Master of Science
Robotic Systems Development

DarkBot
Quadruped Robot for Assistive Search in Narrow and Cluttered Environment

Team NightWalkers

16-682: Fall Test Plan
Group B

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THE ROBOTICS INSTITUTE

Introduction

The purpose of this document is to outline Team B's testing plan for Project DarkBot in the Fall 2023 semester. These tests are specifically designed to validate the alignment of our subsystems with the performance criteria specified in Appendix A. We are committed to keeping stakeholders well-informed about the progress of these tests through regular progress reviews, and we will present the outcomes during the Fall Validation Demonstration (FVD).

Additionally, this document provides a comprehensive overview of the key milestones in our project. Our testing strategy follows a progressive approach, commencing with smaller-scale tests before moving on to more complex ones. Our team employs an integration-first approach to ensure the early development of minimal viable autonomous systems. The results of these tests will be presented during the FVD. We added possible FVD Encore test plans, which are subject to change.

Logistics

Location

Preliminary autonomy and software-only tests will take place on the 4th floor of Newell-Simon Hall, specifically in Room 4222. The final autonomy tests, on the other hand, will be conducted in the RoboLounge, situated on the 1st floor of Newell-Simon Hall.

Personnel

The Nightwalkers team will oversee all testing procedures. Within the team, specific roles have been assigned as follows:

1. One team member will assume the role of first responders responsible for deploying the robot into the search room.
2. Another team member will act as the stranded individual, positioned on the ground to simulate a real-world scenario.
3. A third team member will remain in close proximity to the robot, ensuring safety without interfering with its operations.
4. An additional team member will observe the entire process and provide explanations to the audience regarding the ongoing activities.

Occasionally, team members may also be called upon to simulate additional stranded individuals in the environment, showcasing the robot's capability to detect multiple humans effectively.

Equipment

The majority of our tests will require the following equipment:

- **Unitree Go1 Robot**: Essential for showcasing the developed locomotion functionalities.
- **AirLab Payload**: To demonstrate the mapping and computing capabilities of our system.
- **RealSense D435**: Utilized for human detection demonstrations.
- **Team B MRSD Computer**: This computer will be used to view and interpret visualized information sent from the robot.
- **Display Device**: Necessary for transmitting audio/video feeds during testing.
- **Obstacles of Different Shapes and Sizes**: These will be used to create a varied and cluttered environment to test the robot's capabilities effectively.

Schedule

Date	PR-#	Capability Milestones	Tests	Associated Requirements
09/27/2023	8	• Show preliminary capability of human detection & localization • 3D SLAM performed on mounted payload • Simple curve trajectory following by Untree Go1	Test 1 Test 3	• RPM-3 • RPM-4
10/11/2023	9	• Demonstrate reasonably accurate human location on map (error within 1m) • Go1 explores a small obstacle-free room upon door entrance to detect and localize a human	Test 2 Test 4	• RPM-1 • RPM-3 • RPM-4
11/01/2023	10	• Go1 explores a segment of hallway and enter a large cluttered room to spot and localize a human	Test 5	• RPM-1 • RPM-2 • RPM-3 • RPM-4
11/15/2023	11	• Go1 explores multiple cluttered rooms connected by a corridor to spot and localize human	Test 6	• RPM-1 • RPM-2 • RPM-3 • RPM-4
11/20/2023	FVD	• Same as PR-11	FVD	• RPM-1 • RPM-2 • RPM-3 • RPM-4
11/29/2023	FVD Encore	• Go1 explores multiple cluttered rooms connected by a corridor to spot and localize human	FVD Encore	• RPM-1 • RPM-2 • RPM-3 • RPM-4

Tests

Test Task 1: Trajectory Following Algorithm Testing	
Objective	
To evaluate the trajectory following algorithm independently of the controller in a simulated environment.	
Equipment	MRSD computer
Elements	Legged controller, trajectory following algorithm, gazebo
Personnel	Andrew
Location	NSH-B506
Procedure	
1. Initialize the Robot and World in Gazebo Simulation: Set up the robot and the simulated environment within the Gazebo simulation platform. 2. Generate a Spline Trajectory in the World: Create a spline trajectory within the simulated world to define the path the robot will follow. 3. Position the Robot at the Path's Starting Point: Place the robot at the initial point of the trajectory. 4. Execute Trajectory Following: Start the robot along the generated trajectory, ensuring it follows the path accurately. 5. Halt at the Destination: Once the robot reaches the end of the trajectory, bring it to a stop at that location.	
Validation	
1. Stationary Trotting: The robot remains stationary unless it receives the "go" command. 2. Precise Straight-Line Navigation: The robot follows a straight path with a deviation of under 10 cm. 3. Accurate Turning: The robot maintains a turning angle error within 10 degrees. 4. Steady Gait: The robot exhibits a smooth and stable gait without jitter or wobbling during locomotion. 5. Goal-Driven Halting: The robot comes to a halt once the final translation error to the goal is less than 10 cm.	

