Affordable 3D Printed Automation for Self-Driving Laboratory: Expanding Access to High-Throughput Experimentation

Sayan Doloi[1], Maloy Das[2], Yujia Li[3], Zen Han Choa[4], Xingchi Xiaoa[5], Matthew Osvaldo[6], John Hanna[7], Leonard Ng Wei Tat [8]

[1-8]*School of Materials Science and Engineering (MSE), Nanyang Technological University, 50 Nanyang Ave, Singapore 639798.*

[7]*University of Warwick, Department of Physics, Millburn House, Coventry CV4 7AL, United Kingdom*

Correspondence to: [Assistant Prof. Leonard Ng Wei Tat] Email: leonard.ngwt@ntu.edu.sg

1. Introduction

Laboratory automation through self-driving labs represents a transformative approach to accelerating scientific discovery, particularly in chemical sciences, biological sciences, materials science, and high-throughput experimentation. However, widespread adoption of these technologies faces a significant barrier: the prohibitive costs of commercial automation systems, which can range from tens to hundreds of thousands of dollars. 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. 3D printing technology emerges as a democratizing force in this landscape, offering a revolutionary solution to the accessibility challenge. By enabling the production of customizable laboratory equipment at a fraction of the cost of commercial alternatives, 3D printing is transforming how researchers approach laboratory automation. This approach not only reduces financial barriers but also promotes innovation through open-source designs, allowing researchers to share, modify, and improve upon existing solutions. This review addresses a critical gap in the current literature by exploring both the transformation of low-cost Fused Deposition Modelling (FDM) 3D printers into sophisticated automation platforms and the use of FDM 3D-printed components to develop a broad range of affordable laboratory automation systems. Furthermore, we explore how strategic modifications enable these systems to serve as automatic liquid handlers, robotic arms, automated sample preparation and detection systems, chemical reactionware, automated imaging systems and bioprinting units. The integration of these modified 3D-printed components with machine learning and artificial intelligence algorithms creates unprecedented opportunities for developing accessible, highly flexible self-driving laboratories.

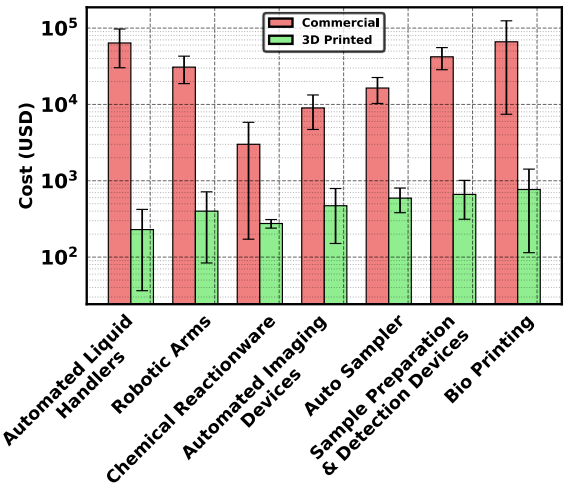

Fig. 1 Cost comparison between Commercially available systems to 3D-printing alternatives

2. Use of 3D Printing for SDL applications

Self-driving laboratories (SDLs) represent a rapidly advancing field that integrates automated physical experimentation with intelligent, algorithm-driven decision-making. By combining robotics, artificial intelligence, and automation technologies, SDLs autonomously select and execute experiments without human intervention. These systems have the potential to transform research in chemistry, materials science, biology, and beyond by enabling iterative experimentation at unprecedented speeds and scales [1-3]. Through the automation of repetitive tasks and the integration of intelligent decision-making, SDLs enhance experimental efficiency, reproducibility, and scalability, paving the way for rapid advancements in scientific discovery [4–7]. However, widespread adoption of these technologies faces a significant barrier due to the prohibitive costs of commercial automation systems, which can range from tens to hundreds of thousands of dollars. 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. In this context, 3D printing technology emerges as a democratizing force, offering a

