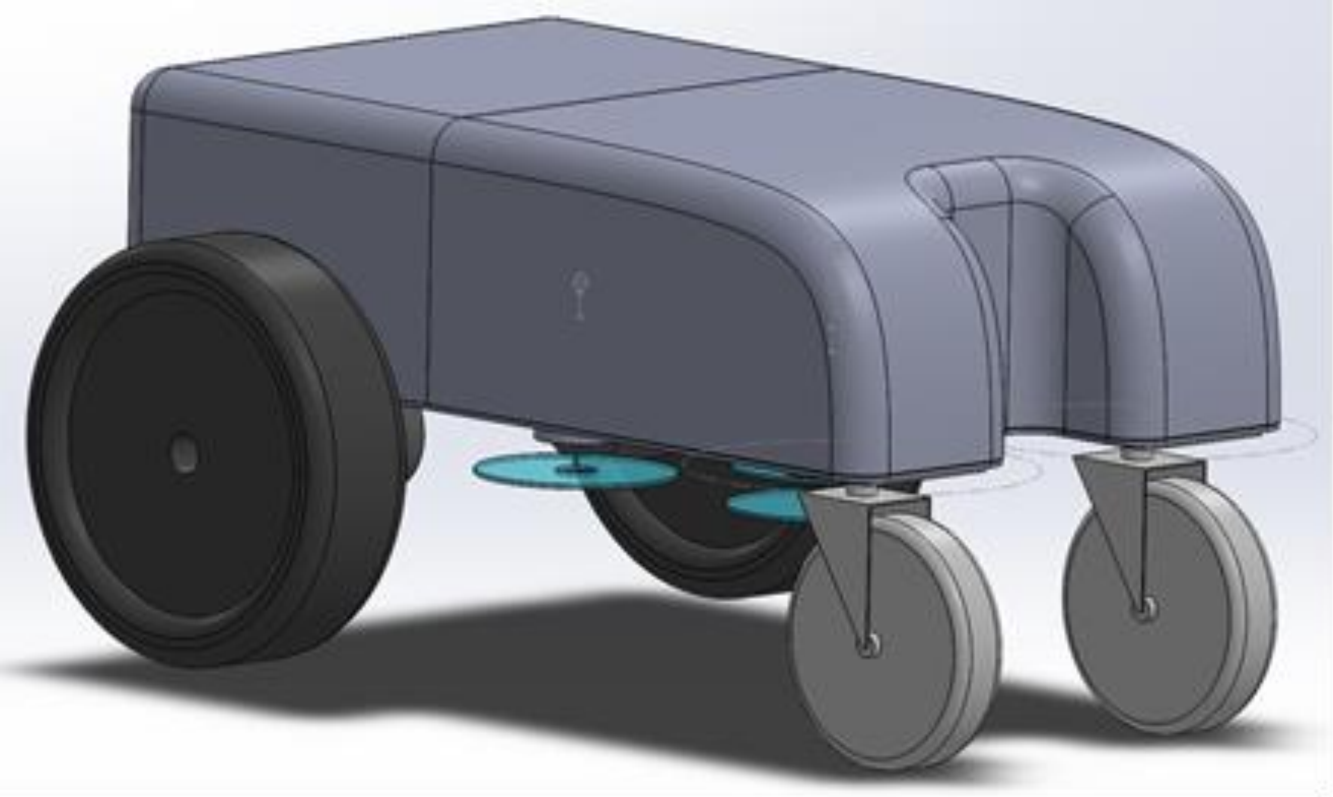
E-Goat Robotic Solar Farm Mower



Group 26:

- Steven Cheney - CpE
- Jordan Germinal - CpE
- Eduardo Guevara - CpE
- Davis Rollman - CS
- Jonathan Smith - EE

Project Description

- Device will be an autonomous vehicle designed to navigate obstacles
- A portable device that is highly durable to the elements of the environment
- Using a proximity wire, vehicle will be able to maneuver and maintain a specific area to navigate
- Mower will utilize sensors to detect objects (beams or people) and stop based on proximity

