Ze-Tong Li, Ph.D.

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Education

2021. Mar. – 2025. Jun.(Exp) — **Ph.D., Southeast University**
School of Information Science and Engineering.
Supervisor: Prof. Xu-Tao Yu

Recent Focus: Spatial-Temporal Correlations, Quantum Comb, QCVV.

Early Research Topics: Variational Quantum Algorithm, Quantum Circuit Architecture Search, Qubit Mapping & Routing.

2019. Sept. – 2021. Mar. — **M.Sc., Southeast University**
School of Cyber Science and Engineering.
Transit to Ph.D. student at Mar., 2021.

2015. Sept. – 2019. Jun. — **B.Eng., Nanjing University of Posts and Telecommunicatios**
in Electronic Information Engineering.
School of Communications and Information Engineering

Summary

During my doctoral research, I studied a wide range of topics in quantum information and quantum engineering, encompassing:

- Spatial-Temporal Correlation (by Quantum Comb),
- Quantum Characterization, Verification, and Validation (QCVV),
- Variational Quantum Algorithm (VQA),
- Quantum Circuit Architecture Search (QAS),
- Qubit Mapping & Routing (QMR).

Recently, my research interests center on the **quantum comb**. Ongoing research topics include

- Quantum Comb Tomography (QCT),
- Non-Markovian Gate Set Tomography (NM-GST).

Further, I plan to make more progresses on the **quantum comb**, especially on

- Quantum Comb with QCVV: Compressive QCT, Efficient NM-GST.
- Non-Markovian Error Correction and Mitigation: Strategic Code.

Moreover, I demonstrate strong coding skills in **C++** and **Python** for experiment implementations. Additionally, I possess experience in co-supervising undergraduate and postgraduate students in their research endeavors.

I believe that my research experience and coding skills can contribute to your research group. Details of research experiences, publications, skills, and other notable achievements are presented below.

Recent Research & Future Plan

My recent research interest is the **Quantum Comb**. I am conducting and/or passionate about the **quantum comb tomography**, **non-Markovian gate set tomography**, and **non-Markovian Error Correction & Mitigation**.

Quantum Comb Tomography

Quantum combs are extremely important in quantum communication, computation, and metrology. They have capabilities to perform complex tasks that require multiple input-output states at different time steps as a non-Markovian quantum process, and model spatial-temporal correlations, such as the non-Markovian quantum noise. Quantum comb tomography plays a significant role in developing quantum information science.

Quantum Network Tomography via Learning Isometries on Stiefle Manifold – Leading

We proposed an efficient step-wise method for quantum comb tomography by learning isometries on the Stiefel manifold, which addresses computationally non-ignorable encumbrances resulting from tremendous parameter requirements and physical constraint implementations in reconstructing quantum networks.

Tasks are tackled by solving a series of unconstrained optimization problems on the Stiefel manifold with significantly less parameters and intrinsic satisfaction of physical constraints. The step-wise isometry estimation shows the capability for providing information of the truncated quantum comb while processing the tomography. Remarkably, this method enables the low-rank quantum comb approximation by specifying the dimensions of isometries with bounded Hilbert-Schmidt distance.

As a result, our proposed method exhibits high accuracy and efficiency. This work [1] has been submitteed to PRL, and is currently under revision. Moreover, this work achieves the **Silver Prize of Best Student Poster Reward** in AQIS 2024.

Data Driven Non-Markovian Quantum Process Tomography – Supervising

I supervised the research on data driven non-Markovian quantum process tomography. We proposed a neural network based method to reconstruct non-Markovian quantum process [8]. This method achieves reconstruct the process tensor with limited measurement data. Furthermore, the reconstructed process tensor satisfies causality constraints.

Compressive Quantum Comb Tomography – Planning

Recent QCT methods invoke massive measurements such that the input states, POVMs, and the instruments are tomographically complete. However, there exist quantum combs whose temporary correlations are mild and limited such that they can be approximated by low-rank quantum combs. The measurement requirements could be reduced to save both quantum and classical resource.

I plan to research on the compressive QCT to approximate the quantum comb with less measurements via compressive sensing. This technique may be implemented accompanied with the QCT on the Stiefel manifold.

Non-Markovian Gate Set Tomography

Quantum gate set tomography (GST) provides a self-consistent method for simultaneously characterizing quantum gates, initial quantum states, and quantum measurements, under Markovian situation. However, sufficient evidence indicates that the non-Markovian quantum noise impacts current generation quantum devices.

