Carnegie Mellon University

The Robotics Institute, School of Computer Science

MRSD Project

Pit Navigator

Team G: The Pit Crew

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Introduction

This document details the goals that The Pit Crew (Team G) has set for the fall semester, and the planned tests that will demonstrate completion of those goals. These goals will be met according to a schedule presented in this document. Each goal relates to a subset of the project requirements established previously (requirements are listed in *Appendix A*). The tests corresponding to each goal are described in detail, including the necessary equipment, procedures, and criteria for success. These tests and goals will showcase Team G's progress throughout the semester, culminating in an integrated demonstration of the entire PitRanger system at the Fall Validation Demonstration.

Logistics

Personnel

All team members will be present during tests which involve a rover surrogate. One team member will monitor the rover's operation, another will be responsible for engaging safety features in the event of a malfunction, and the third will record the test with a cell phone camera. During simulation tests, one team member will operate the simulation computer while the other team members explain the test procedures and answer questions. Some simulations will be pre-recorded and sped up for ease of presentation.

Equipment

1. Blue Rover
2. Personal Computers
3. Rope
4. Simulation Computer*
5. Cell Phone Camera
6. PPE
7. ROS Framework
8. WeBots Simulation Software

*To qualify as a simulation computer, the computer is recommended to contain a GPU, an i7 intel processor equivalent, and 16 GB RAM.

Location

Simulation tests will use the WeBots simulation software, running on the personal computer of one team member. Within WeBots, multiple simulations will be used, ranging from representations of a lunar pit and surrounding terrain to smaller test environments used to easily verify specific software features.

Field tests will occur in the vicinity of team members' apartments, or at the Gascola site. Gascola has historically been a testing bed for off road autonomous vehicles, and has large cliffaces that are accessible. These cliffaces are excellent test beds for our rover to approach a terrestrial brink.

Schedule

ID	Date	Capability Milestones	Associated Tests	Associated System Requirements
8	Sept 30	1. Add edge detection behavior to simulator 2. Create pit capturing control sequence	Test 8.1 Test 8.2	M.P.4 M.P.3 & 6
9	Oct 14	1. Generate and interpret triangle mesh 2. Use heuristic to detect unsafe slopes in simulation	Test 9.1 Test 9.2	M.P.4 M.P.4
10	Oct 28	1. Use heuristic to detect sheer brinks in simulation 2. Navigate to multiple waypoints with Blue	Test 10.1 Test 10.2	M.P.4 M.P.5
11	Nov 11	1. Integrated System in Simulation Dry Run 2. Integrated System on Blue Dry Run	Test 11.1 Test 11.2	M.P.1-7 M.P.1-5 & 7
FVD	Nov 18	1. Integrated System in Simulation 2. Integrated System on Blue	FVD1. Mission Execution in Simulation Test FVD2. Terrestrial Pit Edge Approach Test	M.P.1-7 M.P.2-5 & 7

Tests

Test 8.1: Brinkmanship

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstrate the generation of point clouds from simulated terrain that is within 2.5 meters of the front of the rover, and interpret those point clouds to stop the simulated rover from moving when it reaches a brink.</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>Brinkmanship</td><td>Simulation Computer
WeBots Simulation Software
ROS Framework</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>Simulation Environment</td><td>Awadhut, Alex, Justin</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Start the simulator
2. Start the planning and navigation node
3. Rover starts moving toward the pit edge
4. Execute point cloud processing
5. Display results in the simulator</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">1. The rover uses the point cloud data to successful stop near a brink
2. The rover should stop within 0.5 m of the edge
3. The behavior is successfully replicated for 5 tests</td></tr>
</table>

Test 8.2: Image Capture Sequence

Objective	
Operate the pan and tilt controls of the rover camera to capture a panoramic image for every tilt angle of a pit interior.	
Elements	**Equipment**
Camera Operation	Blue Rover Personal Computer
Location	**Personnel**
A team member's apartment	Justin, Awadhut, Alex
Procedure	
1. Start the camera operation node on the rover 2. The rover camera moves to various pan-tilt angles to capture images 3. All images captured at the same tilt angle are used to generate panoramas on the rover 4. A composite image is formed using all the captured images	
Validation Criteria	
1. Save all images captured at different angles in local directory on rover computer 2. Generate the panoramas and save them in a separate directory 3. Repeat the process at 3 different locations	

