Auto-Knight

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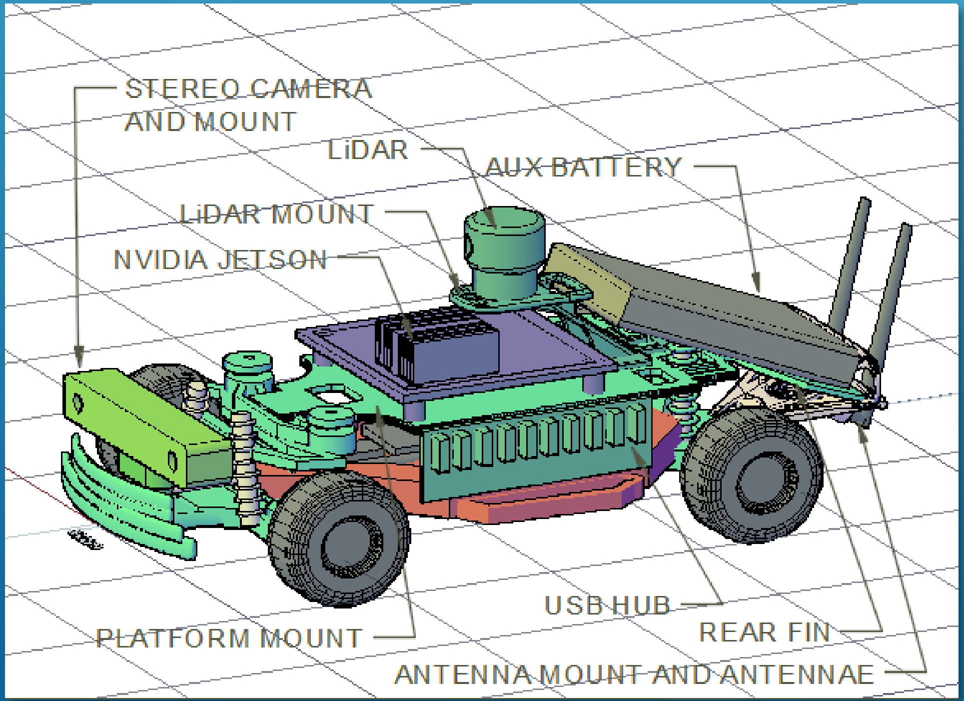

Group 30

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

Sponsor:
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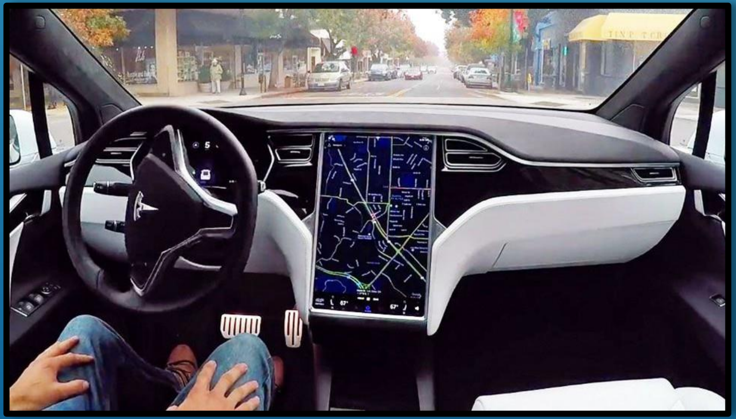
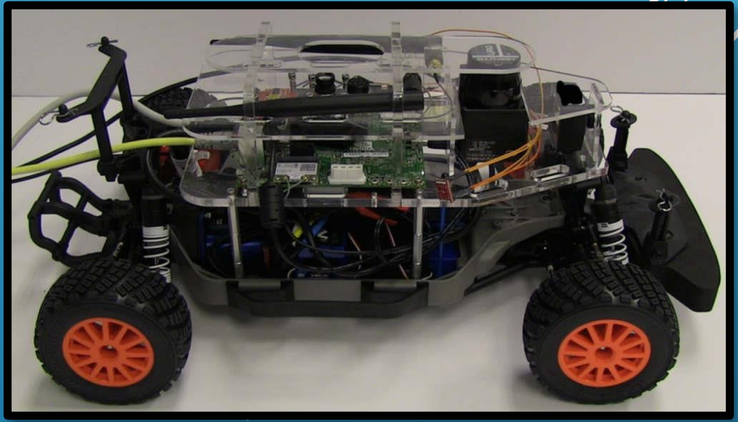
Project Motivation

- 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 to create a car that can be situationally aware and accurately maneuver its environment

Changes to Project Scope

- When we accepted this project, we had goals to try to implement Mapping, LiDAR, Computer Vision, Localization, and Vehicle to Vehicle Communication(V2V).

- Due to time constraints and hardware issues, some of these features were scaled back to refine other aspects of the project.
    - LiDAR
    - Mapping
    - V2V
    - Localization

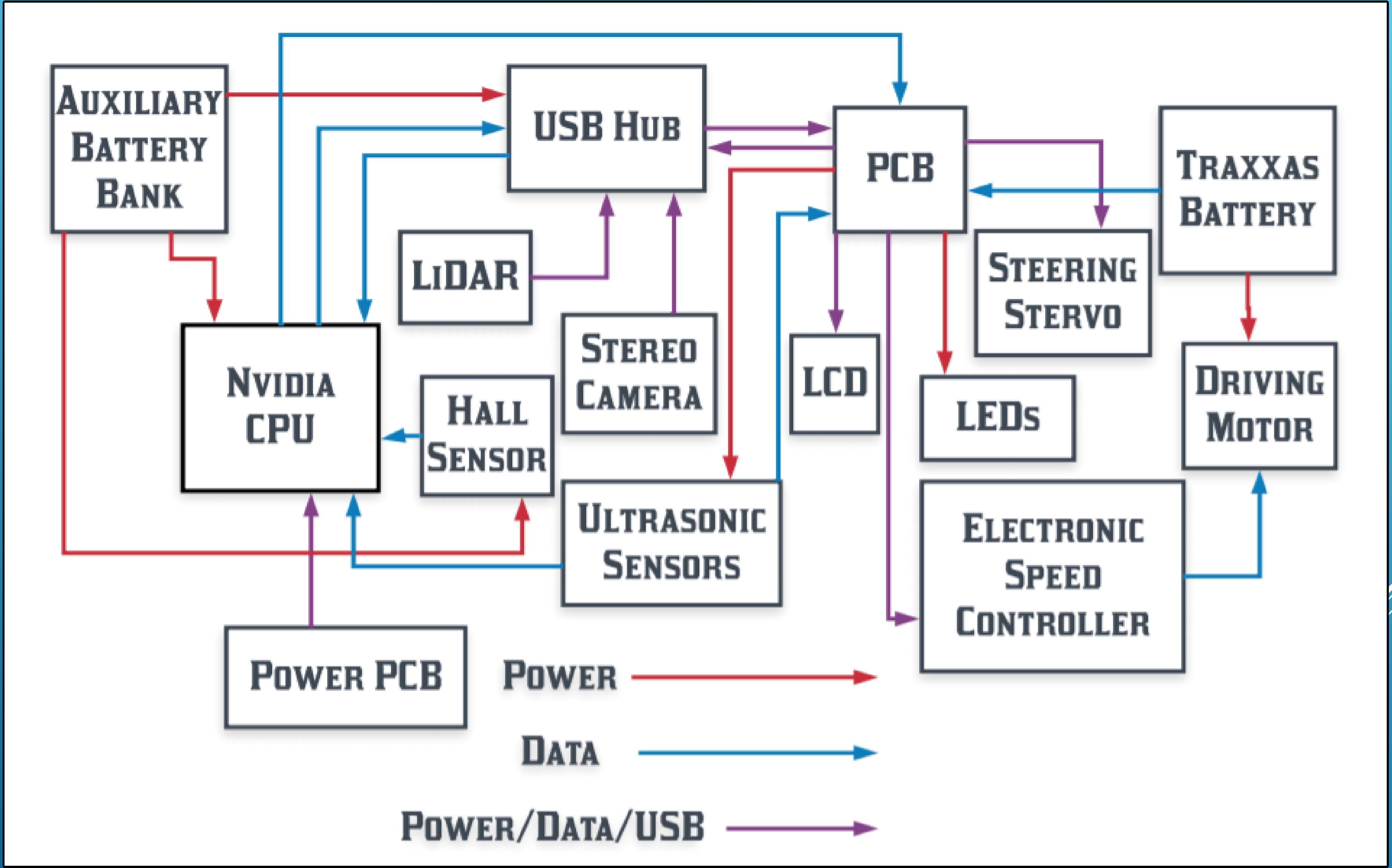
Changes to Project Scope

- LiDAR/Mapping
  - Scanse LiDAR did not deliver the performance we anticipated.
- V2V
  - The most recent updates to the Jetson TX2 did not allow for ad-hoc mode
  - Most USB Wi-Fi adapter chipsets are not supported by Linux
- Localization
  - Requires mapping and was subsequently removed

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 Range	>=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

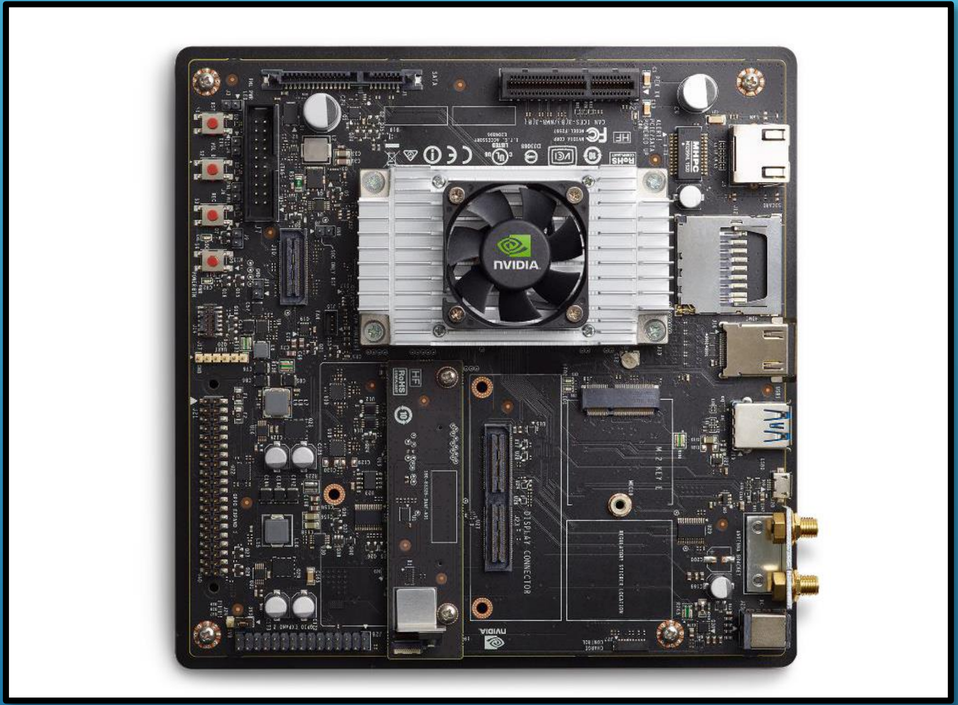
Traxxas Slash Platinum

RC CAR SPECIFICATION COMPARISON

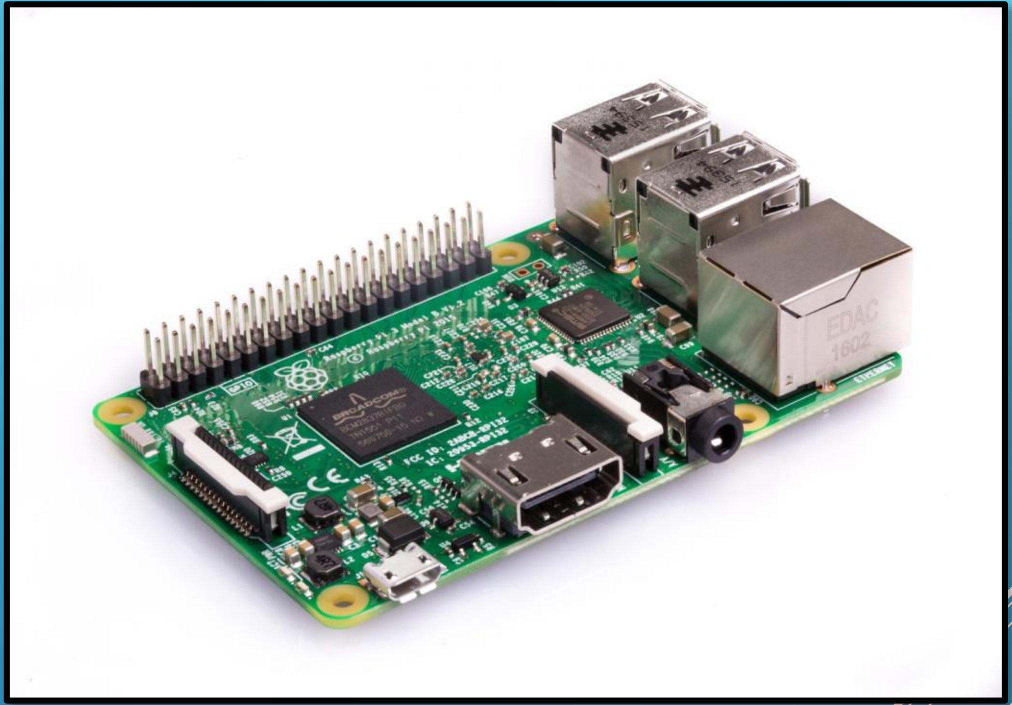
Specification	Sunfire Pro	Iron Track E8XBL	Traxxas Rally Racer	Traxxas Slash Platinum
Scale	1/10	1/8	1/10	1/10
Cost	$192	$245	$300	$429
Motor	Brushless 3300KV	2075KV	Brushless 3500KV	Brushless 3500KV
Suspension	Aluminum Shocks	Independent and Adjustable	Adjustable Oil-filled	Aluminum Shocks
Differential	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



Raspberry Pi



Drawbacks:

- Expensive
- Little Documentation

Advantages:

- Exceptional Image Processing ability

Drawbacks:

- Not Sufficient for image processing

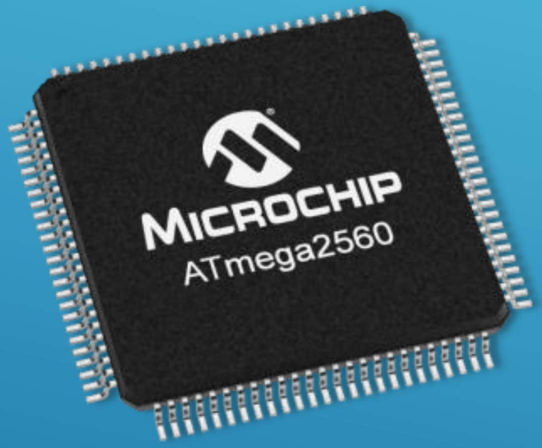
Advantages:

