Experimental simulation of quantum dynamics using environments based on spatial variables of light

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Introduction

At first glance, the interaction of a quantum system with an environment may seem to be detrimental for the information codified in the system. However, it is possible for the system to recover this information [1]. In this project, we used photonic systems to simulate quantum dynamics. We used the polarization as the quantum system and the transverse momentum of light as its environment [2]. Manipulating the environment by means of interference effects [3], we studied the transition from Markovian to Non-Markovian. We identified the type of dynamics generated by means of the trace distance, fidelity and relative entropy.

Quantum System + Environment

<table>
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<tr>
<th>Light Sources</th>
<th>Environment preparation (spatial variable)</th>
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<td>Quantum system preparation (polarization)</td>
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<td>Coupling/Temporal Evolution</td>
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\[
|\psi\rangle = \int d\Omega (|\psi\rangle |\psi\rangle |\psi\rangle = N e^{-i\vec{p}\cdot\vec{q}} |1 - \cos(2\delta q)| \]

\[
|\varphi\rangle = \alpha |H\rangle + \beta |V\rangle
\]

\[
U(y)|\psi\rangle = e^{-i\Phi(y)}|\psi\rangle, \quad U(y)|\Phi\rangle = U(y)|\Phi(0)\rangle
\]

- Where \( y \) simulates the temporal variable.

\[
\rho^s(y) = \left( \begin{array}{cc} |\alpha|^2 & \alpha^*\beta \kappa(y) \\ \alpha\beta^* \kappa(y) & |\beta|^2 \end{array} \right)
\]

\[
\kappa(y) = \int dq f(q) |q|^2 e^{i2\delta q}
\]

Characterization of systems dynamics

Trace Distance

\[
D(\rho_1, \rho_2, y) = \frac{1}{2} \text{Tr}(|\rho_1 - \rho_2|)
\]

Fidelity

\[
F(\rho_1, \rho_2, y) = \sqrt{\text{Tr}[\rho_1 \rho_2] + 2\sqrt{\text{det}(\rho_1)\text{det}(\rho_2)}}
\]

Relative Entropy

\[
S(\rho_1, \rho_2, y) = \frac{1}{2} \ln \left( \frac{1 - \kappa(y)}{1 - \kappa(y)} \right) + \frac{1}{2} \ln \left( \frac{1 + \kappa(y) - \gamma_1 \kappa(y) - 1}{1 + \kappa(y) - \gamma_2 \kappa(y) - 1} \right)
\]

Experimental Results

The experimental results of the dynamics of the quantum system for different environments. The experimental data corresponds to diagonal and anti-diagonal initial polarization states. The Dots are the experimental data and the solid lines are the theoretical model.

Markovian

Non-Markovian

Conclusions

- We simulated different quantum dynamics using photons. In particular, the polarization and transverse momentum of light serve as system and environment, respectively.
- Engineering of the transversal profile of light offers us the possibility to change the dynamics of the system. i.e., the transition from Markovian to non-Markovian.
- The dynamics of a quantum system were characterized by the relative entropy, \(S(y)\), fidelity, \(F(y)\), and trace distance, \(D(y)\).

Bibliography