Robotic Automated Platform for Item Delivery - R.A.P.I.D.

Group 23 - Antonio Duchesneau, Alex Green, Arthur Radulescu, & Brandon Holtzman

Meet the Team

Antonio Duchesneau - EE

Alexander Green - CpE

Brandon Holtzman - CpE

Arthur Radulescu - EE

Motivation

Brandon Holtzman CpE

- Workplace deliveries take time from employees
- Reduce impact of inefficiencies
- Assist human labor

Overview

Brandon Holtzman CpE

- Create an autonomous robot to deliver items
- Create a driving system that uses both LiDAR and Computer Vision
- Create a user interface to select a destination for delivery and then verify recipient with RFID

Engineering Specifications

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	Parameter	Specification
Cameras, MCU	Object Detection and Avoidance	OpenCV can detect all objects larger than 6in^3 with 80% success rate
Motors, Motor Controller Boards, PSU	Speed of Delivery	> 6 in/sec travel speed
Touch Screen Display, RFID, Solenoid Locks	Package Delivery User Interface Time	< 45 sec interaction time receiving packages
PSU	Battery Life	> 30 minutes
Platform Body	Weight and Size	< 30 lbs weight & smaller than 36” x 24” x 12”
Package Container	Package Container Size	> 6” x 6” x 6” Package size

Overall Hardware Block Diagram

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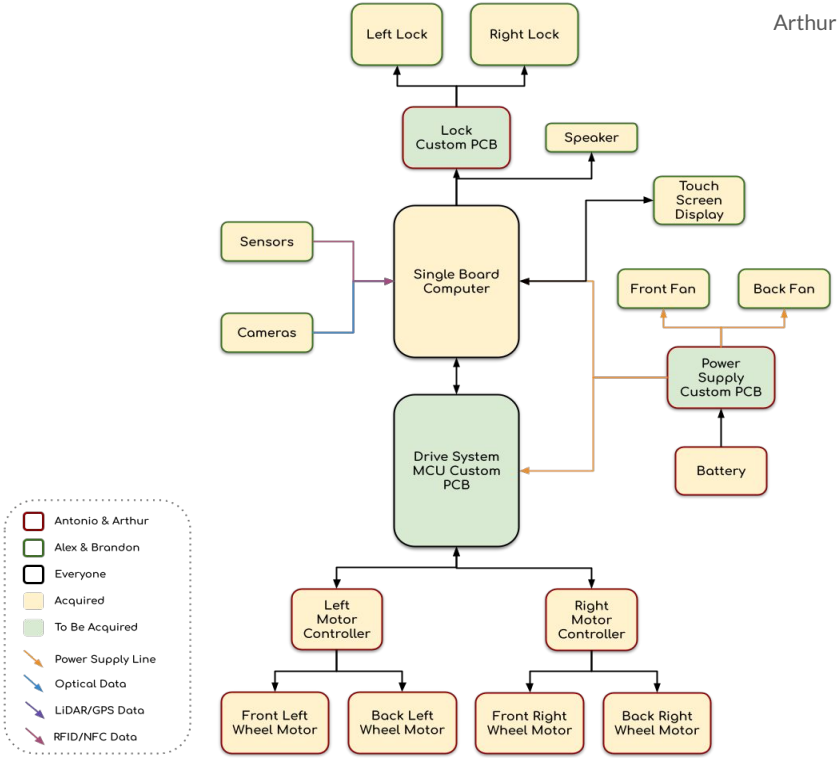
- Single Board Computer handles computations and processing
- Sensors needed to provide “vision” to the platform, allows for obstacle detection and avoidance
- Touch screen display acts as user interface and provides ID verification using tag reader
- SBC communicates with Drive System MCU PCB to drive the platform and avoid obstacles.
    - Two motor controllers used to control four motors total
- 12V battery connected to Power Distribution PCB, provides 12V and 5V rails.
- Front and Back fans used for active cooling



Driving System

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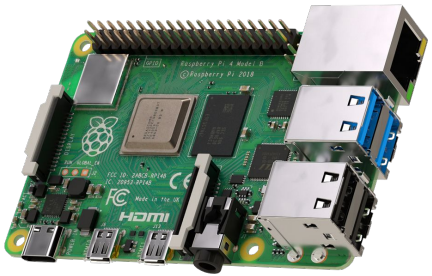
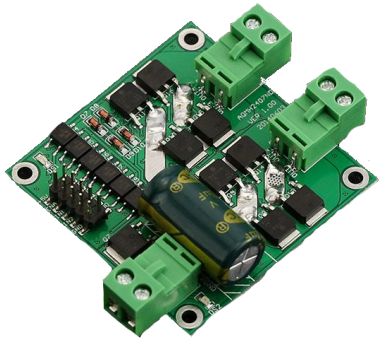
- Consists of four gearmotors that each drive individually
- The two dual channel motor drivers
- Raspberry Pi for generating driving commands (Tx to ATMega)
- ATMega PCB provides logic necessary for motor drivers (Rx from Pi)





Drive System Components & Organization

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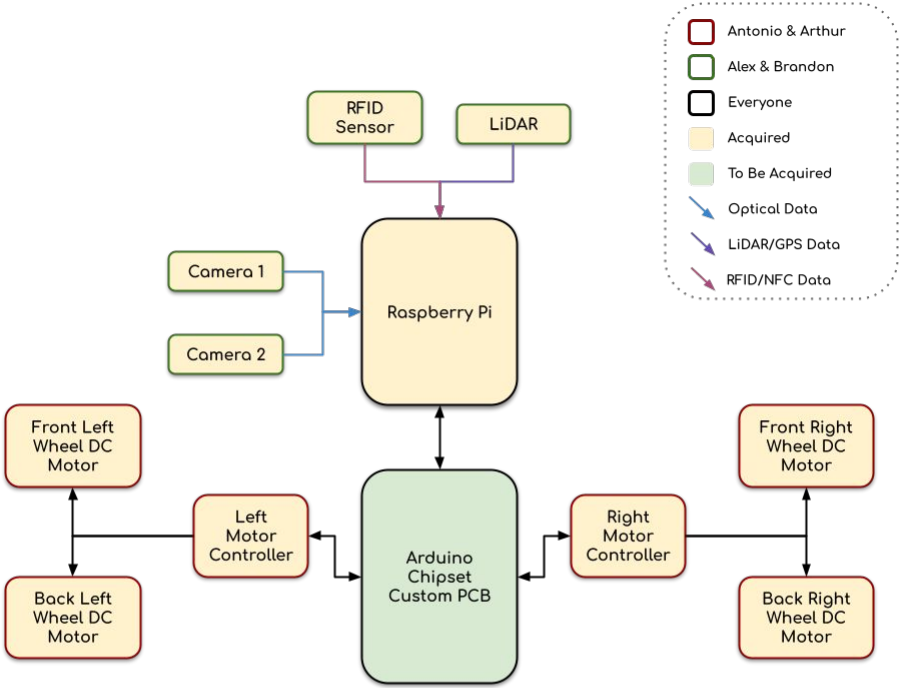
- Motors: GB37Y3530-12V-251R
- Motor Drivers: DRI0041
- SBC: Raspberry Pi 4
- MCU: ATMega2560 PCB



Motor Selection

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- High torque necessary for load capability of the vehicle
  - DC Gearmotors were considered options
- Include encoders for ease of integration
  - Encoders are easily implemented on Arduino IDE

Specification	DF Robot 251 RPM Gearmotor	DF Robot 350 RPM Gearmotor	Stepper Online 171 RPM Gearmotor
Voltage	12V	12V	24V
Speed	251 RPM	350 RPM	171 RPM
Torque	1.75 N-m	1.17 N-m	1.9 N-m
Gerbox Reduction Ratio	43.8:1	34.0:1	26.8:1
Price	$29.99	$29.00	$12.04

Motor Driver

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Driver	2x3A DC Motor Driver (L298N)	15A Single DC Motor Driver (DRI0042)	2x7A DC Motor Driver (DRI0041)
Maximum Current	6A	12A	7A
Voltage Range	5V-35V	12V-36V	7V-24V
Number of Channels	2	1	2
Price	2.3	$18.90	$21.00

Single Board Computer Selection

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Specifications	Raspberry Pi 4b	Raspberry Pi 3	Nvidia Jetson Nano
Price	$82	$40	$152
CPU	Quad-core Cortex-A72 @ 1.8GHz	Quad-core Cortex-A53 @ 1.4 GHz	Quad-core ARM A57 @ 1.43 GHz
GPU	Broadcom BCM2711 (no dedicated GPU IC)	Broadcom BCM2837B0 (no dedicated GPU IC)	128-core Maxwell dedicated GPU IC
Memory	8GB	1 GB	4 GB
Video Encode	H.264 1080p @ 30	H.264 1080p @ 30	H.264/H.265 4K @ 30
Video Decode	H.264 1080p @ 60 H.265 4K @ 60	H.264 1080p @ 60	H.264/H.265 4K @ 60 | 2x 4K @ 30
USB	2 USB 3.0 ports; 2 USB 2.0 ports.	4x USB 2.0	4x USB 3.0, USB 2.0 Micro-B

