NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Global Connect Fellowship

Developing Robotic Systems for High Throughput Thin Film Fabrication for Materials Discovery

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Introduction

Self-Driving Laboratories (SDLs) integrate automated workflows with data-driven decision-making to accelerate materials discovery [1,2]. Conventional lab work is labor-intensive, slow, and prone to reproducibility issues [3]. Automation enables high-throughput, precise experimentation, greatly improving efficiency [4]. A mobile robotic chemist performed 688 experiments in eight days, 1,000 times faster than manual methods [4]. Thin-film device fabrication is a prime application, requiring optimization across a vast parameter space (a general workflow shown in figure 1) [2]. Automated platforms enable efficient execution of techniques like spin coating and lay the groundwork for multilayer thin-film fabrication [2].

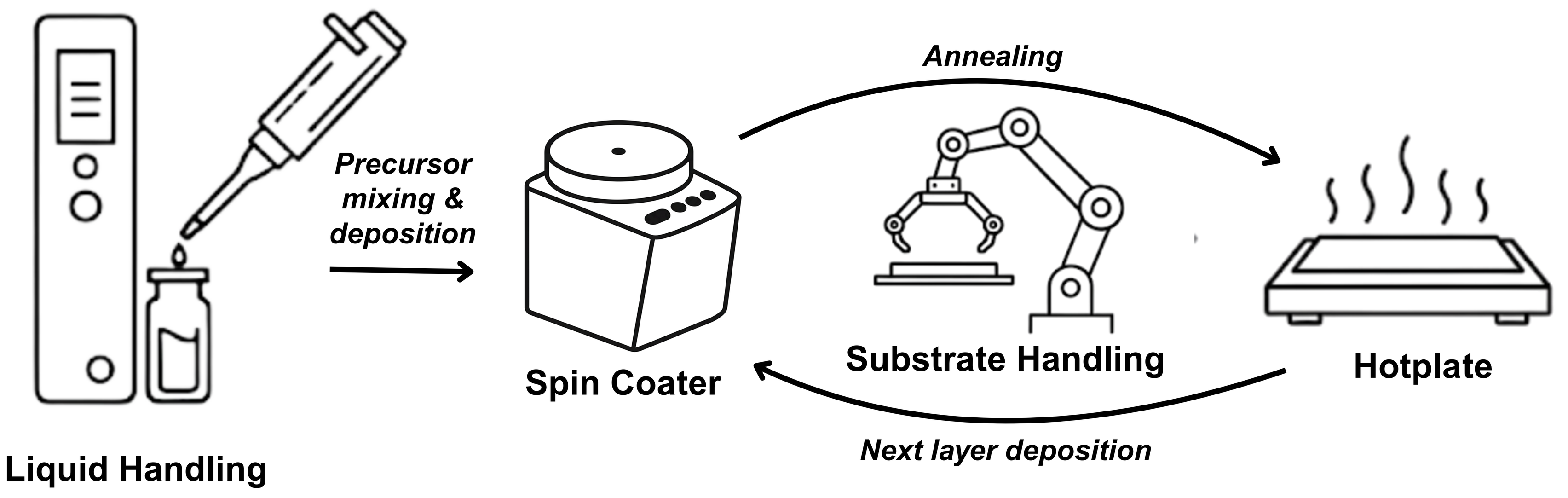

Figure 1. Automated thin-film fabrication workflow: liquid handling, spin coating, robotic transfer to hotplate for annealing, and return for multilayer deposition.

Discussion

- **Teleoperation & Waypoints:** Teleop is reliable (e.g., glove box use) but human-dependent; waypoints are stable yet rigid, small substrate shifts break sequences and motions are abrupt.
- **IK (MuJoCo):** Smooth, scalable trajectories in simulation; not hardware-ready due to solver instabilities and servo dynamics mismatch.
- **RL (100 episodes)**: Trained up to 40k epochs; 20k sorted one vial, 40k sorted one red + one blue (best attempt). Robustness expected with depth perception (extra cameras), more episodes, and ~300k epochs.

Conclusion

We demonstrate a proof of concept for substrate transfer using the SO-101 robotic arm, with teleoperation and waypoints providing reliable control but lacking flexibility, IK offering smooth trajectories in simulation, and RL showing potential despite limited training.

Future scope: Combining RL with IK, plus extended training and depth sensing, can enable scalable self-driving thin-film automation.

