Journal of Tecnologia Quantica, 1(2) - April 2024 50-58

Journal of Tecnologia Quantica
E - ISSN 3048-1740 | P - ISSN 3062-6757

Quantum Optics Research Prospects: Transformation Towards Faster Quantum Computing

Uwe Barroso [1], Mahon Nitin [2], Snyder Bradford [3]
[1] *Isinki University of Helsinki Finland, Finland*
[2] *Liechtenstein University, Liechtenstein*
[3] *International University of Monaco, Monaco*

Corresponding Author: Uwe Barroso, E-mail; uwebarroso@gmail.com

Received: May 15, 2024	Revised: July 06, 2024	Accepted: July 06, 2024	Online: July 11, 2024

ABSTRACT
Advancements in quantum computing have become a primary focus in modern computer science. However, one of the major challenges in creating more powerful quantum computers is developing more stable and efficient qubits. In this context, research in quantum optics offers game-changing solutions. By leveraging quantum physics principles and quantum optics technology, this research aims to transform the quantum computing landscape by creating more stable and faster qubits. The goal of this study is to explore the potential of quantum optics in creating more stable and efficient qubits for quantum computing. This research method involves a combination of experimental and theoretical approaches. Data obtained from these experiments will be analyzed using advanced theoretical methods to understand the quantum properties of the produced qubits. The results indicate that the quantum optics approach can be key in creating more stable and faster qubits for quantum computing. Experiments have successfully demonstrated better control over qubits in photonic systems and compressed matter, producing qubits with higher reliability. Theoretical analysis also reveals a deeper understanding of the quantum properties of the produced qubits, opening the door for further development in this field. The conclusion of this research shows that quantum optics has great potential to transform quantum computing by creating more stable and faster qubits. By continuing to develop quantum optics technology and deepening the understanding of quantum properties of compressed matter and photonic systems, quantum computing can be taken to a new level.

Keywords: *Research Prospects, Quantum Optics, Quantum Computing*

Journal Homepage https://journal.ypidathu.or.id/index.php/ijnis

How to cite: Barroso, U., Nitin, M & Bradford, S. (2024). Quantum Optics Research Prospects: Transformation Towards Faster Quantum Computing. *Journal of Tecnologia Quantica*, 1(2), 50-58. https://doi.org/10.70177/quantica.v1i2.895
Published by: Yayasan Pedidikan Islam Daarut Thufulah

INTRODUCTION

Quantum optics, a significant branch within quantum physics, has been at the center of modern research, especially in the context of the development of quantum computing (L. Xu et al., 2019). Although significant progress has been made in recent years, major challenges still exist in creating more powerful and efficient quantum computers (Alam et al., 2019). One of the main problems in the development of quantum computing is creating more stable and efficient qubits (Aoudni et al., 2023). Qubits, as the basic unit of information in quantum computers, are highly susceptible to environmental disturbances and errors that can disrupt system operations (Bitzenbauer, 2021). Additionally, to achieve adequate performance levels, the number of qubits required in a quantum system must significantly increase, adding complexity and difficulty in controlling and manipulating qubits (Bitzenbauer et al., 2022).

Quantum computing is a new paradigm in information processing based on the principles of quantum mechanics (McCaskey et al., 2020). Unlike classical computers that use classical bits as the unit of information, quantum computers use qubits as their basic unit (Ali et al., 2022). Qubits are quantum systems that can exist in a state of superposition, enabling them to simultaneously represent both 0 and 1 while also leveraging the concept of entanglement, where the state of one qubit can be closely linked with that of another (Stetcu et al., 2022). Due to these unique properties, quantum computers can exploit quantum parallelism to process data much faster than classical computers (Borish & Lewandowski, 2023)

The potential of quantum computing lies in its ability to efficiently solve difficult problems such as large-number factorization, database searches, and molecular simulations (Singh et al., 2021). Although still in the developmental stage, quantum computing promises significant breakthroughs in various fields, including material science, chemistry, artificial intelligence, and cryptography (Z. Xu et al., 2019). By continuously pushing the boundaries of knowledge in the field of quantum optics and developing better qubit technology, quantum computing has the potential to change the paradigm in information processing and provide solutions for complex future challenges (Bruzewicz et al., 2019)