MCU Selection

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Microcontroller	ATmega2560	ATmega328P	ESP32
Digital I/O Pins	54	14	36
Analog Input Pins	16	6	18
PWM Outputs	15	6	16
Interrupt Pins	6	2	34
Flash Memory	256 KB	32 KB	4 MB
SRAM	8 KB	2 KB	520 KB
EEPROM	4 KB	1 KB	-
Clock Speed	16 MHz	16 MHz	80 MHz
Input Voltage	7-12V	7-12V	5V

Sensors

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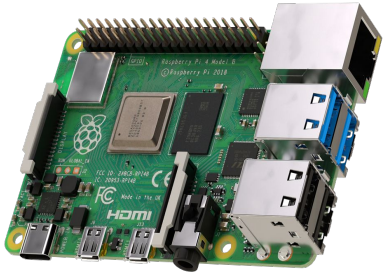
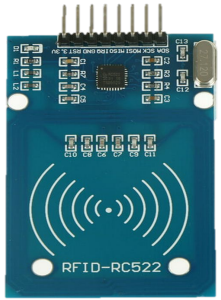
- Consists of two camera modules, a LiDAR module, and an RFID tag reader module
- Cameras and LiDAR provide visual input to the Raspberry Pi
- RFID module reads ID card, sends card ID to Raspberry Pi to validate recipient





Sensor System

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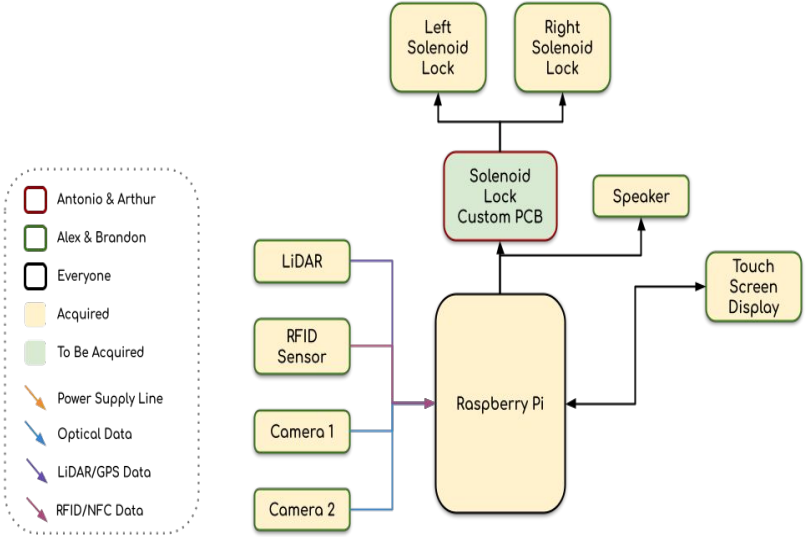
- Cameras: Raspberry Pi Camera Module V3 Wide
- LiDAR: RPLiDAR A1M8-RG
- SBC: Raspberry Pi 4
- RFID Module: Sunfounder RC522 Module RFID Reader



Camera Selection

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Camera	Resolution	External Driver Support Required	Field of View	Price
Logitech C270	720P / 30fps	Yes	60°	$39.99
Logitech C920	1080p / 30fps	Yes	60°	$79.99
ToLulu Pro	1080p / 30fps	Yes	110°	$22.99
Raspberry Pi Camera Module V2	1080p / 30fps 720p / 60fps	Natively Supported	60°	$24.99
Raspberry Pi Camera Module V3 Wide	1536x864 / 120fps 2304x1296 / 56fps	Natively Supported	120°	$35.00

LiDAR Selection

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Specification	RPLiDAR A1M8-RG	YDLiDAR X2	Slamtec Mapper M1M1
Price	$99.99	$99.99	$250
Rotation Frequency	5.5Hz	5-8Hz	5-10 Hz
Sample Frequency	8KHz	3kHz	7kHz
Range	0.15 to 12 meters	0.12 to 8 meters	20 meters
Resolution	< 0.5 mm	Not specified	5cm
Power Consumption	0.5W	0.5W-2W	2W-5W
System Current	100mA	300mA	500mA
Accuracy	2.50%	3.50%	Not Specified

Component Power Summary

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Component	Voltage	Max Sustained Current Draw	Peak Current Draw	Max Wattage	After DC-DC Loss (95% efficiency)
Raspberry Pi Camera Module V3 Wide x2	3.3V	300mA x 2 = 600mA	450mA* x 2 = 900mA*	1.98W	2.08W
Coral TPU USB	3.3V	500-900mA	900mA	2.97W	3.12W
RC522 RFID	3.3V	13-26mA	26mA	0.09W	0.09W
ATmega2560 Motor Controller Board	5V	200-700mA	700mA	3.5W	3.68W
RPLiDAR A1MG-RG	5V	450mA	700mA	2.25W	2.36W
Raspberry Pi 4	5V	800mA	3000mA	4W	4.21W
Aisichen 7in Touch Screen	5V	500mA	750mA*	2.5W	2.63W
Solenoid Lock	12V	430mA x 2 = 860mA	650mA x 2 = 1300mA	10.32W	10.86W
Hardware Ventilation Fans	12V	120mA	120mA	1.44W	1.51W
DFRobot 251 RPM Motors x4	12V	350-2500mA x 4 = 1400-10000mA	7000mA x 4 = 28000mA	120W	126.31W
			Max Continuous Amperage	**Max Peak Amperage**	**Max Wattage**
			15A	**36.5A**	**149.05W**

Battery Technology Comparison

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	Lead Acid	Nickel-Cadmium	Nickel-Metal Hydride	Lithium Ion
Energy Density	80-90 Wh/L	50-150 Wh/L	140-300 Wh/L	250-693 Wh/L
Specific Power	180 W/kg	150 W/kg	250-1000 W/kg	250-340 W/kg
Charge/Discharge Efficiency	50-95%	70%-90%	66-92%	80-90%
Energy Price	7-18 Wh/$	23 Wh/$	2-10 Wh/$	7.6 Wh/$
Self-discharge Rate	3% - 20% per month	10% per month	10-15 % per month	0.35-2.5% per month
Cycle Durability	<350 cycles	2000 cycles	700-1000 cycles	400-1200 cycles
Nominal Voltage	2.1V	1.2V	1.2V	3.7V

Battery Selection

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	NERNAK 12V 12Ah Lithium LiFePO4 Battery	XZNY 12V 18Ah LiFePO4 Battery	BOMUZIK 12V 15ah LiFePO4 Battery
Cost	$46	$65	$59
Amp Hour	12ah	18ah	15ah
Peak Discharge Current	30A (3 seconds)	40A (5 seconds)	45A (3 seconds)
Maximum Continuous Discharge Current	12A	20A	15A
Dimensions	5.94" x 3.81" x 3.71"	5.94” x 3.9” x 3.7”	6.42” x 4.88” x 4.76”
Weight	3.23 lbs	4.3 lbs	3.25 lbs

Drive System Schematic

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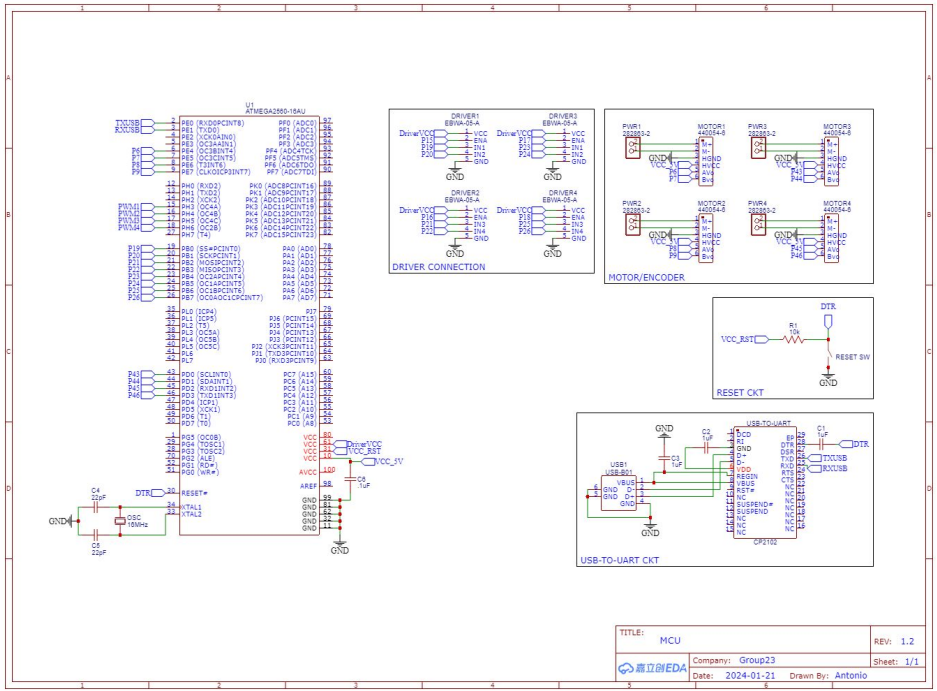
- ATMega2560 is our MCU of choice
  - 20 Digital I/O Pins
    - (4x) PWM capable
    - (6x) Interrupt capable
    - (10x) Regular Digital Pin
- CP2102 is our USB-to-UART bridge
  - On board USB-to-UART function allows for serial communication and power from the Raspberry Pi