Davis

Motivation

- Solar energy provides very cheap power, after the initial large investment
- However, there are a few large upkeep costs, one of which is the upkeep of the grass in the field, which was $200,000 last year at Duke Energy's site
- Most of the cost is human labor
- One potential solution is an autonomous electric rover, which not only save human labor time, but also more environmentally friendly, as it is powered by electric rather than gas

Goals and Objectives

- To produces a rover-based robot and provide the articulated motion needed to move the weed whacker across the terrain and cut grass.
- To produce a Navigation and Control solution to identify grass areas that need attention (i.e., cutting), avoid any obstacles such as solar panel structures, and provide overall motion control of the rover-based robot.
- To produce a power supply unit for the rover. Grass cutting may take place at night and charge during the day. To accommodate such a scenario the system must use a defined battery storage technology with charging capability.
- To complete the challenge competition at during the month of April in 2020. The main objective is to complete the 10-foot-wide, by 50-foot-long course working around obstacles within a 15-minute time constraint.

Davis

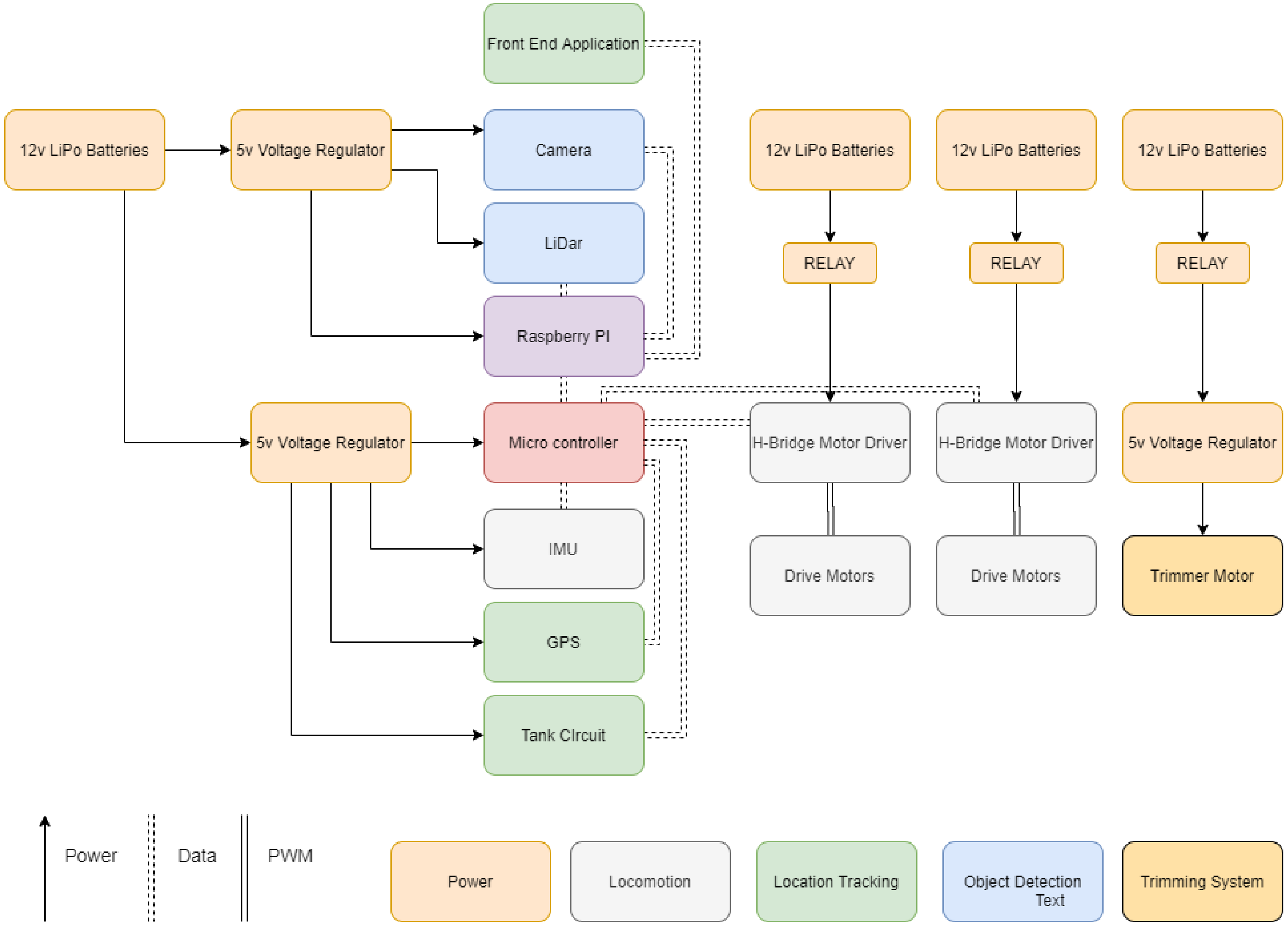
Designation	Description
CSC-01	Robotic rovers must use an off-the-shelf battery powered trimmer (no metal blade must be string-based) to cut grass.
CSC-02	The rover may consist of an off-the-shelf remote-controlled system that is modified for the application but should still have an autonomous mode or capability.
CSC-03	The robotic grass cutting rovers must be equipped with a remote kill switch that can turn off the cutting system and locomotion at a distance of approximately 50 feet.
CSC-04	An off-the-shelf battery and charger must be utilized.
CSC-05	The rover must be capable of safely navigating in uneven terrain (~ 3-inch terrain differential over ~ 2-foot span in any direction) without capsizing while avoiding a series of obstacles.
CSC-06	No part of the system must be of a height no taller than 20 inches from the ground
CSC-07	The system must operate independently and have no attachments to existing solar farm array structures.

