OSU Autonomous Golf Cart

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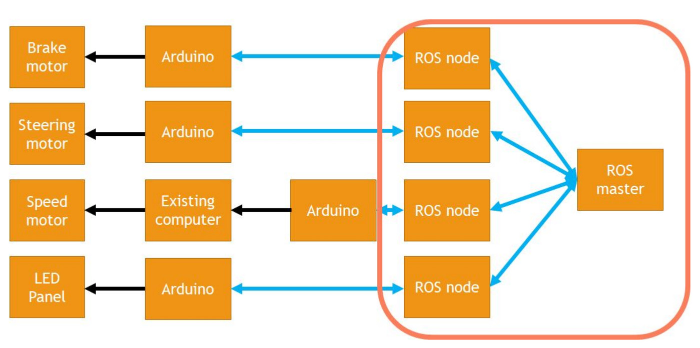
Introduction

Objective:
- Develop an SAE Level 3 Automated Driving System
- Deploy on standard golf cart

Motivation:
- 94% of sampled 5470 automotive accidents caused by driver error [1]

High-Level Design:
- Software
  - Robot Operating System (ROS) [2]
  - Low level controls on embedded microcontrollers
- Hardware
  - Modified standard golf cart to be drive-by-wire
  - Jetson Xavier

OSU Autonomous Golf Cart (AGC)



ROS Node Structure of Low Level Controllers

Jetson Xavier Developer Module

Drive By Wire System

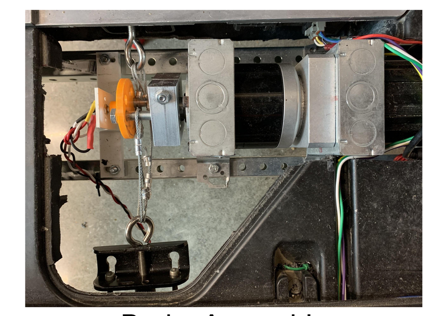
Hardware
- 4 Arduino Uno
- 2 Yumo A6B2 Rotary Encoders

Subsystems
- Wheel speed
- Brakes [3]
- Steering
- Human-machine-interfaces

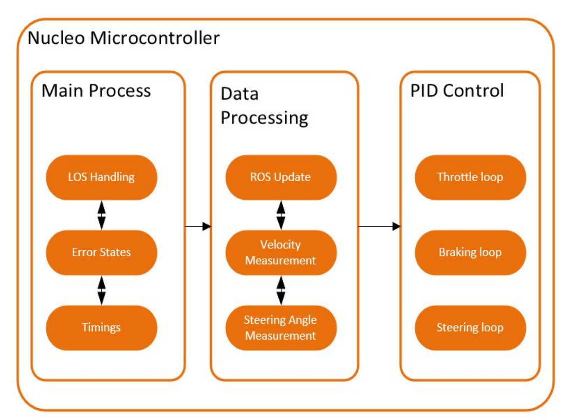
PID control

Loss of Signal (LoS) Response
- Fully redundant heartbeat system
  - Watchdog timer on hardwired connection
  - Timeout function through ROS
- Trigger LoS state after 3 loop cycles
- Return to manual control