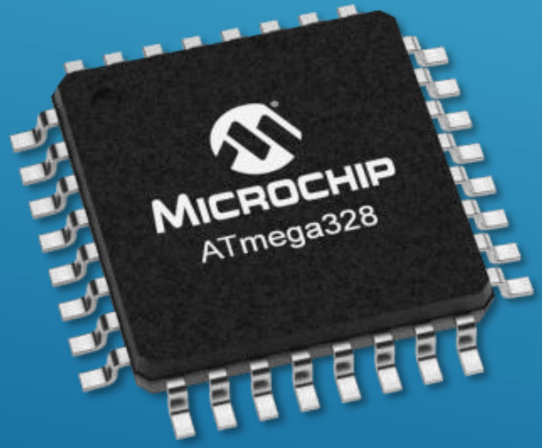
- Online Community
- Affordable

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

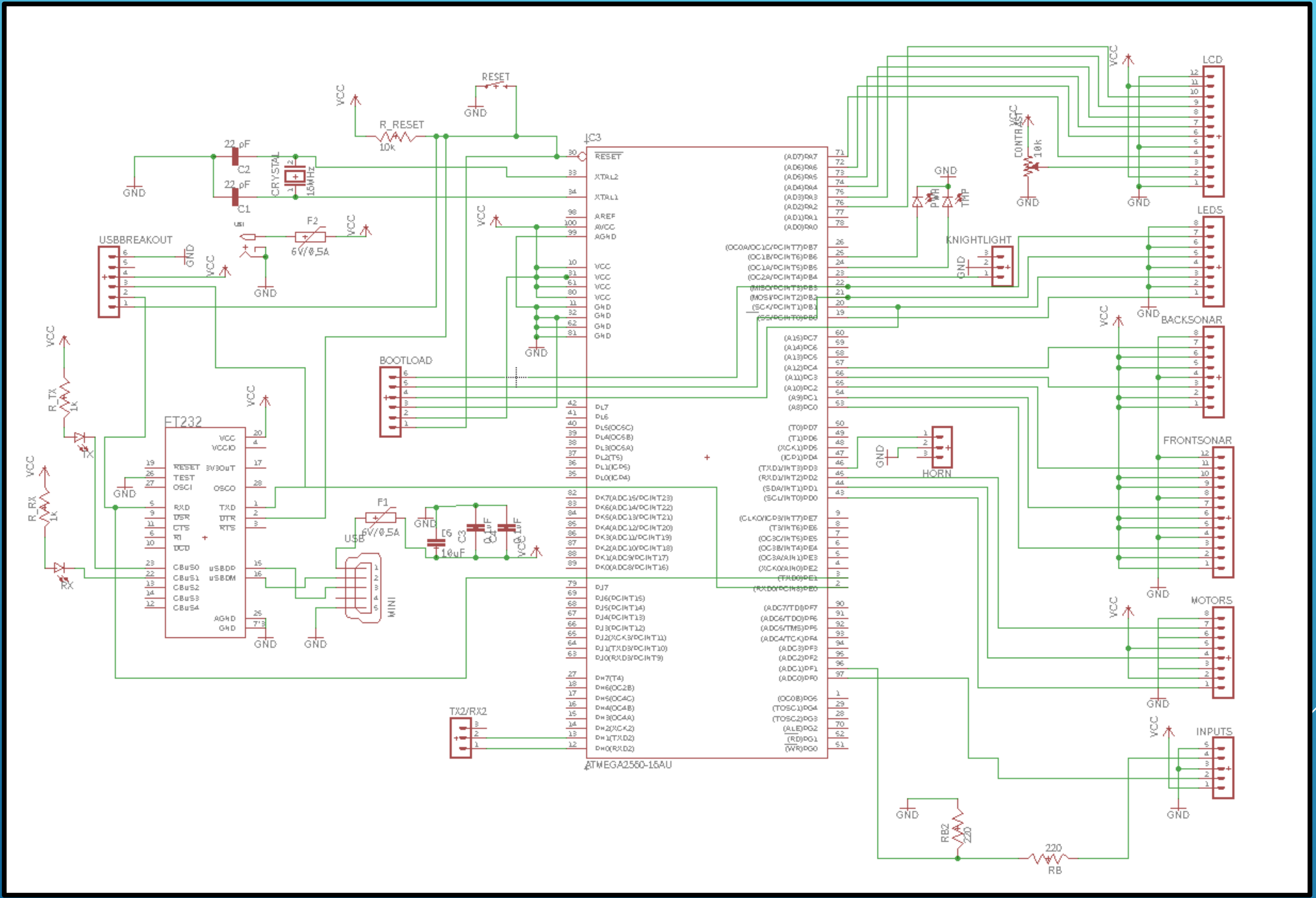
Scanse Sweep SEN 14117

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

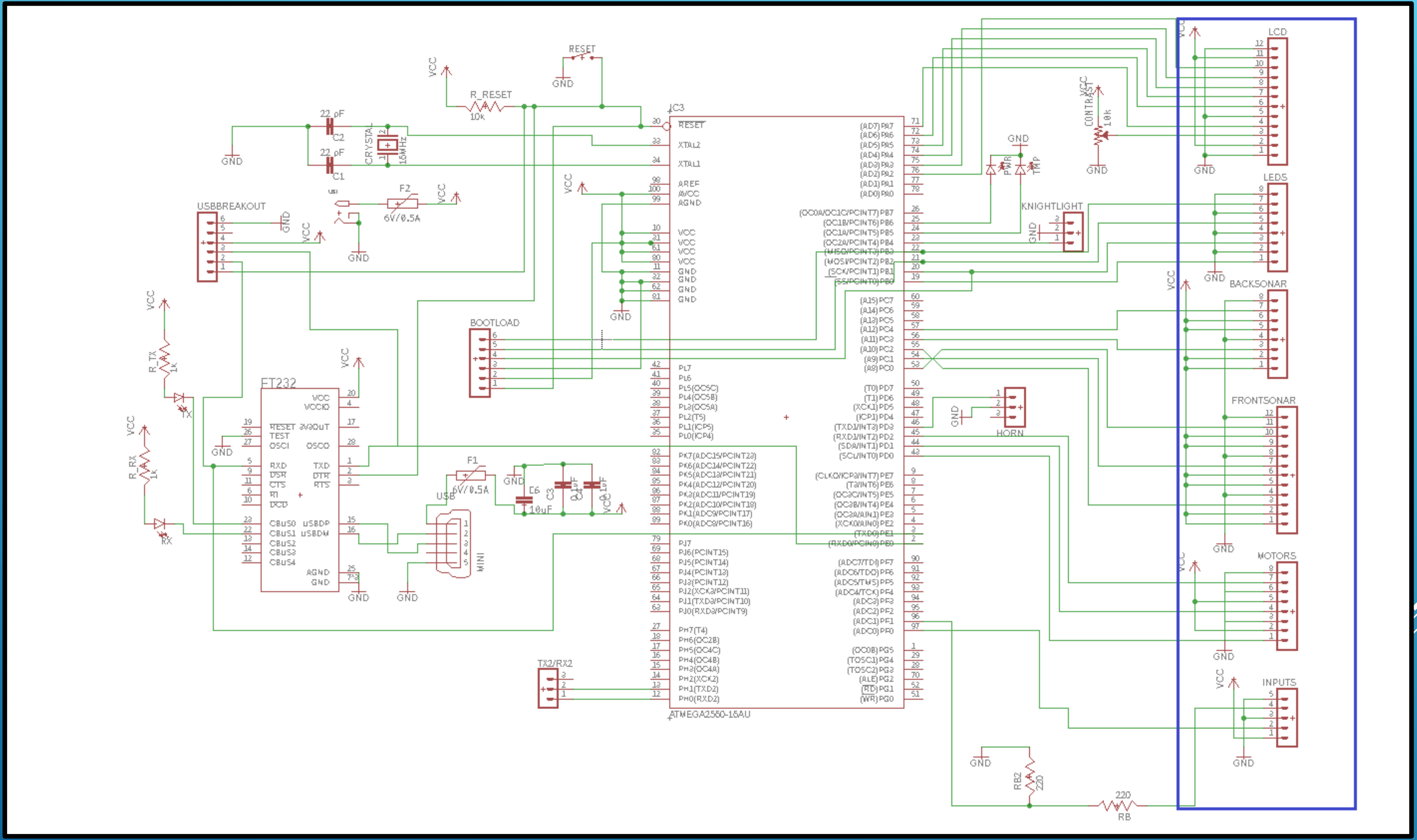
Parts Selection: SENSORS AND OTHER ITEMS

- ***Ultrasonic Sensor***
  - SparkFun HC-SR04 Ultrasonic Sensor Pack
- ***Hall Sensor***
  - *Traxxas RPM Telemetry Sensor*
- ***Auxiliary Battery***
  - MAXOAK 50,000mAH
- **Powered USB Hub**
  - Aukey Powered USB hub
- ***Wireless Router***
  - TP-Link TL-WR940N

