
2015 International Symposium on Display Holography
(ISDH2015)
Image Formation of Hologram Reconstruction by
Liquid Crystal on Silicon Device
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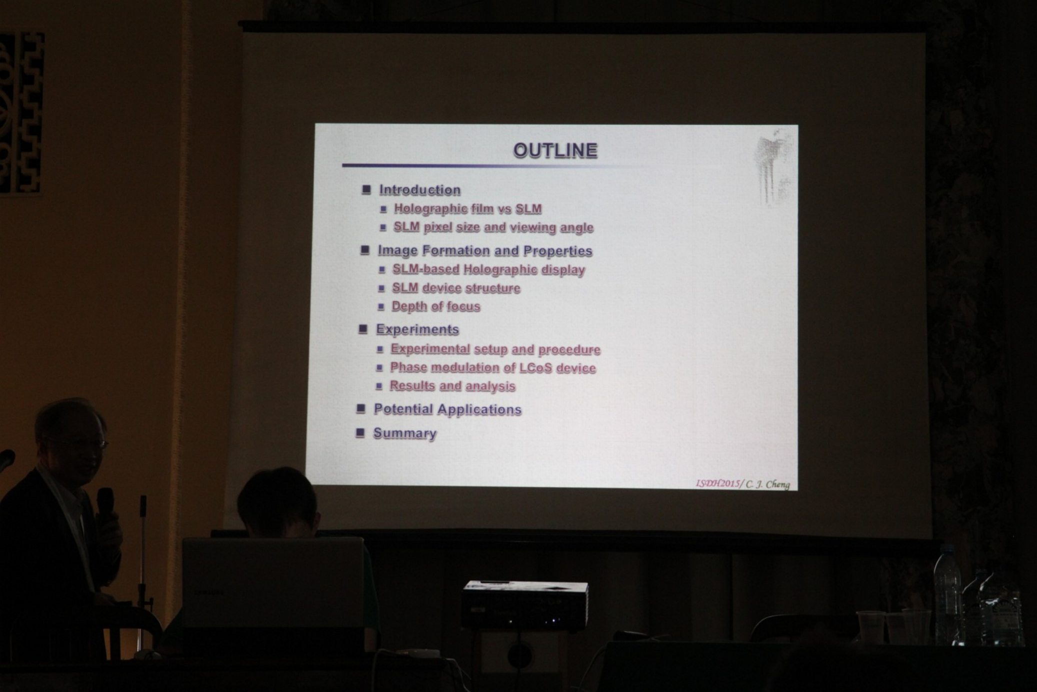
OUTLINE
Introduction
Holographic film vs SLM
SLM pixel size and viewing angle
Image Formation and Properties
SLM-based Holographic display
SLM device structure
Depth of focus
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Phase modulation of LCoS device
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Summary
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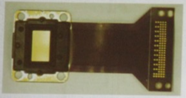
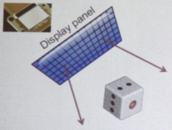
Introduction
– Technical performance of SLM device

