Auto-Knight

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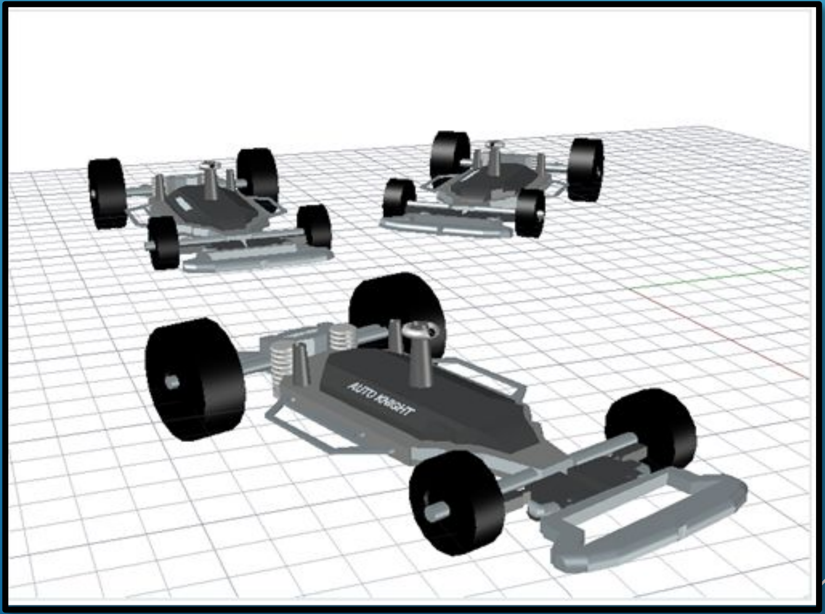
University of Central Florida
Dept. of Electrical and Computer Engineering
Senior Design 2018



Sponsor:
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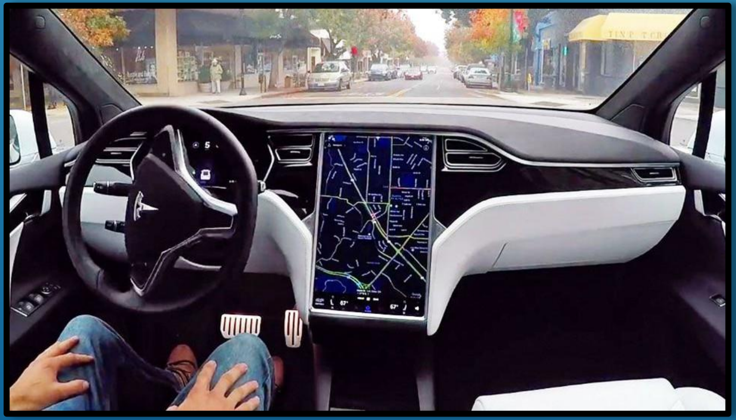
Behrad Toghi

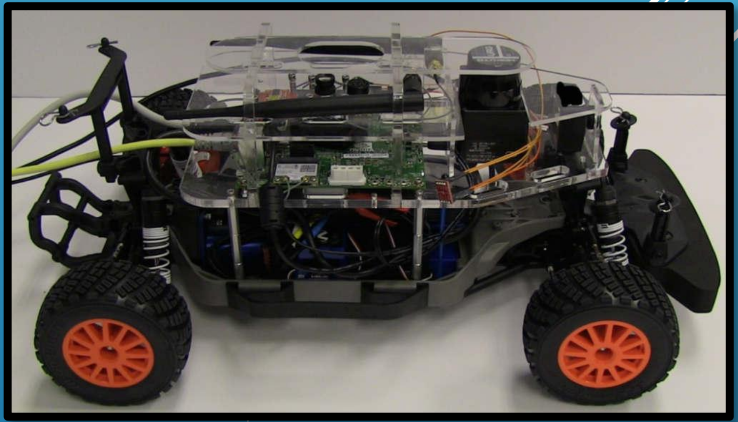
Project Motivation

- 37,000 People die in car accidents within the United States alone
- Road crashes are the leading cause of death in people ages 15-29
- Globally, cost of damages due to Automotive crashes is roughly $518 billion
- The Autonomous vehicle industry is projected to reach a value of $800 billion
  By the year 2050



Left:
Tesla
Self-Driving
Vehicle

Right:
M.I.T.
Small-Scale
Autonomous
Vehicle



Project Description & Goals

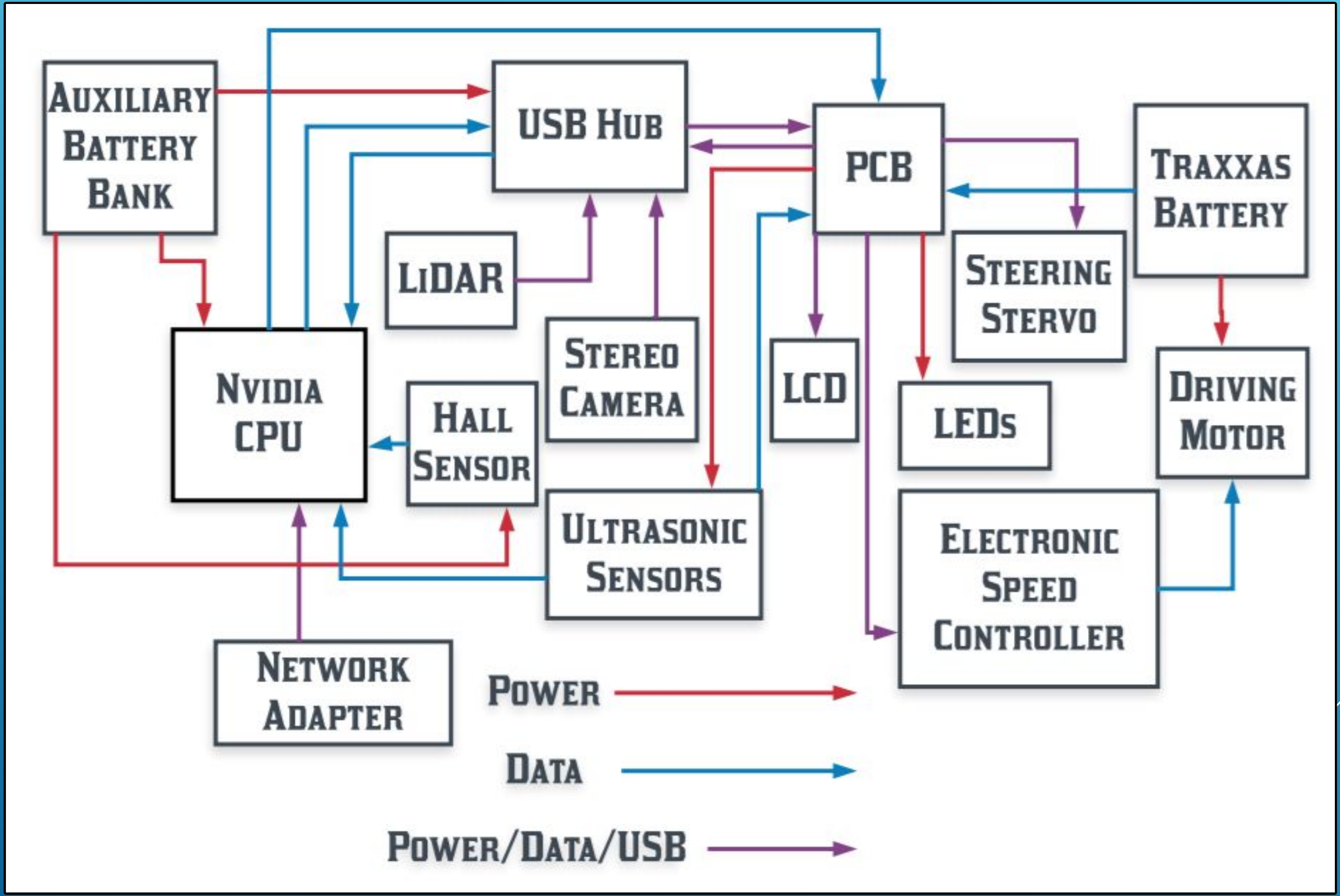
- Create a small scale autonomous vehicle that can be used to gather data for used UCF’s Networked Systems Lab for research

- Using a variety of sensors and computer vision technology to create a car that can be situationally aware and accurately maneuver its environment

Requirements & SPECIFICATIONS

Component	***Specification***
Vehicle Speed	>= 24 km/h
Battery Lifetime	>= 15 min
Camera Range	>= 10 m
2 Control Modes	Manual and autonomous function
Emergency Collision Avoidance	If main processor/localization crashes, the vehicle should be able to continue moving and avoiding direct collisions
Control Distance	>=10 m

Hardware Diagram



Parts Selection: RC CAR

Sunfire Pro

Traxxas Rally Racer

Iron Track E8XBL

Traxxas Slash Platinum

Parts Selection: RC CAR

Sunfire Pro

Traxxas Rally Racer

Iron Track E8XBL

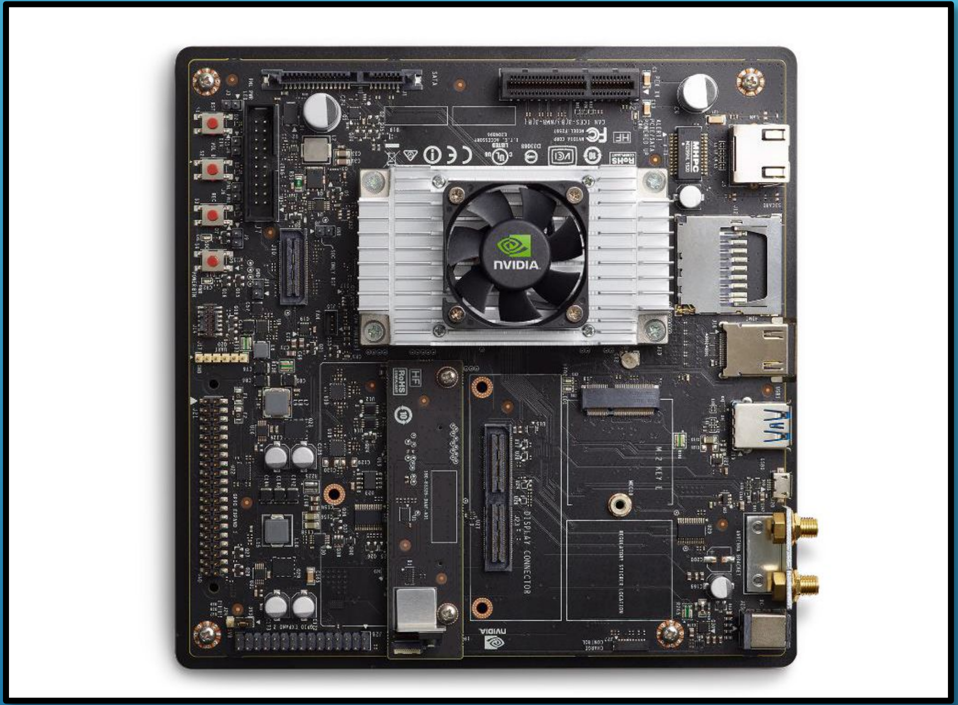
Traxxas Slash Platinum

RC CAR SPECIFICATION COMPARISON

Specification	Sunfire Pro	Iron Track E8XBL	Traxxas Rally Racer	Traxxas Slash Platinum
Scale	1/10	1/8	1/10	1/10
Cost	$192	$245	$300	$429
Motor	Brushless 3300KV	2075KV	Brushless 3500KV	Brushless 3500KV
Suspension	Aluminum Shocks	Independent and Adjustable	Adjustable Oil-filled	Aluminum Shocks
Differential	Metal Gears	Gear Ratio: 11.3	Hardened Steel Bevel, LSD	Hardened Steel Bevel, LSD
Chassis	Not Specified	Plastic Nylon	Nylon Composite	Nylon Composite
Battery	3000mAh	3 Cell Li-Po	7-cell NiMH	Optional
Drive	4 Wheel Drive	4 Wheel Drive	4 Wheel Drive	4 Wheel Drive

Parts Selection: CPU

NVIDIA Jetson TX2



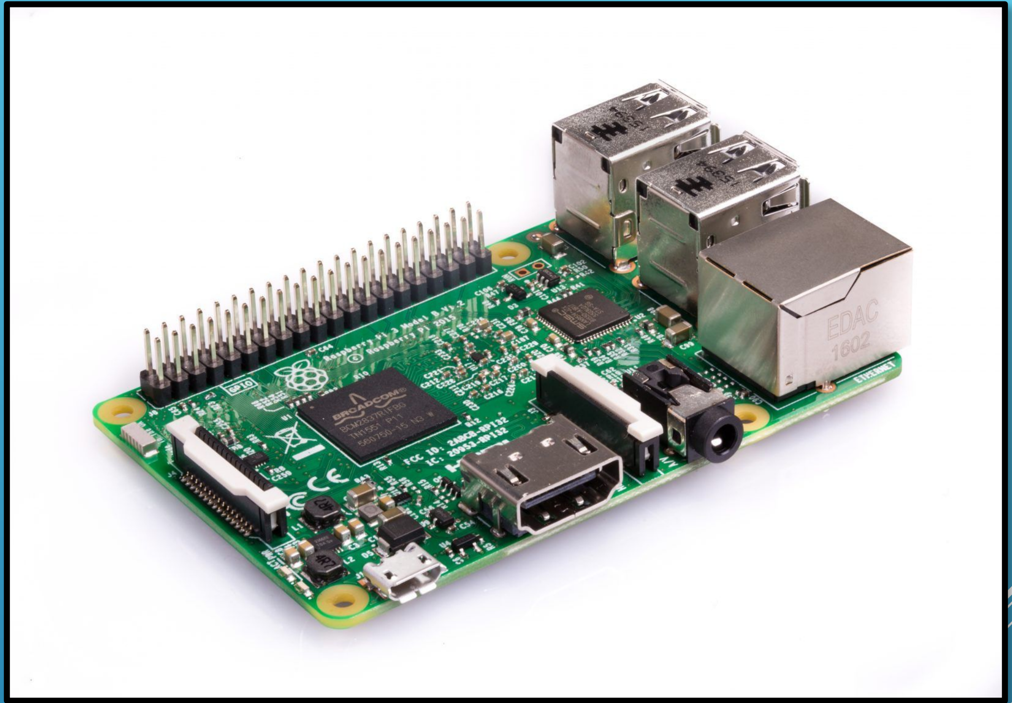
Drawbacks:

- Expensive
- Little Documentation

Advantages:

- Exceptional Image Processing ability

Raspberry Pi



Drawbacks:

- Not Sufficient for image processing

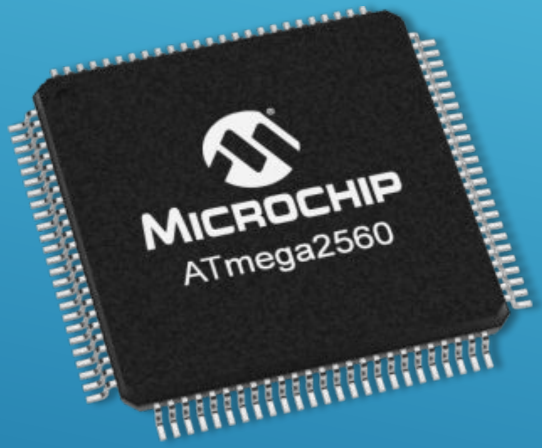
Advantages:

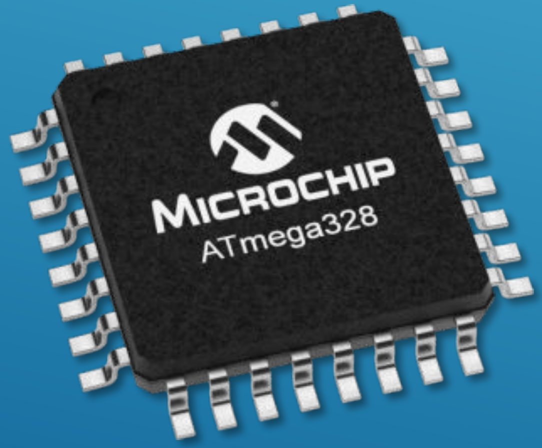
- Online Community
- Affordable

NVIDIA CPU COMPARISON

Specification	***NVIDIA Jetson TX2***	***NVIDIA Jetson TX1***
CPU	Quad ARM A57 and a HMP Dual Denver	Quad ARM A57
Video Processing	Encoding: HEVC 4K x 2K at 60Hz Decoding: 4K x 2K at 60Hz with 12-bit Support	Encoding: HEVC 4K x 2K at 30Hz Decoding: 4K x 2K at 60Hz with 10-bit Support
Memory	8 GB / 128-Bit / 59.7 GB per sec	4 GB / 64-Bit / 25.6 GB per sec
Display	2x DSI, 2x DP 1.2 / HDMI 2.0 / eDP 1.4	2x DSI, 1x eDP 1.4 / DP 1.2 / HDMI
Camera Serial Interface	6 Cameras in 2 Lanes 2.5 Gbps per Lane	6 Cameras in 2 Lanes 1.5 Gbps per Lane
Data Storage	32 GB	16GB
Serial Communication	CAN, UART, SPI, I2C, I2S, GPIOs	UART, SPI, I2C, I2S, GPIOs

Parts Selection: MICROCONTROLLER





Controllers Researched:

- Arduino
- Texas Instruments

Texas Instruments Drawbacks:

- 3.3V Operating Voltage
- Less extensive resources

ARDUINO MCU COMPARISON

Specification	Uno R3	101	Due	Mega 2560
RAM	2 KB	24 KB	96 KB	8 KB
Memory	32 KB	196 KB	512 KB	256 KB
Power	1.8-5V	3.3V	3.3V	5V
Serial Communication	UART,SPI,& I2C	UART,SPI, & I2C	UART,SPI & I2C	(4)UART,SPI & I2C
I/O Pins	Digital: 14 Analog: 6 PWM: 6	Digital: 14 Analog: 6 PWM: 4	Digital: 54 Analog: 12 PWM: 12	Digital: 54 Analog: 16 PWM: 15
Size	68.6mm x 53.4mm	68.6mm x 53.4mm	101.52mm x 53.3mm	101.5mm x 53.3mm
Weight	25 g	45 g	36 g	37 g
Cost	$22	$30	$37	$40

PARTS SELECTION: STEREO CAMERA

Sense 3D Sensor

Stereolabs ZED Camera

Specification	Sense 3D Sensor	Stereolabs ZED Camera
Resolution	1344x376 megapixels (max)	640x480 megapixels
Range	20 meters	3.5 meters
Frame Rate	100 fps	30/60 fps
Field of Vision	110 degrees Horizontal and vertical	58 degrees horizontal 45 degrees vertical
Illumination Method	Visible light	Visible light and Infared
Power	5 VDC	5 VDC
Hardware Requirements	Windows, Linux, ROS	Windows, IOS, Linux, Android Operating Systems
Cost	$449	$449

PARTS SELECTION: LIDAR

RPLiDAR A1M8

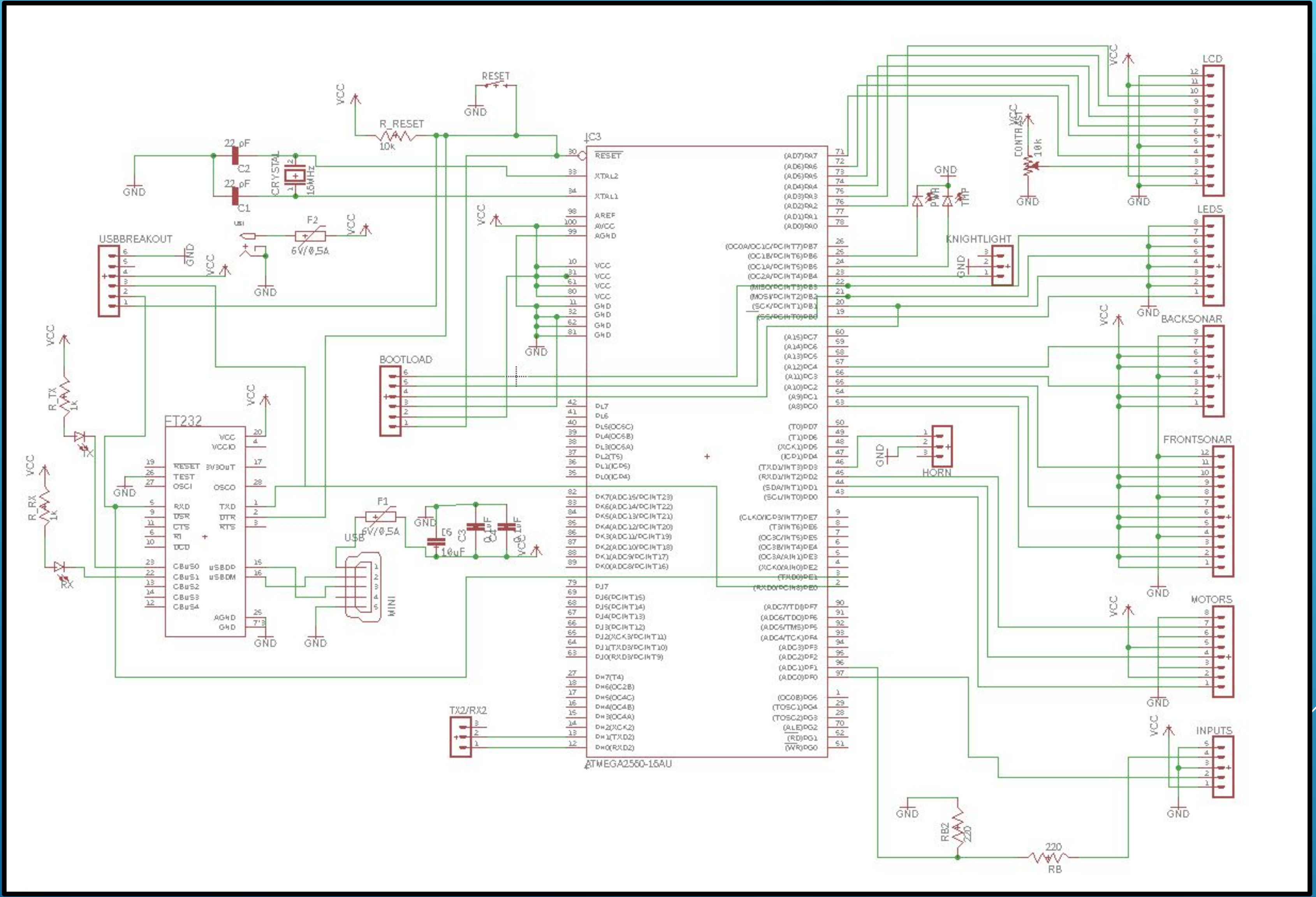
Scanse Sweep SEN 14117

Specification	RPLiDAR A1M8	Scanse Sweep SEN 14117
Resolution	0.019 inches	0.4 inches
Range	6 meters	40 meters
Field of Vision	360 degrees horizontal	360 degrees horizontal
Rotation Frequency	Up to 10 Hz	Up to 1075 Hz
Power	4.9-5.5 VDC	5 VDC
Hardware Requirements	Intel core i5 or equivalent	Windows, IOS, Linux, Android Operating Systems
Cost	$199	$349

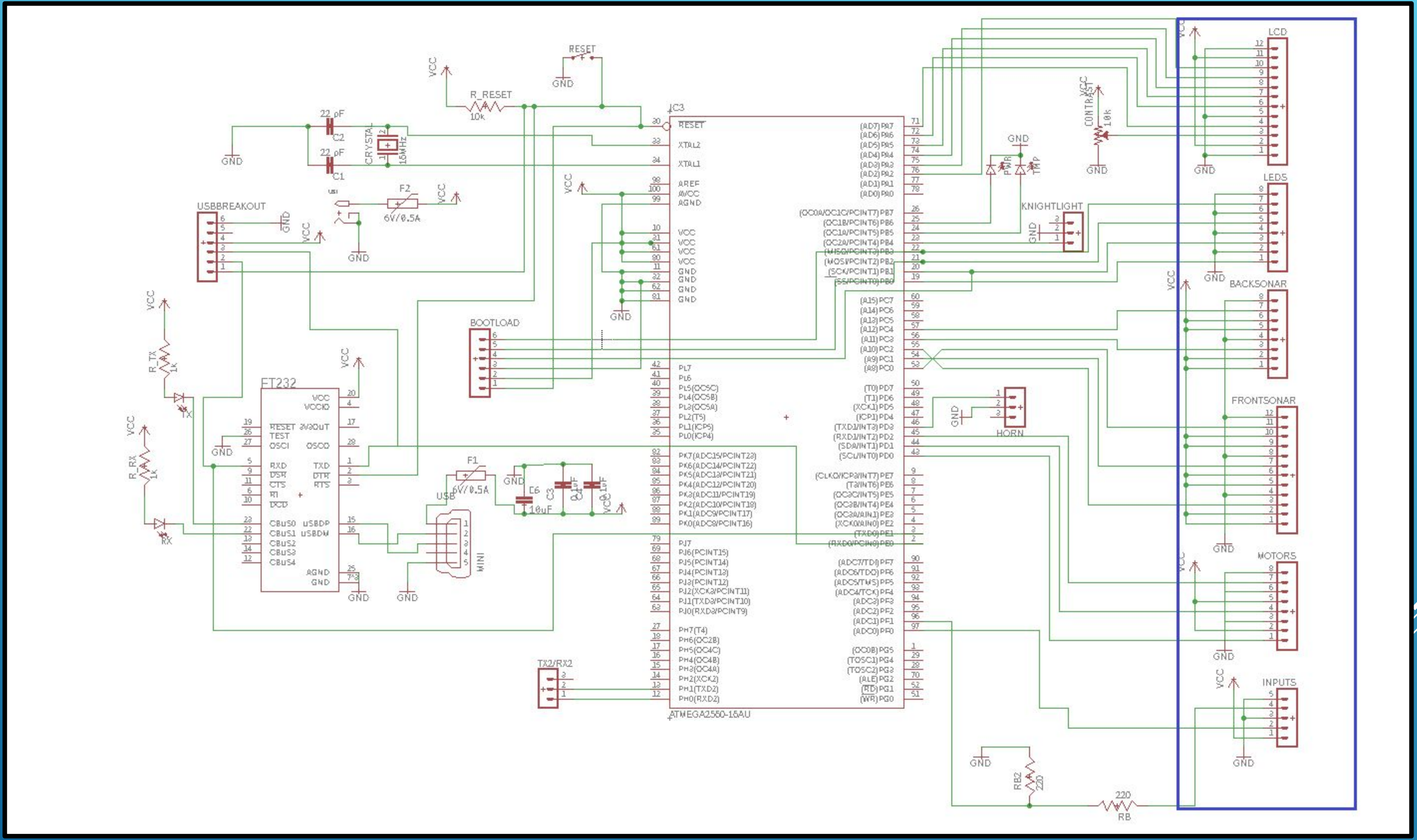
Parts Selection: SENSORS AND OTHER ITEMS

- ***Ultrasonic Sensor***
  - SparkFun Ultrasonic Sensor Pack
- ***Inertial Measurement Unit***
  - SparkFun 9DoF Breakout IMU
- ***Temperature Sensor***
  - TMP36
- ***Hall Sensor***
  - *Traxxas RPM Telemetry Sensor*
- ***Auxiliary Battery***
  - MAXOAK 50,000mAH
- **Powered USB Hub**
  - Aukey Powered USB hub
- ***Wireless Router***
  - TP-Link TL-WR940N
- ***USB Network Adapters***
  - TP-Link N-300 Adapter

PCB Design


LCD
LEDS
KNIGHTLIGHT
BACKSONAR
FRONTSONAR
MOTORS
INPUTS
HORN
RESET
R_RESET
USBBREAKOUT
BOOTLOAD
FT232
TX2/RX2
ATMEGA2560-16AU
CRYSTAL
16MHz
GND
VCC

PCB Design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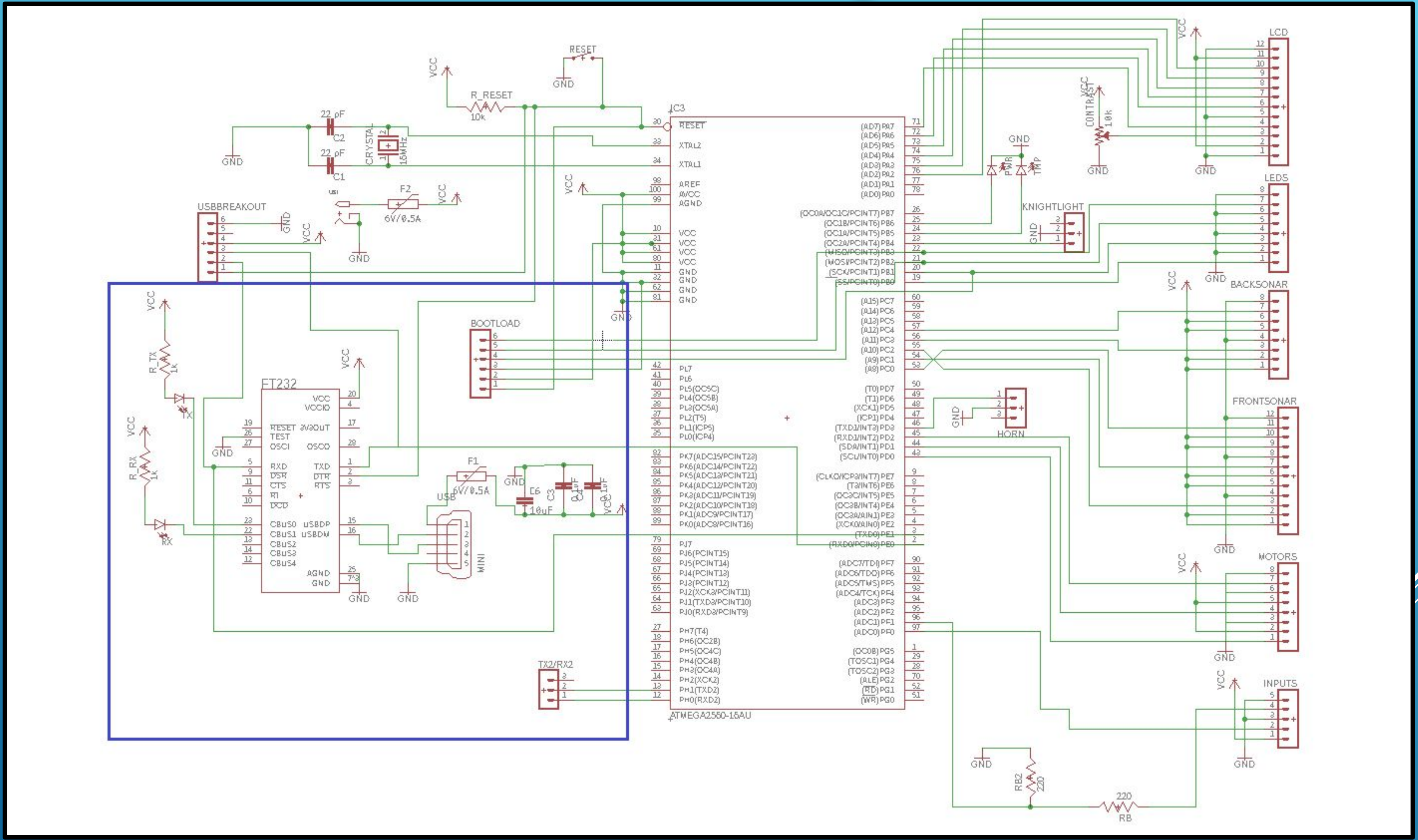
BOOTLOAD
USBBREAKOUT
FT232
RESET
R_RESET
CRYSTAL
16MHz
USB
MINI
TX2/RX2
ATMEGA2560-16AU
CONTRAST
VCC
GND