Test 9.1: Terrain Modeling

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Produce a triangular mesh from the point clouds generated in the simulator to model the terrain in the rover’s field of view.</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>Brinkmanship</td><td>Simulation Computer
WeBots Simulation Software
ROS Framework</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>Simulation Environment</td><td>Awadhut, Justin, Alex</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Start the simulation
2. Poll a point cloud from the simulator
3. Input the point cloud to a conversion algorithm which outputs a triangular mesh
4. Display a visualization of the triangular mesh</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">1. Visual inspection of the generated mesh and confirmation that it matches the shape of the terrain</td></tr>
</table>

Test 9.2: Terrain Classification

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstrate that the normals of the terrain model will differentiate traversable and untraversable terrain.</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>Brinkmanship</td><td>Simulation Computer
WeBots Simulation Software
ROS Framework</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>Simulation Environment</td><td>Justin, Alex, Awadhut</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Start the simulation
2. Start the planning and navigation node in the simulation
3. Start node to classify different parts of the terrain
4. The node outputs a visualization of the the terrain and categorization of each segment into the two classes (traversable and untraversable)</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">1. Visually inspect that the rover classifies the terrain segments with over 80% accuracy</td></tr>
</table>

Test 10.1: Map Update

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Identify gaps in the triangular mesh and/or point cloud which represent sheer drop-offs in the terrain and incorporate these drop-offs into the planning map.</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>Brinkmanship</td><td>Simulation Computer
WeBots Simulation Software
ROS Framework</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>Simulation Environment</td><td>Awadhut, Justin, Alex</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Poll the triangular mesh or the point cloud from the simulation
2. Use a developed heuristic to identity gaps in the terrain
3. Record the position of the found drop-offs (if any)
4. Run code to modify the map to reflect the drop-offs</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">1. The rover updates the map when it detects a drop-off
2. Manual inspection of the result to verify that the correct position has been recorded within 2 map cells</td></tr>
</table>

Test 10.2: Waypoint Navigation

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Using the surrogate rover Blue, demonstrate path-following behaviors between multiple waypoints in a physical environment.</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>Planning</td><td>Blue Rover
Cell Phone Camera
PPE</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>A team member’s apartment</td><td>Justin, Alex, Awadhut</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Predefine waypoints for the rover to navigate through
2. Start rover from the initial point (origin)
3. Start the planning and navigation node on the rover</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">1. The rover moves to each waypoint and is within 0.5m of each waypoint
2. The test is successfully repeated for 2 different sets of waypoints</td></tr>
</table>

Test 11.1: Simulated Mission Dry Run

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstration of the integrated system, showcasing the capabilities of risk assessment, obstacle avoidance, and pit edge detection within the simulation.</td></tr>
<tr><td>Elements</td><td>Equipment</td></tr>
<tr><td>Brinkmanship
Planning</td><td>Simulation Computer
WeBots Simulation Software
ROS Framework</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>Simulation environment</td><td>Alex, Awadhut, Justin</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Start the WeBots simulator
2. Execute the complete mission in the simulator:
● The system starts with the planning and navigation node on the rover. The rover moves to a specified waypoint along the ‘highway’ near the circumference of the pit.
● The brinkmanship node runs when the rover reaches the specified waypoint.
● The rover stops close to the edge of the pit and executes the image capture sequence
● The rover returns to the initial ‘highway’ point
● The rover then moves to the next waypoint along the circumference of the pit
● The rover returns to the lander if the estimated risk is large</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">1. Average distance to pit when image capturing: <1m
2. Amount of usable data over a single cycle in the mission: >75 MB
3. Total amount of usable data captured: >500 MB
4. Speed made good: >0.21m/s
5. Risk never goes over threshold: 5:1
6. Mission Completion</td></tr>
</table>

