Q 53: Quantum Control

Time: Thursday 14:30–16:30 Location: HS 3118

Q 53.1 Thu 14:30 HS 3118

Quantum Control on a Quantum Computer: Theory and experiment — •Nikolay Vitanov — Sofia University, Bulgaria

Recent results from quantum control experiments on some quantum processors offered by IBM Quantum will be reported. The experiments have been performed using the back-end Qiskit Pulse package, which offers full control over the experimental parameters: pulse amplitude, frequency, phase and shape. The results include the demonstration of composite pulses - trains of pulses with well-defined relative phases used as control parameters - for complete (X gates) and partial (Hadamard and general rotation gates) population inversion, which cancel the experimental errors to an arbitrary order. Another example is the newly proposed quantum control technique of polychromatic pulse trains - sequences of pulses of different appropriately chosen frequencies used, instead of the phases, as control parameters.

Conventional wisdom suggests that the excitation line profile should broaden when the Rabi frequency increases - this is the textbook effect of power broadening. Earlier work demonstrated that power broadening may not occur in pulsed excitation and revealed the near absence of power broadening in excitation by Gaussian pulses. Quite remarkably, we have observed the counterintuitive phenomenon of power narrowing with driving pulses of Lorentzian shape - the squeezing of the excitation line profile when the Rabi frequency increases. While this stunning effect had been predicted earlier it has never been observed in an experiment.

Q 53.2 Thu 14:45 HS 3118

Determining the ability for universal quantum computing: Testing controllability via dimensional expressivity — •Fernando Gago-Encinas[1], Tobias Hartung[2,3], Daniel M. Reich[1], Karl Jansen[4], and Christiane P. Koch[1] — [1]Freie Universität Berlin, Berlin, Germany — [2]Northeastern University London, London, United Kingdom — [3]Northeastern University, Boston, Massachusetts, USA — [4]NIC, DESY, Zeuthen, Germany

Universal quantum computing requires a quantum system that is operator-controllable. However, the number of resources required for controllability in complex systems is not obvious and, moreover, assessing this property on the systems themselves is a difficult task to achieve in practice. In this project we present a hybrid quantum-classical algorithm, uniting quantum measurements and classical calculations.

The key to our approach is the design of a parametrized quantum circuit (PQC), which can be run on the original system with some auxiliary qubits. By applying dimensional expressivity analysis we are able to count the number of independent parameters in the PQC. This represents the dimensional expressivity of the PQC, which is then linked back to the controllability of the initial system.

Q 53.3 Thu 15:00 HS 3118

Optimizing bosonic two-qubit quantum gates — •Marcus Meschede[1] and Ludwig Mathey[1,2] — [1]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

Qubits that are encoded in the bosonic modes of cavities have emerged as a compelling platform for robust quantum computing. This is due to their high dimensional encoding of the logical qubit states, for which several error correcting schemes exist. Circuit and cavity QED setups realize this system through microwave cavities, coupled by additional ancillary transmon qubits. In this work, we optimize local driving pulses of the cavities and the transmon in order to implement two qubit quantum gates. We evaluate different choices for the logical qubit encoding in the presence of realistic decoherence processes and find high-fidelity quantum gate implementations.

Q 53.4 Thu 15:15 HS 3118

Applying optimal control to atomic quantum simulators — •Matthias Hüls[1], Robert Zeier[1], Felix Motzoi[1], and Tommaso Calarco[1,2,3] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), Jülich 52425, Germany — [2]Institute for Theoretical Physics, University of Cologne, Köln 50937, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

We study how optimal control can enhance the efficiency and robustness of atomic quantum simulators. We develop effective control pulses adapted to experimental platforms based on neutral atoms in optical lattices and Rydberg atoms. We compare optimization techniques using model-based numerical simulations and black-box feedback directly operating on the experimental setup. We employ the quantum-control software library QuOCS [1] which provides a unified framework for applying control algorithms such as d-CRAB and GRAPE. We highlight how technical and experimental challenges influence the choice of control techniques.