Basic structure of SLM device

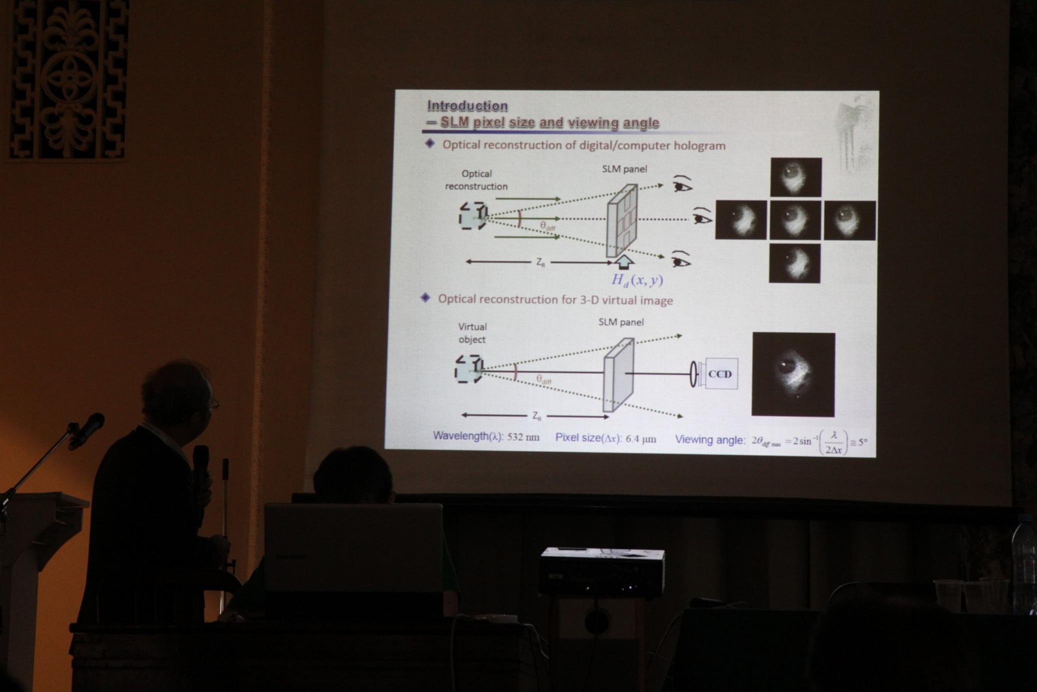




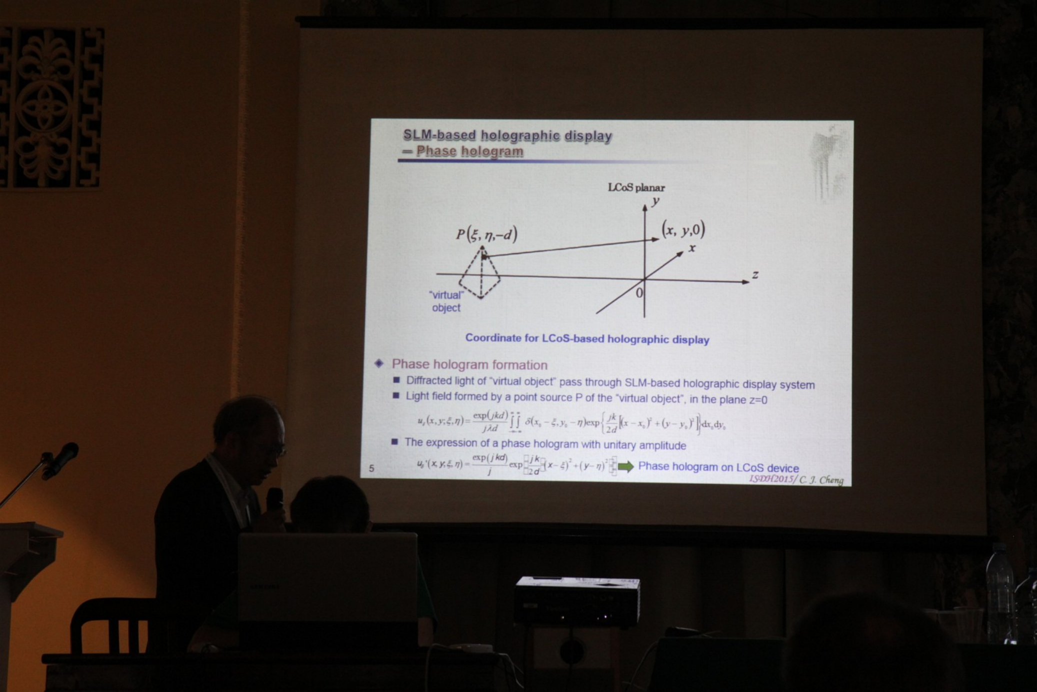
Holographic film v.s. SLM

Technical data	Holographic film	SLM
Imaging process	Wet/Dry-chemical process	Electro-optical conversion
Display type	Transmission/ Reflection	Transmission/Reflection
Display area	> 50 ×60 cm^2	1.5 × 0.7 cm^2
Resolution	> 3,000 lps/mm	6.4 μm (3.74 μm)*
Structure	Continues	Pixelated
Operation	Static	Dynamic & Reconfigurable

*Jasper Display : http://www.jasperdisplay.com/tw/



Introduction
– SLM pixel size and viewing angle
Optical reconstruction of digital/computer hologram
Optical reconstruction
SLM panel
θdiff
ZR
Hd(x, y)
Optical reconstruction for 3-D virtual image
Virtual object
SLM panel
θdiff
ZR
CCD
Wavelength(λ): 532 nm
Pixel size(Δx): 6.4 μm
Viewing angle: 2θdiff max = 2 sin⁻¹(λ/2Δx) ≅ 5°