Results

Thin Film Fabrication

Liquid Handling

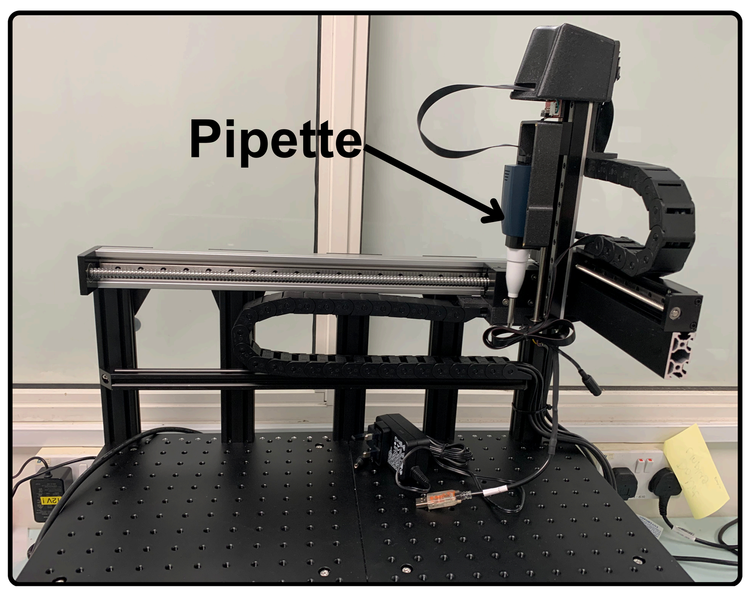

Figure 2. Pip-Bot: Pipetting gantry system with XYZ control, designed and built by A*STAR Laboratory for automated liquid handling

Substrate Handling

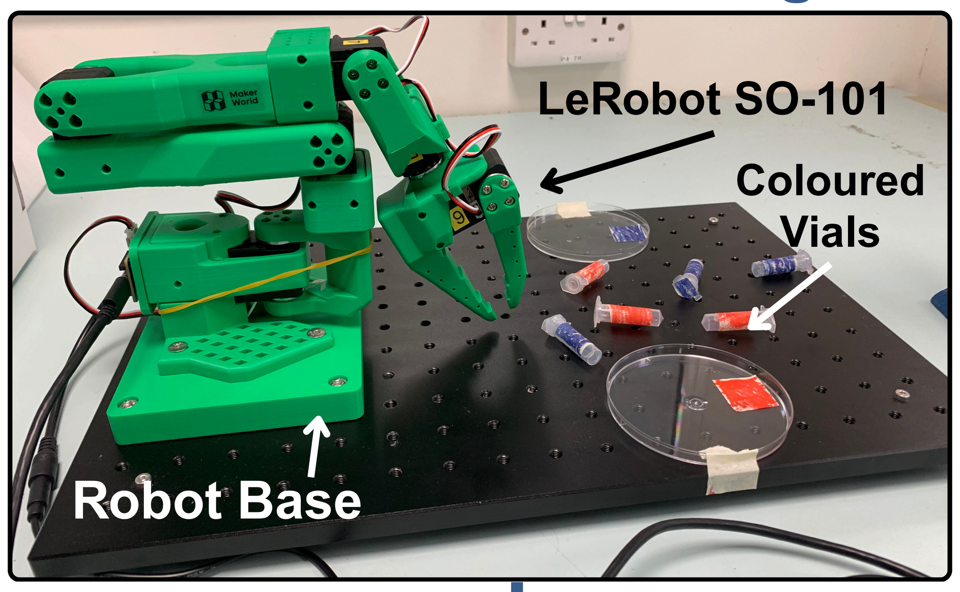

Figure 3. LeRobot SO-101 Robotic Arm[5]. 6-DOF used for substrate handling, mounted on a custom base compatible with optical breadboard slots.

Spin Coating

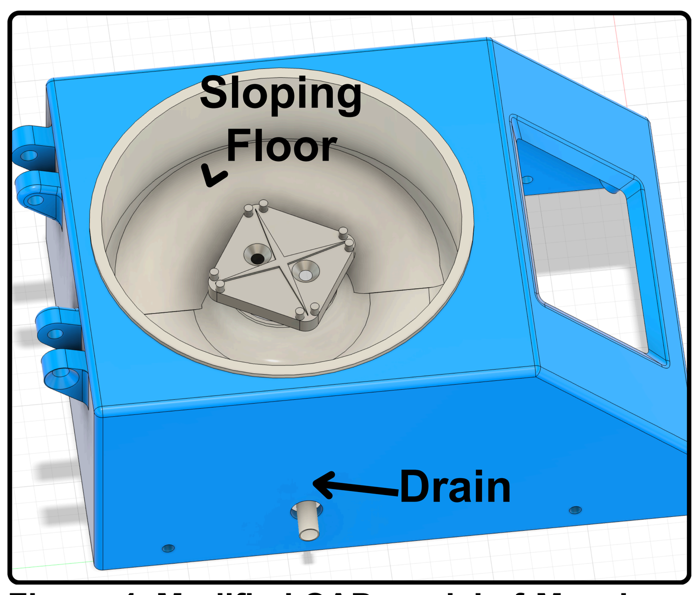

Figure 4. Modified CAD model of Massi Spin Coater with tilted floor and drain.[6]