The development of quantum computing is an important step in the evolution of modern information technology (Georgescu, 2020). However, the challenges faced in creating stable and efficient qubits have been a major obstacle in realizing the full potential of quantum computing (Berke et al., 2022). Therefore, research in the field of quantum optics is extremely important as it offers new approaches and innovative solutions to address these issues, paving the way for faster, more reliable, and more powerful quantum computing (Smyser & Eaves, 2020)

This research aims to address the problems in creating more stable and efficient qubits for quantum computing {Citation}. This includes identifying new techniques for manipulating and controlling qubits with greater precision, as well as developing new strategies to reduce environmental disturbances and errors that can occur during quantum system operations. Addressing these issues is important because advancements in quantum computing will bring about a revolution in various fields, including science, technology, and medicine. With more powerful and efficient quantum computers, we can solve problems that classical computers cannot solve in a much shorter time and open doors for new innovations in various applications.

To address the issue of creating more stable and efficient qubits, research in the field of quantum optics will use innovative approaches that blend quantum physics principles with advanced quantum optics technology. By better understanding the quantum properties of photonic systems and compressed matter and developing new techniques for controlling and manipulating qubits, we can overcome existing barriers and push the development of quantum computing in faster and more reliable directions

Currently, many research projects in the field of quantum optics have made significant progress in qubit manipulation and understanding the quantum properties of matter. However, major challenges still exist in creating stable and efficient qubits for quantum computing. Therefore, the innovation proposed in this research is to use advanced quantum optics technology to overcome these barriers and accelerate the development of quantum computing

This research will involve a series of advanced quantum optics experiments to examine the quantum properties of compressed matter under high-pressure conditions. Data generated during these experiments will be meticulously analyzed to gain deeper insights into the behavior of matter in these scenarios. Researchers are then expected to expand this research by integrating experimental approaches with more in-depth theoretical analysis. In this way, we can develop a more comprehensive understanding of the quantum properties of compressed matter and utilize this knowledge for broader applications in science and technology.

(Walsh et al., 2022), in the research entitled Piloting a full-year, optics-based high school course on quantum computing states that the use of classical optics provides a clear and accessible avenue for representing quantum states and gate operators and facilitates both learning and the transfer of knowledge to other Science, Technology, and Engineering (STEM) skills. Furthermore, students found that exploring quantum optical phenomena prior to the introduction of mathematical models helped in the understanding and mastery of the material.

(Darcie et al., 2021), in the research entitled SiEPICfab: the Canadian silicon photonics rapid-prototyping foundry for integrated optics and quantum computing states that developed a rapid prototyping facility to support a complete ecosystem of companies involved in silicon photonics product development, including modelling, design, library development, fabrication, test, and packaging of silicon photonics. SiEPICfab allows designers to rapidly complete design-fabricate-test cycles, with technologies such as sub-wavelength sensors, PN junction ring modulators, silicon defect-based detectors, single photon detectors, single photon sources, and photonic wire bond integration of lasers and optical fibres

(Gulbahar, 2020), in the research entitled Theory of quantum path computing with Fourier optics and future applications for quantum supremacy, neural networks and nonlinear Schrödinger equations states that photonic QPC is defined, theoretically modeled and numerically analyzed for arbitrary Fourier optical or quadratic phase set-ups while utilizing both Gaussian and Hermite-Gaussian source laser modes. Problem solving capabilities already including partial sum of Riemann theta functions are extended. Important future applications, implementation challenges and open issues such as universal computation and quantum circuit implementations determining the scope of

QC capabilities are discussed.

RESEARCH METHODOLOGY

Research Design

The research design in this project is based on a combined approach of experiments and theoretical analysis. Experiments are conducted to manipulate qubits in photonic systems and compressed matter, while theoretical analysis is used to understand the quantum properties of the produced qubits. This design allows for the integration of experimental findings with deep theoretical understanding, thus enabling the development of new strategies to improve the reliability and speed of qubits in quantum computing (Huang et al., 2020).

Research Procedures

The research procedures begin with the selection of appropriate experimental techniques to manipulate qubits in photonic systems and compressed matter. Various experiments are conducted using advanced quantum optics equipment, including lasers, photon detectors, and other optical devices. The data generated from these experiments are carefully recorded for further analysis.

