Carnegie Mellon University
The Robotics Institute, School of Computer Science

Fall Test Plan

TouRI

Team H

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Introduction

This document gives an overview of the main tests that Team H (TouRI) will conduct during the fall semester (Fall 2022) of the MRSD Project. The purpose of these tests is to verify that we have met the requirements planned for the fall semester of our project (Appendix A-list of requirements) and to demonstrate the developed functionalities of our Telepresence Mobile Manipulator - TouRI. These tests aim to demonstrate the gradual progression of the various features that will be developed during the fall semester. The results of these tests will be reported during the Fall Validation Demonstration (FVD).

Logistics

Location

Preliminary Autonomy tests and software-only tests will occur in Wean Hall, 3rd floor, Room no. 3119 (workspace provided to us by our sponsors). Latter autonomy tests will be performed in AI Makerspace of Tepper School of Business with a traversal track of around 50m along the hallway.

Personnel

The team members of TouRI will conduct all the tests. One team member will be the remote user to command the robot and monitor the robot remotely during the autonomous tests. One team member will constantly monitor the physical robot movement for safety reasons. Another member will be observing and recording the test results. Occasionally, some members may be required to act as dynamic obstacles in the environment and demonstrate user interaction with the robot.

Equipment

The following items are typically required to perform our tests:

1. Stretch Hello Robot: To demonstrate the developed functionalities.
2. User device: To run the user app to remotely interact with the robot.
3. Gimbal Mount: To mount the display device.
4. Display device: For audio/video feed transmission.
5. Objects of different shapes and sizes: For a demonstration of souvenir pick and place, and object identification with the Robot.
6. Wi-Fi Connection: To demonstrate all the functionalities.
7. Dynamic Obstacles: To demonstrate obstacle avoidance during autonomous navigation with humans or other moving objects.

Schedule

Date	PR	Milestone(s)	Test(s)	Requirements
09/29/22	8	• Bring up the autonomous navigation stack and ensure it is working as it was in SVD. • Implement object detection for shipping box • Implement autonomous manipulation pipeline for placing an object in the box • Develop user interface with Audio/Video communication	Test 2, Test 7	MF8, MF9
10/13/22	9	• Re-map the hallway (due to change in environment) and integrate with the autonomous navigation stack. • Fine tune user interface + implement asynchronous communication • Refine grasping pipeline for multiple objects • Implement object detection for souvenir objects	Test 3, Test 1, Test 8	MF1, MF2, MF8, MF9
11/03/22	10	• Design servo actuator bracket, test E-kill with a new app, Update firmware for CMU DEVICE and switch to failback wifi access points in case of the lost primary network. • Tune the autonomous navigation stack and the stack with the new map. • Integrate all-subsystems	Test 10, Test 5	MF1, MF2
11/17/22	11	• Assemble Pan/Tilt display on TouRI, Test teleoperation. • Integrate obstacle detection using lidar during teleoperation • Test data flow throughout the system	Test 9, Test 6 Test 4	MF1, MF2, MF10, MF11
11/27/22	FVD	• Demonstrate full system functionality	All	All

Tests

Test 1 – Object Grasp Test

Objective	
To test the capability of the manipulator to autonomously grasp and pick up different objects	
Equipment	Hello Robot's Stretch, Objects for grasping
Elements	TouRI autonomous manipulation stack: manipulator pose estimation, motion planning, perception stack
Personnel	2 People (Shivani Sivakumar & Jigar Patel)
Location	Wean hall, 3rd floor, Team H workspace (room no. 3119)
Procedure	
1. Calculate the centroid of the object to grasp 2. Extract the x,y, and z positions of the object in camera frame 3. Transform into base frame 4. Do path planning for robot base 5. Do error correction of base based on visual feedback 6. Do path planning for manipulator 7. Grasp the object	
Validation	
1. The manipulator successfully detects and calculates the centroid of the object to grasp 2. The manipulator autonomously generates trajectory to goal location 3. The manipulator is successfully able to reach goal pose 4. The gripper can grasp the object firmly 5. The gripper holds the object firmly without dropping it	

