SENSOR SCAN SIMULATION FOR AUTOMATED TUNING OF GATE-DEFINED SEMICONDUCTOR QUANTUM DOTS

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1. WHO AM I?

- Researcher at the ICA Institute of the Forschungszentrum Jülich
- M.Eng. in Information Systems Engineering – FH Aachen
- B.Sc. in Applied Mathematics and Computer Science (dual study program) – FH Aachen

2. MOTIVATION

- Tuning large numbers of qubits requires automation
- Algorithm development (especially ML) requires much labeled data
- Manually measuring & labeling is time consuming

→ Solution: Simulation

- A stable and sensitive sensor dot is needed for qubit tuning and readout
  - Sensor scans can be used for sensor dot tuning
  - Needed to sense charges in the double quantum dot

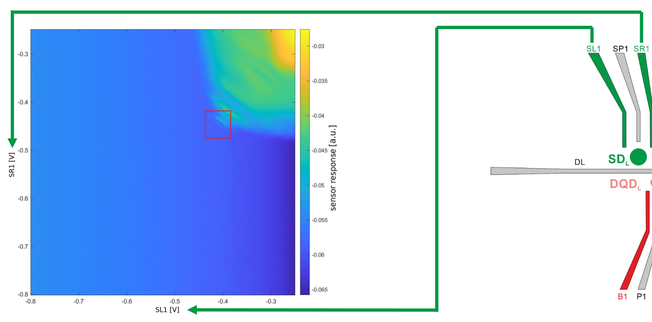


Fig. 1: Example of a sensor scan. The green arrows show the two gates that are swept over a certain voltage range to result in such a sensor scan. Figure taken from [1].

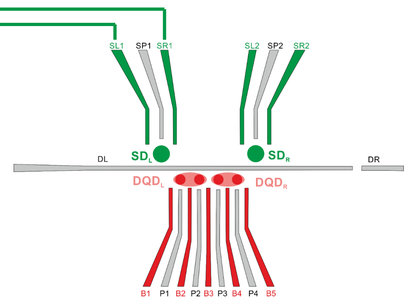


Fig. 2: Example of the gate layout of a semiconductor quantum dot sample (by T. Hangleiter, RWTH, similar to [2]). The green/red circles illustrate the regions in which sensor/quantum dots are formed. Figure taken from [3].

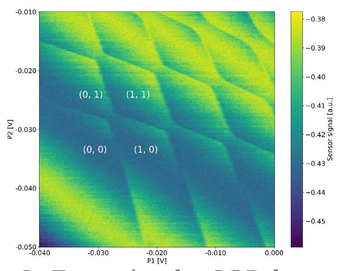


Fig. 3: Example of a CSD for a well behaving double quantum dot.

3. SIMCATS

- **Sim**ulation of **C**SDs for **A**utomated **T**uning **S**olutions [4]
- A general, flexible simulation framework with interfaces for:
  - Idealistic CSD simulation
  - Sensor reaction simulation
  - Simulation of distortions affecting
    - Number of charges
    - The corresponding sensor potential
    - The sensor responses
- Includes standard implementations and corresponding configurations
  - Geometric CSD model, Lorentzian sensor peak, dot jumps, white noise, pink noise, random telegraph noise

4. REPLICATIVE MODEL

- Available simulation software for sensor scans often use physical models
  - Simplified models, not capable of reconstructing all relevant effects
  - Physical properties of the sample must be known
  - High computational complexity

→ Replicative approach for the modeling of sensor scans

- Simple and more flexibile way to represent different structures
- No physical parameters required
  - → Easy to reconstruct measurements
- Fast calculation of the idealistic data & large voltage spaces

- Sensor simulation fully integrated into the SimCATS framework

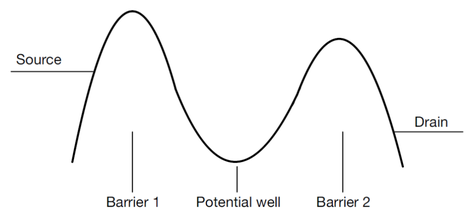


Fig. 4: Visualization of the potential landscape of the sensor dot. The potentials are influenced by the voltages applied to the gates.

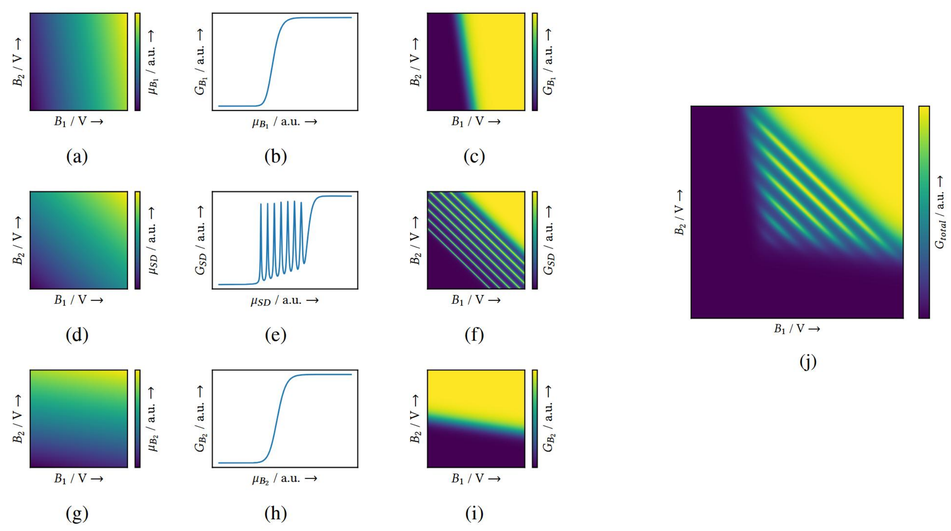
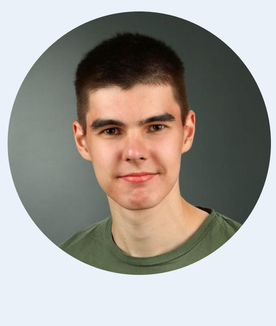


Fig. 5: Visualization of the calculation of a simulated sensor scan.
For the simulation, the three potentials of barrier 1 (a), the sensor dot itself (d), and barrier 2 (g) are first calculated. By applying barrier and sensor functions (b), (e), (h) the respective conductance values are then calculated (c), (f), (i). These are then combined in series like three resistances. This combination leads to simulation result (j).

5. OUTLOOK

- SimCATS extension and approach for simulating sensor scans will be published soon
- Possibility to further develop and test sensor tuning approaches
  - Simulated datasets as a basis and common ground for comparison
- Usage of sensor simulation in combination with CSD simulation
  - Continuously improve the sensor while moving through the CSD space



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[1] C. Volk et al. - Loading a quantum-dot based Qubyte register; DOI: 10.1038/s41534-019-0146-y
[2] F. Hader. “Noise Analysis and Estimation in Sensor Dot Fine Scans for Automated Tuning of Gate Defined Quantum Dots”. MA thesis. Fachhochschule Aachen, 2021.
[3] S. Fleitmann. “Characterization of Distortions in Charge Stability Diagrams and Their Simulation in Modeled Data”. Master thesis. Jülich: FH Aachen, 2023, p. 84. DOI: 10.34734/FZJ-2024-00621.
[4] F. Hader, S. Fleitmann and F. Fuchs. SimCATS. URL: https://github.com/fhader/SimCATS