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Demonstration of a robust hybrid classical/quantum accelerometer

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We present the experimental realization of a hybrid accelerometer that combines the large bandwidth and measurement dynamics of a mechanical accelerometer with the extreme stability of a quantum accelerometer based on atom interferometry. We will present our experimental setup and hybridization algorithm, a new real-time system that permits robust operation in an arbitrary orientation.

Since their first demonstration in the early 1990s [1], atom interferometers (AIs), which measure the trajectory of atoms falling under vacuum with respect to a reference mirror, have proven to be excellent absolute inertial sensors. They have been exploited as ultra-high sensitivity instruments for fundamental tests of physics and as state-of-the-art gravimeters with accuracies in the range of 1-10 ng achieved in laboratories, as well as with compact transportable systems [2]. As a result, they start to be used for gravimetry and gradiometry surveys and have been proposed for the next generation of inertial navigation sensors [3]. However, they generally possess a small bandwidth and suffer from low repetition rates and dead times during which no inertial measurements can be made. In comparison, mechanical accelerometers exhibit broad bandwidths compatible with navigation and seismology applications but suffer from long-term bias and scale factor drifts. These two types of sensors can thus be hybridized in order to benefit from the best of both worlds.

We use correlations between an atom interferometer in a Mach-Zender configuration and a mechanical accelerometer to track the bias drifts of the latter (see Fig. 1), and we present an approach based on a non-linear Kalman filter (KF) to optimally track all of the atom interferometer fringe parameters—making the estimation of the accelerometer bias robust against variations of experimental parameters. We simulate a mobile environment in the laboratory by adding simultaneously vibration noise, temperature variations and laser intensity fluctuations (see Fig. 2). Even under these conditions, we are able to track the accelerometer bias to less than 1 μg. In a normal laboratory environment, our hybrid accelerometer then reaches a precision of 10 ng after 11 hours of integration (see Fig. 3) [4].

During the free-fall of the atoms in the AI, the frequency of the interrogating lasers must be adjusted to compensate for the varying Doppler shift which is the reason why virtually all current AI measure acceleration along a fixed (generally vertical) direction. We will present recent results using a new real-time system which permits one to automatically compensate phase shifts due to vibrations and frequency shifts that occur when changing the AI orientation. This allows us to operate the AI in an arbitrary direction—opening the way toward truly mobile operation.