Optimal control in atom interferometry

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Background – Interference experiments allow us to measure physical quantities with unprecedented accuracy, which in turn can be used as basis for highly sensitive devices or as test for predictions of physical theories. In practice, however, it is extremely hard to experimentally achieve the theoretically possible accuracy since numerous experimental imperfections affect functionality of an interferometer. This project is about an atomic interferometer built in Birmingham that measures minuscule gravity fields, such as the ones created by magma flows below the Earth crust.

The instrument uses laser cooling to prepare a cloud of more than 100 million atoms at a few millionth of a degree above absolute zero and launches these atoms to perform a free-fall parabolic trajectory. During the free fall, the atoms are interrogated by three laser pulses, the first putting them into a superposition of two momentum states, traveling at different height in the gravitational potential. The second pulse reverses the momentum states, such that the atomic wavepacket trajectories converge and the third pulse creates an interference pattern at the point of overlap. Limiting imperfections are inhomogeneous beam profiles and a spread of initial momenta in the ensemble of atoms [1]. The different atoms will thus undergo slightly different dynamics, and the observed pattern is the average of many slightly different interference patterns.

Quite strikingly, one can make systems insensitive to such fluctuations by manipulating them with temporally shaped laser pulses as depicted in the Figure. That is, one can construct pulses such that the dynamics that an atom undergoes does not depend on the intensity of the beam (at least within some range of intensities), and such that it does not depend on the velocity with which the atom passes the beam [2, 3].

We do this with a pulse shaping algorithm [4] that can be used to construct control pulses with desired properties. The idea of the project is to apply this technique to the laser pulses for the Birmingham atom interferometer, in order to achieve optimum sensitivity in scenarios with real-world imperfections. The project will be focused (about 80% of your time) at Imperial, where you would work in the QOLS theory group with many activities on quantum control. During the entire project, you would stay in close contact with the experimental atom interferometry team in Birmingham, in order to initially determine feasible parameter ranges for the pulse shapes and ultimately see the derived pulses implemented in the experiment.

Six month project – You would start learning about pulse shaping techniques and atom interferometry. During visits to Birmingham, you would discuss the experimental imperfections with the atom interferometry team, and identify individual aspect to address. In particular, it will be important to identify which imperfections can be addressed with analytic techniques that apply to perturbative regimes, and which imperfections require a numerically exact approach. Once you have mastered the control techniques, you would start out constructing pulses that address selected imperfections. Comparing the theoretical expectation with the experimental findings will help you to gauge how good our theoretical models for the experiments are, and discrepancies between observations and expectations might indicate towards the need to improve our models or towards the existence of an additional experimental imperfection.

PhD project – In the PhD project, you would aim at devising control sequences that address all relevant imperfections together. This will require very accurate modelling of the system, and a detailed analysis on the interplay between the different relevant effects – roughly speaking, you want to make sure that becoming insensitive to one effect does no make the system more sensitive to another one. In addition to constructing controls that help to improve experiments, the Imperial team also actively develops control techniques. Working with our existing techniques, you will likely also come across new ideas to tackle questions of quantum control. That is, if you are interested (or develop this interest during the project), there will also be ample opportunities to get involved in the design of new approaches.

If you have any questions, please contact Florian (f.mintert@ic.ac.uk, level 12 EEE) or Kai (K.Bongs@bham.ac.uk).

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