Atmega2560 Based PCB Design



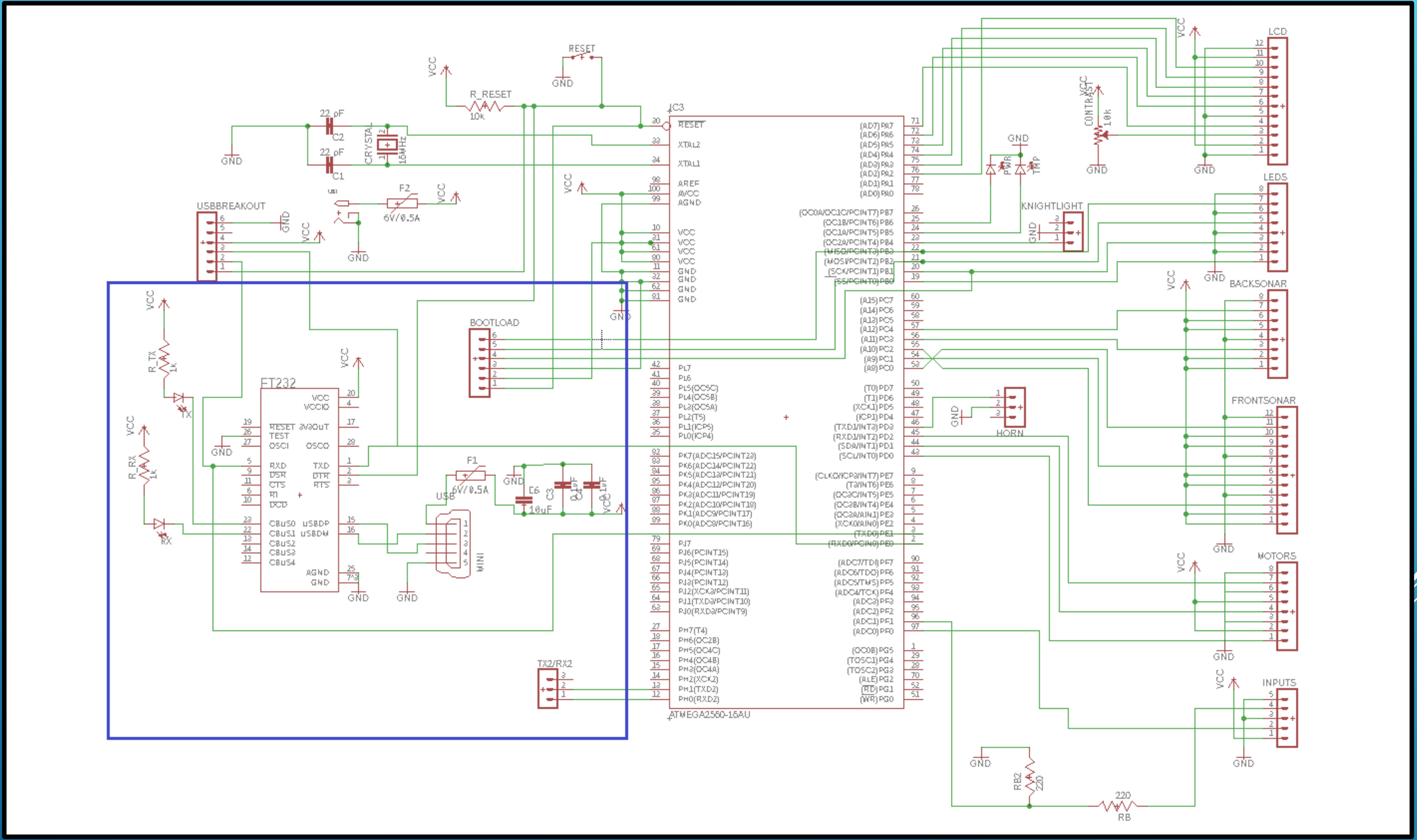
Atmega2560 Based PCB Design



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

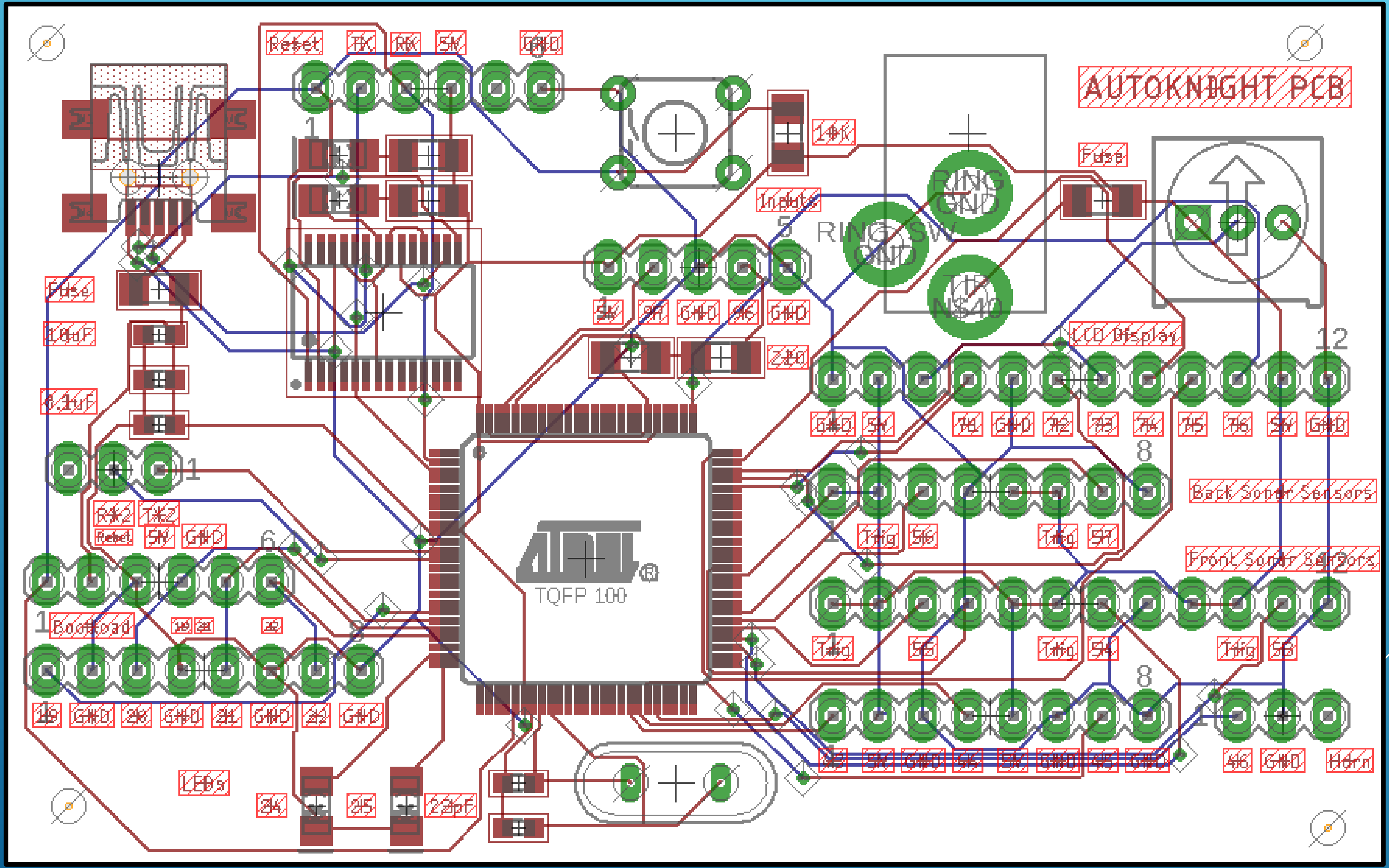
Atmega2560 Based PCB Design

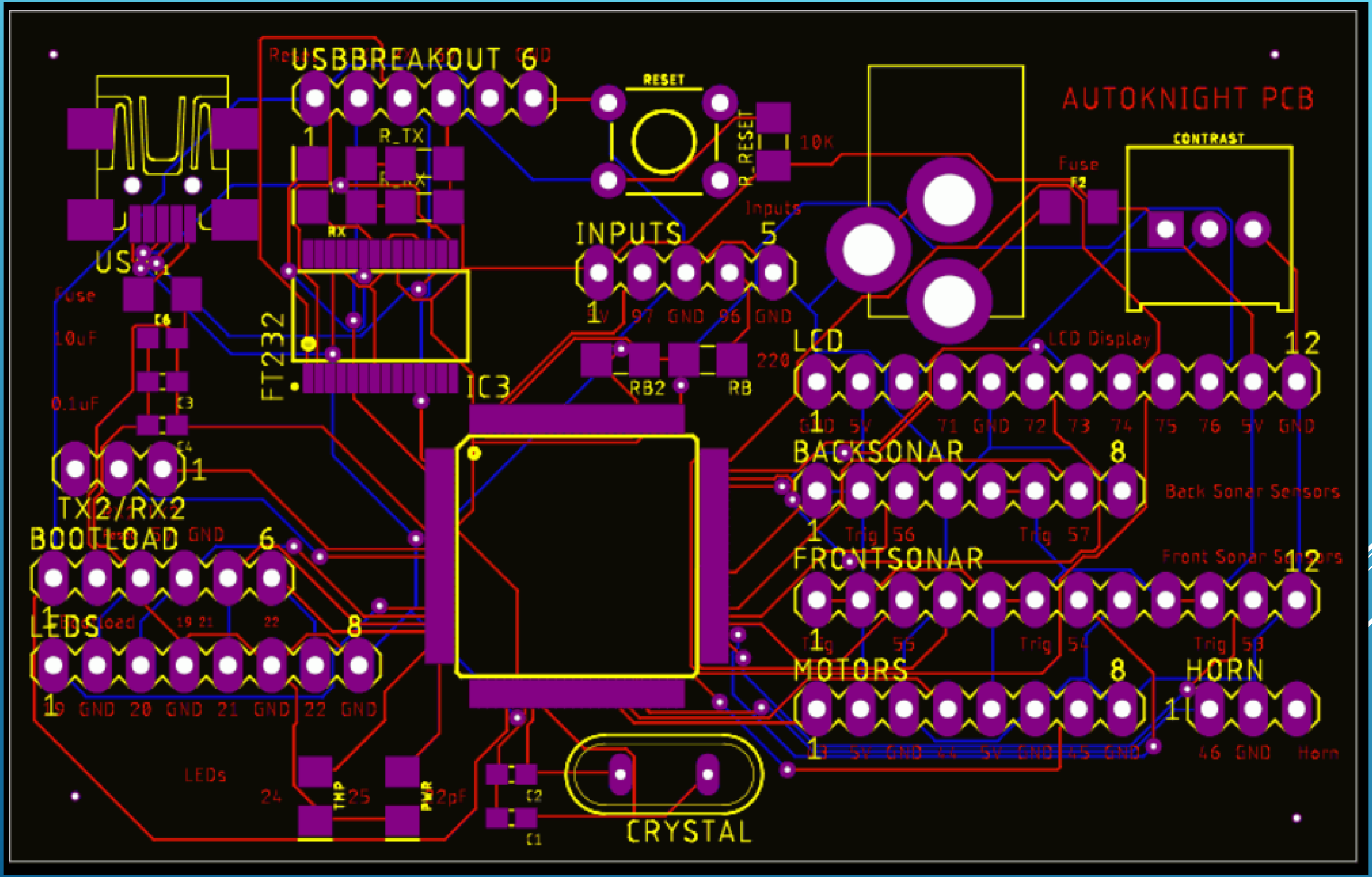


PROGRAMMING

- USB to UART for data transmission with Jetson using FT232RL
- Mini USB Connector
- Bootloader Header ICSP
- Addition Header for backup USB Breakout
- Spare TX and RX Pins for dedicated Ultrasonic Alerts

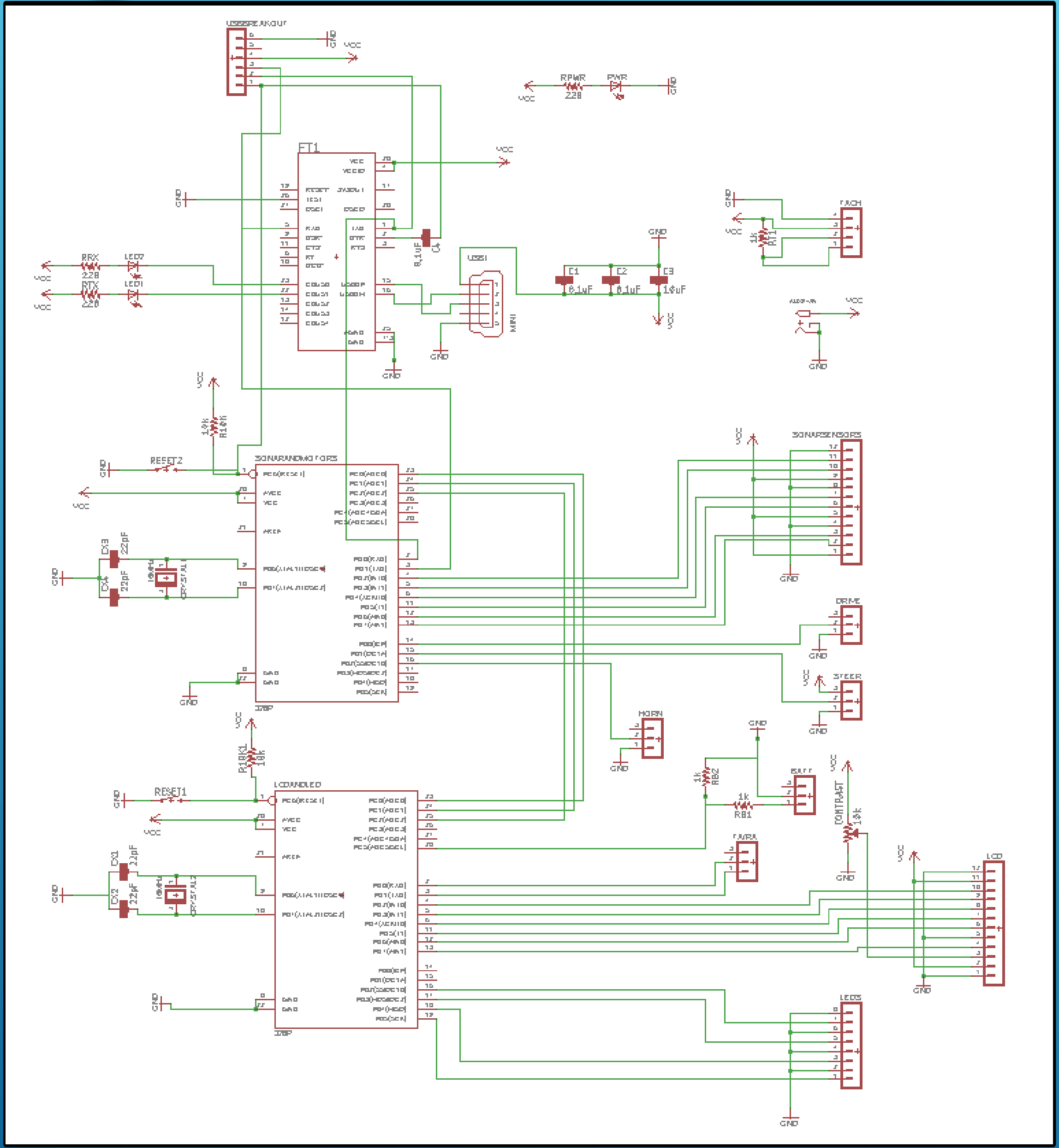
Atmega2560 Based PCB Design



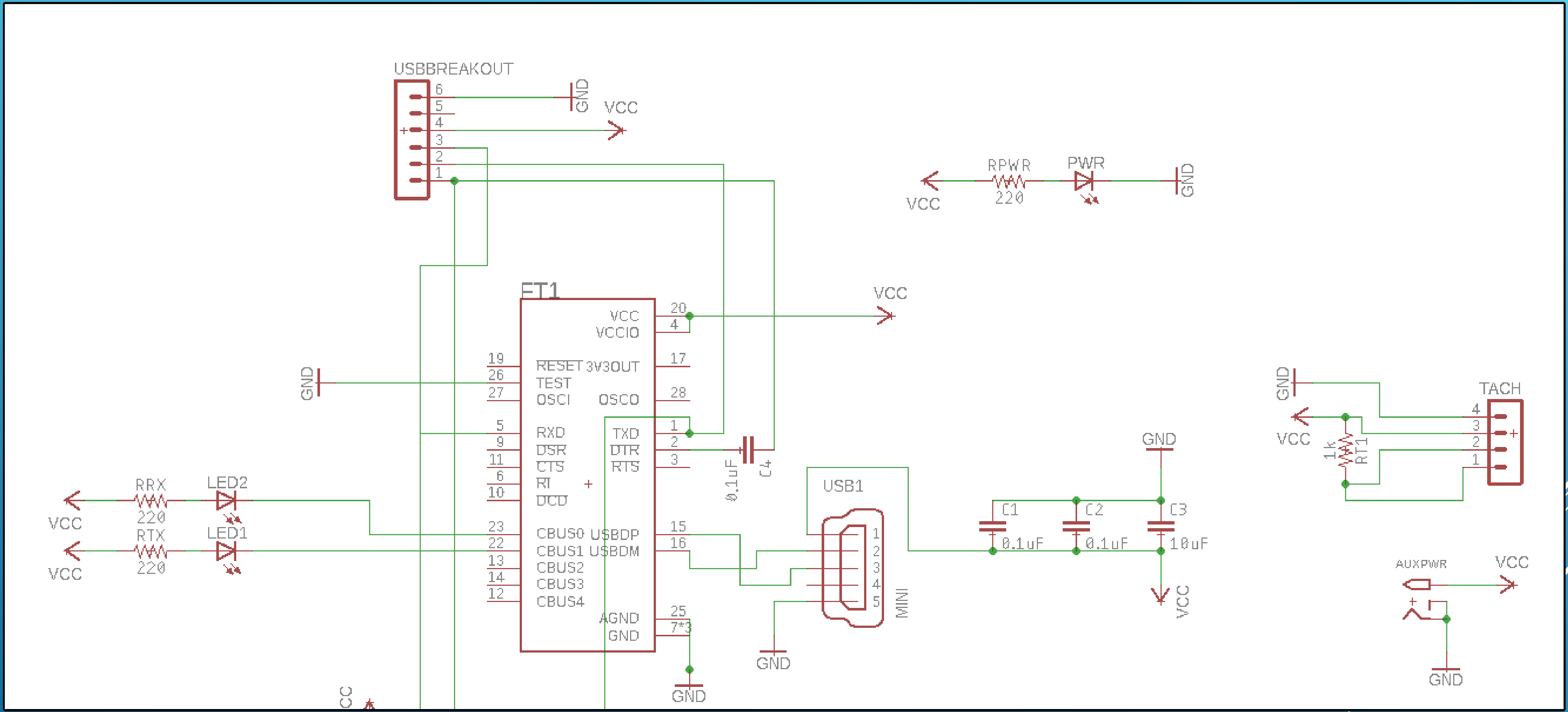


AUTOKNIGHT PCB
USBBREAKOUT 6
RESET
R_RESET
10K
CONTRAST
Fuse
F2
R_TX
RX
FT232
IC3
USB
Fuse
10uF
0.1uF
C3
C4
INPUTS 5
Inputs
1 5V 97 GND 96 GND
220
RB2
RB
LCD
LCD Display
12
GND 5V 71 GND 72 73 74 75 76 5V GND
BACKSONAR 8
Back Sonar Sensors
Trig 56 Trig 57
FRONTSONAR
Front Sonar Sensors
Trig 55 Trig 54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

