Polaris GEM e2 Vehicle

The Center for Autonomy at University of Illinois at Urbana-Champaign

User Manual

Version 1.0

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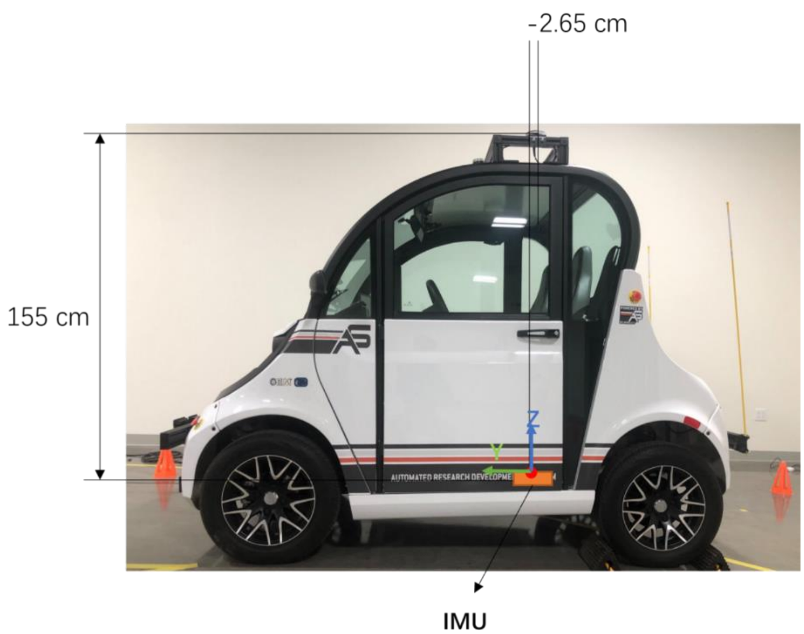
1. Polaris GEM e2 - Hardware

1.1 Polaris GEM e2 Vehicle

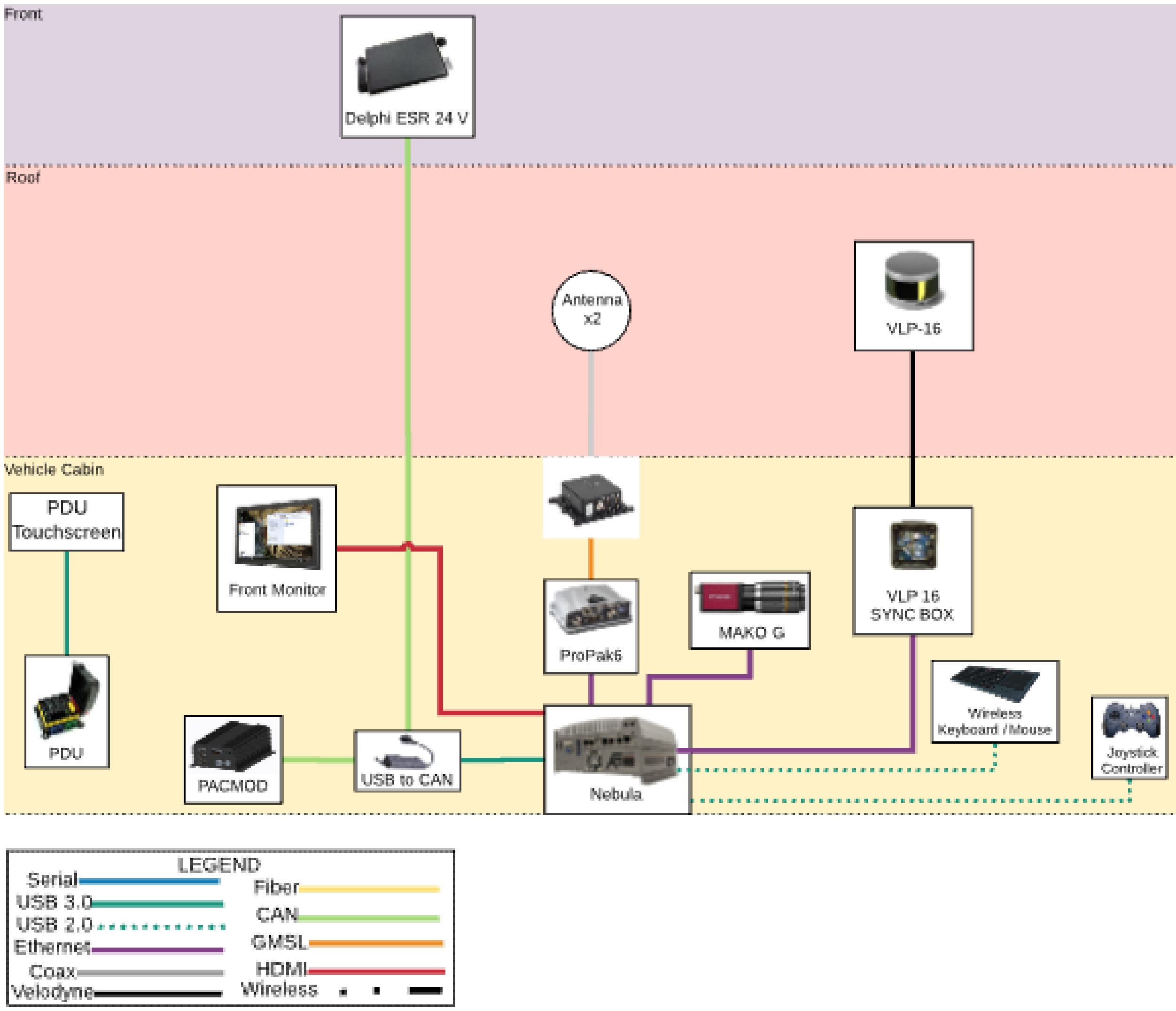
Software interfaces to the controls: steering, braking, acceleration

Software access: left and right blinkers, reverse and drive gear selection, speed feedback

Convenience features: Dash mounted display screen, Power distribution terminals



1.2 Hardware Overview



1.3 Master Power Switch

Switch will allow operator to cut power to power distribution system

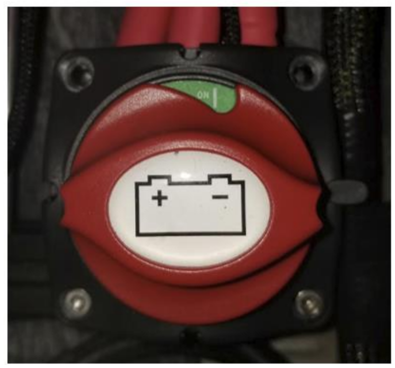
ON will supply power to power distribution system from vehicle battery

OFF will remove power to the power distribution system

Location: under the driver's seat

OFF

ON



1.4 Automated Research Development Platform

All front and rear racks are made with 3 inch x 1.5 inch 15 series 80/20

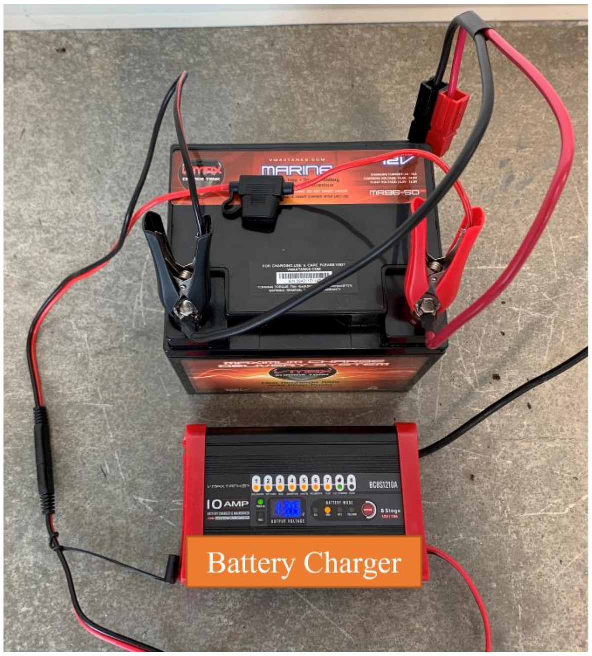
1.5 AStuff Spectra 2 Computer

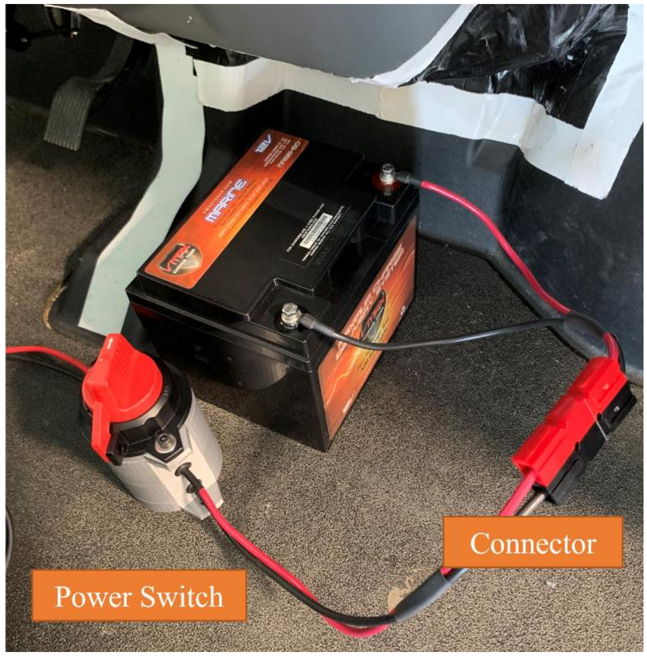
The AutonomouStuff Spectra 2 is the world's first dual GPU edge ai platform with industrial-grade design and in-vehicle features. Designed specifically to support two high-end 250W NVIDIA® graphics cards, it offers tremendous GPU power up to 28 TFLOPS in FP32 for emerging GPU-accelerated edge computing, such as autonomous driving, vision inspection and surveillance/security.

Datasheet link: https://autonomoustuff.com/-/media/Images/Hexagon/Hexagon%20Core/autonomousstuff/pdf/as-spectra-2-datasheet.ashx?la=en&hash=3FBD8D8C48469BBC65773BA4752AACAD

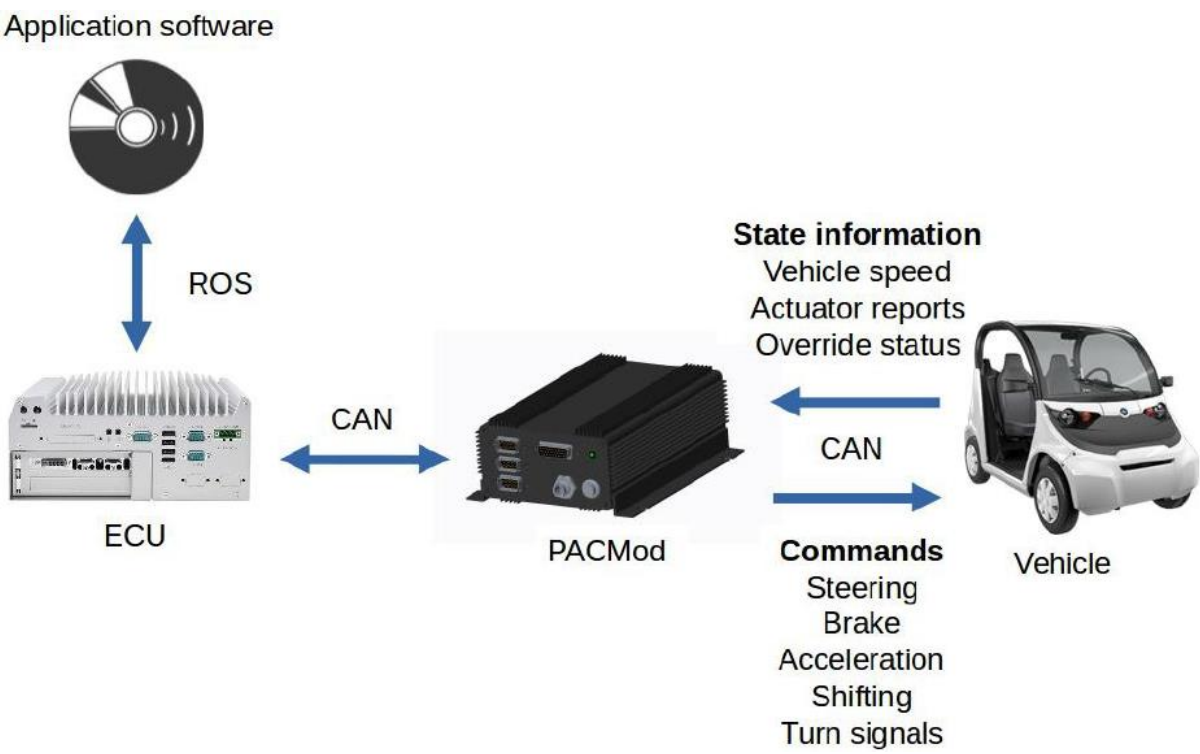
1.6 Power Devices of AStuff Spectra 2 Computer

The Astuff Spectra 2 computer is powered a 12V lead-acid battery. To charge the battery, put the battery on the concrete floor, clip both terminals correspondingly, wait until the green LED on the charger lights. To use the battery, put the battery on the passenger side on the vehicle's floor, connect the battery to the power switch, then switch on the battery.