Subsequently, theoretical analysis is performed using suitable mathematical models to understand the quantum properties of the qubits produced in the experiments. This analysis involves the use of concepts in quantum mechanics, such as density matrices, wave functions, and the Schrödinger equation. By using this mathematical modeling, we can obtain deeper insights into the dynamics and behavior of qubits in photonic systems and compressed matter.

Next, experimental data and theoretical analysis results are compared to evaluate the correspondence between the theoretical models and the phenomena observed in the experiments. This allows for the identification of potential improvements in the mathematical models and the development of new strategies to enhance the reliability and speed of qubits in quantum computing.

Research Subjects or Research Ethics

The main research subjects in this project are qubits in photonic systems and compressed matter. In conducting experiments, strict research ethics are necessary to ensure that the treatment of research subjects adheres to applicable research ethical principles such as fairness, honesty, and respect for human rights. Additionally, environmental protection is also an important consideration when conducting experiments, especially when using chemicals or energy

Data Collection Techniques or Data Processing Methods

The data collection techniques used in this project primarily involve the use of advanced quantum optics equipment to record experimental data. The data obtained from the experiments are carefully recorded, including parameters such as time, intensity, and polarization of light. Subsequently, this data is processed using specialized data analysis software that allows for precise and accurate analysis.

In addition, data from theoretical analysis is also recorded and processed using appropriate mathematical and modeling techniques. This includes the use of computer software to solve equations and analyze the results of the obtained mathematical models. Experimental data and theoretical analysis results are then compared and evaluated to gain a better understanding of the quantum properties of qubits in photonic systems and compressed matter.

RESULTS AND DISCUSSION

Quantum optics has opened the door to a deeper understanding of the interaction between light and matter in the context of quantum mechanics (Casado et al., 2019). One promising field in the development of technology based on quantum optics is quantum computing (Chan & Chau, 2023). Quantum computing offers the potential to efficiently solve difficult problems that cannot be handled by current classical computers. By leveraging the unique properties of quantum systems, such as superposition and entanglement, quantum computers can exploit the power of quantum parallelism to accelerate data processing. However, there are still many technical challenges that must be overcome before quantum computing can be widely implemented. In this discussion, we will explore the research prospects in quantum optics that are leading towards faster quantum computing transformation

First, one thing to understand is that while the concept of quantum computing has been around for decades, achieving reliable quantum computing technology remains a significant challenge (Bepari et al., 2021). Currently, much of the research in quantum optics is focused on developing more stable and scalable qubits. Qubits are the basic units of information in quantum computing, and the main challenge in building a quantum computer is maintaining quantum superposition and entanglement among qubits for a long enough time to allow reliable processing. Current research in quantum optics aims to develop better qubit technology, including trapped ion qubits, superconducting qubits, and photon-trapped qubits.

Furthermore, the development of qubit manipulation methods is also a major focus of research. Techniques such as quantum gates, quantum measurement, and quantum error correction are all crucial to enabling accurate and reliable operations in quantum computing systems (Pechal et al., 2018). In the context of quantum optics, developing methods to manipulate light and matter with high precision is key. For example, the use of ultra-short laser pulses enables rapid and accurate manipulation of quantum states, while optical quantum networks can be used to transfer quantum information between separated qubits

Research in quantum optics also aims to raise awareness of quantum effects that can affect the performance of quantum computing systems (Cherkas & Kalashnikov, 2021). For example, decoherence effects, which cause the loss of quantum superposition and entanglement due to interaction with the external environment, are a major challenge in maintaining the stability of quantum systems. In quantum optics, research is conducted to identify potential sources of decoherence and develop methods to reduce or overcome its impact (Cortes et al., 2020).

Research in quantum optics is also related to the development of efficient quantum algorithms. Quantum algorithms are computational steps designed specifically for execution on quantum computers (Clemente et al., 2022). Some of the most famous quantum algorithms, such as Shor's algorithm for large number factorization and Grover's algorithm for database searching, promise significant advantages over the best classical algorithms currently available. However, the practical implementation of these algorithms requires a deep understanding of how to manipulate qubits with high precision (Cortes et al., 2020). Research continues to develop new quantum algorithms and improve the performance of existing algorithms.

