PHYSIQUE – CHIMIE INGÉNIERIE	NANOSCIENCES – PHOTONIQUE – SCIENCES DES MATERIAUX & CARACTERISATION

PhD Thesis project – Laboratory ICB

Optimal control and quantum sensing for quantum technologies: Application to superconducting qubits and qudits

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Summary and relevance of the PhD project

Controlling quantum systems with high efficiency and minimum resources and time is of paramount importance for quantum computing and more generally quantum technologies. Their operational implementation remains a major challenge due to the fragility of quantum states and to the high-fidelity requirements for achieving quantum advantage. The main obstacle comes from the exposure of the system to various errors, such as systematic errors or noise, while standard processes used at present do not exploit the full potential of the underlying Hilbert space. This is even amplified by the limitation of the dominant qubit circuit model, which imposes decomposing an algorithm into a sequence of many two-state system gates.
This project will focus on optimized control of both qubit circuit models as well as of alternative computational models using qutrits and, more generally, qudits. On the basis of established results for relatively simple systems, we will identify different routes in these extended Hilbert spaces, which are potentially more robust and faster, in particular with the use of machine learning techniques. The processes will be designed theoretically and numerically, and will be implemented on IBM's quantum computers freely available and in laboratories of our partners on superconducting platforms.

Details and objectives of the PhD project

Our project aims to develop optimal and robust control schemes of high fidelity for applications into the superconducting platform, one leading candidate for realizing large-scale quantum information processing [10,11]. Limiting factors, such as imperfection of the controls and model inaccuracies or noise, still prevent quantum technology from clearly outperforming classical technology.
Imperfections of the model can sometimes be alleviated by open-loop (non-feedback) control, such as adiabatic, composite pulses (see e.g. [1]) or shortcut to adiabaticity techniques [12]. However, these lack optimality, requiring unnecessary resources and time of operation, and are thus exposed to decoherence. One of the tasks of our project will be to implement optimal and robust open-loop control methods using advanced methods incorporating both ingredients:

robustness and optimality [8]. Similar techniques will be developed for the problem of optimal quantum sensing.

An important issue in superconducting platforms is the definition of the qubit model as a two-state approximation from a weakly anharmonic potential, which induces a leakage from the ideal qubit subspace that has to be eliminated. Several techniques have been proposed and implemented [13,14], but to date no optimal reduction method has been established. We will extend our method [8] to suppress optimally such leakage.

We will focus on alternative qudit-based models (e.g. qutrit) [2], offering different control routes in a larger Hilbert space that are less time-consuming than traditional qubit circuit models.

For these objectives, we will employ various machine learning techniques (such as deep reinforcement learning) (see, e.g. [15]) for the optimization procedures.

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