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## Quantum complexity in the presence of quantum error correction and prevention

SILVA, Adonai Hilario da[1]; MORAZOTTI, Nícolas André da Costa[1]; NAPOLITANO, Reginaldo de Jesus[1]

adonai.silva@usp.br

[1]Instituto de Física de São Carlos - USP

Complexity theory is the study of temporal and spatial resources required for solving computational tasks. With the advent of quantum computation, the complexity of quantum algorithms was usually treated as how the number of necessary quantum gates increased as the size of the input grew. An alternative approach, presented by M. A. Nielsen, is based on the idea that geodesics on the manifold of the symmetry group of transformations on $n$ qubits, the $\mathrm{SU}(2^n)$ group, are curves whose length is a lower bound of the usual definition of complexity, that is, the number of required quantum logic gates. (1) The general proposal is to use some suitable Riemannian metric that penalizes directions that correspond to hard-to-make operations. More recently, an alternative method was proposed, in which a sub-Riemannian metric is used instead, meaning some dimensions of the manifold are completely forbidden and the geodesics live in a subgroup. (2-3) In the current developments of quantum computers, sometimes called the NISQ era, the main obstacle to reaching high-scale quantum computers is the presence of noise in such devices. With that in mind, the objective of this work is to utilize the sub-Riemannian geometry formalism to investigate the influence of noise and error correction on the complexity of a problem. Initially, we study the case of a single noisy qubit, which can be simulated using quantum purification with an ancillary qubit. We aim to identify geodesics that connect the identity to a unitary operation, sufficiently close to the ideal case, despite the presence of noise. The main challenge lies in determining the unknown initial conditions for the desired unitary operator. An approach that has shown promising results involves utilizing a neural network to correlate unitary operations with the initial conditions. Interestingly, the predicted initial conditions can lead to high-fidelity gates using control fields that do not require rapid oscillations or pulses, as seen in dynamic decoupling methods, for example. Future work includes extending this idea to a two-qubit case, as high-fidelity single-qubit gates combined with entanglement enable universal quantum computation. Furthermore, we might consider testing the calculated control fields on practical devices, such as those provided by IBM and other companies.

**Palavras-chave:** Geodesic. Unitary group. Complexity.

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