Designation	Description
CSC-08	Total systems materials and assembly cost target: $1500
CSC-09	The ability to cut grass at an acceptable height (3 to 6 inches) is considered a plus.
CSC-10	The system must traverse the large areas and maneuver around PV support structures.
CSC-11	Avoid any damage to surrounding infrastructure, the environment and humans
CSC-12	Provide a math model to estimate how much grass area the robot can cut per hour.
CSC-13	System to provide a secondary safety protocol to deal with rogue objects, in addition to the remote kill switch.
CSC-14	The System also to include location beacon with independent power supply for a defined period of time.

Customer Specifications and Constraints

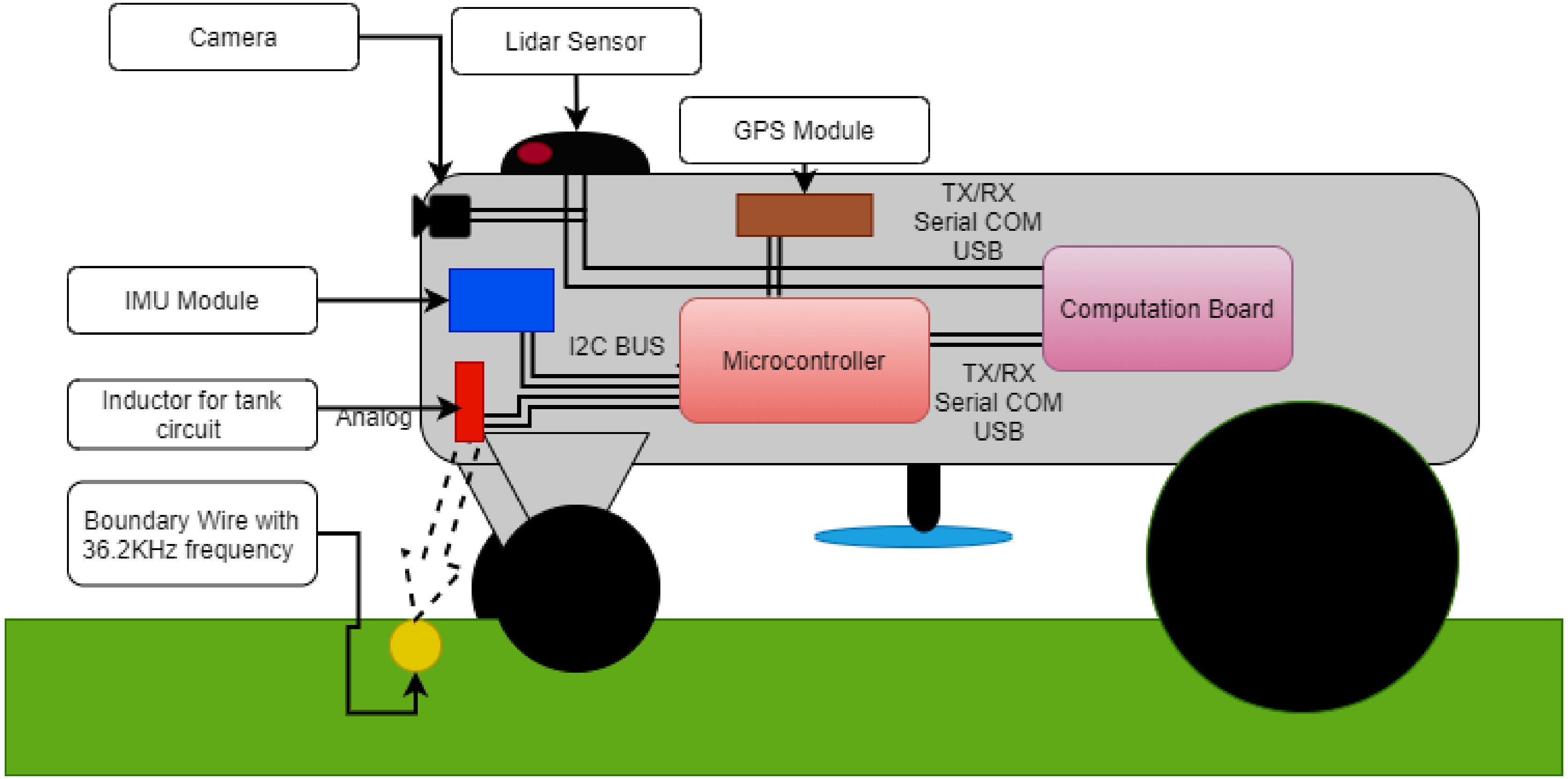
Davis

Hardware Block Diagram



Steven

Communication Block Diagram



Steven

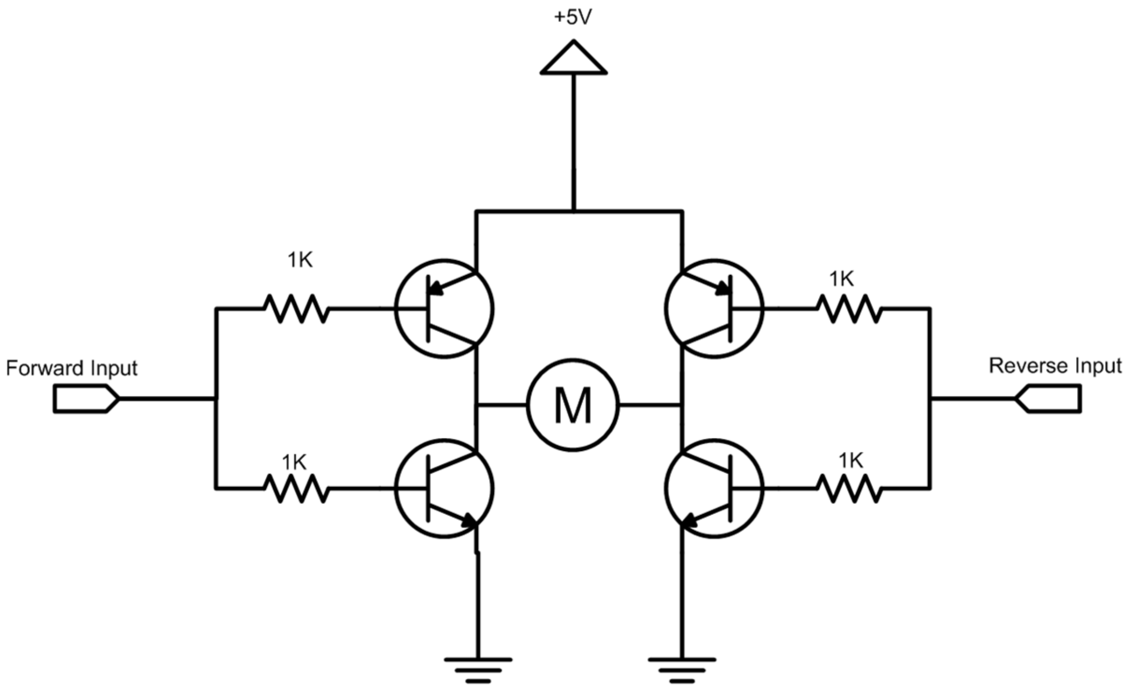
Division of work

