APEX Labs

Automated Precision EXperimentation Laboratories

Task 5: Spring Project Test Plan

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Introduction

The purpose of this document is to provide a high level framework to test the APEX Labs system throughout the spring semester. The aim of this framework is to validate that all of the system requirements that have been previously identified are appropriately addressed in a timely manner. This framework is structured such that the APEX Labs system can be built in a parallel bottom-up approach - from subsystem creation to high level integration. This plan also provides an overall timeline that the team can use to deduce whether work is getting done at an appropriate pace - or whether effort must be increased in order to meet expected milestones. Ultimately, by using this plan, our team will be able to showcase a minimal viable product version of APEX Labs by the spring validation demo (SVD).

Logistics

Personnel

The team does not require external support in conducting any of the tests. For subsystem-level tests, the owners of the particular subsystem will be involved. However, for a system-level test involving interactions between multiple subsystems, the entire team will be present.

Equipment

We would be using Our Custom Mobile Base, which includes swerve modules, a robot arm, and 2x ZEDx Cameras (one on top of the mobile base and another on the wrist of the Robot arm), the PC, and wellplates for all our tests.

Location

Most of these tests will occur at the Mellon Institute (Room 179). However, since we want to assure ourselves that the mechanics and electronics are functioning properly prior to transporting our equipment to the Mellon Institute location, there may be some tests that have to be performed at Newell Simon Hall (near the RI shop).

Schedule

Event	Date	Capability Milestones	Tests	Requirements
PR1	02/12	- Started data collection using the XArm 6. - Initial hardware build is complete. - Can command the lab machines remotely.	T.LMI.1, T.MA.1, T.MA.2, T.MA.3, T.PE.1	M.F.8 M.P.6
PR2	02/26	- Able to view the logs in the subsystem. - The shaker PCB is operational. - The planning subsystem generates the output needed by the manipulation subsystem.	T.LMI.2, T.PL.1	M.F.5, M.F.8 M.P.3, M.P.6
PR3	03/19	- Can command the XArm 6 to grasp, move, and open grasp. - The manipulation subsystem can execute actions autonomously. - Can detect and localize lab equipment.	T.PL.2, T.PL.3, T.PL.4, T.PE.2	M.F.3, M.F.4, M.F.5, M.F.6, M.F.7 M.P.1, M.P.2, M.P.3, M.P.4, M.P.5
PR4	04/02	- Can command the XArm 6 to grasp well plates and transfer them. - Able to see the camera streaming from the UI.	T.MA.4, T.PE.3	M.F.6, M.F.7 M.P.4, M.P.5
SVD	04/16	- The subsystem logs are centralized. - The end-user can start an experiment from the UI and monitor the status of their experiment.	T.MON.1, T.SVD	D.F.3, D.F.10 D.P.1
SVD Encore	04/23	Fine-tune performance.		

Tests

T.LMI.1 - Lab Machine Commands	
Objective	Verify that the lab machines can be commanded remotely.
Elements	Lab Machine Integration
Location	Mellon Institute
Equipment	Computer, Opentrons OT-2, custom shaker module
Personnel	Juan
Procedure	☐ Turn on the OT-2. ☐ Start the REST API on the OT-2. ☐ Run the lab machine Python test script. ☐ Repeat the above for the custom shaker module.
Verification Criteria	**OT-2** ☐ Liquid is pipetted from the test tube rack into well plates. ☐ Pipette is disposed of into the internal trash can. **Custom shaker module** ☐ The shaker is moving at a desired speed. ☐ The shaker module stops when desired.

T.LMI.2 - Shaker PCB	
Objective	Verify that the custom shaker module's PCB is functional.
Elements	Lab Machine Integration
Location	Mellon Institute
Equipment	Computer, custom shaker module
Personnel	Juan
Procedure	☐ Wire the shaker module into the PCB. ☐ Run the shaker module Python test script. This script will command the shaker directly over PWM without external communication.
Verification Criteria	☐ The shaker is moving at multiple desired speeds. ☐ The shaker module stops when desired.

T.MON.1 - Subsystem Logging Centralization	
Objective	Verify that the subsystem logs are being collected appropriately.
Elements	Monitoring
Location	Mellon Institute
Equipment	Computer
Personnel	Juan
Procedure	☐ Start the planning subsystem. ☐ Issue commands to the planning subsystem. ☐ Let the planning subsystem run and generate logs.
Verification Criteria	☐ The centralized monitoring system contains the logs that are generated by the planning subsystem.