Drive System PCB (Rev A)

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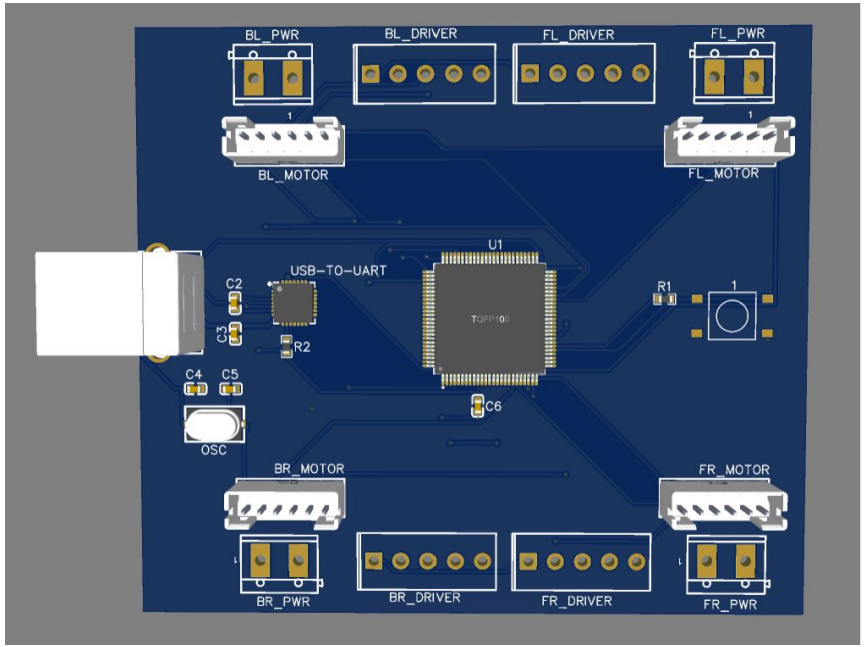

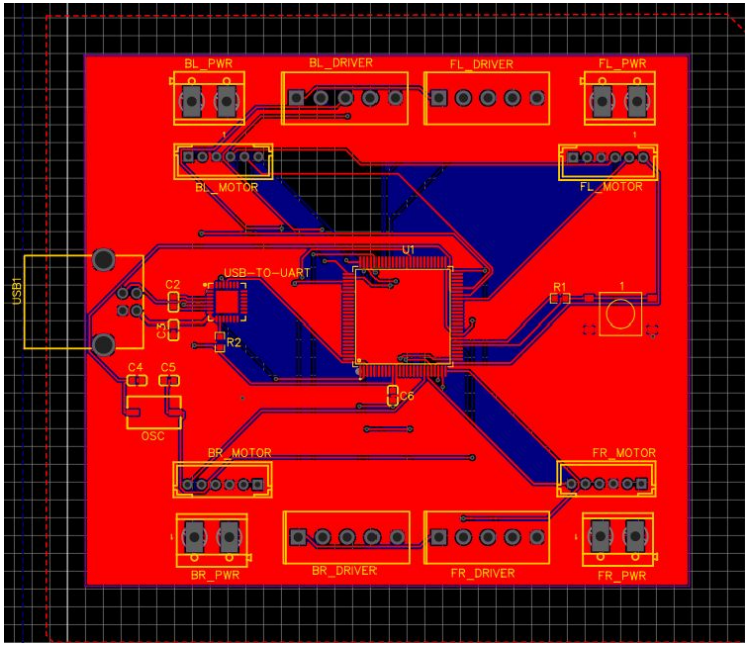

Drive System PCB (Rev B)

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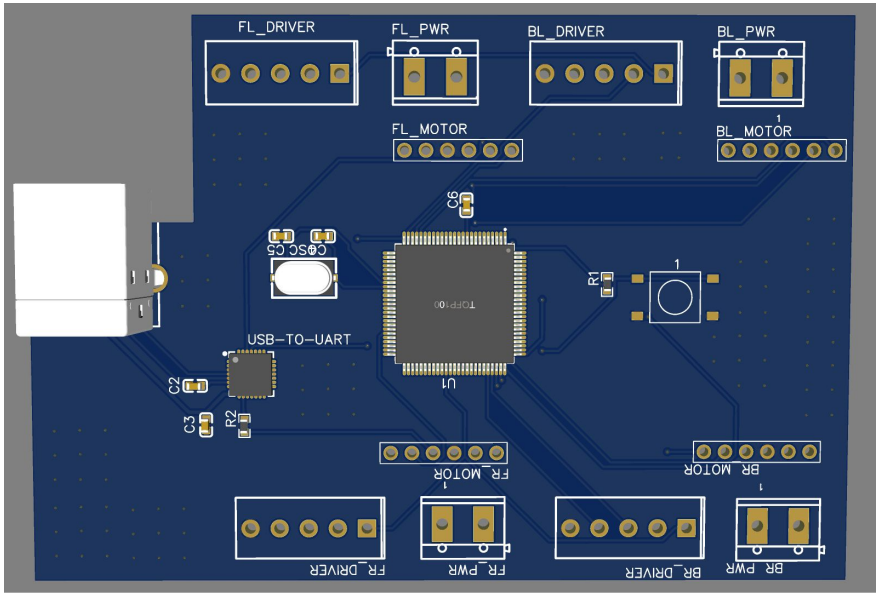

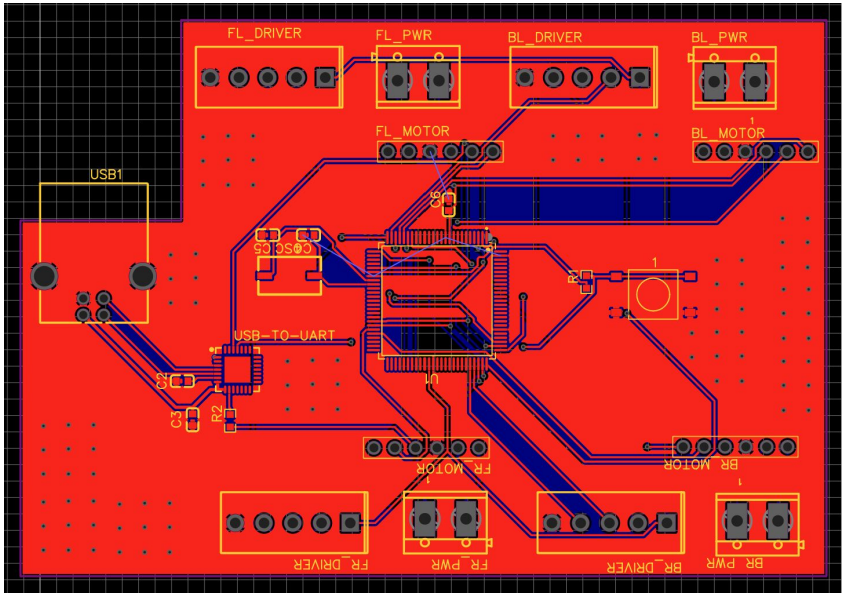

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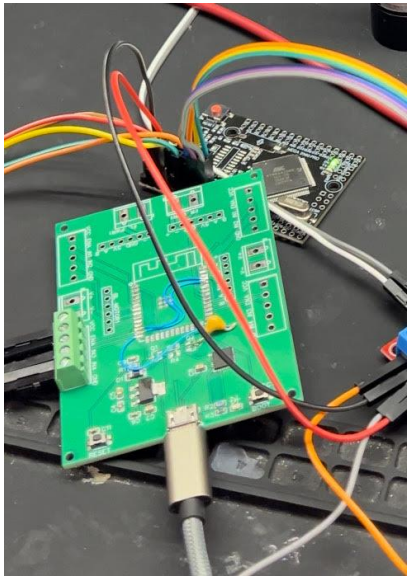
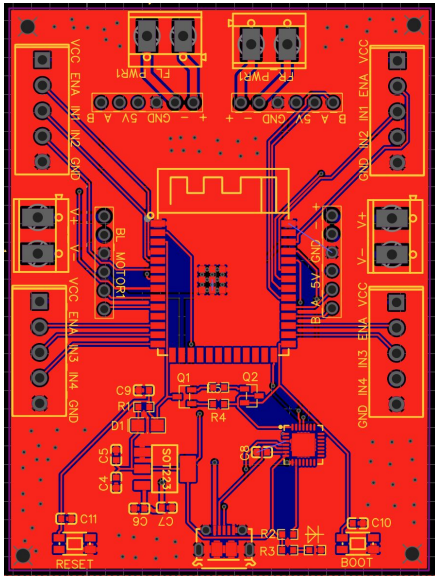
ESD Development Issues

