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Curso: Proyecto Experimental

Generation and transformation of Light Beams with Orbital Angular Momentum with the aim of implementing high-dimensional quantum logic gates

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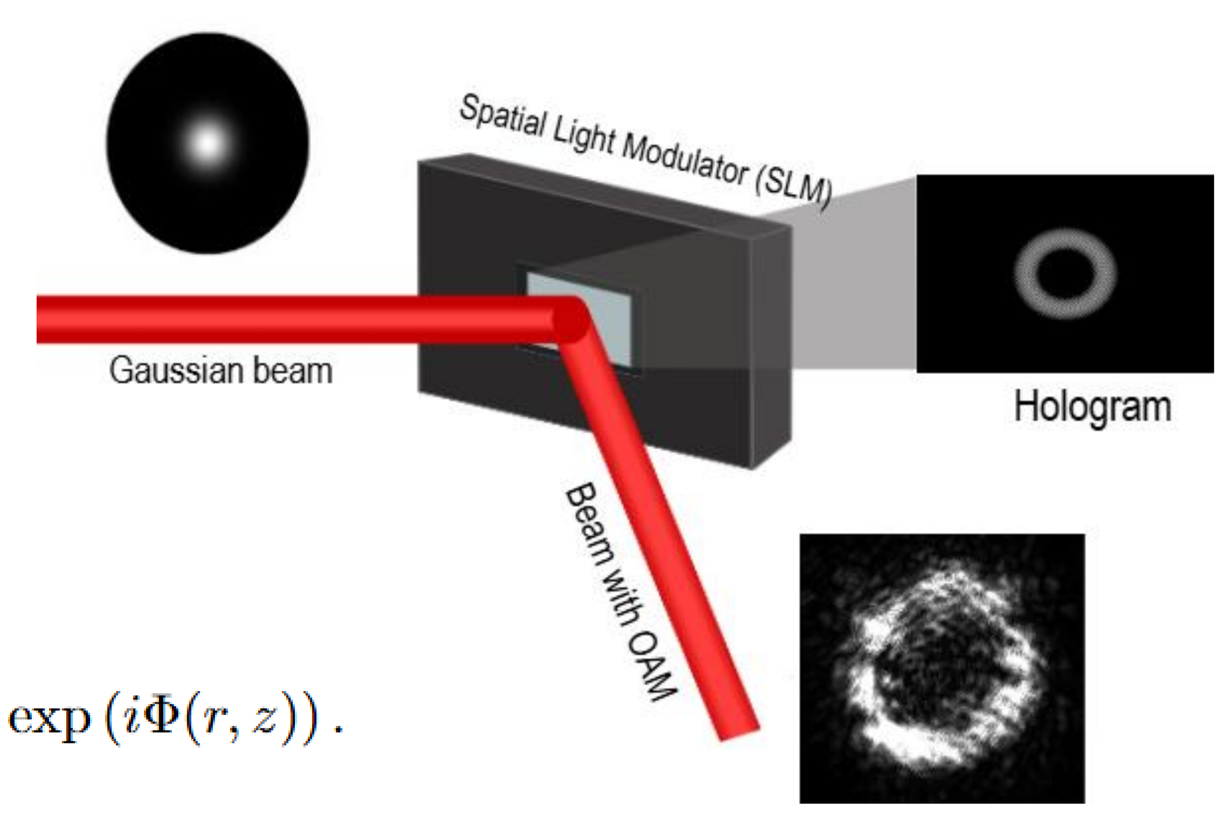
Introduction

Quantum computing aims to outperform classical computing in certain tasks, traditionally using two-level systems called qubits. Recently, higher-dimensional systems known as qudits have gained attention due to advantages like greater information density, increased noise resistance in quantum key distribution, and improved efficiency in some algorithms [1-3]. Light, with its various degrees of freedom—such as orbital angular momentum (OAM)—can be used to implement qudit-based quantum computing. Manipulating OAM requires applying quantum logic gates, which is made possible by holograms. While earlier methods involved physical holograms, modern setups use Spatial Light Modulators (SLMs) to dynamically project any hologram, allowing precise control of OAM and enabling optical quantum logic operations [4].