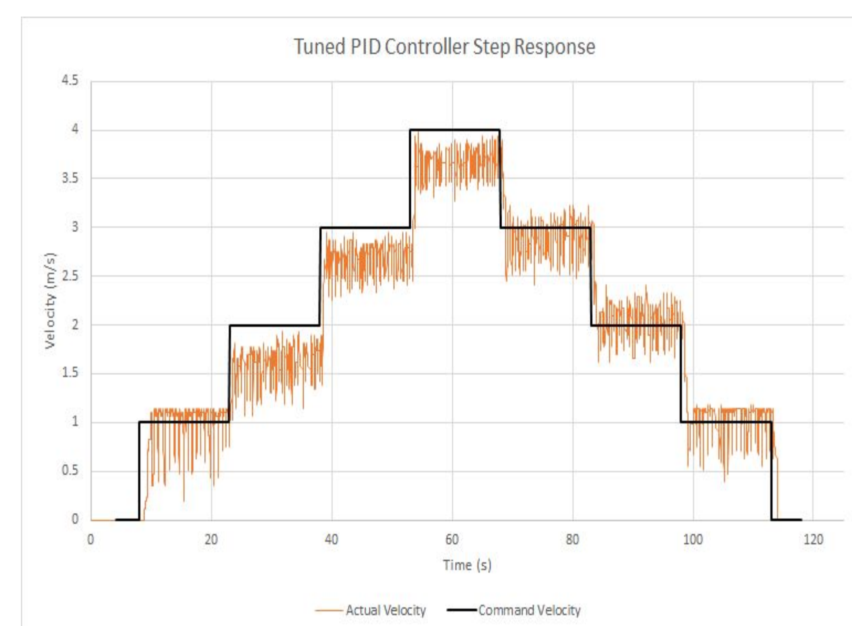
Steering Assembly



Brake Assembly
Fall 2019 Senior Design Team [3]



Block Diagram of Updated Architecture



Step Response of Speed Controller

Navigation

ROS Navigation Stack:
- Global planner
- Global costmap
- Local costmap
- Localization

Odometry:
- Wheel speed (ω) -> Rotary Encoder
- Steering angle (ϕ) -> Potentiometer
- Measurements integrated over time

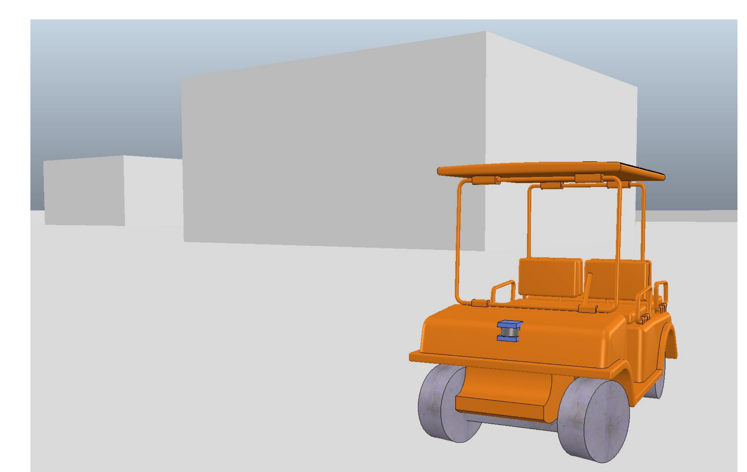
GPS Assisted Navigation:
- Offset odometry error
- Compared with map of OSU

Local Planning:
- Ackermann steering model
- Time Elastic Band (TEB) Planning [4]

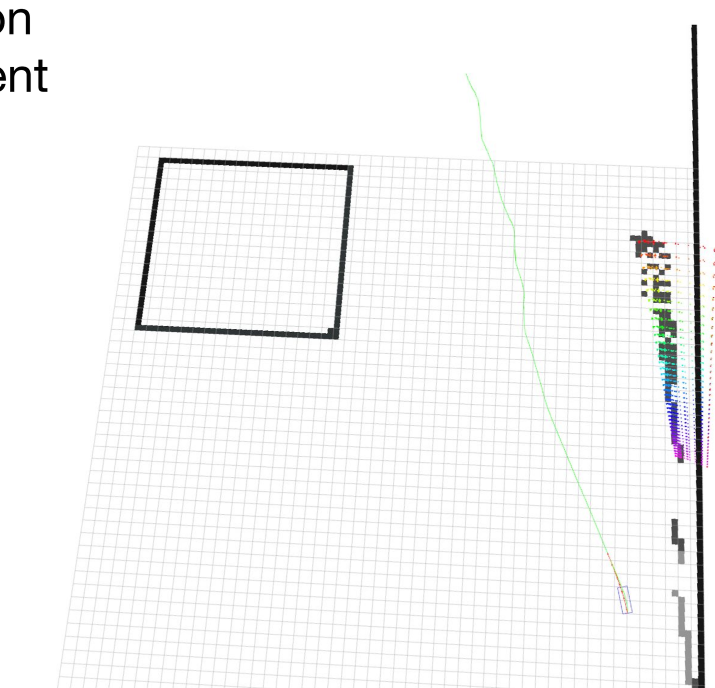
Testing:
- Hardware-in-the-loop simulation
  - Created in V-REP environment
- Deliver waypoints with rviz

