Recreating the double-slit experiment with photons using a smartphone camera

Ritwic Verma

Abstract

The double-slit experiment has been a cornerstone in understanding modern-day physics. From interference of photons, and electrons to Bose-Einstein condensates, it has been the most fundamental measure of the quantum nature of a particle. In this work, it has been triedto make this experiment more accessible by using a phone camera and readily available apparatus. A smartphone camera uses a CMOS sensor. This is a sensitive sensor and in principle can also be used to observe ionized electrons produced by gamma rays. If a doubleslit is placed over a smartphone camera, an interference pattern can be observed by using theproper thresholding and image processing algorithms. In this work, an experiment has been designed that shows this most fundamental quantum phenomenon through a normal phone camera.

Introduction

The double slit experiment is believed to have been first performed by Thomas Young in 1801, as proof of the wave nature of visible light. It was pivotal in displacing Newton's corpuscular theory in the favour of Huygens' wave theory, for the propagation of light [1]. Ina simple setup, a beam of light is sent towards two slits placed close to each other, since bothslits receive light from the same beam, they act as two independent coherent sources and cause the formation of an interference pattern on a screen. According to Feynman, the experiment contains, "...the heart of quantum mechanics. In reality, it contains the only mystery. We cannot make the mystery go away by explaining how it works…"[2]
The traditional setup includes sending coherent light toward two slits placed very close toeach other and observing a pattern on the screen. In this paper, this classic experiment hasbeen recreated by using a simple phone camera, with an aim to make the understanding ofthis experiment accessible even for a handheld device.

Setup

For the purpose of this experiment, an iPhone X (2017) was used. The iPhone X has camera two lenses, a "wide angle" lens which is normally used for taking photographs, and a speciallong-range telephoto lens. For the purpose of this paper, the "wide angle" lens shall be used.

Two small holes were punched into a plastic piece with separation d = 0.4mm. The piece with slits was placed on the top of the “wide-angle” lens of the phone. The entire setup was covered with black electrical tape from all sides to prevent the entry of photons indirectly into the setup.

Experiment

The setup was held in front of three different monochromatic sources of light, namely- red,blue, and green. The shutter speed was reduced to one-thousandth of a second and ISO waschanged to 100. A “raw” image was taken from the phone camera, to prevent any on-phoneprocessing to hamper the results. Such methods have been used for building radiation detectors using CMOS sensors [3]. These images were obtained in the .png format.

Processing algorithm

To increase the efficiency and reduce the time taken for execution, the images were put through a lossy jpeg conversion which compressed the images by about 99%. Because of theblack tape on the phone camera, only a limited number of photons entered the setup. To account for this, an extreme thresholding algorithm was implemented using Python’s OpenCV library, wherein any pixel that corresponded to black, (#000000) was converted to black. In contrast, any other pixel color was converted to white (#ffffff) for easy identification of interference patterns.

Calculation of fringe width

Owing to the fact that the experiment was carried out under non-laboratory conditions, whichis consequently the aim of this paper, the circular fringes obtained had jagged and grainy edges. In order to calculate the fringe width with some degree of accuracy, a thin slice of a width of 10px was taken from the center of the image. A width calculation algorithm was developed, wherein an entire row of 10 pixels was set as white or black depending on whether the average value of all pixels in that row was closer to black (#000000 or RGB(0,0,0)) or white (#ffffff, or RGB(255,255,255)). This was a reliable measure since therewere only two colors in the processed and thresholded image i.e. black and white. From the list of average row values, fringe widths were calculated in pixels by looping through all the rows until a row of a different color was encountered.

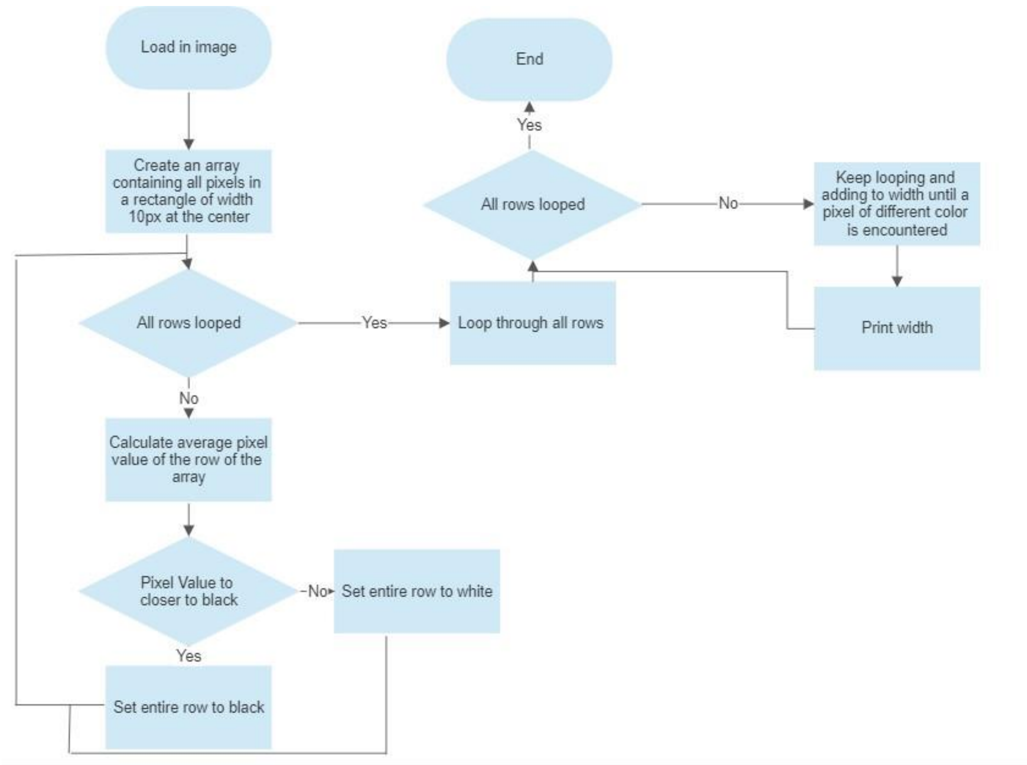


Figure A: Flowchart for width calculation algorithm

Trends observed in fringe width

The fringe width was taken as the width of the first dark fringe, between the central brightand the second bright. The width of the fringes was calculated in pixels. The widths of thefringes in pixels along with their corresponding wavelengths can be seen in Table 1.

