LabDroid "Maholo"-Centered Automation and Autonomization of Life Science Experiments

Akari Kato[1] Koji Ochiai[2] Ryosuke Matsuzawa[2] Haruka Ozaki[2] Genki Kanda[3]
[1][Institute of Science Tokyo, 1-5-45, Yushima, Bunkyo-ku, Tokyo, Japan] [2][RIKEN Center for Biosystems Dynamics Research, 2-2-3 Minatojima-minamimachi, Chuo-ku, Kobe, Hyogo, Japan]

Correspondence to: [Akari Kato] akari16k@gmail.com

1. Introduction

LabDroid "Maholo" is a versetile humanoid robot equipped with two 7-axis industrial robotic arms, designed to automate a broad range of basic operations in life science laboratories — including labware handling, reagent dispensing, microscope imaging, and sample storage. By executing these operations with extremely high precision and reproducibility, Maholo serves as a reliable experimental platform capable of contributing to complex life science research that demands consistent accuracy across repeated trials.

Despite these capabilities, the current graphical user interface (GUI)-based control paradigm was designed with human operators in mind and was not architected to support AI-driven or programmatic control. Conversely, human operators bear the full burden of ensuring the success of automated experiments — managing all preparatory, supervisory, and logistical tasks that lie outside the robot's operational scope. This work presents development cases for reducing this burden and improving the overall efficiency of laboratory automation through AI and software integration.

2. Automation of Life Science Experiments Using LabDroid "Maholo"

Maholo has been applied to the automation of induced pluripotent stem (iPS) cell culture workflows. By standardizing these processes, culture outcomes are made independent of the specialized techniques of individual researchers, enabling consistent and reproducible results. These capabilities have been further extended toward clinical-grade cell manufacturing, where regulatory requirements for process consistency and traceability are particularly demanding.

In addition to executing predefined protocols, Maholo has been integrated into an active experimental optimization loop. Using Batch Bayesian Optimization (BBO), the conditions for differentiation induction of iPS cells have been systematically explored across a combinatorial parameter space[1]. In this framework, Maholo serves as the experimental executor, performing each candidate condition prescribed by the optimization algorithm, while the AI system feeds outcomes back to inform subsequent experimental batches. This closed-loop approach substantially accelerates the identification of optimal induction conditions.

3. Automated Experiment Execution

In the original operational model, initiating an experiment required either a human operator to manually trigger each run by pressing a "Run" button, or reliance on a fixed schedule established in advance. Both approaches are inflexible: the former introduces unnecessary human dependence for routine triggers, while the latter cannot accommodate the natural variability in experimental timelines, such as cell growth rates that deviate from nominal expectations, nor timing dependencies between protocols, as unpredictable variations in execution duration make pre-fixed scheduling unreliable.

To address this limitation, an experiment execution controller has been tightly integrated with the robot control system. The resulting architecture enables automated experiment execution that dynamically adjusts the timing of subsequent operations based on the actual progress of ongoing experiments. By monitoring real-time status signals from the robot and associated instruments, the scheduler triggers the next experimental step at the biologically appropriate moment, eliminating the need for manual intervention at runtime and enabling continuous, responsive operation without operator presence.

4. Efficient Data Management in the Automated Laboratory

Although many experimental robotic systems achieve high levels of physical precision and reproducibility, current automated laboratories frequently remain "semi-automated" in practice. The fundamental bottleneck is not the robot's physical capabilities but rather the human involvement required at critical junctures that cannot yet be reliably delegated to the robot. These human touchpoints create operational dependencies that prevent continuous, fully autonomous execution.

Realizing the full potential of a robotic experimental platform therefore requires not only mechanical precision but also meticulous management of the human preparatory activities that surround each experimental run. Operators must record provenance information about reagents, equipment settings, and preparation steps — metadata that is essential for interpreting robot-generated data yet is frequently captured inconsistently or not at all. Without a systematic mechanism for integrating human-derived metadata with robot-generated data, the value of automation is significantly diminished, as reproducibility claims cannot be properly substantiated.

To address this challenge, a software system has been implemented that supports human preparation and post-experiment analysis workflows through a conversational chat user interface (UI), while managing the associated data in the background. Operators interact with the system using natural language to receive workflow support such as automated SOP generation and data analysis; in turn, the system collects experiment-specific metadata from the operator as needed. The system automatically associates the collected metadata with the corresponding machine-generated data, producing a unified, traceable experimental dataset. This approach improves data management quality in the automated laboratory without increasing operator burden, and represents a practical step toward fully integrated human–robot experimental workflows.

Acknowledgments

We are grateful to Junichi Maruyama and Katsuyuki Yugi for provide experimental protocols, cell-preparation and post-experimental analysis, to Rio Kitano for generation and evaluation of Maholo's robot protocols.

References

[1] Genki N. Kanda*, Taku Tsuzuki*, Motoki Terada, Noriko Sakai, Naohiro Motozawa, Tomohiro Masuda, Mitsuhiro Nishida, Chihaya T. Watanabe, Tatsuki Higashi, Shuhei A. Horiguchi, Taku Kudo, Motohisa Kamei, Genshiro A. Sunagawa, Kenji Matsukuma, Takeshi Sakurada, Yosuke Ozawa, Masayo Takahashi, Koichi Takahashi, Tohru Natsume. Robotic search for optimal cell culture in regenerative medicine, eLife,2022