$$v = \omega r$$
$$\dot{x} = v\cos\theta$$
$$\dot{y} = v\sin\theta$$
$$\dot{\theta} = \frac{v}{l}\tan\phi$$

Kinematic Constraints of Ackermann Steering Model



HIL V-REP Simulation Environment



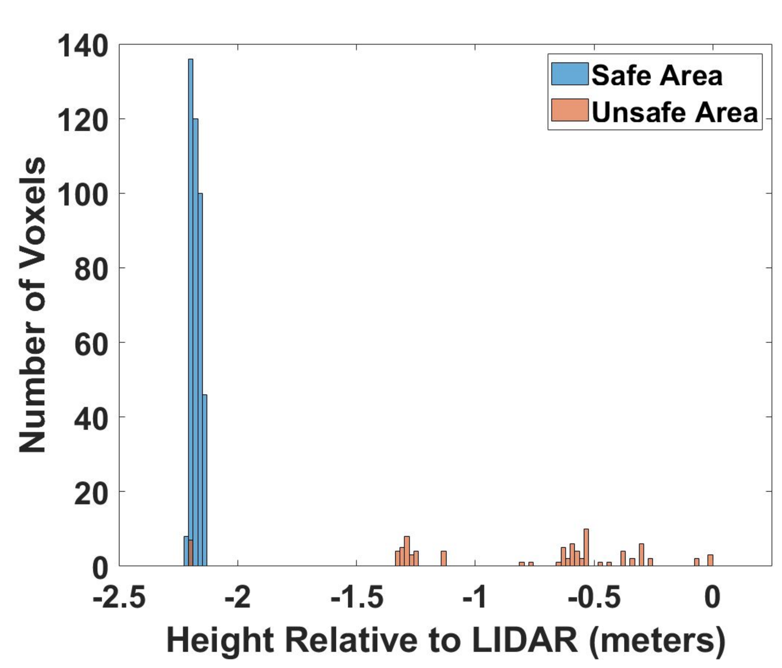
Visualized Output of ROS Navigation Stack in rviz

Perception

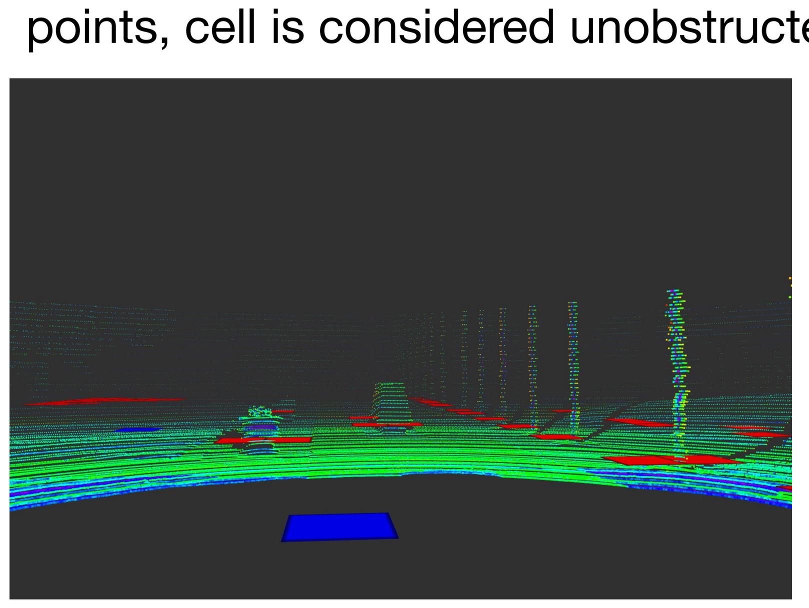
Hardware:
- Velodyne HDL-64E S2.1 LIDAR
- Bumblebee XB3 Stereo Vision System