SLM-based holographic display
– Phase hologram
LCoS planar
y
$P(\xi, \eta, -d)$
$(x, y, 0)$
x
z
0
"virtual" object
Coordinate for LCoS-based holographic display
Phase hologram formation
Diffracted light of "virtual object" pass through SLM-based holographic display system
Light field formed by a point source P of the "virtual object", in the plane z=0
$u_z(x, y; \xi, \eta) = \frac{\exp(jkd)}{j\lambda d} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \delta(x_0 - \xi, y_0 - \eta) \exp\left\{\frac{jk}{2d}\left[(x - x_0)^2 + (y - y_0)^2\right]\right\} dx_0 dy_0$
The expression of a phase hologram with unitary amplitude
$u_z'(x, y, \xi, \eta) = \frac{\exp(jkd)}{j} \exp\left[\frac{jk}{2d}\left((x - \xi)^2 + (y - \eta)^2\right)\right]$
Phase hologram on LCoS device
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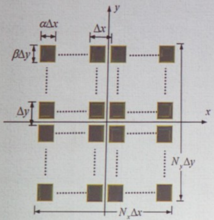
SLM-based holographic display – Image formation and properties



Device structure and coordinate definitions

- The phase hologram formed in LCoS

$$H_\xi(x,y;\xi,\eta)=u'_\xi(x,y;\xi,\eta)\mathrm{w}(x,y)$$

- The window function of SLM device

Aperture of the SLM

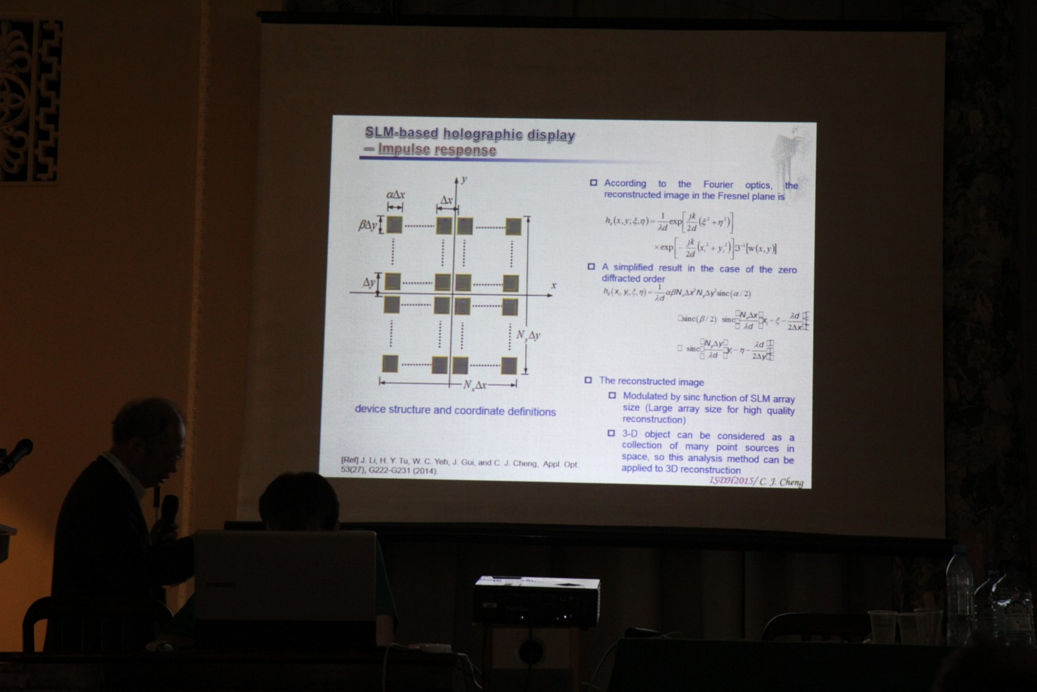
$$w(x,y)=\mathrm{rect}\left(\frac{x}{N_x\Delta x}\right)w_\alpha(x)\,\mathrm{rect}\left(\frac{y}{N_y\Delta y}\right)w_\beta(y)$$

Pixel of the SLM

$$\begin{cases} w_\alpha(x)=\left[\mathrm{rect}\left(\frac{x}{\alpha\Delta x}\right)*\mathrm{comb}\left(\frac{x-\Delta x/2}{\Delta x}\right)\right] \\ w_\beta(y)=\left[\mathrm{rect}\left(\frac{y}{\beta\Delta y}\right)*\mathrm{comb}\left(\frac{y-\Delta y/2}{\Delta y}\right)\right] \end{cases}$$

- Image formation and properties
  - LCoS parameters
  - Pixel number (Nx,Ny), pixel size (Δ_x,Δ_y), and fill factor (α,β)

[Ref] J. Li, H. Y. Tu, W. C. Yeh, J. Gui, and C. J. Cheng, Appl. Opt. 53(27), G222-G231 (2014).


