

Using Large-language Models for Performing Trial-and-Error Experiments for Autonomous Scientific Laboratories



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1. Abstract

A survey by Nature revealed that about 70% of biological experiments are not reproducible. Autonomous scientific laboratories envision robots conducting experiments autonomously, reducing human-induced uncertainties, and improving reproducibility. Argonne National Lab's Workflow Execution Interface (WEI) library integrates multiple devices and sensors for complex scientific workflows. However, due to the expensive nature of existing equipment, which makes them inaccessible for most researchers, we designed a low-cost experiment using Arduino robots, web cameras, along with Large Language Models (LLM) and object detection to perform autonomous experiments and overcome this challenge. Specifically, we perform a pick-and-drop experiment using the Arduino Braccio robot and a web camera, controlled by a locally fine-tuned Llama-3.1 LLM and YOLO-v3 object detection network. An interactive web app uses our fine-tuned LLM to fix or adjust errors during the experiment. Overall our proposed model offers an accessible learning experience for scientific laboratories.

2. About WEI

The **Workflow Execution Interface (WEI)** is a set of tools and software for autonomous scientific discovery. It includes:

- Workcells:** A group of scientific instruments, robots, devices, and software that work together to execute scientific workflows, defined in WEI.
- Workflows:** Steps performed on a workcell, with each steps specifying actions for a module defined in WEI using YAML file.
- Modules:** Software packages that control scientific instruments, robots, or devices, including hardware, drivers, and integrations, following WEI's Module Interface.
- Experiments:** A collection of workflow runs and logic that uses WEI to manage workcells.

5. Prompt Design

This prompt helps the LLM act like a math expert to adjust coordinates for a Braccio Robot so that the robot can handle objects accurately.

Example Prompt

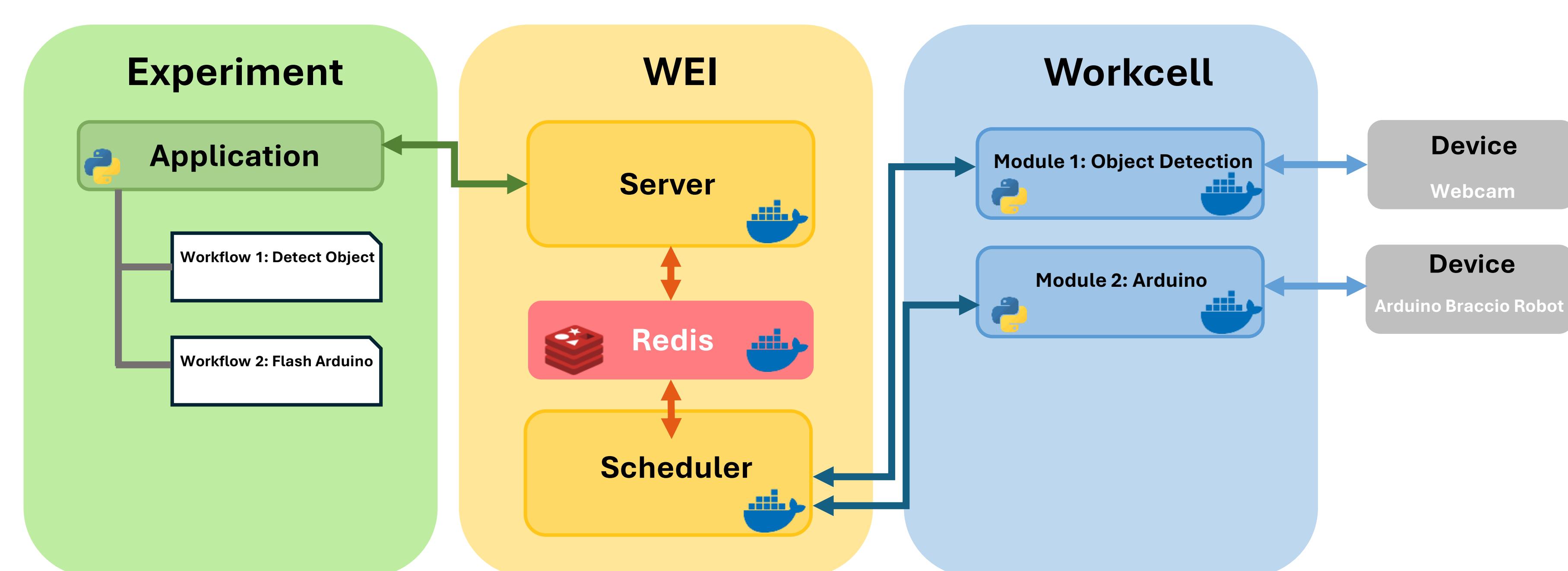
SYSTEM You are an expert mathematician with specialization in coordinate plane. The user will provide four robot coordinates for a Braccio Robot. Two for pickup location (GOTOXB, GOTOYB) and two for drop location (GOTOXL, GOTOYL). The coordinates are inaccurate and need slight modification. Depending on the user input, adjust those coordinates.

USER Here are the coordinates:
#define GOTOXB 328.57971014492756
#define GOTOYB 82.929292929294
#define GOTOXL 84.19289855072465
#define GOTOYL 332.62626262626264
Move the pickup location to the right.