1.7 PACMod Hardware Interface



PACMod Override

Steering

Brake / Throttle

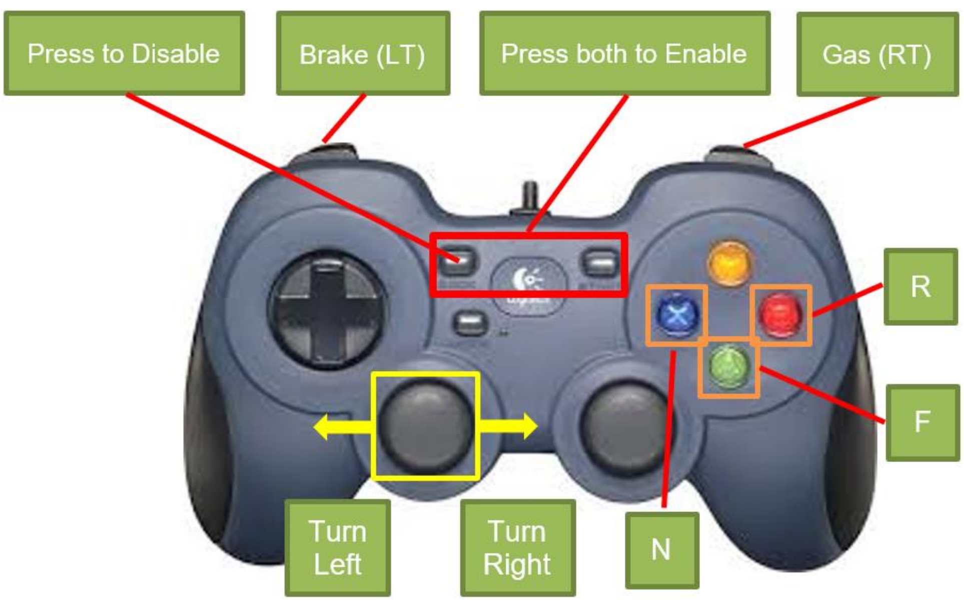
1.8 Joystick Controller Interface

Launching the Joystick Demo

$ roslaunch basic_launch gem_dbw_joystick.launch

```
<launch>
  <include file="$(find pacmod_game_control)/launch/pacmod_game_control.launch">
    <arg name="launch_pacmod" value="false" />
    <arg name="is_pacmod_3" value="false" />
    <arg name="pacmod_vehicle_type" value="POLARIS_GEM" />
  </include>

  <include file="$(find platform_launch)/launch/$(env platform_name)/platform.launch">
    <arg name="use_dbw" value="true" />
  </include>
</launch>
```



1.9 ZED2 Stereo Camera

Neural Depth Sensing

ZED 2 is the first stereo camera that uses neural networks to reproduce human vision, bringing stereo perception to a new level.

Built-in IMU, Barometer & Magnetometer

Multi-sensor capture made easy. Gather real-time synchronized inertial, elevation and magnetic field data along image and depth.

120° Wide-Angle Field of View

With its 16:9 native sensors and ultra sharp 8-element all glass lenses, capture video and depth with up to 120° field of view.

Spatial Object Detection

Detect objects with spatial context. Combine AI with 3D localization to create next-generation spatial awareness.

Improved Positional Tracking

Benefit from a wide angle FOV, advanced sensor stack and thermal calibration for a greatly improved positional tracking accuracy.

Cloud Connected

Monitor and control your camera remotely. Using a dedicated cloud platform, capture and analyze 3D data anywhere in the world.

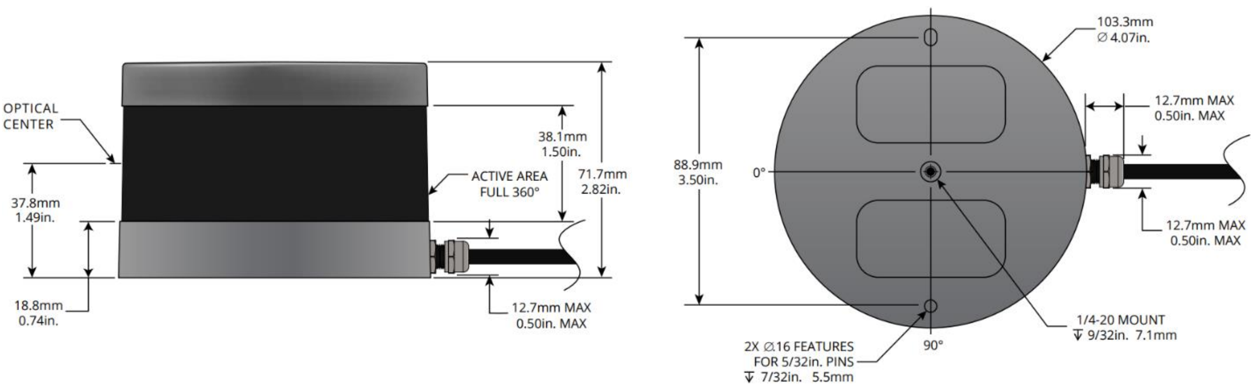
Video Mode	Frames per second	Output Resolution (side by side)
2.2K	15	4416x1242
1080p	30 / 15	3840x1080
720p	60 / 30 / 15	2560x720
WVGA	100 / 60 / 30 / 15	1344x376

The default image size of ZED2 stereo camera with ROS driver is **1280 x 720** at 30Hz for both left and right cameras.

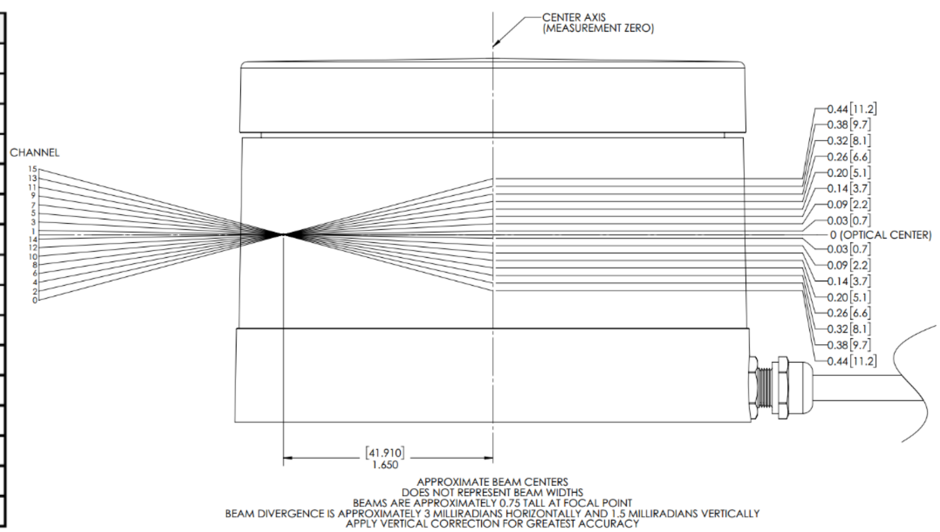
1.10 Velodyne VLP-16 LiDAR

Roof Rack

Dimensions



Laser ID	Vertical Angle
0	-15°
1	1°
2	-13°
3	-3°
4	-11°
5	5°
6	-9°
7	7°
8	-7°
9	9°
10	-5°
11	11°
12	-3°
13	13°
14	-1°
15	15°



Sensor

- 16 Channels
- Measurement Range: 100 m – 120 m
- Range Accuracy: Up to ±3 cm (Typical)1
- Field of View (Vertical): +15.0° to -15.0° (30°)
- Angular Resolution (Vertical): 2.0°
- Field of View (Horizontal): 360°
- Angular Resolution (Horizontal/Azimuth): 0.1° – 0.4°
- Rotation Rate: 5 Hz – 20 Hz
- Integrated Web Server for Easy Monitoring and Configuration

Mechanical / Electrical / Operational

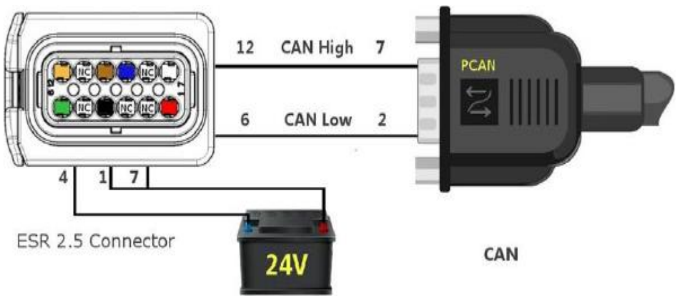
- Power Consumption: 8 W (Typical)2
- Operating Voltage: 9 V – 18 V (with Interface Box and Regulated Power Supply)
- Weight: ~590 g (without Cabling and Interface Box)
- Dimensions: See diagram on previous page
- Environmental Protection: IP67
- Operating Temperature: -10°C to +60°C3
- Storage Temperature: -40°C to +105°C

Outputs

- 3D LiDAR Data Points Generated:
  - Single Return Mode: ~300,000 points per second
  - Dual Return Mode: ~600,000 points per second
- 100 Mbps Ethernet Connection
- UDP Packets Contain:
  - Time of Flight Distance Measurement
  - Calibrated Reflectivity Measurement
  - Rotation Angles
  - Synchronized Time Stamps (µs resolution)
- GPS: $GPRMC and $GPGGA NMEA Sentences from GPS Receiver (GPS not included)

1.11 Delphi ESR 2.5 Radar

CAN / USB Connection Wiring



Pin #	Signal	Color
1	Battery (+24V)	Red
2	USB D+ (green wire)	Green (USB)
3	USB D- (white wire)	White (USB)
4	Ground	Black
5	USB Ground (black wire)	Black (USB)
6	PRVCANL	Green
7	Ignition (+24V)	White
8	USB +5V (red wire)	Red (USB)
9	VEHCANL	Blue
10	VEHCANH	Brown
11	VEHCAN Shield	
12	PRVCANH	Orange

USB-to-CAN (Kvaser Hybrid 2xCAN/LIN)

