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Introduction

This document describes the various tests to be performed by team GHAR during the Fall, 2023 semester in order to validate and verify that the subsystems as well as the whole system are meeting stated functional and performance requirements. The tests are designed such that there is an incremental increase in the complexity of the test and the necessary state of the system in order to properly perform the task, which will provide a good deadline for finishing functionalities. The results of these tests will be reported during the progress reviews. Each test has a name/number, an objective, elements, a location, equipment, personnel, procedure, and verification criteria. By the fall validation experiment, all subsystems should be integrated and working.

Logistics

Location

All the hardware tests will be performed in the NSH lobbies on either of the possible floors: A/1/2/3.

Personnel

No additional personnel besides the four members of the team are required for conducting any of the tests documented herein.

Schedule

PR	Date	Milestone(s)	Test(s)	Associated Requirements
8	September 27th	1. Integration on RTAB-MAP with grid maps library. 2. Implementation of path smoothening of global path. 3. Deploy the implemented planner on the locobot.	4	M.F.R.3
9	October 11th	1. Improve the UI 2. Set up the A1-unitree hardware or simulation 3. Implement yaw planning in global planner	1, 5	M.F.R.1, M.F.R.3, M.N.F.R.4
10	October 25th	1. Make local planner work with MBF and Grid Map 2. Deploy the implemented planner on the A1 unitree. 3. Implement the Data Management block	2, 6	M.F.R.3, M.N.F.R.1, M.N.F.R.2
11	November 8th	1. Clear any backlogs 2. Start full system testing	3, 7	M.N.F.R.3, M.F.R.1, M.F.R.3
FVD	November 20th	1. Run the entire navigation stack on at least 2 robots	8	M.N.F.R.1, M.N.F.R.2, M.F.R.3
Encore	November 29th			

Tests

Test 1	
Test the navigation stack on the locobot	
Objective	
The planner, given a map, should be able to plan a path to the goal and successfully be able to make the locobot follow that plan	
Requirements	M.F.R.3
Elements	Hardware agnostic path planning
Location	MRSD A Level
Equipment	Locobot
Personnel	● Kshitij Kabeer ● Madhu Korada
Procedure	
● Create a map using the SLAM subsystem or using the map builder from Spring Semester ● Start the navigation system on the locobot ● Give a goal location, and let the robot plan and follow the trajectory	
Verification Criteria	
● The locobot doesn’t collide with any obstacle ● The locobot is able to reach the goal location	

Test 2	
Test the navigation stack on the A1- Unitree	
Objective	
The planner, given a map, should be able to plan a path to the goal and successfully be able to make the A1-Unitree follow that plan	
Requirements	M.F.R.3
Elements	Hardware agnostic path planning
Location	MRSD A Level
Equipment	A1-Unitree
Personnel	● Kshitij Kabeer ● Madhu Korada
Procedure	
● Create a map using the SLAM subsystem or using the map builder from Spring Semester ● Start the navigation system on the A1 - Unitree ● Give a goal location, and let the robot plan and follow the trajectory	
Verification Criteria	
● The locobot doesn't collide with any obstacle ● The locobot is able to reach the goal location ● The A1-Unitree is able to go over obstacles that it can walk over	

Test 3	
Test the elevation map that is generated from SLAM Subsystem	
Objective	
When creating a plan, the planner must consider the robot's capability to traverse different terrains and objects using the generated map as a reference.	
Requirements	M.F.R.2, M.F.R.3, M.N.F.R.1
Elements	RTAB-Map, GridMap
Location	MRSD Lab
Equipment	MRSD Computer 2
Personnel	● Madhu Korada ● Harshad Zade
Procedure	
● Create a traversability map with the height, width, & orientation of objects present in each grid cell. ● Add multiple objects in the map and test the map quality. ● Map several environments and verify the map quality.	
Verification Criteria	
● The elevation map should look accurate visually. ● The obstacles in the map should not make the terrain too rough.	

Test 4	
Test efficiency and functionality of the User Interface (UI)	
Objective	
The UI should be able to handle all input being received from the graphical user interface (GUI)	
Requirements	M.F.R.1
Elements	UI, GUI (Control Panel for Planner)
Location	MRSD Lab
Equipment	MRSD Computer 2, Laptop
Personnel	● Kshitij Kabeer
Procedure	
● Launch User Interface ● Launch navigation stack ● Input parameters (Obstacles, FSOH, Robot Parameters, etc.) into the GUI ● Display planned path and environment via the User Interface (launched on separate machine)	
Verification Criteria	
● Verify the output is clearly visualize ● Parameters inputted via the GUI is passed through to the UI without any issues	