7. Video demonstration

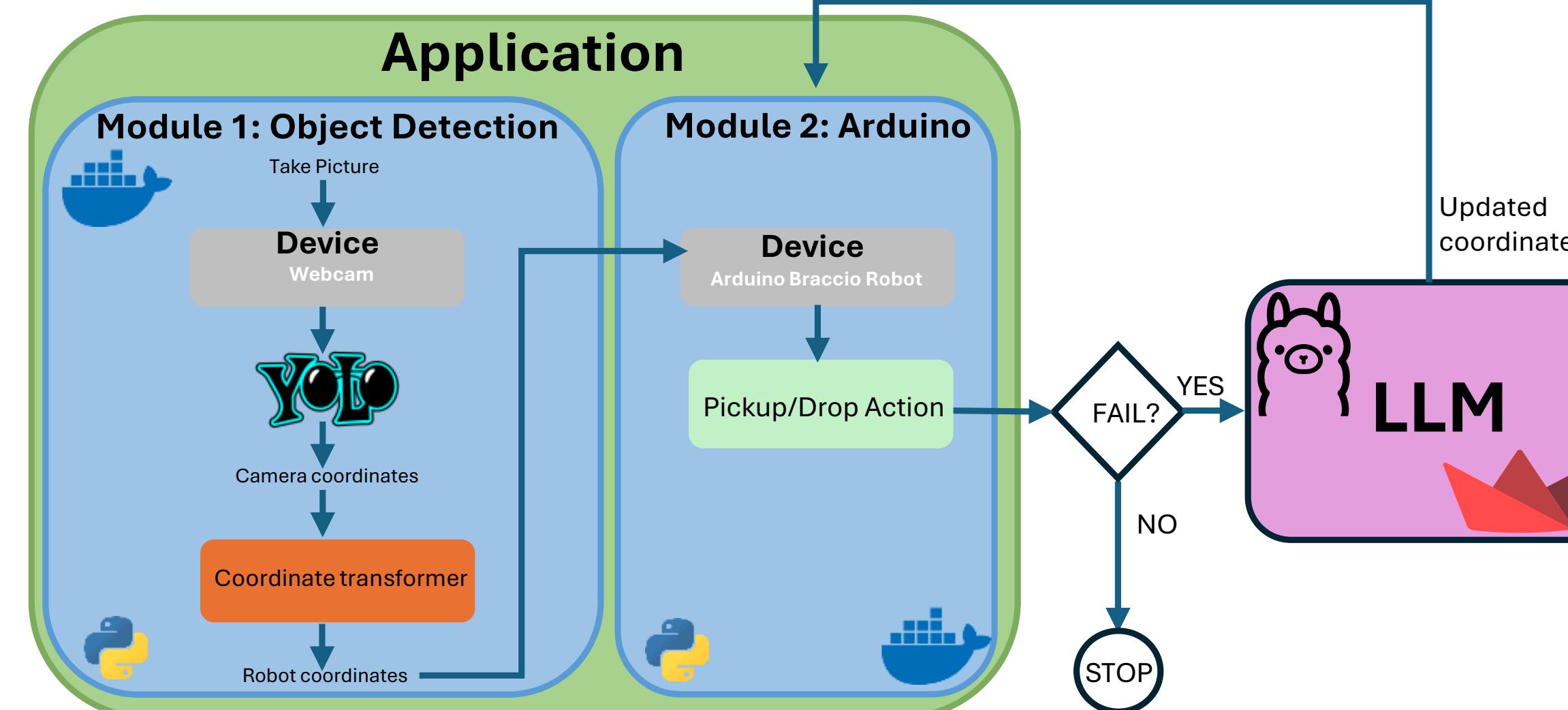


3. WEI Framework



4. Method

The experiment involves a webcam, which takes the picture of the pickup and drop objects. The picture is sent through an image detection model, **YOLOv4-tiny** in this case. The detection process uses a linear coordinate transformation function that does not account for camera depth, resulting in imprecise pickup and drop coordinates. Due to the inaccuracies in the initial robot coordinates generated by the image detection model, a trial-and-error approach is needed. By intentionally using this imperfect transformation, the system mimics real-world scenarios where conditions are not always ideal. The Large Language Model (LLM) is then tasked with adjusting these coordinates based on user input in natural language, enhancing accuracy through iterative adjustments. Each cycle of error correction helps improve the robot's movements, thereby simulating real-world experimentation dynamics.



6. Interactive Coordinate Adjustment

The Meta Llama-3.1-8B model allows users to interact with the Braccio Robot using natural language. The LLM is tailored to understand and adjust robot coordinates for pickup and drop tasks. Positioned as an AI mathematician specializing in coordinate plane adjustments, it processes user instructions to improve the robot's movement precision. The chatbot ensures smoother operation, making it easier to fine-tune the robot's performance for real-world applications. The **load** keyword loads the initial, approximate pickup and drop-off coordinates from **YOLO** predictions. Once the user is satisfied with the adjustments, the **done** keyword finalizes the coordinates, which are then sent to the robot for testing.

Robot Coordinate Correction System

```
load
Coordinates Loaded
Move the coordinate for the pickup location to the right.

To move the coordinate for the pickup location to the right, we need to decrease its X-coordinate.

#define GOTOXB 328.57971014492756 - 10 // decreased by 10 units to move to the right
#define GOTOYB 82.929292929294

#define GOTOXL 84.19289855072465
#define GOTOYL 332.62626262626264

GOTOXB = 318.57971014492756, GOTOYB = 82.929292929294, GOTOXL = 84.19289855072465,
GOTOYL = 332.62626262626264

done
Coordinates Updated
Clear History
```

