Quantum Control for Atom Interferometry

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Our team at SYRTE develops inertial sensors (gyrometers, accelerometers…) based on atom interferometry technics. The development of this technology is linked to the use of cold atoms and laser beamsplitters, easy to implement and efficient, namely two photon transitions and more specifically stimulated Raman transitions. These methods allow now for the development of commercial products with applications in geophysics on the field, and of onboard instruments in ships or planes for inertial navigation and geoscience. Despite promising pioneering demonstrations, operation of these quantum sensors outside the laboratory, in concrete and varied use cases, remains an important challenge in the field, which generally requires adapting the sensor architecture to suit the environmental conditions. Our ambition is to remove the technological barriers that hinder the deployment of these sensors, in particular through the development of new methods for optimising the efficiency and robustness to environmental variations of interferometer light beamsplitters. The development of pulse shaping methods based on optimal quantum control will open up a wider range of applications for these sensors in the field.

The use of optimal control methods will make it possible to reduce drastically the sensitivity of the sensors to the various fluctuations and inhomogeneities of the physical parameters of the measurement, linked to the sensor itself or to its environment (laser intensity, magnetic field, velocity and position of atoms, coupling with lasers ...). We can here draw largely on the methods of pulse shaping commonly used in NMR, such as adiabatic passage, or even more so as composite pulses, based on sequences of pulses whose phases and amplitudes are adjusted to optimise the transfer from one spin state to another. Various demonstrations of the transposition of these methods have been carried out in the context of atomic interferometry. Optimal control represents the culmination of these methods, by determining, generally numerically, the variations, necessary to achieve the final quantum state sought, of a number of parameters of the pulse, used as control parameters, such as the phase, intensity or detuning to resonance.

The PhD project aims at implementing in state of the art atom interferometers these new methods, carrying both experimental and theoretical studies of new methods for shaping laser beams of atomic interferometers. These methods will allow to optimize the efficiency of the beamsplitters, and more particularly their robustness against fluctuations of the measurement conditions and inhomogeneities of the parameters determining their efficiency (such as the velocity of the atoms and the intensity of the lasers), whether they are intrinsic to the sensors or degraded by the variations of the environment.

On the theory side, the PhD student will continue the development already started in the team of optimal control simulation codes based on gradient methods. On the experimental side, he will use a test bench to test different methods of fast modulation of pulse parameters (phase/frequency, amplitude), in order to validate the ability of varying control parameters with the required amplitude and bandwidth. He will use as a test bed for experimental demonstration a gradiometer experiment currently being optimised, whose expected performance in the short term will be comparable to the best atomic gradiometers. This well characterised experiment, for which we have complete performance models, will be a considerable asset for carrying out a precise characterisation of the benefits and limits of the new beamsplitting control methods that we propose to study here. In particular, they will allow us to highlight possible measurement biases, and their fluctuations, with levels of sensitivity that very few instruments in the world are capable of achieving.