CuBi: Room Decluttering Robot

MRSD Team D

The Team:

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Customer:

Cyert Center for Early Education

Carnegie Mellon University
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Introduction

This test report contains various tasks and test plans associated with each of those tasks. A schedule containing the capability milestones that CuBi is supposed to achieve for every Performance Review (PR) is tabulated along with the requirements that it satisfies. Test plans are then explained along with the procedure to be performed and the validation criteria that needs to be met for successful completion of the test.

Personnel:

Team CuBi, Cyert Staff (tentatively)

Equipment:

10 tennis ball-sized toys, CuBi, box with AprilTags, and any necessary replacements for any major subsystems which are at high risk of breaking.

Location:

Cyert Center for Early Education (tentatively). It will have obstacles like chairs and small tables placed in the area. The area will be closed with walls created by furniture. Carpets in the area will have a maximum thickness of 1.2 cm.

Schedule

PR	Task #	Sub-System	Capability Milestone(s)	Owner	Associated Test(s)	Associated System Requirements
9	1	Perception	Robust object detection	L	3	M.P.6
10, 11	2	Perception	Obstacle detection	L, N, J	6	M.P.4
9	3	Perception	Validating pickup	L	2	M.P.7
8	4	Localization & Mapping	Create base map without obstacles	L, N	1	M.P.1
10	5	Localization & Mapping	Localize robot	B, N	5	M.P.3
11	6	Localization & Mapping	Data fusion	N, B, J, L	5	M.P.3
8	7	Localization & Mapping	Odometry drift reset	J	5	M.P.3
9, 10	8	Planning	Exploration	B, J	10	M.P.1
11	9	Planning	Obstacle avoidance	B, J, N	7	M.P.4
10	10	Planning	Local planning optimization: pick up toys	P, J	9	M.P.2
9	11	Controls	Tune gains & speed	P	9	M.P.2
9	12	Controls	Improve grasping: strategy and dynamics	P	9	M.P.2
8	13	Manipulator	Failure detection & recovery -torque feedback -recovery strategy	P, J	5	M.P.7
7	14	Mobility	Improve traction	P	10	M.P.2
11	15	System	Reset robot failure	B, P	FVD	M.N.1
12	16	State Machine	Integrate all subsystems	B, P	FVD	M.N.1

B - Changsheng Shen (Bobby), L - Laavanye Bahl, J - Jorge Antón, N - Nithin Meganathan, P - Paulo Camasmie

<table>
<tr><th colspan="2">TEST NUMBER: 1</th></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstrate room base map creation without obstacles</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>● Localization and mapping</td><td>● Room with only walls and static obstacles (e.g. fixed cabinets)
● Measuring tape</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>NSH 4th Floor</td><td>Team CuBi</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Place CuBi in the testing location and initialize the robot.
2. Turn CuBi on.
3. Move CuBi manually with joystick to map the room.
4. Construct and save the map.</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">● Area mapped should be roughly 90% of the total actual area of the room.
● A distinctive boundary of the room should be visible.
● Static objects should be distinctively indicated on the map.</td></tr>
</table>

<table>
<tr><th colspan="2">TEST NUMBER: 2</th></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstrate that CuBi can validate whether a pick-up is successful</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>● Perception
● State machine</td><td>● Three different toys</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>NSH 4th Floor</td><td>Team CuBi</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Place three different toys for CuBi to pick up.
2. Place CuBi in the testing location and initialize the robot.
3. CuBi starts to search, approach and attempts to pick up the toys.
4. When CuBi starts to pick up the toy, manually take the toy away from the tray to simulate an unsuccessful pick-up.
5. CuBi validates whether the pick-up is successful.
6. If the pick-up is not successful, CuBi should continue searching for toys instead of going to the destination box with the empty tray.</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">● CuBi should continue searching for new toys whenever a pick-up is unsuccessful, instead of going to the destination box with the empty tray.</td></tr>
</table>