1.12 ProPak 6 & SPAN-IGM-S1

ProPak-6D1

Dual Antenna Support

Cellular

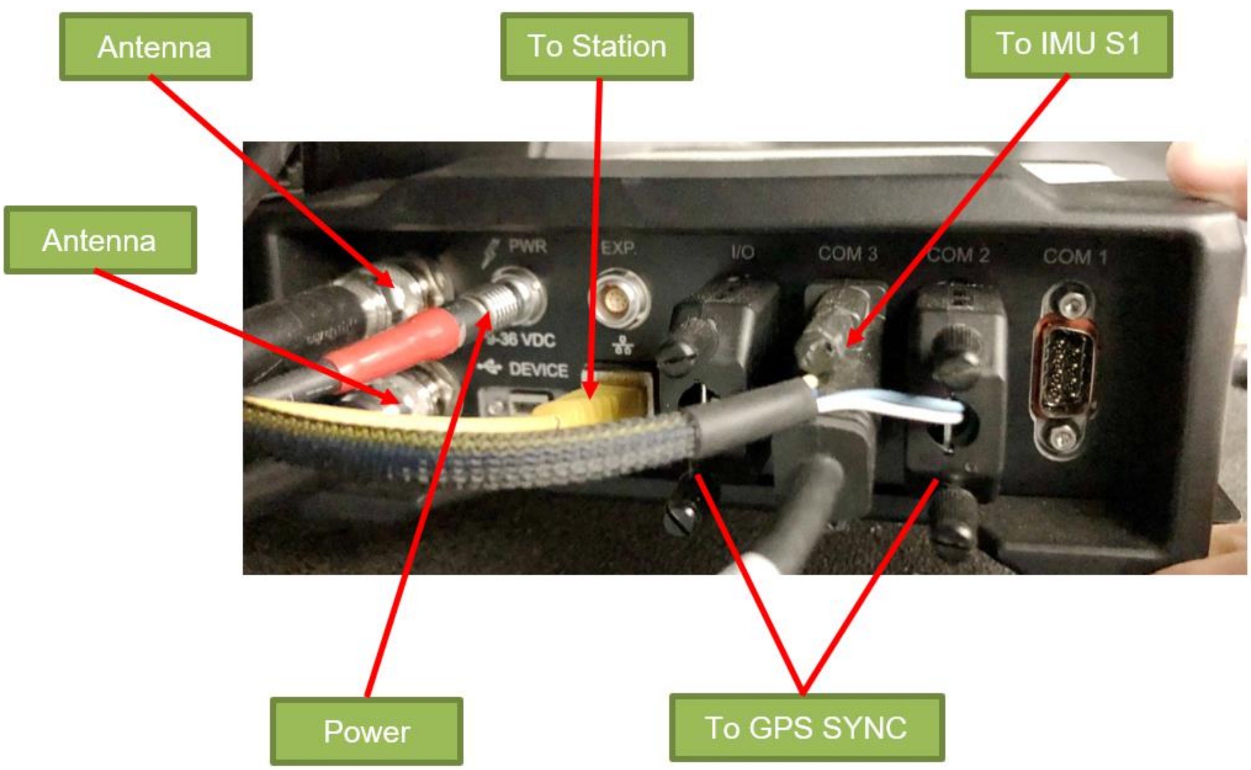
L1/L2 GPS+GLONASS

L-Band TerraStar-C PPP Corrections

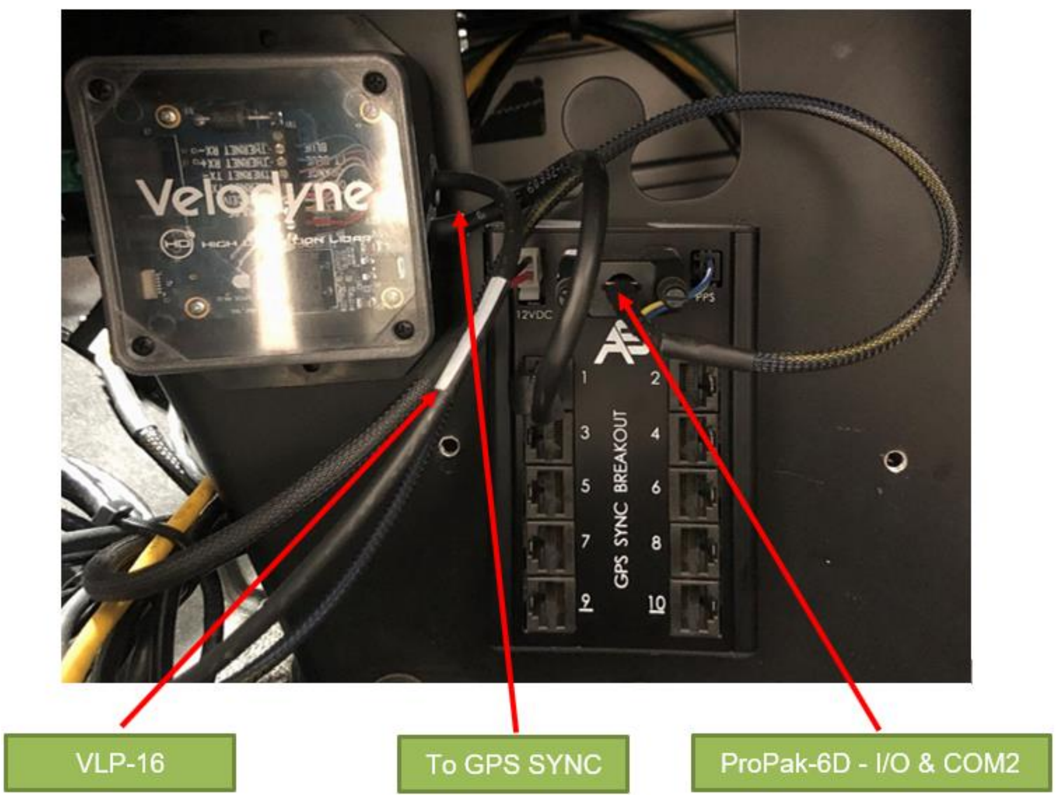
-3 Grade IMUs

20 Hz Positions and Measurements

4GB Internal Memory



Connector Type	Connector Label	Description
GNSS Antenna External Oscillator	ANT 1 ANT 2 or ANT1 OSC	GNSS GPS1 and GPS2 antennas (TNC) (model dependant) or GNSS GPS1 antenna (TNC) and external oscillator (BNC) (model dependant)
Power	PWR	4-pin LEMO power connector
Expansion	EXP.	9-pin LEMO expansion port for CAN1 and CAN2
USB	DEVICE	USB Device (Type micro B) connector (high speed only) 480 Mbps
Ethernet		Ethernet RJ45 connector
I/O	I/O	4 Event Input/3 Event Output (DB9 female connector) I/O port is configurable
Serial Communication Ports	COM1 COM2 COM3/IMU	COM1, COM2, COM3/IMU DB9 male communications port RS-232 (RS-422 selectable via software)



SPAN-IGM-S1

200Hz/125 Hz Inertial Measurements

Direct Wheel Sensor Support

Commercially Exportable

Small and lightweight design

G5Ant-3AMT4

Matte black finish without branding

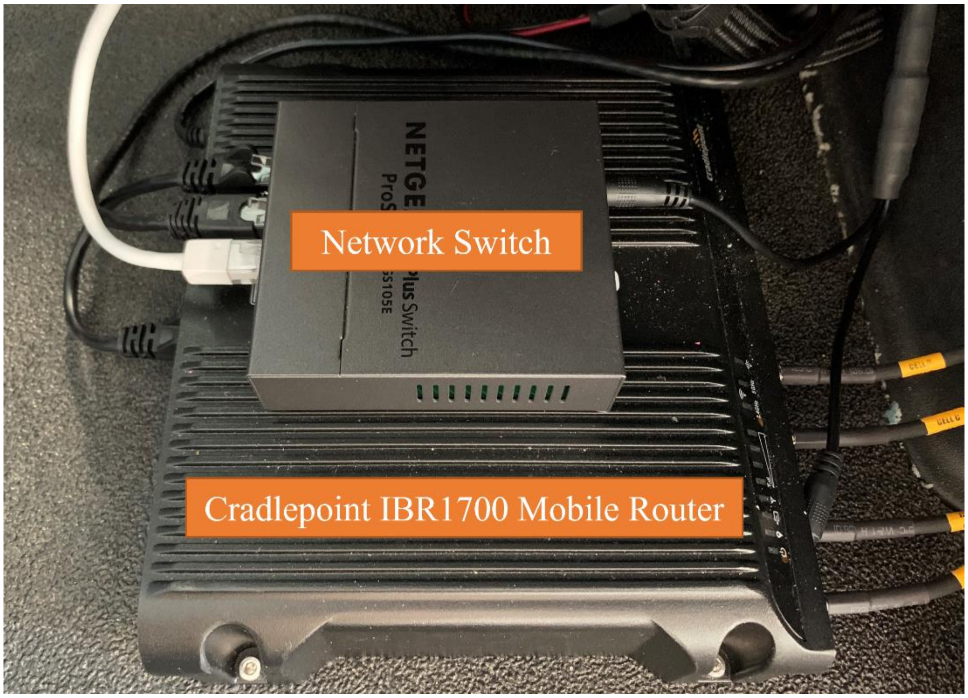
Various mounting options and connectors

Size: 89 mm dia. x 25 mm hgt

Weight: 368 g

1.13 Cradlepoint IBR1700 Mobile Router

By using a SIM card with data plan, the Cradlepoint IBR1700 mobile router and network switch provide Internet access for AStuff Spectra 2 computer when the Polaris GEM e2 vehicle runs outside the building. The master power switch in 1.3 is in charge of powering these devices.



2. Polaris GEM e2 - Software

2.1 Software Setup

ROS Noetic Installtion

http://wiki.ros.org/noetic/Installation

AutonomouStuff Driver Installation

$ sudo apt update && sudo apt install apt-transport-https

$ sudo sh -c 'echo "deb [trusted=yes] https://s3.amazonaws.com/autonomoustuff-repo/ $(lsb_release -sc) main" > /etc/apt/sources.list.d/autonomoustuff-public.list'

Install Kvaser linuxcan SDK:

https://autonomoustuff.atlassian.net/wiki/spaces/RW/pages/17475947/Driver+Pack+Installation+or+Upgrade+Instructions

https://www.kvaser.com/download/

$ sudo apt install ros-$ROS_DISTRO-kvaser-interface ros-$ROS_DISTRO-delphi-esr

Software Installation

$ sudo apt install solaar
$ sudo apt install preload
$ sudo apt install meld
$ sudo apt-get install indicator-multiload

Summary

Ubuntu 20.04 with ROS Noetic (Python3)
NVIDIA Driver Version: 450 (valid for RTX2080 Ti)
CUDA 11.0.3
OpenCV 4.6.0
pytorch 1.7.1

2.2 Frame Setup

platform_launch/launch/white_e2/platform.launch

platform_launch/launch/core/all_supported_drivers.launch

veh_frame (default=base_link)

front_radar_frame (default=front_radar)

lidar1_frame (default=lidar1)

novatel_frame (default=novatel)

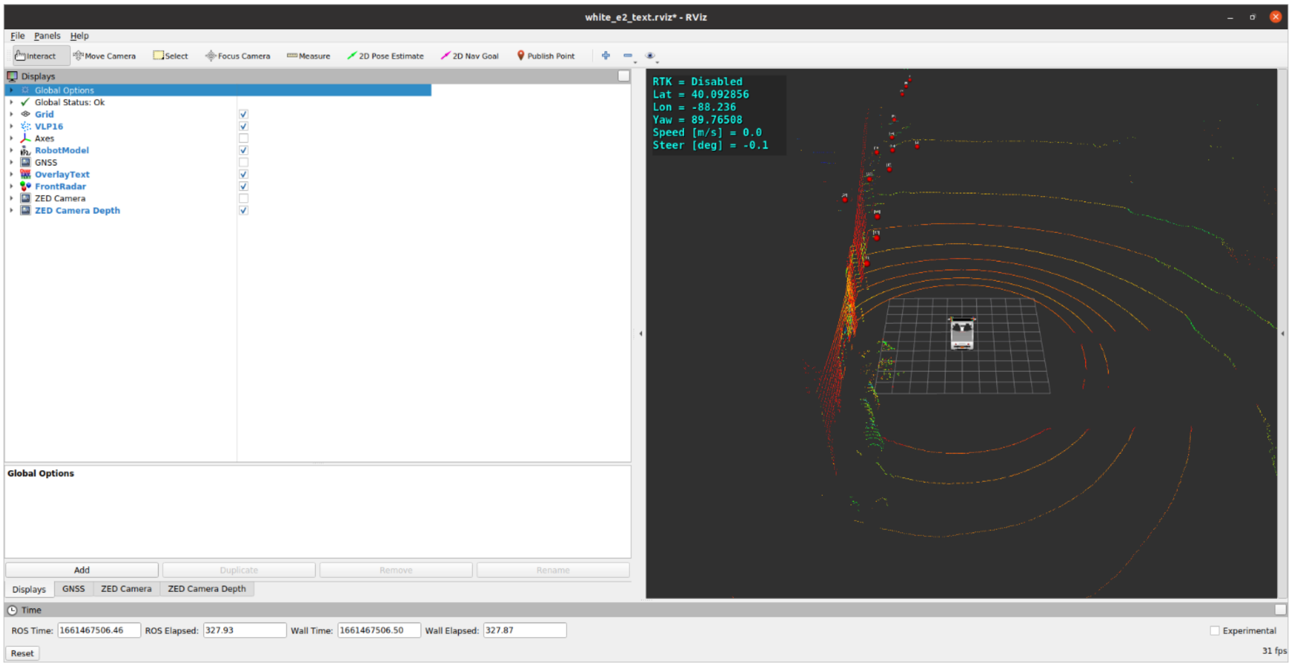
novatel_imu_frame (default=imu)

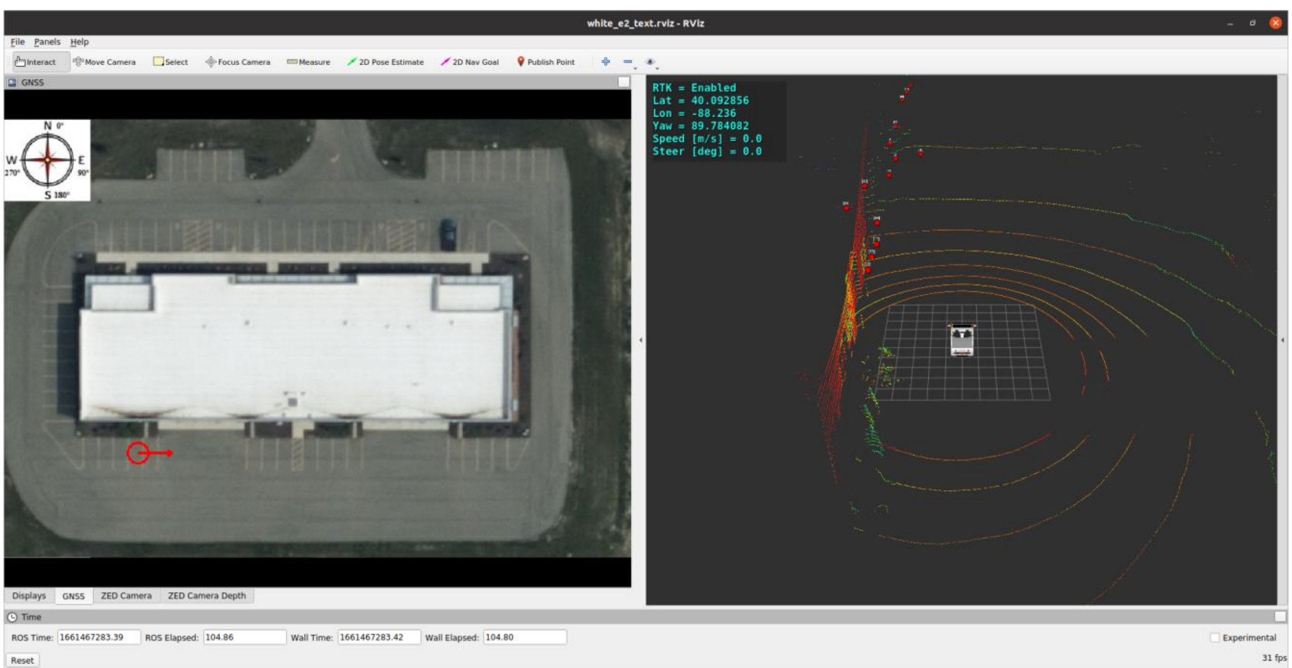
Usage: static_transform_publisher x y z yaw pitch roll frame_id child_frame_id period (ms)

