AnyWill

Fall Project Test Plan

MRSD 2025 Team A: Autonomous Wheelchair

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Submitted Date: Sept. 17, 2025

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1. Introduction

This document outlines the testing plan for our MRSD project (AnyWill) in developing an Autonomous Wheelchair for Urban Environments. Our progressive validation approach starts with individual component tests and advances to full system integration, ensuring each function meets system requirements.

We define clear milestones, each linked to at least one test, to guide development. Our test framework includes software and hardware demonstrations, covering perception, localization, planning, control, user interaction, and safety mechanisms. Key hardware components include the wheelchair platform, sensors, emergency stop button, and remote E-STOP, ensuring reliable performance in real-world conditions.

These tests will lead to our Fall Validation Demonstration, showcasing the wheelchair's ability to navigate autonomously, avoid obstacles, adapt to terrain, and respond to user commands. We aim to validate all functions that are needed to meet system requirements. Through rigorous testing, we strive to develop a safe, reliable, and accessible autonomous wheelchair for urban mobility.

2. Logistic

2.1. Personnel

No additional personnel beyond the core team are required for testing. Team members will handle all setup, execution, and evaluation of the tests.

2.2. Location and Equipment

Most testing will be conducted on a designated on-campus road, providing a realistic environment for evaluating the wheelchair's navigation capabilities. The testing location is subject to change. Potential locations include (1) on-campus sidewalks (extended SVD route from the gate of NSH to "Walking to the Sky") (2) Sidewalks in Schenley Park (3) Sidewalks in Squirrel Hill (from Manor Theatre to Shady Ave + Beacon bus stop). Currently, the wheelchair is located and tested at the gate of NSH.

The key equipment includes:

- Wheelchair platform – Base for all autonomous navigation and mobility tests.
  - ZED X Camera – Used for environment perception and obstacle detection.
  - Jetson AGX Orin – Onboard computing unit for real-time processing.
  - Emergency stop button & remote E-STOP – Safety mechanisms for immediate intervention.
- iPhone – Used as the UI interface for user command input and system monitoring.
- PC – Used for running Isaac Sim Simulations.
- Real human – A real user to test system performance under realistic payload conditions.

- Test environment setup – Includes predefined routes, markers, and obstacles such as potholes, curbs, and uneven terrain to assess the wheelchair's adaptive navigation capabilities.

3. Schedule

Date	PR	Capability Milestones(s)	Test(s)	Requirements
09/10/2025	7	Formulate a Semester Plan	-	-
09/24/2025	8	Hardware Setup Complete	6, 7	F.M.12
10/08/2025	9	Core System Validation & Optimization	1, 2, 3	F.M.1 F.M.2 F.M.4 F.M.7 F.M.8 F.M.10 F.M.11 F.M.13
10/29/2025	10	Full Outdoor Autonomy Voice-Activated Tasking & Control	4, 5, 8	F.M.3 F.M.4 F.M.6 F.M.8 F.M.9 F.M.12
11/12/2025	11	Full Software and Hardware Stack Integration Test	9	F.M.1 F.M.2 F.M.3 F.M.4 F.M.5 F.M.6 F.M.7 F.M.8 F.M.9 F.M.10 F.M.11 F.M.12 F.M.13
11/17/2025	FVD	Full Software and Hardware Stack Demonstration		

4. Tests

4.1. Hardware Stability Test (1)

<table>
<tr><td colspan="2">Objectives</td></tr>
<tr><td colspan="2">To ensure the stability and safety of both mechanical and electrical system, also ensure it meets some requirements in standard ISO 7176-14:2022</td></tr>
<tr><td>Elements</td><td>Mechanical and Electrical Subsystems</td></tr>
<tr><td>Location</td><td>Road between Cyert Hall and GHC (40.444475, -79.944490),
NSH B506</td></tr>
<tr><td>Equipment</td><td>Wheelchair platform, Jetson AGX Orin, Joystick</td></tr>
<tr><td>Personnel</td><td>Thomas Chan, Sonic Kuo</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. In lab, connect wheelchair with reversed polarity to the electrical system and turn on the wheelchair
2. Switch back to correct polarity and drive out to the outdoor testing location
3. Have a person sit on the wheelchair and drive up to the parking lot
4. Drive down in 1 m/s and stop, measure the stop distance L_i
5. Redo the procedure as 4, and turn the power of wheelchair off at the same point, measure the stop distance L_i'</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">1. With the battery set connections reversed, there shall be no damage to the controller or any part of the drive system other than blown fuses (ISO 7176-14, 14.1.2)
2. The wheelchair should able to complete the route from (40.444475, -79.944490) to (40.443943, -79.943780) in 90 seconds with human payload
3. $L_i' <= 2 \times L_i$ (ISO 7176-14, 7.4.2)</td></tr>
</table>

