$\mathcal{PT}$ symmetry for nonunitrary quantum walks and the extention to disordered systems

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Recently, non-Hermitian systems with $\mathcal{PT}$ (combined parity and time-reversal) symmetry have been realized in various experiments, and many interesting phenomena have been observed in these systems. However, difficulty in controlling gain and loss effects makes most experimental systems have only a small number of elements. In contrast, quantum walks can overcome this difficulty.

Quantum walks recently attract attentions as a versatile platform for quantum computations and quantum simulations. Quantum walks describe quantum dynamics of particles (walkers) with several internal states by a time-evolution operator composed of coin operators, shift operators, and so on. The coin operator varies the internal states of walkers, and the shift operator changes the positions of walkers depending on the internal states. Quantum dynamics is described by acting the time-evolution operator to a quantum state at each time step. In 2012, a quantum walk built by optical fiber loops was experimentally implemented, in which highly tunable gain and loss effects are included with additional optical amplifiers [1]. Effects of gain and loss make the time-evolution operator nonunitary, which means the effective Hamiltonian is non-Hermitian. It is known that, in certain parameter regions, the system has entirely real quasienergy.

In the present work, we explicitly show that the reality of quasienergy obtained in Ref [1] stems from $\mathcal{PT}$ symmetry [2]. We find that parameters of operators must have correlations not only in spatial direction but also in time direction in order to preserve $\mathcal{PT}$ symmetry of the time-evolution operator. In addition, we numerically show that although parameters of the coin operator are random over the position space and the time-evolution operator does not hold $\mathcal{PT}$ symmetry in the explicit sense, the system can have entirely real quasienergy. Then, we discuss the reason why this occurs and study the effects of randomness on nonunitary quantum walks.

References

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