PERIPHERAL HEADER PINS

- 1 Ultrasonic Sensor
- Temperature Sensor and Fan
- LCD Display
- LED Headlights and Taillights
- Motor Control
- Traxxas Battery Monitoring
- Additional Pins for Integration of Other Sensors

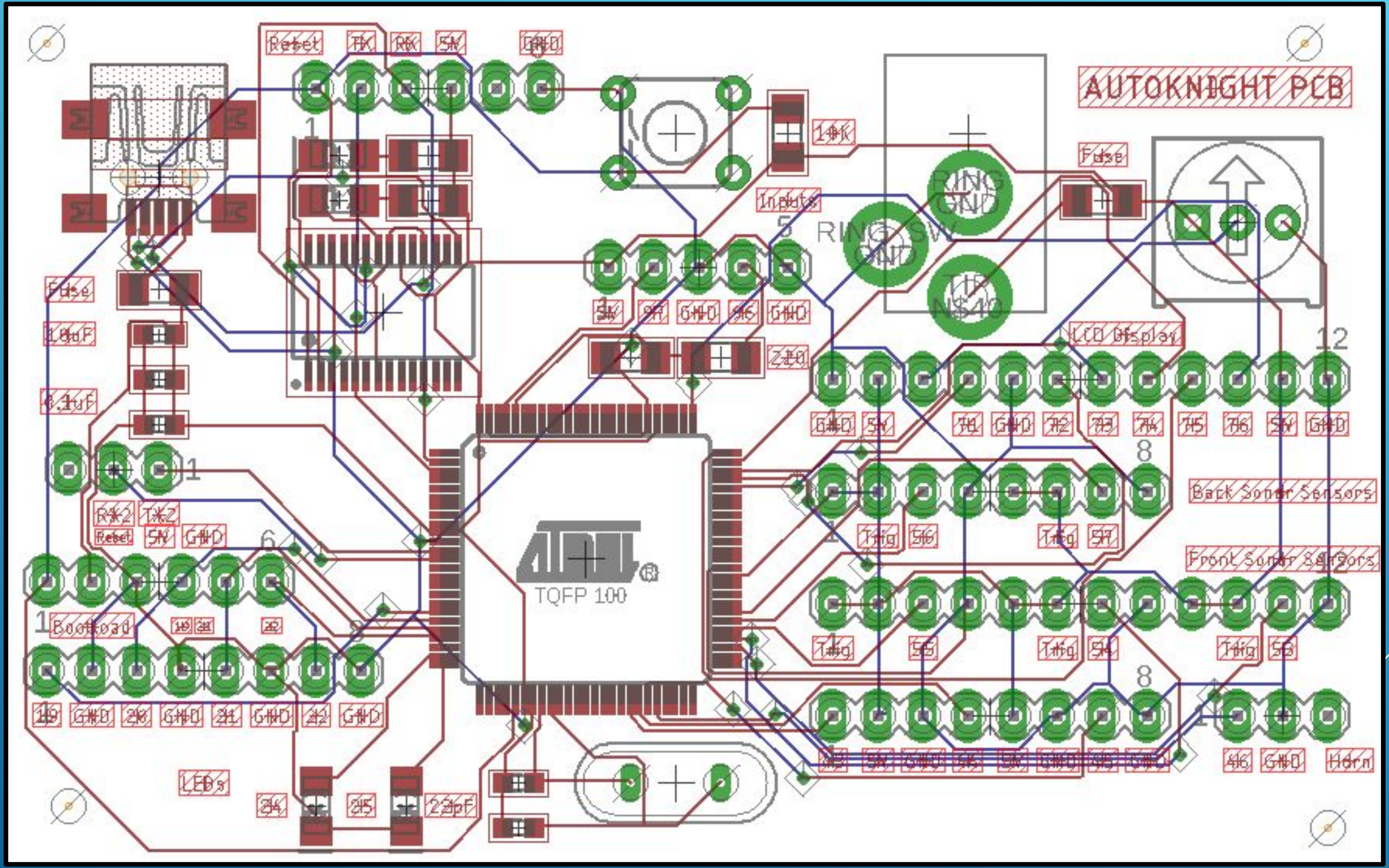
PCB Design

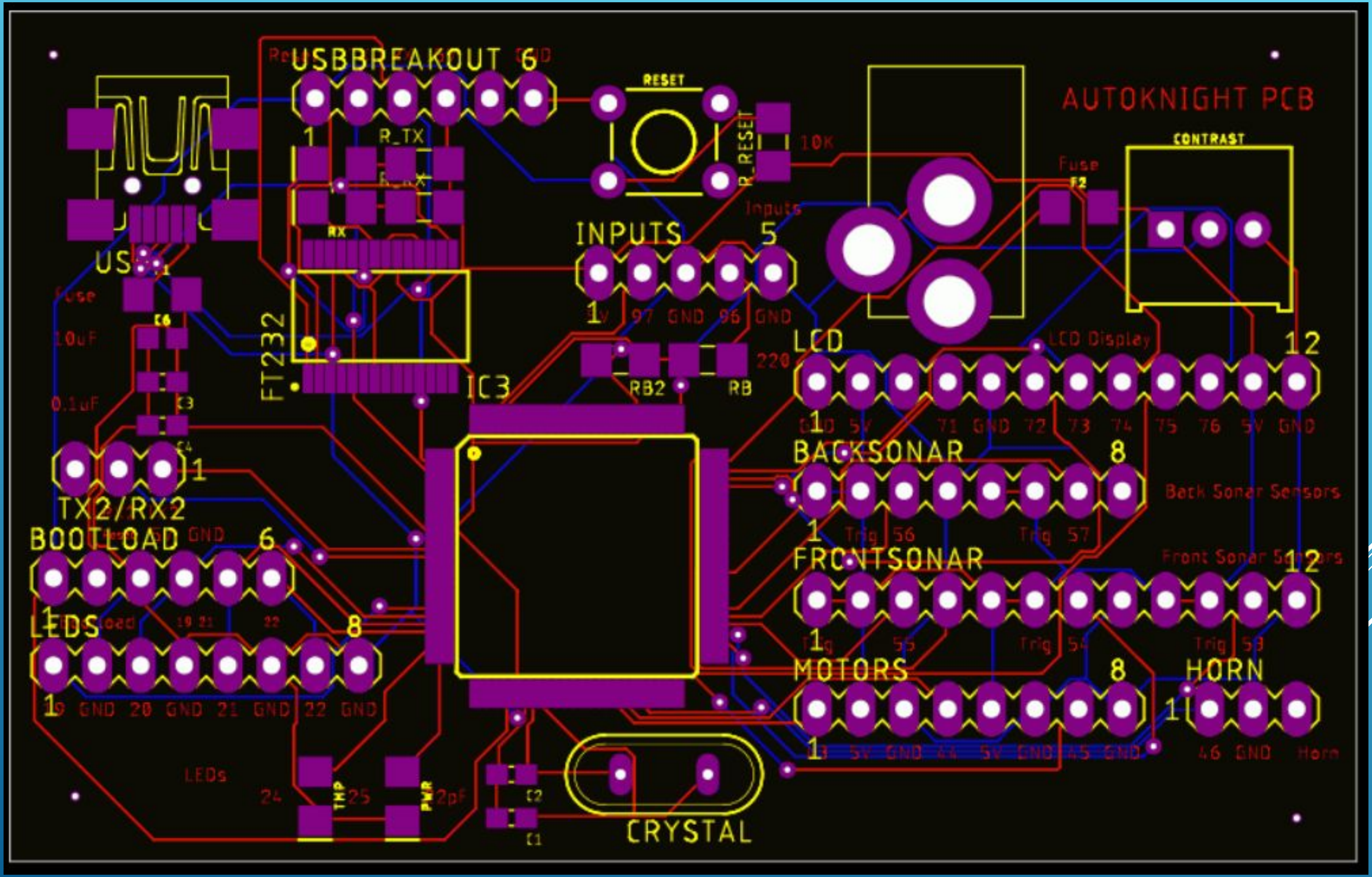


PROGRAMMING

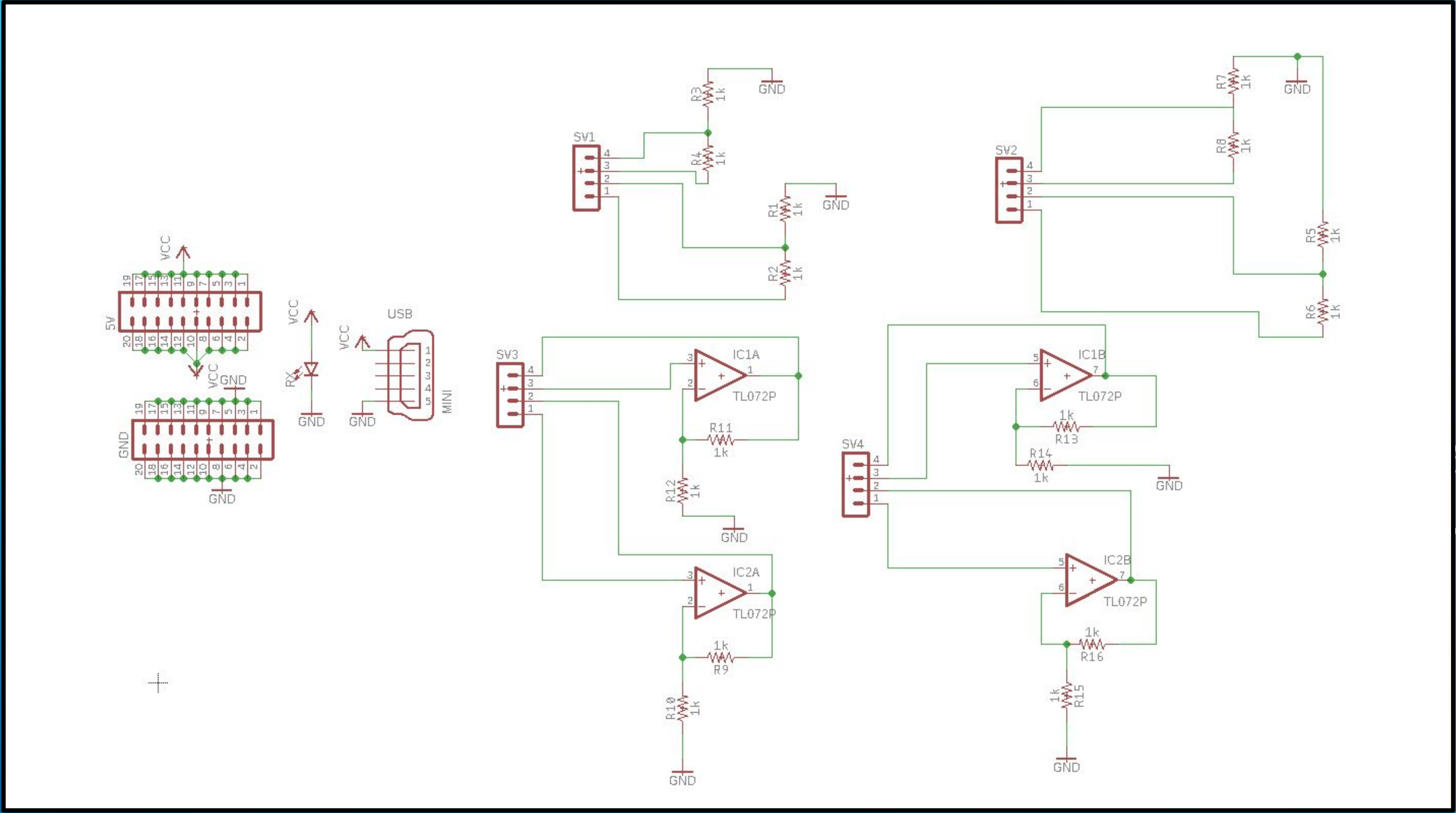
- USB to UART for data transmission with Jetson
- Mini USB Connector
- Bootloader Header
- Addition Header for backup USB Breakout
- Spare TX and TX Pins for dedicated Ultrasonic Alerts

PCB Design


AUTOKNIGHT PCB
TQFP 100
LCD Display
Back Sonar Sensors
Front Sonar Sensors
RING GND
RING SW
TIP
Fuse
Inputs
LEDs
Bootload
22pF

