Autonomous Aerator, Trinity College

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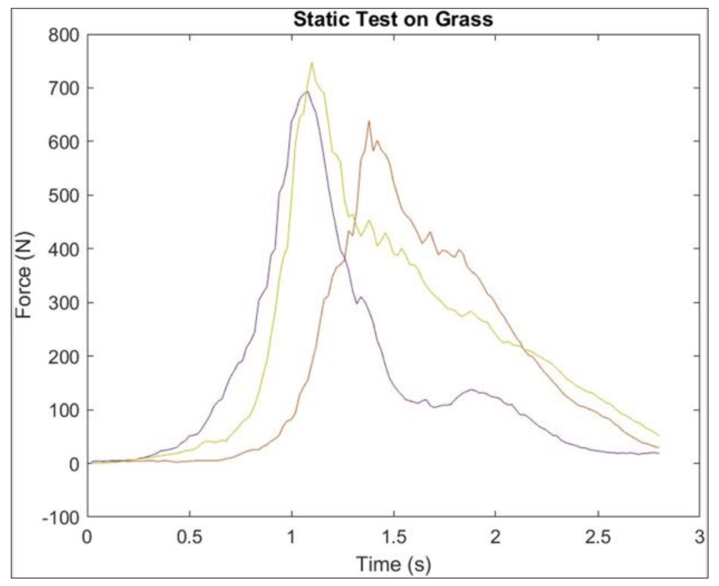
ABSTRACT

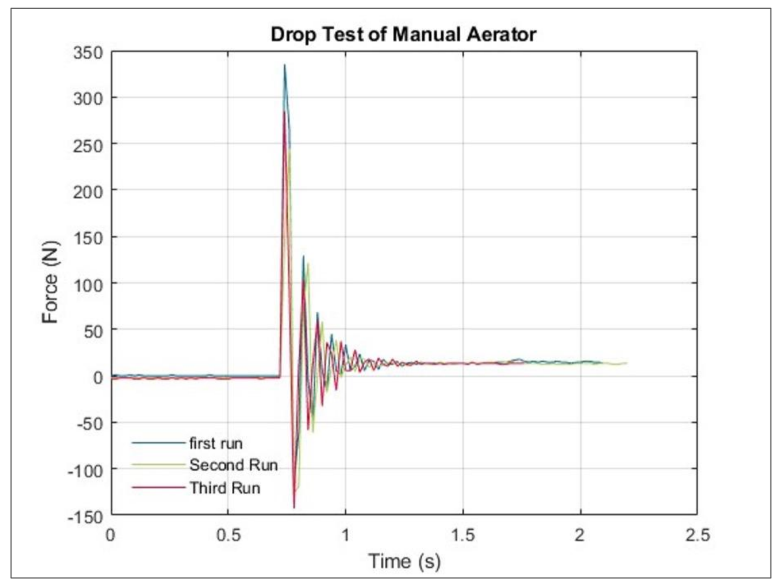
Maintaining a green and healthy yard is a labor-intensive activity. In addition to watering and cutting the grass, the soil on which it grows needs to be aerated. Aeration involves loosening the compacted soil to improve drainage and increase the availability of water, nutrients, and air to the roots of grass and other plants. The aerating tools currently available are either time-consuming and labor-intensive or expensive. The purpose of this project is to design a small-scale autonomous core-plug aerator prototype that can reduce the amount of labor, time, and cost needed to aerate a lawn relative to current devices. Our project aimed to design an effective aerating mechanism based on carefully chosen parameters that we validated using comprehensive soil testing data. We were also able to generate a point cloud map of the robot's environment for localization.

PROBLEM STATEMENT

In this project, our aim is to design an autonomous core-plug aerator prototype. To achieve this, we need to construct a physical model of a robot with a mechanism for locomotion capable of withstanding outdoor environments. The aerating system takes inspiration from current tow-behind aerators but utilizes a smaller engine. We also need to implement mapping technology to enable the robot to accurately localize itself and gather spatial information to avoid obstacles. Finally, fully automated navigation capabilities are necessary for the robot to plan its trajectory.