1. Generation of beams carrying OAM

The method described by Bolduc *et al.* [5] was used to generate light beams carrying orbital angular momentum (OAM). Specifically, we aim to reproduce, in the first diffraction order, a complex optical field of the form:



$$E_{\text{out}}(r,z) = \mathcal{A}(r,z)\exp\left(i\Phi(r,z)\right).$$

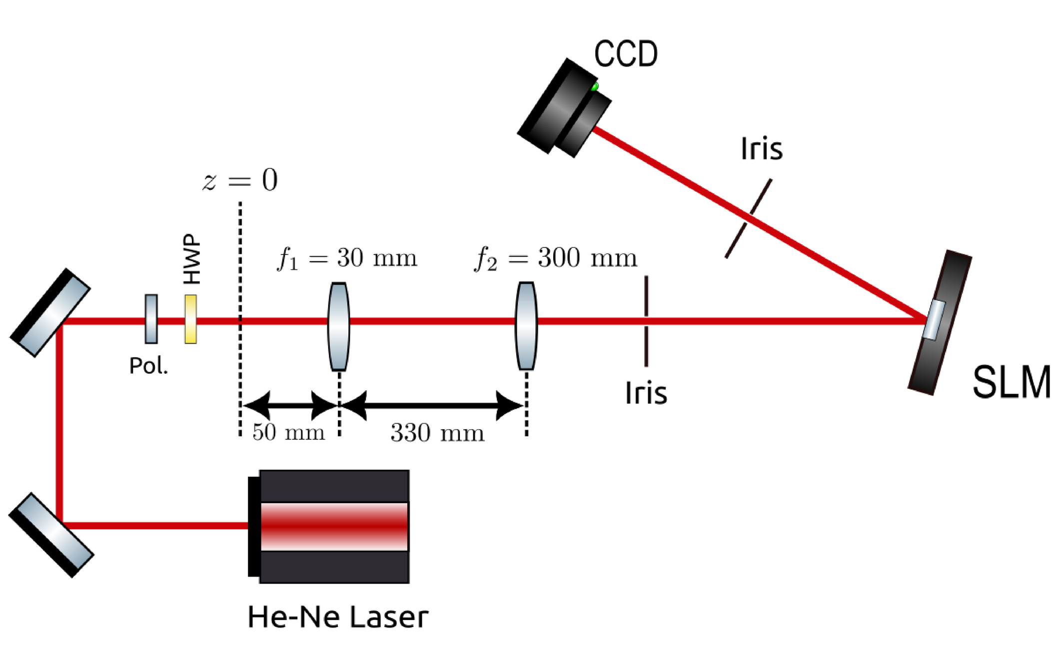
The Holograms displayed on the SLM are given by

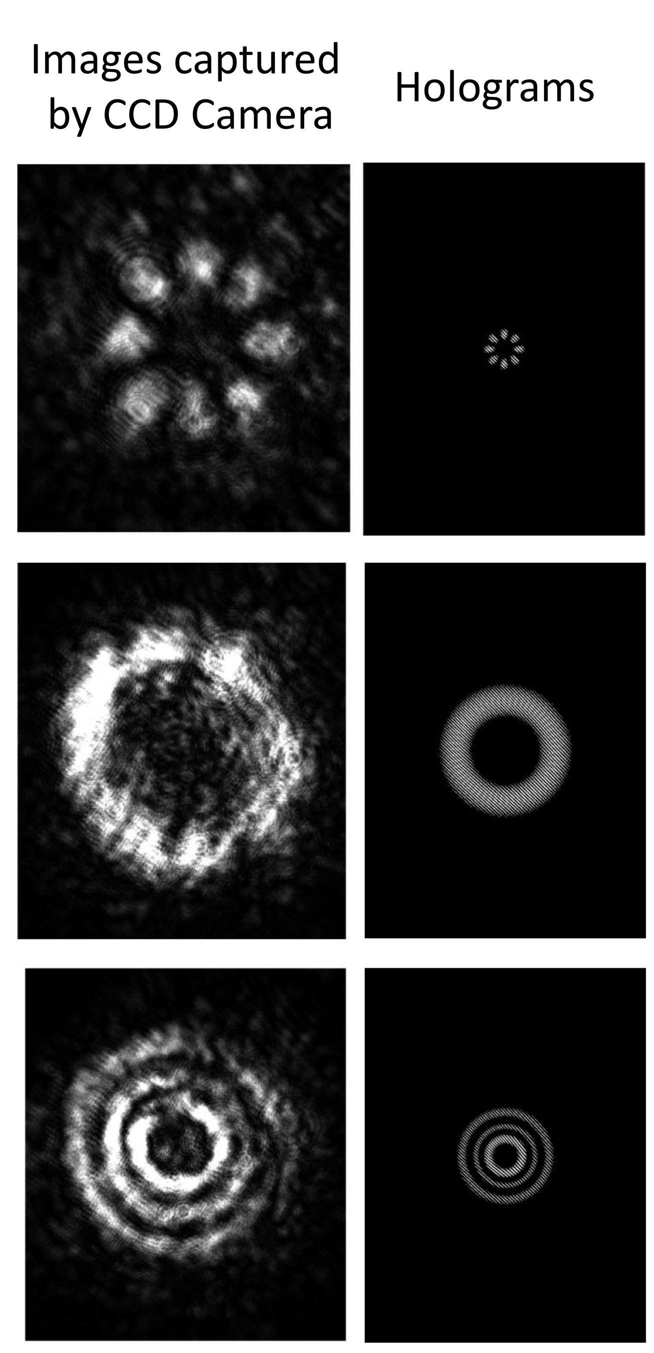
$$\Psi(m,n) = \mathcal{M}(m,n)\text{mod}\left(\mathcal{F}(m,n) + 2\pi m/\Lambda + 2\pi n/\Lambda, 2\pi\right)$$