Non-Markovian Quantum Gate Set Tomography – Leading

We first propose a self-consistent operational method [2], named instrument set tomography (IST), for non-Markovian GST. Based on the stochastic quantum process, the instrument set is defined to describe instruments, the initial state, and non-Markovian system-environment (SE) correlations. We propose both linear inversion IST (LIST) and maximum likelihood estimation IST (MLE-IST) to describe instruments and initial states under non-Markovian quantum noise with gauge freedom. As a result, the IST provides an essential method for benchmarking and developing quantum devices in the aspect of instrument set.

Non-Markovian Quantum Gate Set Tomography on Riemannian Manifold – Planning

Non-Markovian quantum gate set tomography, a.k.a. instrument set tomography (IST), is a non-convex constrained problem with multiple optima. There are two main obstacles to implement IST. First, IST requires massive entries to represent the quantum comb and instruments, which leads to computational difficulties in solving optimization problem. Second, the implementations of completely positive & causal (CPC) constraints to the quantum comb and completely positive & trace-non-increasing (CPTNI) constraints to the instruments are non-trivial.

Generalized from the QCT on the Stiefel manifold, we plan to derive representations to the quantum comb and instruments on the Riemannian manifold partially such that the constraints can be easily implemented and the entries could be reduced.

Non-Markovian Quantum Error Correction & Mitigation

Quantum error correction (QEC) and mitigation (QEM) are key techniques to the fault tolerant quantum computing. However, non-Markovian quantum noise may degrade the performances of the recent QEC and QEM schemes. Developing non-Markovian-adaptive QEC and QEM methods is important to forward the fault tolerant quantum computing.

Efficient Strategic Code – Planning

Strategic code utilizes the quantum comb to achieve QEC with the capability to dealing with non-Markovian quantum noise. However, recent strategic code is complex to impelment and requires time-consuming post processes.

We plan to develop a new scheme of strategic code enpowered by the quatnum comb and the classic shadow verification, to enhance the performance of strategic code. Moreover, we plan to introduce the Riemannian optimization to the post processes to enhance the efficiency.

Research Publications

[1] **Ze-Tong Li**, Xin-Lin He, Cong-Cong Zheng, Xu-Tao Yu, and Zai-Chen Zhang. "Quantum network tomography via learning isometries on stiefel manifold". Physical Review Letters **134**, 010803 (2025).

[2] **Ze-Tong Li**, Congcong Zheng, Fanxu Meng, Han Zeng, Tian Luan, Zaichen Zhang, and Xutao Yu. "Non-markovian quantum gate set tomography". Quantum Science and Technology **9**, 035027 (2024).

[3] **Ze-Tong Li**, Fan-Xu Meng, Han Zeng, Zhai-Rui Gong, Zai-Chen Zhang, and Xu-Tao Yu. "A gradient-cost multiobjective alternate framework for variational quantum eigensolver with variable ansatz". Advanced Quantum Technologies, Page 2200130 (2023).

[4] **Ze-Tong Li**, Fan-Xu Meng, Xu-Tao Yu, and Zai-Chen Zhang. "Quantum algorithm for laplacian eigenmap via rayleigh quotient iteration". Quantum Information Processing **21**, 1–20 (2022).

[5] **Ze-Tong Li**, Fan-Xu Meng, Zai-Chen Zhang, and Xu-Tao Yu. "Qubits' mapping and routing for nisq on variability of quantum gates". Quantum Information Processing **19**, 1–25 (2020).

[6] Fan-Xu Meng, **Ze-Tong Li**, Xu-Tao Yu, and Zai-Chen Zhang. "Quantum circuit architecture optimization for variational quantum eigensolver via monto carlo tree search". IEEE Transactions on Quantum Engineering **2**, 1–10 (2021).

[7] Fan-Xu Meng, **Ze-Tong Li**, Yu Xu-Tao, and Zai-Chen Zhang. "Quantum algorithm for music-based doa estimation in hybrid mimo systems". Quantum Science and Technology **7**, 025002 (2022).

[8] Yingwen Wu, **Zetong Li**, Dafa Zhao, Tian Luan, Xutao Yu, and Zaichen Zhang. "Data driven non-markovian quantum process tomography". In 2024 5th Information Communication Technologies Conference (ICTC). Accepted. IEEE (2024).

Research Publications (continued)

[9] Han Zeng, **Ze-Tong Li**, Tian Luan, Yulong Fu, Xu-Tao Yu, and Zai-Chen Zhang. "Optimized meta-vqe algorithm for better trend learning of ground state energy". In 2022 14th International Conference on Wireless Communications and Signal Processing (WCSP). Pages 800–803. IEEE (2022).