Atmega328 Based PCB Design

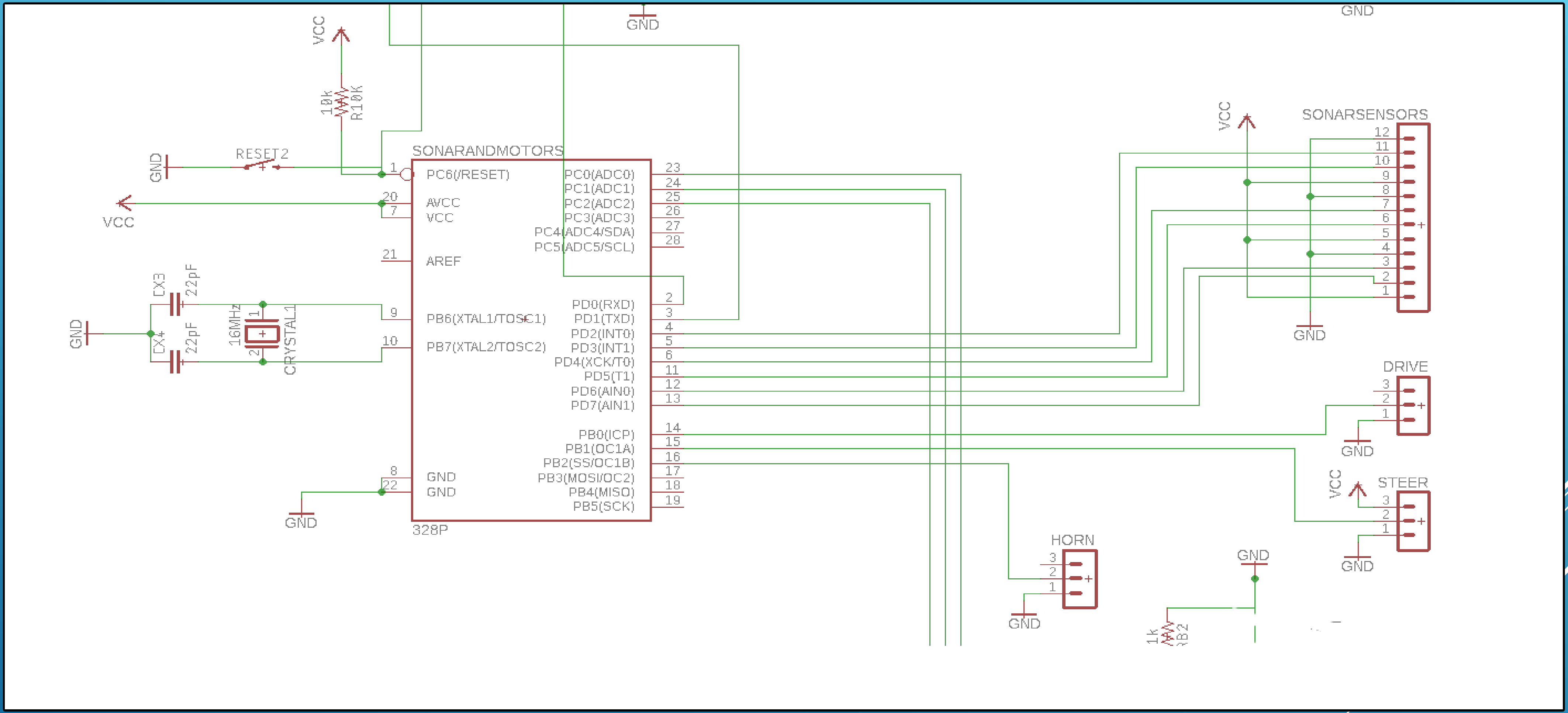


Atmega328 Based PCB Design



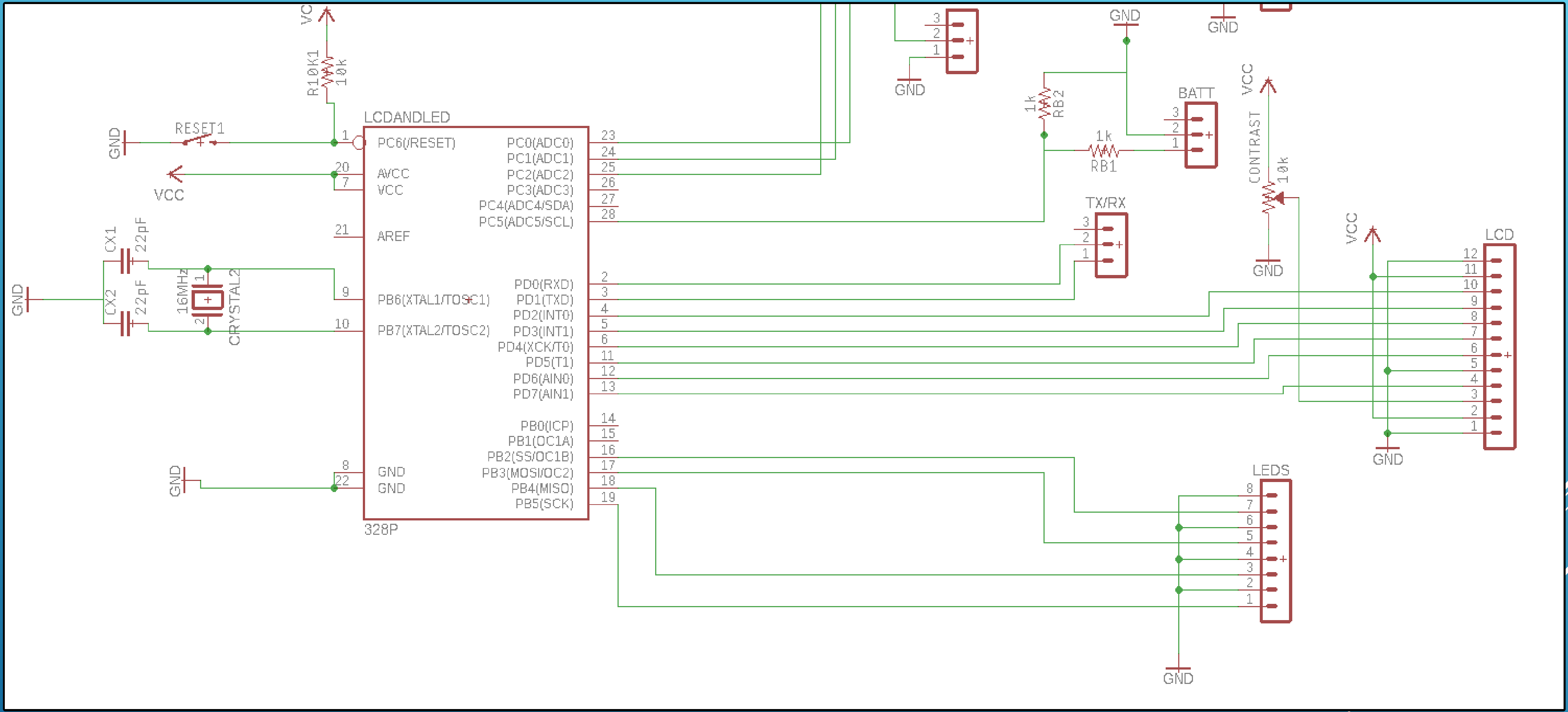
Serial to UART USB Communication and Programming circuit

Atmega328 Based PCB Design



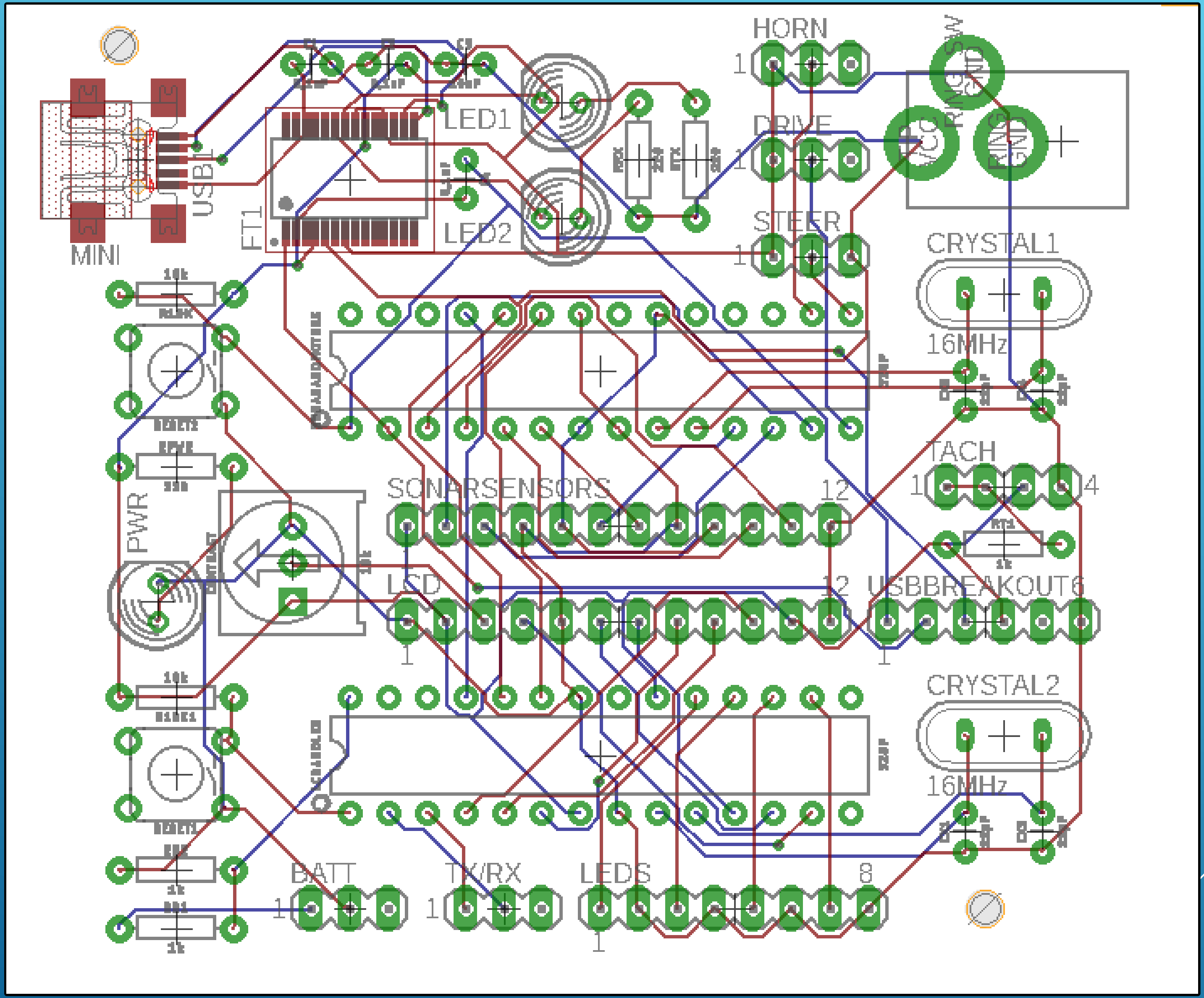
Motor Control and Sonar MCU

Atmega328 Based PCB Design



LCD and LED Display MCU

Atmega328 Based PCB Design

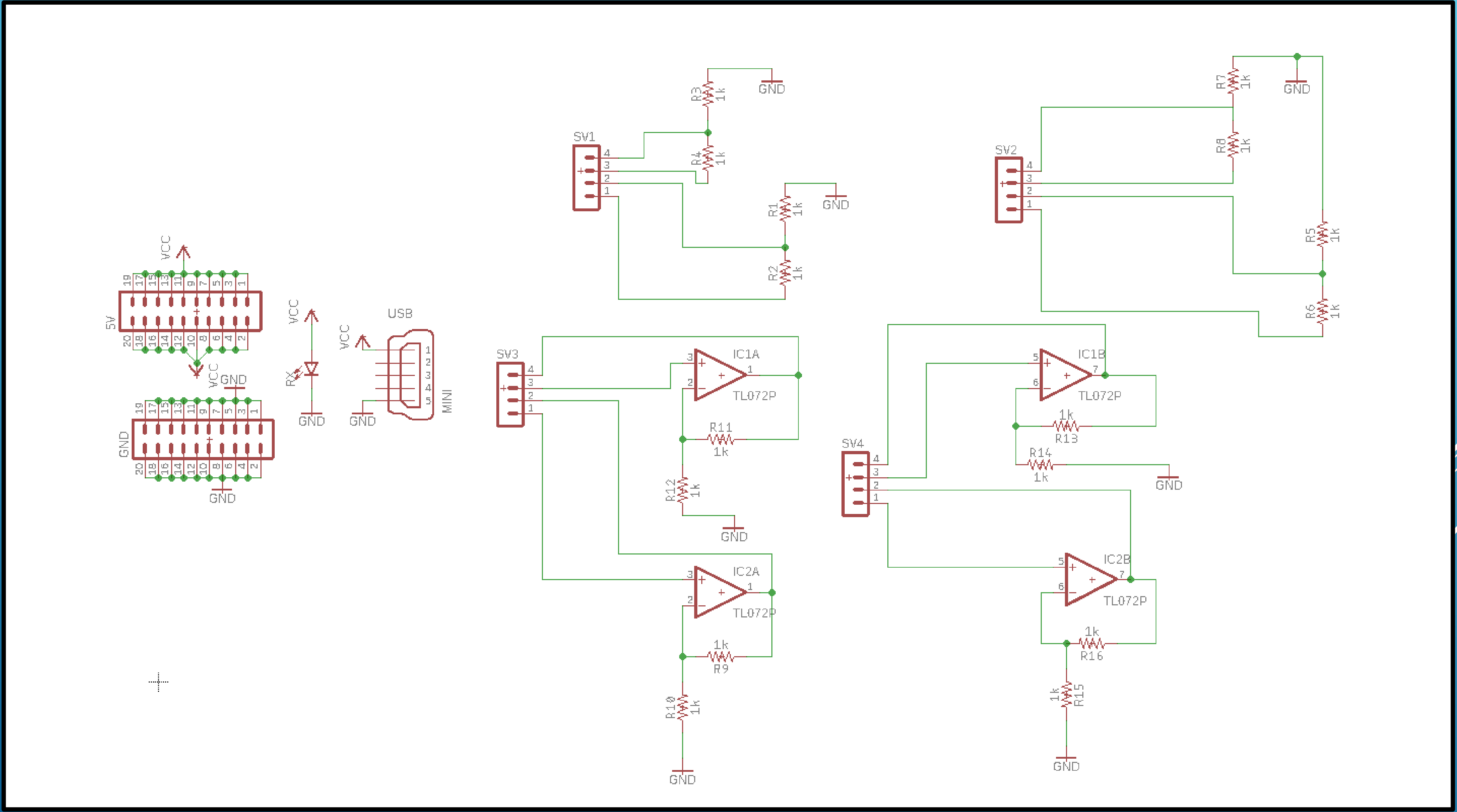


Atmega328 Based PCB Design

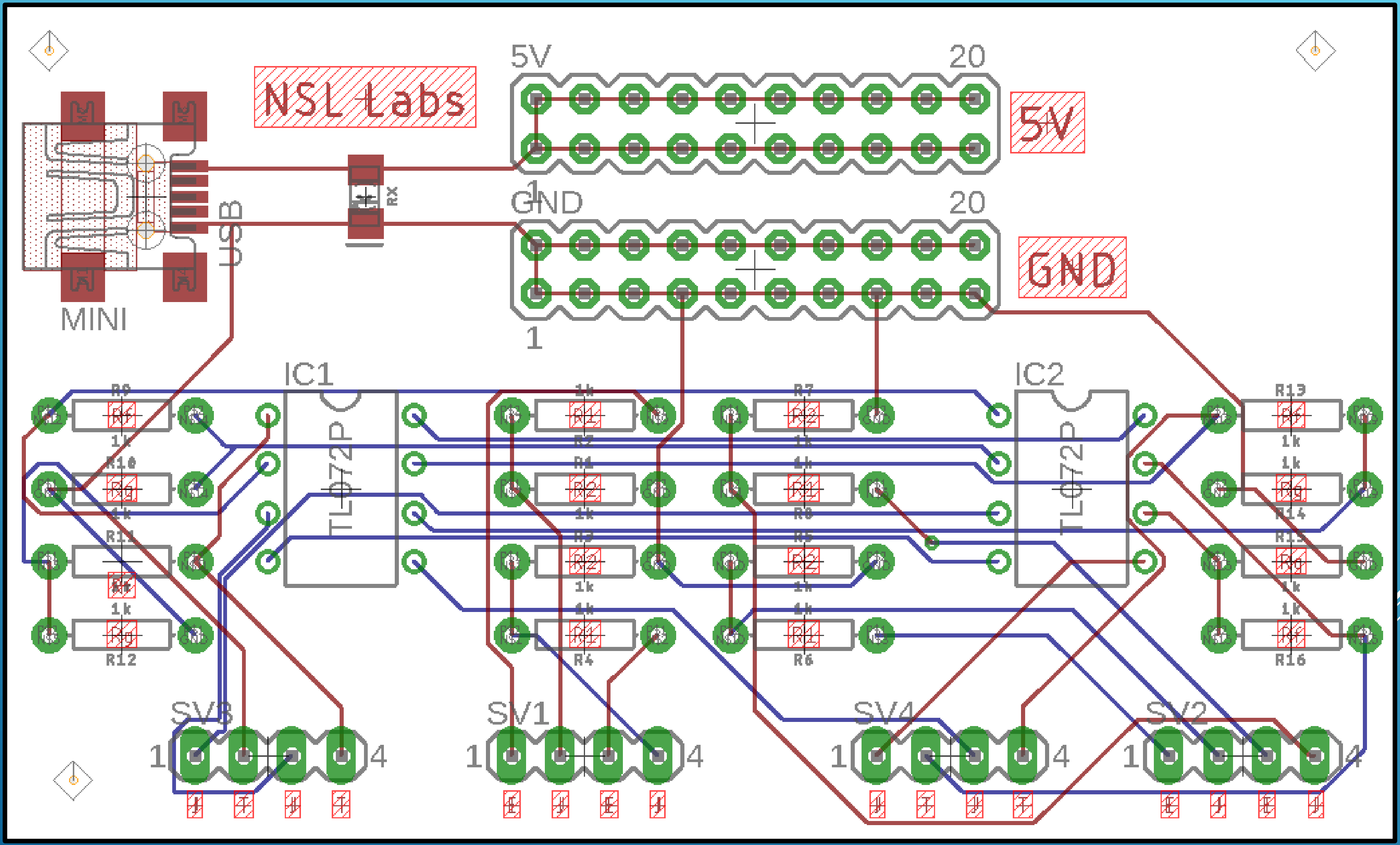
Communication between Microcontrollers is achieved by connecting analog pins 1, 2 & 3 on both MCUs together to signify drive states:

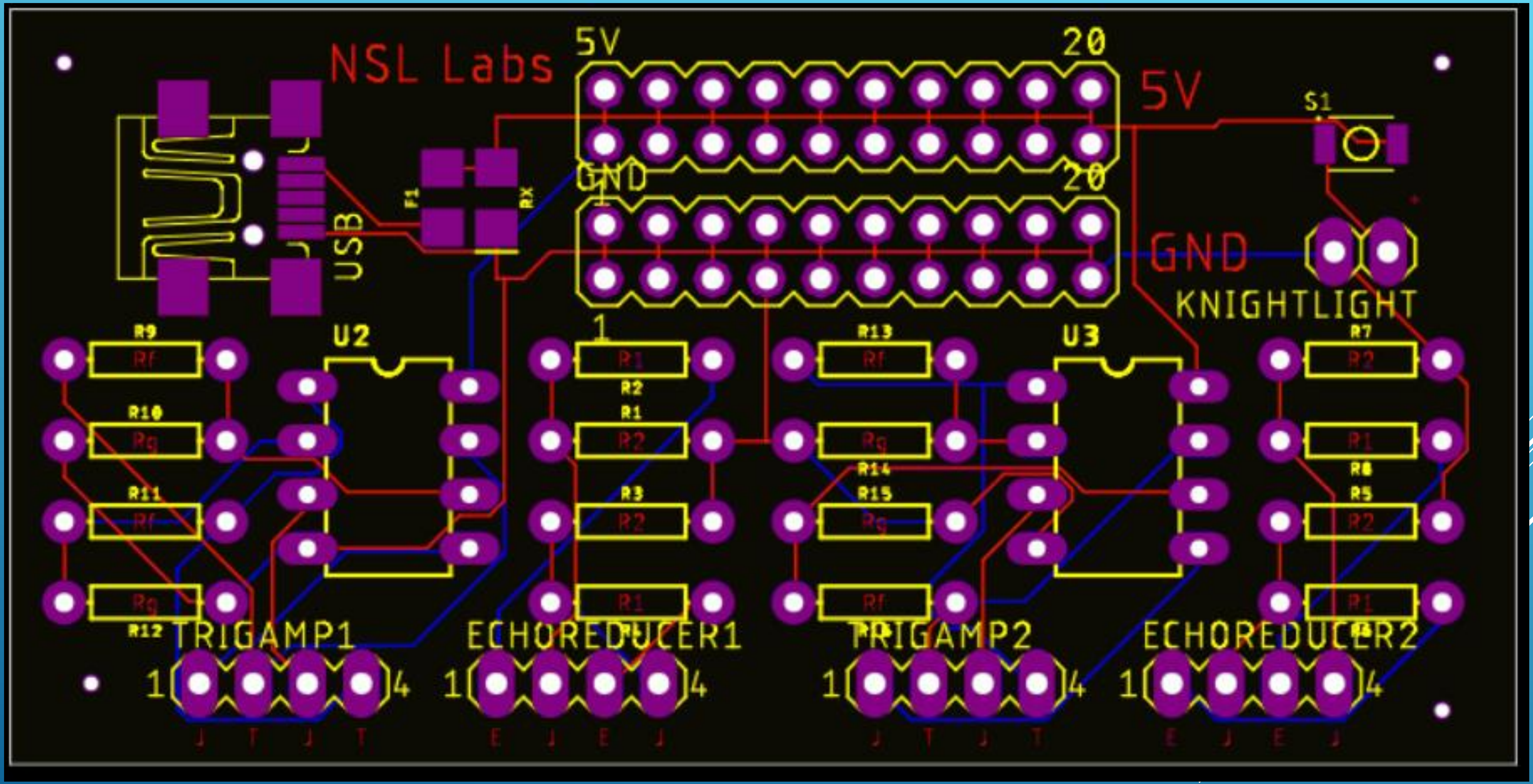
000 - Park
001 - Stop
010 - Teleop Control
011- Reverse
100- Forward
101- Right Turn
110- Left Turn
111- Error

Logic Level Shifter PCB Design



Logic Level Shifter PCB Design




NSL Labs
5V
20
GND
20
5V
GND
S1
USB
F1
KNIGHTLIGHT
U2
U3
R9
R10
R11
R12
R13
R14
R15
R7
R8
R5
R1
R2
R3
TRIGAMP1
ECHOREDUCER1
TRIGAMP2
ECHOREDUCER2
1
4
1
4
1
4
1
4

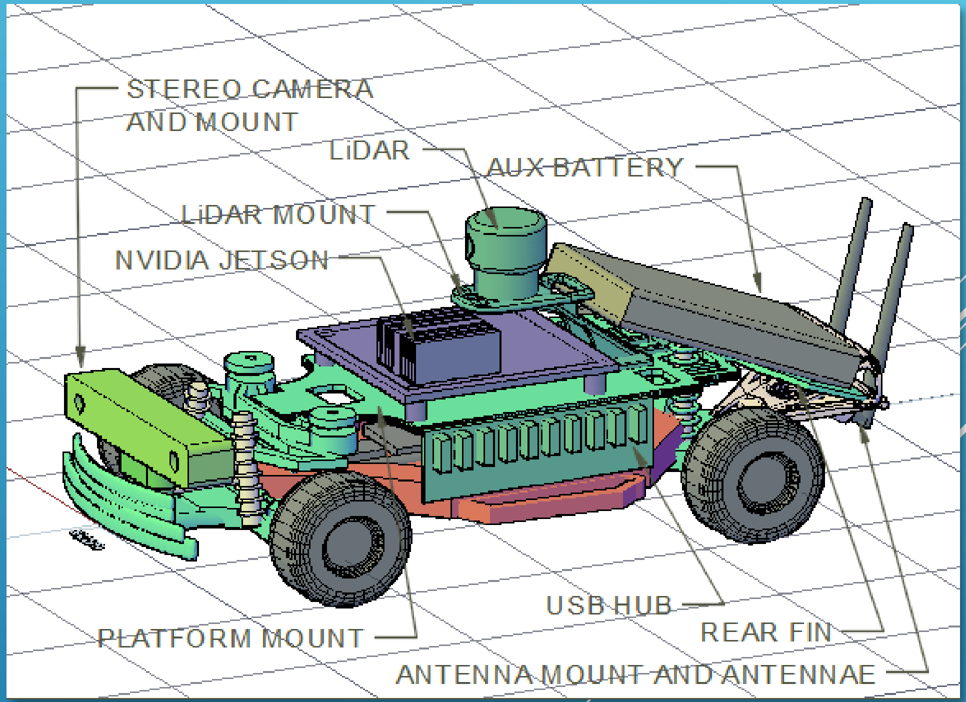
STRUCTURE DESIGN & 3D PRINTED MODELS

- 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.

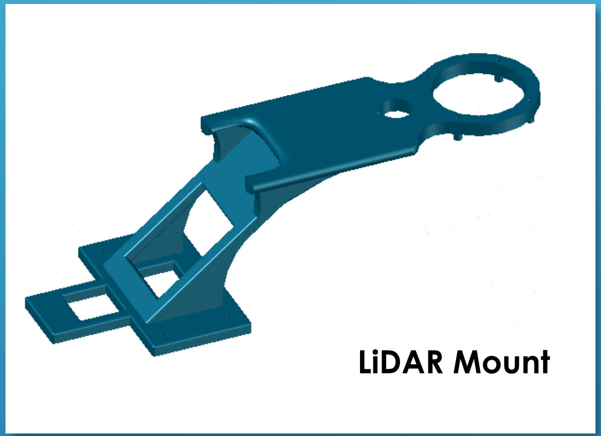
- All sensors, processing boards, and the PCB were integrated into the design and each possessed a personalized mount or designated area.

- AutoCAD software was used to construct all designs to precision.

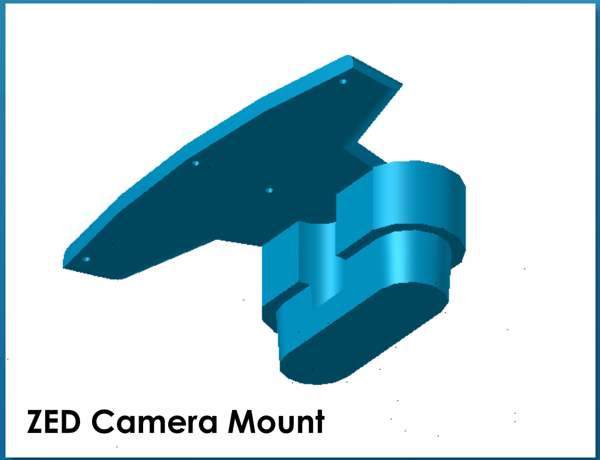


Current 3D Model

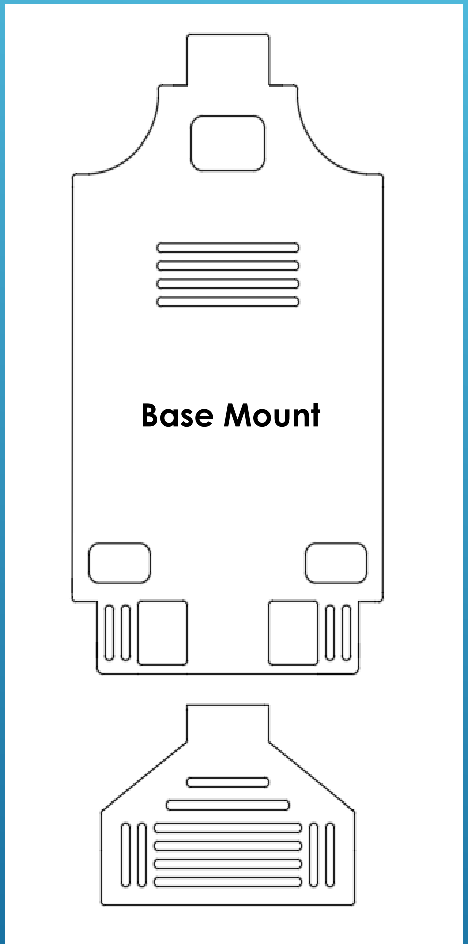
STRUCTURE DESIGN & 3D PRINTED MODELS



Designed for minimal vibration – fixed to Jetson Board

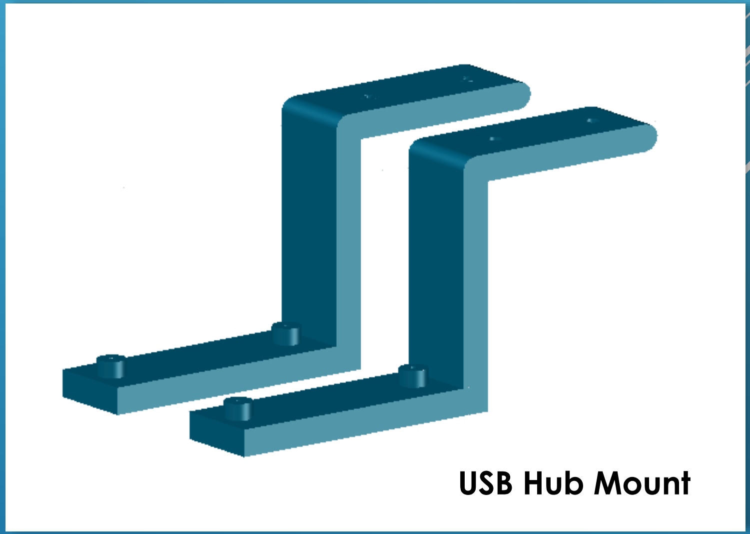


Designed with tapered insert – fixed to front bumper



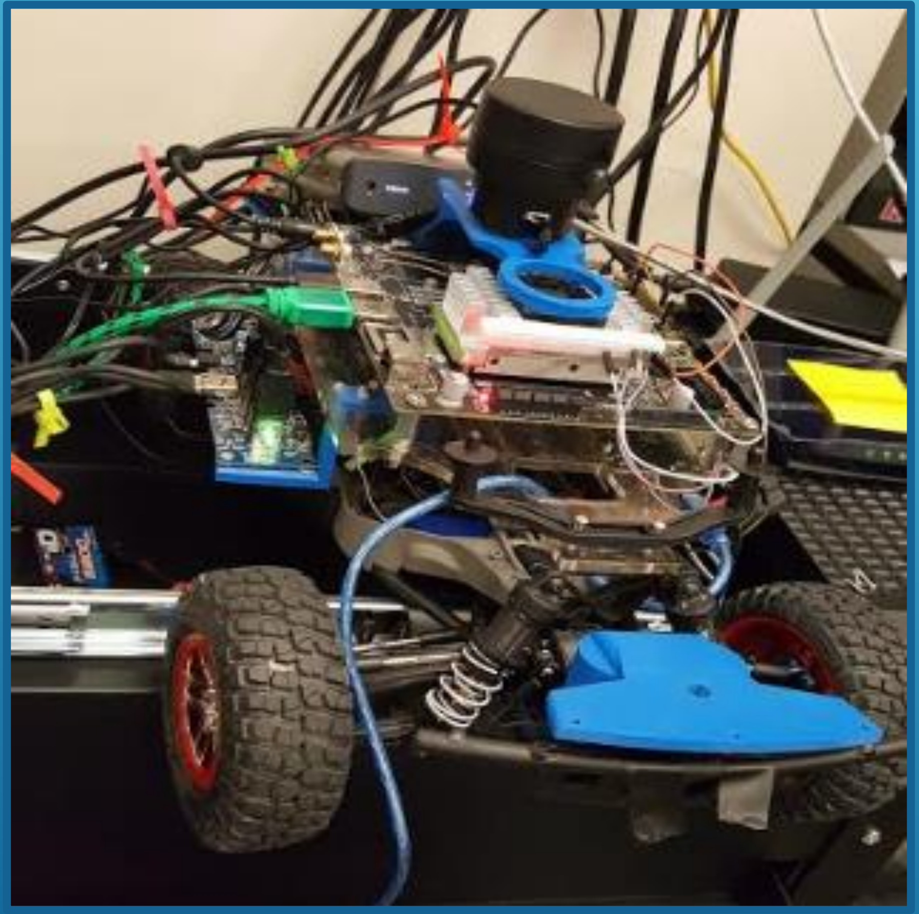
Designed for support, ventilation, and for ample cable access

