Skoltech Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Andrey Kardashin

PhD Program: CDSE

Title of thesis: On applications of variational quantum circuits

Supervisor: Professor, Jacob Daniel Biamonte

Name of the Reviewer: Vladimir V. Palyulin

I confirm the absence of any conflict of interest	**Signature:** **Date: 17-04-2023**

Reviewer's Report

The manuscript "ON APPLICATIONS OF VARIATIONAL QUANTUM CIRCUITS" submitted as a PhD thesis by Andrey Kardashin is devoted to variational quantum algorithms and their implementation. The thesis consists of 4 chapters and is based on 4 published first author papers and 2 other papers published in refereed journals. Among them 3 first author papers are published in Q1 journals indexed in WOS/Scopus and one first author paper is published in Q2 WOS/Scopus indexed journals while the two articles with Andrey being the second or the third author are Q1 journals. This securely fulfils the requirements of the PhD thesis defence policy of Skoltech.

The text consists of 2 introductory review chapters, 2 chapters describing the results obtained by the defendant, the short conclusion and 3 appendices. The first introductory part includes a detailed description of the concept of quantum computations, mathematical notations, examples of diagram technique for tensor networks, notions of quantum circuits and quantum gates. The second chapter is devoted to review of the basics of variational quantum computing with examples from the papers of the defendant. The variational quantum computing is a hybrid quantum-classical approach to the computation. First, the variational quantum eigensolver (VQE) is introduced. Then the experimental realisations of VQE are

discussed including superconducting, ion traps and photon polarisation qubits. As an example of usage the case of a soliton solution for the spin system with Dzyaloshinskii-Moria interaction is discussed in detail with figures from Andrey's publications.

The next section, chapter 3, already shows the new results obtained by the defendant and is devoted to variational algorithms and tensor networks. The diagram techniques for tensor networks introduced in chapter 1 are applied to the terms appearing in variational quantum computations. The example of numerical experiments conducted for diagonalising random 5-qubit Hamiltonians with this method are presented. Then the diagrams are applied for variational state preparation, variational linear system solver and variational quantum state diagonalisation.

The chapter 4 focusses on the variational quantum channel discrimination and classification. Multiple numerical experiments are performed for the discrimination of two channels and then compared with the theoretical optimum. The variational approach produces very decent results for 10 layers or more in the quantum ansatz. However, the variational result is asymmetric unlike the theoretical limit. The conclusion summarises the findings and the novelty of the whole thesis.

Overall I am very impressed by the depth and the scope of the techniques used in this thesis. Yet the text is very cohesive and makes a very good impression of the consistent and ideologically unified study. The treatise presents a significant advancement of the field. In combination with high quality papers it highlights the ability of the author to implement the cutting-edge techniques, his deep knowledge of the pertinent literature and the capability to use them to produce trustworthy scientific results.

As remarks I would like to point out a few points which were not covered in the text but could present an interest for a reader.

1. The defendant describes the photon polarisation qubits which is one of the main physical realisations of quantum computations. However, there is no mentioning of the nature of the noise in photonic schemes.

2. In the third chapter in Figure 3-1 quite a general statement is made that reduces the Eq. 3.2 to $<\psi|M|\psi>$ form. In the later parts of the chapter similar statements are produced for other terms appearing in the computations. Are there any quantum algorithms where the needed terms does not allow this kind of reduction?

3. In the fourth chapter it is not clear how the sampling size (number of independent realisations) affects the work of VQE.

4. The name of chapter 4 sounds quite misleading. While it is claimed that "variational quantum computing approach can be utilized for solving machine learning tasks" the words "machine learning" appear just twice in the whole chapter and the connection between the classical machine learning and the quantum version is not well explained neither the presents a content of the chapter. I suggest

renaming of the chapter to something more descriptive of the content.

Besides I have spotted a few typos/needed minor corrections

In the pdf file clicking on the references [2]-[5] leads to the beginning of the file to the list of defendants publications. There [5] is denoted as 1 in the second list. I suggest that the hyperlinks lead to the end of the file or to be deleted.

The first sentence in the chapter two the part after colon " the input and output for a quantum algorithm is commonly a quantum state" should be substituted with "The input and output for a quantum algorithm are commonly quantum states"

In the numerated list after Eq. 2.1 the articles are to be checked and corrected

The sentence in the beginning of 2.1 "In Section 1.5 we mentioned the time-dependent Schrödinger's equation which is very important in quantum physics." should be modified. It is a common knowledge that quantum physics is basically built on the Schrödinger's equation. I would reformulate the sentence such that it sounds more professional

Two typos spotted in the caption of Fig. 4-7, "of of" and "whine"

Provisional Recommendation

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

☐ ~~*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*~~