Digitally Controlling Light for Optical Interference

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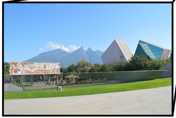

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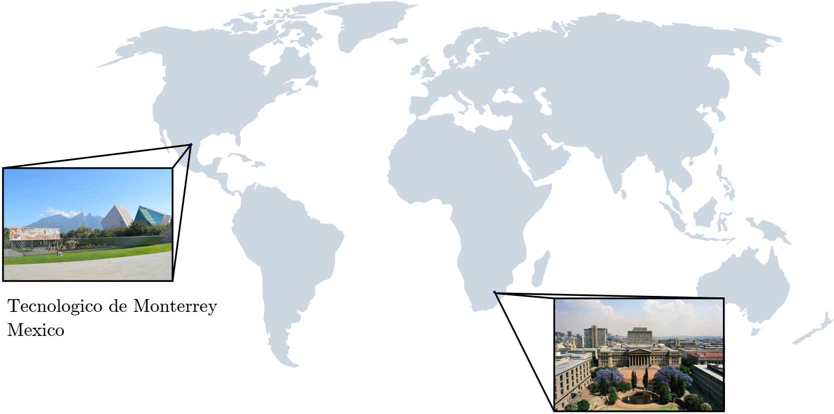

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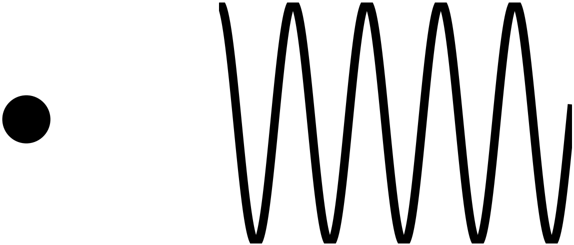
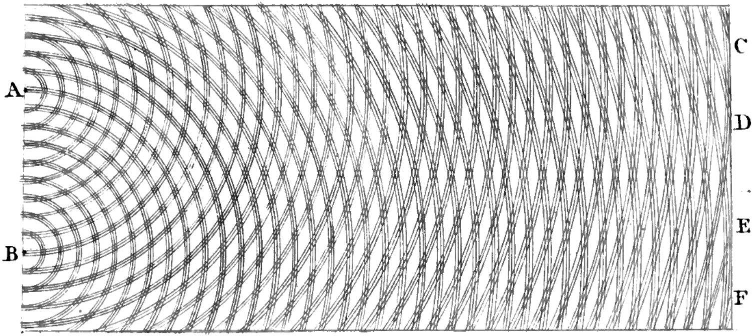
The nature of light has been an intriguing topic since the very beginning of science.

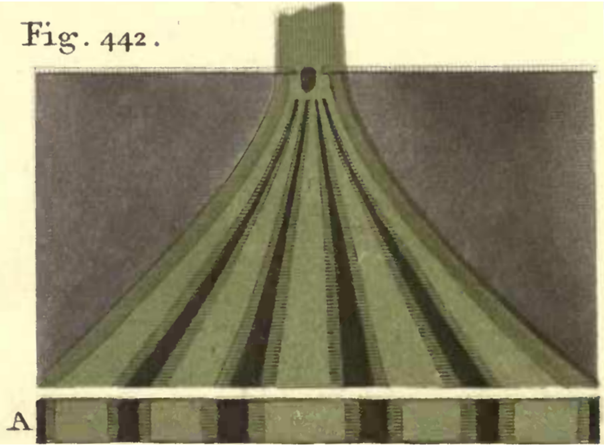


In 1804, Young presented his famous double–slit experiment, proving the wave nature of light.



T. Young, A Course of Lectures on Natural Philosophy and the Mechanical Arts, 1807.

"When two equal portions of light have been separated and coincide again, they will either co–operate, or destroy each other."



T. Young, A Course of Lectures on Natural Philosophy and the Mechanical Arts, 1807.

Now, we can ask ourselves “fringes in what?”