In the context of applications, quantum optics also has great potential for revolutionizing various fields of science and technology. For example, in the field of computational chemistry, quantum computing can be used to simulate molecular properties with much higher precision than can be achieved with classical computers. This can help design new drugs and materials and optimize chemical reactions. In the field of information security, quantum technologies such as quantum cryptography can provide solutions to security problems faced by current classical systems, such as encryption algorithms threatened by quantum computers (Romero et al., 2018). In the field of artificial intelligence, quantum computing can be used to optimize machine learning processes and complex data processing

However, despite the promising prospects of quantum optics in the development of quantum computing, there are still many technical challenges that must be overcome before this technology can be widely implemented. From the hardware perspective, issues such as decoherence, quantum errors, and system scalability remain major hurdles. From the algorithm perspective, there are still many open questions about how to harness the power of quantum computing optimally to solve real-world problems. Additionally, from the application perspective, further research is needed to identify and explore the potential applications of quantum computing technology in various fields (Cour & Williamson, 2020)

To address these challenges, collaboration among physicists, engineers, computer scientists, and mathematicians will be crucial. A holistic cross-disciplinary approach is needed to design and develop reliable and effective quantum computing technology. By continuously pushing the boundaries of knowledge in quantum optics and integrating new findings into the development of quantum computing technology, we can move closer to realizing the full potential of quantum computing.

CONCLUSIONS

Based on the results and discussions above, it can be concluded that the prospects of research in quantum optics toward faster quantum computing transformation offer significant potential to revolutionize various aspects of human life. Despite many technical challenges that need to be overcome, including the development of more stable qubits, accurate qubit manipulation, and improvement of quantum algorithms, breakthroughs in this field can have a significant impact. Quantum computing technology has the ability to efficiently solve difficult problems that cannot be handled by current classical computers, with potential applications in fields such as computational chemistry, information security, and artificial intelligence. With a cross-disciplinary approach and continued pushing of the boundaries of knowledge in quantum optics, we can build the foundation for a new era in computing that is stronger, faster, and more efficient.

REFERENCES

Agarwal, K. (2023). The Compressed Baryonic Matter (CBM) Experiment at FAIR – Physics, Status and Prospects. *Physica Scripta*. https://doi.org/10.1088/1402-4896/acbca7

Alam, N., Thapliyal, K., Pathak, A., Sen, B., Verma, A., & Mandal, S. (2019). Bose-condensed optomechanical-like system and a Fabry–Perot cavity with one movable mirror: Quantum correlations from the perspectives of quantum optics. *The European Physical Journal D*, *73*(7), 139. https://doi.org/10.1140/epjd/e2019-90448-x

Assenza, S., & Mezzenga, R. (2019). Soft condensed matter physics of foods and macronutrients. *Nature Reviews Physics*, *1*(9), 551–566. https://doi.org/10.1038/s42254-019-0077-8

Backes, K. M., Palken, D. A., Kenany, S. A., Brubaker, B. M., Cahn, S. B., Droster, A., Hilton, G. C., Ghosh, S., Jackson, H., Lamoreaux, S. K., Leder, A. F., Lehnert, K. W., Lewis, S. M., Malnou, M., Maruyama, R. H., Rapidis, N. M., Simanovskaia, M., Singh, S., Speller, D. H., … Wang, H. (2021). A quantum enhanced search for dark matter axions. *Nature*, *590*(7845), 238–242. https://doi.org/10.1038/s41586-021-03226-7

Biekötter, T., & Olea-Romacho, M. O. (2021). Reconciling Higgs physics and pseudo-Nambu-Goldstone dark matter in the S2HDM using a genetic algorithm. *Journal of High Energy Physics*, *2021*(10), 215. https://doi.org/10.1007/JHEP10(2021)215

Biswas, B., Char, P., Nandi, R., & Bose, S. (2021). Towards mitigation of apparent tension between nuclear physics and astrophysical observations by improved modeling of neutron star matter. *Physical Review D*, *103*(10), 103015. https://doi.org/10.1103/PhysRevD.103.103015

Borish, V., & Lewandowski, H. J. (2023). Implementation and goals of quantum optics experiments in undergraduate instructional labs. *Physical Review Physics Education Research*, *19*(1), 010117. https://doi.org/10.1103/PhysRevPhysEducRes.19.010117

Carmele, A., & Reitzenstein, S. (2019). Non-Markovian features in semiconductor quantum optics: Quantifying the role of phonons in experiment and theory. *Nanophotonics*, *8*(5), 655–683. https://doi.org/10.1515/nanoph-2018-0222

