Automating PCR with the UFACTORY xArm 6 Lite

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Introduction

Polymerase Chain Reaction (PCR) is a fundamental technique in molecular biology, extensively employed in genetic analysis, disease diagnostics, and forensic science. Despite its critical role, the preparation of PCR reactions remains a labor-intensive process that relies on precise pipetting of reagents, a task susceptible to human error and variability. Manual pipetting can lead to inconsistencies in sample preparation, impacting the accuracy and reproducibility of experimental results. To address these challenges, computer automation has gained significant attention, aiming to improve efficiency, precision, and scalability in laboratory workflows.

This work presents an innovative robotic system designed to automate the pipetting process for PCR preparation using the xArm 6 Lite robotic arm. Our approach combines computer vision for precise object localization and volume verification, a custom 3D-printed gripper for micropipette manipulation, and motorized actuation controlled by an Arduino-based system. By leveraging the Robot Operating System (ROS) and Python, along with deep learning-based image analysis techniques, we enhance the precision and repeatability of the PCR process.

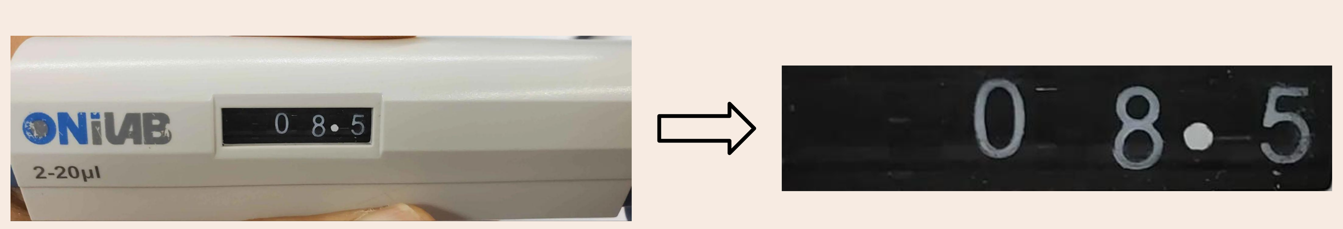
Research Goal

Our objectives are to: 1) develop a vision pipeline for beaker and micropipette detection, 2) design a 3D-printed gripper, 3) implement motorized micropipette actuation, and 4) evaluate system performance.

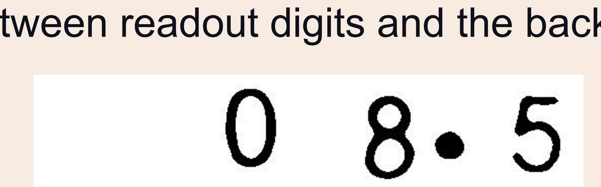
Number Detection

To get an accurate readout from the micropipette, we have created a three-step process that takes in captured frames and outputs the readout into a parsable format. This three-step process consists of cropping, binary thresholding, and running an OCR engine:

- **Cropping:** The captured image undergoes a series of prefix scans, which are layered to create a bounding box and crop out the volume readout.



- **Binary Threshold:** Otsu's method uses a binary threshold to create a strong contrast between readout digits and the background.

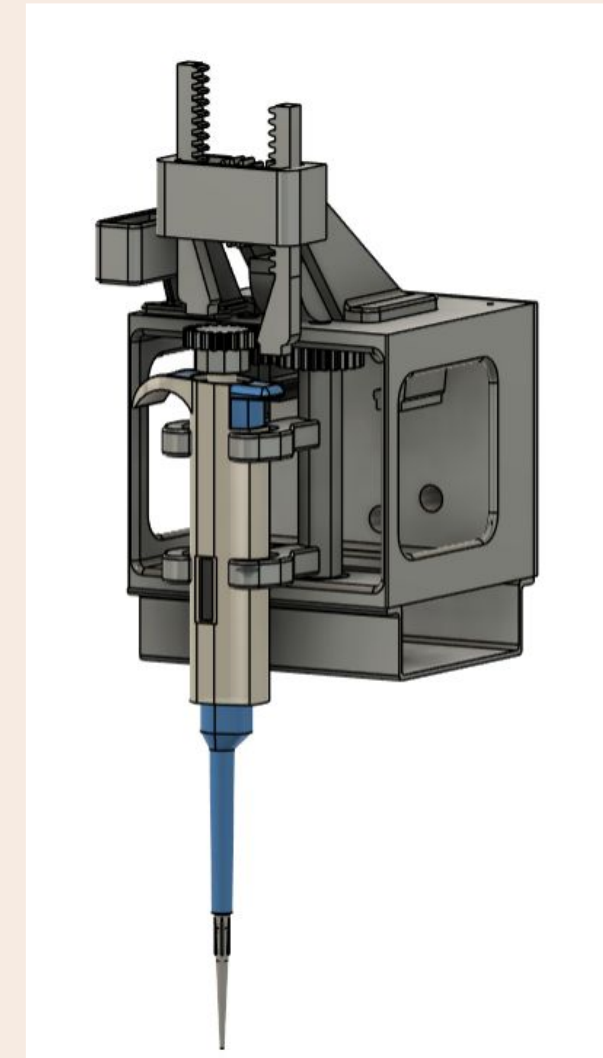


- **OCR Engine:** We utilize the Tesseract OCR engine trained with data specialized in detecting digits, which takes in our processed image and outputs the number as a string

With our process, we were able to get 95% accuracy from sample test images in under 30 milliseconds, making the process suitable for real-time applications.

