Visualization of Quantum Dynamical Nature Utilized Quantum Measurements

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Awards
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Due to great development on experimental technologies, it is possible to capture quantum dynamics in some physical and chemical systems. On the other hand, all experiments are in principle open and dissipative systems. Up to now, the well explained experiments are approximated to the equilibrium situation. However, by recent technological development, some experiments reach to a transition from equilibrium to non-equilibrium situations. While there are the well-known tools on the non-equilibrium situations; the linear response theory and the Keldysh Green function method, this analysis cannot basically catch dynamical situations. Our goal is to construct the time-resolved theoretical models included the non-equilibrium situations. However, the quantum measurement theory is needed on measuring quantum dynamics, especially considering the measurement back action. Our current activities are to resolve how sensitive (quantum) measurement can we carry out in principle, to build up some toy models on quantum dynamic and to explain unique quantum-mechanical phenomena using precise quantum-state engineering technology.

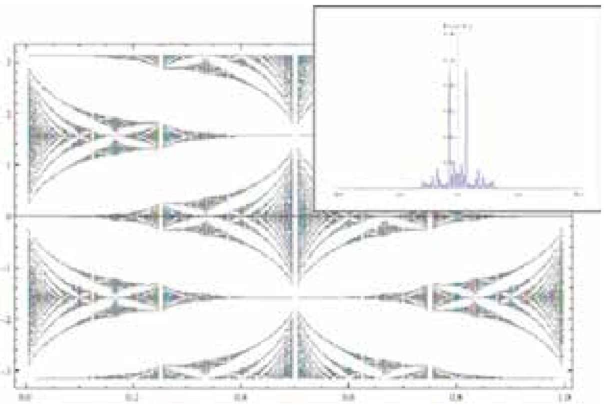

Figure 1. Example of the complex but regular phenomena from the simple law; the discrete-time quantum walk, which is a mathematical toy model to be defined as a quantum-mechanical analogue of the random walk. The probability distribution is depicted in the left top panel. This main distribution is called Hofstadter's butterfly to show the multi-fractal structure.

Selected Publications

- Y. Shikano and A. Hosoya, "Weak Values with Decoherence," *J. Phys. A* **43**, 025304 (15 pages) (2010).
- Y. Shikano and H. Katsura, "Localization and Fractality in Inhomogeneous Quantum Walks with Self-Duality," *Phys. Rev. E* **82**, 031122 (7 pages) (2010).
- A. Noguchi, Y. Shikano, K. Toyoda and S. Urabe, "Aharonov-Bohm Effect in the Tunnelling of a Quantum Rotor in a Linear Paul Trap," *Nat. Commun.* **5**, 3868 (6 pages) (2014).
- H. Kobayashi, K. Nonaka and Y. Shikano, "Stereographical Visualization of a Polarization State Using Weak Measurements with an Optical-Vortex Beam," *Phys. Rev. A* **89**, 053816 (5 pages) (2014).

1. Exciton–Polariton Condensates in High Density Regime[1,2]

Exciton–polaritons are a coherent electron–hole–photon (e–h–p) system where condensation has been observed in semiconductor microcavities. In contrast to equilibrium Bose-Einstein condensation (BEC) for long lifetime systems, polariton condensates have a dynamical nonequilibrium feature owing to the similar physical structure that they have semiconductor lasers. One of the distinguishing features of a condensate to a laser is the presence of strong coupling between the matter and photon fields. Irrespective of its equilibrium or nonequilibrium nature, exciton–polariton have been observed to maintain strong coupling. We show that by investigating high density regime of exciton–polariton condensates, the negative branch directly observed in photoluminescence. This is evidence that the present e–h–p system is still in the strong coupling regime, contrary to past results where the system reduced to standard lasing at high density.

2. Large-Amplitude Quasi Phase Squeezed State[3]

Phase-squeezed light can enhance the precision of optical phase estimation. The larger the photon numbers are and the stronger the squeezing is, the better the precision will be. We propose an experimental scheme for generating phase-squeezed light pulses with large coherent amplitudes. In our scheme, one arm of a single-photon Mach-Zehnder interferometer interacts with coherent light via a non-linear optical Kerr medium to generate a coherent superposition state. Post-selecting the single photon by properly tuning a variable beam splitter in the interferometer yields a phase-squeezed output.

3. Visualization of Quantum States[4,5]

Since entanglement is not an observable *per se*, measuring its value in practice is a difficult task. Here we propose a protocol for quantifying a particular entanglement measure, namely concurrence, of an arbitrary two-qubit pure state via a single fixed measurement set-up by exploiting so-called weak measurements and the associated weak values together with the properties of the Laguerre-Gaussian modes. The virtue of our technique is that it is generally applicable for all two-qubit systems and does not involve simultaneous copies of the entangled state. We also propose an explicit optical implementation of the protocol.

4. Contact Geometry Description of Thermodynamics[6]

Contact geometry has been applied to various mathematical sciences, and it has been proposed that a contact manifold and a strictly convex function induce a dually flat space that is used in information geometry. Here, such a dually flat space is related to a Legendre submanifold in a contact manifold. In this paper contact geometric descriptions of vector fields on dually flat spaces are proposed on the basis of the theory of contact Hamiltonian vector fields. Based on these descriptions, two ways of lifting vector fields on Legendre submanifolds to contact manifolds are given. For some classes of these lifted vector fields, invariant measures in contact manifolds and stability analysis around Legendre submanifolds are explicitly given. Throughout this paper, Legendre duality is explicitly stated. In addition, to show how to apply these general methodologies to applied mathematical disciplines, electric circuit models and some examples taken from nonequilibrium statistical mechanics are analyzed.

5. Quantum Dynamical Simulation in Solid System[7]

One-dimensional discrete-time quantum walks (DTQWs) can simulate various quantum and classical dynamics and have already been implemented in several physical systems. This implementation needs a well-controlled quantum dynamical system, which is the same requirement for implementing quantum information processing tasks. Here, we consider how to realize DTQWs by Dirac particles toward a solid-state implementation of DTQWs.

References

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2) T. Horikiri, T. Byrnes, K. Kusudo, N. Ishida, Y. Matsuo, Y. Shikano, A. Löffler, S. Höfling, A. Forchel and Y. Yamamoto, *Phys. Rev. B* **95**, 245122 (5 pages) (2017).
3) F. Matsuoka, A. Tomita and Y. Shikano, *Quant. Stud.: Math. Found.* **4**, 159–169 (2017).
4) M. Tukiainen, H. Kobayashi and Y. Shikano, *Phys. Rev. A* **95**, 052301 (6 pages) (2017).
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6) S. Goto, *J. Math. Phys.* **57**, 102702 (41 pages) (2016).
7) Y. Shikano, *Interdiscip. Inform. Sci.* **23**, 33–37 (2017).

Award

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