Arbor Robotics

Spring Project Test Plan

MRSD Team H

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Project title

Reforestation Project

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1 Introduction

We depend on milestones to establish clear deadlines for our project. These deadlines, in turn, create an actionable sequence of work that aligns us with our goals and keeps us productive. To ensure that each of our milestones is well-formed and demonstrable, we assign at least one test to each milestone. Individual milestones and their associated tests are packaged into **demos**.

We divide our demos, including their tests, into **software** and **hardware** demos.

2 Logistics

Our software tests will be performed in ArborSim, our custom, realistic simulator developed using Unity. We believe that ArborSim's simulated physics, lighting, and terrain will provide sensor inputs comparable to a real-world environment.

Our hardware tests will be performed in different locations based on the progression of our planting mechanism. Early tests involving SolidWorks will be conducted on one of our PCs. Once we begin fabrication, we will conduct tests either in FRC or on the B level based on space constraints. For that, we will have to discuss with Francisco for approval based on the specific test. Laster on when we work with the Warthog, we will have to do testing in FRC or outside.

3 Schedule

Event	Date	Capability Milestones	Test(s)	Requirement(s)
PR 1	2/15	Perform minimal simulation (ArborSim beta); bridge sim. with ROS stack Complete field tests for mechanism planning; Create minimal design concept for chute	TS1, TP1	MX2, MX9
PR 2	2/29	Generate simple planting plans (Druid); generate complete routes; calculate minimum viable trajectories; generate basic motion control commands. Complete basic final mechanism design concept	TS2, TS3, TP1*	MX4, MX5, MX6, MX7, MX9*
PR 3	3/21	Simulator improvements; simulated planting mechanism; simulated RGBD, pointclouds; obstacle avoidance; fabricate components for planting mechanism [*stretch: assemble]	TS4, TS5, TP2, TP3	MN1, MX3, MX8, MX10
PR 4	4/04	Switch to MPC; basic web UI; Complete assembly of planting mechanism with mounts and actuators; Reconfigure warthog layout	TS6, TP4, TP5	MX1, MX6, MX10, MX11
PR 5: SVD	4/18	Realistic planting demo with full s/w stack in sim; Install planting mechanism on Warthog	TS7, TP6	MN2, MN3, MX12
PR 6: SVD Encore	4/25	Additional experimental algorithms in sim, such as RL-based planner; possible improvements to web UI; Fine-tune positioning of planting mechanism; Basic integration of planting mechanism with rest of the system		

4 Tests

Since our project is divided this semester into simulated work and work on our planting system, we have accordingly divided our tests. The tests performed in simulation begin with "TS" and the tests relating to the planting system begin with "TP."

4.1 Tests performed in our simulator

4.1.1 TS1: ArborSim performance and communication

Objective

Verify that ArborSim runs at an acceptable framerate and uses reasonable memory, while publishing to ROS at an acceptable frequency.

Satisfied Requirements

MX2

Elements

Simulation subsystem

Equipment

- Will's workstation (GeForce 2080S, 64 GB RAM)

Location

In silico

Personnel

- Will Heitman
- Cherry Bhatt

Procedure

[1] Launch ArborSim in debug mode
[2] Check the publish rate of the GNSS and camera sensor streams using the ROS CLI
[3] Check the FPS of ArborSim using its integrated debug tools
[4] Check the memory usage of ArborSim using the Linux system monitor
[5] Repeat 2-4 over the course of ten minutes.

Verification Criteria

- The publish rate of all sensor streams should never drop below 20 Hz.
- The frame rate of ArborSim should never drop below 30 Hz.
- The memory usage of ArborSim and the ROS bridge should not exceed 20 GB total.
- All of the above criteria should be met for a period of at least ten minutes.

4.1.2 TS2: Minimal planting plan generation (Druid) and routing

Objective
Test the individual operation and integration of the planting plan generation system (Druid) and the routing system, ensuring that their results and computation time are acceptable.