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- Intensity
- Polarization
- Orbital angular momentum

We can express an electromagnetic wave with uniform polarization as

$$E(x, y, z, t) = A(x, y, z) \exp[-i\varphi(x, y, z)] \exp(i\omega t). \qquad (1)$$

Let's consider two monochromatic waves with the same polarization

$$E_1(x, y, z) = A(x, y, z) \exp[-i\varphi_1(x, y, z)] \exp(i\omega t), \tag{2}$$
$$E_2(x, y, z) = A(x, y, z) \exp[-i\varphi_2(x, y, z)] \exp(i\omega t). \tag{3}$$

The intensity of the coherent superposition $E = E_1 + E_2$ is

$$I \propto |E|^2 , \tag{4}$$
$$I \propto \cos^2 \left[\frac{\varphi_1 - \varphi_2}{2} \right] . \tag{5}$$

Observe that φ_1 and φ_2 can be space–dependent.

$$E_1(x, y, z) = A(x, y, z) \exp[-i\varphi_1(x, y, z)] \exp(i\omega t), \quad (6)$$

$$E_2(x, y, z) = A(x, y, z) \exp[-i\varphi_2(x, y, z)] \exp(i\omega t). \quad (7)$$

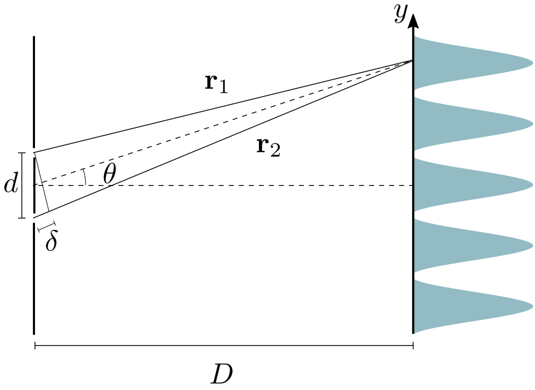
The intensity of the coherent superposition $E = E_1 + E_2$ is

$$I \propto |E|^2 , \quad (8)$$

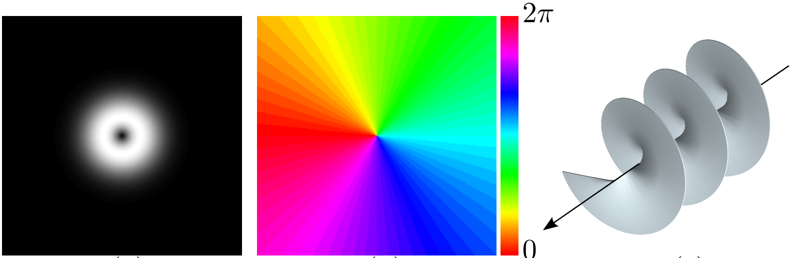
$$I \propto \cos^2 \left[\frac{\varphi_1 - \varphi_2}{2} \right] . \quad (9)$$

If we let $\varphi_1 = k_1 y$ and $\varphi_2 = k_2 y$, the constructive interference will be located at

$$y = \frac{2n\pi}{k_1 - k_2}. \tag{10}$$



Vortex beams belong to the class of helical modes and carry orbital angular momentum (OAM).



(a) (b) (c)

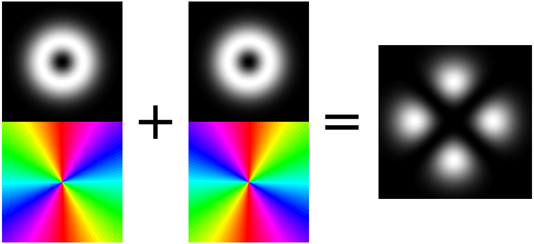
Vortex beams belong to the class of helical modes and carry orbital angular momentum (OAM).

$$U(\rho,\theta) = A(\rho)\exp(i\ell\theta), \tag{11}$$

where ℓ is an integer known as topological charge and (ρ,θ) are the polar coordinates.

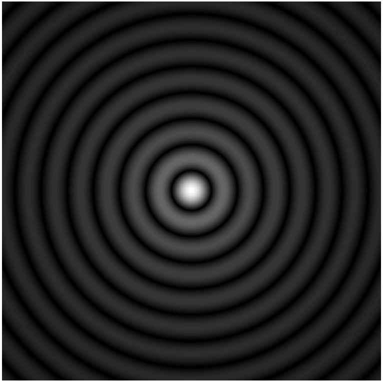
If we let $\varphi_1 = \ell\theta$ and $\varphi_2 = -\ell\theta$, the constructive interference will be at

