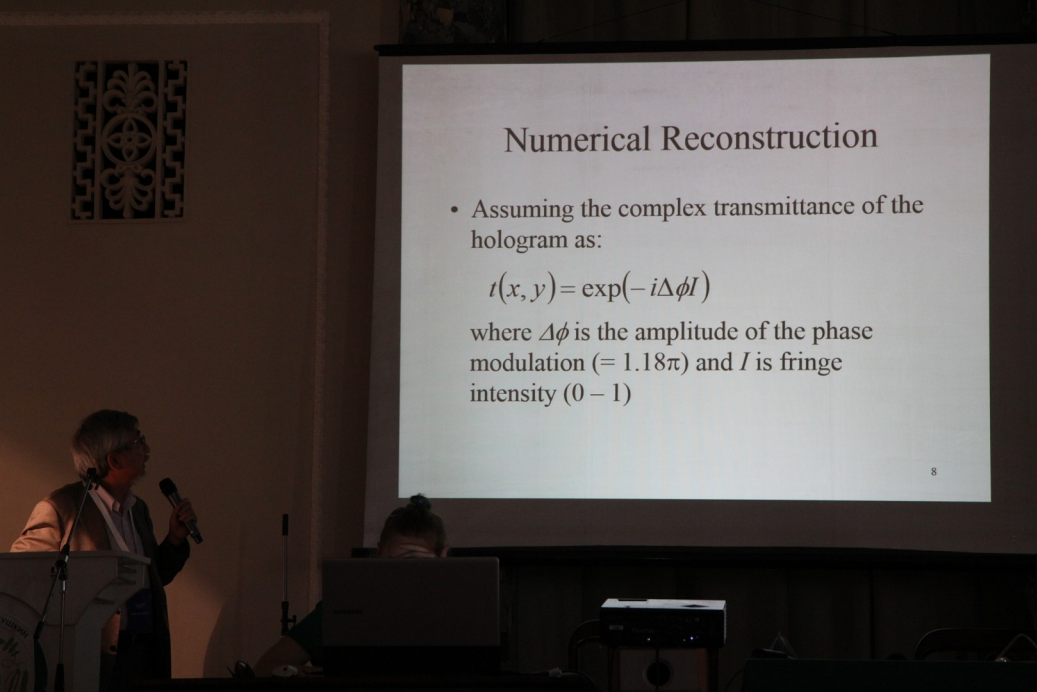
Hologram

Reconstructed and conjugate image


Fourier transform CGH
• Fourier transform of the object (image) becomes the complex amplitude on the hologram plane
$$O(X,Y) = \mathcal{F}\{o(x,y)\}$$
5

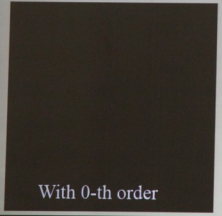

Fourier transform CGH
• Reference beam（Collimated light at an angle of θ_R）
$R(X,Y) = R_0 \exp[i(-kY\sin\theta_R + \psi_R)]$
When $\theta_R = 0$ (normal to the hologram)
$R(X,Y) = R_0$
6


Fourier transform CGH
• Total intensity on the hologram
$I(x,y) = |O+R|^2 = |O|^2 + |R|^2 + R^*O + RO^*$
$= |O|^2 + R_0^2 + 2R_0\,\mathrm{Re}\{O\}$
7

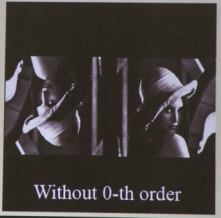

Numerical Reconstruction
• Assuming the complex transmittance of the hologram as:
$t(x, y) = \exp(-i\Delta\phi I)$
where $\Delta\phi$ is the amplitude of the phase modulation (= 1.18π) and I is fringe intensity (0 – 1)
8

Numerical Reconstruction (2)

- The DC term, or non diffracted light is numerically removed from figures but took into account for diffraction efficiency



With 0-th order



Without 0-th order

Diffraction Efficiency

- The absolute diffraction efficiency (DE) defined as:

$$\eta = \frac{I_{+1}}{I_i} \times 100[\%]$$

where, I_i and I_{+1} are the intensity of the incident light and the 1-st order diffraction. In this research, I_{+1} is calculated as total intensity in the reconstructed area

Peak Signal-to-Noise Ratio

- Peak Signal-to-Noise Ratio (PSNR) is defined as:

$$PSNR = 10\log_{10}\frac{255^2 mn}{\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j)-K(i,j)]^2}[\text{dB}]$$

where I is the original image and K is the reconstructed image in the reconstruction area