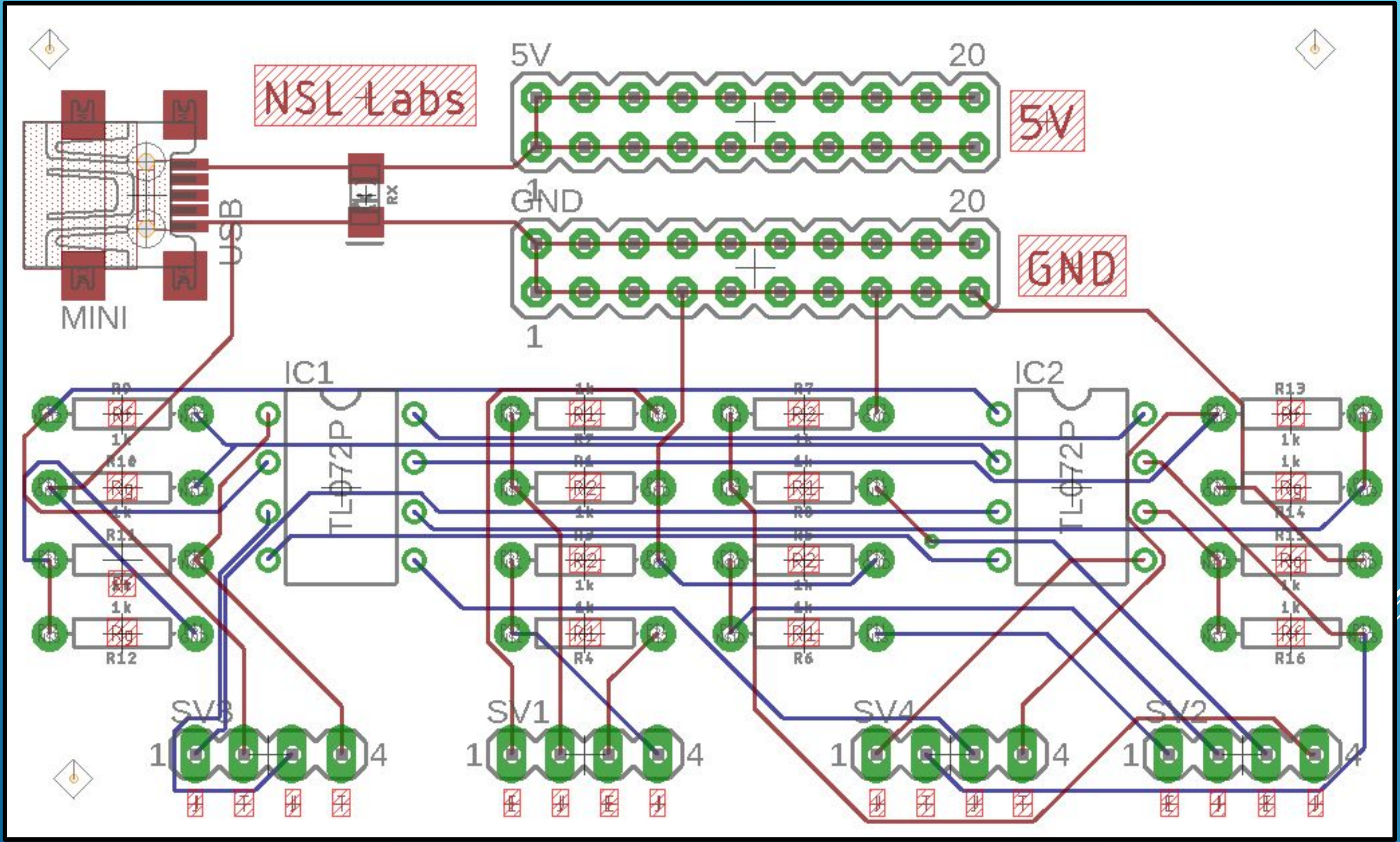

AUTOKNIGHT PCB
USBBREAKOUT
RESET
R_RESET
10K
CONTRAST
Fuse
F2
R_TX
RX
INPUTS
1
5
1v
97
GND
96
GND
FT232
IC3
RB2
RB
220
LCD
LCD Display
12
GND
5V
71
GND
72
73
74
75
76
5V
GND
BACKSONAR
8
Back Sonar Sensors
Trig
56
Trig
57
FRONTSONAR
Front Sonar Sensors
Trig
55
Trig
54
Trig
53
MOTORS
HORN
43
5V
GND
44
5V
GND
45
GND
46
GND
Horn
TX2/RX2
BOOTLOAD
6
GND
LEDS
19
GND
20
GND
21
GND
22
GND
LEDs
24
25
TMP
PWR
22pF
C2
C1
CRYSTAL
10uF
0.1uF
C3
C4
C6
USB

PCB Design

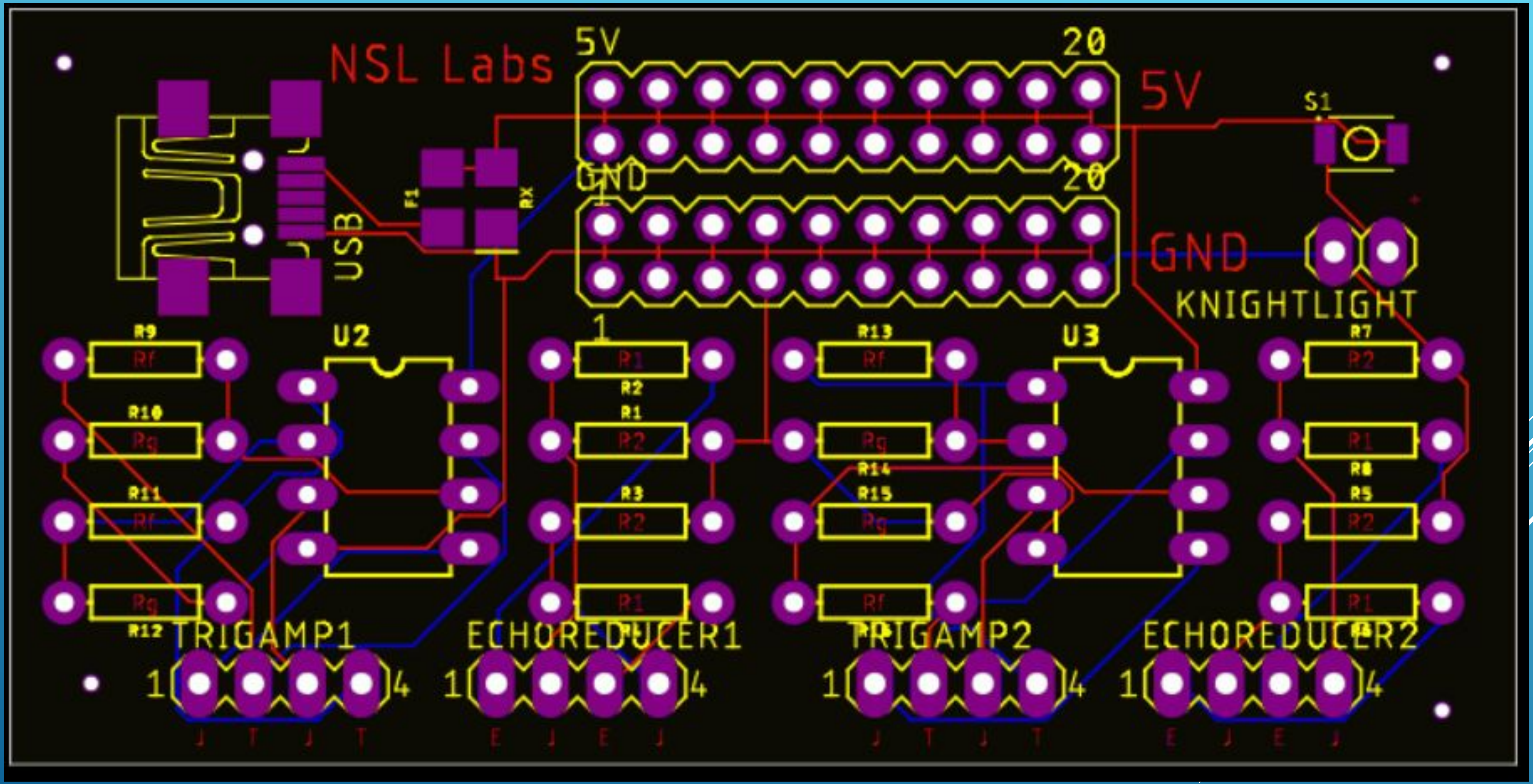


SV1
SV2
SV3
SV4
R1 1k
R2 1k
R3 1k
R4 1k
R5 1k
R6 1k
R7 1k
R8 1k
R9 1k
R10 1k
R11 1k
R12 1k
R13 1k
R14 1k
R15 1k
R16 1k
IC1A TL072P
IC1B TL072P
IC2A TL072P
IC2B TL072P
GND
VCC
5V
RX
USB
MINI

PCB Design

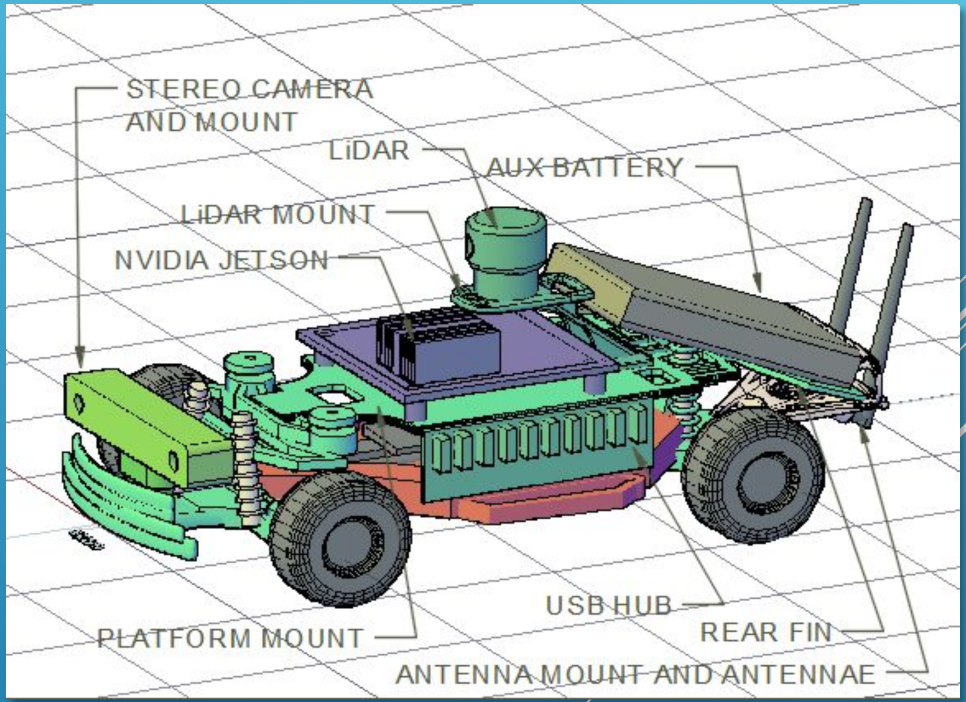


NSL Labs
5V
20
5V
GND
20
GND
USB
MINI
1
IC1
IC2
TL072P
TL072P
SV3
SV1
SV4
SV2


NSL Labs
5V
20
GND
USB
S1
KNIGHTLIGHT
U2
U3
TRIGAMP1
ECHOREDUCER1
TRIGAMP2
ECHOREDUCER2

STRUCTURE DESIGN & 3D PRINTED MODELS

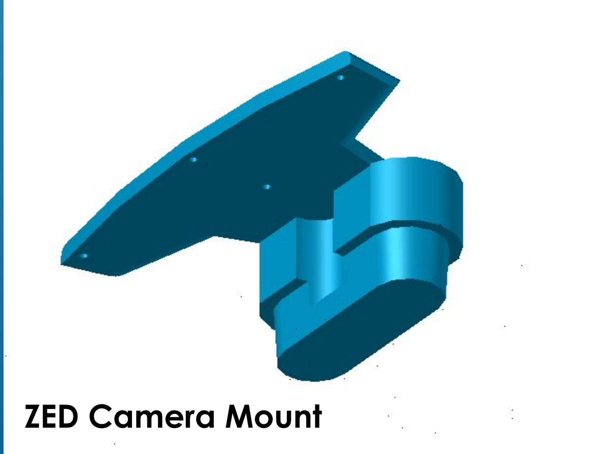
- For a mobile unit of high-speeds, it became apparent standard methods of construction had to be intricately designed to fit within the scale of the selected vehicle chassis.
- To keep design and sleek for proper maneuverability, mounts and structures were either laser-cut or 3D printed.
- All sensors, processing boards, and the PCB were integrated into the design and each possessed a personalized mount or designated area.
- AutoCAD software was used to construct all designs to precision.