- ATMega2560 ESD ruining chips
  - Pre-populated
  - Assembled with ESD mats
- UART Bridge Solution
  - Used a new CP2102 UART bridge PCB
  - Bridged to a unpopulated development





Power Regulation and Distribution Schematic (Rev A)

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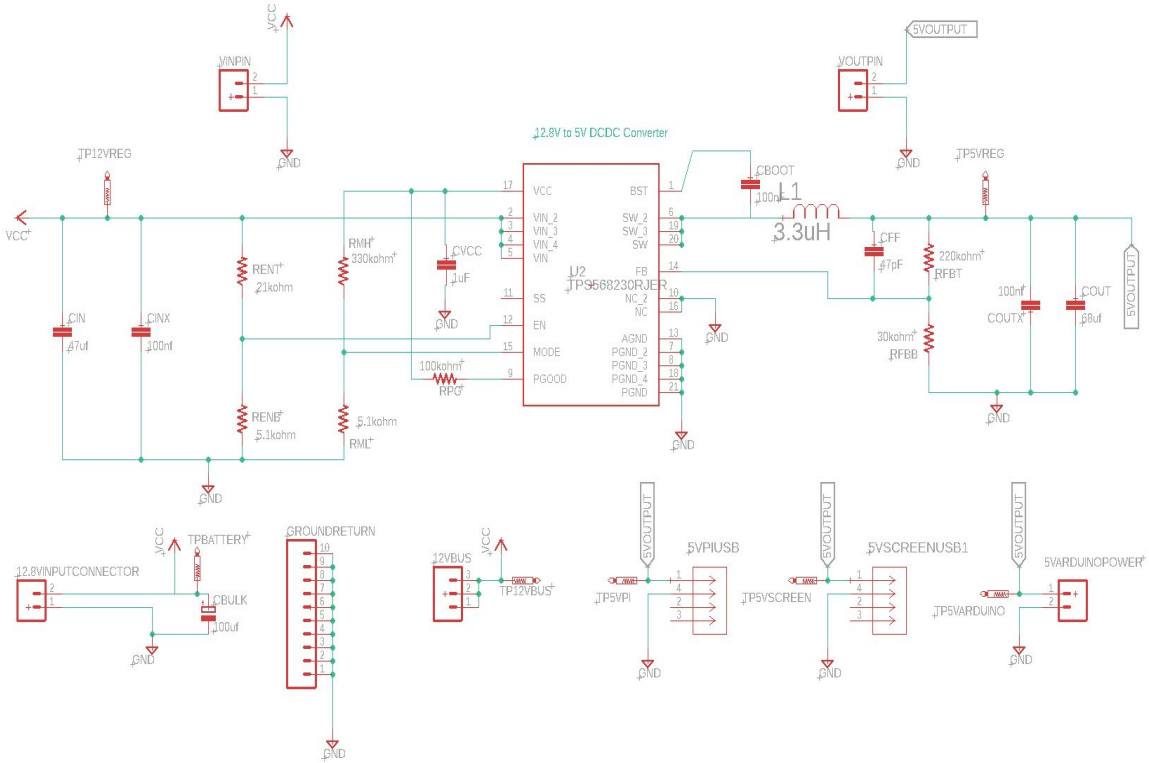
- Texas Instruments TPS568230RJER buck converter (TI Webench)
  - 4.5V-18V Input
  - Up to 8A continuous output current
  - 95% efficiency
- 2x USB-A ports
- Jumpers for 12V and 5V
- Wurth Electronics 7443340330 Power Inductor
  - 8.5A Saturation Current
  - 81 MHz self resonant frequency
  - Shielded Inductor



Power Regulation and Distribution PCB Layout (Rev A)

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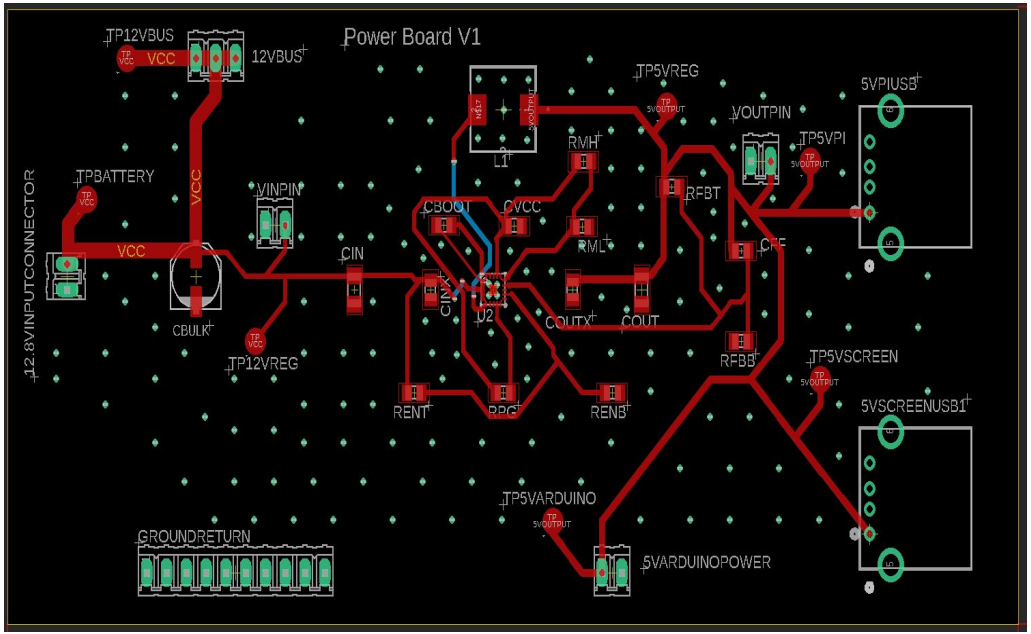
- 2-layer PCB
- Top and bottom layer GND
- Power Distribution Board takes 12V from battery and converts to 5V using TPS568230RJER buck converter IC
- Power is routed to connectors for 12V and 5V (USB and pins)
- Set of connectors dedicated for ground connections for peripherals
- Stitch vias scattered throughout board and thermal vias under IC
- Testpads added to board for signal probing



RFID Lock Schematic

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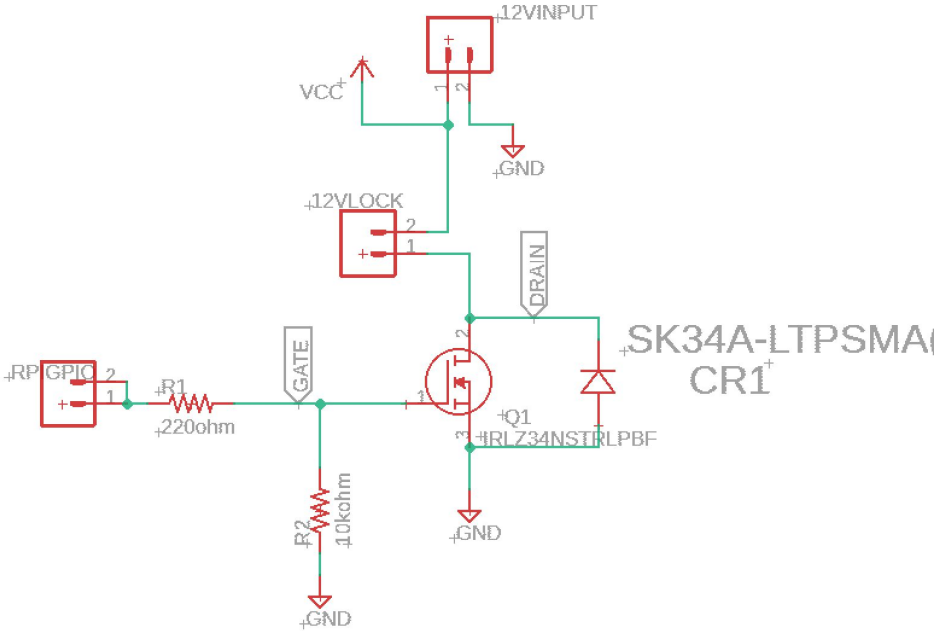
- IRLZ34NSTRLPBF N-channel logic level MOSFET used as switch
  - 55V/30A rated
  - 2V Vth
  - 35mohm Rds
- SK34A Schottky Diode
  - Flyback diode
  - 40V reverse voltage max
  - 3A Io average
- Gate and pulldown resistors
- Amp connectors for 12V input and GPIO input from Raspberry Pi



