Precise signal-tracking with atomic sensors

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We study causal waveform estimation (tracking) of time-varying signals in a paradigmatic atomic sensor, a hot alkali vapor monitored by Faraday rotation probing [1]. We use Kalman filtering, which optimally tracks known linear Gaussian stochastic processes, to estimate stochastic input signals that we generate by optical pumping. Comparing the known input to the estimates, we confirm the accuracy of the atomic statistical model and the reliability of the Kalman filter, allowing recovery of waveform details far briefer than the sensor's intrinsic time resolution. With proper filter choice, we obtain similar benefits when tracking partially-known and non-Gaussian signal processes, as are found in most practical sensing applications. The method evades the trade-off between sensitivity and time resolution in coherent sensing.

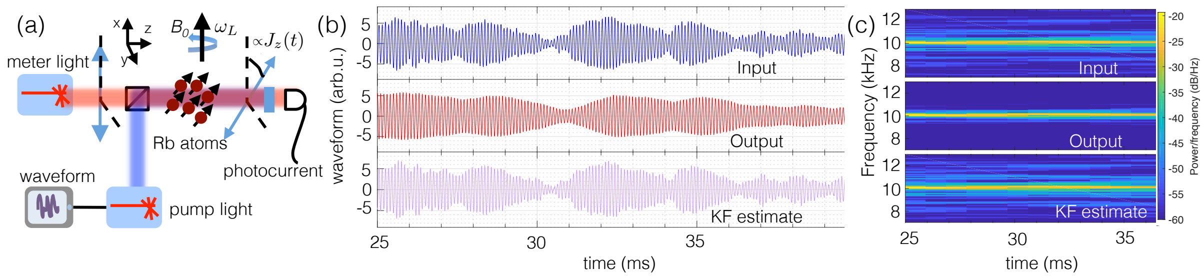

Figure 1. (a):An ensemble of ^{87}Rb atoms precesses at the Larmor frequency $\omega_L = 2\pi \times 10$ kHz defined by an external magnetic field B_0. The spin z-component, $J_z(t)$, is driven by a circularly polarized light-beam (pump) carrying the waveform to be estimated. A second laser-beam (meter) is used for a polarimetry measurement producing a photocurrent, $I(t)$, that is proportional to $J_z(t)$ plus shot noise. Transmitted pump light is blocked by a dichroic filter (shown in blue). (b): A representative applied waveform (input) along with the corresponding measured photocurrent (output) and the recovered waveform (KF estimate). (c): Spectrograms of input, output and KF estimate showing that rapidly-varying features of the input are suppressed in the output yet are recovered in the KF estimate.

[1] R. Jiménez-Martínez, J. Kołodyński, C. Troullinou, V. G. Lucivero, J Kong, and M. W. Mitchell, Signal tracking beyond the time resolution of an atomic sensor by Kalman filtering, Phys. Rev. Lett. **120**, 040503 (2018).