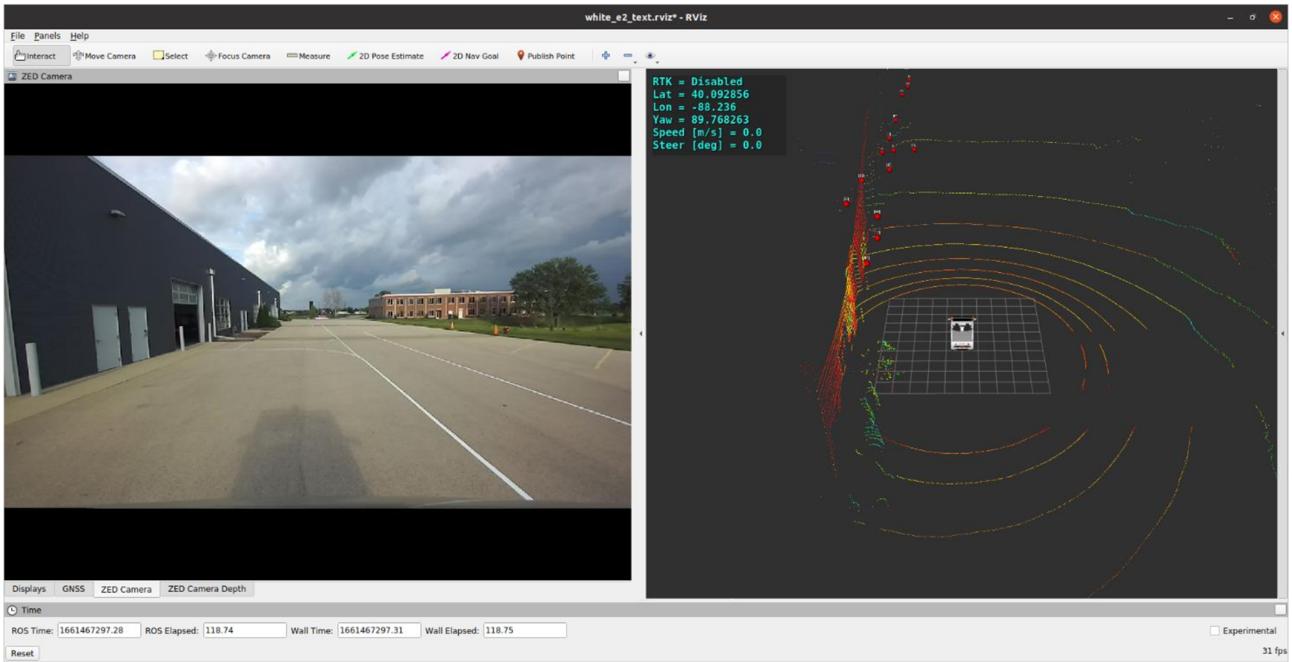
2.3 Rviz Setup

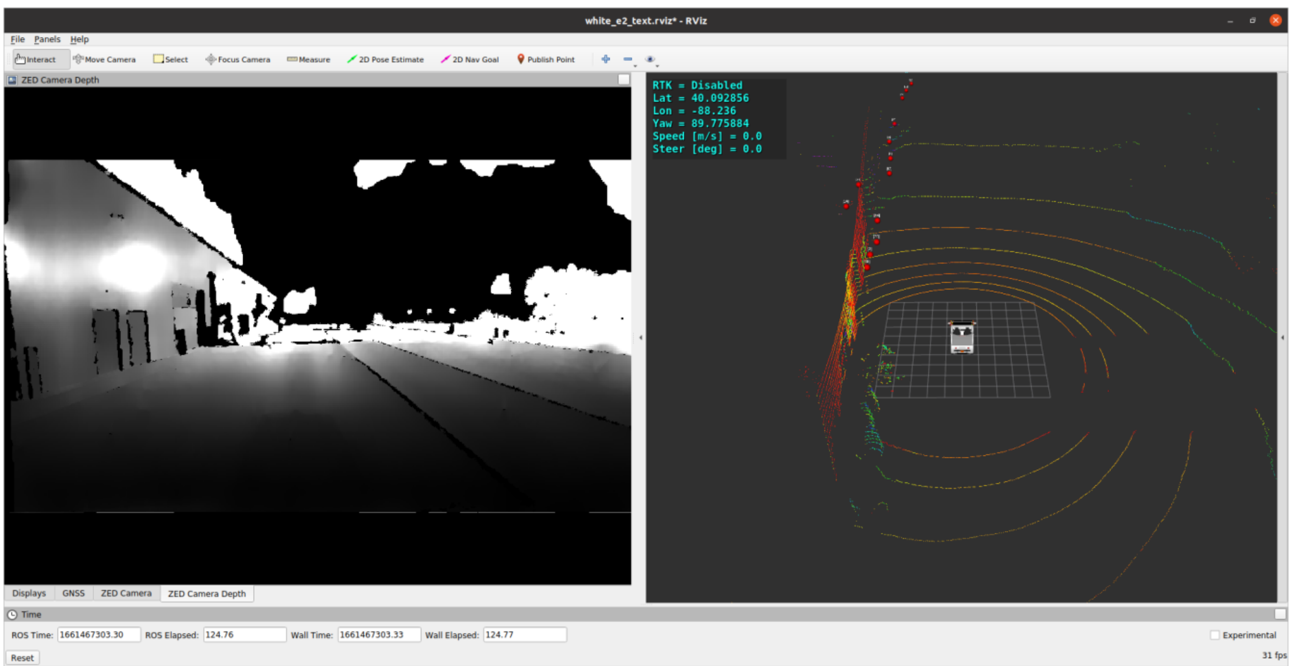
$ source devel/setup.bash

$ roslaunch basic_launch gem_sensor_init.launch






white_e2_text.rviz* - RViz
File Panels Help
Interact Move Camera Select Focus Camera Measure 2D Pose Estimate 2D Nav Goal Publish Point
ZED Camera
RTK = Disabled
Lat = 40.092856
Lon = -88.236
Yaw = 89.768263
Speed [m/s] = 0.0
Steer [deg] = 0.0
Displays GNSS ZED Camera ZED Camera Depth
Time
ROS Time: 1661467297.28 ROS Elapsed: 118.74 Wall Time: 1661467297.31 Wall Elapsed: 118.75
Experimental
Reset
31 fps


white_e2_text.rviz* - RViz
File Panels Help
Interact Move Camera Select Focus Camera Measure 2D Pose Estimate 2D Nav Goal Publish Point
ZED Camera Depth
RTK = Disabled
Lat = 40.092856
Lon = -88.236
Yaw = 89.775884
Speed [m/s] = 0.0
Steer [deg] = 0.0
Displays GNSS ZED Camera ZED Camera Depth
Time
ROS Time: 1661467303.30 ROS Elapsed: 124.76 Wall Time: 1661467303.33 Wall Elapsed: 124.77
Experimental
Reset
31 fps

2.4 ROS Driver of PACMod

ROS wiki: http://wiki.ros.org/pacmod

Source: https://github.com/astuff/pacmod.git (branch: release)

Supported Hardware

- Polaris GEM Series (e2/e4/e6/eLXD)
- Polaris Ranger X900
- International Prostar+ 122
- Lexus RX-450h

can_msgs/Frame.msg

Header header
uint32 id
bool is_rtr
bool is_extended
bool is_error
uint8 dlc
uint8[8] data

CAN Device List

```
dev@dev-gem:/usr/src/linuxcan/canlib/examples$ ./listChannels
CANlib version 5.28
Found 2 channel(s).
ch  0: Kvaser USBcan Light 2xHS 73-30130-00714-7, s/n 11783, v4.1.844  (leaf v8.28.846)
ch  1: Kvaser USBcan Light 2xHS 73-30130-00714-7, s/n 11783, v4.1.844  (leaf v8.28.846)
dev@dev-gem:/usr/src/linuxcan/canlib/examples$
```

Published Topics

Topic	Message Type	Description
can_rx	can_msgs/Frame	All data published on this topic is intended to be sent to the PACMod system via a CAN interface.
parsed_tx/global_rpt	pacmod_msgs/GlobalRpt	High-level data about the entire PACMod system.
parsed_tx/accel_rpt	pacmod_msgs/SystemRptFloat	Status and parsed values [pct] of the throttle subsystem.
parsed_tx/brake_rpt	pacmod_msgs/SystemRptFloat	Status and parsed values [pct] of the steering susbsystem.
parsed_tx/steer_rpt	pacmod_msgs/SystemRptFloat	Status and parsed values [rad] of the steering susbsystem.
parsed_tx/turn_rpt	pacmod_msgs/SystemRptInt	Status and parsed values [enum] of the turn signal subsystem.
parsed_tx/shift_rpt	pacmod_msgs/SystemRptInt	Status and parsed values [enum] of the gear/transmission subsystem.
parsed_tx/vehicle_speed_rpt	pacmod_msgs/VehicleSpeedRpt	The vehicle's current speed, the validity of the speed message [bool], and the raw CAN message from the vehicle CAN.
parsed_tx/vin_rpt	pacmod_msgs/VinRpt	The configured vehicle's VIN, make, model, manufacturer, and model year.
as_tx/vehicle_speed	std_msgs/Float64	The vehicle's current speed [m/s].
as_tx/enable	std_msgs/Bool	The current status of the PACMod's control of the vehicle. If the PACMod is enabled, this value will be true. If it is disabled or overridden, this value will be false.

Subscribed Topics

Topic	Message Type	Description
can_tx	can_msgs/Frame	All data published to this topic will be parsed by the PACMod driver. This should be connected to a CAN interface.
as_rx/accel_cmd	pacmod_msgs/PacmodCmd	Commands the throttle subsystem to seek a specific pedal position [pct - 0.0 to 1.0].
as_rx/brake_cmd	pacmod_msgs/PacmodCmd	Commands the brake subsystem to seek a specific pedal position [pct - 0.0 to 1.0].
as_rx/shift_cmd	pacmod_msgs/PacmodCmd	Commands the gear/transmission subsystem to shift to a different gear [enum].
as_rx/turn_cmd	pacmod_msgs/PacmodCmd	Commands the turn signal subsystem to transition to a given state [enum].
as_rx/steer_cmd	pacmod_msgs/PositionWIthSpeed	Commands the steering subsystem to seek a specific steering wheel angle [rad] at a given rotation velocity [rad/s].
as_rx/enable	std_msgs/Bool	Enables [true] or disables [false] PACMod's control of the vehicle.

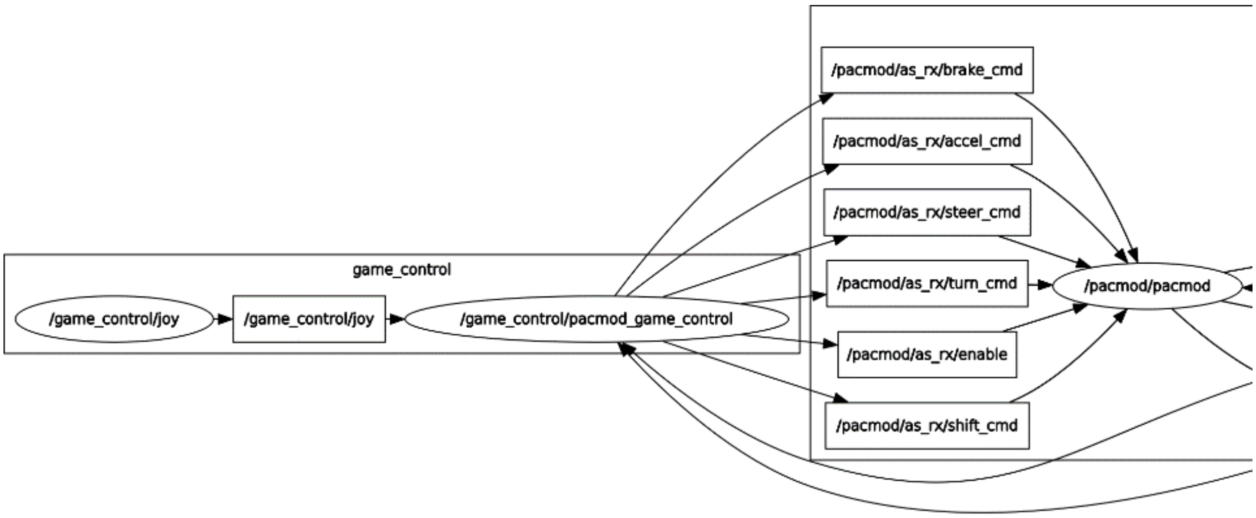
Parameters

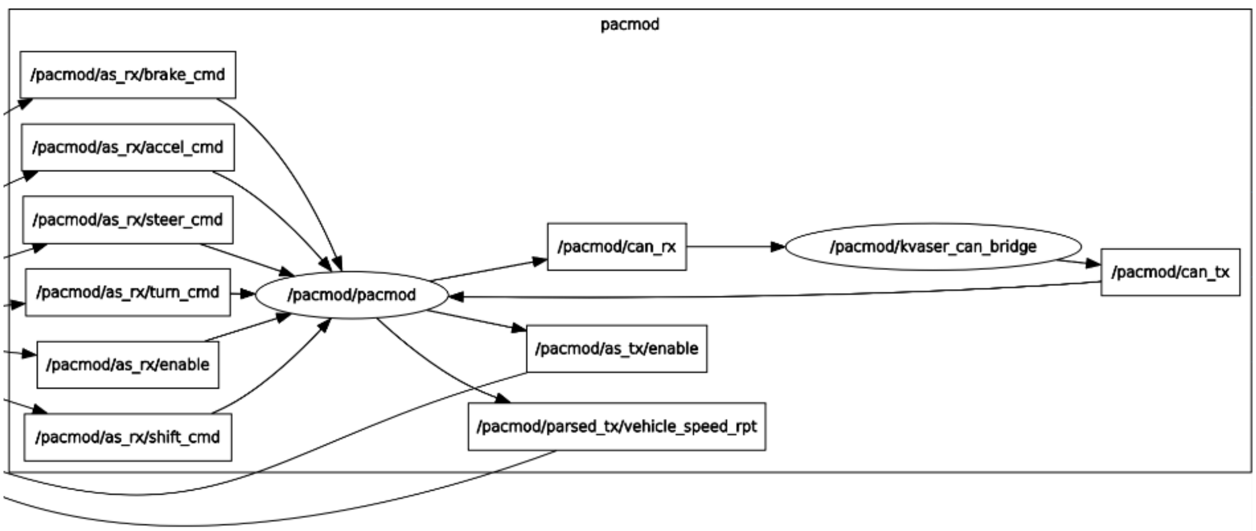
~vehicle_type: a string value indicating the type of vehicle to which the PACMod is connected.

Valid values are:

- POLARIS_GEM
- POLARIS_RANGER
- INTERNATIONAL_PROSTAR_122
- LEXUS_RX_450H

PACMod Graph





/pacmod/as_rx/accel_cmd

/pacmod/as_rx/brake_cmd

/pacmod/as_rx/enable

/pacmod/as_rx/shift_cmd

/pacmod/as_rx/steer_cmd

/pacmod/as_rx/turn_cmd

2.5 ROS Driver of Joystick Controller

ROS wiki: http://wiki.ros.org/pacmod_game_control

Source: https://github.com/astuff/pacmod_game_control.git (branch: release)

Parameters

~steering_stick: sets whether the steering command should be controlled by the left or right joystick on a two-stick controller. Valid values are LEFT or RIGHT.

