C7 SLM-based optical experiment

SUPPLEMENTARY INFORMATION

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Date: 2022.06

Contents

1 Materials and instruments

Table S1: **Materials and instruments**

Name	Total	Model and parameters
Transmissive Spatial light modulator	1	$RL - SLM - T1$, $26.0\mu m$
CCD	1	$MER - 310 - 12UC$, $3.2\mu m$
Laser	1	$GP3 - CC311 - 1 - 0.035 - G650 - 2mWF - 3B$
Power meter	1	$GPM100USB$
Optical elements	/	/

2 Exp.1 Distortion of the convex lens imaging system

2.1 Main parameters

Table S2: **Parameters**

Item	parameters
Checker board resolution	1024×768
Grids of Checker A	8×6
Grids of Checker B	64×48

2.2 Supplementary data and figure

Tab. S3 shows details of distortions in different systems.

β is the amplification, s_1 is the object distance, s_2 is the image distance, g represents the number of grids of sampling points apart from each other, p represents the coordinates of the sampling points, h_1 is the ideal image height, h_2 is the actual image height, dh is the height difference. q is the relative distortion, θ is the optical angle. All distance were measured in μm.

Data are also available in our repository.

2.3 Question

2.3.1 Which types of spatial light modulator is adopted?

As introduced in the thesis, the SLM we used in this experiment is transmissive twisted nematic liquid-crystal spatial light modulator (TTNLC-SLM) controlled by voltage.

2.3.2 For the same amplification, why distortion in shrinking system is greater than the amplifying system?

As explained in the thesis, the distortion is determined by the ”off-axis” degree, which could be represented by the optical angle $\theta = \frac{\beta Y}{s_2}$. Theoretically, comparing to the amplifying system,

Table S3: **Details of distortions in different systems**

Lab	Checker	f	β	s_1	s_2	X_g	Y_g	XY_g	$Center_xp$	$Center_yp$	X_xp	Y_yp	XY_xp	XY_yp	X_{h1}	Y_{h1}	$XY_{h1}x$	$XY_{h1}y$	X_{h2}	Y_{h2}	$XY_{h2}x$	$XY_{h2}y$	X_{dh}	Y_{dh}	$XY_{dh}x$	$XY_{dh}y$	X_q	Y_q	XY_qx	XY_qy	θ
150_4	A	150	0.250	750	187.50	2	2	1.5	984	706	1505	179	1374	324	1664.000	1664.000	1248.000	1248.000	1667.2	1686.4	1248.0	1222.4	3.200	22.400	0.000	-25.600	0.19%	1.35%	0.00%	-2.05%	2.218667
70_4	A	70	0.250	350	87.50	2	2	1.5	1089	752	1662	177	1520	321	1664.000	1664.000	1248.000	1248.000	1833.6	1840.0	1379.2	1379.2	169.600	176.000	131.200	131.200	10.19%	10.58%	10.51%	10.51%	4.754286
50_4	A	50	0.250	250	62.50	2	2	1.5	1085	767	1682	208	1532	337	1664.000	1664.000	1248.000	1248.000	1910.4	1788.8	1430.4	1376.0	246.400	124.800	182.400	128.000	14.81%	7.50%	14.62%	10.26%	6.656000
70_2	A	70	0.500	210	105.00	1	1	1.0	1054	830	1556	320	1562	304	1664.000	1664.000	1664.000	1664.000	1606.4	1632.0	1625.6	1683.2	-57.600	-32.000	-38.400	19.200	-3.46%	-1.92%	-2.31%	1.15%	7.923810
70_6	A	70	0.166	490	81.64	2	2	1.5	1061	690	1466	315	1367	391	1104.896	1104.896	828.672	828.672	1296.0	1200.0	979.2	956.8	191.104	95.104	150.528	128.128	17.30%	8.61%	18.16%	15.46%	2.246604
48x64_2X	B	70	2.000	210	105.00	2	2	1.5	977	734	1541	171	1393	314	1664.000	1664.000	1248.000	1248.000	1804.8	1801.6	1331.2	1344.0	140.800	137.600	83.200	96.000	8.46%	8.27%	6.67%	7.69%	31.695238
48x64_4X	B	70	4.000	350	87.50	1	1	1.0	1071	683	1459	301	1459	301	1664.000	1664.000	1664.000	1664.000	1241.6	1222.4	1241.6	1222.4	-422.400	-441.600	-422.400	-441.600	-25.38%	-26.54%	-25.38%	-26.54%	76.068571

the image distance in shrinking system is smaller, thus the *theta* is greater, the distortion is greater. However, in our experiments, we found that the distortions in the shrinking system are smaller than in the amplifying system. We hypothesize that this may be caused by the measuring error as stated in the limitation.

3 Exp.2 Optical information processing

3.1 Question

3.1.1 Difference between diffraction patterns of real 1D grating and SLM loaded with 1D grating image. Explain the phenomenon of the diffraction patterns based on Abbe's theory of image formation.

This has been explained in detail in the thesis. In brief, the difference, that is, additional spots in vertical orientation, is caused by the gap between pixels of the SLM, which is opaque and will lead to extra diffraction effects in vertical orientation.

Explanation of the phenomena is also covered in the thesis.

3.1.2 Use Abbe's theory of image formation to explain the limitation of resolving power of the microscope

According to Abbe's theory of image formation, the image is formed by interference of beams coming from the Fourier plain, and every spot on the Fourier plain carry detail information about the image. Because the size of the aperture of the microscope is limited, there must be some spots of high order failing to pass through the aperture, which will lead to loss of detail information, and the quality of the image is limited. If we continually increase the amplification, the spots on the Fourier plain will be more and more sparse, thus more spots are blocked due to the limited size of the aperture, and the quality of the image will be greatly impacted.