RFID Lock Mechanism PCB

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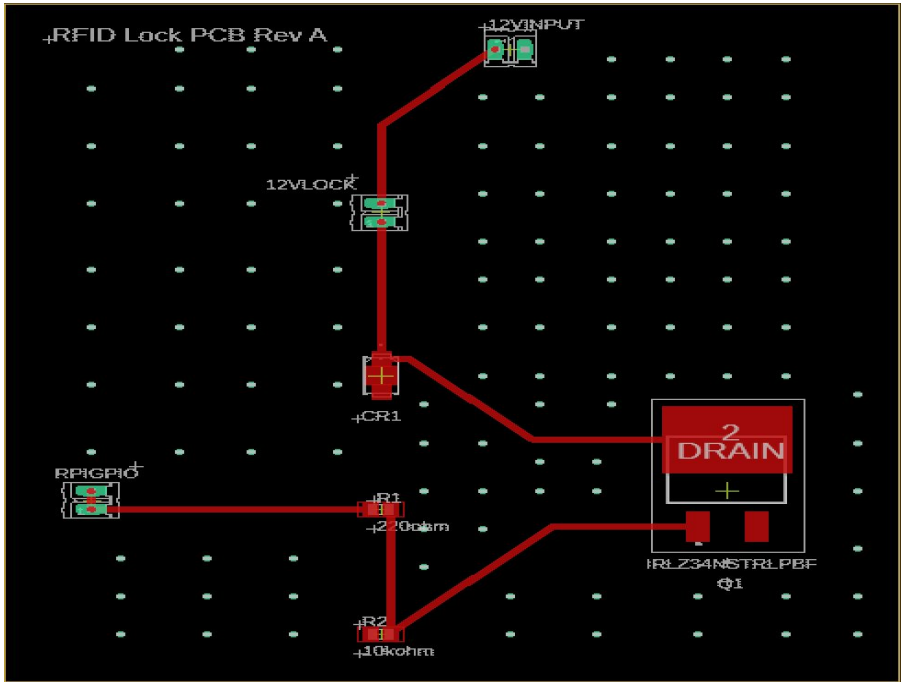
- 2-layer PCB
- Top and bottom layer GND
- 12V powers lock, GPIO pin send signal to MOSFET to turn on or off
- Stitch vias scattered throughout board



Power Distribution + RFID Lock Schematic (Rev B)

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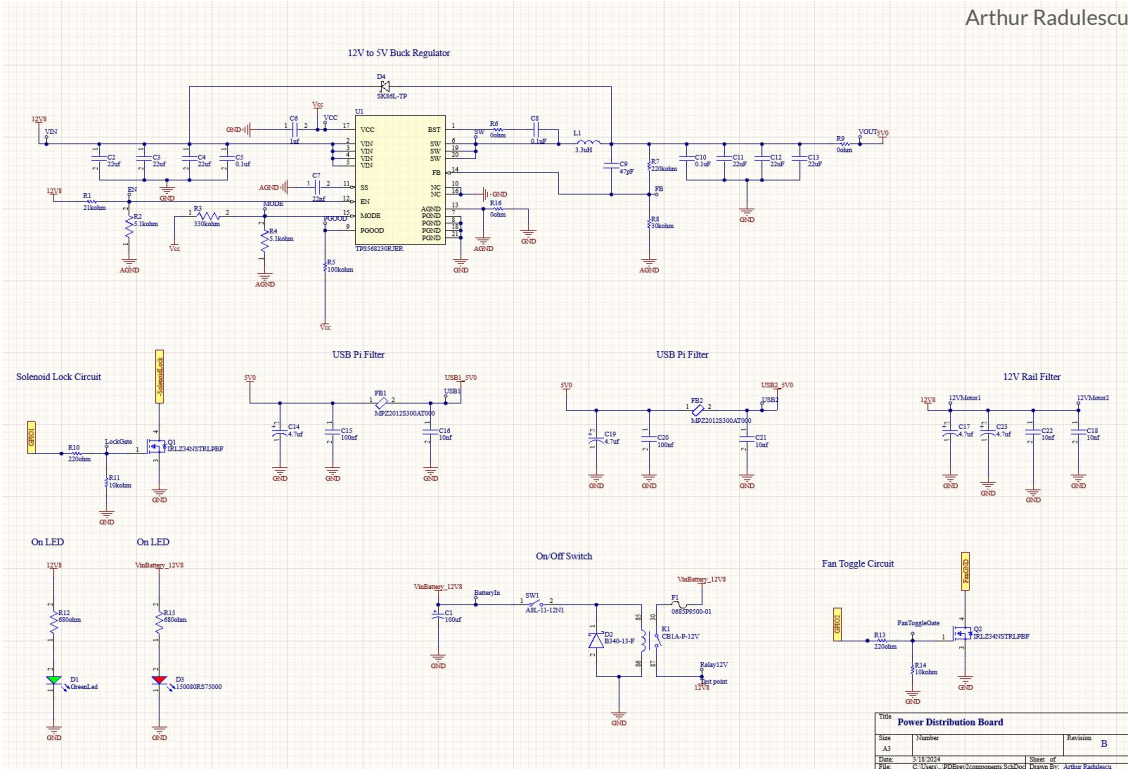
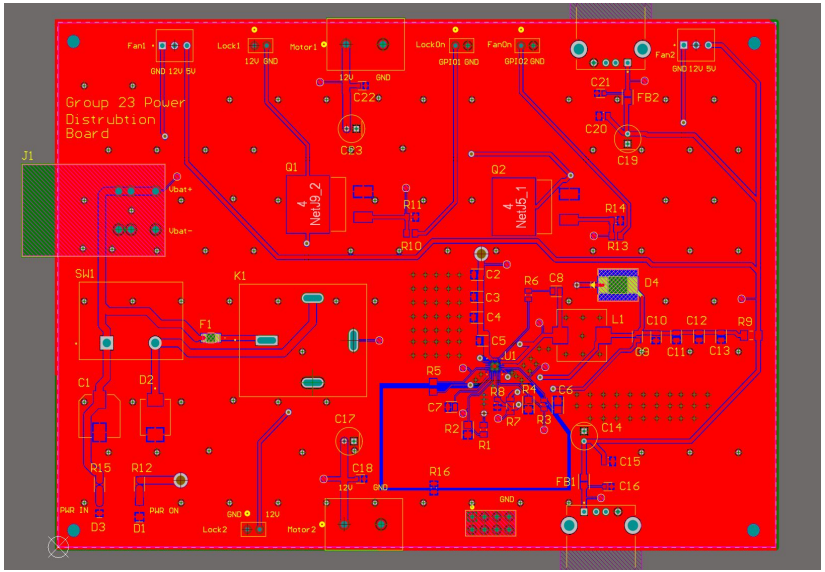
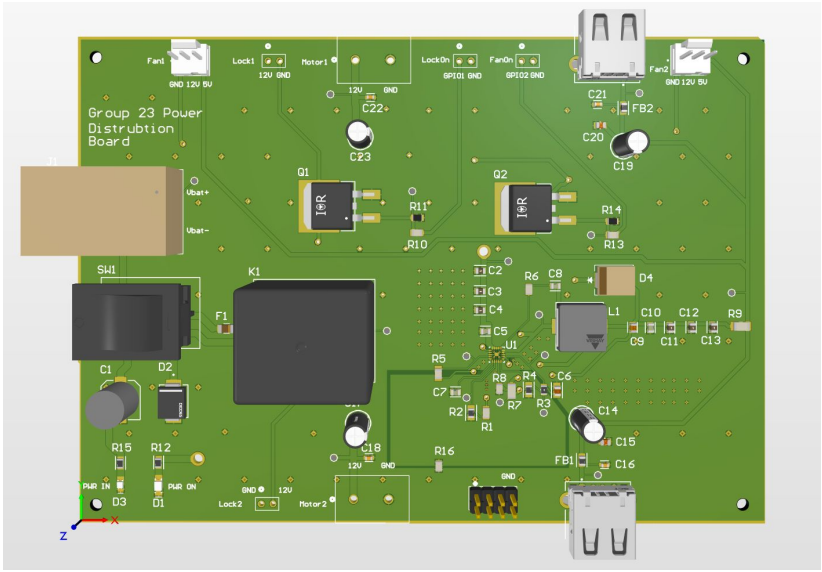
- Redesigned second revision in Altium
- Combined Power Distribution and RFID Locking Subsystem onto one single board
- Added fans and fan toggle switch circuit
- Added switch controlled relay and on diodes
- Added flyback diode across regulator and switch
- Added Pi filters to clean up output voltage rails