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

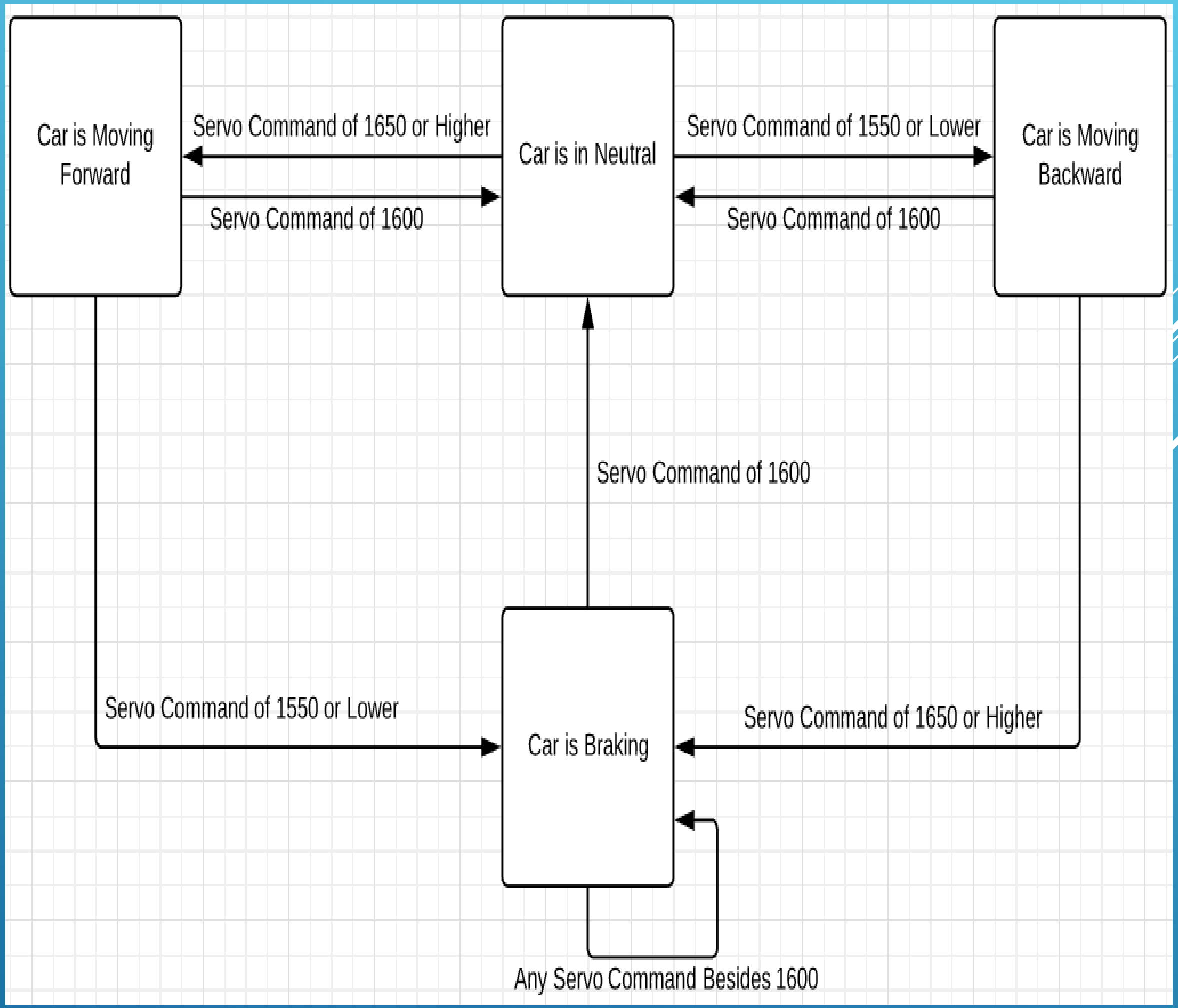
CAR TESTING

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

Motor Testing

- Like Steering, the motor is driven using pulse widths
  - Corresponds to [1000, 2000] in servo.write
  - [1551,1649]=Neutral
  - [1650,2000]=Forward
  - [1000,1550]=Backward
- Braking is done by going from Forward to Backward or vice versa
  - Direction can only be changed from neutral

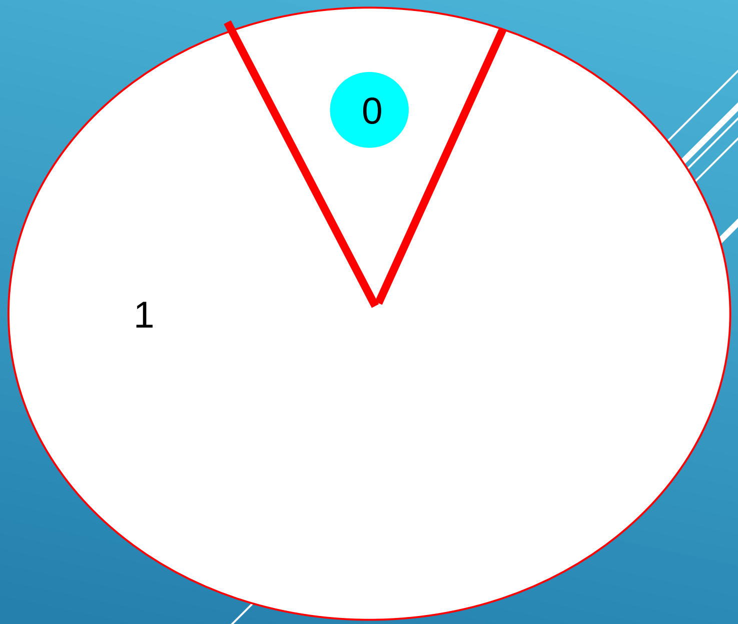


Tachometer

- Measures rotations of the spur gear that turns the wheels
  - Using engine rotations you can calculate the distance the car travels.
  - Needed for braking function and other features to be implemented later e.g localization and collision avoidance.
  - Hall Sensor attached to spur gear logs the rotations

Tachometer

- Only Rising edges are read
  - Edges are asymmetric
  - Reading only the rising or falling edge is simpler and loss of information is minimal.



Odometer Testing

- To verify that the Tachometer works accurately, we implemented an odometer to log data using 2 different tests
  - Forward to neutral distance
  - Forward to brake distance
- Distance measured is then compared to the distance the vehicle thought it moved

Odometer Results

- Forward to Brake

Servo Command	Odometer Distance (Inches)	Actual Distance (Inches)
1650	46.0	47.5
1700	60.49	61.74
1750	132.44	133

- Brake to Neutral

Servo Command	Odometer Distance (Inches)	Actual Distance (Inches)
1650	40.45	45.364
1700	110.27	103.4
1750	-	-

Brake Stopping Distance Results

- Forward to Brake (average of 5 runs)

Servo Command	Odometer Distance (Inches)	Actual Distance (Inches)
1650	46.0	47.5
1700	60.49	61.74
1750	132.44	133

- Brake to Neutral

Servo Command	Odometer Distance (Inches)	Actual Distance (Inches)
1650	40.45	45.364
1700	110.27	103.4
1750	-	-

Collision Avoidance

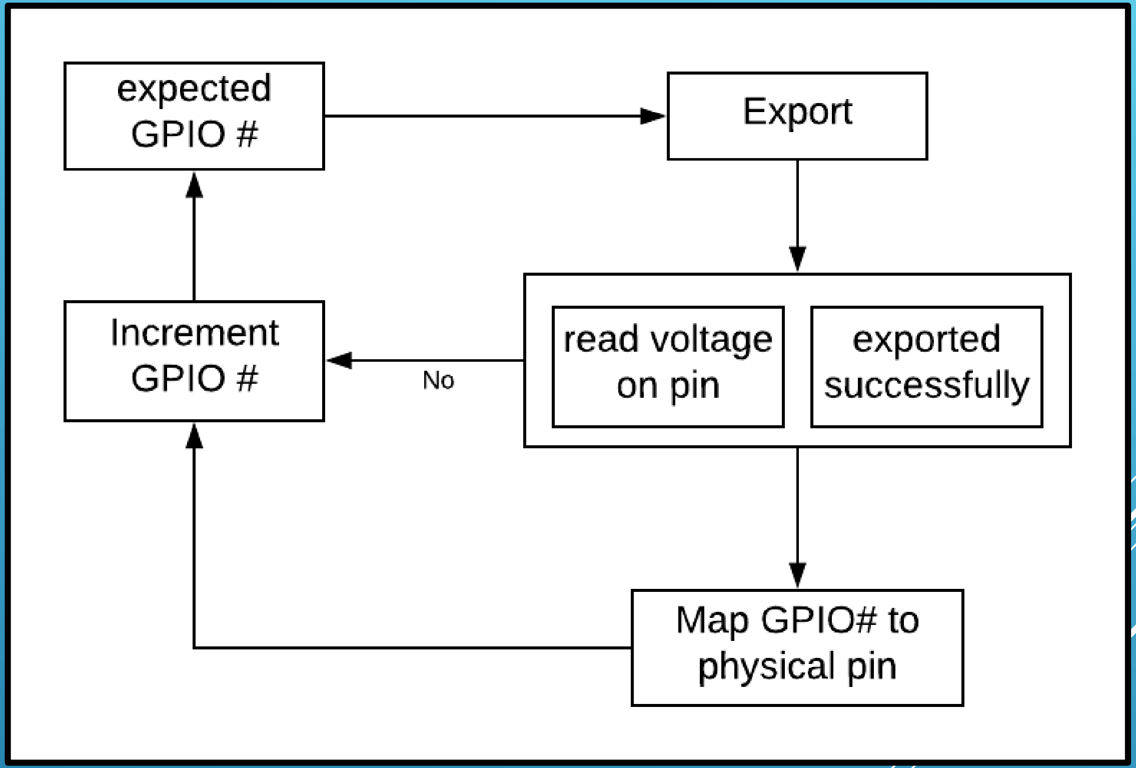
- If “main” ever fails, all the sensors will go down, but the PCB will keep driving the engine and servos using the last received values.

- An ultrasonic 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.
  - We tried to implement this on Jetson, but the latency was too high for them to be useful.

GPIO interfacing

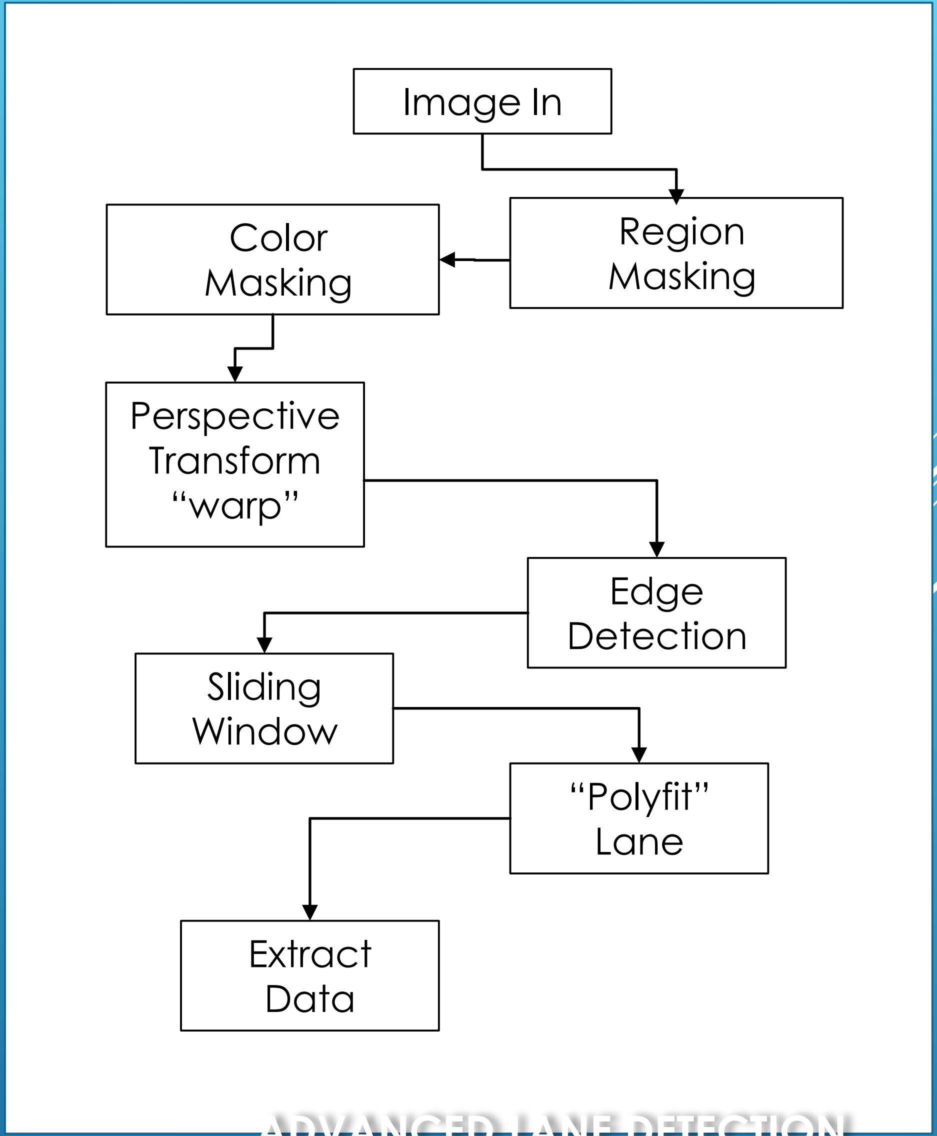
- 28 GPIO pins
  - 14 “true” GPIO pins
    - 1 RPM sensor
    - 1 Brake Pin
    - 1 “Emergency” Pin



ZED STEREO CAMERA – OPEN CV

- A chief component in autonomous vehicle localization is sensing the lanes of a road
- OpenCV provides various algorithms to be employed and manipulated for proper lane detection
- Various methods were tested including:
  - Color Gradient Masking
  - “Canny” Edge Detection
  - Extrapolation of “Hough” Lines
  - Perspective Transform
  - Polynomial fitting to lane contour
  - Sliding window approach

Using a combination of these methods, the algorithm is able to detect a left and right lane and calculate the position of the vehicle between the two