~pacmod_vehicle_type: sets the type of vehicle which is being controlled. This manages vehicle-specific values like the available features and maximum steering angle. Valid values are:

- POLARIS_GEM
- POLARIS_RANGER
- LEXUS_RX_450H
- INTERNATIONAL_PROSTAR_122
- VEHICLE_4
- VEHICLE_5
- VEHICLE_6

~controller_type: sets type of controller being used and associated button mappings. Valid values are:

- LOGITECH_F310
- HRI_SAFE_REMOTE
- LOGITECH_G29
- NINTENDO_SWITCH_WIRED_PLUS
- XBOX_ONE

~steering_max_speed: the maximum rotational speed for the steering wheel in rad/s.

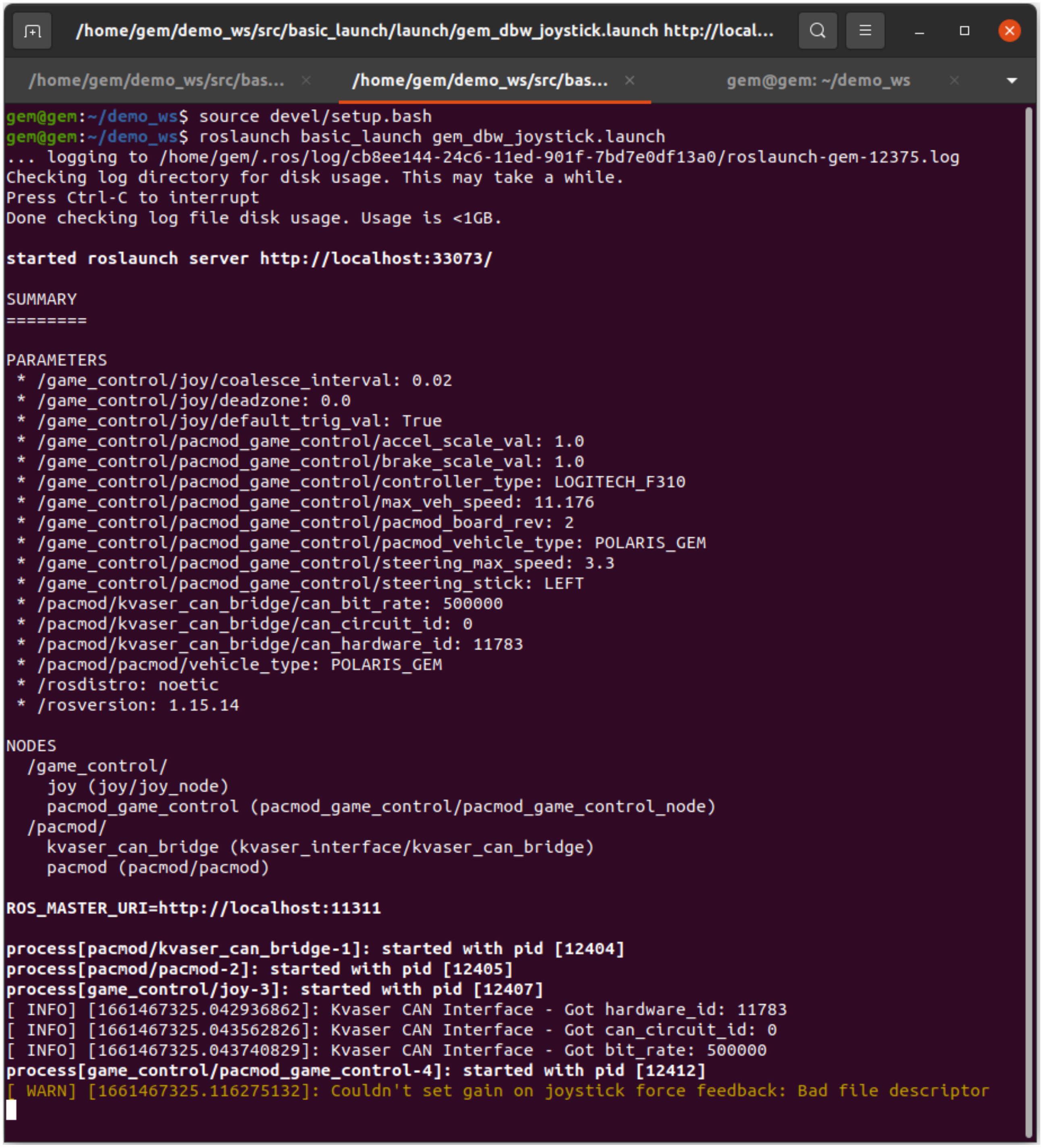
~max_veh_speed: the vehicle speed is used to scale the rotation rate of the steering wheel. This value is the speed, in m/s, at which the most restriction is placed on rotation rate. This helps controllability as speed increases.

~accel_scale_val: a scaling value (0.0 - 1.0) for the accelerator. 1.0 = full throttle range. 0.0 = no throttle control.

~brake_scale_val: a scaling value (0.0 - 1.0) for the brake. 1.0 = full braking range. 0.0 = no brake control.

$ source devel/setup.bash

$ roslaunch basic_launch gem_dbw_joystick.launch



```
/home/gem/demo_ws/src/basic_launch/launch/gem_dbw_joystick.launch http://local...
/home/gem/demo_ws/src/bas...    /home/gem/demo_ws/src/bas...    gem@gem: ~/demo_ws
gem@gem:~/demo_ws$ source devel/setup.bash
gem@gem:~/demo_ws$ roslaunch basic_launch gem_dbw_joystick.launch
... logging to /home/gem/.ros/log/cb8ee144-24c6-11ed-901f-7bd7e0df13a0/roslaunch-gem-12375.log
Checking log directory for disk usage. This may take a while.
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is <1GB.

started roslaunch server http://localhost:33073/

SUMMARY
========

PARAMETERS
 * /game_control/joy/coalesce_interval: 0.02
 * /game_control/joy/deadzone: 0.0
 * /game_control/joy/default_trig_val: True
 * /game_control/pacmod_game_control/accel_scale_val: 1.0
 * /game_control/pacmod_game_control/brake_scale_val: 1.0
 * /game_control/pacmod_game_control/controller_type: LOGITECH_F310
 * /game_control/pacmod_game_control/max_veh_speed: 11.176
 * /game_control/pacmod_game_control/pacmod_board_rev: 2
 * /game_control/pacmod_game_control/pacmod_vehicle_type: POLARIS_GEM
 * /game_control/pacmod_game_control/steering_max_speed: 3.3
 * /game_control/pacmod_game_control/steering_stick: LEFT
 * /pacmod/kvaser_can_bridge/can_bit_rate: 500000
 * /pacmod/kvaser_can_bridge/can_circuit_id: 0
 * /pacmod/kvaser_can_bridge/can_hardware_id: 11783
 * /pacmod/pacmod/vehicle_type: POLARIS_GEM
 * /rosdistro: noetic
 * /rosversion: 1.15.14

NODES
  /game_control/
    joy (joy/joy_node)
    pacmod_game_control (pacmod_game_control/pacmod_game_control_node)
  /pacmod/
    kvaser_can_bridge (kvaser_interface/kvaser_can_bridge)
    pacmod (pacmod/pacmod)

ROS_MASTER_URI=http://localhost:11311

process[pacmod/kvaser_can_bridge-1]: started with pid [12404]
process[pacmod/pacmod-2]: started with pid [12405]
process[game_control/joy-3]: started with pid [12407]
[ INFO] [1661467325.042936862]: Kvaser CAN Interface - Got hardware_id: 11783
[ INFO] [1661467325.043562826]: Kvaser CAN Interface - Got can_circuit_id: 0
[ INFO] [1661467325.043740829]: Kvaser CAN Interface - Got bit_rate: 500000
process[game_control/pacmod_game_control-4]: started with pid [12412]
[ WARN] [1661467325.116275132]: Couldn't set gain on joystick force feedback: Bad file descriptor
```

2.6 ROS Topics of Polaris GEM e2

Joystick:

/game_control/joy
/game_control/joy/set_feedback

Front RADAR:

/front_radar/front_radar/can_rx
/front_radar/front_radar/can_tx
/front_radar/front_radar/can_viz_markers
/front_radar/front_radar/esr_eth_tx
/front_radar/front_radar/esr_status_1
/front_radar/front_radar/esr_status_2
/front_radar/front_radar/esr_status_3
/front_radar/front_radar/esr_status_4
/front_radar/front_radar/esr_status_5
/front_radar/front_radar/esr_status_6
/front_radar/front_radar/esr_status_7
/front_radar/front_radar/esr_status_8
/front_radar/front_radar/esr_status_9
/front_radar/front_radar/esr_track
/front_radar/front_radar/esr_track_motion_power_group
/front_radar/front_radar/esr_valid_1
/front_radar/front_radar/esr_valid_2
/front_radar/front_radar/esr_vehicle_1
/front_radar/front_radar/esr_vehicle_2
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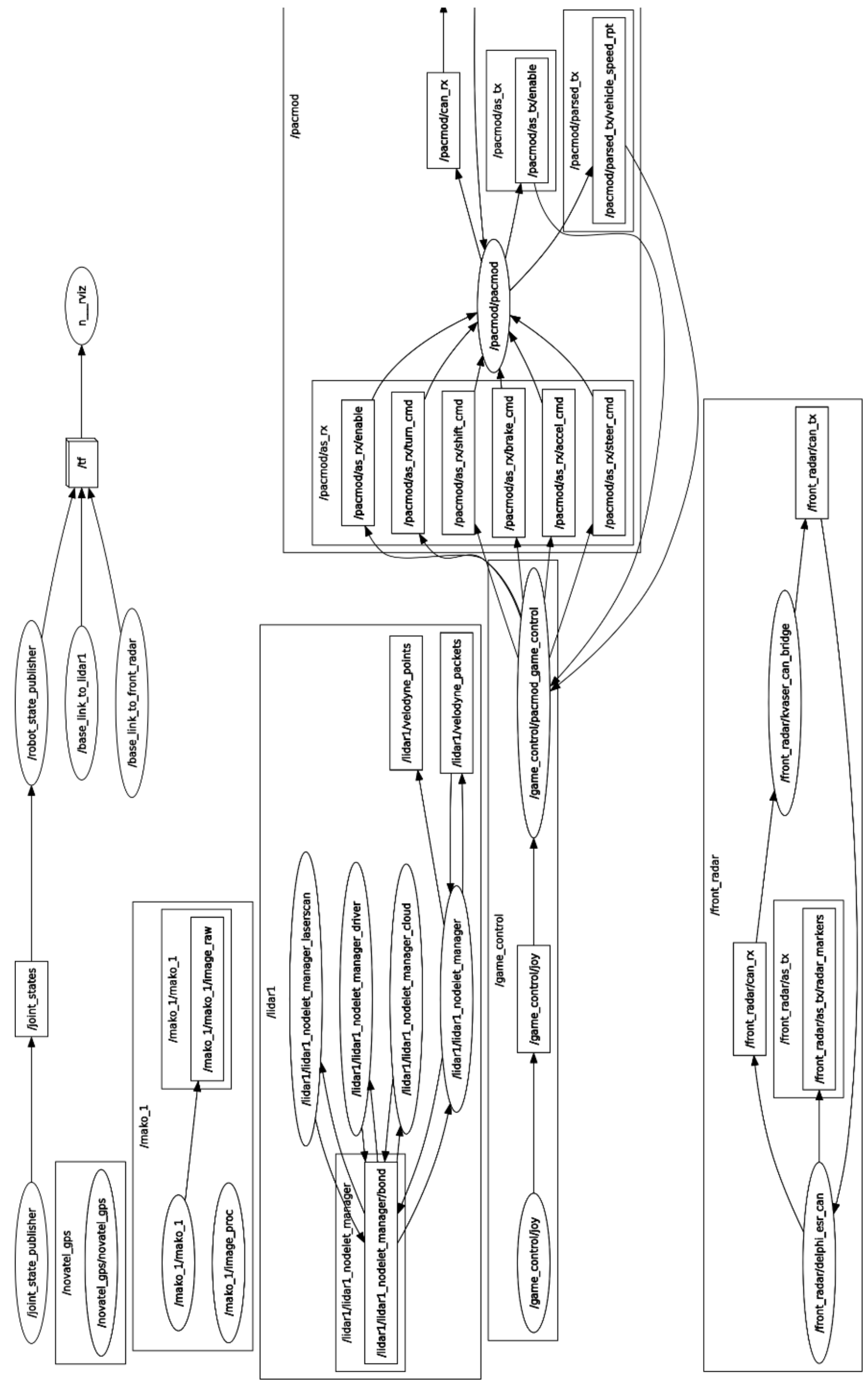
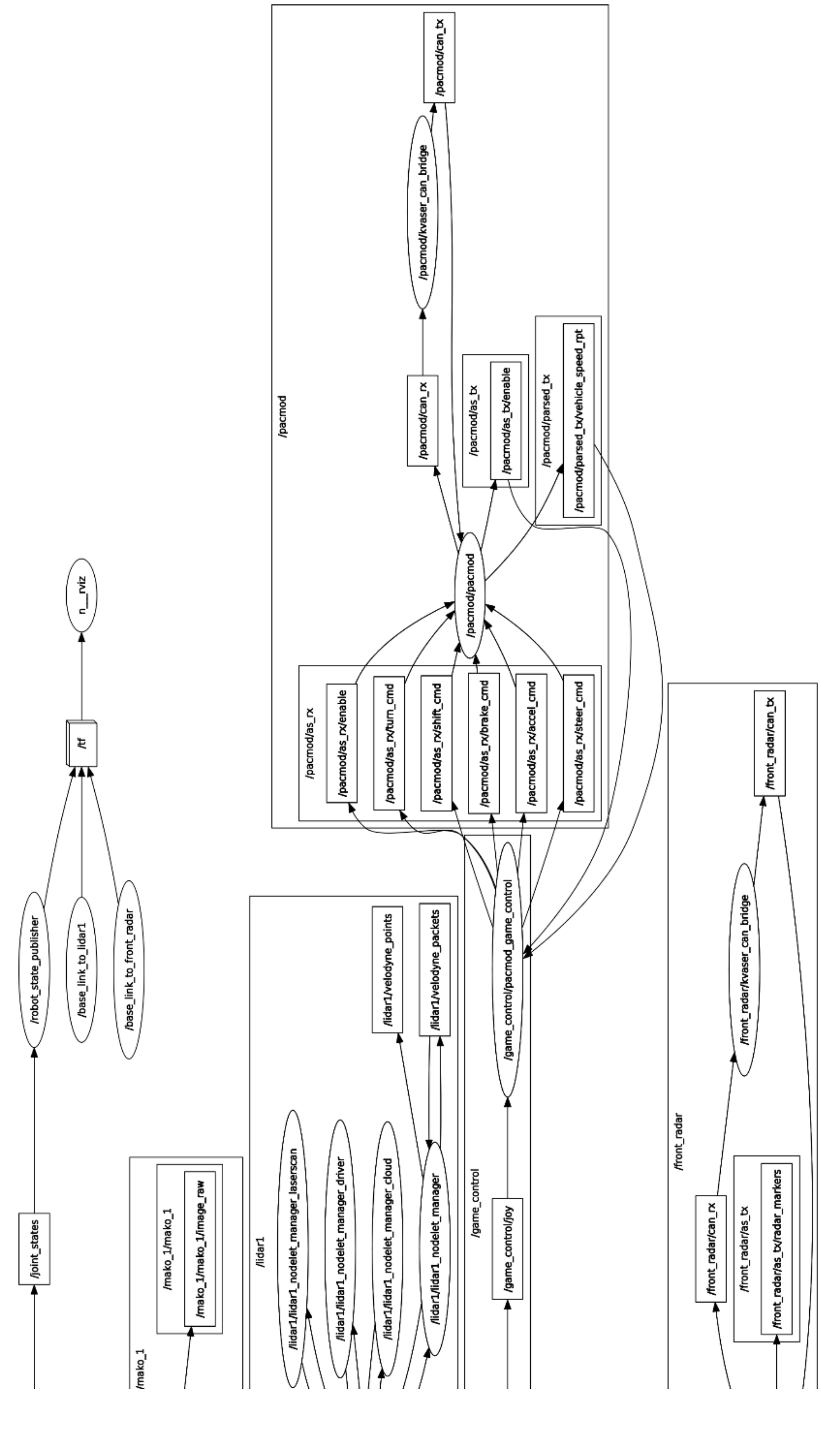
ROS rqt_graph