<table>
<tr><th colspan="2">Test 5</th></tr>
<tr><td colspan="2">Test generation of smooth paths from the global planner</td></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">The global planner should create a plan optimized for the platform’s capabilities and the path generated should be smooth with the correct orientation</td></tr>
<tr><th>Requirements</th><td>M.F.R.3, M.N.F.R.1</td></tr>
<tr><th>Elements</th><td>Global Planner</td></tr>
<tr><th>Location</th><td>MRSD Lab</td></tr>
<tr><th>Equipment</th><td>MRSD Computer 2</td></tr>
<tr><th>Personnel</th><td>● Rolanda Hutson</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">● Generate a map using SLAM subsystem or by using the map builder from SVD
● Input parameters to GUI
● Generate plan on pre-built map from start to goal locations
● Visualize the planned path</td></tr>
<tr><th colspan="2">Verification Criteria</th></tr>
<tr><td colspan="2">● Path visualized should be free of jagged edges (will provide comparison paths before/after path smoothing is applied)
● Orientation will be verified by calculating the desired orientation at each waypoint and comparing this with the actual orientation</td></tr>
</table>

<table>
<tr><th colspan="2">Test 6</th></tr>
<tr><td colspan="2">Test the velocity commands from our planning stack which will be deployed on A1 Unitree.</td></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Ensure that we are getting the velocity commands which can be taken as input by the A1 Unitree.</td></tr>
<tr><th>Requirements</th><td>M.F.R.3, M.N.F.R.1</td></tr>
<tr><th>Elements</th><td>A1 Unitree</td></tr>
<tr><th>Location</th><td>MRSD Lab</td></tr>
<tr><th>Equipment</th><td>Realsense Camera, A1 Unitree, MRSD Computer 2</td></tr>
<tr><th>Personnel</th><td>● Madhu Korada
● Harshad Zade
● Kshitij Kabeer</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">● Map the environment using Realsense.
● Generate hardware agnostic path.
● Deploy the path on the A1 Unitree.
● Analyze how the robot is moving.</td></tr>
<tr><th colspan="2">Verification Criteria</th></tr>
<tr><td colspan="2">● Make sure the robot is taking velocity commands as input and generate planning for foot steps.
● Test if the robot can follow the generated path visually.</td></tr>
</table>

Test 7	
Test the Data Management Subsystem	
Objective	
The data management system should be able to transfer all the data between the base station and the robot correctly and reliably	
Requirements	M.N.F.R.2
Elements	Data Management
Location	MRSD A Level
Equipment	A1-Unitree, Locobot
Personnel	● Kshitij Kabeer ● Harshad Zade
Procedure	
● Start the requisite nodes on the base station as well as the Locobot ● Perform Test 1 ● Start the requisite nodes on the base station as well as the A1-Unitree ● Perform Test 2	
Verification Criteria	
● All verification criterias of Test 1 and Test 2 ● Connection drops should not be prolonged and frequent ● All the subsystems work correctly even with the latency and connection issues	

<table>
<tr><th colspan="2">Test 8</th></tr>
<tr><td colspan="2">Fall Validation Demo</td></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">To demonstrate the entire navigation system on both the locobot and A1-Unitree</td></tr>
<tr><th>Requirements</th><td>M.F.R.1, M.F.R.3, M.N.F.R.1, M.N.F.R.2, M.N.F.R.4</td></tr>
<tr><th>Elements</th><td>Subsystems - SLAM, Planning, UI and Data Management (if present)</td></tr>
<tr><th>Location</th><td>NSH A Level</td></tr>
<tr><th>Equipment</th><td>Locobot, A1-Unitree, and Base Station (if using the Data Management block)</td></tr>
<tr><th>Personnel</th><td>Madhu Korada
Harshad Zade
Kshitij Kabeer
Rolanda Hutson</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">
A map of the testing area that has been pre-built using the SLAM subsystem will be loaded
The instructors will pick a start and goal location
The wheeled robot will be placed at the start location
All subsystems will be started
Run the navigation stack, continuously visualizing the global and local path, and the robot position
Robot reaches the goal location
Repeat the above steps for the legged robot
</td></tr>
<tr><th colspan="2">Verification Criteria</th></tr>
<tr><td colspan="2">
The planner adapts to different obstacle maps and varying robot parameters and generates a path that does not violate the following capability limitations:
Freely Steppable Object Height* (FSOH) - The robot can easily step over the object of height below this threshold.
Robot Radius - The radius of the circular approximation of the robot
The robots are able to follow the generated plan and follow it without crashing or colliding with obstacles
The UI and visualization should work as intended
</td></tr>
</table>