$$\theta = \frac{n\pi}{\ell}. \tag{12}$$



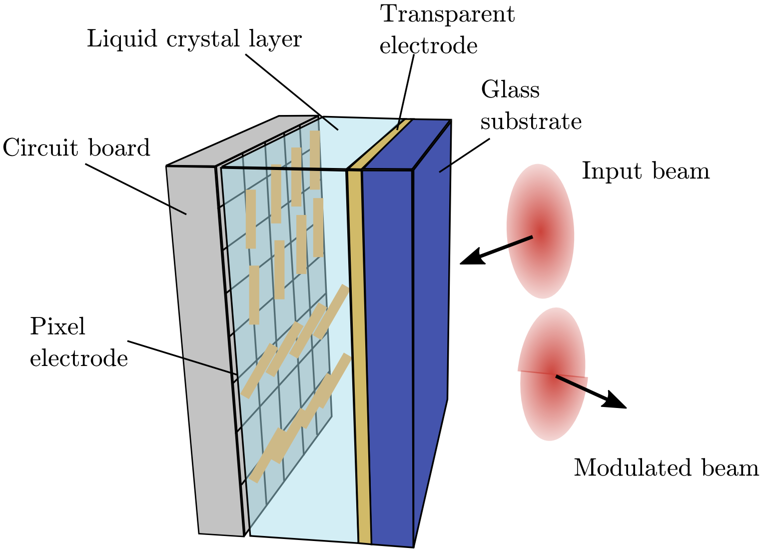
If we let $\varphi_1 = k_\rho \rho$ and $\varphi_2 = 0$, the constructive interference will be at

$$\rho = \frac{2n\pi}{k_\rho}. \tag{13}$$

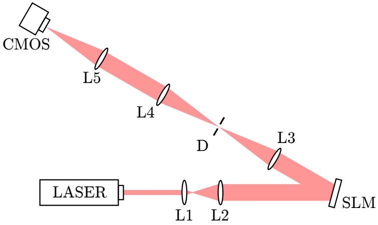


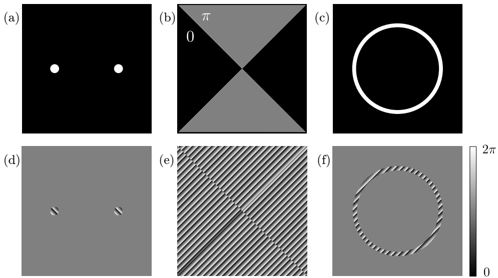
The key ingredient of our technique lies in the use of a Spatial Light Modulator (SLM) to manipulate the optical field.

By encoding the appropriate digital hologram we can generate a diversity of optical fields.

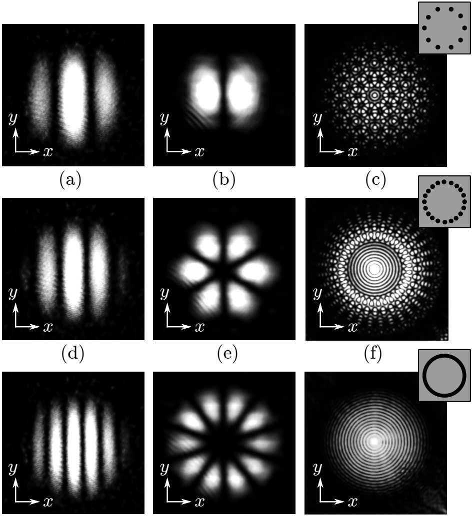


Experimental setup to observe fringes in intensity.





Results of fringes in intensity.



(a) (b) (c) (d) (e) (f) (g) (h) (i)

D. Gossman et al, Optical interference with digital holograms, AJP, 2016.

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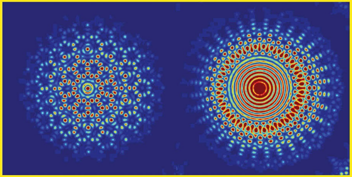

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It is possible to observe fringes in the polarization rather than the intensity. Consider the superposition

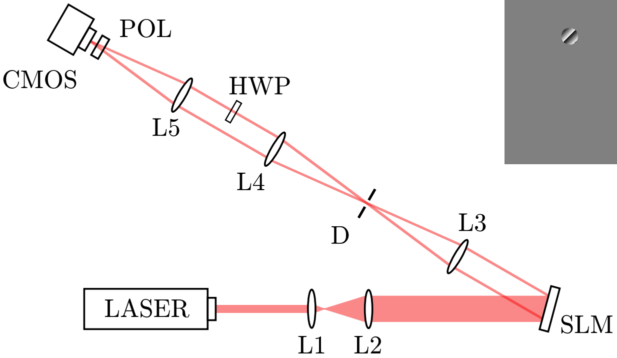
$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2, \tag{14}$$

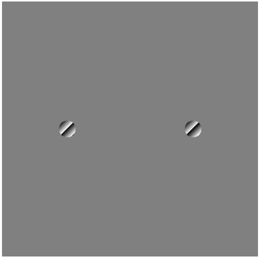
where $\mathbf{E}_1 = \frac{A}{\sqrt{2}} \exp(i\varphi_1)\hat{\mathbf{x}}$ and $\mathbf{E}_2 = \frac{A}{\sqrt{2}} \exp(i\varphi_2)\hat{\mathbf{y}}$.