SOIL TEST DATA COLLECTION

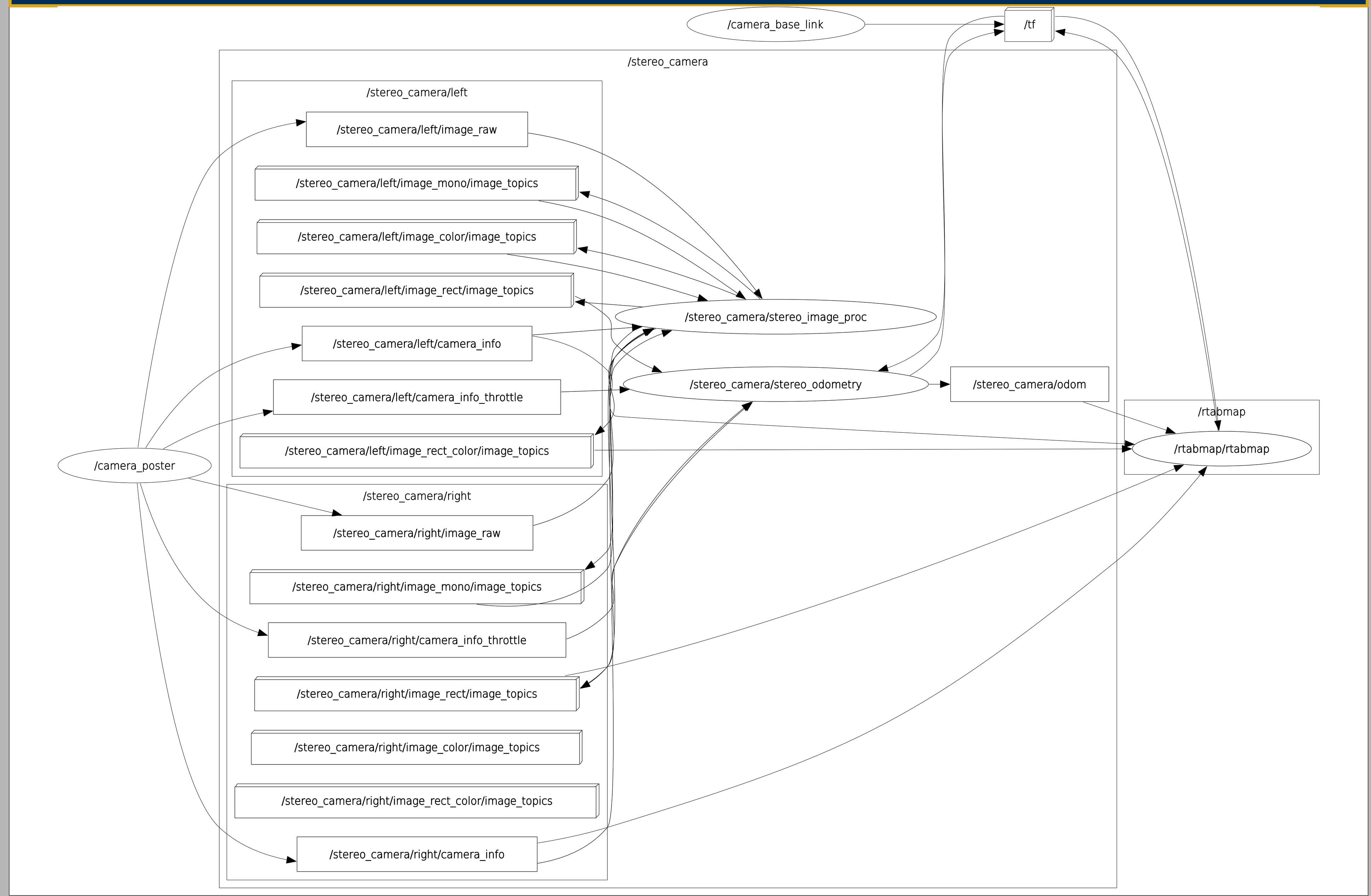




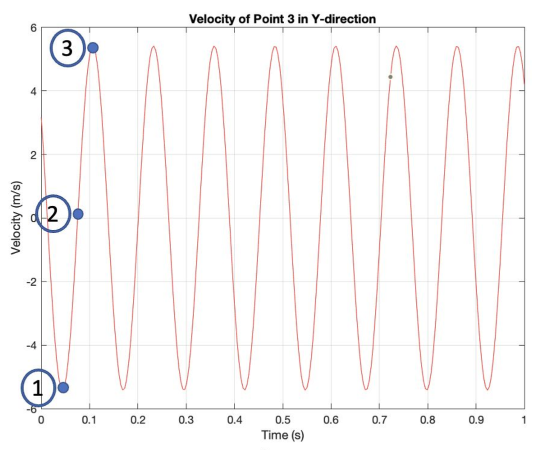
The static soil test determines the minimum force required to create a core plug. In the drop test, a manual aerator was dropped from a height of 40 inches to create a core plug. This test provides information on the minimum speed (4.4 m/s) at which the tines should enter the ground

To power the aerating mechanism, a Honda GX120 Engine was chosen due to the feasibility of increasing the gear ratio while maintaining a high RPM.