[10] Zhairui Gong, Xinlin He, Zhifan Wan, **Zetong Li**, Xianchao Zhang, and Xutao Yu. "Channel modeling based on quantum generative adversarial network". In 2022 14th International Conference on Wireless Communications and Signal Processing (WCSP). Pages 809–812. IEEE (2022).

Previous Research

My previous research topics in Ph.D. studies focused on the quantum advantages of noisy intermediate-scale quantum (NISQ) devices, especially developing **Variational Quantum Algorithms (VQAs)**. Specifically, I studied **applications of VQA**, **Quantum circuit Architecture Search (QAS)** and **Qubit Mapping & Routing (QMR)**.

Applications of VQA

This topic focuses on solving key problems in mathematics and other fields of engineering by VQAs. Problems are transformed into minimizing cost functions with respect to quantum states generated by parameterized circuits, and solved by optimizing parameters of the circuits.

Laplacian Eigenmap via Rayleigh Quotient Iteration – Leading

Laplacian eigenmap (LE) is a geometrically motivated algorithm for dimensionality reduction whose key subprocedure is solving the generalized eigenvalue problem.

We propose a quantum algorithm for LE [4]. In our scheme, we present a quantum subroutine for adjacency graph construction. Then, a variational quantum generalized eigensolver (VQGE) is proposed to solve the generalized eigenvalue problem. The proposed VQGE avoids the need to determine partial derivatives of the Rayleigh quotient and alleviates the difficulty of selecting hyperparameters.

MUSIC-based DOA Estimation in Hybrid MIMO Systems – Participating

The multiple signal classification (MUSIC) algorithm is a well-established method for estimating the direction of arrival (DOA) of signals, whose key subrouting is the construction and eigen-decomposition of the sample covariance matrix (SCM).

We present a novel quantum method for MUSIC [7] with quantum singular vector transformation subroutine for constructing the approximate SCM and a variational density matrix eigensolver to determine the signal and noise subspaces. The proposed quantum method can potentially achieve exponential speedup for certain parameters and polynomial speedup for others under specific moderate circumstances, compared with their classical counterparts.

Quantum Circuit Architecture Search

QAS strategies adaptively search optimal architecture of parameterized quantum circuits to balance the expressibility and trainability of VQAs in solving a specified problem. Consequently, the algorithm achieves better accuracy than fixed-architecture VQAs, at an acceptable time cost for conducting architecture search.

Gradient-Cost Multiobjective Alternate Framework for QAS – Leading

We proposed a QAS method by alternately solving the original VQA problem and a multi-objective optimization problem defined by cost function values and gradient magnitudes [3]. We implemented this method based on the double ϵ-greedy strategy with a candidate tree and a modified multi-objective genetic algorithm is proposed. As a result, the local optima are avoided from both the architecture and parameter perspectives, the BP phenomenon is alleviated, and the stability of the output architecture is enhanced.

This method was further utilized in Meta-VQE [9].

Monte Carlo Tree Search based QAS – Participating

We proposed an efficient QAS scheme based on the Monto Carlo tree (MCT) search [6]. Our approach models the search space with a MCT and regards it as a supernet. Then, a two-stage scheme is proposed for the search space training, where weight sharing and warm-up strategies are employed to avoid huge computation cost. Training results are stored in nodes of the MCT for future decisions, and hierarchical node selection is presented to obtain an optimal VQA architecture. Consequently, our scheme can be efficient to mitigate trainability and accuracy issues by minimizing the depth of parameterized circuits and the number of entanglement gates.

Qubit Mapping and Routing

QMR aims to map and route qubits in circuits (logical qubits) to physical qubits such that all multi-qubit gates in circuits are mapped to physical implementable ones with high circuit fidelities in acceptable running times.

Variability-Aware Policy based QMR – Leading

Most of QMR algorithm assumes that a quantum gate act on different qubits performs identically. However, the reality is that quantum gates and qubits differs from each other.

Systematically considering the variability of quantum gates and qubits, we propose a heuristic algorithm utilizing the error score derived from quantum operation's error rate as the heuristic cost [5]. Combining SWAP gates and CNOT gates, the algorithm transforms the input circuit into an executable output circuit on the quantum computer with lower error score in acceptable execution time and moves forward from local optimal to global optimal.

Skills

Languages	**Academic English**, Japanese, Mandarin Chinese.
Coding	**C++**, Python, LaTeX.

Awards and Achievements

- **Silver Prize of Best Student Poster Award**, Asian Quantum Information Science Conference, 2024.
- **Third Prize of First CCF Origin Pilot Cup Quantum Computing Challenge**, China Computer Federation.
- **National Scholarship**, Ministry of Education of the People's Republic of China.
- **First Prize of Academic Scholarship**, Southeast University.