We can write the superposition in the elliptical basis as

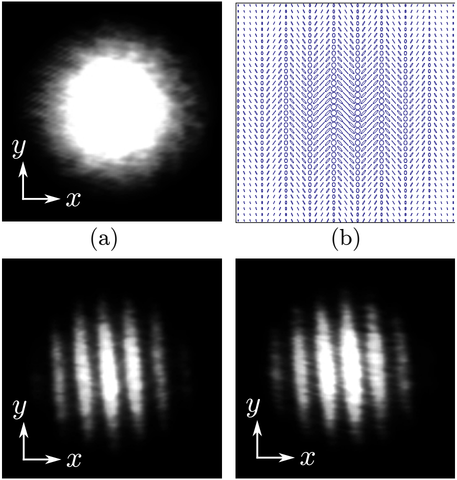
$$\mathbf{E} = \sqrt{2}A \;\; \hat{\mathbf{e}}_1(\varphi_1, \varphi_2). \tag{15}$$

Experimental setup to observe linear fringes in polarization.



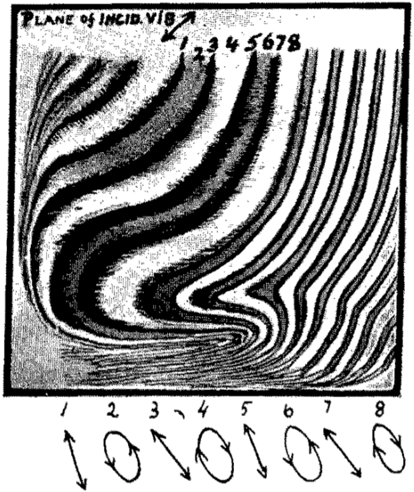


Results of linear fringes in polarization.



(a) (b) (c) (d)

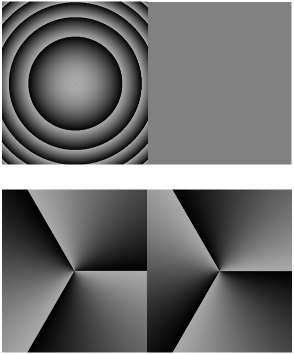
Results of linear fringes in polarization.

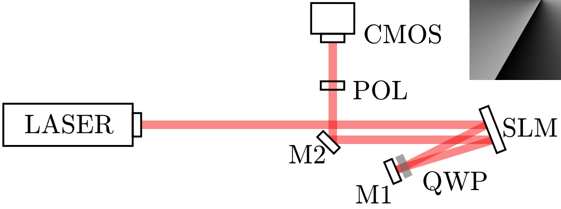


State of Polarization along the fringes.

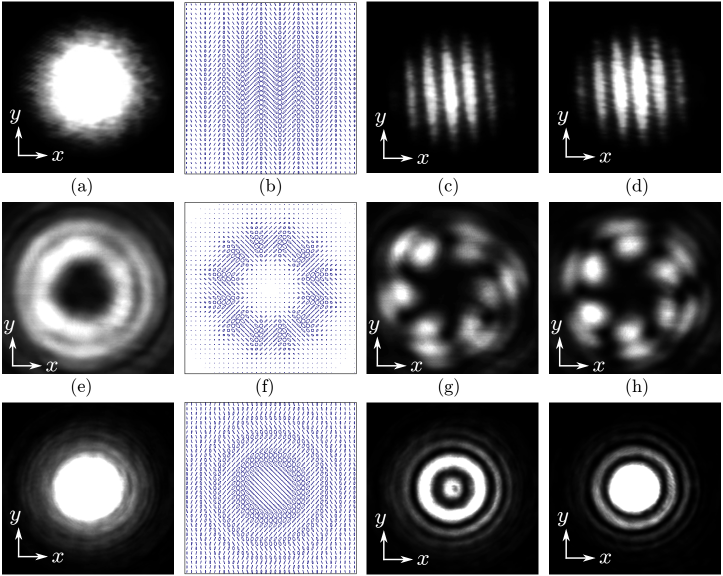
R. Wood, Some new cases of interference and diffraction, 1904.

Experimental setup to observe azimuthal and radial fringes in polarization.