Test 2 – Object Placement Test

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">To test the capability of the manipulator to de-grasp an object and place it in the shipping box</td></tr>
<tr><td>Equipment</td><td>Hello Robot's Stretch, Object to place in the shipping box, shipping box</td></tr>
<tr><td>Elements</td><td>TouRI autonomous manipulation stack: manipulator pose estimation, motion planning, perception stack</td></tr>
<tr><td>Personnel</td><td>2 People (Shivani Sivakumar & Jigar Patel)</td></tr>
<tr><td>Location</td><td>Wean hall, 3rd floor, Team H workspace (room no. 3119)</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Calculate the centroid of the shipping box to place the object in
2. Extract the x,y, and z positions of the box in camera frame
3. Transform into base frame
4. Do path planning for robot base
5. Do error correction of base based on visual feedback
6. Do path planning for manipulator
7. Place the object into the shipping box</td></tr>
<tr><th colspan="2">Validation</th></tr>
<tr><td colspan="2">1. The manipulator successfully detects and calculates the centroid of the box to place objects
2. The manipulator autonomously generates trajectory to goal location
3. The manipulator is successfully able to reach goal pose
4. The gripper can release the grasped object and place it in the box stably</td></tr>
</table>

Test 3 – Asynchronous Communication Test Between User Interface and Robot

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">To test the robot's ability to communicate asynchronously with the user interface (receive commands for multiple subsystems at the same time)</td></tr>
<tr><td>Equipment</td><td>Hello Robot's Stretch, Device with TouRI App installed</td></tr>
<tr><td>Elements</td><td>Interface: User interface, network architecture, system architecture</td></tr>
<tr><td>Personnel</td><td>1 Person (Prakhar Pradeep)</td></tr>
<tr><td>Location</td><td>Wean hall, 3rd floor, Team H workspace (room no. 3119)</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Initialize and home the robot
2. Run Core Node of TouRI's ROS package on robot
3. Send autonomous navigation commands to the robot via the mobile application
4. At the start of autonomous navigation, send tele-operational commands for the gimbal
5. Send acknowledgment signals for tele-operational commands back to user</td></tr>
<tr><th colspan="2">Validation</th></tr>
<tr><td colspan="2">1. The robot can receive commands asynchronously with a latency of no more than 5 seconds
2. The robot executes user commands with a latency of less than 10 seconds</td></tr>
</table>

Test 4 – Bidirectional Data-Flow Testing

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">To test the bidirectional data-flow between autonomous modules and user</td></tr>
<tr><td>Equipment</td><td>Hello Robot’s Stretch, Device with TouRI App installed</td></tr>
<tr><td>Elements</td><td>Interface: User interface, network architecture
Robot: Navigation and Manipulation nodes</td></tr>
<tr><td>Personnel</td><td>3 People (Prakhar Pradeep, Shivani Sivakumar, Shruti Gangopadhyay)</td></tr>
<tr><td>Location</td><td>Room/hallway in Wean Hall, 3rd floor, Team H workspace (room no. 3119)</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Initialize and home the robot and launch the mobile application
2. Run Core Node of TouRI’s ROS package on robot
3. Send manipulation task command to the robot
4. Observe robot acknowledging command (printing on the terminal) and updating user-interface state in accord with robot’s state [Executing task/failed to execute/Unsuccessful completion]
5. Send a navigation task command to the robot
6. Observe robot acknowledging command (printing on the terminal) and updating user-interface state in accord with robot’s state [Executing task/failed to execute/Unsuccessful completion]</td></tr>
<tr><th colspan="2">Validation</th></tr>
<tr><td colspan="2">1. The robot receives the user commands in real-time with a latency of less than 5 seconds
2. The robot shares state-based data to the user in real-time with a latency of less than 5 seconds
3. Core node delegates appropriate tasks to appropriate autonomous modules with an accuracy of 100%</td></tr>
</table>

Test 5 – Autonomous Navigation Test

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">To test the autonomous navigation capability of the robot (with static and dynamic obstacles)</td></tr>
<tr><td>Equipment</td><td>Hello Robot's Stretch, Operator computer, Dynamic obstacles in environment</td></tr>
<tr><td>Elements</td><td>TouRI autonomous navigation stack: localization, mapping, path planning, dynamic obstacle avoidance</td></tr>
<tr><td>Personnel</td><td>1 Person (Shruti Gangopadhyay)</td></tr>
<tr><td>Location</td><td>Room/hallway in Wean Hall, 3rd floor, Team H workspace (room no. 3119)</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Feed the map of the environment with 50 meters of traversal track
2. Set up the testing environment with dynamic obstacles
3. Receive goal location from the user interface
4. Observe and test robot localization
5. Observe and test global and local path planning
6. Observe and test dynamic obstacle avoidance
7. Record the time taken for the robot to reach the assigned goal</td></tr>
<tr><th colspan="2">Validation</th></tr>
<tr><td colspan="2">1. Robot localizes itself within the map
2. The robot receives the goal from the user interface and plans a path to the goal location within 3 minutes
3. The robot executes the trajectory and reaches the goal within 12 minutes
4. Robot avoids dynamic obstacles in its path during trajectory execution</td></tr>
</table>