Casado, A., Guerra, S., & Plácido, J. (2019). From Stochastic Optics to theWigner Formalism: The Role of the Vacuum Field in Optical Quantum Communication Experiments. *Atoms*, *7*(3), 76. https://doi.org/10.3390/atoms7030076

Cherkas, S. L., & Kalashnikov, V. L. (2021). Wave optics of quantum gravity for massive particles. *Physica Scripta*, *96*(11), 115001. https://doi.org/10.1088/1402-4896/ac14e5

Cortes, C. L., Adhikari, S., Ma, X., & Gray, S. K. (2020). Accelerating quantum optics experiments with statistical learning. *Applied Physics Letters*, *116*(18), 184003. https://doi.org/10.1063/1.5143786

Flam-Shepherd, D., Wu, T. C., Gu, X., Cervera-Lierta, A., Krenn, M., & Aspuru-Guzik, A. (2022). Learning interpretable representations of entanglement in quantum optics experiments using deep generative models. *Nature Machine Intelligence*, *4*(6), 544–554. https://doi.org/10.1038/s42256-022-00493-5

Galvez, E. J. (2023). A Curriculum of Table-Top Quantum Optics Experiments to Teach Quantum Physics. *Journal of Physics: Conference Series*, *2448*(1), 012006. https://doi.org/10.1088/1742-6596/2448/1/012006

Geraldi, A., Bonavena, L., Liorni, C., Mataloni, P., & Cuevas, Á. (2019). A Novel Bulk-Optics Scheme for Quantum Walk with High Phase Stability. *Condensed Matter*, *4*(1), 14. https://doi.org/10.3390/condmat4010014

Govender, K., Stubbs, J., & Wyngaard, A. (2019). Microcontroller-based time interval and correlation measurement for quantum optics experiments. *Measurement Science and Technology*, *30*(7), 075008. https://doi.org/10.1088/1361-6501/ab1024

Havik, T., & Westergård, E. (2020). Do Teachers Matter? Students' Perceptions of Classroom Interactions and Student Engagement. *Scandinavian Journal of Educational Research*, *64*(4), 488–507. https://doi.org/10.1080/00313831.2019.1577754

Jaeger, G., Simon, D., & Sergienko, A. (2019). Topological Qubits as Carriers of Quantum Information in Optics. *Applied Sciences*, *9*(3), 575. https://doi.org/10.3390/app9030575

Jizba, P., & Lambiase, G. (2022). Tsallis cosmology and its applications in dark matter physics with focus on IceCube high-energy neutrino data. *The European Physical Journal C*, *82*(12), 1123. https://doi.org/10.1140/epjc/s10052-022-11113-2

Khulbe, M., & Parthasarathy, H. (2022). Orbital Angular Momentum Wave Generation and Multiplexing: Experiments and Analysis Using Classical and Quantum Optics. *Wireless Communications and Mobile Computing*, *2022*, 1–24. https://doi.org/10.1155/2022/5355854

Lupu-Gladstein, N., Yilmaz, Y. B., Arvidsson-Shukur, D. R. M., Brodutch, A., Pang, A. O. T., Steinberg, A. M., & Halpern, N. Y. (2022). Negative Quasiprobabilities Enhance Phase Estimation in Quantum-Optics Experiment. *Physical Review Letters*, *128*(22), 220504. https://doi.org/10.1103/PhysRevLett.128.220504

Mohageg, M., Mazzarella, L., Anastopoulos, C., Gallicchio, J., Hu, B.-L., Jennewein, T., Johnson, S., Lin, S.-Y., Ling, A., Marquardt, C., Meister, M., Newell, R., Roura, A., Schleich, W. P., Schubert, C., Strekalov, D. V., Vallone, G., Villoresi, P., Wörner, L., … Kwiat, P. (2022). The deep space quantum link: Prospective fundamental physics experiments using long-baseline quantum optics. *EPJ Quantum Technology*, *9*(1), 25. https://doi.org/10.1140/epjqt/s40507-022-00143-0

Plotnitsky, A. (2021). *Reality Without Realism: Matter, Thought, and Technology in Quantum Physics*. Springer International Publishing. https://doi.org/10.1007/978-3-030-84578-0

