Reinforcement learning applications for macrospin modelling

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We present simple reinforcement learning applications in spintronics: a controller for real-time tuning of a spintronic oscillator and the energy-efficient current-induced switching controller for magnetic tunnel junctions with voltage-controlled magnetic anisotropy.

Keywords: macrospin modelling, reinforcement learning, LLGS, oscillators, current switching

1. Introduction

Recent advancements in the machine learning space also brought many innovations to the field of reinforcement learning (RL). Many interesting applications of modern methods have been published, such as improving current-induced switching in MRAM cells [1] or guiding the design of spin orbit torque (SOT) and spin transfer torque (STT) based random number generators [2]. Yet, many other control mechanisms of the spintronic element could benefit from real-time control, such as tuning the spin torque oscillator parameters to achieve the desired frequency or optimizing the switching impulse in magnetic tunnel junctions (MTJ) with voltage-controlled magnetic anisotropy (VCMA) for energy efficiency. In the present work, we briefly introduce them.

2. Results and discussion

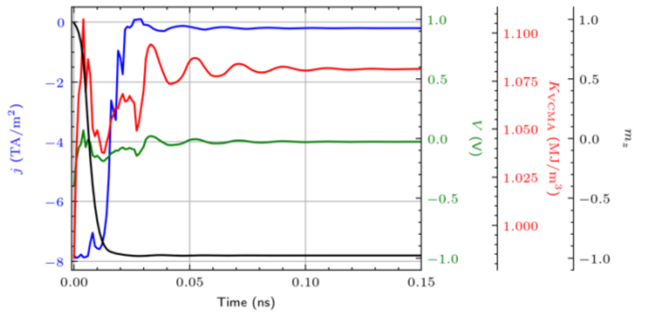

Fig. 1 A sample time series of the magnetization z-component, voltage, magnetic anisotropy and current density. The current and VCMA voltage are controlled by the RL agent.

For a spintronic oscillator, we focus on converging auto-oscillation to the user-specified frequency in the least number of steps. The RL controller can change the input feed current and the position and magnitude of the applied magnetic field. The reward is composed respectively of a frequency alignment reward, Q-factor reward, punishment for large action derivative, and success reward upon achieving the target frequency:

$$\mathcal{R} = \alpha_1|f^* - f| + \alpha_2 Q \; - \; \alpha_3 {a_t}^2 + \alpha_4 I(|f^* - f| < \varepsilon)$$

The action magnitude punishment smoothens the convergence and regulates drastic input changes. α_i are the rewards weights, I is the indicator function of successful synchronisation (within a small margin ε). Q-factor reward promotes selecting oscillation modes with a good Q-factor.
In the second outlined application, we focus on the efficient magnetization switching using SOT with the assistance of VCMA, each with a different impulse shape. The simulation time is divided into N meta-steps, each encapsulating at least 10 integration simulation points. The RL controller can adjust the input current feed and voltage at each meta-step to regulate the perpendicular anisotropy of the MTJ.
Independent terminals for separate current and voltage control are possible either in the SOT configuration or with a large MgO buffer placed atop the MTJ. The reward function promotes low energy use and targets small alignment error:

$$\mathcal{R} = \alpha_{\text{energy}}\left(|j|^2 + \frac{|V|^2}{R^2}\right) + \alpha_{\text{alignment}}|m_z^* - m_z|^2$$

where j is the current density, V is the voltage density, R is the resistance of the MTJ, m_z^* is the target position of the magnetization (-1 or 1) and m_z is the measured position of the magnetization. α_{energy} and $\alpha_{\text{alignment}}$ are weighting factors for the individual rewards. Fig. 1 shows a sample switching trajectory with the VCMA, current, and magnetization position values juxtaposed on a single graph. The controller tries to coordinate both the voltage impulse and the voltage impulse. Fig. 2 shows 25 successful realisations of switching, along with the current and voltage trajectories.

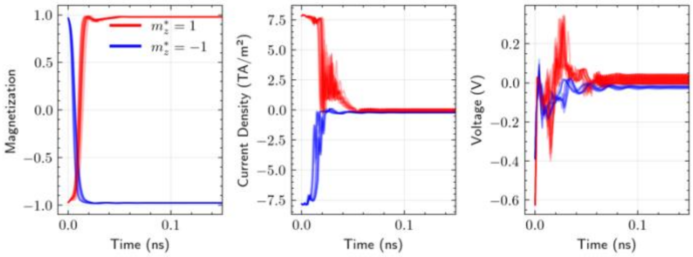

Fig. 2 A set of 25 overlayed realizations of switching. Colors denote target states.

References

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