SLM-based holographic display
– Impulse response
According to the Fourier optics, the reconstructed image in the Fresnel plane is
A simplified result in the case of the zero diffracted order
The reconstructed image
Modulated by sinc function of SLM array size (Large array size for high quality reconstruction)
3-D object can be considered as a collection of many point sources in space, so this analysis method can be applied to 3D reconstruction
device structure and coordinate definitions
[Ref] J. Li, H. Y. Tu, W. C. Yeh, J. Gui, and C. J. Cheng, Appl. Opt. 53(27), G222-G231 (2014).
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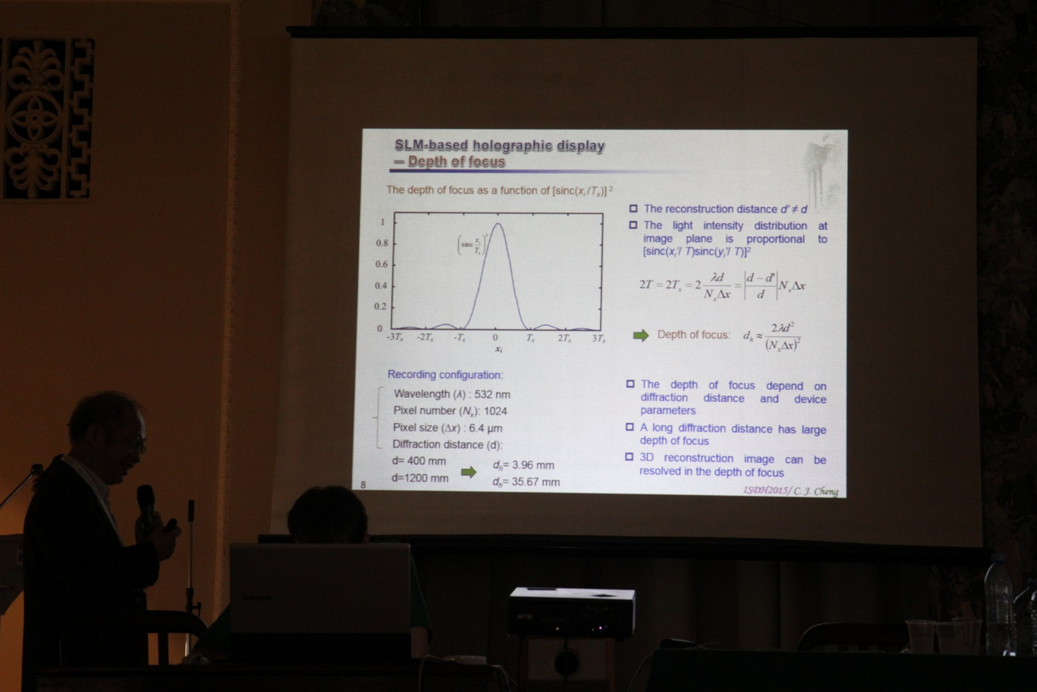
SLM-based holographic display
– Depth of focus
The depth of focus as a function of $[\mathrm{sinc}(x_i/T_x)]^2$
$\left(\mathrm{sinc}\frac{x_i}{T_x}\right)^2$
1
0.8
0.6
0.4
0.2
0
$-3T_x$ $-2T_x$ $-T_x$ 0 T_x $2T_x$ $3T_x$
x_i
The reconstruction distance $d' \neq d$
The light intensity distribution at image plane is proportional to $[\mathrm{sinc}(x_i/T)\mathrm{sinc}(y_i/T)]^2$