Satisfied Requirements
MX4, MX5

Elements
Planting plan generation system (Druid) unit; route generation unit; plan-route interface

Equipment
- Any computer running our stack (Will's workstation, for example)

Location
In silico

Personnel
- Austin Windham
- Cherry Bhatt

Procedure

[1] Run our Druid and routing nodes
[2] Verify that our planting plan is being received by the route generator using a print statement
[3] Visualize the outputs of both nodes (a planting plan and a route) in Rviz

Verification Criteria

- Individual seedling locations in the planting plan should follow the spacing guidelines provided by the Arbor Day Foundation. Specifically, distances between new seedlings should be at least 2m for small species, 8m for medium species, and 12m for large species.
- The route should be generated in less than one minute for a planting area of 10 acres (0.04 sq. km) and a seedling count of 5000.

4.1.3 TS3: Motion planning and control

Objective
Verify the efficacy and speed of the trajectory generator and motion controller, as well as the communication interface between them.

Satisfied Requirements
MX6, MX7

Elements
Trajectory planning unit; motion control unit; trajectory-controller communication interface

Location
In silico

Equipment
- Team computer
- Our software stack

Personnel
- Madhusha Goonesekera
- Cherry Bhatt

Procedure

[1] Launch ArborSim.
[2] Launch our ROS software, including the trajectory planner and motion controller.
[3] Generate a planting plan and route (TS2 depends on TS1).
[4] Visualize the output of the trajectory planner in Rviz.
[5] Inspect the output frequency of both nodes using the ROS CLI.
[6] Observe the robot as it progresses along the trajectory.

Verification Criteria

- The trajectory should have individual points spaced no more than two meters apart.
- The trajectory planner should have a planning horizon of at least 10 seconds.
    - Ex: At a constant speed of 1 m/s, the trajectory should be at least 10 m long.
- The trajectory should achieve a minimum speed of 1 m/s.
- The trajectory planner should run at 10 Hz, at minimum.
- The motion controller should run at 100 Hz, at minimum.
- The simulated robot should follow trajectories over time until the route is completed.
- The robot should drive to within 0.1 m of every planting location (at minimum 500 locations) in a total time of less than one hour (simulated time).

4.1.4 TS4: Enhancements to ArborSim

Objective

Verify that our new simulation features have not degraded the simulator's performance.

Satisfied Requirements

MN1

Elements

Simulation subsystem and depth map calculation node.

Location

In silico

Equipment

- Team computer
- Our software stack

Personnel

- Will Heitman
- Cherry Bhatt

Procedure

[1] Repeat Test 3.
[2] While performing Test 3, record the publish frequency of the calculated depth maps and point clouds.

Verification Criteria

- The depth maps should publish at a rate of at least 10 Hz.
- The fused point cloud should publish at a rate of at least 5 Hz.
- The depth maps should have a maximum RMSE of 0.1m at an point within 5m of the camera.
- The simulated planting mechanism should provide an appropriate planting animation and leave realistic sapling models in the terrain.

4.1.5 TS5: Obstacle avoidance

Objective
Verify the efficacy of obstacle avoidance algorithm in simulation.

Satisfied Requirements
MX3, MX8

Elements
Obstacle avoidance subsystem

Equipment
- Team computer
- Our software stack

Location
In silico

Personnel
- Madhusha Goonesekera
- Will Heitman

Procedure

[1] Launch ArborSim
[2] Launch our ROS stack, including the obstacle avoidance node.
[3] Place a series of simulated obstacles, such as boulders and fenceposts, in the simulated planting area.
[4] Send the Steward on a route through the planting area.
[5] Observe the Steward to ensure that it does not collide with any obstacles.

Verification Criteria

- The Steward should move a minimum distance of 1km over a complex route without hitting any obstacles.
- The Steward should perform the above with an average speed of at least 1 m/s.
- The trajectory planner should adjust to work around detected obstacles.
- The Steward should still visit at least 90% of planting sites along the route.

4.1.6 TS6: Model Predictive Controller

Objective
Verify the efficacy of the MPC motion controller in simulation.

