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A Low-Cost Open-Source Cloud-based Liquid Handling Robotic Platform for Performing Remote Real-Time Collaborative Experiments

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We have developed a robotic-system capable of performing routine liquid-handling experiments, as well as artificial chemical life experiments. Our platform consists of an actuation-layer on top, an experimental-layer in the middle, and a sensing-layer at the bottom. The actuation-layer comprises the robot-head and modules mounted on it. The modules, e.g. pipet-modules, OCT-scanner, extruder, PH-probe, are designed to perform actions on experiments. The head holds modules and moves in the horizontal plane. The experimental-layer holds the reaction vessels. The sensing-layer consists of a camera below the experimental-layer to monitor the experiment. It collects data from experiment, and provides feedback for robot to interact with experiment.

To develop an open-source multi-platform user-interface for remote real-time control of our robotic-system, we decouple user software for programing experiments from robot control-software. Therefore, we use an integrated controller-hardware, namely a Raspberry-Pi3 single-board computer, instead of a dedicated computer. The resulting platform eases software management as installing, and managing software libraries required for feedback-based experiments on different hardware, and operating-systems was difficult. Furthermore, it is affordable owing to the low cost of Raspberry-Pi. This approach also enables us to implement a cloud-based software architecture for our platform.

The cloud-based software architecture for our robotic-system provides resource sharing and reusability of experiment protocols, the ability to work on the robotic-system collaboratively, and parallelizing experiments on different robotic-systems. Sharing resources allows users to benefit from experiment protocol-templates provided for common experiments, and also protocol-examples developed by other users. This is specifically helpful as our liquid-handling robot can be used for numerous applications by different users, therefore sample experiment-protocols can save a significant amount of time for the user-community. Collaboration on robotic-platforms, i.e. multiple users can work on the same experiment simultaneously, provides novel opportunities for researchers. On the user-interface, they see changes other users are making to the experiment protocol real-time. They can modify the same experiment as a team, or receive notifications regarding experiment progress. Moreover, users can continue to work on the same experiment on another machine. Finally, parallelizing experiments improves efficiency, specifically for artificial-chemical-life experiments, as several long-lasting experiments are performed on multiple-platforms.

A cloud-based implementation of the user-interface of our robotic-platform is a paradigm shift from single-user single-platform concept to single-user multi-platform, multi-user single-platform, and multi-user multi-platform approaches. A single-user multi-platform paradigm, i.e. a user being able to control several robotic-systems at the same time, and run the same code on multiple-robots, allows for a high degree of parallelism. A multi-user single-platform, i.e. several users can work on the same robot simultaneously, provides a great potential for collaboration on the robotic-platform. A multi-user multi-platform approach, i.e. several users, e.g. a team, being able to work on multiple-robots, enhances resource sharing, and reusability of experiment-protocols.