

MagNet: machine learning enhanced 3D magnetic reconstruction

Yibo Zhang, Boyao Lyu, Shihua Zhao, Weiwei Wang, Haifeng Du, Jiadong Zang
Department of Physics, University of New Hampshire

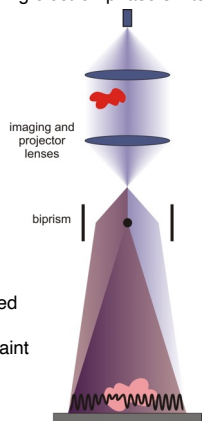
Introduction

- 3D vector field electron tomography (VFET) means 3D magnetic reconstruction from electron phase shifts retrieved from electron holography (EH) or transport of intensity (TIE) equation
- Clean electron phase shifts of two orthogonal can --> two components of the magnetic induction field B by the central slicing theorem
- Conventional analytical algorithms, such as weighted backprojection method (WBP) and regridding reconstruction method (Gridrec) can be directly extended to VFET.
- There are many sources of inevitable errors during electron phase shifts collection:
 - Missing wedge
 - Noise
 - misalignment

$$\partial_y \phi(x, y) = -\frac{e}{h} \int B_x(x, y, z) dz$$

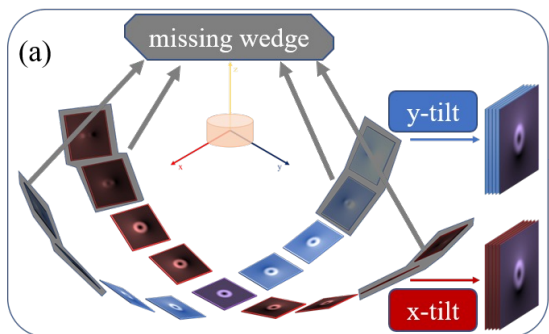
$$\partial_x \phi(x, y) = \frac{e}{h} \int B_y(x, y, z) dz$$

- The reconstruction of Bx and By can be simplified as two scalar tomography
- The third component is calculated by the constraint $\nabla \cdot \mathbf{B} = 0$.

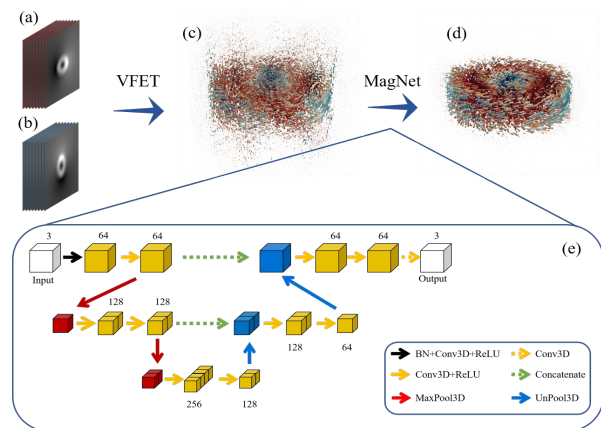


Missing wedge

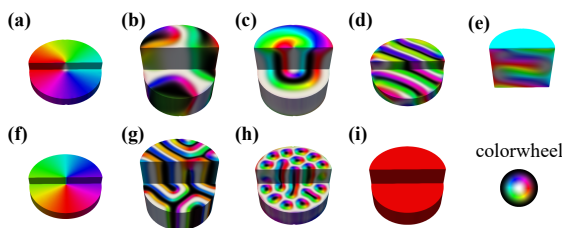
The region where data is not available due to the limited tilt angles of the specimen.



Methods

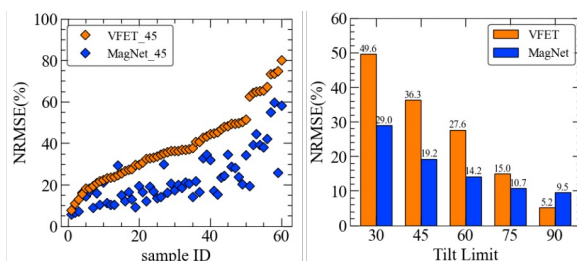


- Keras framework
- Trained on a single NVIDIA Tesla V100-SXM2-16GB graphic card
- One epoch takes about 329 seconds
- takes 100 epochs to get MagNet model ready to use

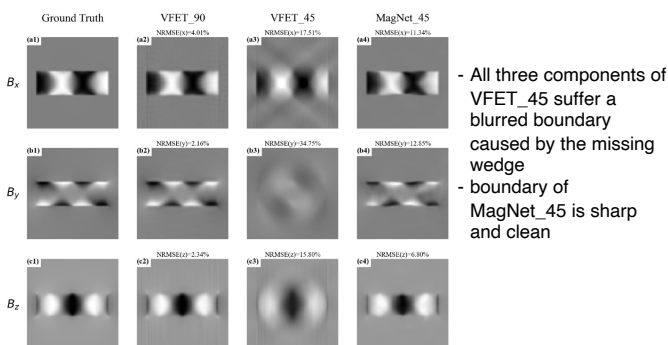


- Generated from micromagnetic software JuMag.jl
- manually selected from simulation results
- Those micromagnetic structures include vortices, skyrmions, skyrmion lattices, spin helix, conical structures, cylindrical domains, and N eel domain structures.

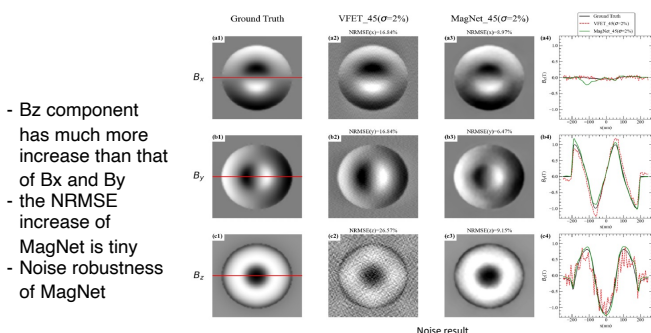
Results



- MagNet reconstruction error is smaller than VFET
- The advantage of the magnet decreases as the angle increases



- All three components of VFET_45 suffer a blurred boundary caused by the missing wedge
- boundary of MagNet_45 is sharp and clean



- Bz component has much more increase than that of Bx and By
- the NRMSE increase of MagNet is tiny
- Noise robustness of MagNet

Conclusion

1. We proposed MagNet to reduce the reconstruction error caused by missing wedge problem.
2. The reconstruction quality are significantly improved when the maximum tilt angle is below ± 60
3. The reconstruction remains stable in the presence of 2% Gaussian noise.
4. MagNet is promising for real experimental applications.

Reference

<https://doi.org/10.48550/arXiv.2210.03066>