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2.7 Demo of Pure Pursuit Tracker on GNSS Waypoints

GitHub link: https://github.com/hangcui1201/POLARIS_GEM_e2_Real

Demo link: https://youtu.be/8l52buLR1zU

```
$ source devel/setup.bash
$ rosrun gem_gnss_control gem_gnss_tracker_pp.py
```

2.8 Demo of Stanley Tracker on GNSS-RTK Waypoints

GitHub link: https://github.com/hangcui1201/POLARIS_GEM_e2_Real

Demo link: https://youtu.be/DItwU_8GVHI

```
$ source devel/setup.bash
$ roslaunch basic_launch gem_pacmod_control.launch
```

```
$ source devel/setup.bash
$ rosrun gem_gnss_control gem_gnss_tracker_stanley_rtk.py
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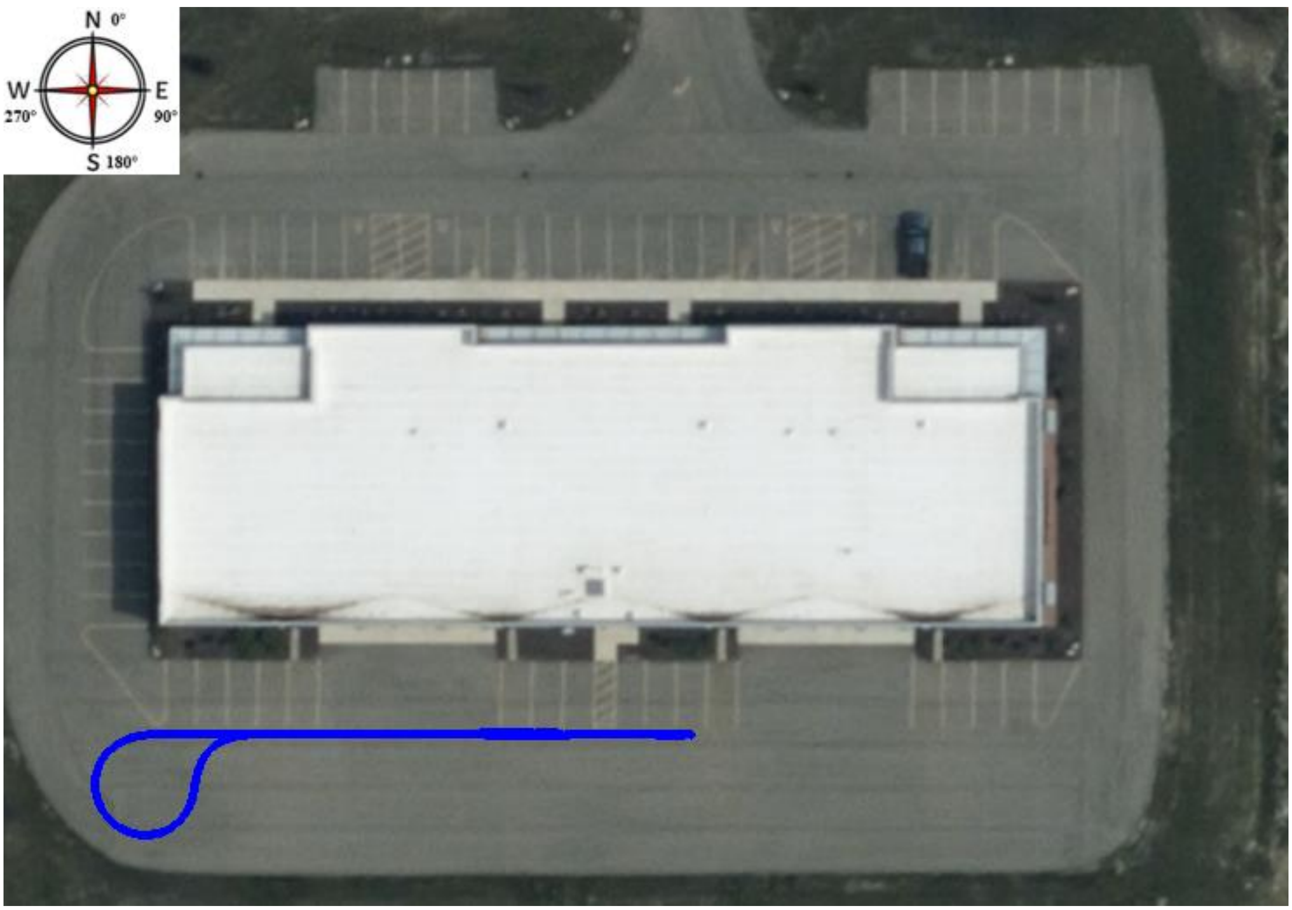


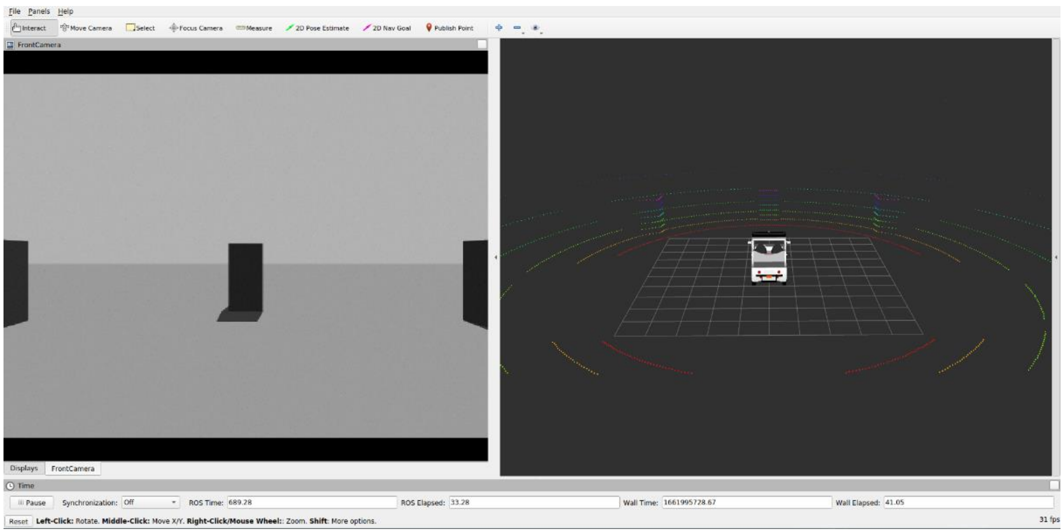
2.9 Coming more …

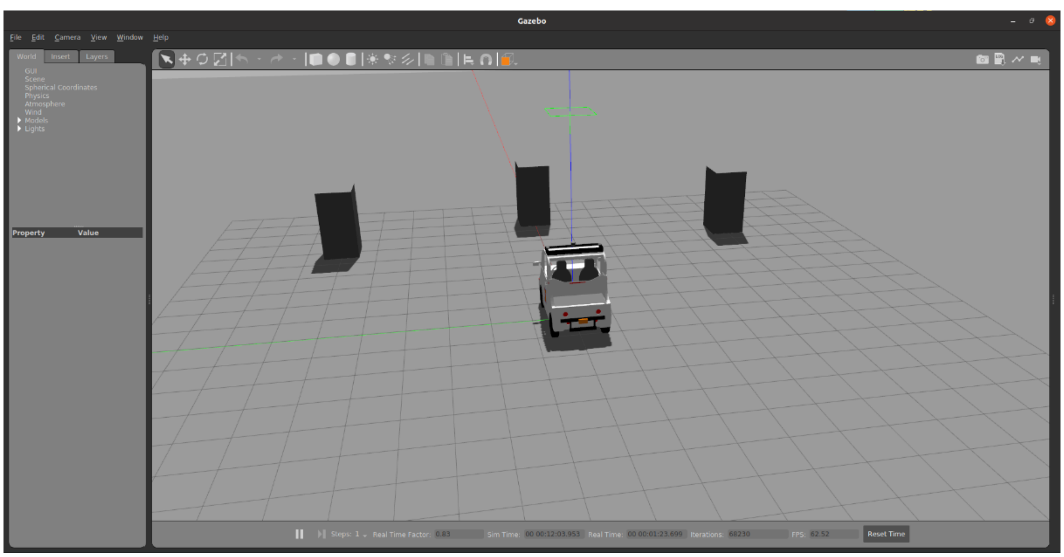
3. Polaris GEM e2 ROS - Simulator

3.1 Introduction

GitHub link: https://github.com/hangcui1201/POLARIS_GEM_e2_Simulator

GEM vehicle with top 3D LiDAR





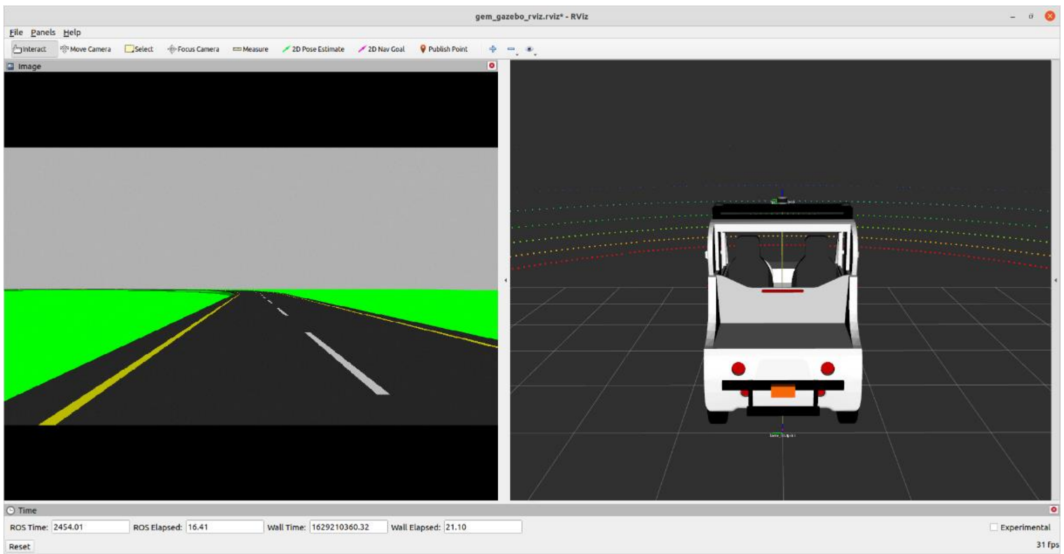
$ source devel/setup.bash
$ roslaunch gem_launch gem_init.launch

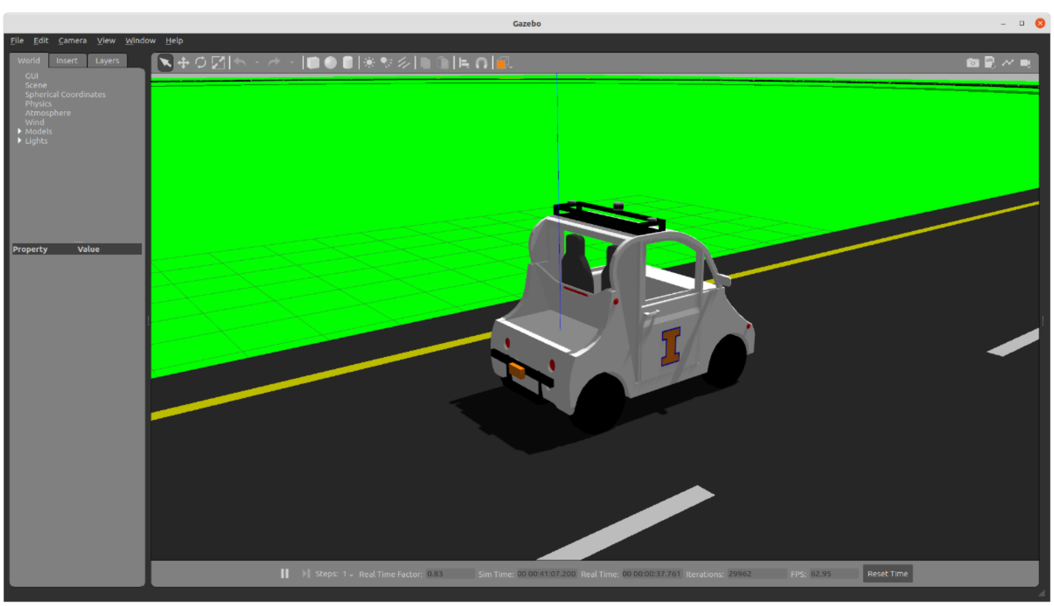
3.2 Launch the Simulator

Track1 Environment