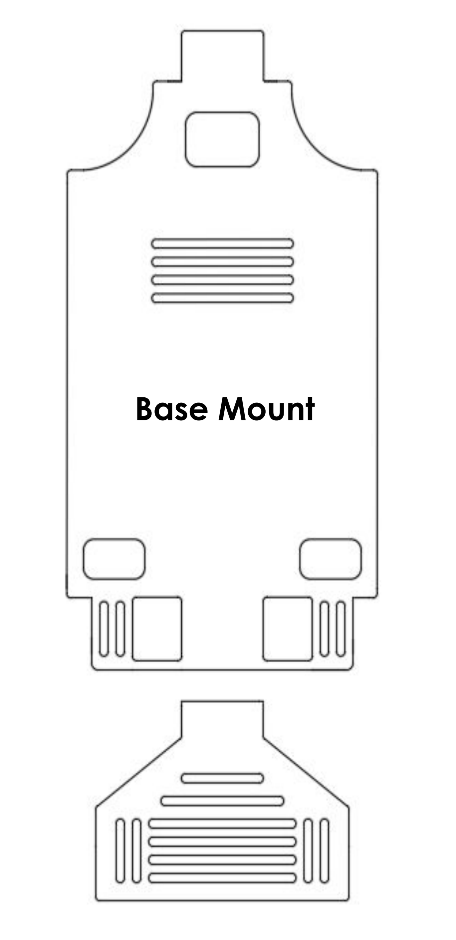
Current 3D Model

STRUCTURE DESIGN & 3D PRINTED MODELS

Designed for minimal vibration – fixed to Jetson Board

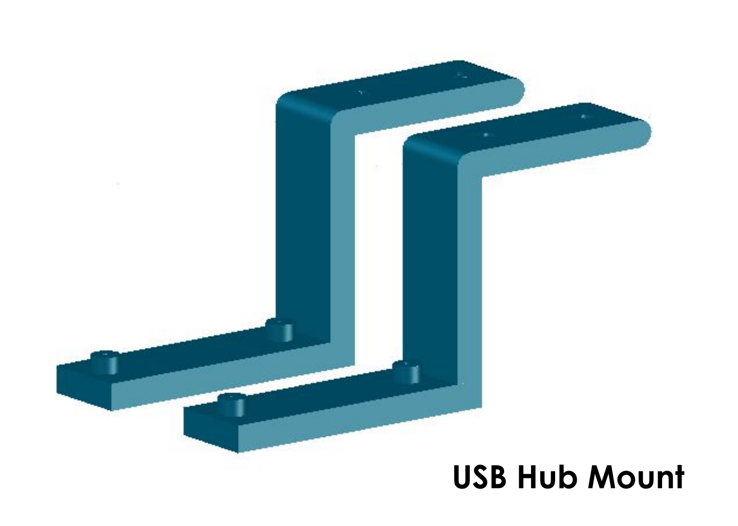


Designed with tapered insert – fixed to front bumper



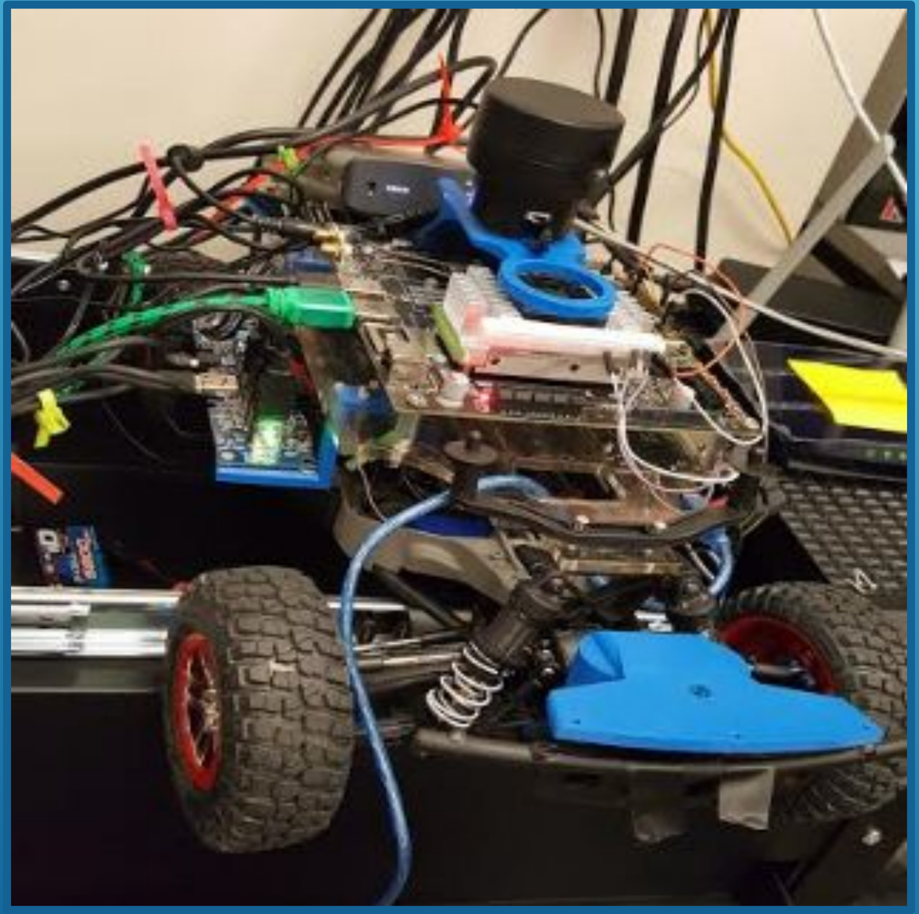
Designed for support, ventilation, and for ample cable access

Designed to mount antenna – fixed to rear bumper



Designed to support USB hub with ports facing upward – fixed to base mount

STRUCTURE DESIGN & 3D PRINTED MODELS



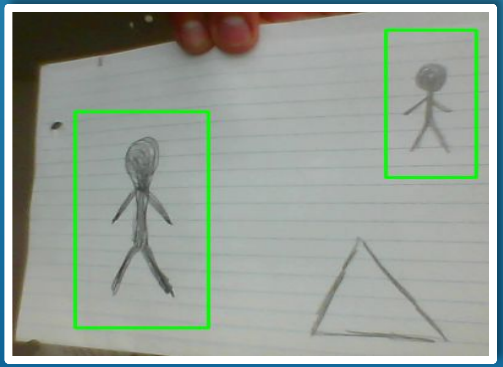
Working Prototype

Final Unit Design with Protective Body

ZED STEREO CAMERA – OPEN CV

- For autonomous vehicles, the ability to track object is essential for localization purposes and predictions of path and velocity of surrounding objects in motion.
- OpenCV is an open-source computer vision library, and is the main tool for customized computer vision.
- Python 3.5 programming language was used to interface with the ZED camera module and feed video into the computer vision algorithms

Early Tests:

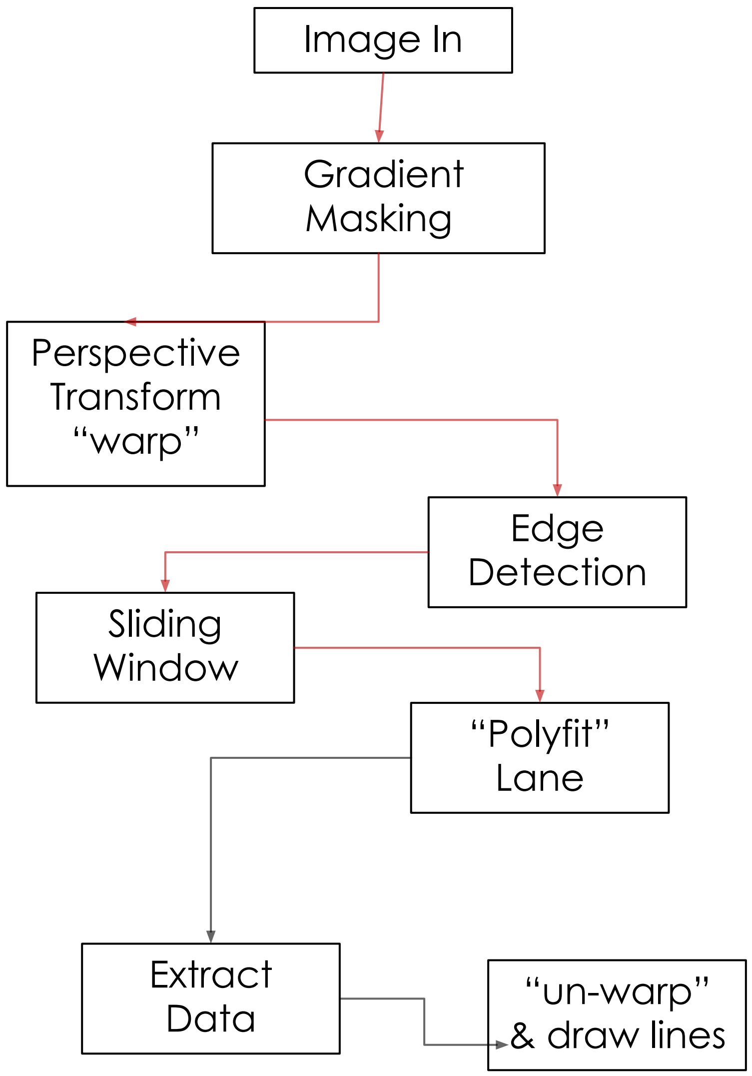

Object Detection & Isolation


Motion Mapping


Motion Detection

CAMERA – OPEN CV

LANE DETECTION ALGORITHM



ZED STEREO CAMERA – OPEN CV

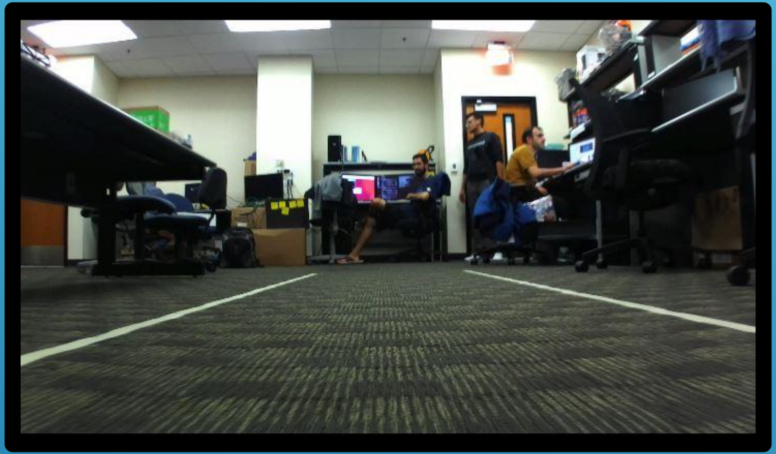
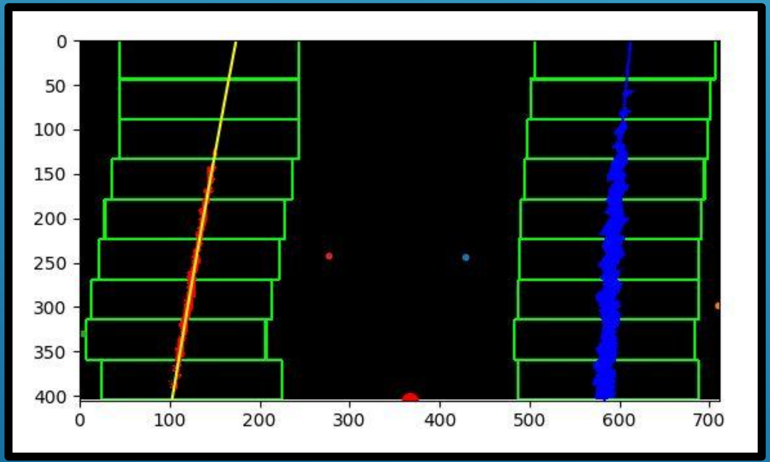


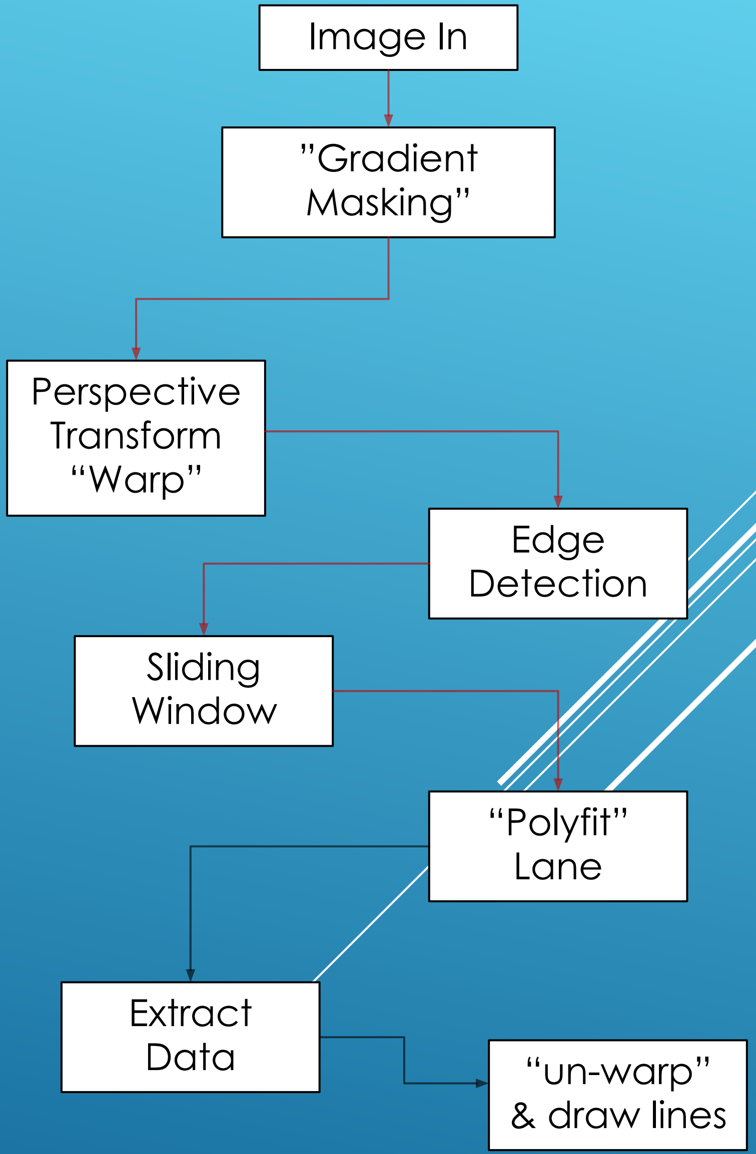
Image in

Gradient Masking

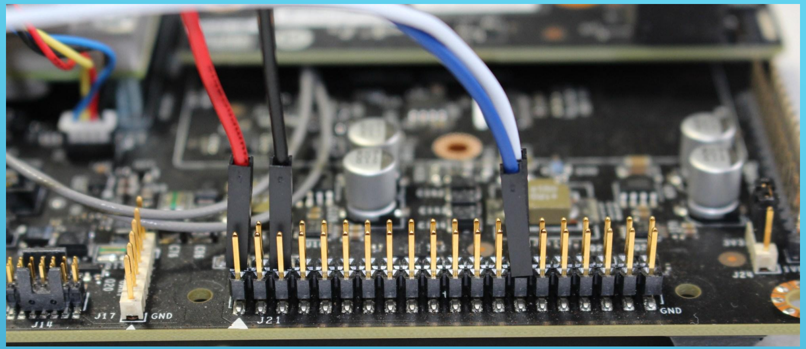
Perspective “Warp”



Polyfit



GPIO INTERFACING



- 14 addressable, true “GPIO” pins

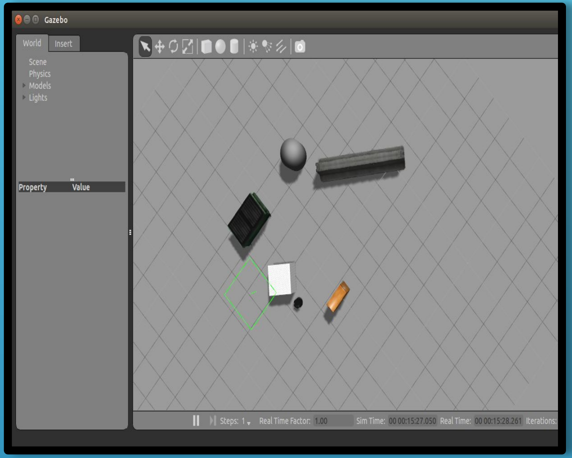
  (out of 28)

- 1 pin: RPM sensor
- 8 pins: 4 Sonar sensors for collision detection
- 5 pins left for an IMU over SPI (Serial Peripheral Interface)

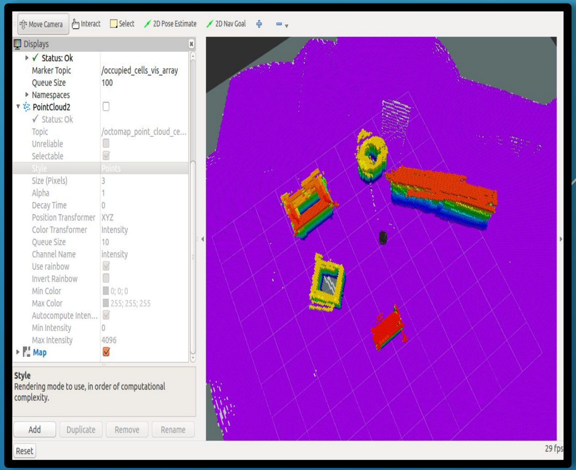
ROS (AND WHY WE CHOSE IT)

ROS: Robot **O**perating **S**ystem: publisher/subscriber framework

- **PROS:**
  - Includes examples for visualizing sensor data, position, velocity, camera image, etc.
  - Rapid development and visualization of real-time data
  - Allows nodes to communicate between each other efficiently
- **CONS:**
  - One ROS master must effectively run in the background – otherwise resulting in system failure