Power Distribution + RFID Lock PCB Layout (Rev B)

Arthur Radulescu EE





- Changed to 4-layer stack up from 2 layer (Signal-GND-12V-GND+Signal)
- Added analog ground pour

- Re-arranged connections to better suit physical design of RAPID and reduce wire crossover

Power Distribution + RFID (Rev C)

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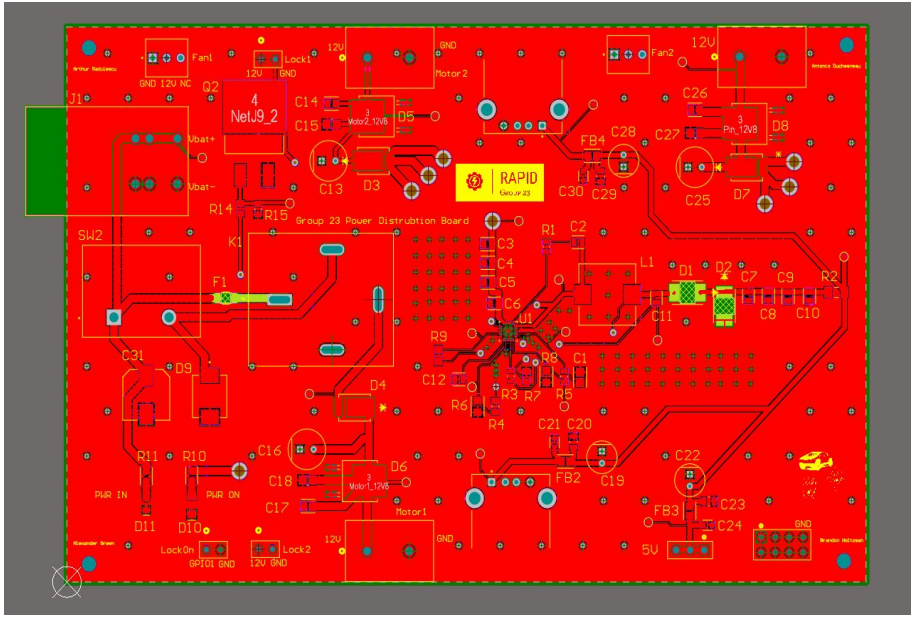
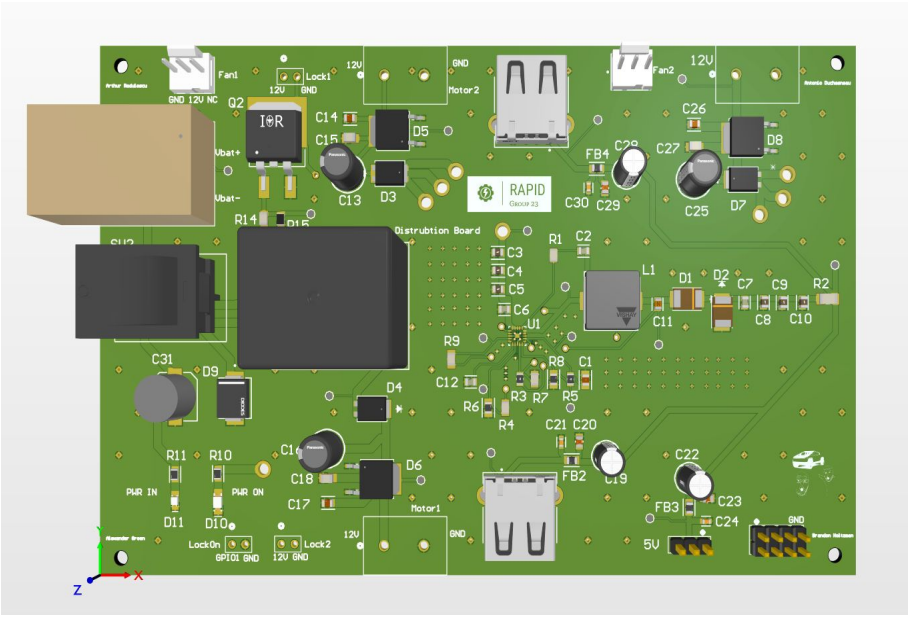




Software Summary

Alexander Green CpE

- Linux Operating System
    - Ubuntu 22.04.03 LTS - Jammy Jellyfish
- Robotic Operating System - ROS
- ROS Visualization - RViz
- Gazebo
- OpenCV
- LiDAR Driver Software
- Motor Driver and Encoder Software
- User Verification Software

Computer Vision Software

Alexander Green CpE

	OpenCV	TensorFlow	TensorFlow Lite	PyTorch
Performance on Edge Devices	May require optimization	Will require optimization	May require optimization	May require optimization
Programing Languages	C++, Python, Java	C++, Python, Java	C, C++, Python	C++, Python, Java
Supported Operating Systems	Linux, macOS, Windows, iOS, Android	Linux, macOS, Windows	Linux, macOS, Windows	Linux, macOS, Windows
Online Resources	Forum, Online Courses	Software Guides, Online Courses	Software Guides, Online Courses	Forum, Online Courses
Resource Quality	Excellent	Good	Alright	Good

