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Editorial

Special Issue on Photonic State Tomography: Methods and Applications

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Citation: Czerwinski, A. Special Issue on Photonic State Tomography: Methods and Applications. *Photonics* **2023**, *10*, 1370. https://doi.org/10.3390/photonics10121370

Received: 18 October 2023
Accepted: 14 November 2023
Published: 13 December 2023

The realm of quantum engineering has undergone a remarkable transformation in recent years. Emerging quantum technology, with its potential to reshape the landscape of computation, communication, and cryptography, relies heavily on the accurate validation and certification of quantum states. Central to this problem is the indispensable domain of state tomography, a cornerstone in ensuring the credibility of quantum technology. In particular, photons, renowned for their versatility across various degrees of freedom such as polarization, spectral, spatial, and temporal modes, have emerged as key players in the quantum landscape. It is within this context that we present the Special Issue "Photonic State Tomography: Methods and Applications", an endeavor to illuminate the latest developments in this dynamic field, spanning theoretical and experimental dimensions. We extended an invitation for manuscripts that not only introduced innovative frameworks founded on mathematical physics but also encompassed feasibility studies assessing model efficiency through numerical techniques. Additionally, we eagerly welcomed experimental contributions, especially those embedded within the broader domain of quantum optics and, where possible, entangled photons.

The submissions we received provided a tapestry of diverse insights, each contributing to our collective understanding of photonic state tomography. Let us briefly traverse through the intriguing contributions within this Special Issue.

One of the papers, "Quantum Tomography of Two-Qutrit Werner States" [1], sets the stage by introducing a novel framework for the tomography of two-qutrit Werner states. The authors tackle the challenge of Gaussian noise, a pervasive phenomenon in practical quantum systems. Their approach involves a measurement scheme based on symmetric, informationally complete positive operator-valued measures. This scheme allows for a successful reconstruction of quantum states. Moreover, based on the reconstructed density matrix, we can perform the assessment of characteristics of the states, including fidelity, purity, entanglement, and coherence. By offering a pragmatic solution to the complexities of quantum state tomography, this paper aligns well with current research trends, where the robustness of state tomography in real-world quantum systems remains a prominent concern; for more information, see, for example, refs. [2,3].

Another contribution to the Special Issue "Fast Quantum State Reconstruction via Accelerated Non-Convex Programming" [4] provides a unique perspective on quantum tomography by introducing the Momentum-Inspired Factored Gradient Descent (MiFGD) method. This groundbreaking approach combines elements from compressed sensing, non-convex optimization, and acceleration methods, effectively extending the applicability of quantum tomography to larger systems. Remarkably, MiFGD, which is a non-convex method, converges toward the actual density matrix with accelerated linear rates in the absence of experimental and statistical noise, under typical assumptions. In a practical aspect, the algorithm's performance is benchmarked against existing methods, demonstrating unparalleled speed and accuracy. Its robustness in the face of experimental and numerical data positions it as a noteworthy contribution, resonating strongly with current trends of enhancing efficiency in quantum state reconstruction.

"Quantum State Tomography in Nonequilibrium Environments" provides us with an insightful perspective into the quantum state tomography of open systems [5]. The authors employ a novel approach, which is based on dynamical maps in the Kraus representation [6], to explore the complexities of nonequilibrium environments [7,8]. This study, driven by the dynamic generation of informationally complete positive operator-valued measures, yields valuable insights into the time-dependent measurement operators crucial for quantum state reconstruction in single and multi-qubit systems. Notably, it is the first known paper, where evolving observables are considered in a non-Markovian regime [9]. The authors have demonstrated that, by properly tailoring the environment, we can obtain a time-dependent measurement that collects more information about the system than in case of the Markovian evolution. By bridging the gap between open quantum systems and state tomography, this paper echoes the current desire to understand the dynamics of quantum states in real-world environments.

Shifting our focus to practical applications, "Statistical Analysis of the Photon Loss in Fiber-Optic Communication" [10] addresses a prevalent challenge in optical communication systems. Photons, the carriers of quantum information, face attenuation in the transmission medium, necessitating a precise description of the loss that can affect state tomography and entanglement quantification [11]. The paper presents innovative statistical methods to estimate the attenuation coefficient of fiber links. By leveraging the Beer–Lambert law and exploiting the properties of exponential distributions, the authors provide computable estimators, particularly for scenarios with censored data. This paper brings to light the growing necessity of addressing quantum communication's practical challenges and limitation, aligning with the broader trend of making quantum technology accessible and reliable for real-world applications.

Insightful results are also included in "Quantum Speed Limit for a Moving Qubit inside a Leaky Cavity" [12]—a paper that explores the theoretical concept of the quantum speed limit (QSL). The QSL, which establishes a lower limit for the time required for a quantum system to transition from an arbitrary initial state to its orthogonal counterpart, bears significant importance in the realm of open quantum systems [13,14]. The study investigates the QSL time for a model featuring a qubit in motion within a leaky cavity. Interestingly, it reveals how the QSL time varies with different coupling regimes. The results provide critical insights into the dynamics of atom–photon couplings, offering a roadmap for enhancing the controllability of quantum systems. This paper touches upon an emerging research area focusing on characterizing and understanding the behavior of quantum systems in dynamic environments.

The last paper of the Special Issue, i.e., "Optimally Controlled Non-Adiabatic Quantum State Transmission in the Presence of Quantum Noise", presents an investigation into pulse-controlled non-adiabatic quantum state transmission, addressing the challenge of environmental noise [15]. By utilizing the Adam algorithm, the authors uncover the potential of optimal pulse sequences to dramatically enhance transmission fidelity in open quantum systems. This paper resonates with the current trend of optimizing control in quantum information processing tasks, highlighting the adaptability and universality of the Adam algorithm in addressing real-world quantum communication challenges.

The collective body of work in this Special Issue presents a mosaic of ideas and insights that push the boundaries of photonic state tomography and related fields. We express our deepest gratitude to the authors for their invaluable contributions and extend an invitation to our readers to explore the wealth of knowledge within these pages. May the research unveiled here inspire, inform, and pave the way for further advances in quantum photonics.

Conflicts of Interest: The author declares no conflict of interest.

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