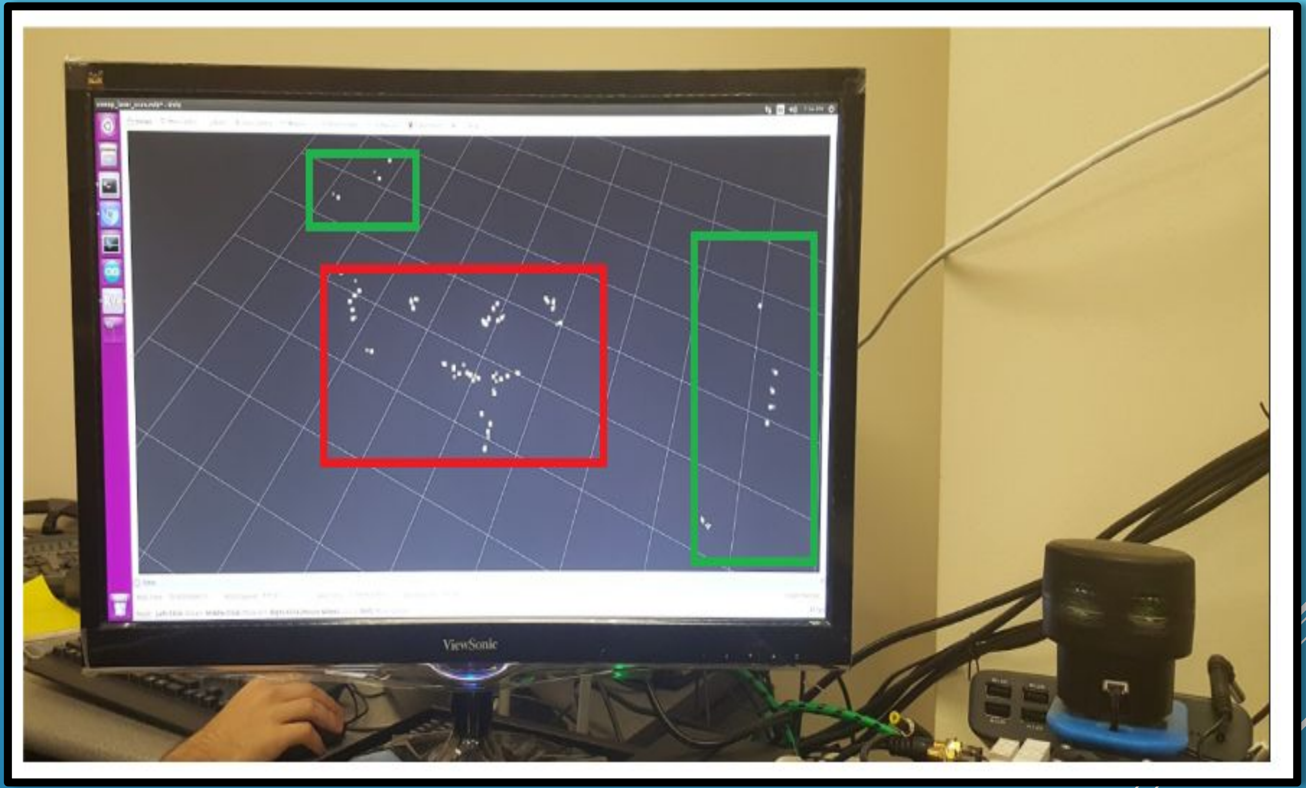
ROS test environment



ROS "Octomapping" Visualized in RVIZ

LIDAR TESTING

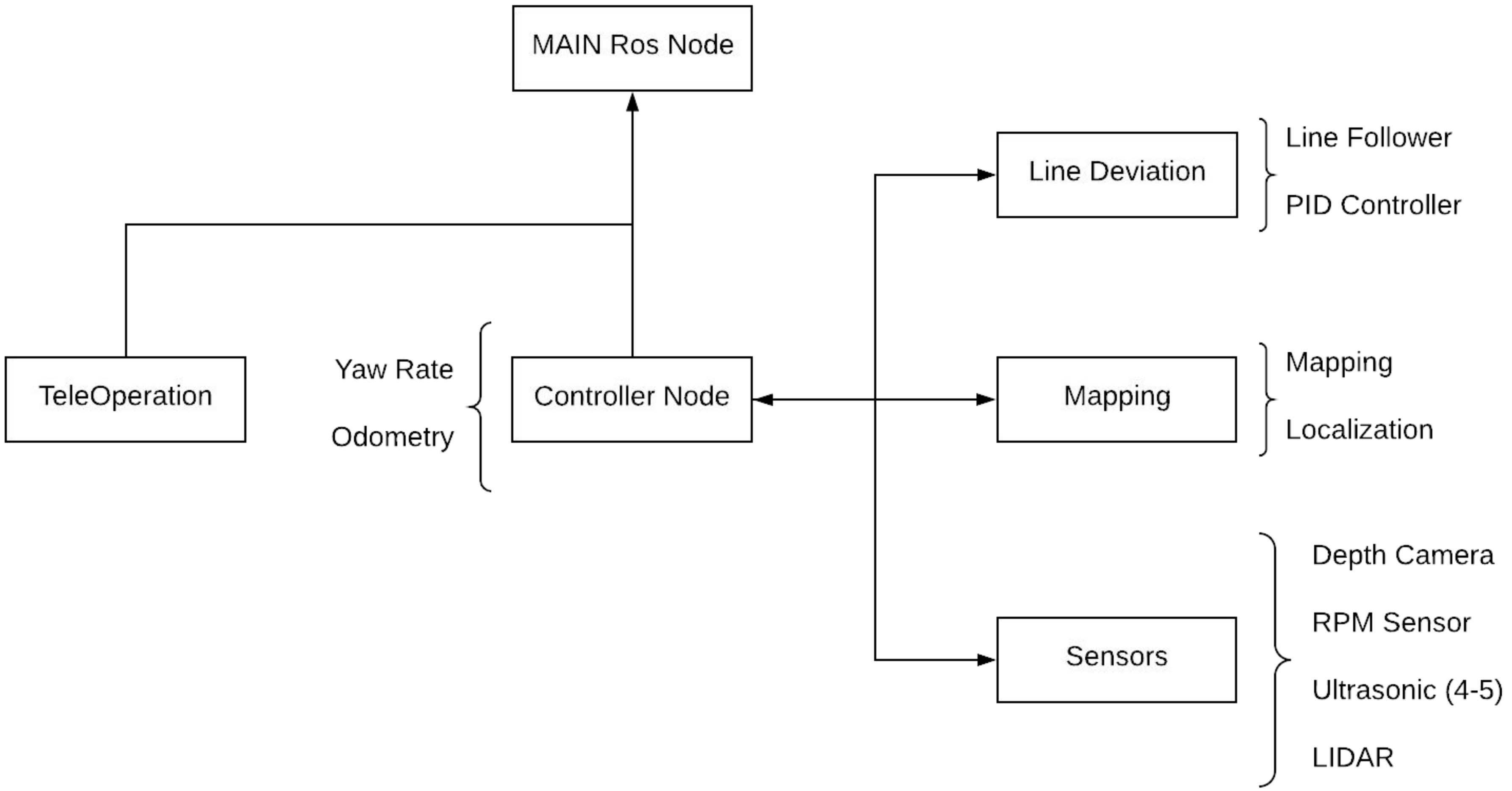
- Currently, LiDAR is still in the testing phase
- LiDAR can detect large obstacles in a given range, which is useful for localization
- For high-speed scenarios, a higher-grade LiDAR should be used for a higher resolution of data



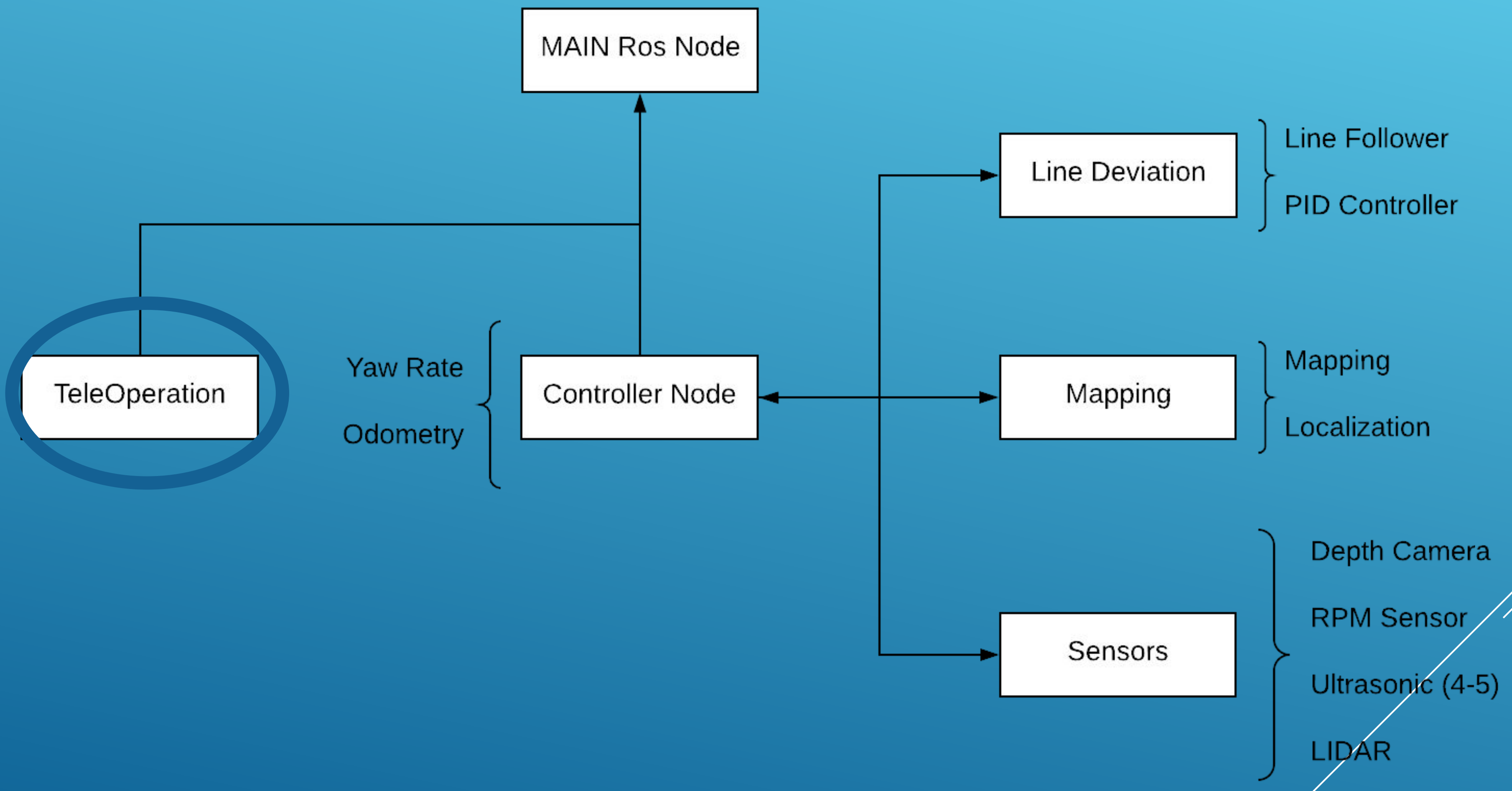
Point Cloud generated by RVIZ using ROS

Red Box: Human operating LiDAR
Green Boxes: Surrounding Walls

Software Diagram



TELEOP



MAIN Ros Node
TeleOperation
Yaw Rate
Odometry
Controller Node
Line Deviation
Line Follower
PID Controller
Mapping
Mapping
Localization
Sensors
Depth Camera
RPM Sensor
Ultrasonic (4-5)
LIDAR

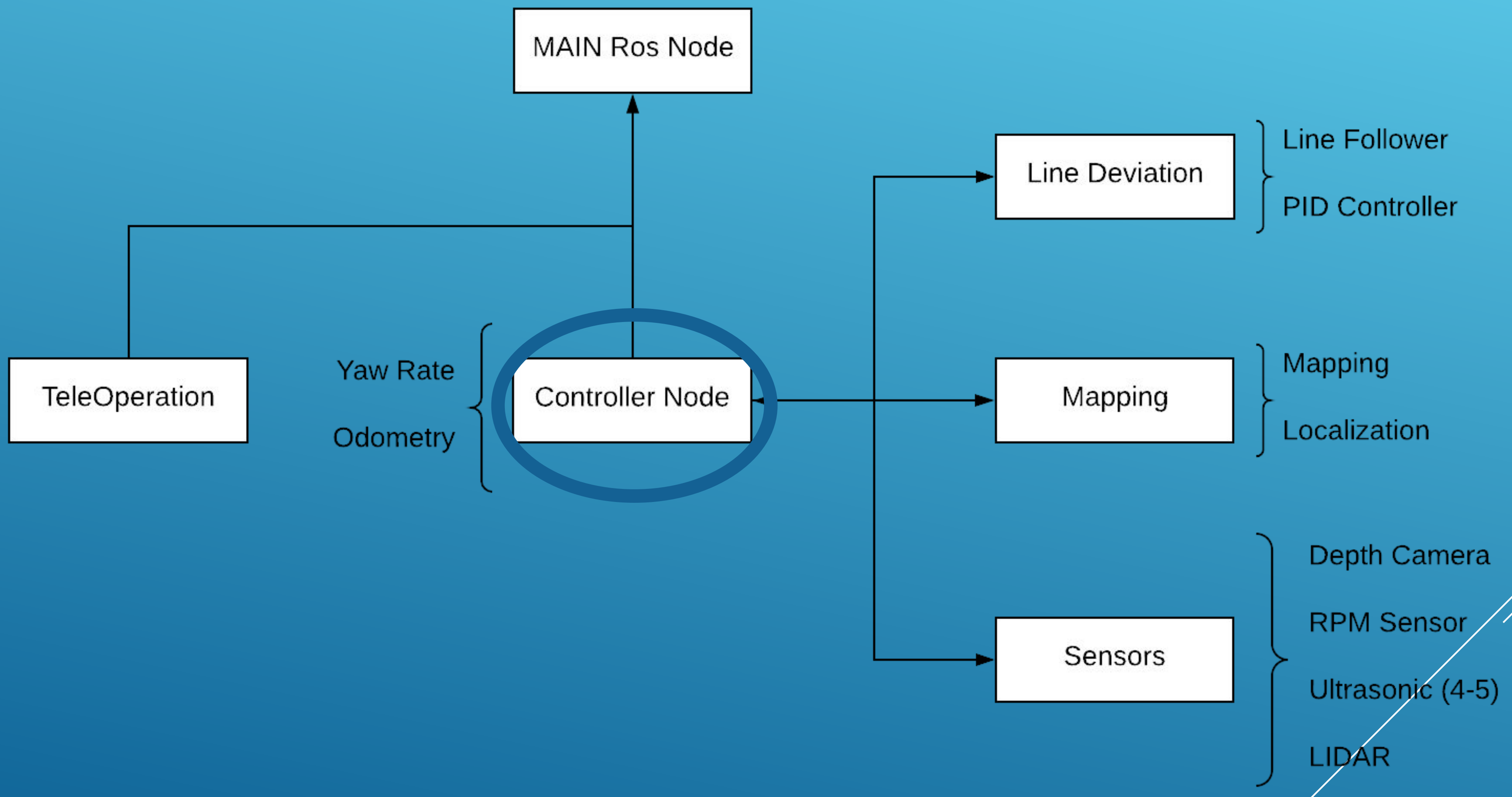
TELEOP

- Move the vehicle with the keyboard
- Manually pause the vehicle for any reason
- 2 bytes sent to PCB over UART
  - 1 for motor speed, 1 for steering angle
- Can be run from a remote computer via ssh