Satisfied Requirements
MX1, MX6

Elements
Model predictive control unit

Equipment
- Team computer
- Our software stack

Location
In silico

Personnel
- Madhusha Goonesekera
- Will Heitman

Procedure

[1] Launch ArborSim.
[2] Launch our ROS stack, including our new MPC motion controller.
[3] Generate a route of at least 1km over hilly terrain. The terrain should include obstacles as in TS5.
[4] Record the RMSE distance error of the Steward w.r.t. the trajectory and the instantaneous speed of the ego vehicle.

Verification Criteria

- The Steward should move a minimum distance of 1km over a complex route without hitting any obstacles.
- The MPC controller should cause an average RMSE distance error of no more than 0.5 m and a max RMSE error of no more than 1m at any point along the route.
- The MPC controller should run at 100 Hz, at minimum.
- The Steward should be able to operate at an average speed of 1.5 m/s (previously 1m/s) along the route.

4.1.7 TS7: Full software test

Objective
Verify the efficacy of obstacle avoidance algorithm in simulation.

Satisfied Requirements
MN2, MN3

Elements
Obstacle avoidance subsystem

Equipment
- Team computer
- Our software stack

Location
In silico

Personnel
- Madhusha Goonesekera
- Will Heitman

Procedure

[1] Perform tests TS1-TS6.
[2] Now, ask a student not involved in our project to use our software via our web interface, Canopy. They should be given no instructions whatsoever, only to play around.
[3] Observe.

Verification Criteria

- Our software should pass all tests TS1-TS6.
- Our web interface, Canopy, should be immediately usable by the student participant.
- Further, the student participant should smile at least once.
    - Reader, you may find the non-technicality of this verification criterion to be insulting. Please do not panic. We are designing this system to be used—and enjoyed—by foresters, farmers, and other non-roboticists. User experience is critical, and we believe it should play an important role in our testing.

4.2 Tests relating to the planting mechanism

4.2.1 TP1: SolidWorks Planting Mechanism Verification

Objective
Ensure SolidWorks assembly for Planting Mechanism is dimensionally accurate, properly mated, abides by all realistic physical constraints, and is accurate to any real-world components you plan to incorporate.

Satisfied Requirements
MX9

Elements
Subassembly / Assembly

Equipment
- PC with SolidWorks

Location
SolidWorks

Personnel
- Kasina
- Austin
- Madhusha

Procedure

[1] Open the Assembly in SolidWorks.
[2] Attempt to move each of the components in the assembly.

Verification Criteria

- Each component that is capable of movement does not move past its threshold.
- No components intersect into each other unexpectedly.

4.2.2 TP2: Digger Mechanical Operation Success

Objective

Ensure the planting mechanism's digging subsystem is able to successfully bore a hole into the ground. This test can also be used when actuation is installed

Satisfied Requirements

MX10

Elements

Planting Mechanism Digger Subsystem

Equipment

- Soil Test Bed
- Digger Subsystem
- Test Rig to hold Digger Subsystem

Location

FRC

Personnel

- Kasina
- Austin
- Madhusha

Procedure

[1] Attach Digger Subsystem to test rig.
[2] Use a soil press to adjust soil compaction for testing digging capability.
[3] Align test rig with soil test bed.
[4] Manually operate the digger subsystem to create a hole.

Verification Criteria

- Hole is at least 8 inches deep.
- Extreme force is not required to bore the hole (less than 50 lbs of force)

4.2.3 TP3: Tamping Mechanical Operation Success

Objective

Ensure the planting mechanism's tamper subsystem can successfully close a hole made using the surface dirt pulled up from the digger. This test can also be used when actuation is installed.

Satisfied Requirements

MX11

Elements

Planting Mechanism Tamping Subsystem

Equipment

- Soil Test Bed
- Tamping Subsystem
- Test Rig to Hold Tamping Subsystem

Location

FRC

Personnel

- Kasina
- Austin
- Madhusha

Procedure

[1] Attach Digger Subsystem to test rig.
[2] If testing separately from digging mechanism, artificially create a hole in soil bed.
[3] Align test rig with soil test bed.
[4] Manually operate the tamping mechanism to push the dirt back into the hole.