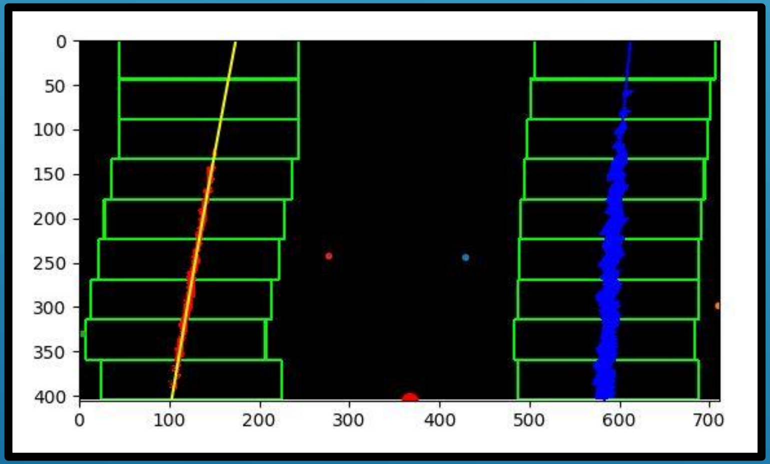
ADVANCED LANE DETECTION

ZED STEREO CAMERA – OPEN CV

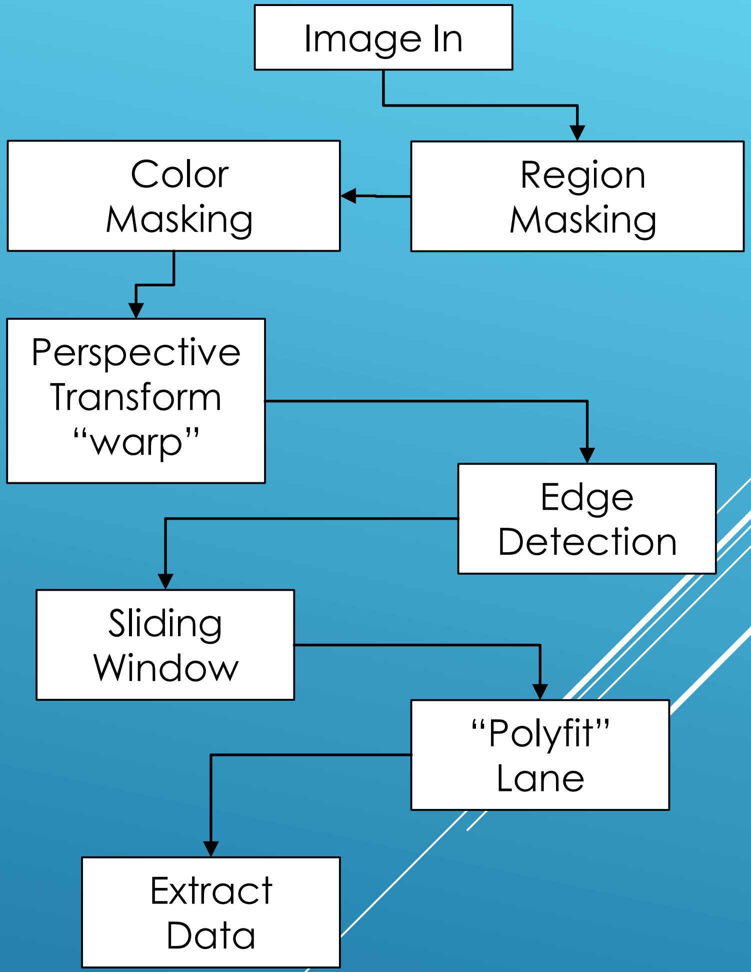
Image in

Color Masking

Perspective “Warp”



Polyfit

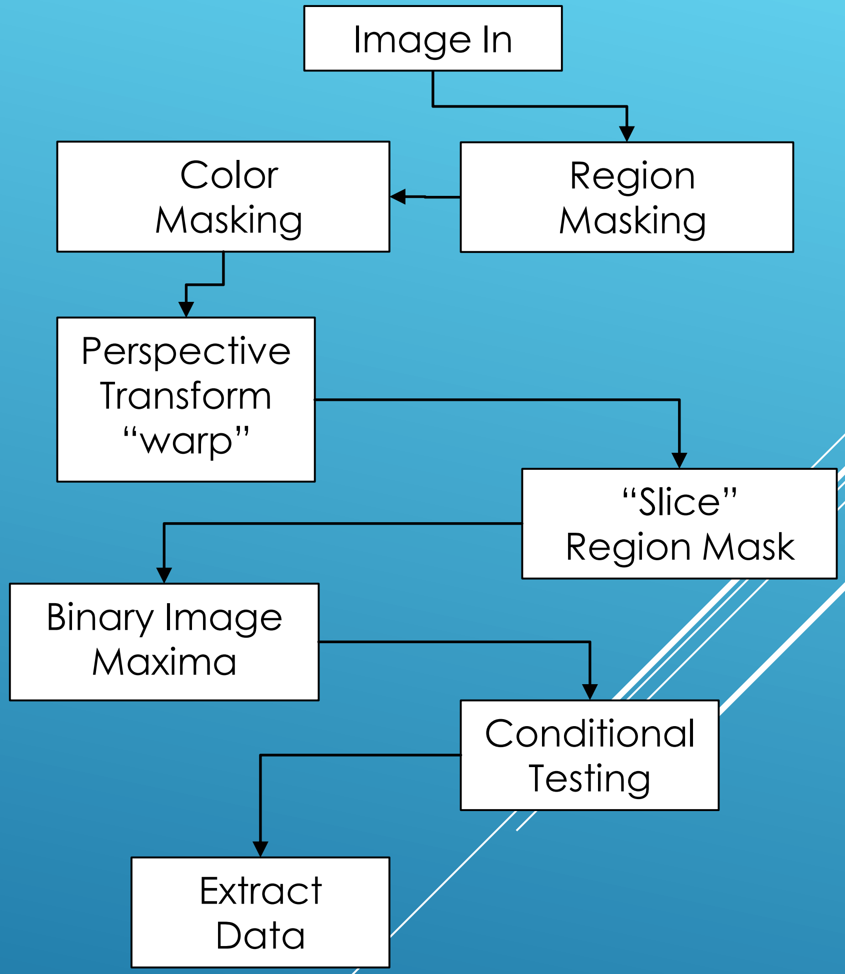


ADVANCED LANE DETECTION

ZED STEREO CAMERA – OPEN CV

- Advanced lane detection proved to be too latent for operation
- Offset, or line deviation was the sole value while yaw angle and radius of curvature was discarded
- Optimized, original code operated at around 0.04 seconds including steering angle writing – same functionality

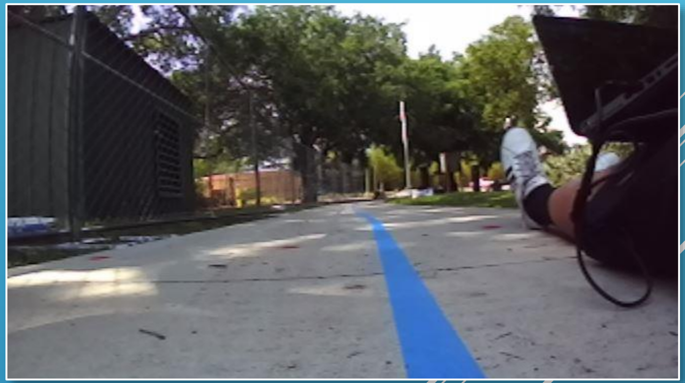
- Improved latency gave way to new feature opportunities:
    - Live camera stop function
    - Ignoring visual noise and horizontal lines



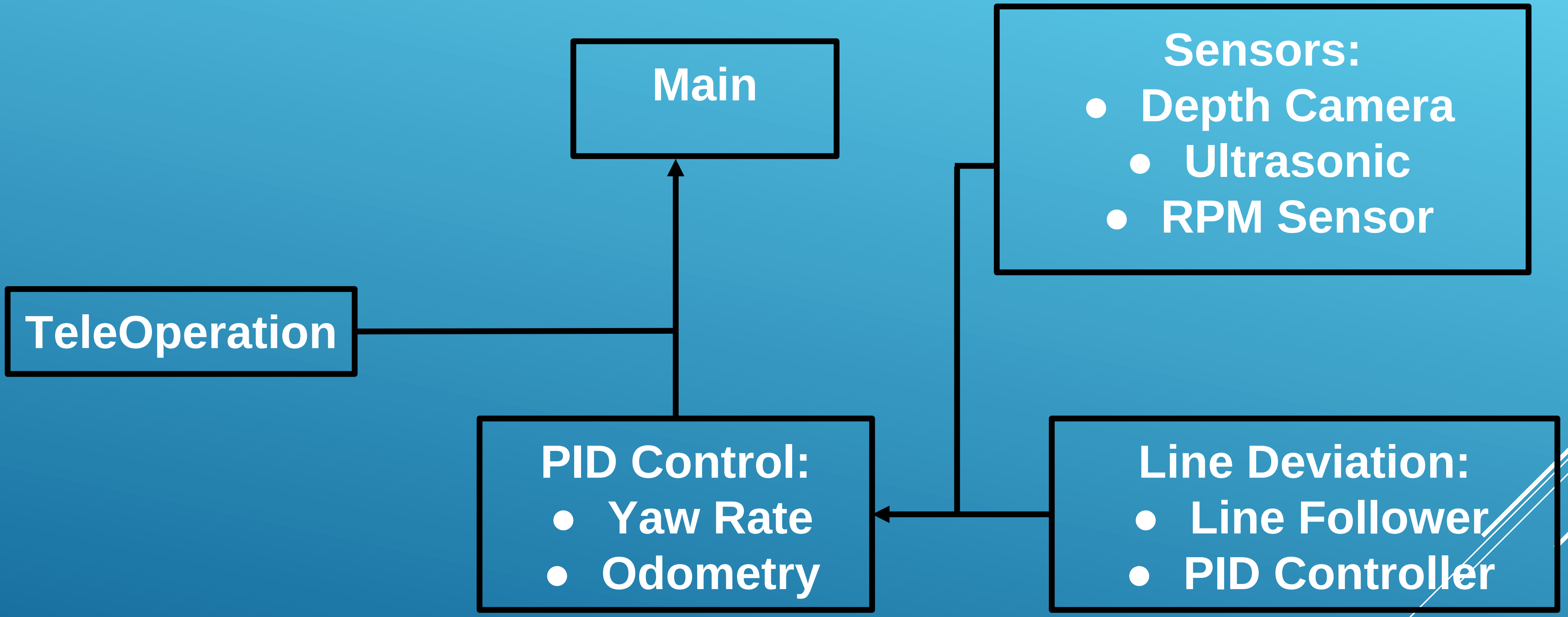
OPTMIZED LANE DETECTION

ZED STEREO CAMERA – OPEN CV

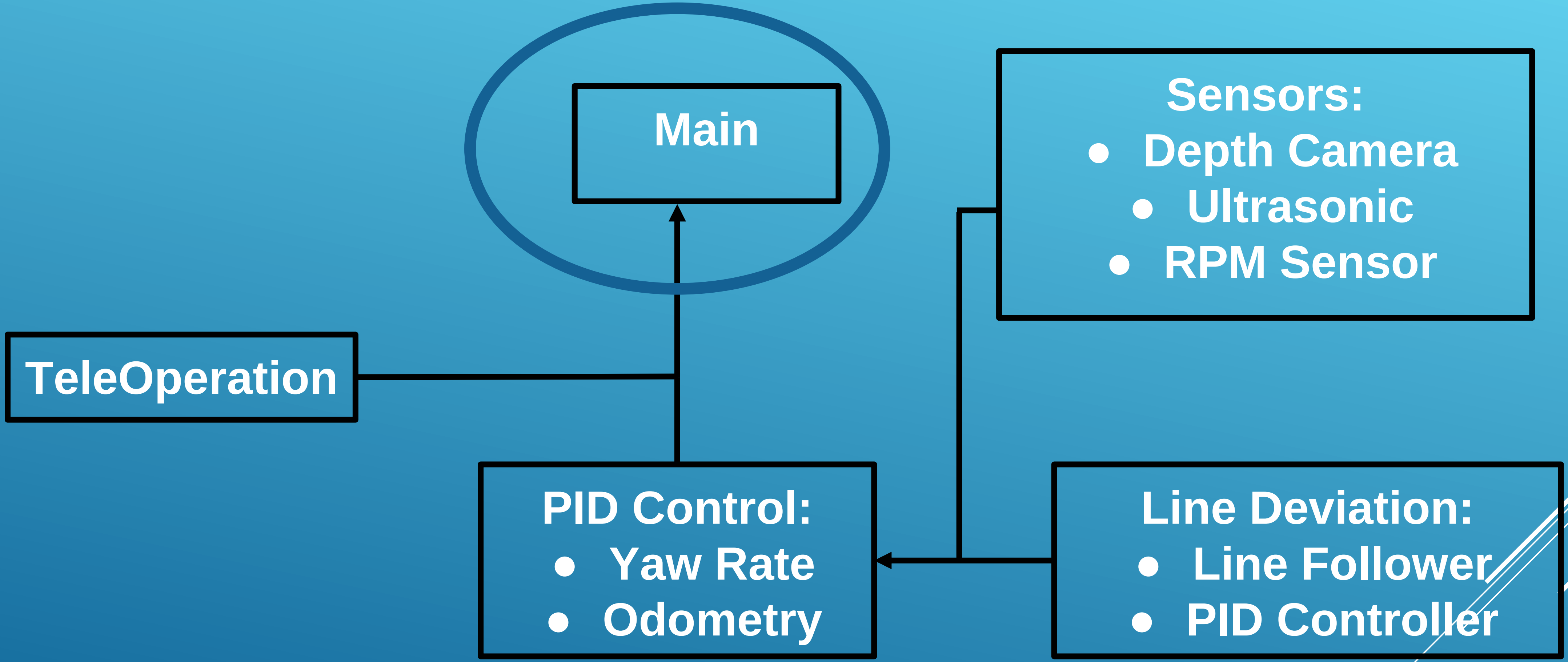
- No deep learning used – visual system still highly adaptable to any environment with a line
- Algorithm functional for straight, angled, or curved lines
- Only parameter to be changed is acceptable RBG range of line color
- Sensitive to light and color: future considerations may include and adaptable color mask



SOFTWARE DIAGRAM



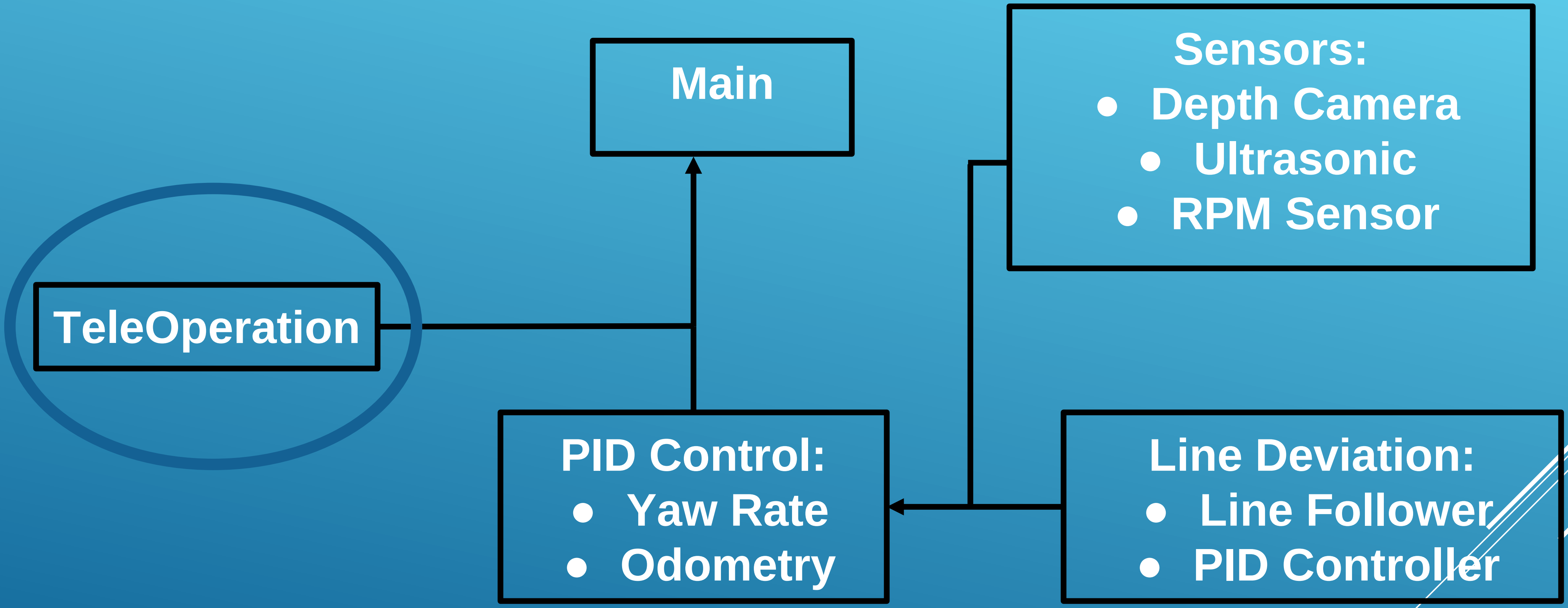
Main


Main
Sensors:
Depth Camera
Ultrasonic
RPM Sensor
TeleOperation
PID Control:
Yaw Rate
Odometry
Line Deviation:
Line Follower
PID Controller

