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Improvement of Time Resolution in Scalar Optically Pumped Magnetometers Using State-Space Model

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In conventional magnetic field estimation using scalar-mode optically pumped magnetometers (OPMs), the goal is to estimate the frequency of a decaying sine curve that best fits a free induction decay (FID) signal. This approach assumes a constant magnetic field during each FID period, limiting its ability to track the temporal dynamics of fields oscillating at high frequencies.

To overcome this limitation, we propose a statistical magnetic field estimation method using a physics-informed state-space model (Fig. 1). The state equation, governing the temporal evolution of magnetic fields and spins (latent variables), is derived from a temporally discretized Bloch equation. The observation equation, representing the FID signal (observed variable), is based on the magneto-optical effect, assuming the probe beam is applied along the x-axis. Using an extended Kalman filter and Rauch-Tung-Striebel smoother, the time-varying magnetic field can be estimated from an FID signal at its sampling rate.

We conducted a simulation experiment with time-varying magnetic fields oscillating at 10 Hz (600 pT amplitude) and 10 kHz (1 nT amplitude). The proposed method was compared to the conventional fitting approach. Results showed that the proposed method successfully tracked the 10 kHz field's temporal evolution. For the 10 Hz field, although the proposed method was less accurate than the conventional method, it still captured the slow dynamics. To enhance performance, we plan to reduce noise in FID signals using a differential OPM array.

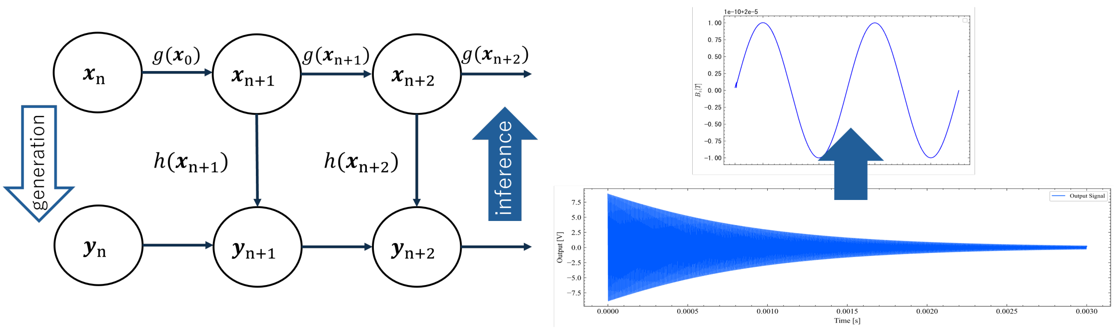

Figure 1: The proposed method based on a state-space model

Author: KINOSHITA, Ryo (Kyoto University)

Co-authors: UEDA, Hiroyuki (Kyoto University); ITO, Yosuke (Kyoto University); YOSHII, Kazuyoshi (Kyoto University)

Presenter: KINOSHITA, Ryo (Kyoto University)

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