Test 6 – Obstacle Avoidance during Teleoperation Test

Objective	
To test the ability of the robot to detect obstacles during teleoperation and alert the user	
Equipment	Hello Robot's Stretch, Operator computer, Dynamic obstacles in environment
Elements	TouRI autonomous navigation stack: localization, mapping, path planning, dynamic obstacle avoidance
Personnel	3 People (Shruti Gangopadhyay, Jigar Patel, Shivani Sivakumar)
Location	Team H workspace (room no. 3119)
Procedure	
1. Teleoprate the robot within room 2. Detect obstacles around the robot using lidar 3. Display proximity of the obstacle to the robot 4. Observe the proximity data as the robot moves toward the obstacle	
Validation	
1. Lidar is able to detect obstacles around it 2. The proximity of the robot to the obstacle is displayed 3. Proximity data is validated by moving the robot closer/further from the obstacle	

Test 7 – Object Detection for objects in souvenir shop

Objective	
To test the accuracy and reliability of prediction of predefined custom souvenir objects	
Equipment	Hello Robot's Stretch, Device with TouRI App installed
Elements	Object detection algorithm, Compute resource
Personnel	3 People (Jigar Patel, Shruti Gangopadhyay, Shivani Sivakumar)
Location	Wean Hall, 3rd floor, Team H workspace (room no. 3119)
Procedure	
1. Navigate the robot manually to the location where pre-defined objects are present 2. Launch the detection node to detect the objects. 3. Observe the prediction of the class of objects and their bounding boxes 4. Check the database for bounding box updates	
Validation	
1. Predefined objects on the table are detected with 70% precision and recall of 60%	

Test 8 – Object Detection for shipping box

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">To test the accuracy and reliability of centroid prediction for shipping box</td></tr>
<tr><td>Equipment</td><td>Hello Robot’s Stretch, Device with TouRI App installed</td></tr>
<tr><td>Elements</td><td>Object detection algorithm, Compute resource</td></tr>
<tr><td>Personnel</td><td>3 People (Jigar Patel, Shruti Gangopadhyay, Shivani Sivakumar)</td></tr>
<tr><td>Location</td><td>Wean Hall, 3rd floor, Team H workspace (room no. 3119)</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Navigate the robot manually to the room where the shipping box is present
2. Launch the detection node to detect the shipping box
3. Observe the bounding box prediction for the shipping box
4. Observe the centroid location for the shipping box</td></tr>
<tr><td colspan="2">Validation</td></tr>
<tr><td colspan="2">1. Shipping objects on the table are detected with 70% precision and recall of 60%</td></tr>
</table>

Test 9 – User app teleoperation test for Pan Tilt Display

Objective	
To test the flow of joystick data fetched from the app and its execution on Pan/Tilt Display	
Equipment	Hello Robot's Stretch, Device with TouRI App installed
Elements	Server Client connection, Mechatronics, System Integration, HRI
Personnel	2 People (Jashkumar Diyora, Prakhar Pradeep)
Location	Wean 3119 or AI Makerspace, Tepper School of Business, CMU
Procedure	
1. Auto launch Pan/Tilt display's software node on robot startup 2. Indicate successful connection with server on App side and/or robot side 3. Move joysticks for display in the app and motions should be executed on Pan/tilt system 4. Should be able to auto-recenter if required.	
Validation	
1. Pan/Tilt display software node should successfully receive commands and execute them only on predefined dynamixels. 2. Smooth operation of Pan/Display with max. latency of 2~3 seconds	

Test 10 – Safety E-kill switch teleoperation test

Objective	
To test execution of E-Kill switch operation in varying wifi bandwidth	
Equipment	Hello Robot’s Stretch, Device with TouRI App installed, E-Kill actuator PCB designed by TeamH
Elements	Server Client connection, Mechatronics, System Integration, Safety
Personnel	2 People (Jashkumar Diyora, Prakhar Pradeep)
Location	Wean 3119 or AI Makerspace, Tepper School of Business, CMU
Procedure	
1. Mount Servo as an E-kill actuator near Hello Robot kills switch 2. From Hello Robot’s developer deck, power the PCB with 12V 3. Actuator servo will auto position at RELEASE position initially. 4. Engage the kill button on the TouRI app to force stop the robot and disengage to bring the robot back to normal operating mode.	
Validation	
1. E-kill should be able to stop all operations like autonomous navigation, manipulation, or teleoperation in an event of danger. 2. Smooth operation of E-kill actuation with max. latency of <= 1 second.	