Cons:

- Latency of the ssh connection may cause noticeable lag
- TeleOp ***MUST*** take priority over all other planning algorithms to allow emergency stopping of the vehicle

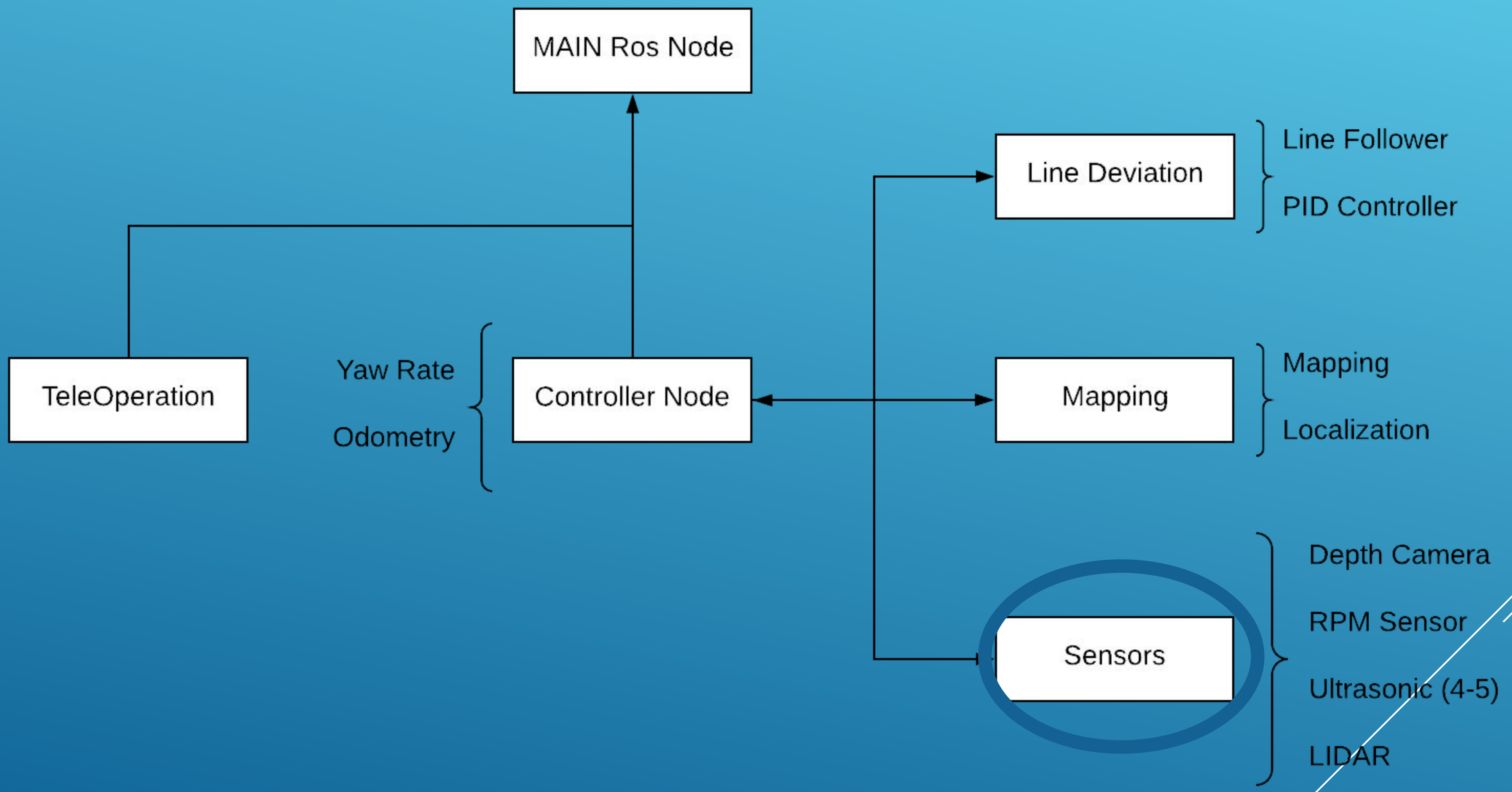
CONTROLLER NODE



CONTROLLER NODE

- Integrates data from all other nodes to decide what speed and angle to set
- Yaw rate is the rate of change of the car's direction; relies upon steering angle and current speed
- Odometry is the steering angle and current speed

SENSORS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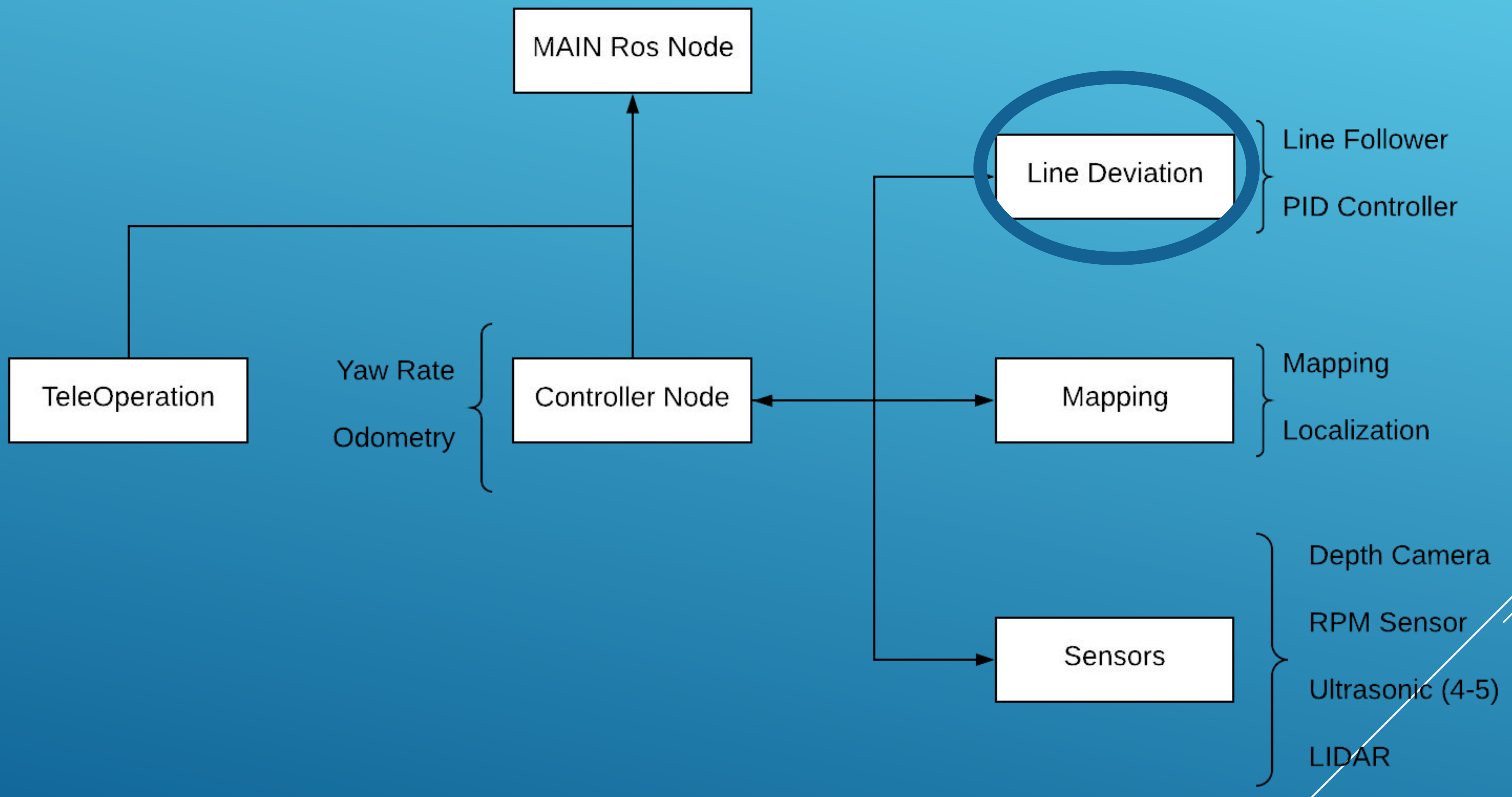
Ultrasonic (4-5)
LIDAR

SENSORS

- ROS has numerous examples for recording, visualizing, and using sensor data
- This node will integrate all of those into one that gives useful information for mapping and localization
- Each sensor has a different purpose
    - Vision is the primary sensor
    - LIDAR used primarily to detect large unmoving objects like walls
    - Sonar sensors use to detect objects approaching from the sides/back

Line Deviation

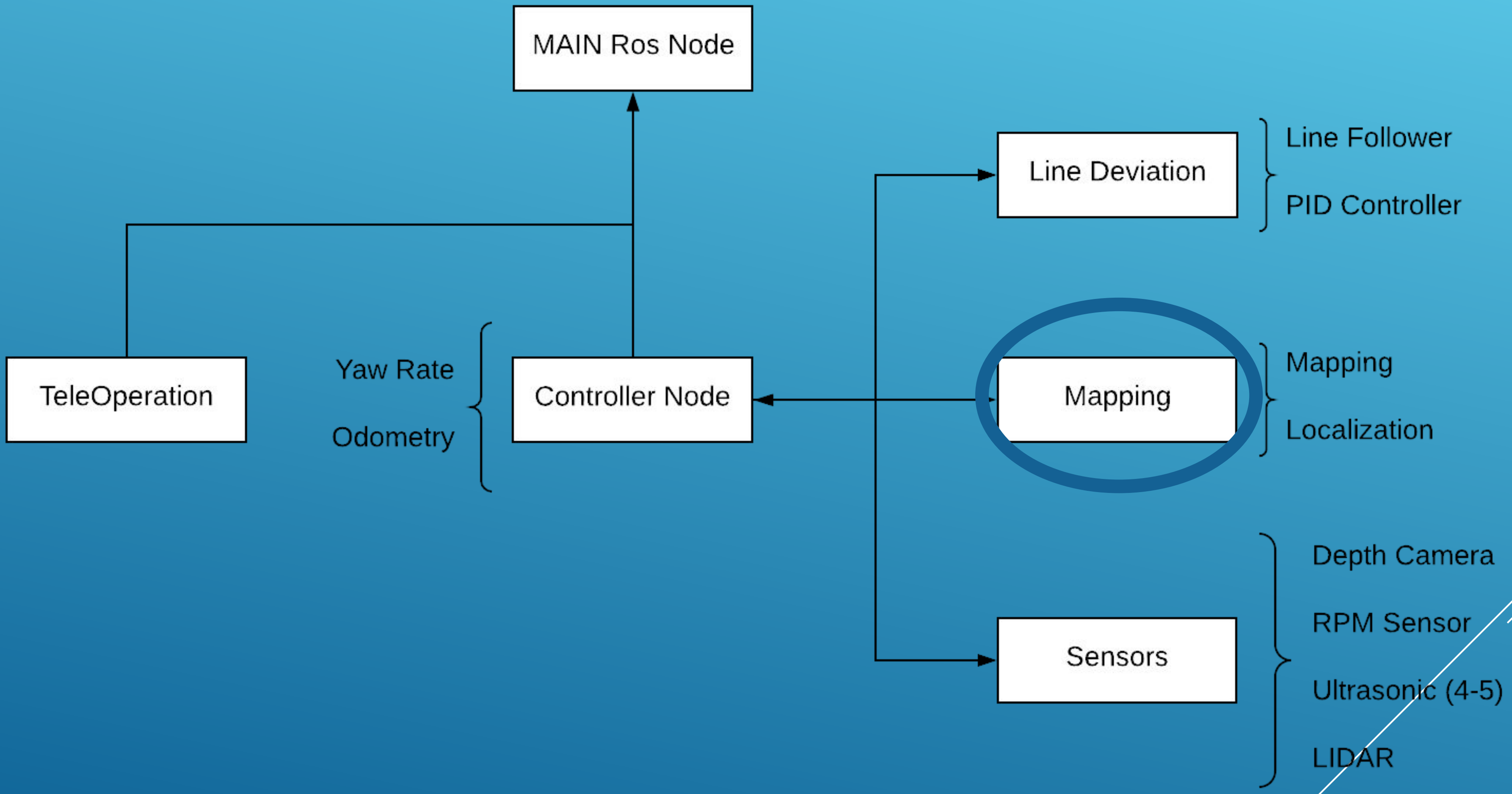


LINE DEVIATION

- Using OpenCV, a line will be drawn in the center of the image captured by the camera that the vehicle will attempt to follow.

