Sequential analysis in a continuous spin-noise quantum sensor

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Many control and detection applications require real-time analysis of signals from sensors, in order to quickly and accurately act upon events revealed by the sensors. Such signal analysis benefits from statistical models of signal and sensor behaviour. This creates a need for data analysis methods that are simultaneously model-based, computationally efficient and causal, in the sense that they employ only sensor data available prior to a specific point in time. In this work, we implement sequential data analysis techniques on a spin-noise-based quantum sensor, to perform two key tasks: hypothesis testing and quickest change-point detection. These online protocols allow us to detect weak magnetic fields by adaptively collecting measurement data until a predefined confidence threshold is reached. We demonstrate these methods in a realistic experimental setting and derive performance bounds for the achievable precision and response time. Our approach has potential utility when detecting small perturbations to the magnetic field, in both applied and fundamental contexts including biomagnetism, geophysical surveys, detection of concealed materials, searches for dark matter candidates and exotic spin interactions. Our results demonstrate that sequential techniques enable faster and more sensitive detection, making them a powerful tool for quantum sensing.

References

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Figures

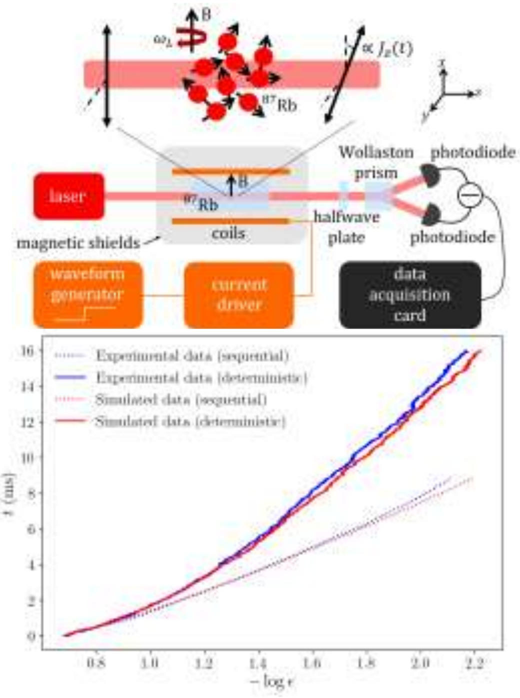

Figure 1: Top: Scheme of the atomic sensor. Bottom: Relation between error probability and required experiment duration for sequential (dotted) and deterministic (solid) strategies. The horizontal axis shows log(ε), where ε is the empirical error probability (i.e. fraction of incorrectly identified hypotheses), and the vertical axis shows the required experiment duration.