Reinforcement Learning

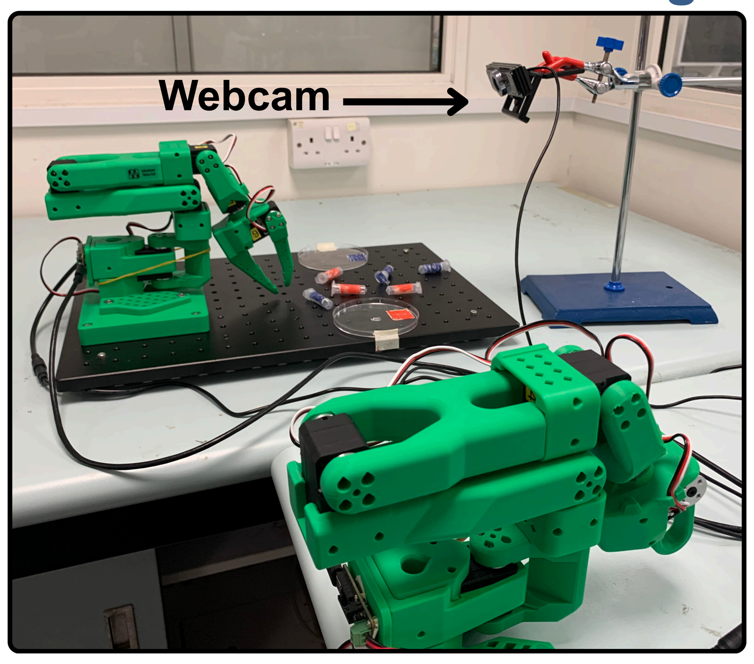

Figure 5. Reinforcement Learning Setup: SO-101 leader–follower arms with overhead camera; vials labeled red/blue.

Inverse Kinematics

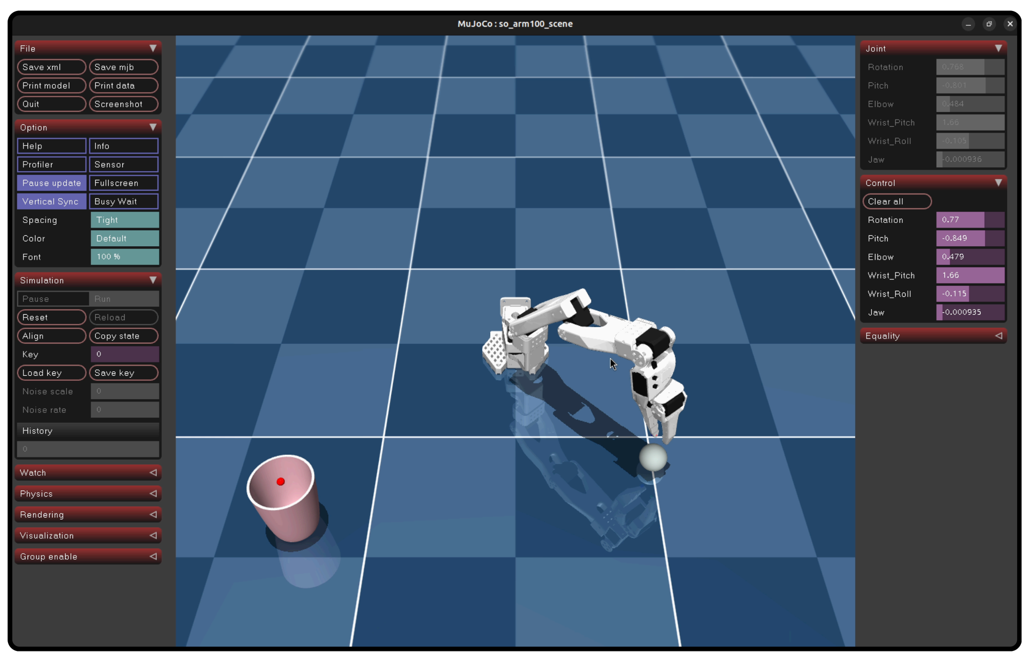

Figure 6. Inverse Kinematics Simulation: MuJoCo model of the 6-DOF SO-101 executing a ball-in-cup pick-and-place task.

