$\mathbb{Z}_2$ Point-Gap Topology of a Non-Unitary Quantum Walk with Time-Reversal Symmetry

Zhiyu Jiang[1] and Hideaki Obuse[1,2]

[1] *Department of Applied Physics, Hokkaido University*

[2] *Institute of Industrial Science, The University of Tokyo*

zhiyu.jiang.t7@elms.hokudai.ac.jp

Introduction

The study of non-Hermitian systems has gained significant attention in recent years due to its potential for novel physical phenomena and practical applications. Non-Hermitian physics is characterized by systems with non-Hermitian Hamiltonian, which can lead to topological properties different from Hermitian systems such as non-Hermitian skin effects (NHSE) [1]. In the Hatano-Nelson (HN) model exhibiting NHSE, the energy spectrum can be significantly affected by the boundary conditions due to a non-zero point-gap topological number which is defined by the winding number ($\in \mathbb{Z}$). However, the winding number vanishes in time-reversal systems consisting of two coupled HN chains with opposite non-reciprocity. Even in that case, the system can remain NHSE because of the emergence of $\mathbb{Z}_2$ topological number, which is called $\mathbb{Z}_2$ non-Hermitian skin effect [2]. One promising area of exploration within topology of non-Hermitian physics is the study of non-unitary quantum walks. The standard quantum walks consist of a walker moving on lattices, whose state is defined by unitary operators with each step. However, the non-unitary quantum walks incorporate gain and loss, resulting in non-Hermitian Hamiltonian dynamics. Some models of non-unitary quantum walks have been realized theoretically and experimentally by temporally alternating photon losses [3,4] while there is limited research focused on the topological properties of time-reversal symmetric non-unitary quantum walks, which is worth studying to realize $\mathbb{Z}_2$ NHSE by quantum walks.

In our work [5], we introduce a quantum walk, where the walker traverses two non-unitary quantum-walk chains to achieve non-Hermitian time-reversal symmetry ($\mathrm{TRS}^\dagger$). We demonstrate that for the quantum walk, the quasi-energy spectrum strongly depends on the boundary conditions at certain energy points that exhibit $\mathbb{Z}_2$ topological behavior [Fig.1 (a)]. Kramers doublets with topologically non-trivial energies are confined to the edges of the chains, indicating the emergence of the $\mathbb{Z}_2$ NHSE in this quantum walk. Our work highlights the potential for non-unitary quantum walks to serve as a platform for exploring novel physical phenomena and paves the way for further investigations into non-Hermitian systems with time-reversal symmetry.

Tables and Figures

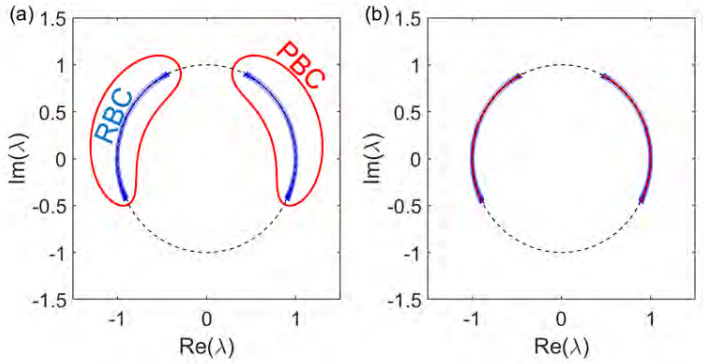

FIG. 1. Eigenvalue spectrum of time evolution operator under period boundaries conditions and reflecting boundary conditions. (a) describes a topological non-trivial quantum walk, while (b) describes a topological trivial quantum walk.

Acknowledgement

Z. J. was supported by JST SPRING (Grant No. JPMJSP2119). This work was supported by JSPS KAKENHI (Grants No. JP19H00658, No. JP20H01828, No. JP21H01005, No. JP22K03463 and No. JP22H01140)

Reference

[1] S. Yao, and Z. Wang, Phys. Rev. Lett. 121, 086803 (2018).

[2] N. Okuma, K. Kawabata, M. Sato, et al., Phys. Rev. Lett. 124, 086801 (2020).

[3] K. Mochizuki, D. Kim, and H. Obuse, Phys. Rev. A 93, 062116 (2016).

[4] L. Xiao, X. Zhan, Z. Bian, et al., Nature Phys. 13, 1117 (2017).

[5] Z. Jiang and H. Obuse (in preparation).