[1] M. Rossignolo, T. Reisser, A. Marshall, P. Rembold, A. Pagano, P. J. Vetter, R. S. Said, M. M. Mueller, F. Motzoi, T. Calarco, F. Jelezko, and S. Montangero, "Quocs: The quantum optimal control suite", Comuputer Physics Communications 291, 108782 (2023), https://doi.org/10.1016/j.cpc.2023.108782

Q 53.5 Thu 15:30 HS 3118

Simulation and optimization methods for collision gates with ultra-cold atoms — •Jan Reuter[1,2], Tommaso Calarco[1,2,3], Felix Motzoi[1,2], and Robert Zeier[1] — [1]Peter Grünberg Institute - Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, Wilhelm-Johnen-Straße, 52428 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, 50937 Cologne, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

Atoms in an optical lattice can be used for various applications of quantum technologies, including quantum simulators or quantum computers. In our study, we simulate fermionic ^{6}Li atoms in an optical lattice using a split-step method to solve the Schrödinger equation in up to three dimensions. We analyze the behavior of one, two or three atoms in a double-well potential in a 1D-confinement under the influence of a SWAP- or $\sqrt{\text{SWAP}}$-gate. For this task, we optimize our time-dependent controls by simulating the gradient and the Hessian matrix of the quantum state with respect to these controls. Furthermore, we can verify our results by showing that the simulation of a two-atom collision in a 1D-confinement agrees with the result of a corresponding simulation assuming a 2D-confinement with a tight potential in one of these dimensions.

Q 53.6 Thu 15:45 HS 3118

Optimal control methods for two-qubit gates in optical lattices — •Juhi Singh[1,2], Felix Motzoi[1], Tommaso Calarco[1,2,3], and Robert Zeier[1] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

We use quantum optimal control to identify fast collision-based two-qubit gates in ultracold atoms trapped in superlattices based on classical Fermi-Hubbard simulations. We manipulate the hopping and interaction strengths inherent in the Fermi-Hubbard model by optimizing the lattice depth and the scattering length. We show that a significant speedup can be achieved by optimizing the lattice depths in a time-dependent manner, as opposed to maintaining a fixed depth. We obtain non-adiabatic fast gates by including higher bands of the Hubbard model in the optimization. Furthermore, in addition to two-qubit states, our optimized control pulses retain their effectiveness for one, three, or four atoms in the superlattice. We compare our Fermi-Hubbard approach with real-space simulations using Wannier functions.

Q 53.7 Thu 16:00 HS 3118

Atom transport optimization: theoretical frameworks, control algorithms, and experimental integration. — •Cristina Cicali[1,2], Robert Zeier[1], Felix Motzoi[1,2], and Tommaso Calarco[1,2,3] — [1]Forschungszentrum Jülich,Peter Grünberg Institute, Quantum Control (PGI-8), 52428 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

Ultracold atoms constitute a promising platform for quantum computing and quantum simulation. We study the transport of individual atoms in optical tweezers using methods of optimal control. As part of the BMBF project FemiQP, we are developing a theoretical framework for numerically optimizing atom transport trajectories, including strategies aimed at maximizing the transport fidelity, velocity, and robustness against experimental imperfections. Quantum control algorithms such as the dressed-CRAB (d-CRAB) and Gradient Ascent Pulse Engineering (GRAPE) are compared with regard to their utility to effectively optimize the atom transport. In collaboration with the group Christian Groß, optimized control protocols are adapted to the experimental platform in Tübingen.

Q 53.8 Thu 16:15 HS 3118

Quantum Error Correction with Quantum Autoencoders — •Diego Alberto Olvera Millán[1], David Locher[2,3], Lorenzo Cardarelli[4], Janine Hilder[1], Markus Müller[2,3], Ulrich Poschinger[1], and Ferdinand Schmidt-Kaler[1] — [1]Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich, D-52425 Jülich — [3]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [4]Pasqal, 7 Rue Leonard de Vinci, 91300 Massy, France

Active quantum error correction is a critical element in realizing robust quantum computation. Quantum Autoencoders have the potential for discovering error correction algorithms [1]. Our study aims to transition this theoretical framework into practical hardware implementation. Our approach involves a trainable circuit. This parameterized ansatz was trained in a simulator backend and subsequently validated on a shuttling-based trapped-ion quantum computer. Future work will center around performing training using the Quantum computer to evaluate the cost function and finding codes for correcting the native error sources of the hardware.