for every (m,n) pixel of the SLM. Where

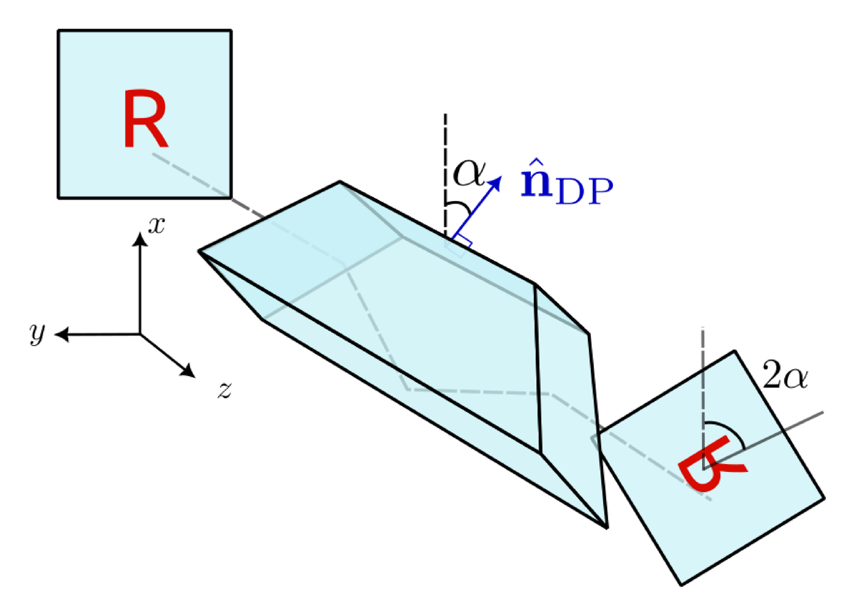
$$\mathcal{M}(m,n) = \mathcal{A}(m,n)/\max(\mathcal{A}(m,n))$$
$$\mathcal{F}(m,n) = \Phi(m,n) - \pi\mathcal{M}(m,n)$$

and Λ is the period of a diffraction grating embedded into the hologram.

