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Report on the PhD thesis manuscript :

Probabilistic quantum error correction codes for general noise channels

Presented by :

Ryszard KUKULSKI

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We are at the dawn of a new quantum revolution, driven by the recent advances in quantum information theory and its many applications. These advances were, in turn, made possible by the technological advancements allowing to achieve experiments that were not possible before. However, despite all these advances, errors induced during the information processing are ubiquitous and the much research recently is focused on dealing with these errors. Enters quantum error correction which is a pivotal framework within quantum computing that addresses the susceptibility of quantum systems to various types of errors caused by external factors or imperfections in hardware.

Just as classical computers use error correction codes to ensure accurate data transmission and storage, quantum error correction employs analogous techniques to safeguard delicate quantum information from the disruptive effects of noise and decoherence. This is crucial because quantum systems are incredibly sensitive to their surroundings, making error correction a fundamental necessity for achieving reliable and fault-tolerant quantum computation. By effectively identifying and rectifying errors, quantum error correction paves the way for the development of robust and scalable quantum technologies, enabling the realization of more powerful and complex quantum algorithms, simulations, and cryptographic protocols.

It is in this context that the PhD thesis in question fits. More precisely, the thesis deals with the so-called probabilistic quantum error correction codes (PQEC). Unlike traditional deterministic quantum error correction, where errors are precisely identified and corrected, PQEC acknowledges that complete error correction might be resource-intensive and instead aims to probabilistically reduce error rates. This allows this approach to offer advantages in terms of efficiency and scalability. This theme of research is of great importance for the development of the field of quantum computing and reaching the next stage of efficient implementation of quantum computers.

The thesis clearly identifies the challenges and tasks that remain to be done in this field and addresses them with success. For instance, it addresses the problem of identifying the cases for which PQEC codes work efficiently and the cases where they don't. In the case of deterministic quantum error correction codes, this is obtained by applying the Kill-Laflamme theorem. The author clearly identifies and formulates this problem, the importance of such results and how they are missing in the case of PQEC codes. He addresses it by presenting a generalization of the Kill-Laflamme theorem that identifies the conditions on a given noisy quantum channel, for which PQEC codes are successful. This constitutes the main result of the thesis and the author's original contribution to the filed on a theoretical ground. In addition to that, on the practical level, a method of constructing approximate probabilistic quantum error correction codes is presented in the thesis and it is applied to randomly generated quantum channels. With these original contributions, it can be asserted that the author has solved the problem posed, using the right methods.

The cognitive significance of the these contributions resides in demonstrating the applicability of PQEC codes in the first place then in identifying the cases where they can be successfully applied. The practical relevance, on the other side, resides in providing practical methods for constructing such PQEC codes. If there are any weaknesses in this study, they reside in this practical side, as in order to test the method presented, the author uses randomly generated quantum channels. As this method is based on numerical methods, it does not provide a general analytic proof of the validity of the method.

The thesis manuscript is written in English and consists of six chapters, including an introduction and a concluding section that includes the summary of findings and relevant discussions. Three of the chapters (chapters 3, 4 and 5) present the different findings of the thesis research related work, while the chapter 2, includes the theoretical tools needed to understand the different results. The manuscript is self-contained, making it an easy read. It is well-written overall and the pedagogical effort in the is clear, demonstrating the candidate's mastery of the subject of the thesis.

The thesis manuscript is based on two papers published by the candidate in specialized international peer-reviewed journals that are indexed in all prominent academic databases. The performance of the journals in which the papers are published are summarized in the following tables.

Article 1	Generating random quantum channels.	
	Journal of Mathematical Physics, 62 (2021) 062201	
	Impact factor: 1.3	SJR: Q2

Article 2	On the probabilistic quantum error correction	
	IEEE Transactions on Information Theory, 69 (2023) pp. 4620-4640	
	Impact factor: 2.978	SJR: Q1

It is very important to emphasize that the candidate has coauthored other significant publications that go beyond the scope of the thesis. This achievements highlights his capacity to contribute to the field and demonstrate his sufficient knowledge of the technical sciences and detailed knowledge in the field of quantum error correction. The thesis work establishes him as a promising young researcher in the field.

In conclusion, the research work of Mr. Ryszard Kukulski constitutes a very PhD thesis with important contributions. The author demonstrates remarkable expertise on the subject and sheds light on relevant fundamental questions. I obviously recommend authorizing the defense of this very interesting thesis.

Signed : Morad EL BAZ (Prof.)