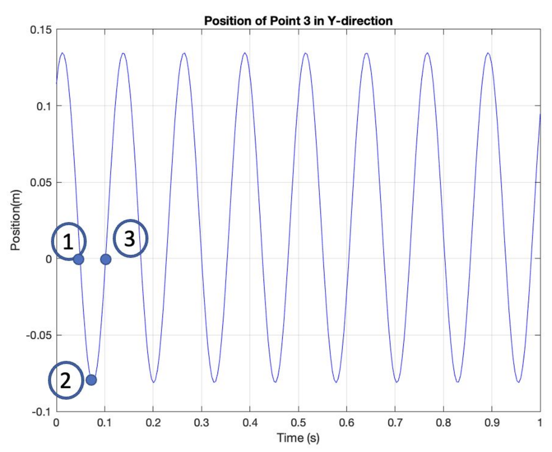
ROS (Robot Operating System)



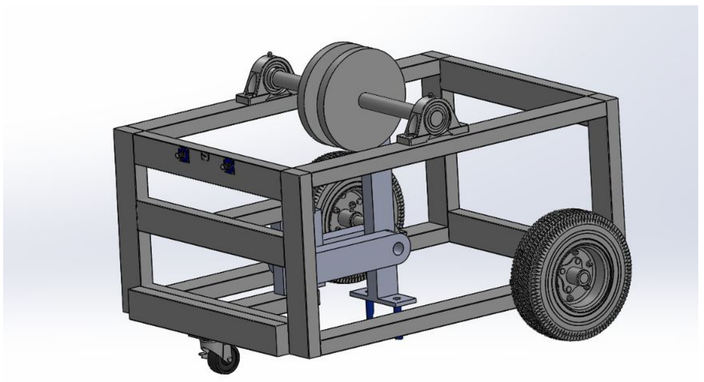
MECHANICAL DESIGN



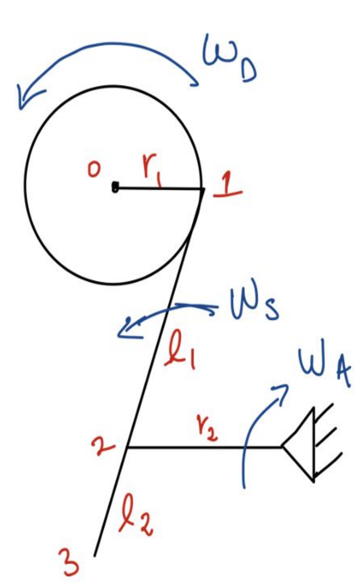
Point 1: 5.3 m/s @ 0.048 seconds
Point 2: 0.0 m/s @ 0.070 seconds
Point 3: 5.3 m/s @ 1.040 seconds



Point 1: 0.00 m @ 0.048 seconds
Point 2: 0.06 m @ 0.070 seconds
Point 3: 0.00 m @ 1.040 seconds



A full scale CAD model of our autonomous aerator model



Kinematic Aerating System

$$V_{1/O_1} = \begin{bmatrix} V_{1,x} \\ V_{1,y} \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \omega_{Disk} \end{bmatrix} \times \begin{bmatrix} r_1 * \cos(\theta) \\ r_1 * \sin(\theta) \\ 0 \end{bmatrix}$$

$$V_{2/O_2} = \begin{bmatrix} V_{2,x} \\ V_{2,y} \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -\omega_{arm} \end{bmatrix} \times \begin{bmatrix} r_2 * \cos(-\phi) \\ r_2 * \sin(-\phi) \\ 0 \end{bmatrix}$$

$$V_{2/1} = \begin{bmatrix} V_{2,x} \\ V_{2,y} \\ 0 \end{bmatrix} = \begin{bmatrix} V_{1,x} \\ V_{1,y} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega_{Shaft} \end{bmatrix} \times \begin{bmatrix} -l_1 * \sin(\gamma) \\ -l_1 * \cos(\gamma) \\ 0 \end{bmatrix}$$

$$V_{3/1} = \begin{bmatrix} V_{3,x} \\ V_{3,y} \\ 0 \end{bmatrix} = \begin{bmatrix} V_{1,x} \\ V_{1,y} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \omega_{Shaft} \end{bmatrix} \times \begin{bmatrix} -l_{total} * \cos(\zeta) \\ -l_{total} * \sin(\zeta) \\ 0 \end{bmatrix}$$

