HyperFIB: Vision-Guided Closed-Loop AI for Commercial FIB–SEM Enabled by a Dedicated Python Control API

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Modern electron microscopy workflows (FIB–SEM, SEM, TEM) remain heavily dependent on expert operators and instrument-specific scripting, which limits reproducibility and makes it difficult to transfer advanced workflows between laboratories. While commercial systems increasingly provide packaged automation for well-defined tasks, extending automation to new samples and evolving experimental goals often requires custom scripting, robust perception, and runtime decision-making. Open-source efforts such as OpenFIBSEM [1] and SerialFIB [2] reflect the community's push toward methods that can be inspected, shared, and reproduced as software. Our objective is to demonstrate how closed-loop AI workflows can be deployed on a commercial FIB–SEM through a stable programming interface, enabling reusable, software-defined methods.

We present HyperFIB [3], an open source AI-enabled framework that targets closed-loop control in FIB–SEM by combining (i) an intent/planning layer that translates user goals into executable steps, (ii) a scheduling/orchestration layer that sequences atomic operations under process constraints, and (iii) a perception layer (computer vision) that estimates state from SEM/FIB images to support localization, alignment, and endpoint cues (Figure 1a). These components form a feedback loop in which observations update decisions during execution, enabling adaptation beyond fixed "script-only" automation.

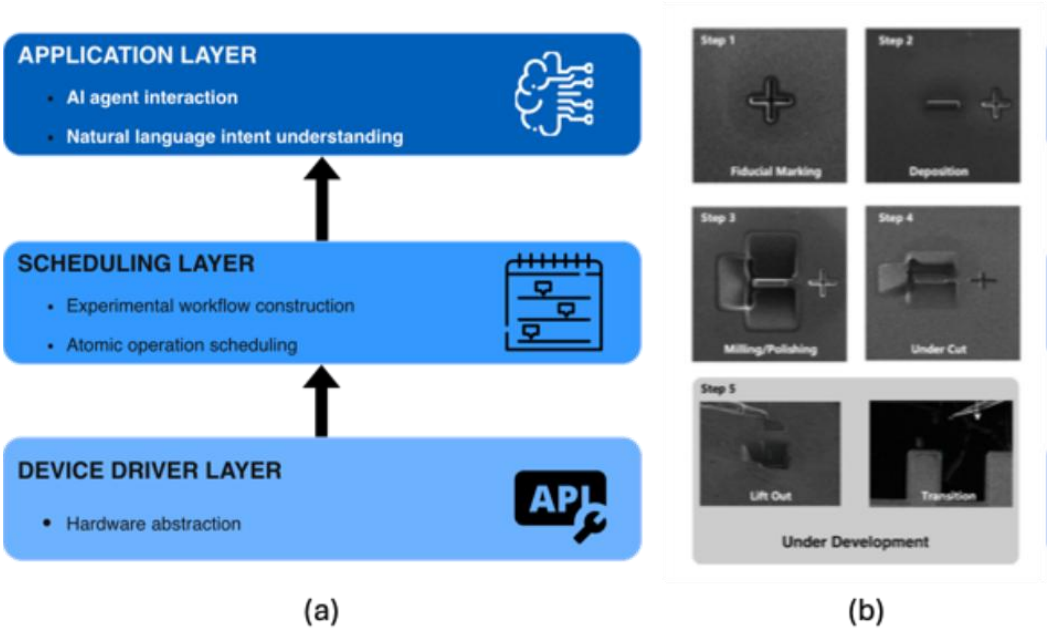

Figure 1 (a) Diagram of HyperFIB's three-layer control architecture: Application layer (AI agent interaction, natural-language intent understanding), Scheduling layer (workflow construction, atomic operation scheduling), and Device-driver layer (hardware abstraction via API). (b) Sequence of SEM images showing automated preparation and milling steps on a Tescan FIB-SEM; transition (lift-out) and polishing are labelled "under development" which are currently implemented in the workflow but still under test in experiments.

For deployment on commercial instruments, HyperFIB connects to the microscope through a maintained programming interface (Python-accessible control interface) that exposes primitives for imaging, stage operations, FIB process steps and other functions. This separation keeps the AI method logic (workflows, decision rules, analysis routines) portable and versionable, while instrument execution remains stable through a supported control boundary.
On a Tescan platform, the demonstrated workflow automates preparation and milling stages (localization/marking/calibration; deposition and rough/fine milling) (Figure 1b). Transition (lift-out) and polishing steps are under development in a simulation environment and planned for deployment and validation on the physical microscope. Overall, the work illustrates how AI layers coupled to scripting interfaces can extend automation from predefined routines toward adaptable, shareable methods that better support reproducibility and method transfer. These observations support the objective of moving beyond predefined automation toward workflows that adapt to imaging feedback while remaining transferable as software.
The key outcome is that closed-loop AI workflows can be executed on a commercial FIB–SEM using a stable programming interface, enabling software-defined methods that are easier to reproduce and transfer across sites.

1.) Cleeve, P., Naegele, L., Kannachel, R., & de Marco, A. OpenFIBSEM: A universal API for FIBSEM control. Ultramicroscopy (2023).
2.) Klumpe, S. et al. A modular platform for automated cryo-FIB workflows. eLife (2021).
3.) Beijing DP Technology Co., Ltd. and Beijing AI Science Institute. (2026). Hyper-FIB: an artificial intelligent FIB-SEM system (Version 1.0) [Computer software]. Registration No. 2026SR0180772.