Test 11.2: Terrestrial Pit Edge Validation Dry Run

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstration of the integrated system, showcasing the capabilities of pit edge detection, and waypoint following in a physical environment on a physical rover.</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>Brinkmanship
Planning</td><td>Rope
Blue Rover
Cell Phone Camera
PPE</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>Gascola</td><td>Justin, Awadhut, Alex</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Place rover at starting point far from the edge of a cliff/pit
2. Execute the mission code:
a. The system starts with the planning and navigation node on the rover. The rover moves to a specified waypoint
b. The brinkmanship node runs when the rover reaches the specified waypoint.
c. The rover stops close to the edge of the pit and executes the image capture sequence
d. The rover returns to the initial ‘highway’ point
e. The rover then moves to the next waypoint along the cliff/pit edge
f. The rover executes the image capture sequence again</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">1. Average distance to pit when the image capturing: <0.5m
2. Amount of usable over a single cycle in the mission: >75 MB
3. Amount of usable data captured per location: >15 MB
4. Produces tagged data and the stitched panorama</td></tr>
</table>

Fall Validation Demonstration

Test 1

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstration of the integrated system, showcasing the capabilities Risk Assessment, obstacle avoidance, and pit edge detection within the simulation.</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>Brinkmanship
Planning</td><td>Simulation Computer
WeBots Simulation Software
ROS Framework</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>Simulation environment</td><td>Alex, Awadhut, Justin</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Start the webots simulator
2. Execute the complete mission in the simulator:
a. The system starts with the planning and navigation node on the rover. The rover moves to a specified waypoint along the ‘highway’ near the circumference of the pit.
b. The brinkmanship node runs when the rover reaches the specified waypoint.
c. The rover stops close to the edge of the pit and executes the image capture sequence
d. The rover returns to the initial ‘highway’ point
e. The rover then moves to the next waypoint along the circumference of the pit
f. The rover returns to the lander if the estimated risk is large</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">1. Average distance to pit when image capturing: <1m
2. Amount of usable data over a single cycle in the mission: >75 MB
3. Total amount of usable data captured: >500 MB
4. Speed made good: >0.21m/s
5. Risk never goes over threshold: 5:1
6. Mission Completion</td></tr>
</table>

Test 2

<table>
<tr><th colspan="2">Objective</th></tr>
<tr><td colspan="2">Demonstration of the integrated system, showcasing the capabilities of pit edge detection, and waypoint following in a physical environment on a physical rover.</td></tr>
<tr><th>Elements</th><th>Equipment</th></tr>
<tr><td>Brinkmanship
Planning</td><td>Rope
Blue Rover
Cell Phone Camera
PPE</td></tr>
<tr><th>Location</th><th>Personnel</th></tr>
<tr><td>Gascola</td><td>Justin, Awadhut, Alex</td></tr>
<tr><th colspan="2">Procedure</th></tr>
<tr><td colspan="2">1. Place rover at starting point far from the edge of a cliff/pit
2. Execute the mission code:
a. The system starts with the planning and navigation node on the rover. The rover moves to a specified waypoint
b. The brinkmanship node runs when the rover reaches the specified waypoint.
c. The rover stops close to the edge of the pit and executes the image capture sequence
d. The rover returns to the initial ‘highway’ point
e. The rover then moves to the next waypoint along the cliff/pit edge
f. The rover executes the image capture sequence again</td></tr>
<tr><th colspan="2">Validation Criteria</th></tr>
<tr><td colspan="2">1. Average distance to pit when the image capturing: <0.5m
2. Amount of usable over a single cycle in the mission: >75 MB
3. Amount of usable data captured per location: >15 MB
4. Produces tagged data and the stitched panorama</td></tr>
</table>

Appendix A

Mandatory System Requirements

The system will:
M.P.1 Capture 500 MB image data on a surface similar to the moon terrain.

M.P.2 Capture 75 MB image data over a single cycle in the mission.

M.P.3 Capture 15 MB image data from specific coordinates on the surface of the moon.

M.P.4 Calculate the relative distance to the pit edge within 2% error.

M.P.5 Calculate an optimal navigation plan within 20 seconds.

M.P.6 Capture images covering 20 degree angle of pit circumference from one position.

M.P.7 Operate such that chance of occurance of a mission ending incident is less than 5:1

The system shall:
M.N.1 Operate in the vicinity of a pit on the moon.

M.N.2 Operate using hardware that meets specifications of overall rover design and mission.

M.N.3 Operate within a Linux operating system environment

M.N.4 Be compatible with other software systems running on the rover.

M.N.5 Maintain a mission clock.

M.N.6 Operate when the rover is not experiencing any major subsystem faults.