<table>
<tr><th colspan="2">Fall Validation Demo</th></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">To demonstrate the entire navigation system on the LoCoBot and Unitree Go1</td></tr>
<tr><th>Elements</th><td>Subsystems - SLAM, Hardware Agnostic Path Planning, Robots</td></tr>
<tr><th>Location</th><td>NSH Level 4 - Towards the end of the lobby near student’s common room.</td></tr>
<tr><th>Equipment</th><td>LoCoBot, Unitree Go1, Router for Local Network</td></tr>
<tr><th>Personnel</th><td>● Madhu Korada
● Harshad Zade
● Kshitij Kabeer
● Rolanda Hutson</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">● We demonstrate the capabilities of both the robots using teleop.
● A map of the testing area that has been pre-built using the custom map generator module will be loaded.
● The instructors will pick a start and goal location.
● The wheeled robot will be placed at the start location.
● All subsystems will be started.
● Run the navigation stack, after which the robot starts tracking the plan it received.
● Robot reaches the goal location.
● Repeat the above steps for the legged robot.
● Demonstrate this in different environments.
    ○ We will have pre defined multiple environments with obstacles in different locations to showcase the best test cases.
    ○ Robot parameters can be varied, but not all parameters can be replicated on real robots as the hardware is unchanged. However, the plan, and traversability map that gets generated for different robot parameters can be visualized.
● Instructors get to choose a custom start and goal points.</td></tr>
<tr><th colspan="2">Verification Criteria</th></tr>
<tr><td colspan="2">● The planner adapts to different obstacle maps and varying robot parameters and generates a path that does not violate the following capability limitations:
    ○ Freely Steppable Object Height* (FSOH) - The robot can easily step over the object of height below this threshold.
        ■ 0 cm for LoCoBot
        ■ 5 cm for Unitree Go1
    ○ Robot Radius - The radius of the circular approximation of the robot
● The robots are able to follow the generated plan and follow it without crashing or colliding with obstacles 85% of the times for LoCoBot and 65% of the times for Unitree Go1.
● The UI and visualization should work as intended</td></tr>
</table>

<table>
<tr><th colspan="2">Fall Validation Demo Encore</th></tr>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">To demonstrate the entire navigation system on a new robot.</td></tr>
<tr><th>Elements</th><td>Subsystems - Localization, Hardware Agnostic Path Planning, Robots</td></tr>
<tr><th>Location</th><td>NSH Level 4 - Towards the end of the lobby near student’s common room.</td></tr>
<tr><th>Equipment</th><td>Unitree Go1, Router for Local Network</td></tr>
<tr><th>Personnel</th><td>Harshad Zade
Kshitij Kabeer
Madhu Korada
Rolanda Hutson</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">
We demonstrate the new capabilities of the legged robot using teleop and compare them to those showcased in FVD.
A map of the testing area that has been pre-built using the custom map generator module will be loaded.
We will pick a start and goal location.
The robot will be placed at the start location.
All subsystems will be started.
Run the navigation stack, after which the robot starts tracking the plan it received.
Robot reaches the goal location taking the path by leveraging the new capabilities.
Instructors get to choose a custom start and goal points.
Get a thin obstacle that can be traversed by LoCoBot and showcase that planner can take into consideration that traversability and generate the plan accordingly.
</td></tr>
<tr><th colspan="2">Verification Criteria</th></tr>
<tr><td colspan="2">
The planner adapts to different obstacle maps and varying robot parameters and generates a path that does not violate the following capability limitations:
Freely Steppable Object Height* (FSOH) - The robot can easily step over the object of height below this threshold.
10 cm for Unitree Go1
The robot is able to follow the generated plan and follow it 80% of the times.
No crashing or colliding with obstacles 85% of the times.
</td></tr>
</table>

Appendix

A. Mandatory Functional Requirements

ID	Requirement	Performance Metric
M.F.R.1	Receive commands from the user	100%
M.F.R.2	Simultaneously Map and Localize in the environment	Relative pose error(T) <= 15cm Relative pose error(R) <= 15 deg
M.F.R.3	Achieve hardware agnostic navigation to the goal point	Avoid 90% Collisions Reaches the goal 85% of the time 1 Wheeled Robot, 1 Legged Robot 1 more Wheeled Robot (desirable)

B. Mandatory Non-Functional Requirements

ID	Requirement	Performance Metric
M.N.F.R.1	Software should not compromise the mobility of the platform	Path for both the robots should be smooth
M.N.F.R.2	Software should be extensible	GHAR will run on platforms that have enough compute to run ROS.
M.N.F.R.3	Clean and Well Documented Code	Follows ROS Style Guide
M.N.F.R.4	Real-time visualization of the working of the navigation stack	Show global path, local path, the current pose of the robot