Towards single-shot waveform magnetometery via quantum compressive sensors

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Quantum sensors appear to be a necessary choice for resolving the weak magnetic fields produced by individual neural firings [1]. However, capturing a unique neural time-series requires single-shot waveform magnetometry. We demonstrate reconstruction of a synthesised neural-like magnetic waveform from an undersampled set of quantum measurements. A similar idea was proposed theoretically by Reference [2].

We use compressive sensing [3], a mathematical technique where signals known to be sparse can be inferred from an incomplete set of acquisitions in a different basis. This works if there is an uncertainty relation between the two bases (*e.g.* time and frequency, time and wavelet), and the set is chosen in an unbiased way. The neural-like waveform in Figure 1c is sparse in the time domain. We compressively sense the waveform by taking measurements of sine coefficients at randomly chosen frequencies. To do this we apply rf dressing to trapped ultracold ^{87}Rb atoms. The dressed states are sensitive to sine coefficients at their Rabi frequency. Readout is done via Stern-Gerlach imaging. We repeat the experiment 60 times varying dressing amplitude to obtain 60 sine coefficients; 99 would be required for a complete inverse transform. Finally, the waveform is reconstructed from the sine coefficients via convex optimisation.

To achieve single-shot waveform measurements with cold atoms, an array of traps must be created; one trap required for every sample to be measured. The number of traps in an array is severely limited by available atoms and laser power. Using compressive techniques would allow for a neural signal to be resolved using fewer traps, making a single shot measurement more feasible.

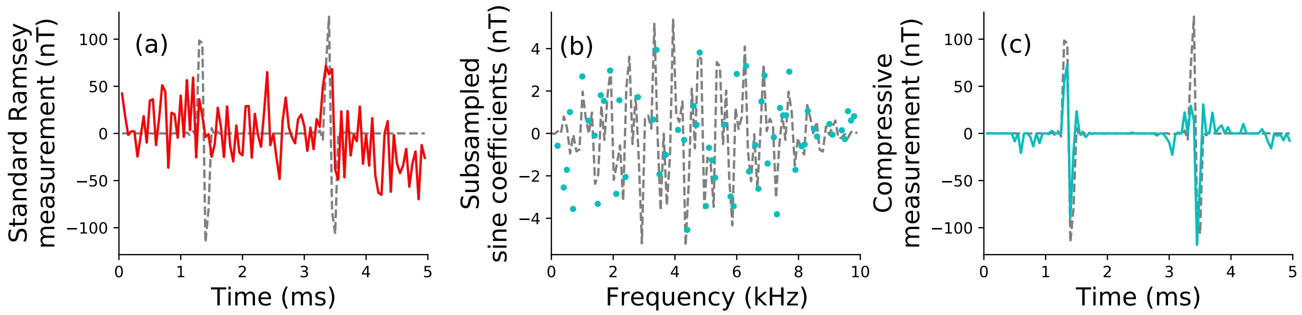

Figure 1: (a) Ramsey sampling fails to reveal neural pulses above noise and drift. (b) Frequency domain sampling (sine coefficients) encodes neural signal and decouples drift. (c) Convex optimisation reconstructs denoised neural pulses from sine coefficients, even though they are undersampled. Grey is the ground truth commanded signal.

[1] J. L. Webb *et al.*, *Scientific Reports 11, 2412* (2021)
[2] E. Magesan, A. Cooper and P. Cappellaro, *Physical Review A 88, 062109* (2013).
[3] N. Koep, A. Behboodi and R. Mathar in *Compressed Sensing and Its Applications* (Springer, 2019) pp. 1–65.