T.PL.1 - Path Planning	
Objective	Verify if the system generates a collision free path for all use cases.
Elements	Planning
Location	Mellon Institute
Equipment	Computer
Personnel	Karthik

Procedure	☐ Load the environment and the robot in the path planning framework.
	☐ Input the following use cases:
	    ☐ Base position to location of plate.
	    ☐ Move plate to liquid handler.
	    ☐ Move from liquid handler to shaker.
	    ☐ Move from shaker to output bin.
	☐ Observe the path generated by the environment.

Verification Criteria	Generated paths should be feasible and collision free.

T.PL.2 - Grasp Planning	
Objective	Verify if the system is able to generate a path to grasp well plate.
Elements	Planning
Location	Mellon Institute
Equipment	Computer
Personnel	Karthik

Procedure	☐ Load the environment and the robot in the position just before grasping.
	☐ Input the following use cases:
	    ☐ Grasp plate from table.
	    ☐ Grasp plate from liquid handler.
	    ☐ Grasp plate from shaker module.
	☐ Observe the path generated by the environment.

Verification Criteria	In all cases, the system is able to generate a path to grasp the wellplate.

T.PL.3 - Anti-spillage	
Objective	Verify if system is able to generate a path to transport well plate without spillage.
Elements	Planning
Location	Mellon Institute
Equipment	Computer
Personnel	Karthik

Procedure	☐ Load the environment and the robot in the path planning framework.
	☐ Input the following use cases:
	    ☐ Move plate to liquid handler.
	    ☐ Move from liquid handler to shaker.
	    ☐ Move from shaker to output bin.
	☐ Observe the path generated by the environment.

Verification Criteria	In all cases, the system generates a path where the z-orientation of the end effector does not change.

T.PL.4 - Trajectory Smoothness	
Objective	Verify if system is able to generate a smooth trajectory.
Elements	Planning
Location	Mellon Institute
Equipment	Computer
Personnel	Karthik
Procedure	☐ Cases to test - all cases from T.Pl.1 - T.Pl.4
Verification Criteria	☐ The trajectory generated is smooth enough for the robot to execute in real-life (differentiable trajectory, no sharp edges).

T.PE.1 - Camera Installation, Streaming, and Data Collection	
Objective	Verify that the cameras are correctly installed, stream reliably and simulation data collection start.
Elements	Perception
Location	Mellon Institute
Equipment	Computer, camera
Personnel	Farnaz
Procedure	☐ Install the overhead and wrist cameras at the intended locations. ☐ Verify the overhead camera fully captures the object at all marked locations. ☐ Verify the wrist camera captures the target region near the end-effector. ☐ Start simulation-based camera data collection.
Verification Criteria	☐ Both cameras run together for ≥ 10 minutes without frame collapse/disconnect.

T.PE.2- Object Detection and Segmentation	
Objective	Verify the system can accurately detect relevant objects and segment objects of interest in the workspace.
Elements	Perception
Location	Mellon Institute
Equipment	Computer, camera
Personnel	Farnaz
Procedure	☐ Load the environment and start the object detection pipeline. ☐ Place target objects in the workspace. ☐ Observe bounding boxes and class labels produced by the system. ☐ Initialize the segmentation module. ☐ Visualize segmentation masks overlaid on sensor input.
Verification Criteria	☐ Correct object class is detected. ☐ Bounding boxes accurately localize the objects. ☐ Segmentation mask correctly outlines the object.

T.PE.3 - Camera Streaming Real-time	
Objective	Verify if the system is able to stream camera data in real time and perform object detection and segmentation.
Elements	Perception
Location	Mellon Institute
Equipment	Computer, Camera
Personnel	Farnaz
Procedure	☐ Connect the camera to the system and initialize the ROS 2 camera driver. ☐ Launch the perception pipeline. ☐ Verify that camera and perception topics are active. ☐ Place target objects in the arm workspace. ☐ Verify detection and segmentation outputs are published in real time. ☐ Enable system-wide logging.
Verification Criteria	☐ The camera stream is continuous and stable. ☐ Object detection and segmentation outputs update in real time.