Hardware

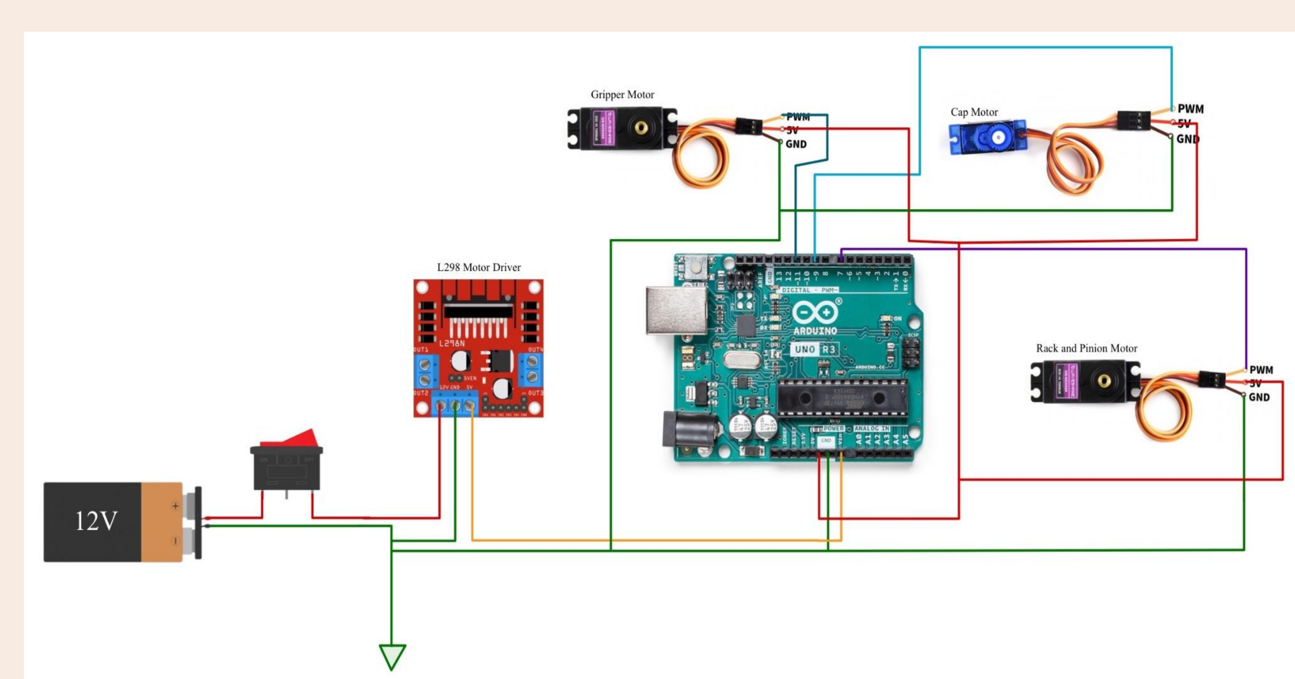
In order to automate the process of PCR, we designed a three part mechanism that can be attached to the xArm 6 Lite robotic arm. This three part system consists of a dispenser actuator, a pipette gripper, and a volume controller.



- **Dispenser Actuator**– This double rack and pinion system is operated by a single MG996R servo motor. These are used to press down on the double stage plunger and the tip ejector.
- **Pipette Gripper** – The gripping mechanism securely holds and releases the micropipette. It employs a three-gear system that actuates a set of mechanical grippers operated by a second MG996R servo motor, ensuring stable and repeatable pipette handling.
- **Volume Controller** – To control the volume dispensed, we modeled a gear attachment to fit around the plunger button. A secondary external gear controlled by a third MG996R servo motor is used to control the rotation.

Each component is designed to ensure precise manipulation of a standard micropipette, improving accuracy and repeatability in PCR preparation. The entire end-effector assembly is housed within an exterior casing that mounts securely onto the robotic arm, ensuring stability and alignment during operation.

Electronics



Our electronic system comprises three motors controlled by an Arduino Uno Rev3 microcontroller. Two MG996R servo motors are responsible for gripping and pressing the pipette, while an SG90 micro servo adjusts the pipette's volume. Each motor is connected to the microcontroller via three wires: one for power (5V), one for ground, and one for signal, assigned to unique output pins. The Arduino Uno is powered by a 5V supply derived from an L298 motor driver, which functions as a buck converter to step down the 12V input from the battery source.

Birds Eye View

To ensure precise robotic movement and pipetting accuracy, our system employs a bird's-eye view detection method using a camera mounted above the workspace. Custom laser-cut beaker holders contain built-in AprilTags, which encode information about beaker size and contents. A fixed AprilTag on the floor serves as a reference point, providing a consistent frame of reference for position calculations. By detecting and measuring the relative positions of these AprilTags, the system accurately computes distances between beakers, enabling the robot to navigate the workspace with precision.

AprilTag detection follows a structured image-processing pipeline to enhance accuracy and robustness:

- **Grayscale Conversion** – The captured image is first converted to grayscale, reducing computational complexity and improving object detection by eliminating color variations.
- **Gaussian Blur** – A Gaussian blur is applied to smooth the image and reduce noise, preventing false edges from interfering with tag recognition.
- **Canny Edge Detection** – This step highlights significant edges within the image, making it easier to identify the distinct black-and-white patterns of AprilTags.
- **AprilTag Detection and Pose Estimation** – The processed image is analyzed using an AprilTag library, which detects tags, decodes their embedded data, and estimates their spatial position and orientation relative to the camera.

By leveraging this vision pipeline, the system ensures reliable and repeatable localization of laboratory beakers, allowing the robotic arm to execute precise pipetting movements.

Future Work

With more refinement, this robot/mechanism can be used in labs across the globe. Our work can be used to build similar robots that can use micropipettes and tubes of various sizes and automate the micropipetting process in PCR.

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