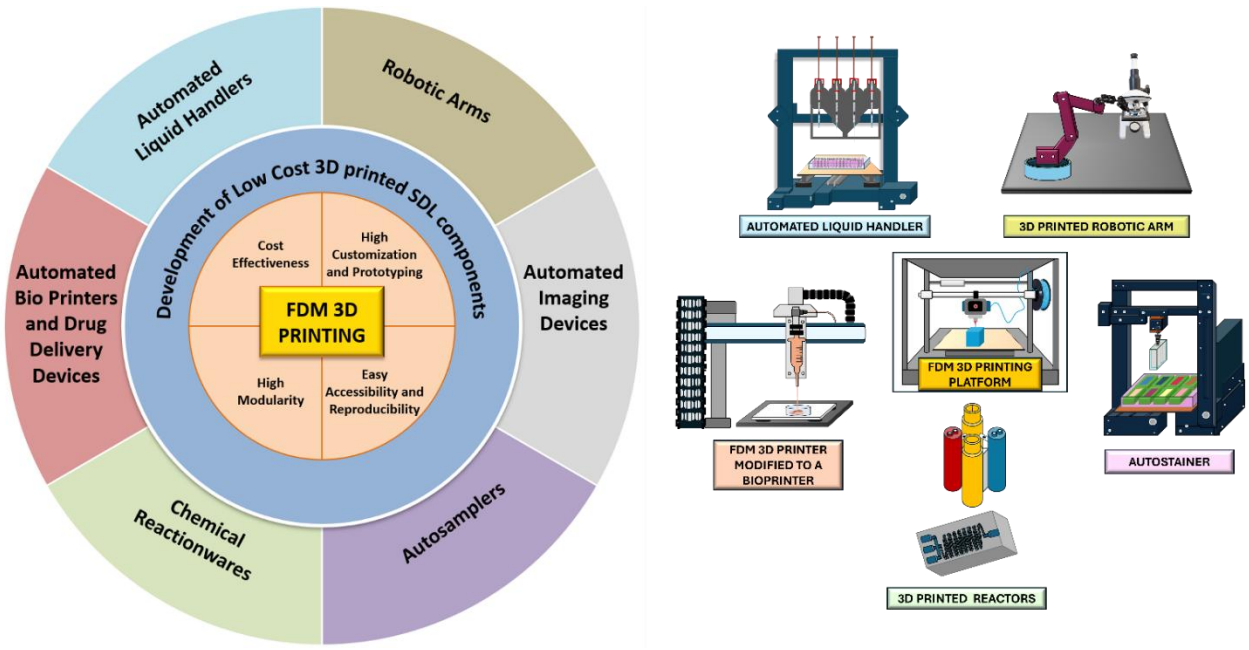

Fig. 2 Development of Low-Cost 3D-Printed SDL Components: A focus on affordable and accessible solutions for self-driving labs.

revolutionary solution to the accessibility challenge. With the rapid growth of 3D printing and the emergence of customizable, open-source, low-cost Fused Deposition Modelling (FDM) 3D printers, it is now possible to develop different components of SDLs as shown in the Fig. 2, tailored to specific needs and integrate them into SDLs. With the ability to fabricate intricate parts layer by layer, FDM stands out for its adaptability, low cost, and accessibility, making it ideal for the development of SDL hardware. Recent advances in open-source 3D printing have further democratized access to this technology, allowing researchers worldwide to design and share bespoke solutions tailored to their unique experimental needs. By enabling the production of customizable laboratory equipment at a fraction of the cost of commercial alternatives as shown in the Fig. 1, 3D printing is transforming how researchers approach laboratory automation. For example, traditional automated liquid handling systems, essential for high-throughput workflows, often cost between $10,000 and $60,000, making them unattainable for many smaller labs. In contrast, 3D-printed solutions like the FINDUS liquid handler and the EvoBot platform offer comparable precision and functionality for tasks such as reagent dispensing, sample mixing, and cell culture maintenance at costs as low as $400 [4,5]. In the realm of sample preparation, detection, and laboratory automation, 3D-printed innovations have led to the development of tools such as automated sampler, mixture and liquid handlers etc [6-14]. Similarly, affordable imaging solutions like FlyPi and OpenFlexure leverage modular components and open-source software to deliver advanced functionalities, including fluorescence and live-cell imaging, for under $1,000 [15,16]. Additionally, 3D-printed alternatives to commercial robotic arms and grippers, such as the Soft Hand and Insta Grasp, provide cost-effective and adaptable solutions for tasks like pipetting, reagent mixing, and sample transfer [17,18]. The integration of 3D printing with open-source principles is pivotal in democratizing SDLs. Platforms like Arduino and Raspberry Pi enable the creation of low-cost, programmable devices that seamlessly integrate with 3D-printed hardware [19,20].

This open-access, collaborative approach drives innovation by allowing researchers to rapidly prototype, share designs, and improve upon existing solutions. 3D printing technology will generate the scope of further research interest for democratizing SDL considering different aspects of laboratory automation and digitization at economic and sustainable way. By highlighting the versatility, cost-effectiveness, and accessibility of 3D printing technology, this review aims to inspire a broader audience within the scientific community to actively adopt and innovate with these technologies. Researchers, educators, and industry professionals are encouraged to leverage 3D printing for the development of customized, low-cost laboratory equipment tailored to specific experimental needs. Ultimately, this democratization of SDLs through 3D printing has the potential to accelerate scientific discoveries, improve resource optimization, and make advanced research methodologies accessible to laboratories with limited funding and infrastructure.

Acknowledgments

L. N. W. T. acknowledges funding from the Singapore Ministry of Education Tier 1 grants (RS14/23 and RG86/23).

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