4.2. Sensor - GPS test (2)

Objectives	
Test GPS's robustness throughout the FVD test route	
Elements	Sensing Subsystem
Location	FVD test route
Equipment	Wheelchair platform, Jetson AGX Orin, ZED-X camera, QG7 dual antenna RTK-GPS, iPhone
Personnel	Thomas Chan, Chiawen Liao
Procedure	
1. Connect RTK-GPS and ZED-X Camera to Jetson AGX Orin 2. Start ntrip-client, gps node, and camera node on the Jetson AGX Orin 3. Do a few circles to calibrate the initial heading at the starting location 4. Start ROS bag recording 5. Start publishing waypoints from the app 6. Follow waypoint and complete the whole route (teleoperate) 7. Repeat two times, and do it at 9 a.m., 12 p.m., and 3 p.m. Total 6 tests	
Verification Criteria	
1. For all 6 tests, the average RTK-GPS error shall be less than 50cm 2. For all 6 tests, the average heading error shall be less than 15 degrees	

4.3. Feature to Cost Mapping Test (3)

Objectives	
Validate the full image-to-cost pipeline from RGB to BEV cost maps, and quantify mapping fidelity and robustness across lighting/terrain conditions.	
Elements	Software Subsystem
Location	Road between Cyert Hall and GHC (40.444475, -79.944490), NSH B506, FVD route
Equipment	Wheelchair platform, Jetson AGX Orin, ZED-X camera, iPhone (UI), safety E-STOPs
Personnel	ChaoI Tuan, Sonic Kuo, Thomas Chan
Procedure	
1. End to End Rosbag Test: ○ Evaluate outputs with expert metrics using the existing evaluation framework. 2. Field Test: ○ Drive the FVD route and alternative paths at different times of day to capture lighting variation and ensure robustness in cost mapping. ○ Enable MPPI with live cost maps and check if the wheelchair can stop smoothly in front of obstacles.	
Verification Criteria	
1. Visualization Quality a. Cost maps must look reasonable to human inspection (cost height/ color) b. At least 5 test scenes produce interpretable visualizations. 2. Topic Frequency to ensure real-time MPPI response a. Dino feature extraction ≥10 hz b. Costmap publication ≥5 hz 3. Quantitative Metrics for Maxent IRL Costmap a. KL divergence of (expert and learner distributions) ≤ 0.5 b. Trajectory similarity measured by Modified Hausdorff Distance (MHD) ≤ 1.0 m (ensuring the learner's path does not deviate more than ~1 m from the expert's path on average) 4. Field Test: a. MPPI must stop in front of obstacles within ≤ 1 s.	

4.4. Planning and Control Test (4)

Objectives	
Evaluate global planning + local MPPI tracking over learned cost maps; verify replan responsiveness and goal-reach quality.	
Elements	Software Subsystem
Location	Road between Cyert Hall and GHC (40.444475, -79.944490), FVD route
Equipment	Wheelchair platform, Jetson AGX Orin, ZED-X camera, QG7 RTK-GPS, iPhone UI, onboard/remote E-STOPs
Personnel	ChaoI Tuan, Sonic Kuo, Thomas Chan
Procedure	
1. Define start and goal locations for the wheelchair within the environment. 2. Execute path planning algorithms to compute optimal paths based on cost metrics. Adding Disturbance ● Add dynamic obstacles (moving pedestrians) ● Update waypoints and check if the replan is smoothly Repeatability ● Perform ≥ 3 runs per route, at least 2 different routes (≥ 6 runs total). ● Different terrain conditions and environmental variations.	
Verification Criteria	
1. Replan latency ≤ 50 ms. 2. ≥ 90% success rate in dynamic avoidance. 3. Goal reach error ≤ 5 m with ≤ 1 teleop intervention (< 5 m correction).	

