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Report on the PhD thesis written by Stancho Georgiev Stanchev under the supervision of N.V. Vitanov at Sofia University (Bulgaria).

The dynamic evolution of a selected initial state of a quantum physical system satisfies appropriate equations of motion and defines a quantum process.

Achieving a high degree of fidelity in the experimental characterization of a quantum process is crucial at a fundamental level, also from a theoretical perspective. In fact, it allows the critical evaluation of the robustness of theoretical frameworks for modeling the quantum system under scrutiny. On the other hand, high fidelity becomes a non-negligible requirement for quantum applications where the ability to control the process must be high to enable viable technological approaches.

The urgency of improving the performance of Quantum Process Tomography (QPT) has stimulated the birth of novel theoretical-computational schemes and related experimental techniques. Such proposals ideally aim to circumvent possible sources of uncertainty (SPAM, readout, and shot noise in QPT) in the control of the measurements of physical observables and therefore in the reconstruction of the time-dependent density matrix of the system (the true goal of QPT). To achieve this goal, refinements to standard QPT techniques have recently been suggested in the literature. These refinements exploit the idea that using repetitive approaches enhances the precision and accuracy in measuring and analyzing the quantum process, thanks to the accumulation and subsequent amplification of a specific error.

In general, and ideally, Quantum Tomography (but also Classical Tomography) performs the analytical or computational reconstruction of an unknown state, for example, the initial density matrix, starting from the knowledge (acquired experimentally) of the probability distributions of appropriate physical quantities. It is thus a remarkable example of solving an inverse problem, meaning that the unknown density matrix of a system is determined, hopefully with high fidelity, starting from knowledge of the instant-by-instant behavior of its observables.

This doctoral thesis fits into this important research context (fundamental and applied) of great topicality and international scope, whose main objective is the production of a new class of quantum computers that are better controllable and therefore more performing.

In the thesis the technical aspects and the narrative part are well balanced. The motivations of the thesis project are recalled in several points of the manuscript, thus offering the reader the opportunity to refresh them. The presentation is clear and written in good English.

The extensive bibliography appears very appropriate. A short concluding section summarizes the content of the thesis and succinctly exposes possible developments of the original contributions that appear starting from the fourth chapter.

The second and third chapters essentially respond to the pedagogical needs of the reader who is not familiar with the topic being discussed and try, in a certain sense, to make the thesis self-consistent. The presentation in these two chapters proceeds rapidly, since it essentially aims to establish the notation and to collect in a consequential way concepts, mathematical tools and useful results for a profitable reading of the successive three chapters.

Chapter 4 introduces a specific tomographic technique called Multipass Quantum Process Tomography and contains an in-depth discussion of the properties resulting from the use of repetitive methods. It is worth highlighting that, in addition to the increase in precision and accuracy, the peculiar choice of always repeating the same gate (here used as synonym of “quantum process”) provides complete information on the quantum process, allowing the evaluation of errors attributable to the different existing sources. In the same chapter, appropriate simulations carried out on the real IBM quantum processor IBMQ_MANILA seal the greater accuracy of the MQPT method compared to standard Quantum Tomography techniques.

Chapter 5 demonstrates the applicability of the previous ideas by analytically studying the interaction of a multistate quantum system with a driving field consisting of N identical single step fields that is a pulse train. It is shown exactly that, when the quantum system model possesses Wigner-Majorana SU(2) or Morris-Shore symmetries, the propagator of the multistate system can be expressed in terms of the propagators of two-state systems and the number of MQPT steps. This result, besides its intrinsic value. Is important since it suggests the possible extension of the method to more complex systems (with the same symmetries), such as those investigated in the following chapter 6, where the characterization of a high-fidelity Raman qubit gates is successfylly investigated.

The results obtained by S.G. STANCHEV as PHD student under the supervision of prof. N.Vitanov have led to three publications in the following international physics journals:

1. Stanchev S.G., Vitanov N.V., “Coherent interaction of multistate quantum systems possessing the Wigner–Majorana and Morris–Shore dynamic symmetries with pulse trains.” *J. Phys. B: At. Mol. Opt. Phys.* 56 014001 (2023).

2. Stanchev S.G., Vitanov N.V., “Characterization of high-fidelity Raman qubit gates.” *Phys Rev A* 109, 012605 (2024).

3. Stanchev S.G., Vitanov N.V., “Multipass quantum process tomography.” *Sci Rep* 14, 18185 (2024).

The results achieved in this thesis by S.G. Stanchov provide a solid theoretical platform for the construction of applications to even more complex systems than those, already of considerable interest, examined in chapters 5 and 6.

The presentation of the formal analytical developments is elegant and above all, in my opinion, pregnant. The reported computational simulations legitimize the expectation that the specific MQPT introduced in chapter 4 may still inspire ideas for subsequent qualitative leaps in improving the fidelity of quantum tomographic processes.

In closing my report, I believe that S.G. Stanchov well deserves admission to the PHD defense in 2024.

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