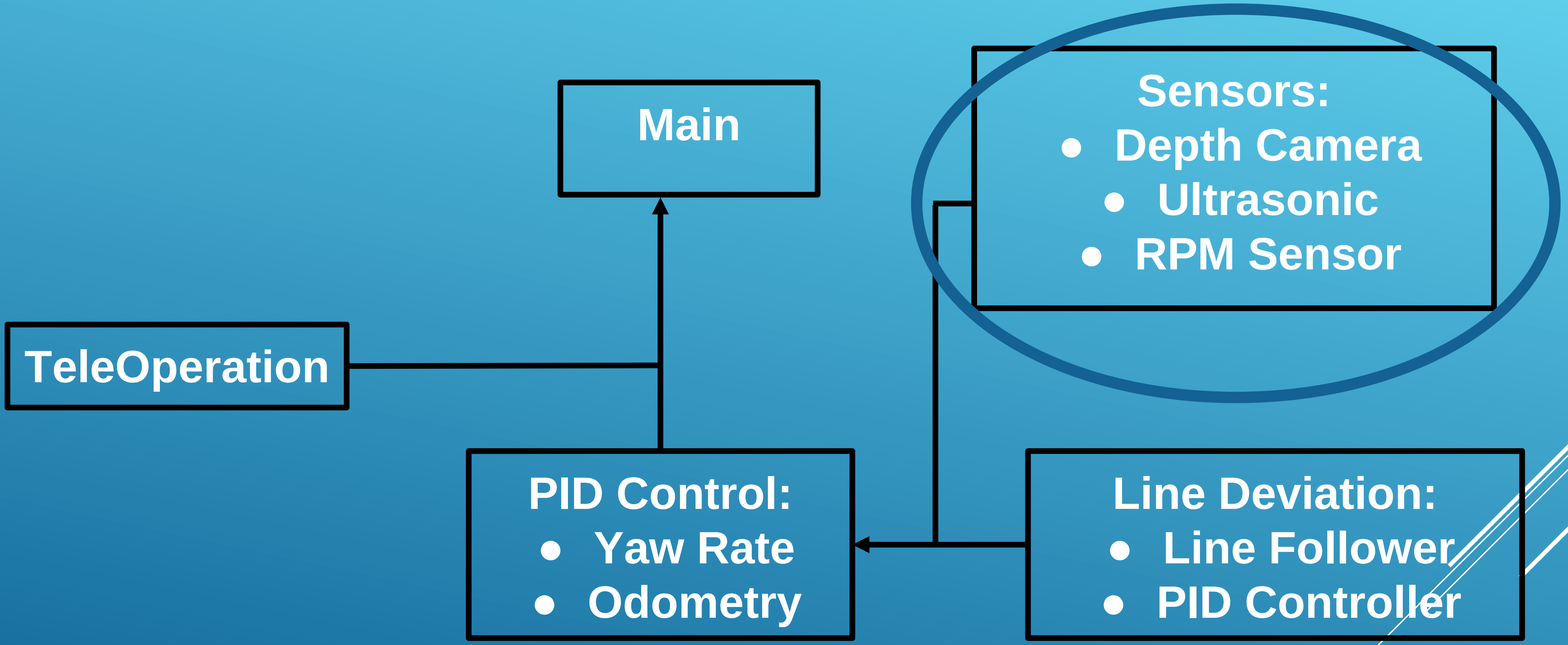
MAIN

- To coordinate all processes and threads running in the TX2
  - Directly launches threads controlling tachometer, serial write/read, keyboard input, and teleoperation
  - Integrates the offset angle returned from the Vision and PID process
  - Inform the PCB about the TX’s state through auxiliary GPIO pins
- Uses distinct threads for tachometer, serial input, serial output, and keyboard to allow for multiple tasks to execute simultaneously in a compact manner
  - Shared resources are mutex-protected to prevent cross-talk and undefined behaviour from occurring

TELEOPERATION



SENSORS


Main
TeleOperation
Sensors:
Depth Camera
Ultrasonic
RPM Sensor
PID Control:
Yaw Rate
Odometry
Line Deviation:
Line Follower
PID Controller

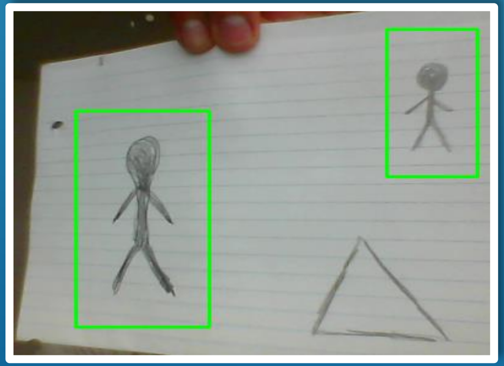
SENSORS

- Each sensor has a different purpose
  - Vision is the primary sensor
  - Tachometer used to implement a coherent and safe brake function
  - Sonar sensors use to detect objects in front of the vehicle

ZED STEREO CAMERA – OPEN CV

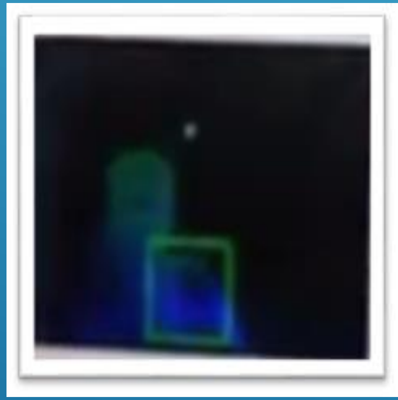
- For autonomous vehicles, the ability to track object is essential for localization purposes and predictions of path and velocity of surrounding objects in motion.
- OpenCV is an open-source computer vision library, and is the main tool for customized computer vision.
- Python 3.5 programming language 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

TELEOPERATION

- Move the vehicle with the keyboard from a remote computer via SSH

- Manually pause the vehicle for any reason

- 1 byte sent to PCB over UART, interpreted as an int
  - 0 <= value <= 100: motor command
  - Value < 0: steering command

Cons:

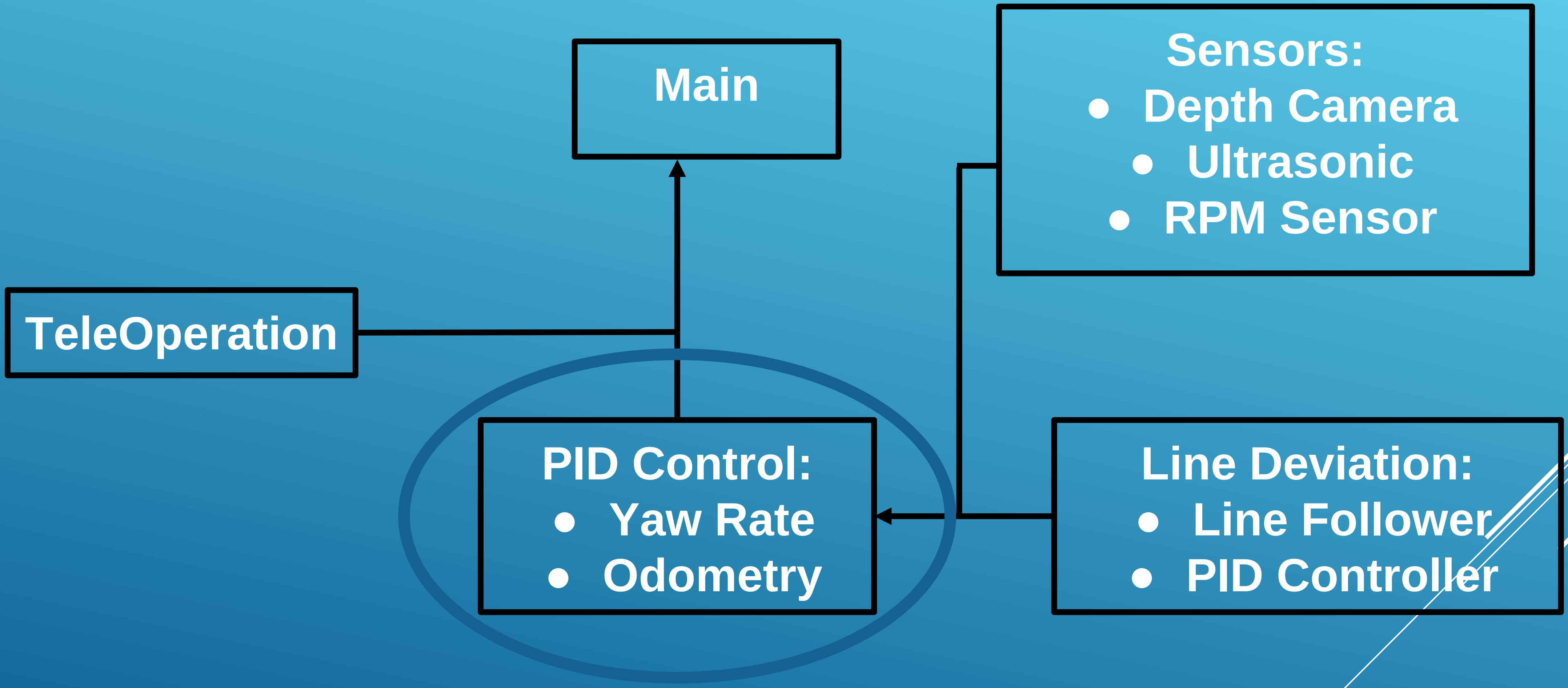
- Latency of the ssh connection may cause noticeable lag

- TeleOp ***MUST*** take priority over all other planning algorithms to allow emergency stopping of the vehicle

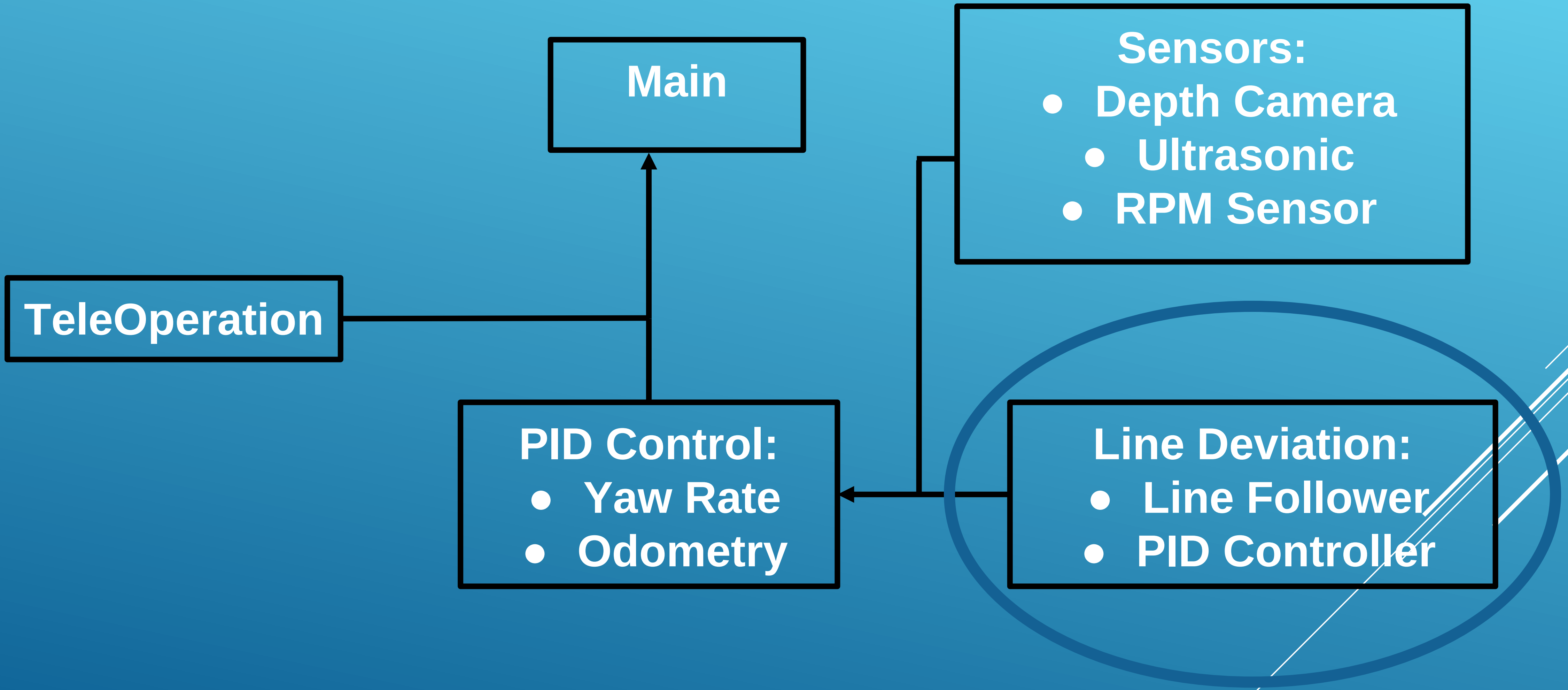
Brake Function

- The ESC expects a remote controller
  - PCB simulates this based on the last valid received motor byte
  - TX2 simulates this based on the knowledge of whether it's commanding the PCB to move forward, brake, or neutral
- Issues:
  - PCB and TX2 try to simulate braking at the same time
  - If the wheels are still "moving," the Jetson may misinterpret its state as unintentional movement

PID CONTROLLER



LINE DEVIATION



LINE DEVIATION/PID

- 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 a straight line
    - Maximum settling time of 5 seconds

PID Tuning

- A PID controller was used to control the steering angle of the vehicle
  - Controlling Yaw Rate proved difficult to simulate due to the number of variables ()
- PID tuning was done manually as opposed to simulated
  - Varying speeds, turning radii, etc. made it difficult to create an acceptable simulation
- The method:
  - Start with all values at 0
  - Set a value for P (P_0=1)
  - Choose a Step Size (S=0.5)
  - Run the vehicle at P=P_0-S (0.5) and P=P_0+S (1.5)
  - Choose the value that lead to better results (P_0=1.5)
  - Halve the step size and repeat until satisfactory results are obtained.
  - Repeat procedure for D, and then I

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 Oscillator	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	X	X	X
OpenCV Computer VIsion		X		
Lane Detection		X		
PID Control Design			X	
System Integration			X	X
Nvidia Programming Setup				X

OBSTACLES

- Linux and OpenCV learning curve
- Unavailability of NVIDIA documentation
- Zed Camera software and library installation on Jetson
- Interprocess and interprocessor communication

Line Following Demo

- Test Run With:

P = 1.8
I = 0.01
D = 0.1

Thank You
For Your Time