MagTetris[+]: A rapid simulator for magnetic field and force calculation for ferromagnetic materials and permanent magnets

<u>Jing Han Heng[1]</u>, Junqi Yang[2], Wenwei Yu[2], Shao Ying Huang[1]

[1]Singapore University of Technology and Design, Singapore, [2]Chiba University, Chiba, Japan

<u>Introduction:</u> Ferromagnetic materials play a significant role in many applications due to their strong magnetic responses under an external magnetic field, such as shimming permanent magnet arrays in NMR and MRI. However, rapid and accurate simulations of ferromagnetic materials remain challenging due to nonlinear hysteresis[1] and interactions of magnetization domains[2] which are the regions with uniform magnetization. Conventional numerical methods such as Finite Element Method (FEM) are computationally intensive and time-consuming[3,4], thus creating a growing need for rapid simulations of high accuracy using low computational resources and time.

<u>Method:</u> MagTetris[+] extends the magnet-only simulator MagTetris[5] to calculate magnetic field (**B**) and force of systems comprising both ferromagnetic materials and magnets. Magnetization (**M**) of a single-magnetization domain object is determined using Curie-Weiss Law[6], incorporating the contributions from an external magnetic field ($\mathbf{H}_{\mathbf{Ext}}$), self-demagnetization and hysteresis. Mangetocrystalline anisotrophy field[7] is approximated using the angle between $\mathbf{H}_{\mathbf{Ext}}$ and **M** rather than using the object's easy axes traditionally[7]. MagTetris[+] discretizes a large ferromagnetic object into multiple domains and ensures stable and quick convergence of their interactions with a damping factor which prevents oscillation or divergence of **M**.

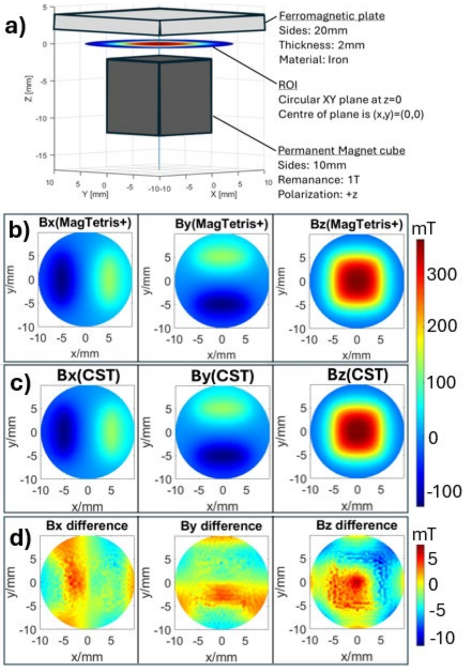

Fig. 1

<u>Results and Discussion:</u> MagTetris[+] is benchmarked against CST magnetostatic solver (with sufficient meshes) [8] on the same setup (Fig.1(a)): a large ferromagnetic plate subjected to $\mathbf{H}_{\mathbf{Ext}}$ generated by a permanent magnet. Fig.1(b)&(c) displays their **B**s on the region of interest (ROI) and Fig.1(d) shows their difference maps. As shown, the calculated **B** by MagTetris[+] is visually and quantitatively consistent with CST, proving high accuracy. To complete the simulation, CST took 40 minutes and 50GB of peak memory consumption while MagTetris[+] only requires 0.1 seconds and 0.5GB. Thus, MagTetris[+] possess speedup of 2400x and is 100x more memory-efficient against CST.

<u>Conclusion:</u> MagTetris[+] is a simulator for ferromagnetic materials and magnets which circumvent the computational bottlenecks of FEM mesh-based solvers. The computation time and resource requirements are significantly reduced, which facilitate integration with optimization algorithms and real-time design workflows. MagTetris[+] offers a practical alternative to FEM-based tools with high computational efficiency and accuracy, thus accelerating research and development in various ferromagnetic applications such as passive shimming and iron yoke design for NMR and MRI.

<u>References:</u> [1] Zheng, Elsevier. (2025) [2] Zeng, Elsevier. (2023) [3] Yan, Pier. (2015) [4] Dular, IEEE. (2024) [5] Liang, JMR. (2023) [6] Mugiraneza, Nature. (2022) [7] Kim, ACM. (2018) [8] www.3ds.com/products/simulia/cst-studio-suite