4.5. Failure Handling Test (5)

Objectives	
Test physical emergency stop, remote emergency stop, and software emergency stop to ensure the wheelchair can stop immediately under different failure case	
Elements	Electrical and Software Subsystems
Location	FVD test route
Equipment	Wheelchair platform, Jetson AGX Orin, ZED-X camera, QG7 dual antenna RTK-GPS, iPhone
Personnel	Thomas Chan, Chao-I Tuan
Procedure	
1. Open each physical emergency stop and send /cmd_vel 2. Start driving and press remote E-STOP 3. Teleoperate the wheelchair from drivable to non-drivable terrain 4. Start autonomy stack, and add noise to GPS such that the position drifts 5. Add noise to heading such that both position and heading drifts	
Verification Criteria	
1. The wheelchair shall stop in 100ms after physical and remote emergency stop pressed 2. The wheelchair shall stop before going to non-drivable terrain	

4.6. Curb Detection Test (6)

Objectives	
Evaluate the feasibility and performance of a curb-detection pipeline.	
Elements	Software Subsystem
Location	Live tests along the extended SVD route or using rosbags at MRSD lab.
Equipment	Wheelchair, user interface, sensors.
Personnel	Chiawen Liao, Haoyang He
Procedure	
1. Measure the success rate and accuracy of the curb detection model. 2. With the autonomy stack running, invoke the curb detection script once and record its latency 3. Integrate it with the human-interaction stack: when a curb cut is detected, generate a waypoint, then drive onto the curb.	
Verification Criteria	
1. ≥ 90% precision and ≥ 90% recall on curb/curb-cut detection at IoU ≥ 0.5 2. E2E detection latency (camera → curb-cut decision) ≤ 150 ms p95 3. Generated curb-cut waypoint arrives within ≤ 0.30 m (p95) of the ground-truth curb-cut position	

4.7. Language-Interactive Planner Test (7)

<table>
<tr><td colspan="2">Objectives</td></tr>
<tr><td colspan="2">Ensure user preferences conveyed via text can be successfully translated by our language-interactive planner to intermediate waypoints highlighting requested preference, while satisfying the basic safety and traversibility constraints.</td></tr>
<tr><td>Elements</td><td>Software Subsystem</td></tr>
<tr><td>Location</td><td>Isaac Sim Environment (Virtual)</td></tr>
<tr><td>Equipment</td><td>PC</td></tr>
<tr><td>Personnel</td><td>Haoyang He</td></tr>
<tr><td colspan="2">Procedure</td></tr>
<tr><td colspan="2">1. Set Up the Test Environment with obstacles en route to the destination.
2. Load next long-horizon waypoint as target.
3. Specify user preference (i.e. “Stay on the left side of the road”).
4. Examine returned intermediate waypoints from language-interactive planner and record preference-following correctness via human evaluation.
5. Run the low-level planning subsystem and evaluate the actual trajectory of the wheelchair in simulation for its obstacle avoidance despite user preference constraints.</td></tr>
<tr><td colspan="2">Verification Criteria</td></tr>
<tr><td colspan="2">1. The returned intermediate waypoints closely align with human expectations of the defined preference given the first-person-view image of the wheelchair's current state.
2. When encountering obstacles en route of the intermediate waypoints, the obstacle avoidance and safety constraints are satisfied.</td></tr>
</table>

4.8. User Preference Communications and Latency Test (8)

<table>
<tr><th colspan="2">Objectives</th></tr>
<tr><td colspan="2">Ensure that the iOS app can successfully receive and communicate with the user for the voice-controlled preferences for wheelchair autonomy.</td></tr>
<tr><td>Elements</td><td>UI Subsystem, Software Subsystem</td></tr>
<tr><td>Location</td><td>Robotic Institute, SQH / NSH B Level</td></tr>
<tr><td>Equipment</td><td>iPhone, Wheelchair Platform</td></tr>
<tr><td>Personnel</td><td>Haoyang He, Chiawen Liao</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Test iPhone’s voice-to-text by comparing high-level alignment between the intention of the user and the transcribed texts.
2. Test user preference integration with the UI’s input/output for communications integrity and latency.
3. Test intermediate waypoint communications with low-level planning for latency.
4. Test real-world performance of user preference following in full autonomy.</td></tr>
<tr><th colspan="2">Verification Criteria</th></tr>
<tr><td colspan="2">1. The app successfully captures high-level intent of user’s voice inputs into texts.
2. The language-interactive planner starts processing user requests within 5 seconds of voice input.
3. The intermediate waypoints are generated by the language-interactive planner within 30 seconds of the start of request processing.
4. The wheelchair is capable of following high-level user preference (i.e. “Stay on left”) when executing autonomy.</td></tr>
</table>