OpenCV

ROS, RViz, GMapping, & Gazebo

Alexander Green CpE

Robot Operating System

- Tools
- Libraries
- Conventions

ROS Visualization - RViz

- Live Sensor Data
  - LiDAR
  - Camera

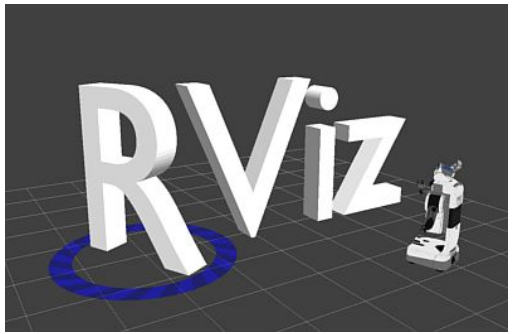
GMapping

- Occupancy grid based map making

Gazebo

- Location Estimation
- Path Generation

ROS



GAZEBO

Software Data Flow Diagram

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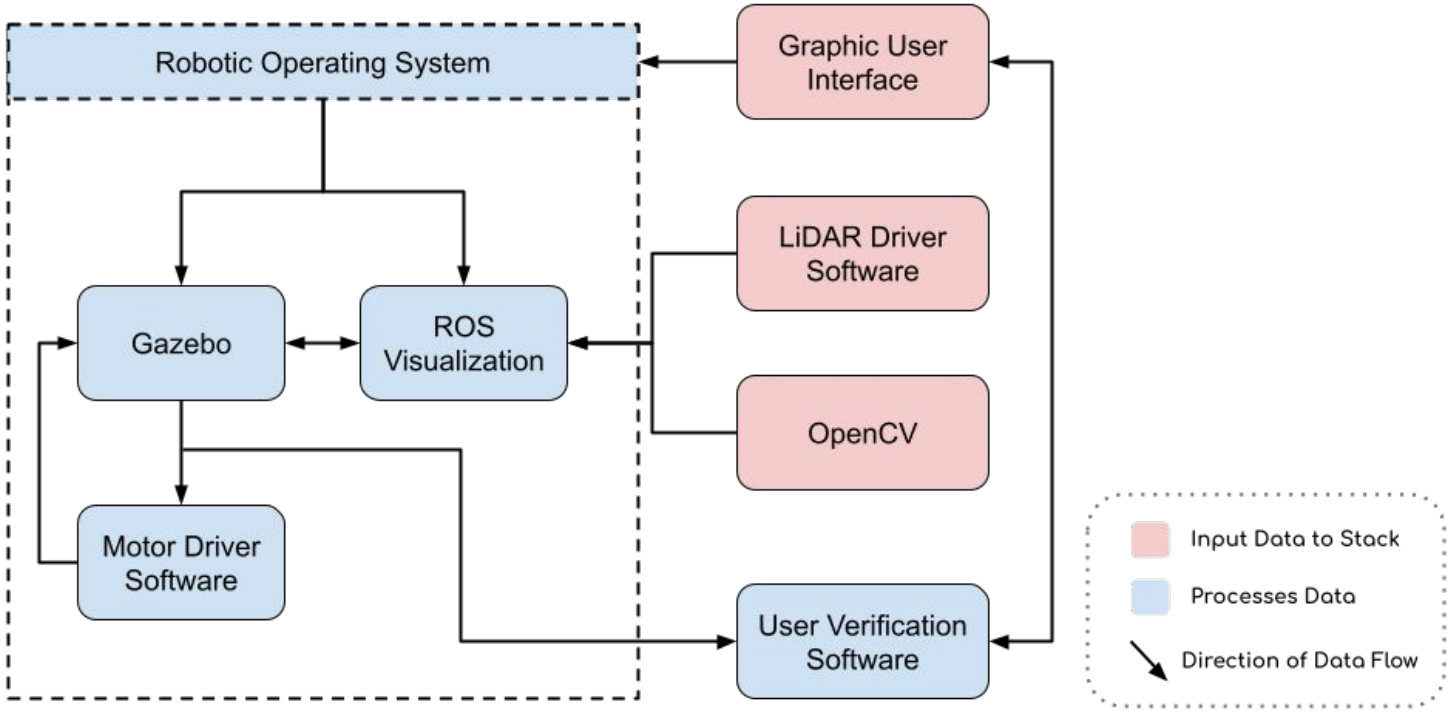
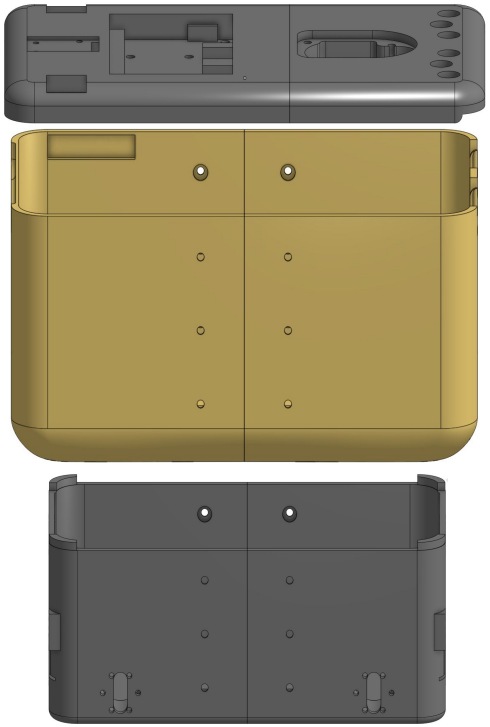
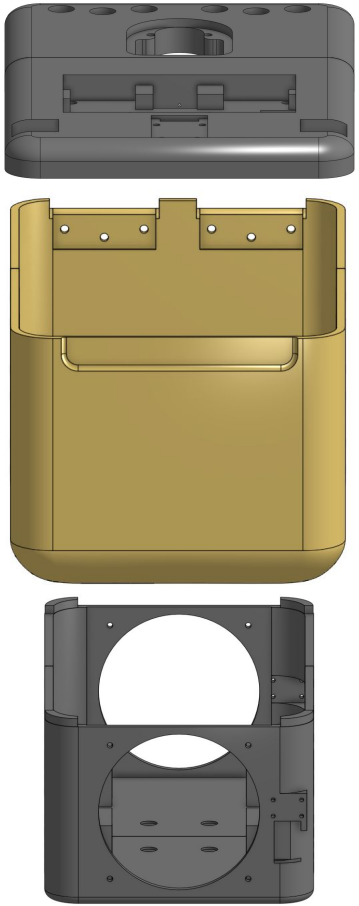


3D Modeling Assembly

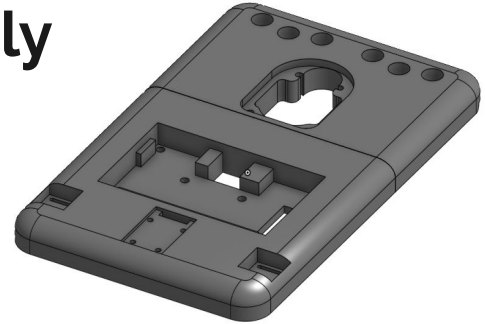
Alexander Green CpE

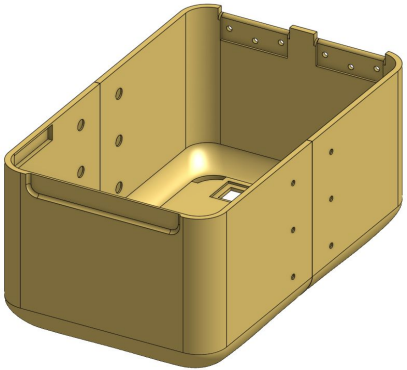


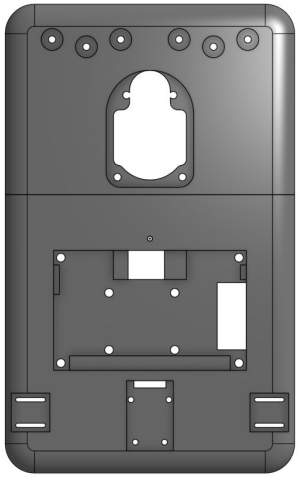


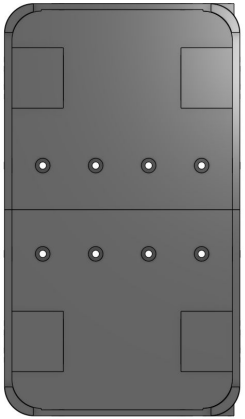
3D Modeling Assembly

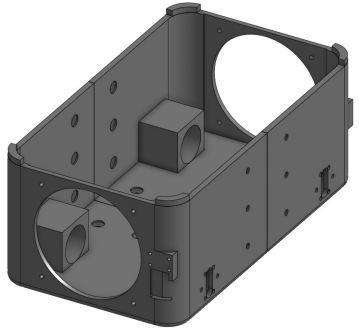
Alexander Green CpE











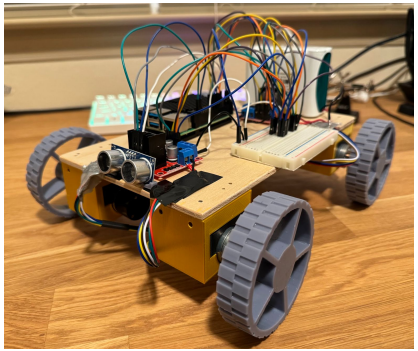
3D Model Prints

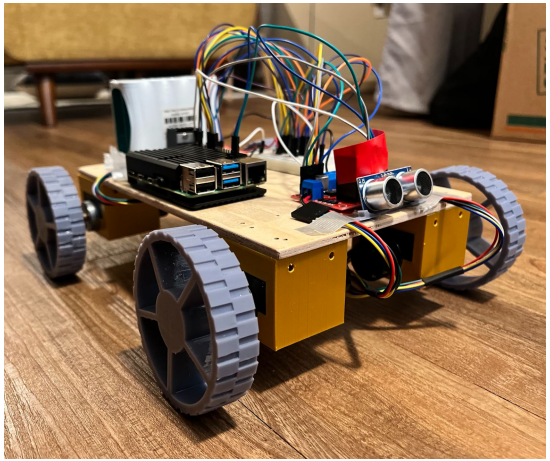
Alexander Green CpE

Brandon Holtzman CpE

Testing - Driving Subsystem

- Our first prototype used direct Raspberry Pi to driver connection.
- Prototype hardware was used to test the base design of our drive system
- Takeaways:
  - An external MCU PCB would control the high population of wires.
  - Difficulties receiving encoder data