```
$ cd ~/demo_ws
$ source devel/setup.bash
$ roslaunch gem_launch gem_init.launch world_name:="track1.world"
```

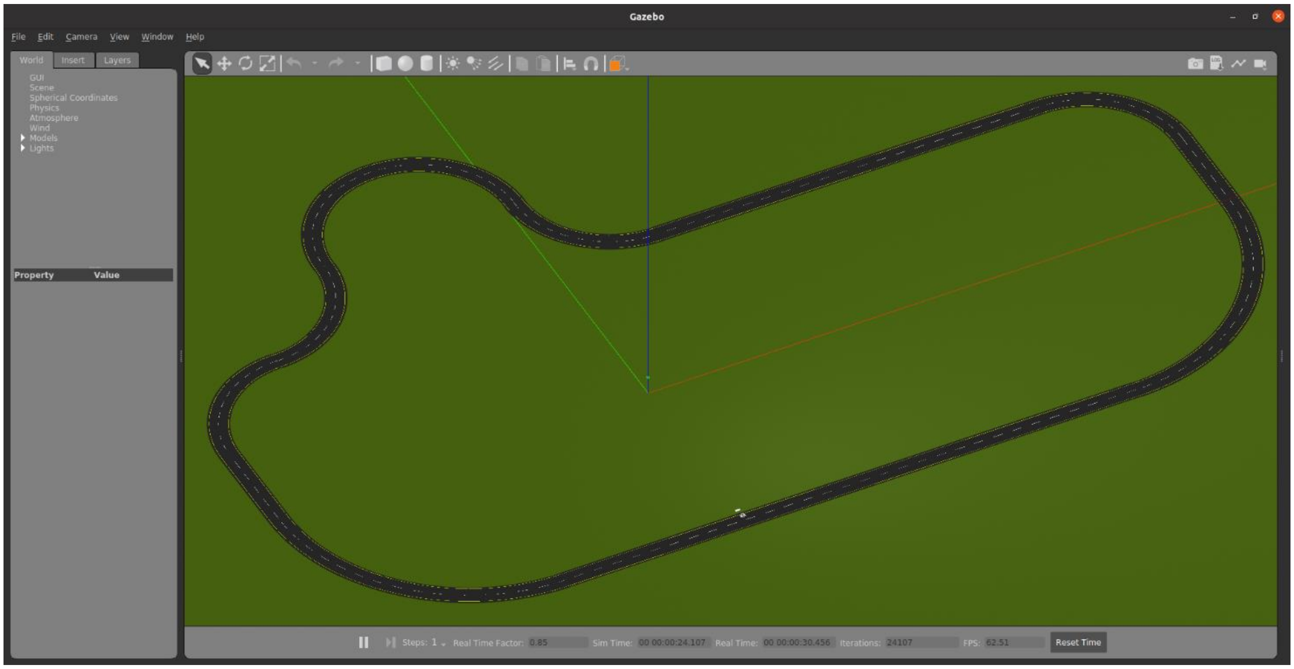
```
$ source devel/setup.bash
$ roslaunch gem_launch gem_sensor_info.launch
```





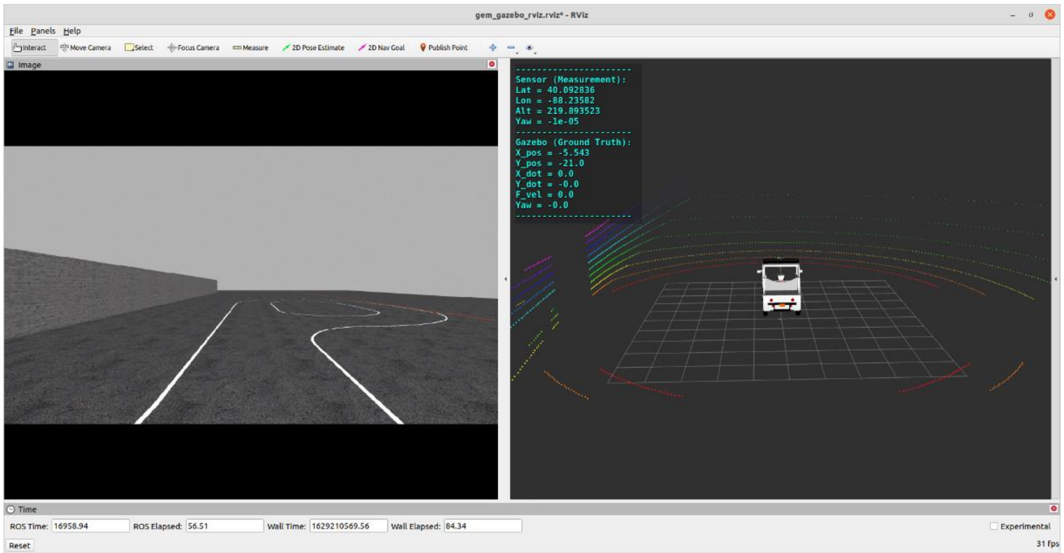
Track2 Environment

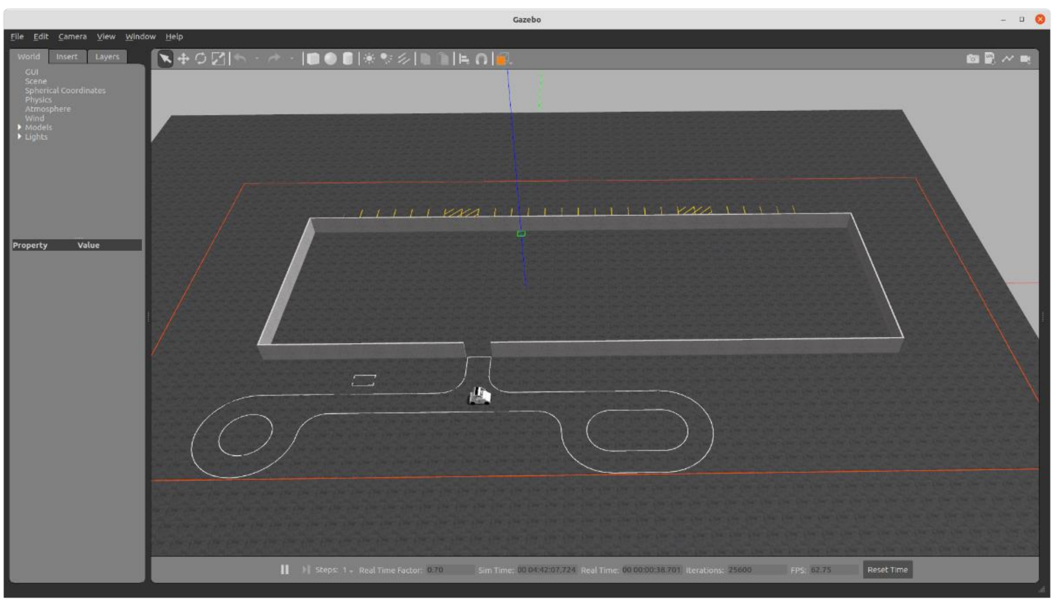
$ source devel/setup.bash
$ roslaunch gem_launch gem_init.launch world_name:="track2.world" y:=-98.5



Highbay Environment

$ source devel/setup.bash
$ roslaunch gem_launch gem_init.launch world_name:="highbay_track.world" x:=-1.5 y:=-21

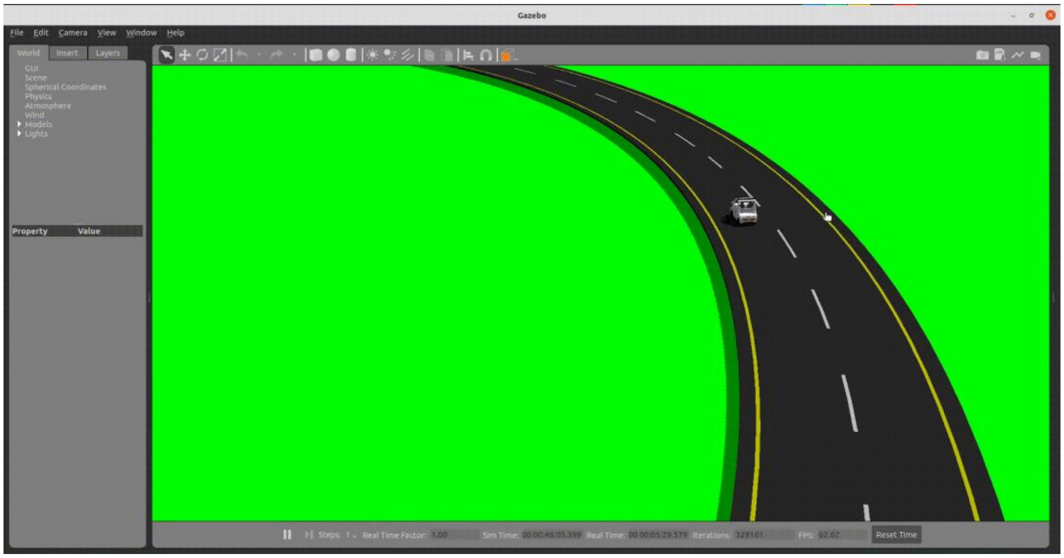




3.3 Demo of Pure Pursuit & Stanley Controllers

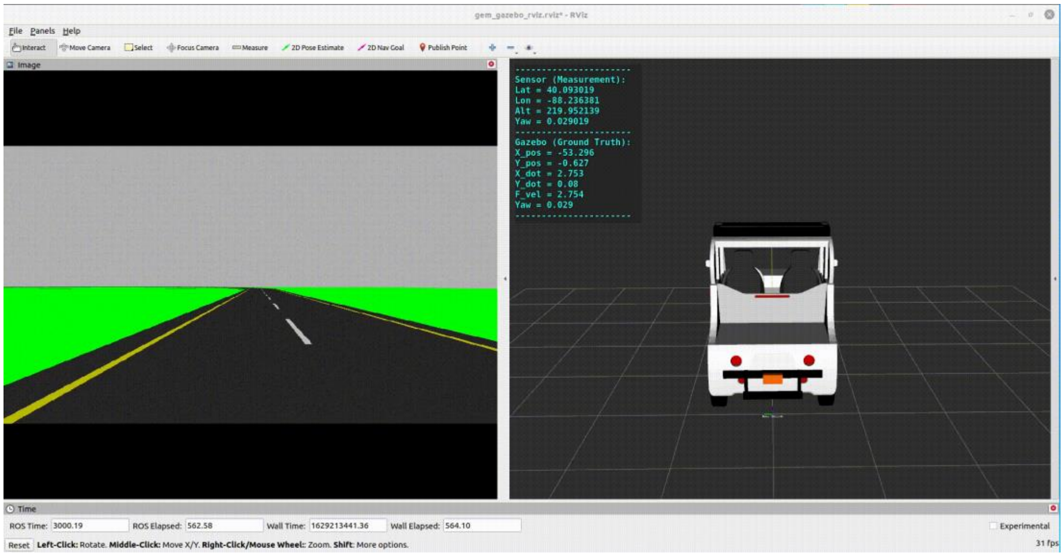
Demo of Pure Pursuit Controller in Track1 Environment

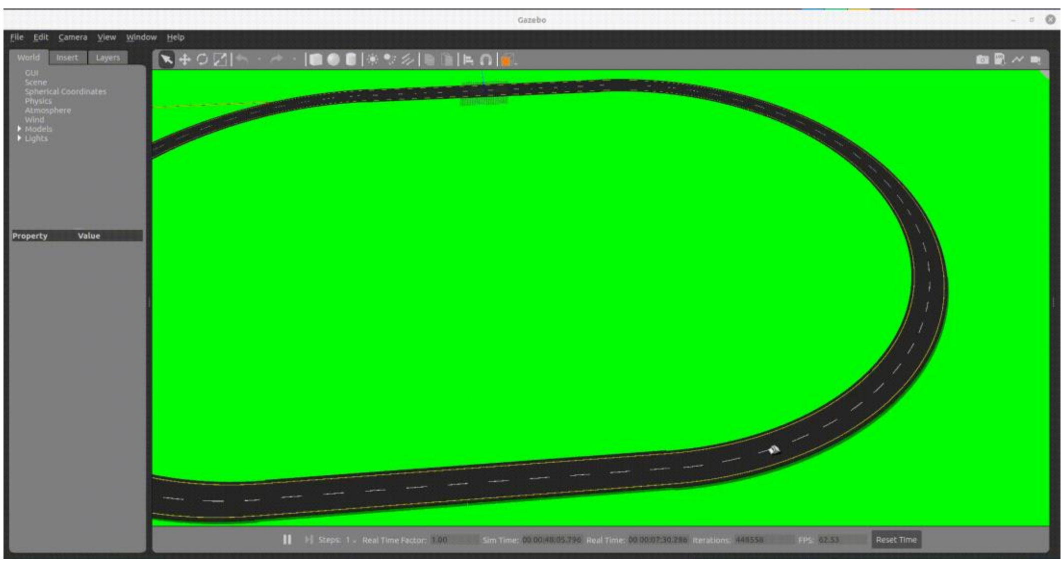
$ source devel/setup.bash
$ rosrun gem_pure_pursuit_sim pure_pursuit_sim.py



Demo of Stanley Controller in Track1 Environment

$ source devel/setup.bash
$ rosrun gem_stanley_sim stanley_sim.py





3.4 Coming more

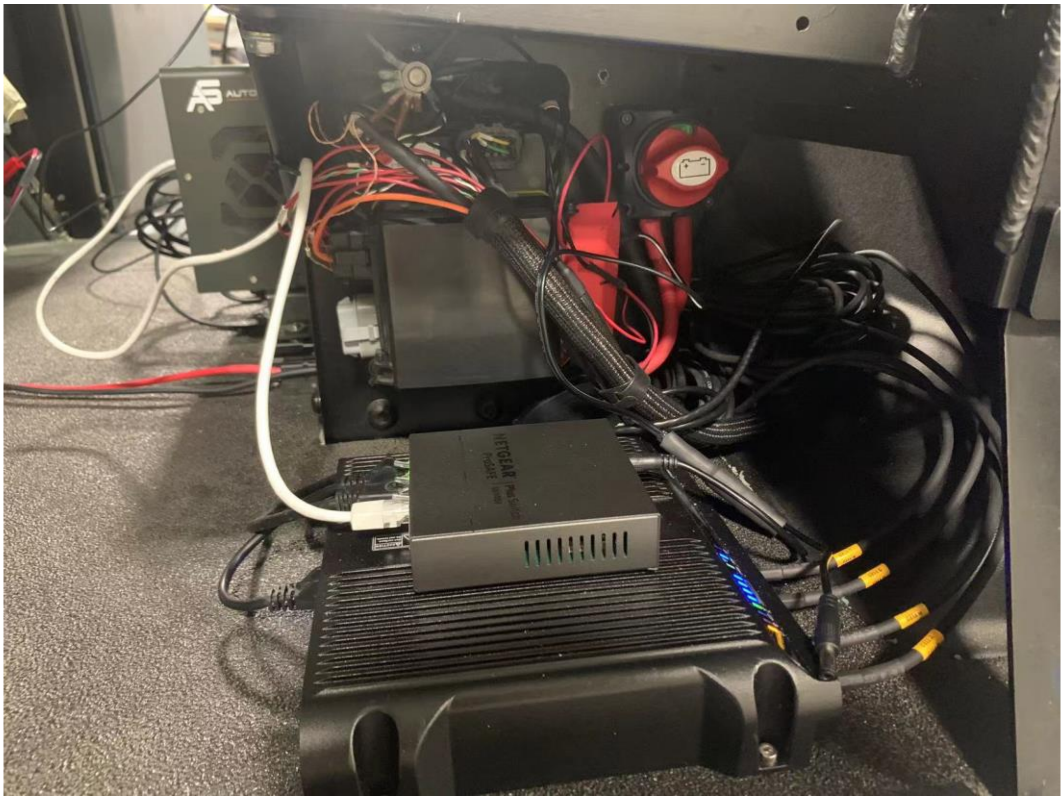