T.MA.1 - Position Commands	
Objective	Verify the arm movement from the pre-grasp or pre-place waypoints to the specified x, y, z locations using an impedance controller.
Elements	Manipulation
Location	Mellon Institute
Equipment	Computer, XArm-6
Personnel	Arnav
Procedure	☐ Run the Python script for 10 waypoints with a scale alongside. ☐ Record average error.
Verification Criteria	☐ End-effector reaches the commanded pose within ±2 mm.

T.MA.2 - Trajectory Commands	
Objective	Execute a hard-coded Trajectory for Picking and Placing the wellplates.
Elements	Manipulation
Location	Mellon Institute
Equipment	Computer + XArm-6
Personnel	Arnav
Procedure	☐ Run the Python script for 2 waypoints with a scale alongside to pick and place (wellplate). ☐ Record the average error across 5 trials.
Verification Criteria	☐ The robot completes the trajectory and places the wellplate within ±3 mm of the target.

T.MA.3 - Test Gripper Commands	
Objective	Test Gripper software.
Elements	Manipulation
Location	Mellon Institute
Equipment	Computer + XArm-6
Personnel	Arnav

Procedure	☐ Run a hardcoded Python file to:
	    ☐ Move on -Z axis 10mm.
	    ☐ Grip Wellplate.
	    ☐ Move on +Z axis 10mm.
	    ☐ Drop wellplate.
	    ☐ Repeat 10 times.

Verification Criteria	☐ The gripper grasps and releases the wellplate without damage.

T.MA.4 - Visual Servoing with Gripper	
Objective	Test Visual Servoing with Gripper to Grasp the wellplate.
Elements	Manipulation
Location	Mellon Institute
Equipment	Computer + XArm-6
Personnel	Arnav
Procedure	☐ Run Python script for visual Servoing above 100mm of the wellplate. ☐ Grip the wellplate when the distance from the wellplate of the gripper is 10mm.
Verification Criteria	☐ The gripper aligns and successfully grasps the wellplate on the first attempt.

T.SVD - Spring Validation Demonstration Test	
Objective	Perform an experiment semi-autonomously.
Elements	User Interface subsystem, perception subsystem, planning subsystem, manipulation subsystem, lab machine integration subsystem, monitoring subsystem.
Location	Mellon Institute
Equipment	Computer, XArm 6, APEX Labs platform, cameras, OpenTron OT-2, custom shaker module, well plates.
Personnel	Arnav, Farnaz, Karthik, Juan
Procedure	☐ A user enters an experiment description. ☐ The XArm 6 scans the environment to detect necessary equipment. ☐ The perception subsystem detects, segments, and localizes the desired equipment. It passes this information to the planning subsystem. ☐ The planning subsystem generates a plan to grasp, move, and place the desired equipment in the OT-2. The manipulation subsystem executes this plan. ☐ A team member presses the equipment into the OT-2 slot. ☐ The OT-2 is commanded to dispense liquid from a test tube rack that has already been filled and placed inside of the OT-2. ☐ The planning subsystem generates a plan to grasp, move, and place the desired equipment in the shaker module. The manipulation subsystem executes this plan. ☐ The shaker module is commanded to shake for 30 seconds. ☐ The planning subsystem generates a plan to grasp, move, and place the desired equipment in the output bin. The manipulation subsystem executes this plan.
Verification Criteria	☐ The system completes the experiment end-to-end. ☐ Grasp and placement of the desired equipment is performed within a 5mm error bound.

Appendices

Mandatory Requirements

FR No.	Functional Requirement	PR No.	Performance Requirement
M.F.3	**Recognize** Lab Equipment	M.P.1	90% accuracy. False-positive of 5%.
M.F.4	**Localize** Lab Equipment	M.P.2	3cm of ground-truth. Orientation with 5 degrees.
M.F.5	**Plan** to Reach Lab Equipment	M.P.3	Collision-free path 95% of the time.
M.F.6	**Grasp** Lab Equipment	M.P.4	70% grasp success rate.
M.F.7	**Place** Lab Equipment	M.P.5	90% placement success rate.
M.F.8	**Command** Lab Machines	M.P.6	100% correct control commands.

Desirable Requirements

FR No.	Functional Requirement	PR No.	Performance Requirement
D.F.3	**Accept** Experiment Description from User	D.P.1	Convert natural language to executable commands with 85% accuracy.
D.F.10	**Communicate** Status	N/A	N/A