Democratizing Discovery: Ultra-Low-Cost Self-Driving Laboratories for Materials Science

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1. Introduction

Self-driving laboratories (SDLs) represent a transformative approach to accelerating scientific discovery, integrating automated physical experimentation with intelligent, algorithm-driven decision-making [1]. By combining robotics, artificial intelligence, and automation technologies, SDLs autonomously select and execute experiments without human intervention, enabling iterative experimentation at unprecedented speeds and scales [2].

However, widespread adoption of these technologies faces a significant barrier: the prohibitive costs of commercial automation systems, which range from tens to hundreds of thousands of dollars [3]. Automated liquid handlers cost $10,000–$60,000, robotic arms range from $8,000–$150,000, and automated microscopes can exceed $500,000. This financial hurdle has created a technological divide, limiting access primarily to well-funded institutions and leaving many research facilities unable to leverage the benefits of automated experimentation.

This talk presents our radical approach to democratizing autonomous experimentation through ultra-low-cost SDL systems built on open-source 3D printing technology in our laboratory and across multiple disciplines of materials science. We demonstrate how commodity hardware, open-source software, and modular design principles can reduce SDL implementation costs by over an order of magnitude while maintaining research-grade performance.

2. Low-Cost SDL Components via 3D Printing

Fused Deposition Modelling (FDM) 3D printing has emerged as a democratizing force in laboratory automation. Figure 1 illustrates the diverse SDL components that can be fabricated using low-cost FDM technology, including automated liquid handlers, robotic arms, microscopes, autosamplers, chemical reactionware, and bioprinters.

The cost reductions achieved through 3D-printed alternatives are substantial, as shown in Figure 2 and Table 1. Traditional automated liquid handling systems cost $10,000–$60,000, while 3D-printed solutions like FINDUS offer comparable precision for under $400 [4]. Similarly, microscopy platforms such as OpenFlexure achieve sub-micron positioning accuracy at costs below $1,000 [5].

3. Integration with AI and Machine Learning

The true potential of low-cost SDLs emerges when 3D-printed hardware is integrated with machine learning algorithms for autonomous exper-

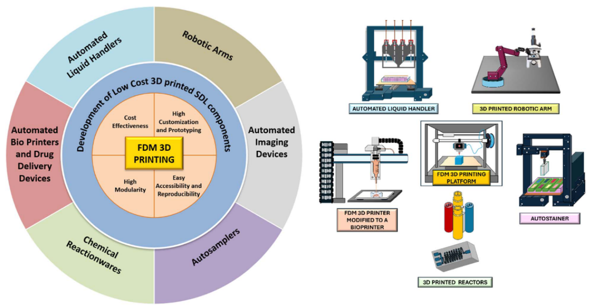

Fig. 1: Development of low-cost 3D-printed SDL components. FDM 3D printing enables fabrication of automated liquid handlers, robotic arms, imaging devices, autosamplers, chemical reactionware, and bioprinters at a fraction of commercial costs. Reproduced from Ref. [3] under CC-BY 3.0.

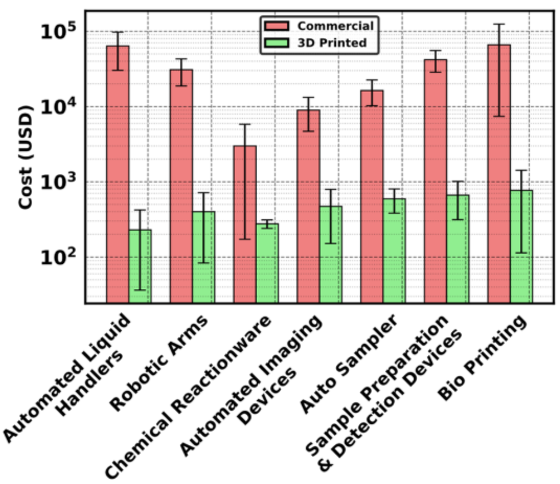

Fig. 2: Cost comparison between commercially available laboratory automation systems and 3D-printed alternatives across multiple categories. Reproduced from Ref. [3] under CC-BY 3.0.

Table 1: Representative cost comparison of commercial versus 3D-printed SDL components.

Component	Commercial	3D-Printed
Liquid Handler	$10k–$60k	$400
Robotic Arm	$20k–$150k	$300–$700
Microscope	$100k–$500k	$200–$1,000
Autosampler	$5k–$100k	$500–$900
Bioprinter	$5k–$1M	$150–$2,000

imentation. Bayesian optimization enables real-time decision-making, where probabilistic models guide the selection of subsequent experimental parameters [6]. Our platform architecture leverages consumer-grade robotics, single-board computers such as Raspberry Pi and Arduino, and open-source software frameworks to create functional autonomous systems.

We present case studies across diverse materials domains including thin-film deposition, electrochemical synthesis, and solution processing, demonstrating how these accessible platforms can match the throughput and optimization capabilities of systems costing ten times more. The software framework enables rapid reconfiguration for different experimental workflows, allowing researchers to pivot between materials systems without significant hardware investment.

4. Outlook

Our roadmap emphasizes creation of an open ecosystem where researchers worldwide can contribute to and benefit from shared SDL development. By highlighting the versatility, cost-effectiveness, and accessibility of 3D printing technology, we aim to inspire broader adoption within the scientific community. The modular nature of these devices offers opportunities for interconnecting SDLs across diverse disciplines and geographical boundaries, ultimately accelerating materials innovation across the scientific community.

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