- Brightness of K is normalized to have the same mean value of I

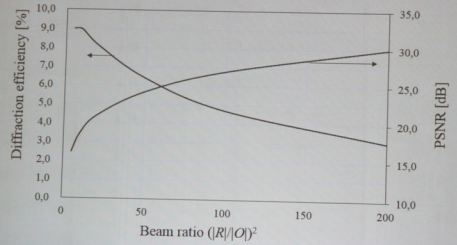
Rigorous calculation

- $|O|^2$ term works as noise to the hologram (BR=5, DE = 9.0 %, PSNR = 16.1 dB)

Original image

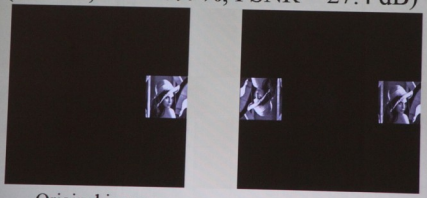
reconstructed image

DE and PSNR against BR



Rigorous calculation

- To separate $|O|^2$ term, reduce image size (or increase hologram size) works, but…
(BR=10, DE = 7.4 %, PSNR = 27.4 dB)

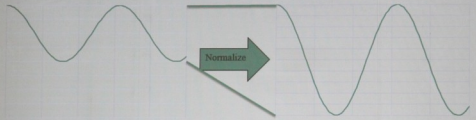


Original image

reconstructed image

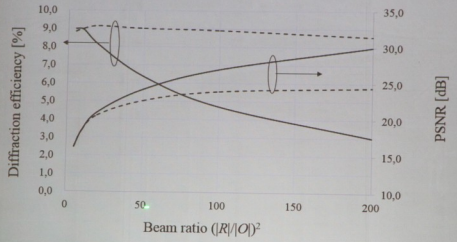
Normalized Hologram

- When BR increases, contrast of *I* decreases



$$I_n = \frac{I - I_{\min}}{I_{\max} - I_{\min}} I_{\max}$$

Dashed line: Normalized



Bipolar Intensity

- Remove $|O|^2$

$$I(x,y) = |O+R|^2 = |O|^2 + |R|^2 + R^*O + RO^*$$

$$= |O|^2 + R_0^2 + 2R_0\,\mathrm{Re}\{O\}$$

$$\Rightarrow \boxed{\mathrm{A} + \mathrm{Re}\{O\}}$$

'A' is a constant to make all value of $I(x, y)$ positive.

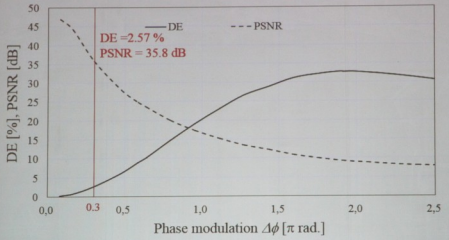
Bipolar intensity calculation

- Eliminating $|O|^2$ term makes hologram clear (DE = 9.2 %, PSNR = 24.6 dB)

Original image

reconstructed image

Bipolar intensity calculation



Comparing calculations

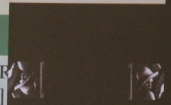
Calculation type	DE [%]	PSNR [dB]	Beam ratio
Rigorous	3.03	30.0	200
Rigorous (large)	7.40	27.4	10
Normalized	8.59	24.4	200
Bipolar	9.16	24.6	-
Smaller $\Delta\phi$	2.57	35.8	

Comparing calculations

	Phase		Amplitude		
Calculation type	DE [%]	PSNR [dB]	DE [%]	PSNR [dB]	Beam ratio
Rigorous	3.03	30.0	0.24	31.8	200
Rigorous (large)	7.40	27.4	0.65	52.0	10
Normalized	8.59	24.4	0.74	31.8	200
Bipolar	9.16	24.6	0.75	47.2	-
Smaller $\Delta\phi$	2.57	35.8			

Comparing calculations

	Phase		Amplitude	
Calculation type	DE [%]	PSNR [dB]	DE [%]	PSNR [dB]
Rigorous	3.03	30.0	0.24	31.8
Rigorous (large)	7.40	27.4	0.65	52.0
Normalized	8.59	24.4	0.74	31.8
Bipolar	9.16	24.6	0.75	47.2
Smaller $\Delta\phi$	2.57	35.8		



Conclusion

- Propose to use DE and PSNR to evaluate image quality objectively
- Bipolar intensity with smaller $\Delta\phi$ shows balanced quality
- Phase hologram can get larger DE than amplitude hologram but smaller PSNR

Future works

- Kinoform?
- Evaluation of 3D characteristics needs to be considered