Technology Offer

Quantum Clock-Based Sampling of System Dynamics for Coherence-Limited Quantum Devices

Ref.-No.: 1402-6826-BC

Abstract

This invention presents a novel quantum simulation technique for accurately sampling the dynamics of quantum systems without requiring long coherence times—an essential limitation in current noisy intermediate-scale quantum (NISQ) devices. It introduces a quantum clock that, when entangled with the quantum system of interest, allows reconstruction of system dynamics from static global states. By preparing an approximate energy eigenstate of the joint system and performing repeated measurements on the clock, the complete time evolution of the system can be sampled. This technique circumvents the conventional time-step-based approach, enabling high-fidelity simulation over extended durations with reduced hardware demands, offering promising utility in areas such as drug discovery, materials science, and quantum algorithm validation.

Background

Traditional quantum simulation methods rely on segmenting system evolution into short intervals and applying successive approximations. While effective, this technique demands high coherence times and precise control, which are challenging with current quantum hardware. NISQ devices suffer from decoherence and noise, limiting their capability to simulate long-duration quantum phenomena. This presents a significant bottleneck, especially in applications that require detailed dynamical information, such as chemical reactions or quantum algorithm development. Therefore, alternative methods that reduce reliance on coherence time while maintaining or improving accuracy are essential to advance practical quantum computing applications.

Technology

The invention introduces a novel approach to simulate the dynamics of a quantum system by embedding temporal evolution into the static configuration of a joint quantum system-clock ensemble. Instead of evolving the system step-by-step using short-time propagators, which are sensitive to noise and limited coherence, the method employs a quantum clock described by a time-independent Hamiltonian H_C that interacts with the target system governed by Hamiltonian H_S and interaction term W. A global Hamiltonian $H = I \otimes H_S + H_C \otimes I + V$, where V couples the clock and system, is constructed such that the effective dynamics of the system mirror those dictated by $H_s + W$.

An approximate energy eigenstate of the global Hamiltonian is prepared using, for example, variational quantum algorithms or imaginary time evolution. Measurements are then performed on the quantum clock, which due to the system-clock entanglement, collapses the system into states corresponding to specific evolution times. This measurement-based sampling is probabilistic but allows complete reconstruction of the system's time evolution through repeated preparations and measurements. Additional features include the

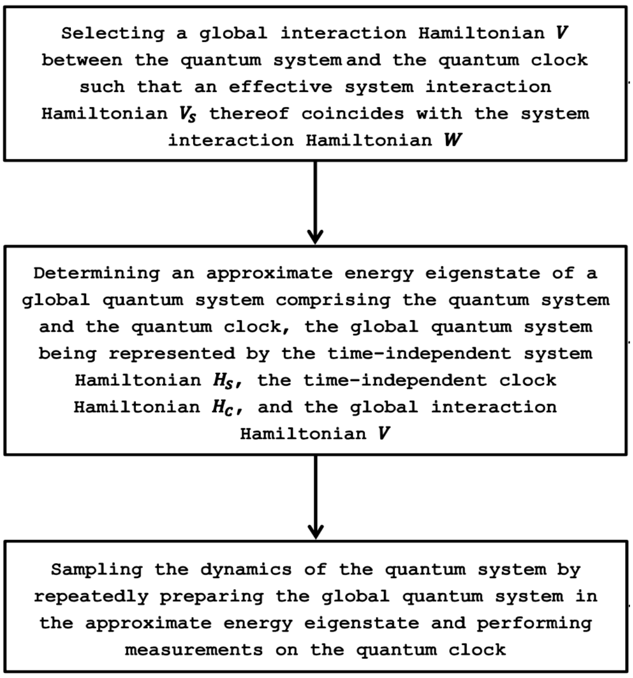

Figure 1: Flowchart of the sampling method.

Max-Planck-Innovation GmbH
Arnulfstr. 58
80335 München
www.max-planck-innovation.de

use of clock transformations to access specific time bins and unitary time-shifting operations to stroboscopically sample the evolution across a desired temporal interval.

Advantages

- **Bypasses Coherence Time Limits:** Embeds temporal dynamics into static states, removing the need for long coherence durations.
- **Accurate Long-Time Simulations:** Eliminates cumulative time-step errors by sampling directly from global energy eigenstates.
- **Efficient Resource Usage:** Uses a quantum clock with logarithmic scaling, minimizing qubit overhead while enabling high temporal resolution.
- **Algorithmic Flexibility:** Compatible with several eigenstate preparation methods, including variational quantum algorithms and imaginary time evolution.
- **Targeted Time Sampling:** Enables precise control over which time points are sampled using clock-based transformations and time shifts.

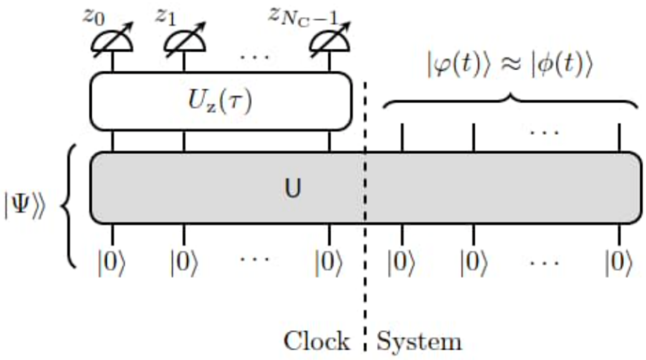

Figure 2: Quantum circuit for time sampling via a quantum clock. The joint state $|\Psi\rangle\rangle$ is prepared by a unitary U acting on clock and system qubits, all initialized in $|0\rangle$. The clock (left, N_C qubits) is advanced by a time-shift unitary $U_z(\tau)$, then measured ($z_0, \ldots, z_{N_C-1}$). This projects the system (right) into the state $|\varphi(t)\rangle \approx |\phi(t)\rangle$, representing the system's evolution at time t. Repeated runs yield full dynamic sampling without time-stepped evolution.

Potential applications

- **Quantum Chemistry:** Simulating molecular dynamics and reactions relevant to drug discovery and catalysis.
- **Material Science:** Investigating time-dependent processes like phase transitions or conductivity.
- **Quantum Algorithm Testing:** Analyzing algorithm behavior over time to support development and optimization.
- **Quantum Sensing:** Enhancing control strategies and interpreting sensor outputs based on quantum dynamics.
- **Time-Resolved Quantum Machine Learning:** Processing sequential or dynamic quantum data for advanced learning models.

Publications

S. Gemsheim, F. Fritzsch, Sampling Continuous Quantum Dynamics from a Single State, arxiv, (2025), 10.48550/arXiv.2509.01633.

Contact

Dr. Bernd Ctortecka

Senior Patent- & License Manager, Physicist
Phone: +49 (0)89 / 29 09 19 – 20
eMail: ctortecka@max-planck-innovation.de

Max-Planck-Innovation GmbH
Arnulfstr. 58
80335 München
www.max-planck-innovation.de