Point Cloud Processing:
- Analyze voxel height in 2-D histogram
- Sparse Distribution -> Obstacle
- Tight Distribution -> Drivable Area
- Fill occupancy grid with obstacles
- ~12 Hz operating frequency

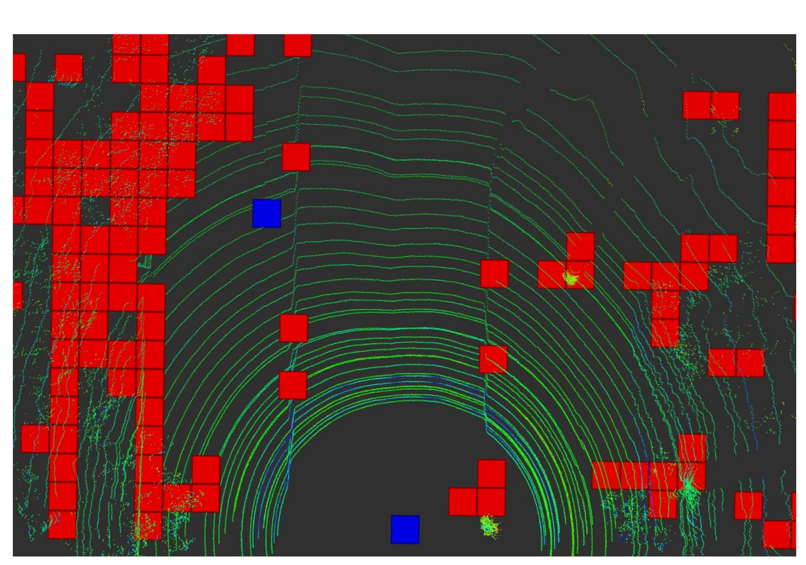
Algorithm:
1. Divide field of interest into 1x1 m cells
2. Create 155 bin histogram for each cell
   a. Bin width = 6.45 cm (z-axis)
   b. Bin height = # points
3. If any 3 adjacent bins contain 45% of points, cell is considered unobstructed



Characteristic Height Distributions



Processed Point Cloud of Noble Research Center



Processed Point Cloud of OSU Roads

Goals and Conclusions

Goals:
1. Implement Extended Kalman Filter (EKF) fusing odometry, GPS, and localization
2. Collect ~10 minutes of outdoor data from all sensor streams
3. Tune EKF, low-level controllers, and TEB planner
4. Implement safety features
   a. Low voltage detection
   b. Software fault management
   c. Clear communication between human and machine
   d. Physical & software switches to disable autonomy
5. Machine Learning with Stereo Camera
   a. Object labeling/classification
   b. Predicted velocity & steering angle

Conclusions:
- Developed low-level controls
- Developed high speed obstacle detection
- Developed odometry nodes
- Developed hardware-in-the-loop simulation
- Developed rudimentary map of OSU
- Implemented ROS Navigation Stack
- Implemented TEB planner

Benefits to Students:
- Opportunities for experience in applied mechanical, electrical, and software engineering
- Experience programming in C/C++, Python, XML, and more.

[1] S. Singh, "Critical reasons for crashes investigated in the national motor vehicle crash causation survey," tech. Rep., National Highway Traffic Safety Administration, 2015.
[2] M. Quigley, K. Conley, B. Gerkey, J. Faust, T. Foote, J Leibs, R. Wheeler, and A. Ng. "ROS: An open-source Robot Operating System. *ICRA Workshop on Open Source Software*. 2009.
[3] J. Hood, M. Sperle, S. Chowdhury, and S. Hair. OSU AGC Senior Design. Fall 2019.
[4] C. Rösmann, F. Hoffmann, and T. Bertram, "Kinodynamic trajectory optimization and control for car-like robots," IEEE/RSJ International Conference on Intelligent Robots and Systems, 2017