Teleoperation

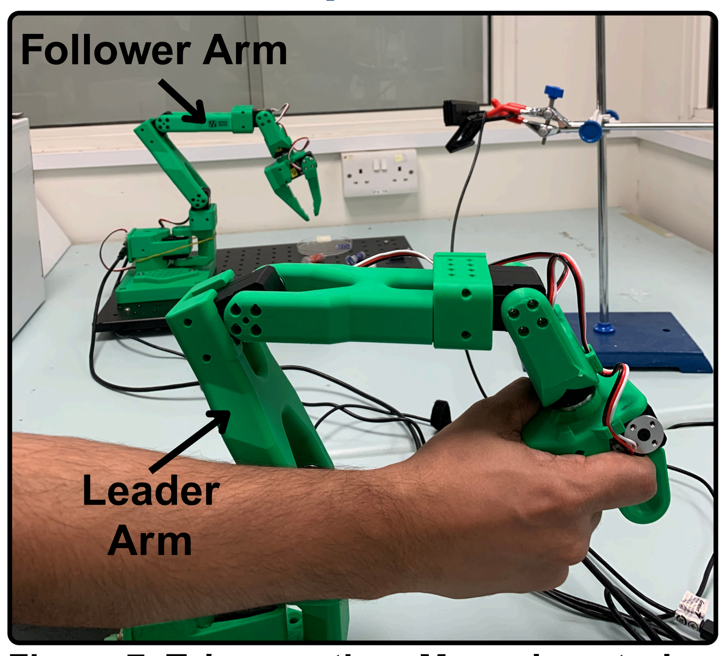

Figure 7. Teleoperation: Manual control of the leader arm replicated in real time by the follower arm,

Waypoints

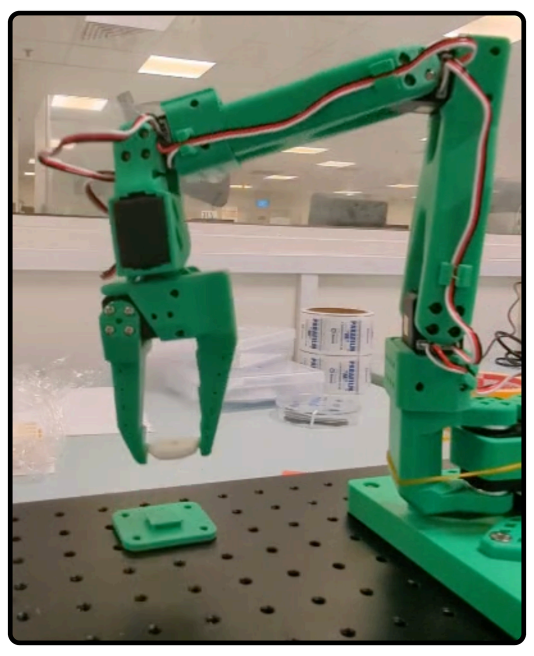

Figure 8. Waypoint Control: SO-101 performing pick-and-place of a test object

References

[1] "Self-Driving Laboratories for Chemistry and Materials Science | Chemical Reviews." Accessed: Aug. 21, 2025. [Online]. Available: https://pubs.acs.org/doi/10.1021/acs.chemrev.4c00055?ref=pdf
[2] B. P. MacLeod et al., "Self-driving laboratory for accelerated discovery of thin-film materials," Science Advances, vol. 6, no. 20, p. eaaz8867, May 2020, doi:10.1126/sciadv.aaz8867.
[3] J.-M. Lu, J.-Z. Pan, Y.-M. Mo, and Q. Fang, "Automated Intelligent Platforms for High-Throughput Chemical Synthesis," Artificial Intelligence Chemistry, vol. 2, no. 1, p. 100057, June 2024, doi: 10.1016/j.aichem.2024.100057.
[4] B. Burger et al., "A mobile robotic chemist," Nature, vol. 583, no. 7815, pp. 237–241, July 2020, doi: 10.1038/s41586-020-2442-2.
[5]R. Cadene, S. Alibert, A. Soare, Q. Gallouedec, A. Zouitine, S. Palma, P. Kooijmans, M. Aractingi, M. Shukor, D. Aubakirova, M. Russi, F. Capuano, C. Pascal, J. Choghari, J. Moss, and T. Wolf, LeRobot: State-of-the-art Machine Learning for Real-World Robotics in PyTorch. [Online]. Available: https://github.com/huggingface/lerobot. Accessed: Aug. 22, 2025.
[6]Dani Carbonell, "klotzsch-lab/Maasi: Release v1.0". Zenodo, Dec. 08, 2021. doi: 10.5281/zenodo.5768034.

Acknowledgements

- We thank **Assoc Professor Kedar Hippalgaonkar** and his research team, in particular **Shreyas Pethe**, for their continuous support, guidance, and collaboration on this project.
- We also thank **A*STAR laboratories** for assembling and developing the Pip-Bot used for liquid handling.

More SO-101 videos and images: scan QR code.