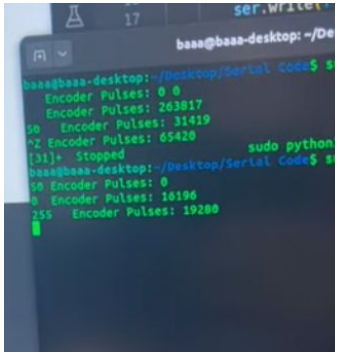




Testing - Serial Connected Driving Subsystem

Brandon Holtzman CpE

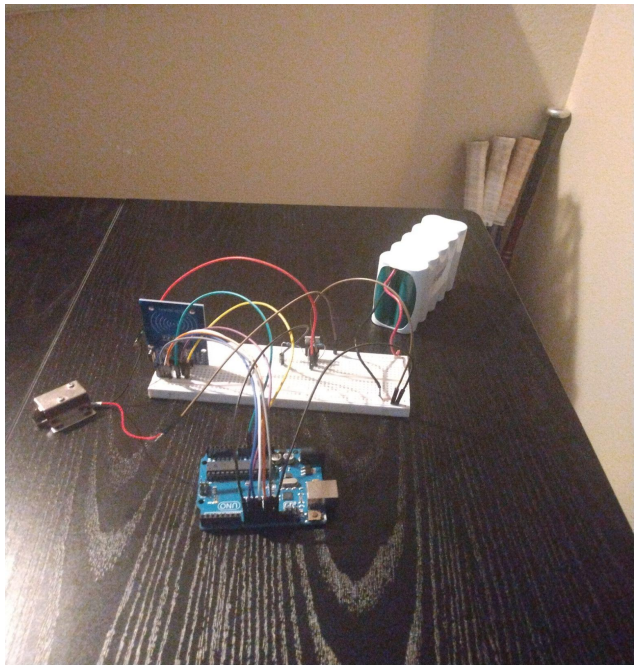
- Our second test used serial communication from the Pi to an ATMega2560 directly connected to our motor driver
  - Arduino Mega was used in place of our PCB
- PWM data was successfully sent from Pi to the Arduino
- Encoder data was successfully received and sent to the Pi



Testing - Recipient Verification Subsystem

Brandon Holtzman CpE

- Constructed on breadboard and tested for functionality
- Arduino Uno was used in place of Raspberry Pi for testing
- The lock successfully engaged when the correct RFID tag was read



Testing - OpenCV Software

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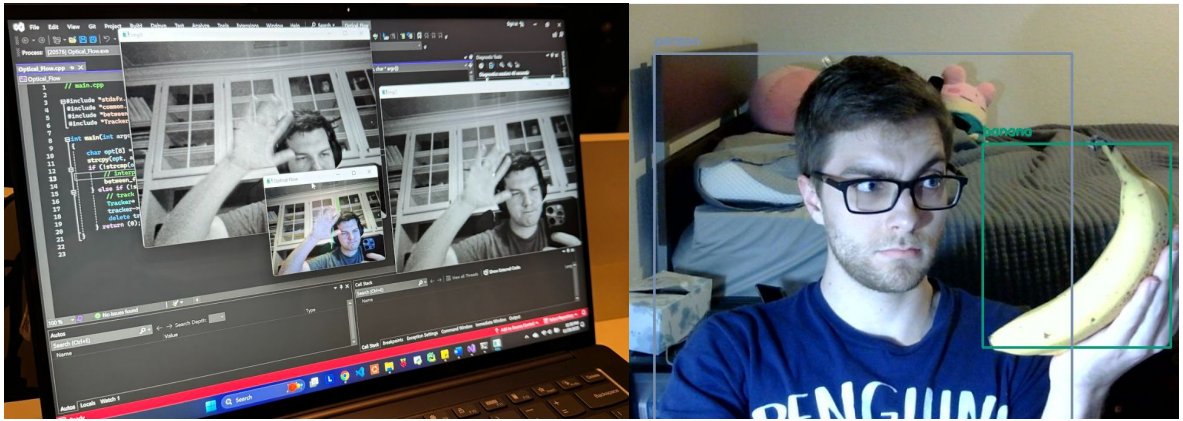
- Testing primarily focused on learning how to use OpenCV to detect objects
- Object recognition was easily implemented on our PCs, but struggled on the Raspberry Pi
- For the final design, blob detection algorithms were used in place of object detection



Testing - LiDAR

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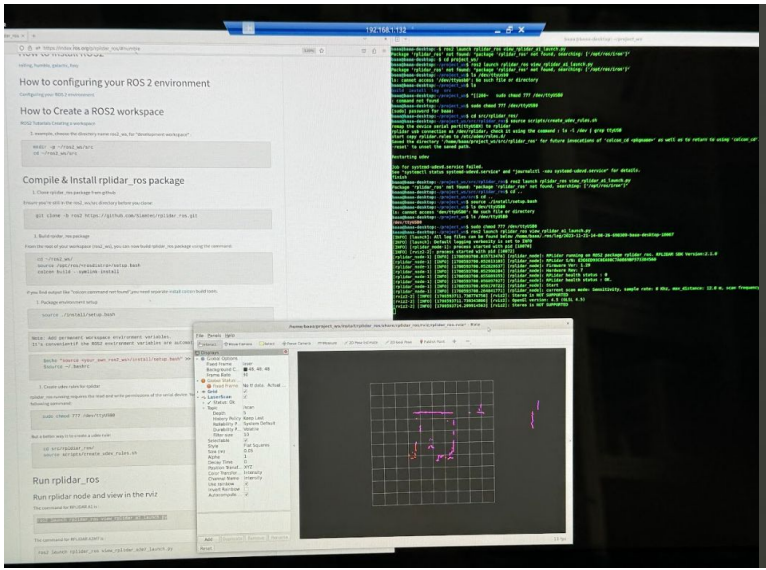
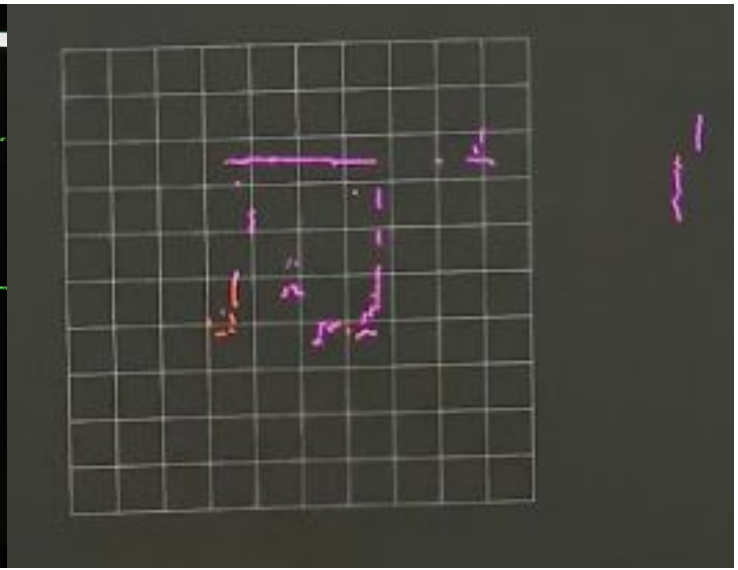
- RPLiDAR A1M8-RG
- Sample Frequency of 8KHz
- Range of 0.15 to 12 meters
- 2.50% Error at 12 meters





Budget/Bill of Materials

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Item	Distributor	Quantity Purchased	Estimated Cost	Actual Cost
3D Print Materials	Amazon	1	$40	$55
Hardware (screws, nuts, bolts,etc)	ACE Hardware	1	$25	$30
Motor Drivers	Amazon	2	$40	$42.00
Screen	Amazon	1	$30	$51.99
Battery	Amazon	1	$65	$53.99
RFID Module	Amazon	1	$10	$9.99
Solenoid Lock	Amazon	2	$15	$15.99
RFID Cards (10 pack)	Amazon	1	$10	$7.99
32GB Micro SD	Amazon	2	$15	$24.00
Arduino Uno	Amazon	1	$25	$30.00
Pi Power Supply	Amazon	1	$10	$11.29
Pi Heat Sink	Amazon	2	$20	$25.18
CPU Fans (2 pack)	Amazon	1	$10	$6.00
HDMI to Micro HDMI Cable	Amazon	1	$10	$9.99
USB C Cables	Amazon	2	$10	$8.00
Raspberry Pi 4	Amazon	2	$75	$100.00
LiDAR	Amazon	1	$100	$99.99
DC Motors	DigiKey	4	$100	$109.60
Wires and Wire Kits	Amazon	1	$40	$60.00
Final PCBs (unassembled) x 5 boards	JLCPCB	2	$70	$114.75
Final PCB Parts	Digikey	1	$100	$174.60
		Total:	$820	$1,040.35

Workload Distribution

Brandon Holtzman CpE

Workload	Primary	Secondary
3D Modeling	Alexander	Brandon
Software Stack Development	Alexander	Brandon
LiDAR Software	Alexander	Brandon
Computer Vision	Brandon	Alexander
Microcontroller PCB Design	Antonio	Arthur
Power PCB Design	Arthur	Antonio
RFID PCB Design	Arthur	Antonio
Driving Subsystem	Antonio	Arthur
Verification (RFID Lock) Subsystem	Arthur	Antonio
Graphic User Interface	Brandon	Alexander

Challenges Faced in Senior Design

Alexander Green CpE

- Hardware
  - Abrupt change in motor speed rebooting Raspberry Pis
  - Physical spacing challenges within platform
  - Major ESD issues with ATmega2560 chips
- Software
  - ROS to Serial Interface
  - Camera compatibility
  - Autonomous Driving Parameters
  - ROS2 Humble Stability

Thank You