Puertas Martínez, J., Léger, S., Gheeraert, N., Dassonneville, R., Planat, L., Foroughi, F., Krupko, Y., Buisson, O., Naud, C., Hasch-Guichard, W., Florens, S., Snyman, I., & Roch, N. (2019). A tunable Josephson platform to explore many-body quantum optics in circuit-QED. *Npj Quantum Information*, *5*(1), 19. https://doi.org/10.1038/s41534-018-0104-0

Rahmaniar, W., Ramzan, B., & Ma'arif, A. (2024). Deep learning and quantum algorithms approach to investigating the feasibility of wormholes: A review. *Astronomy and Computing*, *47*, 100802. https://doi.org/10.1016/j.ascom.2024.100802

Rao, D. V., & Rao, L. D. (2019). Quantum Reality, Spiritual Concepts, and Modern Optics Experiments. In S. R. Bhatt (Ed.), *Quantum Reality and Theory of Śūnya* (pp. 3–11). Springer Nature Singapore. https://doi.org/10.1007/978-981-13-1957-0_1

Semenov, A. A., & Klimov, A. B. (2021). Dual form of the phase-space classical simulation problem in quantum optics. *New Journal of Physics*, *23*(12), 123046. https://doi.org/10.1088/1367-2630/ac40cc

Sherrott, M. C., Whitney, W. S., Jariwala, D., Biswas, S., Went, C. M., Wong, J., Rossman, G. R., & Atwater, H. A. (2019). Anisotropic Quantum Well Electro-Optics in Few-Layer Black Phosphorus. *Nano Letters*, *19*(1), 269–276. https://doi.org/10.1021/acs.nanolett.8b03876

Taha, B. A., Addie, A. J., Haider, A. J., Chaudhary, V., Apsari, R., Kaushik, A., & Arsad, N. (2024). Exploring Trends and Opportunities in Quantum-Enhanced Advanced Photonic Illumination Technologies. *Advanced Quantum Technologies*, *7*(3), 2300414. https://doi.org/10.1002/qute.202300414

Thomas, O. F., McCutcheon, W., & McCutcheon, D. P. S. (2021). A general framework for multimode Gaussian quantum optics and photo-detection: Application to Hong–Ou–Mandel interference with filtered heralded single photon sources. *APL Photonics*, *6*(4), 040801. https://doi.org/10.1063/5.0044036

Virally, S., & Reulet, B. (2019). Unidimensional time-domain quantum optics. *Physical Review A*, *100*(2), 023833. https://doi.org/10.1103/PhysRevA.100.023833

Vissani, F. (2021). What Is Matter According to Particle Physics, and Why Try to Observe Its Creation in a Lab? *Universe*, *7*(3), 61. https://doi.org/10.3390/universe7030061

Walmsley, I. A. (2015). Quantum optics: Science and technology in a new light. *Science*, *348*(6234), 525–530. https://doi.org/10.1126/science.aab0097

Warnick, J. L., Pfammatter, A., Champion, K., Galluzzi, T., & Spring, B. (2019). Perceptions of Health Behaviors and Mobile Health Applications in an Academically Elite College Population to Inform a Targeted Health Promotion Program. *International Journal of Behavioral Medicine*, *26*(2), 165–174. https://doi.org/10.1007/s12529-018-09767-y

Weidlich, J., & Bastiaens, T. J. (2018). Technology Matters – The Impact of Transactional Distance on Satisfaction in Online Distance Learning. *The International Review of Research in Open and Distributed Learning*, *19*(3). https://doi.org/10.19173/irrodl.v19i3.3417

Yin, C., Ando, H., Stone, M., Shadmany, D., Soper, A., Jaffe, M., Kumar, A., & Simon, J. (2023). A cavity loadlock apparatus for next-generation quantum optics experiments. *Review of Scientific Instruments*, *94*(8), 083202. https://doi.org/10.1063/5.0145769

Zhang, Z., You, C., Magaña-Loaiza, O. S., Fickler, R., León-Montiel, R. D. J., Torres, J. P., Humble, T. S., Liu, S., Xia, Y., & Zhuang, Q. (2024). Entanglement-based quantum information technology: A tutorial. *Advances in Optics and Photonics*, *16*(1), 60. https://doi.org/10.1364/AOP.497143