<table>
<tr><th colspan="2">TEST NUMBER: 3</th></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstrate robust object detection and tracking</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>Perception</td><td>Five box-like objects</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>NSH 4th Floor</td><td>Team CuBi</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">Place CuBi in the testing location and initialize the robot.
Place three objects around CuBi within a radius of 0.2 to 1.2m as shown in Fig 1.
Turn CuBi on.
CuBi starts exploring for objects around itself.
If CuBi detects an object, it should assign a label to it and go towards it and pick it.
CuBi should then drop the object at the drop-off location.
If CuBi successfully picks and drops all three objects, then it validates robust object detection, tracking, size estimation, and false positive avoidance.</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">CuBi should be able to detect and assign a unique label to 5/5 objects which is validated visually as well as by CuBi locking and approaching an object for grasping.
There should be no false positives. CuBi should not go to an area and attempt grasping, where the object is actually not present.</td></tr>
<tr><td colspan="2">

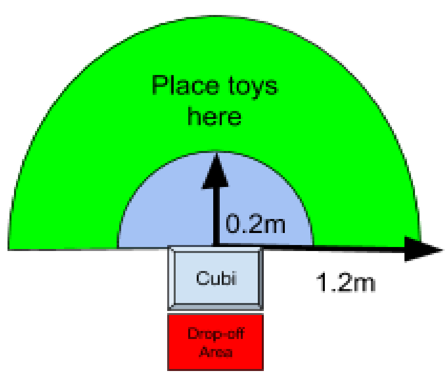

Fig 1. Setup for object detection demonstration</td></tr>
</table>

TEST NUMBER: 4	
Objective	
Demonstrate that CuBi can detect and recover from grasping failures	
Elements	**Equipment**
• Manipulator • State machine	• A flat-shaped toy
Location	**Personnel**
NSH 4th Floor	Team CuBi
Procedure	
1. Place CuBi in the testing location and initialize the robot. 2. Place a toy on CuBi's tray, in the middle of both fingers. 3. Send a command to CuBi to perform a grasp by closing the fingers. 4. If the toy is stuck in between two fingers, CuBi should release it after several seconds. 5. If the toy is not stuck, repeat the procedures above.	
Validation Criteria	
• CuBi should release the toy if grasping fails, and the motors should be able to move instead of getting stuck after failure happens.	

<table>
<tr><th colspan="2">TEST NUMBER: 5</th></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstrate that CuBi can achieve a localization error of less than 10%</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>● Odometry drift reset
● Data fusion of odometry and other sensors</td><td>● Duct tape
● Measuring tape</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>NSH 4th Floor</td><td>Team CuBi</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Place CuBi in the testing location and initialize the robot.
2. Pick three waypoints on the ground each at 2.5cm distance. The waypoints are not on the same line to test out orientation accuracy.
3. CuBi reaches every waypoint one by one.
4. The difference between the pose of CuBi and the pose of goal at each waypoint are measured.
5. Calculate the average of the three measured errors.</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">● The average localization error should be less than 10%.</td></tr>
</table>

TEST NUMBER: 6

Objective

Demonstrate obstacle detection

Elements	Equipment
• Perception	• 3 obstacles of size significantly bigger than objects (E.g stools)

Location	Personnel
NSH 4th Floor	Team CuBi

Procedure

1. Place CuBi in the testing location and initialize the robot.
2. Place three obstacles around CuBi within a radius of 0.2 to 1.2m as shown in Fig 1.
3. Turn CuBi on.
4. Move CuBi manually to detect obstacles around it.
5. If CuBi detects an obstacle, it should indicate its position in the map or visualization.

Validation Criteria

- CuBi should be able to detect and indicate all three obstacles distinctively.

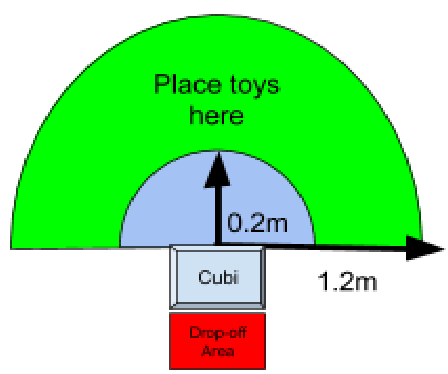

Fig 1. Setup for obstacle detection demonstration

TEST NUMBER: 7	
Objective	
Demonstrate obstacle avoidance	
Elements	**Equipment**
• Local planning and decision making • Obstacle detection	• Five box-like obstacles • Measuring tape
Location	**Personnel**
NSH 4th Floor	Team CuBi
Procedure	
1. Place CuBi in the testing location and initialize the robot. 2. Place five obstacles around the room at random places but not too close to the walls. 3. Turn CuBi on. 4. Send CuBi to a waypoint on the other side of the obstacle. 5. CuBi should approach the waypoint with a path that does not collide with the obstacle.	
Validation Criteria	
• CuBi should avoid 75% of the obstacles present. • CuBi should maintain a clearing distance of at least 10cm from the obstacle at all times.	