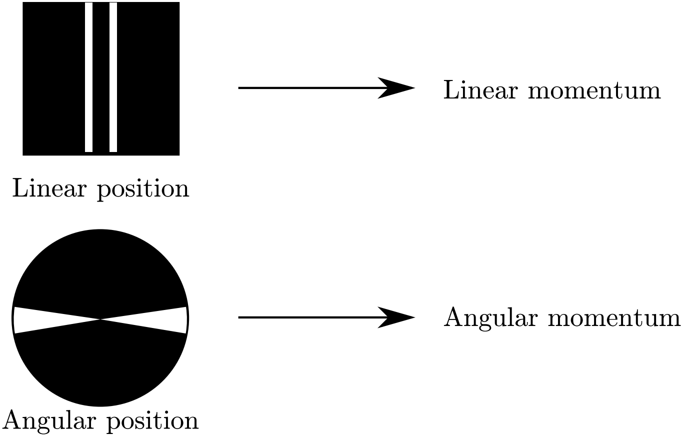


Results of fringes in polarization.

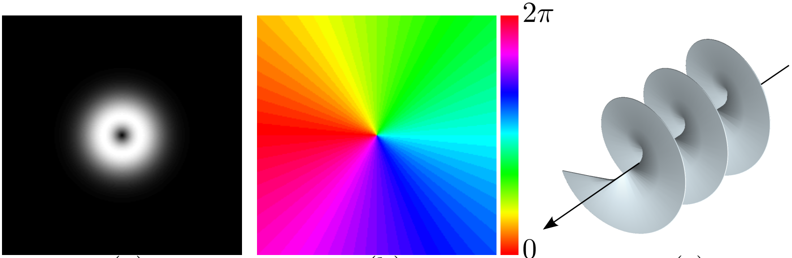


(a) (b) (c) (d)
(e) (f) (g) (h)
(i) (j) (k) (l)

The subject of interference is a manifestation of Heisenberg's uncertainty principle.

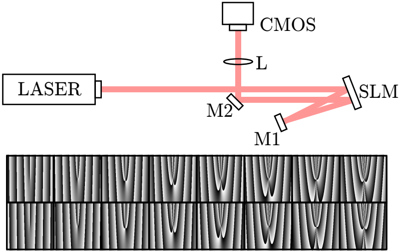


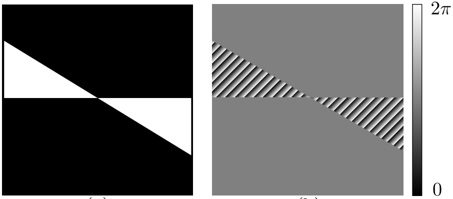
Vortex beams (again)...



(a) (b) (c)

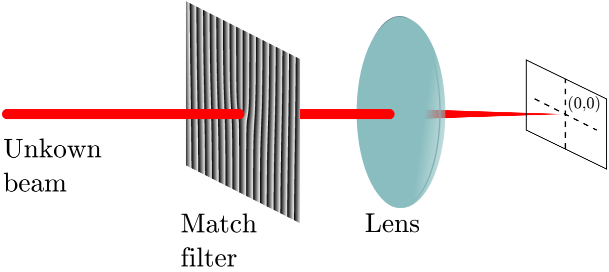
Experimental setup to observe fringes in OAM.



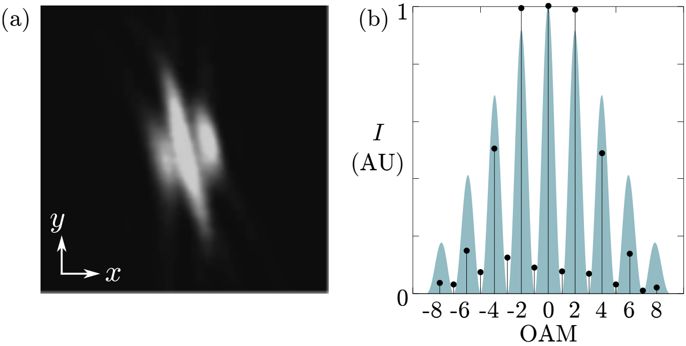


(a) (b)

The modal decomposition can be seen as an inner product of match filters and the input field.



Results of fringes in OAM.



Conclusions

- We presented a general approach to analyze interference fringes in many observables.
- We showed the interference phenomena in different geometries.
- We have revisited this topic with a modern approach using digital holograms as an enabling tool for interference experiments.
- This work can be a useful foundation for students willing to learn the basics of structured light.

Thank you!