$2T = 2T_x = 2\frac{\lambda d}{N_x \Delta x} = \left|\frac{d-d'}{d}\right| N_x \Delta x$
Depth of focus: $d_h \approx \frac{2\lambda d^2}{(N_x \Delta x)^2}$
Recording configuration:
Wavelength (λ) : 532 nm
Pixel number (N_x): 1024
Pixel size (Δx) : 6.4 μm
Diffraction distance (d):
d= 400 mm
d=1200 mm
d_h= 3.96 mm
d_h= 35.67 mm
The depth of focus depend on diffraction distance and device parameters
A long diffraction distance has large depth of focus
3D reconstruction image can be resolved in the depth of focus
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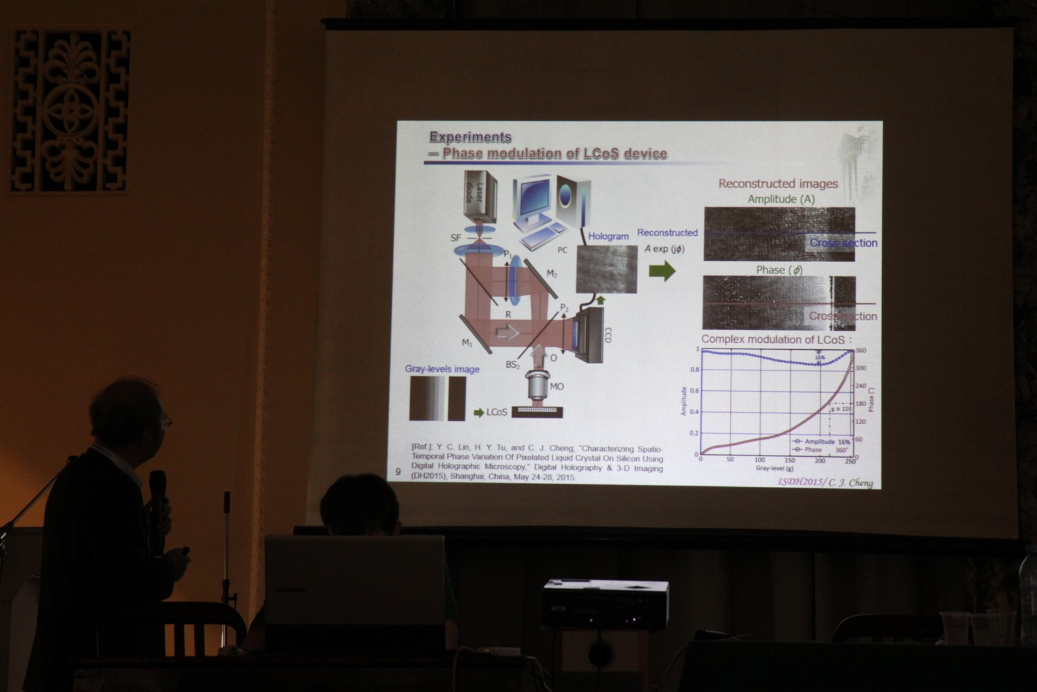
Experiments
– Phase modulation of LCoS device
Laser diode
SF
PC
Hologram
Reconstructed
A exp (jϕ)
Reconstructed images
Amplitude (A)
Cross section
Phase (ϕ)
Cross section
P1
M2
P2
R
M1
BS2
O
CCD
MO
Gray-levels image
LCoS
Complex modulation of LCoS :
Amplitude
Phase (°)
Gray-level (g)
Amplitude 16%
Phase 360°
[Ref.]: Y. C. Lin, H. Y. Tu, and C. J. Cheng, "Characterizing Spatio-Temporal Phase Variation Of Pixelated Liquid Crystal On Silicon Using Digital Holographic Microscopy," Digital Holography & 3-D Imaging (DH2015), Shanghai, China, May 24-28, 2015.
