TU Delft

To

dr hab. Jarosław Miszczak
prof. IITiS

Dr. Sebastian Feld
Assistant Professor

Delft University of Technology

Faculty of Electrical Engineering, Mathematics and Computer Science

Quantum & Computer Engineering

Mekelweg 4, 2628 CD Delft

s.feld@tudelft.nl
+31 15 278 2462

January 8, 2025

Report on the doctoral thesis "Theory and Applications of Hybrid Quantum-Classical Optimization Algorithms" by Ludmila Botelho

Dear professor Miszczak,

what follows is a report on the above-mentioned doctoral thesis submitted by Ludmila Botelho. The structure of the report follows the questions that were provided to me.

Are the themes of the dissertation topical, and how are they related to developments in the discipline?

The dissertation consists of three papers:

1. Hamiltonian-Oriented Homotopy QAOA: This paper introduces a hybrid approach that combines classical homotopy optimization with QAOA. The method enhances the performance on combinatorial optimization problems by efficiently navigating complex energy landscapes.
2. Error Mitigation for Variational Quantum Algorithms through Mid-Circuit Measurements: This work proposes error mitigation techniques for VQAs. It uses mid-circuit measurements and post-selection to keep computations within desired subspaces while avoiding additional qubits.
3. Music Composition Using Quantum Annealing: The paper explores the use of quantum annealing for algorithmic music composition. It shows potential to generate melodies, rhythms, and harmonies through optimization-based techniques.

Regarding the timeline: Paper 1 was posted on arXiv in January 2023 and has been published in February 2024. Paper 2 was posted on arXiv in September 2021 and has been published in February 2022. And paper 3 was posted on arXiv in January 2022 and has been published in November 2022.

The themes addressed in the dissertation are topical. All three papers focus on advancing the application of NISQ computing, particularly in the context of quantum-classical hybrid optimization. Since the timeline for achieving fault-tolerant quantum computing with full quantum error correction remains

SF

uncertain, it is important to explore the capabilities of today's quantum hardware. This includes not only NISQ machines but also transitional technologies such as quantum annealers.

The work is aligned with developments in the discipline, it emphasizes the use of classical techniques to enhance quantum algorithms. The contributions span improving QAOA, mitigating noise in VQAs, and discovering novel applications for quantum technology. This is aligned with and reflects current challenges and opportunities in the field.

What is the scientific problem addressed by the author, and has it been accurately formulated?

The three contributions fall under the broad umbrella of "hybrid quantum-classical optimization algorithms".

Regarding paper 1, it addresses the following question: How can the performance and scalability of QAOA be improved for navigating complex energy landscapes in combinatorial optimization problems? The authors identify the challenge of optimizing QAOA parameters and propose a hybrid method combining classical homotopy optimization with QAOA. The problem is clearly formulated, addressing a well-recognized limitation in existing QAOA implementations.

The scientific question in paper 2 is: How can errors in VQAs be mitigated to make them more reliable for practical use on NISQ devices? The authors define the issue of quantum state fidelity degradation due to errors and propose mid-circuit measurements and post-selection as solutions. The problem is well-defined within the context of NISQ-era challenges and focuses on practical improvements.

Finally, paper 3 explores: How can quantum annealing be utilized for algorithmic music composition, and what is its capability to solve structured optimization problems in a creative domain? The authors present an approach that frames music composition as an optimization task suitable for quantum annealers. This formulation is innovative and extends the application of quantum computing to interdisciplinary and creative domains.

My main critique is the following: While each paper identifies a scientifically relevant problem that is clearly and accurately formulated, the three topics do not build on a common foundation or interact meaningfully with each other. Instead, they stand independently, with little thematic or methodological influence among them. Additionally, the necessity for some of these solutions – such as the use of quantum annealing for algorithmic music composition – is not always well articulated. For example, the broader justification for applying quantum computing to this creative domain could have been presented more convincingly.

Has the author solved the problem posed, and has the right methods been used to do so?

This question is challenging to answer definitively. One approach is to consider the reception of the papers by the scientific community: Paper 2 on error mitigation has gained 44 citations since its publication in 2022, suggesting a reasonable level of recognition and relevance. Paper 3 on music composition has 9 citations in the same timeframe, indicating limited but notable interest. Paper 1 on

SI

QAOA, published in 2024, currently has no citations, which could reflect the early stage of its dissemination or limited acceptance by the community so far.

This lack of substantial citations, particularly for paper 1, raises questions about whether the solutions proposed have been broadly accepted by the field.

However, evaluating the papers individually shows that the author has indeed made progress in addressing the posed problems. The methods employed are innovative and consistent with the current state of the art in quantum computing. While the solutions may not have achieved widespread adoption yet, the work demonstrates a good approach to tackling the identified challenges.