Test Task 2: Quadruped Local Planner Testing	
Objective	
To ensure the trajectory following algorithm's functionality on actual robots, enabling them to successfully navigate around obstacles encountered in their path.	
Equipment	MRSD computer, Unitree Go1, Airlab Payload
Elements	Legged controller, trajectory following algorithm, local planner
Personnel	Andrew
Location	NSH-B506
Procedure	
1. Integrate the Legged Controller Code onto the Nvidia Xavier Payload: Install and configure the legged controller code on the Nvidia Xavier payload. 2. Position the Robot at the Starting Point: Place the robot at its designated starting position. 3. Load the Pre-Defined Trajectory Waypoints: Upload the predefined trajectory waypoints into the robot's control system. 4. Set Up Obstacles: Position two boxes, each one meter in front of the robot, to simulate obstacles. Initiate Movement Command: Transmit the signal to instruct the robot to commence its motion. 5. Cease Motion upon Successful Obstacle Bypass: Halt the robot's movement when it successfully bypasses the boxes and follows the intended trajectory. 6. Actual motion will be measured with physical markings and measuring tapes based on best effort; the commanded motion will be compared against such physical measurement	
Validation	
1. Obstacle Detection: The robot detects obstacles in its path with a precision of less than 20 cm in translation error. 2. Precision in Turning: The robot maintains its turning angle with an error margin of within 10 degrees. 3. Steady and Stable Locomotion: The robot executes its movements with a steady gait, demonstrating a smooth and stable gait devoid of any jitter or wobbling. 4. Goal-Centric Halting: The robot ceases movement once the final translation error to the goal is less than 10 cm, aligning itself precisely. 5. Collision Avoidance: The robot effectively avoids collisions with the boxes, ensuring it does not come into contact with them.	

Test Task 3: Preliminary Human Detection & Localization	
Objective	
Demonstrate preliminary capability of human detection and localization	
Elements	Human detection & localization 3D SLAM Integration hardware
Location	Room 4222, 4th floor of Newell-Simon Hall.
Equipment	Unitree Go1 Robot AirLab Payload RealSense D435 Team B MRSD Computer
Personnel	Andrew: Responsible for deploying the robot. Connie: Positioned on the ground to simulate a real-world scenario. Zack: Ensures robot's safety without interfering. Saha: Observes and explains ongoing activities to the audience.
Procedure	
1. Deploy the Robot in a Controlled Environment: Set up the robot within a controlled and predefined environment. 2. Initiate Navigation with Basic Commands: Start the robot's navigation by issuing fundamental commands. 3. Activate the Human Detection Module: Enable the robot's human detection module to identify individuals in its surroundings. 4. Conduct 3D SLAM for Map Generation: Execute 3D Simultaneous Localization and Mapping (SLAM) to create a comprehensive map of the environment. 5. Map Human Localization: Identify and precisely locate detected humans on the generated map, ensuring accurate positioning. 6. The actual relative pose from human to robot start point will be measured with physical markings and measuring tape which serves as ground truth to the value obtained from generated map	
Verification Criteria	
Detect and localize humans within 50cm error (x direction plus y direction) and 5 seconds (robot stays still in front of human within 5m away), generate a 3D map using SLAM.	

<table>
<tr><th colspan="2">Test Task 4: Exploration and Human Localization in a Small Room</th></tr>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">Demonstrate accurate human location on a map in a small room.</td></tr>
<tr><td>Elements</td><td>Human detection & localization
3D SLAM
Exploration planner
Hardware integration components.</td></tr>
<tr><td>Location</td><td>Room 4222, 4th floor of Newell-Simon Hall.</td></tr>
<tr><td>Equipment</td><td>Unitree Go1 Robot
AirLab Payload
RealSense D435
Team B MRSD Computer</td></tr>
<tr><td>Personnel</td><td>Andrew: Responsible for deploying the robot.
Connie: Positioned on the ground to simulate a real-world scenario.
Zack: Ensures robot's safety without interfering.
Saha: Observes and explains ongoing activities to the audience.</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Place the Robot at the Room's Entrance: Position the robot at the entrance of the room.
2. Engage the Exploration Planner: Activate the exploration planner to initiate the autonomous navigation process.
3. Autonomously Explore the Room: Enable the robot to navigate and explore the room independently, making decisions on its own.
4. Detect and Localize a Human: Employ the robot's sensors to detect and precisely determine the location of any human presence within the room.
5. Display Human Location on the Generated Map: Accurately represent the detected human's position on the map generated during exploration.
6. The actual relative pose from human to robot start point will be measured with physical markings and measuring tape which serves as ground truth to the value obtained from generated map</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
</table>

Accurately localize humans on map within 30cm error (x direction plus y direction) and 3 seconds (robot stays still in front of human within 5m away), map consistent with actual room layout.