4.9. Fall Validation Demonstration (9)

Objectives	
Demonstrate fully functional system	
Elements	Integrated systems (hardware platform, perception, navigation, UI)
Location	TBD, 3 potential routes: 1. FVD extended route (from 40.443695, -79.945530 to 40.443988, -79.943992) 2. Sidewalks in Squirrel Hill (from Manor Theatre to Shady Ave + Beacon bus stop) 3. Sidewalks in Schenley Park (from 40.441562, -79.947260 to 40.441152, -79.94760)
Equipment	UI Equipment, Wheelchair Platform, Weighted Mannequin or Real Human, Test Environment Setup
Personnel	ChaoI Tuan, Chiawen Liao, Haoyang He, Sonic Kuo, Thomas Chan
Procedure	
1. Ready the Software and Hardware 2. Start the Integrated script to launch ROS nodes, perception scripts and mppi scripts. 3. Specify a target destination in the user interface. 4. Start the procedure of autonomous nitrate insertion which consists of the following tasks - a. Wheelchair listens to global waypoints and project it to local map. b. Generate dynamic cost map. c. Wheelchair listents to and follows human commands. d. Wheelchair starts planning and go along waypoints. 5. Follow the wheelchair in its autonomous navigation towards the destination, ensuring the safety of the wheelchair and the surrounding environment with onboard and remote e-stop systems. 6. Repeat two times, and do it at 9 a.m., 12 p.m., and 3 p.m. Total 6 tests. Ideally test under different weather conditions.	
Verification Criteria	
1. Verify if all subsystems are working appropriately to deliver the passenger to the specified destination. 2. Verify at destination that all subsystems are online without unexpected errors. 3. Should meet all requirements.	

5. Appendix

Functional Requirements

Mandatory	
F.M.1	Localize itself
F.M.2	Map environment
F.M.3	Plan path
F.M.4	Actuate the wheel
F.M.5	Detect static obstacles
F.M.6	Adjust path dynamically
F.M.7	Afford payload
F.M.8	Identify safe zones
F.M.9	Ensure emergency stop
F.M.10	Reach Destination

Table 5.1 Mandatory Functional Requirement

Desirable	
F.M.11	Climb slope
F.M.12	Interact with user
F.M.13	Detect and avoid dynamic obstacles

Table 5.2 Desirable Functional Requirement

Performance Requirements

System Level Performance Requirement		
F.M.10	Reach Destination	
	M.P.10.1	Reach goal within drift <= 5m
	M.P.10.2	Number of teleop intervention <= 1, teleop distance <= 5m
F.M.6	Preplan safe path to go	
	M.P.6.1	Complete 0.5km traversable route <=10min
F.M.9	Ensure emergency stop	
	M.P.9.1	Number of E-stop safety intervention <= 2

Table 5.3 System Level Performance Requirement

Desired System Level Performance Requirement		
F.M.11	Climb slopes	
	D.P.11.1	Traverse sidewalk ≤ 15 degrees
F.M.13	Detect dynamic obstacles, avoid dynamic obstacles	
	D.P.13.1	Replan trajectories <= 50 msec Consider moving pedestrian >=2
F.M.12	Receive commands from the user	
	D.P.12.1	success rate >=70%

Table 5.4 Desired System Level Performance RequirementTable

Subsystem Level Performance Requirement			
Mechanical	**F.M.7**	Afford payload	
		M.P.7.1	Carry payload <= 200lb
Robotic Software System- Navigation	**F.M.6**	Preplan safe path to go	
		M.P..6.2	Reach every navigation waypoint <= 5m
Robotic Software System- Local Planning	**F.M.5** **F.M.6**	.	Detect **static obstacles**, adjust path dynamically
		M.P.6.3	Replan trajectories <= 50ms
Robotic Software System- Perception, Localization & Mapping, Planning, Navigation, Controls	**F.M.5** **F.M.6**		Detect **static obstacles**, adjust path dynamically.
		M.P.6.4	Avoid Curbs of height >= 5cm
		M.P.6.5	Avoid Potholes of radius >= 5cm and depth >= 10cm
Powertrain- E-Stop	**F.M.9**		Ensure emergency stop
		M.P.9.2	React to emergency stop <= 50ms

5.5 Subsystem Level Performance Requirement

Non-Functional Requirement

Non-Functional Requirements		
M.N.1	Size & Weight:	Compact and lightweight for easy navigation
M.N.2	Reliability	Consistent, smooth operation with payload
M.N.3	Safety	Maximum Speed: between 3 to 5 mph
		Range:10 miles on a single charge
M.N.4	Modularity	Modular design for easy maintenance
M.N.5	Affordability	Cost-efficient, priced at 150-200% of standard non-autonomous wheelchairs
M.N.6	User interface	Generate wheelchair traversable path

Table 5.6 Desired Non-Functional Requirements