Physical model of the locomotive platform

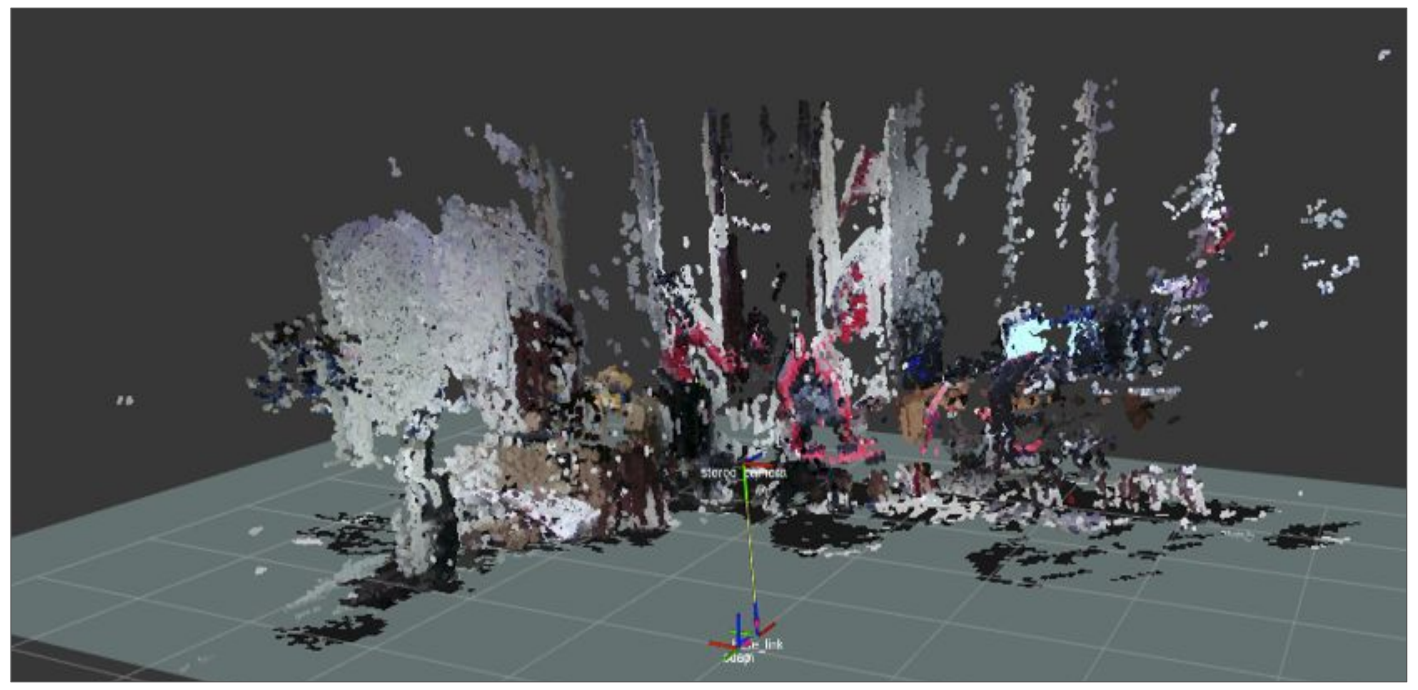
MAPPING

The 2 RGB cameras used for stereovision to generate to generate a point cloud map using Real-Time Appearance Mapping

To ensure mapping accuracy, camera images were calibrated to remove lens distortion

Before Calibration

After Calibration



A point cloud and 2D occupancy grid generated using Real-Time Appearance-Based Mapping (RTAB-MAP)

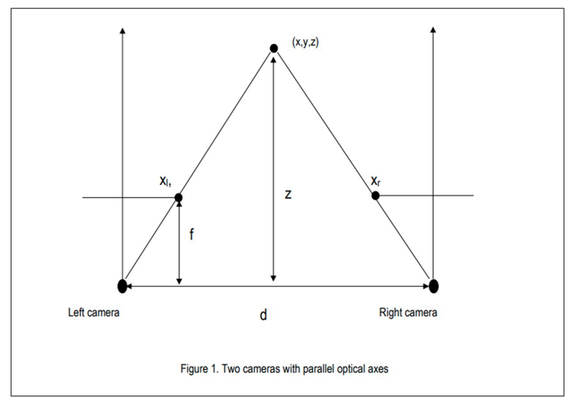


Figure 1. Two cameras with parallel optical axes

Source: POINT CLOUDS REGISTRATION AND GENERATION FROM STEREO IMAGES, Aram Gevorgyan Vladimir

$$\frac{z}{d} = \frac{f}{x_l - x_r} \Rightarrow z = \frac{df}{x_l - x_r}$$

Depth prediction: Stereo Vision
f: focal length
z: depth
xl,xr: x position of the same point in image plane of left and right cameras

RESULTS

- Mechanical
  - Mathematically modeled the velocity and position of the aerating mechanism.
  - Assembled an aerating mechanism
  - Built a small scale robot for the navigation team to test vision disparity

- Navigation and Mapping
  - Calibrated images from RGB cameras to remove lens distortion.
  - Generated a point cloud of an environment to aid in localization and navigation.