What is the author's original contribution to the discipline?

Assessing the author's original contribution to the discipline is challenging due to the unclear attribution of individual contributions within the publications. The authorship structure across the three papers complicates the evaluation:

- Paper 1 has three authors, with the candidate listed as the second author. It is stated that the first and second authors share first authorship, but the exact nature of the candidate's contribution remains unclear. The candidate's supervisor is not an author of this paper.
- Paper 2 lists six authors, with the candidate as the first author, which suggests a leading role in this work. The supervisor is listed as the fourth author.
- Paper 3 includes five authors, with the candidate as the second author. The supervisor is mentioned only in the acknowledgments.

While the PhD thesis indicates that the chapters are based on these three papers, it does not provide a detailed account of the candidate's specific contributions to each publication. This information is also not given in the papers themselves. Without this clarity, it is difficult to ascertain the precise extent and originality of the candidate's input in comparison to the co-authors.

To provide a more robust assessment, the thesis could have explicitly outlined the candidate's contributions to the research design, methodology, analysis, and writing for each paper. Such information is critical for evaluating the author's independent contribution to the field. I propose to hand in this information later.

What is the cognitive significance and practical relevance of the author's contribution?

The author's work has practical relevance, particularly in the application of quantum computing to real-world problems. Each paper contributes to advancing our understanding and application of quantum algorithms in distinct ways:

- Hamiltonian-Oriented Homotopy QAOA: This contribution enhances the understanding of hybrid optimization methods by improving the performance and scalability of QAOA. Its practical relevance lies in its potential to address real-world combinatorial optimization problems more effectively, which are common in industries such as logistics, finance, and engineering.

SF

- Error Mitigation for Variational Quantum Algorithms (VQAs): This work introduces innovative techniques for managing noise in quantum computations, specifically through mid-circuit measurements and post-selection methods. These approaches enhance the reliability of quantum algorithms on NISQ devices, with practical applications in fields such as quantum chemistry and optimization, where noise presents a significant challenge.
- Quantum Annealing for Music Composition: While less traditional, this contribution demonstrates the versatility of quantum computing by solving structured optimization problems in a creative domain. It showcases how quantum annealing can be applied to interdisciplinary fields, and it inspires broader applications of quantum technologies beyond their conventional boundaries.

Overall, the author's contributions are cognitively significant as they extend the theoretical and practical horizons of quantum computing.

Does the dissertation demonstrate the author's sufficient knowledge of the technical sciences and detailed knowledge in the relevant field of research?

The papers themselves demonstrate that the author possesses sufficient knowledge of technical sciences and detailed expertise in the relevant field of research. Each paper engages with current challenges in quantum computing and presents innovative approaches to address them. They reflect a strong understanding of both the theoretical and practical aspects of the field.

However, the thesis as a whole may lack depth. This is likely a consequence of its broader scope, as the three papers stand independently rather than building upon each other in a cohesive, in-depth progression. While this approach highlights versatility and breadth of knowledge, it somewhat limits the opportunity to demonstrate deeper, interconnected insights across the chosen topics.

What are the weaknesses of the dissertation?

I see a few weaknesses that could have been addressed to strengthen the thesis' impact.

First, the general applicability of the methods proposed in the papers is not thoroughly explored. Providing more context for the results and critically discussing their broader implications would have been beneficial.

Second, the dissertation lacks a discussion on the value of the proposed methods in the context of future advancements in quantum computing. For example, if fault-tolerant quantum computing becomes widely available, it is unclear whether the techniques developed in this work would still hold relevance.

Third, the evaluations could have been more robust. Re-running experiments specifically for the thesis to place the results in context, compare them comprehensively to alternative methods, and provide additional insights would have added significant value.

Fourth, the thesis would have significantly benefited from thorough proofreading. It contains numerous typographical and grammatical errors. While these do not diminish the significance of the results, they detract from the overall presentation and may distract the reader.

Assessment of whether the submitted dissertation meets the statutory requirements for doctoral dissertations in the field of Engineering and Technology in the discipline of Information and Communication Technology. If it should be distinguished, include reasons.

As far as I can assess, the thesis meets the statutory requirements for a doctoral dissertation in the field of Engineering and Technology, specifically in the discipline of Information and Communication Technology.

The content demonstrates the author's ability to conduct independent research, to contribute to the field, and to engage with state-of-the-art challenges in quantum computing. It satisfies the academic and technical criteria for a doctoral dissertation.

In conclusion, the thesis meets the requirements but should not be distinguished.

Yours sincerely,

Sebastian Feld

Delft, January 8, 2025

SF