Test Task 5: Exploration of Hallway and Cluttered Room	
Objective	
Explore hallway segments, enter a cluttered room, detect and localize humans.	
Elements	Human detection & localization 3D SLAM Exploration planner Local Motion planner Hardware integration components.
Location	Room 4222, 4th floor of Newell-Simon Hall.
Equipment	Unitree Go1 Robot AirLab Payload RealSense D435 Team B MRSD Computer Display Device Obstacles of different shapes and sizes
Personnel	Andrew: Responsible for deploying the robot. Connie: Positioned on the ground to simulate a real-world scenario. Zack: Ensures robot's safety without interfering. Saha: Observes and explains ongoing activities to the audience.
Procedure	
1. Commence from the Hallway's Starting Point: Begin the process by positioning the robot at the starting point of the hallway. 2. Traverse the Hallway Utilizing TARE Planner: Navigate through the hallway employing the TARE (Terrain-Aware Reactive Execution) planner for precise path determination. 3. Enter the Cluttered Room: Access the cluttered room while maintaining the navigational context. 4. Autonomously Explore the Room: Enable the robot to autonomously explore the room, employing obstacle detection mechanisms and dynamic navigation to navigate around obstacles effectively.	

5. Detect and Precisely Localize Humans in the Room: Utilize the robot's sensory capabilities to identify and accurately determine the location of any humans present within the room. 6. The actual relative pose from human to robot start point will be measured with physical markings and measuring tape which serves as ground truth to the value obtained from generated map
Verification Criteria
Accurately localize humans on map, map consistent with actual room layout.

Test Task 6: Exploration of Two Rooms	
Objective	
Explore two cluttered rooms connected by corridors, detect and localize humans.	
Elements	Human detection & localization 3D SLAM Exploration planner Global path planner Local Motion planner Hardware integration components.
Location	Room 4222 and Room 4224, 4th floor of Newell-Simon Hall.
Equipment	Unitree Go1 Robot AirLab Payload RealSense D435 Team B MRSD Computer Display Device Obstacles of different shapes and sizes
Personnel	Andrew: Responsible for deploying the robot. Connie: Positioned on the ground to simulate a real-world scenario. Zack: Ensures robot's safety without interfering. Saha: Observes and explains ongoing activities to the audience.
Procedure	
1. Commence from the Corridor: Begin the process by positioning the robot at the entrance of the corridor.	

2. Sequentially Navigate and Explore Each Room: Systematically navigate through and explore each room in a sequential manner, ensuring complete coverage. 3. Obstacle Detection and Global Path Planning: Employ a global path planner to detect obstacles and navigate around them effectively while exploring each room. 4. Human Detection and Localization: Utilize the robot's sensors to detect and precisely locate humans within each room during exploration. 5. Create an All-Encompassing Map: Generate a comprehensive map of the entire area by combining data from each room, ensuring a holistic representation of the environment. 6. The actual relative pose from human to robot start point will be measured with physical markings and measuring tape which serves as ground truth to the value obtained from generated map 7. The 3D point cloud will be compared with actual dimensions of rooms mapped, which can be measured with measurement tape between corners
Verification Criteria
1. Humans are comfortably detected with 70% accuracy and registered at 5 meter of range with an accuracy of 0.3 m from ground truth (including SLAM drift) 2. Able to traverse around obstacles and doors 3. Able complete the area (containing a few $2m^2$ cluttered areas) with a minimal rate of 16 m^2/min

Fall Validation Demonstration Preparation	
Objective	
Re-produce an ideal run for test task 6. To test human detection and localization performance on the robot with slam. To test autonomous exploration in an environment with	
Elements	Human detection & localization 3D SLAM Exploration planner Global path planner Local Motion planner Hardware integration components.
Location	Robo Lounge, 1st floor of Newell-Simon Hall.
Equipment	Unitree Go1 Robot AirLab Payload