Verification Criteria

- Most of the surface dirt around the hole is back in the hole, a visual inspection where approximately 80% of the dirt is no longer on the surface.
- Extreme force is not required to cover the hole (less than 50 lbs)

4.2.4 TP4: Planting Mechanism Plunge Operation Success

Objective
Ensure the plunging motion (and subsequent retraction) for the planting mechanism it working as expected

Satisfied Requirements
MX12

Elements
Planting Mechanism System

Equipment
- Planting Mechanism Assembly
- Test Rig to Hold Planting Mechanism

Location
FRC

Personnel
- Kasina
- Austin

Procedure

[1] Attach Planting Mechanism to Test Rig
[2] For each configuration of the planting mechanism, test the plunge function.

Verification Criteria

- The plunging mechanism pushes the planting subsystems down most of the time it is tested (80% sequential success), eventually tuned to 100% success
- When the plunging mechanism retracts, the subsystems return to the raised state (Boolean verification, 100% sequential success)

4.2.5 TP5: Planting Mechanism Subsystem Rail Success

Objective

Ensure the subsystems on the planting mechanism accurately and consistently slide to the appropriate position during operation

Satisfied Requirements

MX12

Elements

Planting Mechanism System

Equipment

- Planting Mechanism Assembly
- Test Rig to Hold Planting Mechanism

Location

FRC

Personnel

- Kasina
- Austin

Procedure

[1] Attach Planting Mechanism to Test Rig

[2] Actuate the mechanism rail.

Verification Criteria

- The mechanism rail moves the planting subsystem to the right position the majority of the time (80% sequential success), eventually to be tuned to 100% success.

4.2.6 TP6: Planting Mechanism Subsystem – System Integration

Objective
Ensure the integration of the planting mechanism subsystems still allows each of the parts to work as they should

Satisfied Requirements
MX12

Elements
Planting Mechanism System

Equipment
- Planting Mechanism Assembly
- Test Rig to Hold Planting Mechanism

Location
FRC

Personnel
- Kasina
- Austin
- Madhusha

Procedure

[1] Attach Planting Mechanism to Test Rig
[3] Run each of the subsystems individually.
[4] Run the full system sequentially as it would be done for a real planting operation.

Verification Criteria

- Each of the individual subsystems work when run.
- The full system works 80% of the time (4 out of 5 sequential tests)

5 Appendix

5.1 Functional requirements

ID	Description	Perf. Rec. ID	PR description
MP1	The Steward should be as fast as an average person.	MX1	The steward should move at an average speed of at least 1.5 m/s along a route of at least 1km.
MP2	The Steward should include a fast simulator.	MX2	Our simulator should run at 30 FPS minimum on a modern, mid-tier GPU.
MP3	The Steward should reliably visit planting locations.	MX3	The Steward should visit at least 90% of planting locations along any generated route.
MP4	Generated planting plans (greenprints) should follow planting guidelines from expert arborists.	MX4	Distances between new seedlings should be at least 2m for small species, 8m for medium species, and 12m for large species.
MP5	Route generation should be quick at scale.	MX5	Route generation should take no more than 100m/s per seedling (route node), regardless of scale.
MP6	The Steward should be quick to adapt to changes	MX6	The low-level motion controller should run at a frequency of at least 100 Hz.
		MX7	The trajectory planner should run at a frequency of at least 10 Hz.
		MX8	The obstacle avoidance should operate at a rate of at least 1km per impact.
MP7	The Steward should have a functional planting mechanism	MX9	The planting mechanism should be constructed properly without getting stuck or locked
MP8	The Steward should be able to dig a hole for seedling insertion	MX10	The planting mechanism should place the seedling at a depth of 8 inches
MP9	The Steward should be able to cover the seedling to prevent root drying	MX11	The planting mechanism should use the raised dirt to cover the hole it made
MP10	The Steward should be able to operate consistently and accurately	MX12	The planting mechanism should plant a seedling correctly 80% of the time

5.2 Non-functional requirements

ID	Requirement
MN1	The Steward should include a realistic simulator.
MN2	The Steward, its software, and its user interface should be fun to use.
MN3	The Steward, its software, and its user interface should be easy to use with little to no training.