- If the vehicle has issues achieving this, a PID controller will be designed to reduce error.
  - 3 cm maximum deviation from the line
  - Maximum settling time of 5 seconds

MAPPING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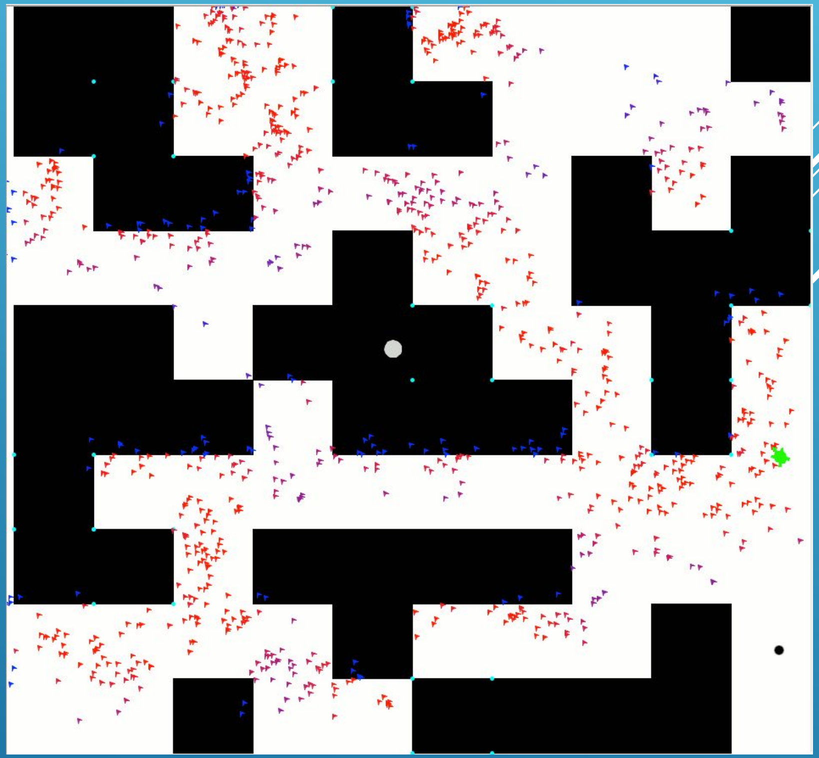
Controller Node
Mapping
Mapping
Localization
Sensors
Depth Camera
RPM Sensor
Ultrasonic (4-5)
LIDAR

MAPPING

- Saves and updates a map of the vehicle's environment
- Uses sensor data to create a map and odometry to assign a current location
- Updates the map where old data has been recorded, or adds it if seeing a new area
- Can be saved between sessions; useful for comparing teleop and autonomous runs through the same area(s)

LOCALIZATION

- Particle Filter
  - "Particles" represent different states of the vehicle
- Pros:
  - Easy to program/conceptually understand
- Cons:
  - Can fail if too little "particles" are used
  - Complexity increases exponentially



LOCALIZATION

- Extended Kalman Filter
  - Uses updates from odometer data and sensors to localize
- Pros:
  - Lower complexity
  - Already implemented in ROS
- Cons:
  - Bad initial estimates can make the filter fail

CAR TESTING

STEERING ANGLES

- Arduino Servo.write() Command sends pulses with different duty cycles at 50 Hz.
  - FInd the range of inputs where Servo.write() works
- Attached a ruler to the wheel of the vehicle
  - Took photos as we incremented duty cycle by .01%
  - Used Photoshop tools to measure Steering Angles

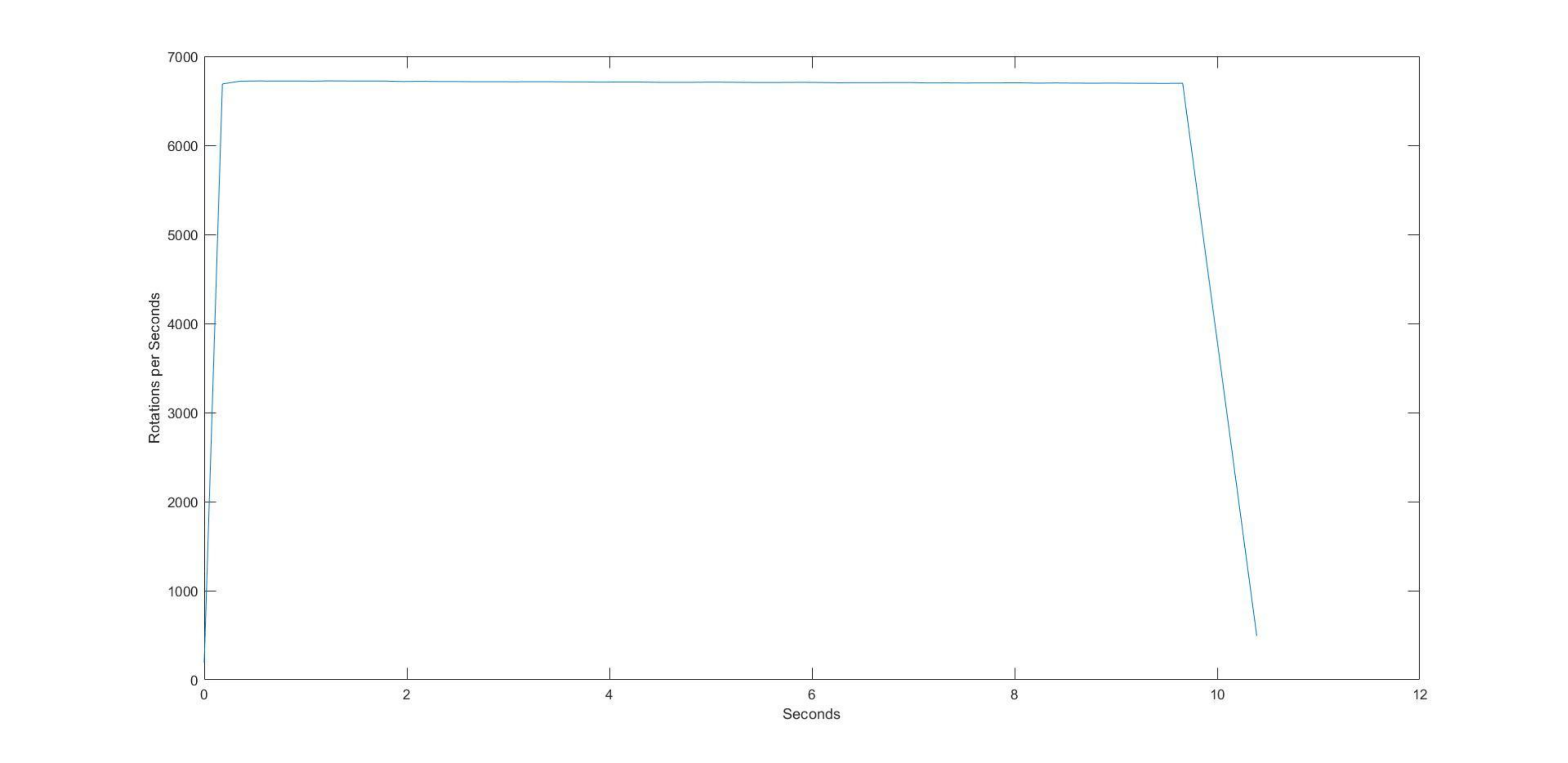
TACHOMETER

- Measures rotations of the spur gear that turns the wheels
  - Using engine rotations you can calculate the distance the car travels.
  - Needed for localization and collision detection

- Attached a magnet to the spur gear and placed a traxxas hall sensor near the gear
  - Pull-up Resistor between signal and VCC pins
  - When the sensor detects the magnet, the voltage across the sensor drops to millivolts
  - We measure the rising and falling edges of the tachometer

Motor Speed Testing

- We have the car run at varying speed for 10 seconds and then have it brake
  - Every 20 measurements from the tachometer it writes the calculated rotations per millisecond and the time between writes to a text file



Collision Avoidance

- If ROS ever fails, all the sensors will go down, but the PCB will keep driving the engine and servos using the last received values
- A sonar sensor on the front of the vehicle will determine if we have an object near the vehicle
- if the vehicle is moving at a certain “servo” value and detects an object near it, the car will begin to brake

Communication

- Sponsor asked us to use an Ad Hoc network at 5-5.9 GHz
  - Simulates the protocol for wireless communication between vehicles
- The vehicles will communicate by sending each other text files that contain their locations and orientations.
- Issues
  - Jetson Wifi card doesn’t support Ad-Hoc mode
  - USB adapters do not consistently have a chipset that is compatible with Ad-Hoc mode in Linux
  - PCI is the only solution, but is expensive.

PROJECT EXPENSES

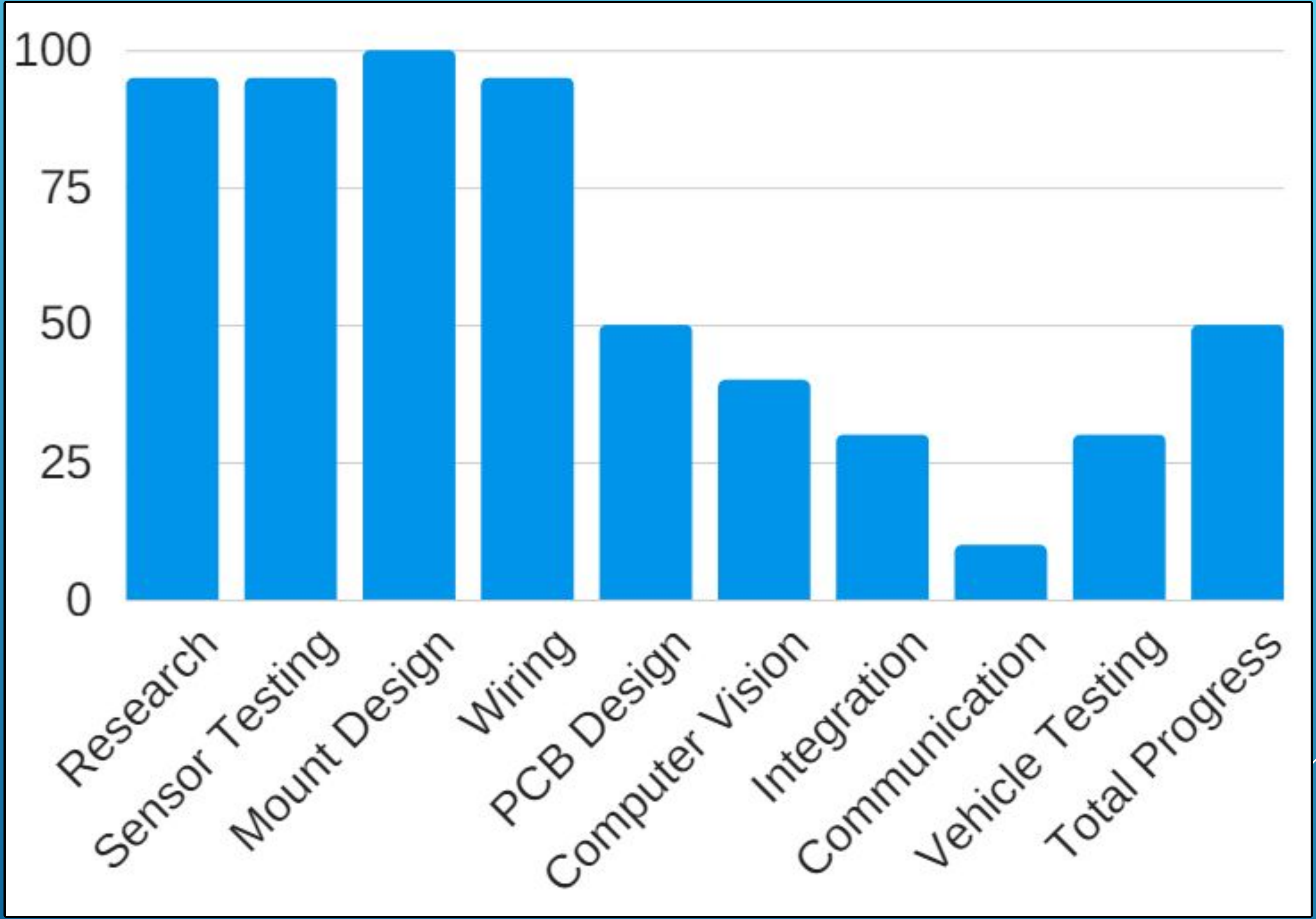
PCB And Prototyping				
Product	Location	Qty	Price	Total
10K Trimmer	Mouser Electronics	6.00	$0.77	$4.62
12 Pin Header	Mouser Electronics	6.00	$0.88	$5.28
4 Pin Headers	Mouser Electronics	24.00	$0.32	$7.70
3 Pin Headers	Mouser Electronics	10.00	$1.05	$10.50
2 Pin Header	Mouser Electronics	6.00	$0.22	$1.32
Fuse Holder	Mouser Electronics	6.00	$0.61	$3.66
16MHz Crystal Ocillator	Mouser Electronics	6.00	$0.39	$2.34
5V Voltage Regulators	Mouser Electronics	6.00	$1.32	$7.92
Momentary Pushbutton	Mouser Electronics	6.00	$0.26	$1.56
2.1mm x 5.5mm Power Jack	Mouser Electronics	6.00	$0.59	$3.54
5V Brushless Fan 2 Pack	Amazon	2.00	$7.99	$15.98
Arduino Uno	Amazon	2.00	$10.90	$21.80
ATMEGA2560-16AU	Mouser Electronics	4.00	$14.22	$56.88
FT232RL-REEL	Mouser Electronics	4.00	$4.50	$18.00
10K Variable Resistor	Mouser Electronics	4.00	$0.95	$3.80
SMD 0402 Resistor	Mouser Electronics	8.00	$0.11	$0.88
SMD 10uF 10V	Mouser Electronics	4.00	$0.41	$1.64
SMD 0.1uF	Mouser Electronics	4.00	$0.34	$1.36
SMD 22pF	Mouser Electronics	8.00	$0.10	$0.80
1206 LED Red	Mouser Electronics	8.00	$0.33	$2.64
1206 LED Green	Mouser Electronics	8.00	$0.36	$2.88
Mini USB Connector	Mouser Electronics	8.00	$0.90	$7.20
1206 SMD 500mA Fuse	Mouser Electronics	8.00	$0.48	$3.84
SMD Switch	Mouser Electronics	4.00	$0.97	$3.88
SMD Resistor 1K	Mouser Electronics	6.00	$0.83	$4.98
PCB Manufacturing	Seeed Studio	1.00	$34.00	$34.00
Total				**$229.00**

Car, Sensors and Wiring		
Product	Location	Price
Plastic Knife	Ace Hardware	$4.99
Gorilla Glue	Ace Hardware	$5.99
4" Cable Ties	Ace Hardware	$4.99
1/4" Heat Shrink Tubing	Ace Hardware	$2.99
Fasteners	Ace Hardware	$4.99
Breadboard	RadioShack	$4.16
18GA 300V Wire Blk	RadioShack	$4.18
Electrical Tape	RadioShack	$0.98
Universal Power Cable	Radioshack	$9.99
2.1mm x 5.5mm Male Jacks	Amazon	$9.99
Dupont Connector and Header Kit	Amazon	$14.79
USB 2.0 Male Solder Connectors	Amazon	$6.99
USB 3.0 Solder Connectors	Amazon	$7.99
8mm Heat Shrink Length:5m	Amazon	$7.42
Rainbow DuPont Wires	Amazon	$7.99
WiFi Antenna Connector Cables	Amazon	$24.57
2.5mm X 5.5mm Solder Connectors	Amazon	$6.99
Arcyllic Sheet	Home Depot	$25.00
Traxxas Slash 4x4 Platinum	Traxxas	$429.00
Traxxas Battery Pack and Charger	Traxxas	$99.00
Nvidia Jetson TX2	Nvidia	$299.00
Scanse LiDAR	Scanse	$349.00
Zed Stereo Camera	StructuredIO	$449.00
Ultrasonic Sensors	Amazon	$15.00
IMU Breakout	SparkFun	$25.00
GPS Breakout	SparkFun	$13.00
TP-Link N450 Wireless Router	Amazon	$30.00
7 Port USB Hub	Amazon	$27.00
50,000mAh Auxiliary Battery Pack	Amazon	$136.00
Laser Cutting	UCF	Free
3D Printed Mounts	UCF	Free
Total		**$2,025.99**

Work Distribution

Task	Bruce	Tyler	Eduardo	Christian
Purchasing and Product Research	X	X		
Mount Design	X	X		
Sensor Testing			X	X
PCB Design	X			
Electrical Wiring and Soldering	X			
OpenCV Computer VIsion		X		
Lane Detection		X		
PID Control Design			X	
ROS System Integration			X	X
Nvidia Programming Setup				X
Ad Hoc Network Setup			X	

PROGRESS


100
75
50
25
0
Research
Sensor Testing
Mount Design
Wiring
PCB Design
Computer Vision
Integration
Communication
Vehicle Testing
Total Progress

OBSTACLES

- Linux and OpenCV learning curve
- Unavailability of Nvidia documentation
- Zed Camera software installation on Jetson

Questions?