Dynamical decoupling based spatio-temporal noise spectroscopy with multi-qubit probes

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Single qubits in semiconductors have been recently used to characterize the temporal spectrum of environmental fluctuations that lead to their coherence [1]. Such sensors, with a prominent example of NV centers in diamond [2], are controlled using sequence of equidistant Rabi pulses (typically rotations by π of the qubit's Bloch vector), which makes them vulnerable to particular frequency of noise.

On the other hand, the use of two qubits gives information not only about the spectra of noises present at two points in space, but also allows for reconstruction of the spectrum of cross-correlations of the noises affecting the qubits [3]. This is due to the fact that the two-qubit coherence is sensitive to the presence, and the character, of correlations of locally experienced noises.

As an extension of both schemes, the multi-qubit coherence is expected to contain a wealth of information about both spatial and temporal correlations of the noise. Thus, we propose a protocol that fully reconstructs the spatio-temporal spectral density $S(\mathbf{k}, \omega)$ of a uniform and stationary noise, with corresponding correlation function $C(\Delta x, \Delta t)$.

We propose to supplement the aforementioned temporal filtering, by an additional degree of freedom – the shift of an applied pulse sequence. We show how such shifts, when described by a linear function of qubits position, give rise to discrete spatial filter in a Fourier space. Thus, a multi-qubit sensor driven at single spatial and temporal modes directly relates a multi-qubit decoherence rate with a spectral density $S(k_p\,\mathbf{n}_k, \omega_p)$ of the environment, and as a consequence enables one to reconstruct the latter. Finally, in analogy to [4] we show how multiple measurements with distinct sequences can be used to diminish reconstruction errors resulting from finite time of data collection and sensor length, as well as discard the aliasing caused by discrete character of the spatial filter.

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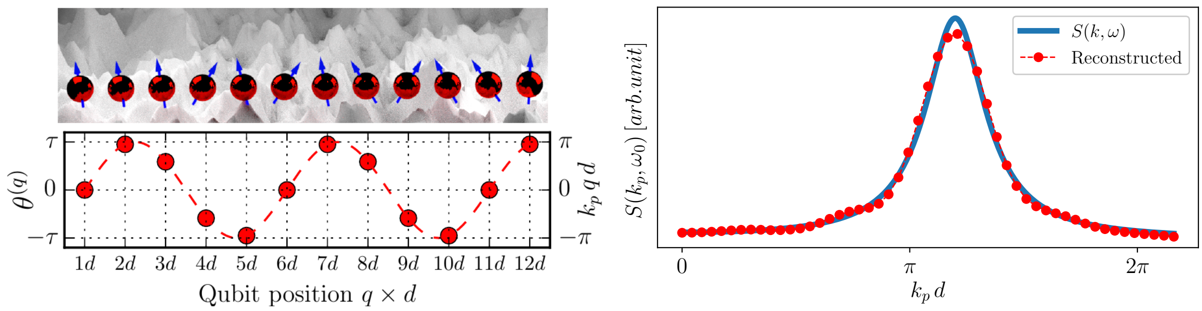

(Left) Schematic register of 12 qubits, with activated spatial mode $k_p d = 2\pi/5$,
(Right) Reconstructed Lorenzian spectrum $S(k, \omega)$ for fixed ω, plotted as a function of k.

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[2] T. Staudacher et al., *Science.* **339**, 6119 (2013).
[3] P. Szańkowski, M. Trippenbach, Ł. Cywiński, *Phys. Rev. A* **94**, 012109 (2016).
[4] P. Szańkowski, Ł. Cywiński, *Phys. Rev. A* **97**, 032101 (2018).