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# Jury Member Report – Doctor of Philosophy thesis.

**Name of Candidate:** Oksana Borzenkova

**PhD Program:** Computational and Data Science and Engineering

**Title of Thesis:** Linear optical realization of variational quantum algorithms

**Supervisor**: Professor Jacob Biamonte
**Co-supervisor**: Dr. Stanislav Straupe

**Name of the Reviewer: Vladimir V. Palyulin**

| I confirm the absence of any conflict of interest | **Signature:**<br><br>**Date: 25-11-2024** |
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| **Reviewer's Report** |
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| The manuscript "Linear optical realization of variational quantum algorithms" submitted as a PhD thesis by Oksana Borzenkova is devoted to the implementation of variational quantum algorithms on photonic devices. The thesis consists of 6 chapters (the last one being the conclusion section) and is based on 3 published Q1 papers with 2 out of 3 being first author publications. This securely fulfils the requirements of the PhD thesis defence policy of Skoltech.<br><br>The text consists of 2 introductory review chapters, 3 chapters describing the results obtained by the defendant and the conclusion chapter. The first introductory chapter describes the current state of the quantum algorithms especially emphasising the high relevance of variational quantum framework in the era of noisy intermediate scale quantum circuits. Thus, the principles of variational quantum eigensolver (VQE) and quantum approximate opimisation algorithm (QAOA) are elaborated. The second chapter reviews the literature on the physical realisation of qubits coverig atomic, superconducting systems as well as photonic processors. The latter are covered more in detail. In particular the different ways of encoding, the basic elements of a photonic processor, the methods of controlled photon generation as well as the schemes of quantum state preparation are described. The ways of implementation of the gates are also discussed thoroughly. The chapter ends with the overview of implementation of variational quantum algorithms introduced in chapter 1. The third chapter talks |

about the phase transition of the Schwinger Hamiltonian and the effect of the noise on it. The study is performed through the implementation of VQE algorithm in a photonic system. An investigation into the limitations of variational algorithms on NISQ architectures for the identification and quantification of quantum phase transitions is conducted through the exploitation of engineered noise and decoherence in polarization qubits. The chapter number 4 introduces the concept of quantum error correction delving first into phase flip and a bit flip errors framework and discussing the up-to date approaches to the error correcting codes including Three-Qubit Bit-Flip code, Five-Qubit Phase-Flip code, Bacon-Shor code and surface codes. The next section of the chapter brings in an idea that currently the error mitigation is a more relevant alternative to the correction. The efficiency of one of the mitigation methods, namely, zero noise extrapolation (ZNE) is then tested in real experiment for the VQE algorithm for finding the minimal eigenvalue of the Schwinger Hamiltonian on a photonic quantum processor. The match between the simulations, theory and experiments for the values of the ground energy looks excellent. The thesis then describes a new strategy for speeding up the VQE with error mitigation based on a delayed application of ZNE. The last chapter with original results, Chapter 5, is devoted to the details of preparation of a good quality multi-photon sources.

This thesis is a comprehensive body of work that combines theoretical and experimental contributions. The text is well-written and presents a unified and coherent study. The research presented in this thesis significantly advances the field of quantum computing based on photonic devices. In addition to the high quality of the publications on which it is based, the thesis demonstrates the author's ability to apply cutting-edge techniques, their deep knowledge of the relevant literature, and their skill in using these resources to produce reliable scientific results.

While reading the text the questions came my mind:

From the Fig 4.8 it seems that the relative error decreases monotonously with the delay of the error mitigation. The question is whether there is a lower limit for this method of error reduction? Because currently it looks that the best strategy is to delay the mitigation as much as possible which is rather counter-intuitive.

Apart from the question I have spotted some minor typos such as initials of SA Akhmanov in Ref. 4 (should be SA not CA) or “unimoal” on page 47, the conflicting notations (H is used both for a horizontal polarisation and a Hamiltonian, V is both a vertical polarisation and a HOM visibility). Also, some figures such as, for instance, 4.4 and 4.5 do require an improvement of captions. The latter have to be more self-explanatory.

**Provisional Recommendation**

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

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| ☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report* |
| ☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense* |