	RealSense D435 Team B MRSD Computer Display Device Obstacles of different shapes and sizes
Personnel	Andrew: Responsible for deploying the robot. Connie: Positioned on the ground to simulate a real-world scenario. Zack: Ensures robot's safety without interfering. Saha: Observes and explains ongoing activities to the audience.
Procedure	
1. Preparation for Robo Lounge: Ensure the Robo Lounge is vacant, with no individuals inside. 2. Obstacle Setup: Arrange prescribed wooden boards and blocks within the Robo Lounge to create a cluttered environment. 3. Human Evacuation: Safely relocate any "trapped" individuals sitting on the ground with the door open. 4. Area Measurement: Measure the dimensions of the Robo Lounge and initiate timer counting. 5. Darkbot Deployment: Dispatch the Darkbot into the lounge to conduct environmental mapping and search for humans. 6. Mapping Completion: Once the robot concludes its room search, stop the timer. 7. Visualization: Visualize the generated environmental map, annotating human poses within the map for comprehensive analysis during the FVD.	
Verification Criteria	
1. Humans are comfortably detected with 70% accuracy and registered at a 5-meter range with an accuracy of 0.3 m from ground truth (including SLAM drift) 2. Able to traverse around obstacles and doors 3. Able to complete the area (containing a few 2m² cluttered areas) with a minimal rate of 16 m²/min	

Possible Fall Validation Demonstration Encore Preparation	
Objective	
Explore multiple rooms, localize humans with 10% less exploration time than previous tests.	
Elements	Human detection & localization

<table>
<tr><td></td><td>3D SLAM
Exploration planner
Global path planner
Local motion planner
Hardware integration components.</td></tr>
<tr><td>Location</td><td>Room 4222, 4th floor of Newell-Simon Hall.</td></tr>
<tr><td>Equipment</td><td>Unitree Go1 Robot
AirLab Payload
RealSense D435
Team B MRSD Computer
Display Device
Obstacles of different shapes and sizes</td></tr>
<tr><td>Personnel</td><td>Andrew: Responsible for deploying the robot.
Connie: Positioned on the ground to simulate a real-world scenario.
Zack: Ensures robot's safety without interfering.
Saha: Observes and explains ongoing activities to the audience.</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Preparation for the closed scene containing more than 2 rooms and the corridor: Ensure the scene is vacant, with no individuals inside.
2. Obstacle Setup: Arrange prescribed wooden boards and blocks within the scene to create a cluttered environment.
3. Human Evacuation: Safely relocate any "trapped" individuals sitting on the ground with the door open.
4. Area Measurement: Measure the dimensions of the scene and initiate timer counting.
5. Darkbot Deployment: Dispatch the Darkbot into the lounge to conduct environmental mapping and search for humans.
6. Mapping Completion: Once the robot concludes its room search, stop the timer.
7. Visualization: Visualize the generated environmental map, annotating human poses within the map for comprehensive analysis during the FVD.</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">1. Explore total area in reduced time (i.e., minimal explorate rate = 18 m^2/min)
2. Accurately localize human within 30cm error (x direction plus y direction) and 3 seconds (robot stays still in front of human within 5m away), consistent with functional requirements.</td></tr>
</table>

Appendix

A) Mandatory functional requirements

ID	Description
RFM-1	The robot shall perform autonomous path planning
RFM-2	The robot shall traverse over debris
RFM-3	The robot shall traverse through narrow entrances
RFM-4	The robot shall detect humans
RFM-5	The robot shall allow teleoperation
RFM-6	The system will show user real time visualization of camera stream, human position, and 3D map.

B) Mandatory Performance Requirements

ID	Name	Description	Goal
RPM-1	Autonomous Exploration	Coverage Rate	16 m^2/min
RPM-2	Maneuverability	Navigate through narrow Space (e.g. Door Width)	Doors in Robo Lounge 86 cm
RPM-3	Mobility Robustness	Move on uneven terrain. Maximum stacked debris height of 8 cm	5 wood boards (100cm*30cm*2cm) randomly placed in 2m2 space.
RPM-4	Human Detection and Localization	Detect people in the robot's field of view when a human is 5m or less away from the robot. Localize humans on a global map.	Detect and localize humans within 5s with position error smaller than 1m.

C) Mandatory Nonfunctional Requirements

ID	Name	Description
RNM-1	Battery Life	The system will have enough battery life to complete its work

RNM-2	Computing Capacity	The system will have enough computing capacity to complete the task
RNM-3	Safety	The system will have an emergency stop feature and return-home function to ensure its safety
RNM-4	Physical Constraints	Small size to pass through doors.
RNM-5	System Extensibility	The system will be developed with good programming principles and be ready for future expansion, maintenance, and reuse.