Thus, the resolving power is limited unless we continually increase the size of the aperture, which is usually unpractical.

4 Exp.3 Holography

4.1 Question

4.1.1 Factors that impact the effects of the quality of hologram

1. Correct relationship between object and reference beams.
2. Stability and characteristics of the holographic table used.
3. Proper fixing of all elements of the system.
4. Characteristics of the surface of the object to holography.
5. Stability of lasers used.

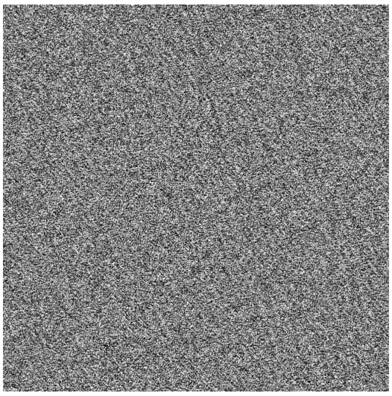
4.1.2 Code for computational holography and digital holography

Codes are available in our Github repository. Here, we only provide the core part of the codes. The code of computational holography and an example are shown in Fig. S1. The code of digital holography and an example are shown in Fig. S2. We specially thank @JackHCC and @OptoManishK for their inspiration.

```python
class GS:
    def __init__(self, image):
        self.raw_image = np.array(image)
        self.width, self.height = self.raw_image.shape[0], self.raw_image.shape[1]
        self.amplitude = self.norm_amplitude()
        self.phase = 2 * np.pi * np.random.rand(self.width, self.height)
        self.complex_amplitude = self.amplitude * np.exp(1j * self.phase)
        self.RMSE = None
        self.phase_result = None
        self.result = None

    def norm_amplitude(self):
        return self.raw_image / np.max(self.raw_image)

    def train(self, epoch=500):
        self.RMSE = np.zeros(epoch)
        for i in tqdm(range(epoch)):
            freq_img = ifft2(fftshift(self.complex_amplitude))
            f_img_phase = np.angle(freq_img)
            f_img_norm = self.amplitude * np.exp(1j * f_img_phase)
            space_img = fft2(fftshift(f_img_norm))
            error = np.abs(self.amplitude) - fftshift(np.abs(space_img) / np.max(space_img))
            self.RMSE[i] = np.sqrt(np.mean(np.power(error, 2)))
            self.complex_amplitude = np.abs(self.amplitude) * (space_img / np.abs(space_img))
        self.phase_result = np.abs(f_img_phase)
        self.result = np.abs(fftshift(space_img))

        plt.figure(0)
        plt.imshow(self.raw_image, cmap="gray")
        # Phrase hologram
        plt.figure(1)
        plt.imshow(self.phase_result, cmap="gray")
        # Simulated reconstructed image
        plt.figure(2)
        plt.imshow(self.format_image(self.result), cmap="gray")
GS(image).train()
```

(a) Code (GS algorithm)

(b) Raw image



(c) Hologram

(d) Simulated reconstructed image

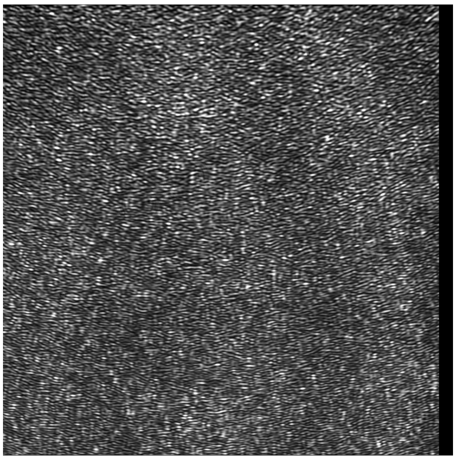
Figure S1: **Computational holography**

5 Data and code availability

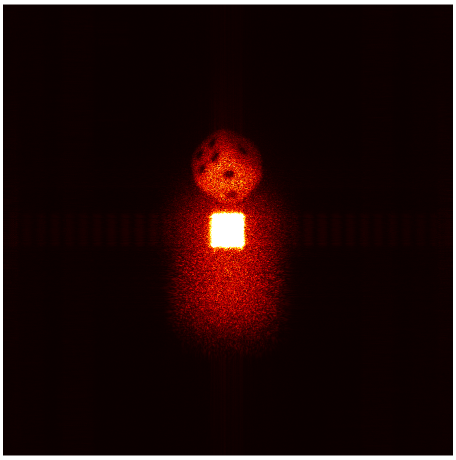
Data and code are available at https://github.com/Zweig-Wong/SYSU-PHY-EXP

```
Nr,Nc = np.shape(hologram)
wavelength = 632.8e-9
dx = 6.8e-6
d = 1

Nr = np.linspace(0, Nr-1, Nr)-Nr/2
Nc = np.linspace(0, Nc-1, Nc)-Nc/2
k, l = np.meshgrid(Nc,Nr)
factor = np.multiply(hologram, np.exp(-1j*
                     np.pi/(wavelength*d)*(np.multiply(k, k)*dx**2 +
                                           np.multiply(l, l)*dx**2)))
reconstructed_field = np.fft.ifftshift(np.fft.ifft2(np.fft.ifftshift(factor)))

I = np.abs(reconstructed_field)/np.max(np.abs(reconstructed_field))
fig = plt.figure(figsize=(10,10))
plt.imshow(I, cmap="hot", clim=(0.0, 0.3))
```

(a) Code



(b) Hologram



(c) Digital reconstructed image

Figure S2: **Digital holography**