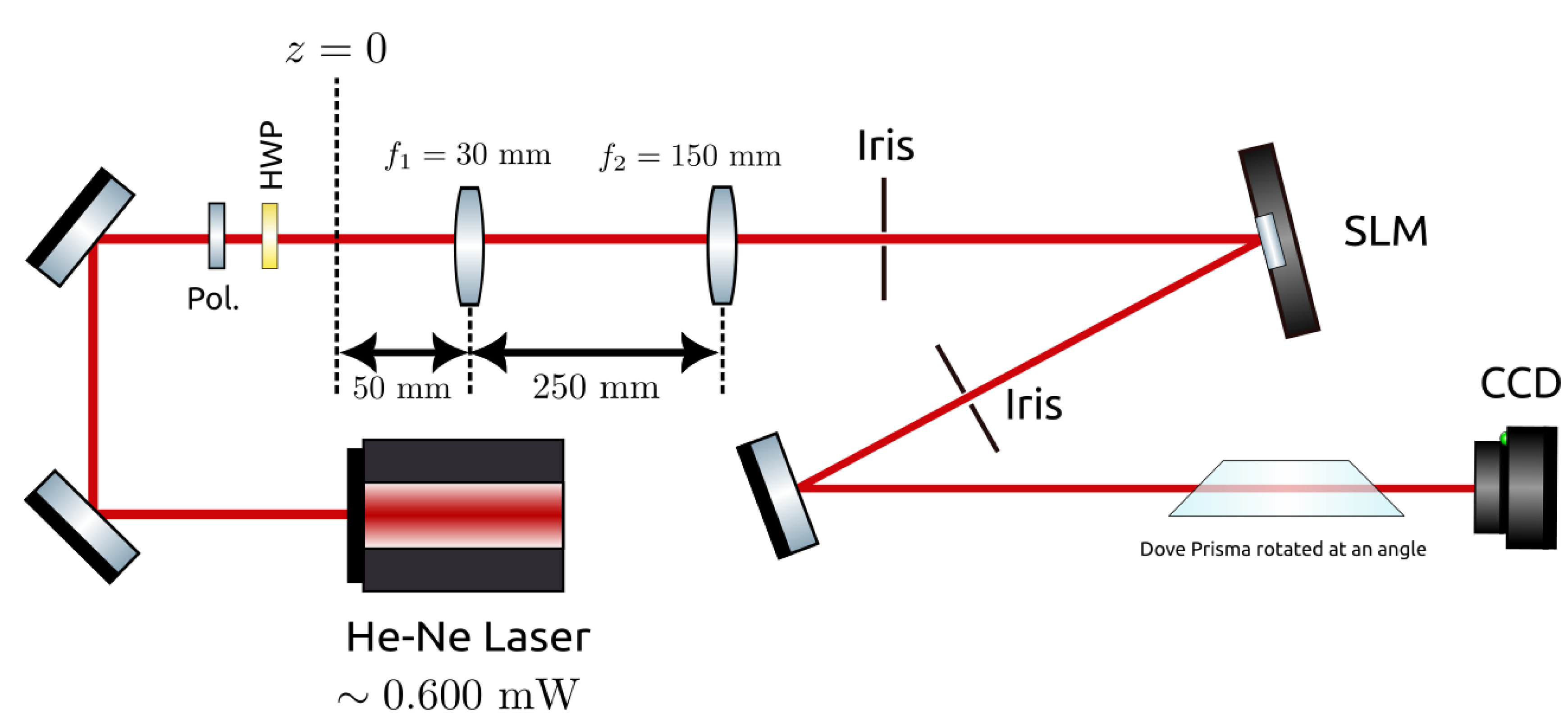




2. Transforming light beams OAM with optical elements



Due to properties of Dove Prisms, it is used to apply Z d-dimensional gates.



3. Theoretical description of a $\hat{Z}_d$

The definition of a d-dimensional Z gate goes as follows

$$\hat{Z}_d = \sum_{\ell=0}^{d-1} \omega^{\ell} |\ell\rangle\langle\ell|$$

where is a phase $\omega = e^{\frac{2\pi i}{d}}$. Note that $|\ell\rangle$ are eigenvectors of the $\hat{Z}_d$. Due to properties of a certain optical component, one can be able to perform a Z gate operation over any superposition of $|\ell\rangle$. This optical component is called Dove Prism; this component, when rotated at an $\frac{\pi}{d}$ angle performs a d-dimensional Z gate operation.

Conclusions and perspectives

- The theoretical process to program the SLM was shown.
- A process to generate Laguerre-Gauss beams with diferente l,p values was achieved using the setup showed in section 1.
- The use of a Dove Prisma that transforms OAM was reported.
- A way to perform a Quantum State Tomography on the outcoming light is needed in order to ensure that, in indeed, the Z gate operation is perfomed.

Bibliography

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