Fall Validation Demonstration

Location: AI Makerspace

Equipment: Hello Robot's Stretch, gimbal mount, a display device, user device, Wi-Fi network, objects for grasping, dynamic obstacles in the environment

Objective: Demonstrate that the user can teleoperate and autonomously navigate the robot to the desired location, detection of pre-defined objects, autonomous grasping/placement of pre-defined objects, manually controlled gimbal motion

Autonomous Navigation & Teleoperation for Touring

a) Procedure:
   i) Place the robot at the start location and observe the robot localize.
   ii) Pick a goal for the robot on the interface and observe the robot plan the path.
   iii) Observe the robot autonomously navigating to the goal while avoiding static and dynamic obstacles.
   iv) Allow the user to control the pan-tilt display during the autonomous traversal of the robot to view the surroundings.
   v) On reaching the location, teleoperate the robot to tour the AI Makerspace and observe the robot alert the user about obstacles during teleoperation.
   vi) Control the pan-tilt display through the user interface to observe the surroundings and observe audio-visual communication between the remote user and the people in the environment.

b) Validation:
   i) The user can pass the location to tour the robot, through the user interface.
   ii) The robot is able to localize within the map and plan global and local paths.
   iii) The robot is able to autonomously navigate to the goal with obstacle avoidance.
   iv) The user is able to teleoperate the robot and control the pan-tilt display mounted on the robot for interaction.
   v) The robot is able to detect obstacles around it and alert the user.

Autonomous Pick and Place of Souvenirs

c) Procedure:
   i) After touring, select the souvenir shop to autonomously navigate the robot to it.
   ii) Select the picking option on the interface to select the souvenir to be picked up.
   iii) Observe the robot detects the souvenirs and returns the list to the interface.
   iv) Select the souvenir to be picked through the interface.
   v) Observe the robot autonomously pick up the selected souvenir and drop it in a box at the counter to be shipped.

d) Validation:
   i) The robot is able to autonomously navigate to the souvenir shop.
   ii) The user is able to teleoperate the robot inside the souvenir shop.
   iii) The robot is able to detect the souvenirs in its field of view.
   iv) The user is able to select the souvenir to be picked up from the interface.
   v) The robot is able to autonomously pick up the selected souvenir and place it in a shipping container on the counter.

Appendix A – List of Requirements

Functional Requirement	Performance Requirement	Justification/Assumptions
M.F.3. Plan path & traverse to the desired location	M.P.1. Traverse on hard, flat indoor floors reliably at *0.4 m/s* during teleoperation	Presence of limited obstacles in the surrounding such that a path exists for robot to avoid obstacles and traverse ahead
M.F.3. Plan path & traverse to the desired location	M.P.2. Reach the desired location within *30 minutes*	Assuming latency in receiving user input, obstacle detection, avoidance, and arm manipulation Goal location in the operating area and 100m away from start location of the robot
M.F.1. Facilitate remote user access M.F.2. Receive inputs: room location and teleoperation	M.P.3. Receive user input from interface with a *latency less than 5 seconds*	Assuming >100mbps broadband connectivity is available to user and robot
M.F.3. Plan path & traverse to the desired location	M.P.4. Plan global path to the desired location *within 3 minutes*	The algorithms of the system will be optimized to use onboard compute capability to achieve this
M.F.4. Detect and avoid obstacles	M.P.5. Detect and avoid obstacles (during autonomous navigation and teleoperation) *with mAP of 80%*	For obstacles lying in the FOV of sensing modalities
M.F.6. Detect objects for object grasping and placement.	M.P.6. Detect objects with a *precision of 70%* and *recall of 60%*	For predefined set of objects in the environment and appropriate lighting
M.F.7. Estimate grab points and pose of the objects	M.P.7. Estimate grab points and pose of objects with a *precision of 65%*	For predefined set of objects in the environment and appropriate lighting
M.F.8. Plan manipulator motion for object grasping and placement	M.P.8. Plan manipulator motion to grasp object *within 3 minutes*	The algorithms of the system will be optimized to use onboard compute capability to achieve this
M.F.9. Autonomously grasp and release object	M.P.9. Grasp or release object within 5 minutes, with *70% success*	Accounting for slippage of end-effector due to physical properties (torque required, material) of objects

	rate (7 successful trails out of 10)	
M.F.10. Provide gimbal control of tablet	M.P.10. Provide gimbal motion of *60 degrees in pitch and 120 degrees in yaw* for the display device	To mimic natural human perspective FOV
M.F.11. Provide a video call interface to user	M.P.11. Provide a *1080*720 resolution* video call interface for user to interact with surroundings with a *lag less than 2 seconds*.	The system aims to provide a HD and a real-time experience to the user
M.P.12. Provide traversal feedback	M.P.12. Provide traversal feedback to user *every 5 seconds*	The system aims to provide a real-time experience to the user