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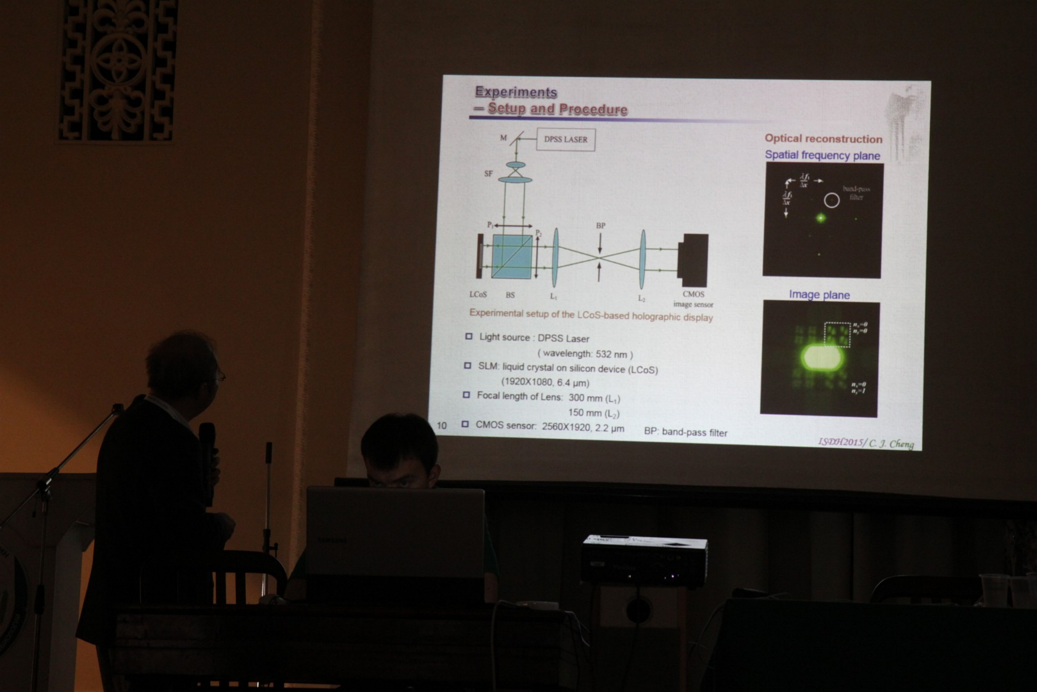
Experiments
– Setup and Procedure
M
DPSS LASER
SF
P_1
P_2
BP
LCoS
BS
L_1
L_2
CMOS image sensor
Experimental setup of the LCoS-based holographic display
Light source : DPSS Laser
(wavelength: 532 nm)
SLM: liquid crystal on silicon device (LCoS)
(1920X1080, 6.4 μm)
Focal length of Lens: 300 mm (L_1)
150 mm (L_2)
CMOS sensor: 2560X1920, 2.2 μm
BP: band-pass filter
Optical reconstruction
Spatial frequency plane
band-pass filter
Image plane
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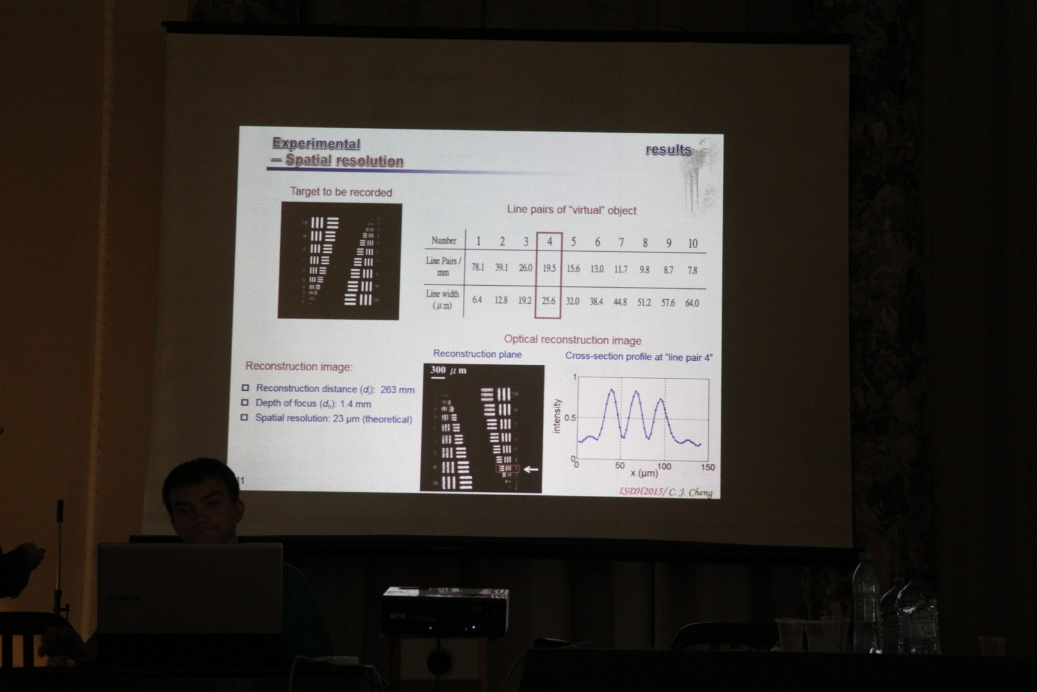
Experimental
– Spatial resolution
results
Target to be recorded
Line pairs of "virtual" object
Number 1 2 3 4 5 6 7 8 9 10
Line Pairs / mm 78.1 39.1 26.0 19.5 15.6 13.0 11.7 9.8 8.7 7.8
Line width (μm) 6.4 12.8 19.2 25.6 32.0 38.4 44.8 51.2 57.6 64.0
Optical reconstruction image
Reconstruction plane
Cross-section profile at "line pair 4"
300 μm
intensity
x (μm)
Reconstruction image:
Reconstruction distance (d_i): 263 mm
Depth of focus (d_h): 1.4 mm
Spatial resolution: 23 μm (theoretical)
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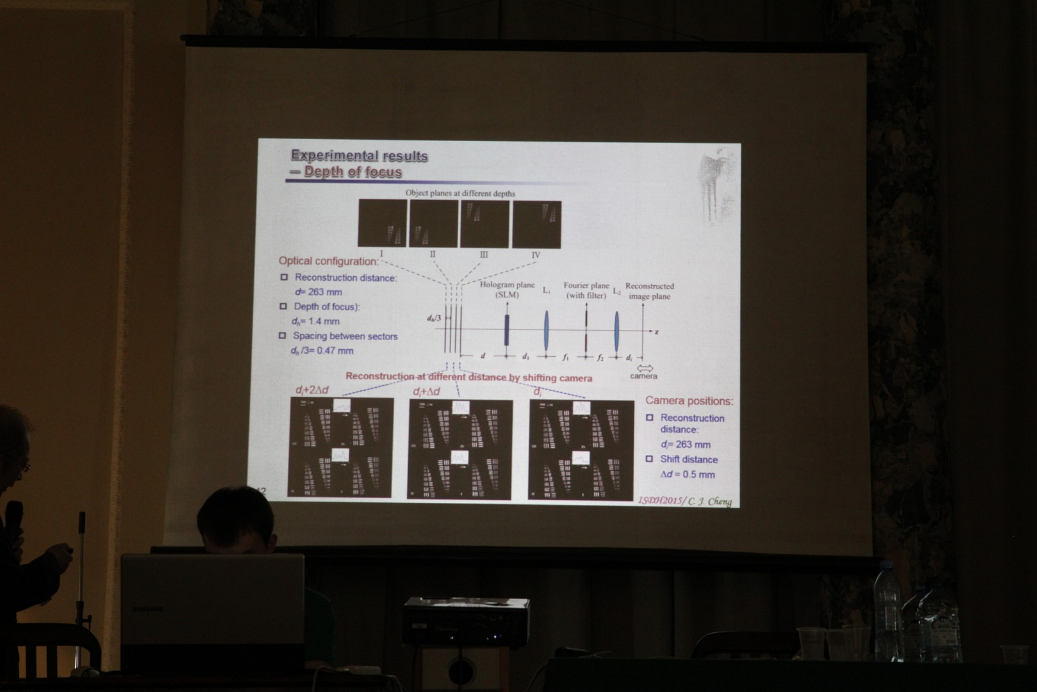
Experimental results
– Depth of focus
Object planes at different depths
I
II
III
IV
Optical configuration:
Reconstruction distance:
d= 263 mm
Depth of focus):
dh= 1.4 mm
Spacing between sectors
dh/3= 0.47 mm
Hologram plane (SLM)
L1
Fourier plane (with filter)
L2
Reconstructed image plane
dh/3
z
d
d1
f1
f2
di
camera
Reconstruction at different distance by shifting camera
di+2Δd
di+Δd
di
Camera positions:
Reconstruction distance:
di= 263 mm
Shift distance
Δd = 0.5 mm
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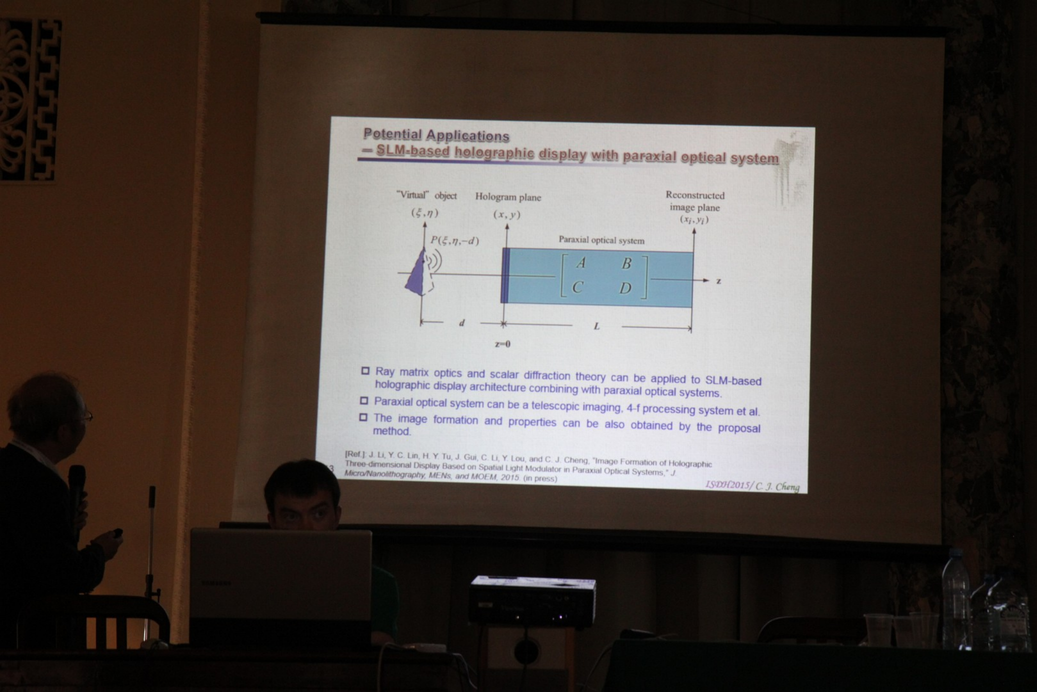
Potential Applications
– SLM-based holographic display with paraxial optical system
"Virtual" object
Hologram plane
Reconstructed image plane
(ξ,η)
(x, y)
(x_i, y_i)
P(ξ,η,−d)
Paraxial optical system
A B
C D
z
d
L
z=0
Ray matrix optics and scalar diffraction theory can be applied to SLM-based holographic display architecture combining with paraxial optical systems.