Color	Fringe Width in pixels	Wavelength in nm
Red	294	620-750
Green	267	495 -700
Blue	259	450-495

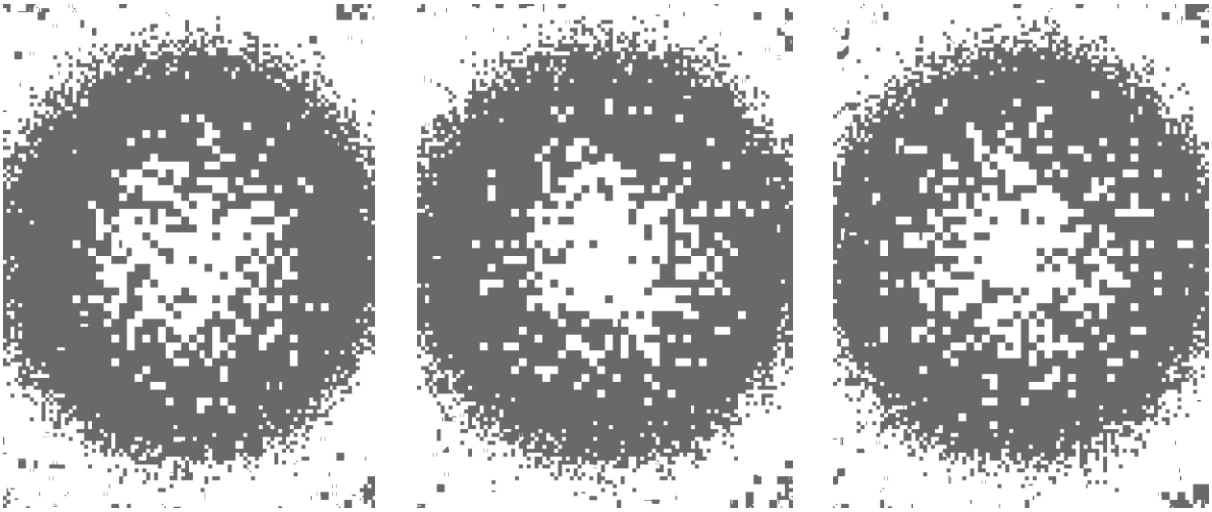
Table A: Fringe widths and corresponding wavelengths

From the table, there is a clear correlation (directly proportional) between the fringe widthand the wavelength of the color of light. This correlation is in accordance with the formulafor fringe width.

$$\beta = \frac{D\lambda}{d}$$

Therefore, $\beta \, \alpha \, \lambda$

Where β is the fringe width, λ is the wavelength, D is the distance between the screen and theslits, and, d is the distance between the slits.
The processed images after thresholding can be seen in Figure 2.



Red Green Blue

Figure B: Processed images exhibiting interference patterns

Discussion

The double-slit experiment is the foundation of wave theory and quantum physics. It is the most elementary yet elegant experiment which can be performed to understand the wave natureof very small particles. Not just light, but even particles like electrons [4], neutrons [5], and Bose-Einstein [6] condensates also show such interference patterns. In this paper, I have beenable to recreate this experiment using readily available instruments and objects. This has not only demonstrated the beautiful experiment of double-slit interference but according to me hasalso opened an avenue to observe quantum mechanical phenomena using everyday handheld devices

Conclusion

Interference fringes were observed as expected in the double-slit experiment. The change of fringe width with the frequency of incident light, could thus be studied easily. To implement the experiment, it had to be ensured that the slit was covered with a black filter to limit the number of photons entering the system. The advanced image processing algorithms assisted inrecognizing the limited exposure of photons on the camera sensor, thus revealing the underlying photon interference pattern. Due to the non-laboratory conditions in which the experiment was carried out, the back-calculation of wavelength from fringe width yielded veryinaccurate results. An exact formula for the back-calculation of wavelength is a potential topicfor further research.

References

[1] P. Ghose, “The Central Mystery of Quantum Mechanics,” arXiv, 2009, doi: 10.48550/ARXIV.0906.0898.
[2] R. P. Feynman, The Character of Physical Law, BBC Publications (1965).
[3] J. J. Cogliati, K. W. Derr, and J. Wharton, “Using CMOS sensors in a cellphone forgamma detection and classification,” arXiv.org, https://arxiv.org/abs/1401.0766
[4] A. Tonomura, J. Endo, T. Matsuda, T. Kawasaki and H. Exawa, “Demonstration of single-electron buildup of an interference pattern,” Amer. J. Phys., vol. 57, p. 117, 1989
[5] R. Gähler and A. Zeilinger, “Wave-optical experiments with very cold neutrons,” Amer.J. Phys., vol. 59, p. 316, 1991.
[6] M. R. Andrews, C. G. Townsend, H.-J. Miesner, D. S. Durfee, D. M. Kurn, and W. Ketterle, “Observation of Interference Between Two Bose Condensates,” Science, no. 5300,pp. 637–641, Jan. 1997, doi: 10.1126/science.275