TEST NUMBER: 8	
Objective	
Demonstrate that CuBi can handle to hard to grasp objects	
Elements	**Equipment**
• Local planning and decision making • Controls	• A hard-to-grasp object (e.g. a flat object)
Location	**Personnel**
NSH 4th Floor	Team CuBi
Procedure	

1. Place CuBi in the testing location and initialize the robot.
2. Place one flat object on the floor.
3. Turn CuBi on.
4. CuBi identifies the object.
5. CuBi will move towards object and attempt grasping.
6. If CuBi object gets stuck between its paddles:
  a. CuBi will sense the fail state through motor feedback.
  b. CuBi will back off enough and go back to step 4.
7. CuBi uses a different approach to pick up the object.
8. If CuBi fails a second attempt:
  a. It will give up on that object.
  b. It will back off and stop.	

Validation Criteria	
• CuBi should detect that an object got stuck. • CuBi should retry to grasp that object one time. • CuBi should not continue attempting to pick up objects after failing twice.	

<table>
<tr><th colspan="2">TEST NUMBER: 9</th></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstrate that CuBi can pick up toys in a timely manner</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>● Manipulator
● Mobility
● Motor controller</td><td>● Ten toys</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>NSH 4th Floor</td><td>Team CuBi</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Place 10 toys randomly in the testing location for CuBi to pick up.
2. Place CuBi in the testing location and initialize the robot.
3. CuBi starts to explore, search, pick up, bring back and drop the toys one-by-one.
4. When 8 out of 10 toys are picked up, evaluate the amount of time taken.</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">● CuBi should successfully pick up 8 out of 10 toys within 20 minutes.</td></tr>
</table>

<table>
<tr><th colspan="2">TEST NUMBER: 10</th></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Given a map with the walls of the room, ensure that our exploration policy will guide CuBi to scan 90% of the room</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>● Exploration Algorithm</td><td>● A room which has large obstacles acting as walls to make it non-rectangular shaped</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>NSH 4th Floor</td><td>Team CuBi</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. CuBi is placed in a space which has already been mapped.
2. Place CuBi at the starting location and turn it on.
3. It should explore the whole room.
4. Given its field-of-view determine what percentage of the room it covered and compare it to the total reachable area.</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">● Will explore, scan and map 90% of the reachable area in a room.</td></tr>
</table>

Appendix

1.1. Mandatory Performance Requirements

The system will:

M.P.1. Explore, scan and create a 2D map for 90% of the reachable area in a room

M.P.2. Clean up a $20m^2$ room with a dozen tennis-ball-sized objects within 30 minutes.

M.P.3. Navigate to a designated reachable location in a room with pose error < 10%.

M.P.4. Go over carpets and rugs with thickness less than 12mm.

M.P.5. Detect and avoid 75% of the obstacles with a clearing distance of 10cm.

M.P.6. Classify all tennis ball-sized objects with classification error < 20%.

M.P.7. Pick up and collect each classified object within 5 attempts.

M.P.8. Pick up at least 80% of the classified objects in the room

M.P.9. Carry at least 2 tennis ball-sized object to the drop-off location.

M.P.10. Drop the clutter in a designated container marked with AprilTag with success rate > 90%

3.2. Mandatory Non-Functional Requirements

The system shall:

M.N.1. Operates autonomously.

M.N.2. Be mechanically safe (i.e. no sharp edges).

3.3. Desirable Performance Requirements

The system will:

D.P.1. Continuously operate for at least 2 hours once fully charged.

D.P.2. Have a sensing range of 15 cm to 4 m.

D.P.2. Have a physical dimension limit of 0.5 x 0.5 x 0.5 m.

D.P.3. Be affordable with a maximum cost of $5000 USD.

3.4. Desirable Non-Functional Requirements

The system shall:

D.N.1. Be easy to use by pressing buttons or through a GUI.

D.N.2. Have an inconspicuous, seamless appearance.

D.N.3. Be reliable and not get stuck or malfunction frequently.