Paraxial optical system can be a telescopic imaging, 4-f processing system et al.
The image formation and properties can be also obtained by the proposal method.
[Ref.]: J. Li, Y. C. Lin, H. Y. Tu, J. Gui, C. Li, Y. Lou, and C. J. Cheng, "Image Formation of Holographic Three-dimensional Display Based on Spatial Light Modulator in Paraxial Optical Systems," J. Micro/Nanolithography, MENs, and MOEM, 2015. (in press)
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Summary
This work describes the image formation and properties of the SLM-based holographic 3D display.
The impulse response and the depth of focus of hologram reconstruction depend on both optical configuration and SLM device structure.
This approach can be applied to analyze a more general case of SLM-based holographic display with paraxial optical system.
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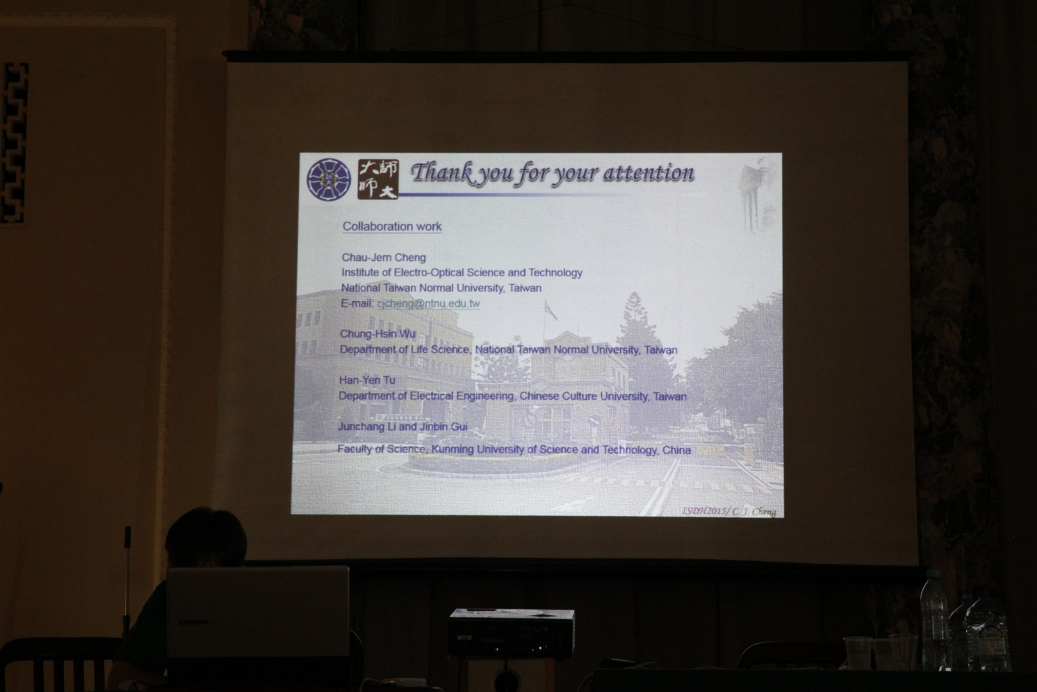
Thank you for your attention
Collaboration work
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