4. Polaris GEM e2 - Operation

4.1 Power of Computer & Vehicle

(1) Unplug the power cord of Polaris GEM e2

(2) Connect battery of computer on the passenger’s side and switch on

(3) Switch on the battery of sensors under the driver's seat



(4) Turn on vehicle by using the key, the computer should also be turned on automatically

(5) Remove the chokes and drive the vehicle outside

(6) When finishing using the Polaris GEM e2, do reverse steps from (5) to (1)

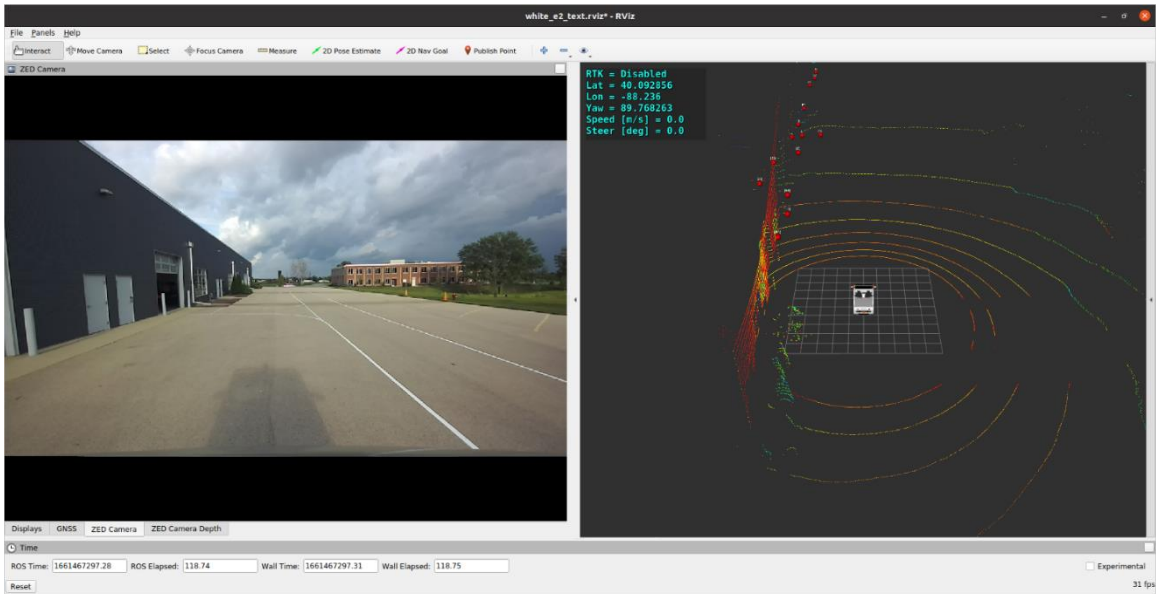
(7) The battery of the computer can be charged as below

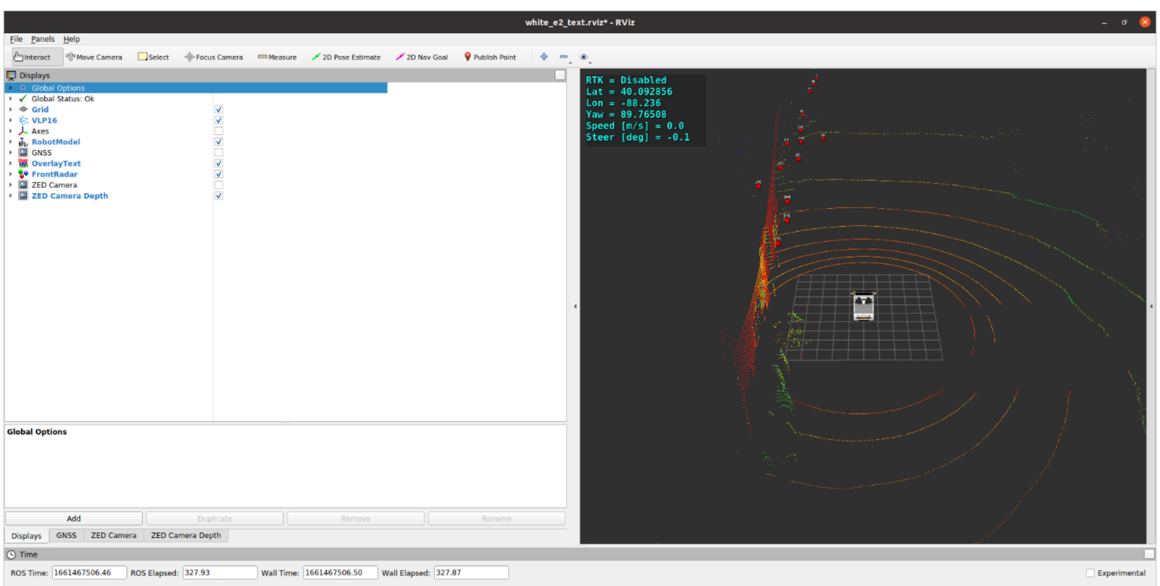
4.2 Launch of ROS Programs

$ cd ~/demo_ws/
$ catkin_make

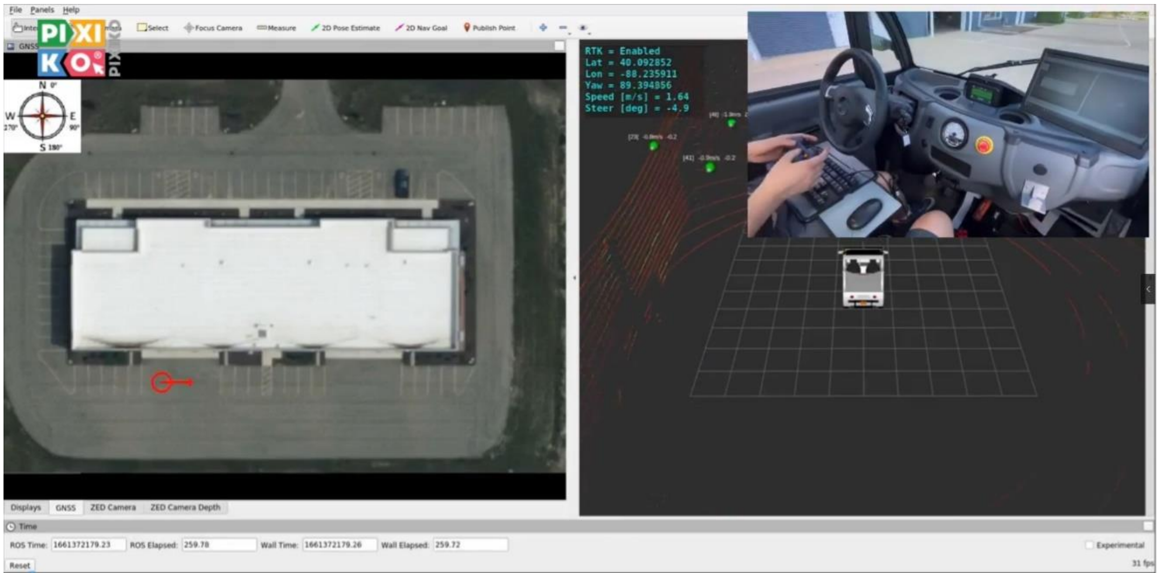
$ source devel/setup.bash
$ roslaunch basic_launch gem_sensor_init.launch

$ source devel/setup.bash
$ roslaunch basic_launch gem_dbw_joystick.launch

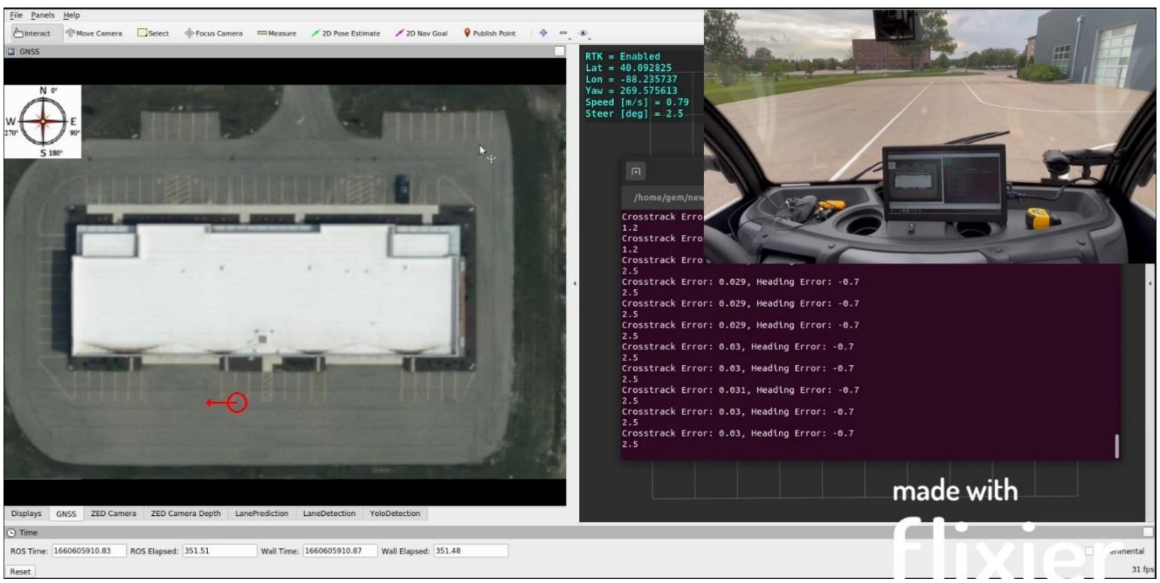




Section 2.7: Demo of Pure Pursuit Tracker on GNSS Waypoints



Section 2.8: Demo of Stanley Track on GNSS-RTK Waypoints



4.3 Coming more …