	Steven	Jordan	Eduardo	Davis	Jonathan
ROS		Primary	Primary	Secondary	
Human and obstacle Detection		Secondary		Primary	
Power systems	Secondary				Primary
Locomotion	Primary		Secondary		Secondary
PCB Design	Secondary		Secondary		Primary
Wireless communication / control app		Secondary		Primary	
Navigation sensors		Secondary	Primary	Secondary	Secondary

Steven

Driver/Motor

- H bridge design to control motor movement
- Series of On-Off pulses (PWM)
  - Controls the amount of power delivered without wasting power
- Pulse bit to control the direction of the wheels
  - Clockwise vs anti-clockwise



Steven

Trimmer Head

- Fast but efficient
- Pre-purchased motor
- RPM Requirement: 6,000

Commercial vs Custom Mower Head

Ryobi one+: 9300 rpm, $69, largest   Jiaruixin RS550: 30000 rpm, $15, smallest   MD5-2450: 50000 rom, $85, medium size

Criteria	Weight	Evaluation			Score		
		Ryobi one+ 18v 	Jiaruixin RS550 	MD5-2450 	Ryobi one+ 18v 	Jiaruixin RS550 	MD5-2450 
Speed	(5)	1	2	3	5	10	15
Cost	(3)	2	3	1	6	9	3
Size	(2)	1	3	2	2	6	4
Total score					**13**	**27**	**22**

Steven

Trimmer Motor

Comparing Custom Trimmer Motors

Criteria	Weight	Evaluation			Score		
		RS550	JD3-24135-CVC	MD5-2450AS-AA-C	RS550	JD3-24135-CVC	MD5-2450AS-AA-C
Speed	5	2	1	3	10	5	15
Size	3	3	1	2	9	3	6
Cost	2	3	1	2	6	2	4
Total Scores					**25**	**10**	**25**

Steven

Wheel Motor

- Torque > Speed
- Weight requirement
- Accuracy in navigation

Driving Motors (Amp Flow)

A28-150: 2237.1 Watts (3hp), $344

E30-150: 745.7 Watts (1hp), $79

F30-150: 1715.11 Watts (2.3hp), $239

Criteria	Weight	Evaluation			Score		
		A28-150 	E30-150 	F30-150 	A28-150 	E30-150 	F30-150 
Power	3	3	1	2	9	3	6
Cost	5	1	3	2	5	15	10
Size	2	1	3	2	2	6	4
Total Scores					**16**	**24**	**20**

Steven

MCU

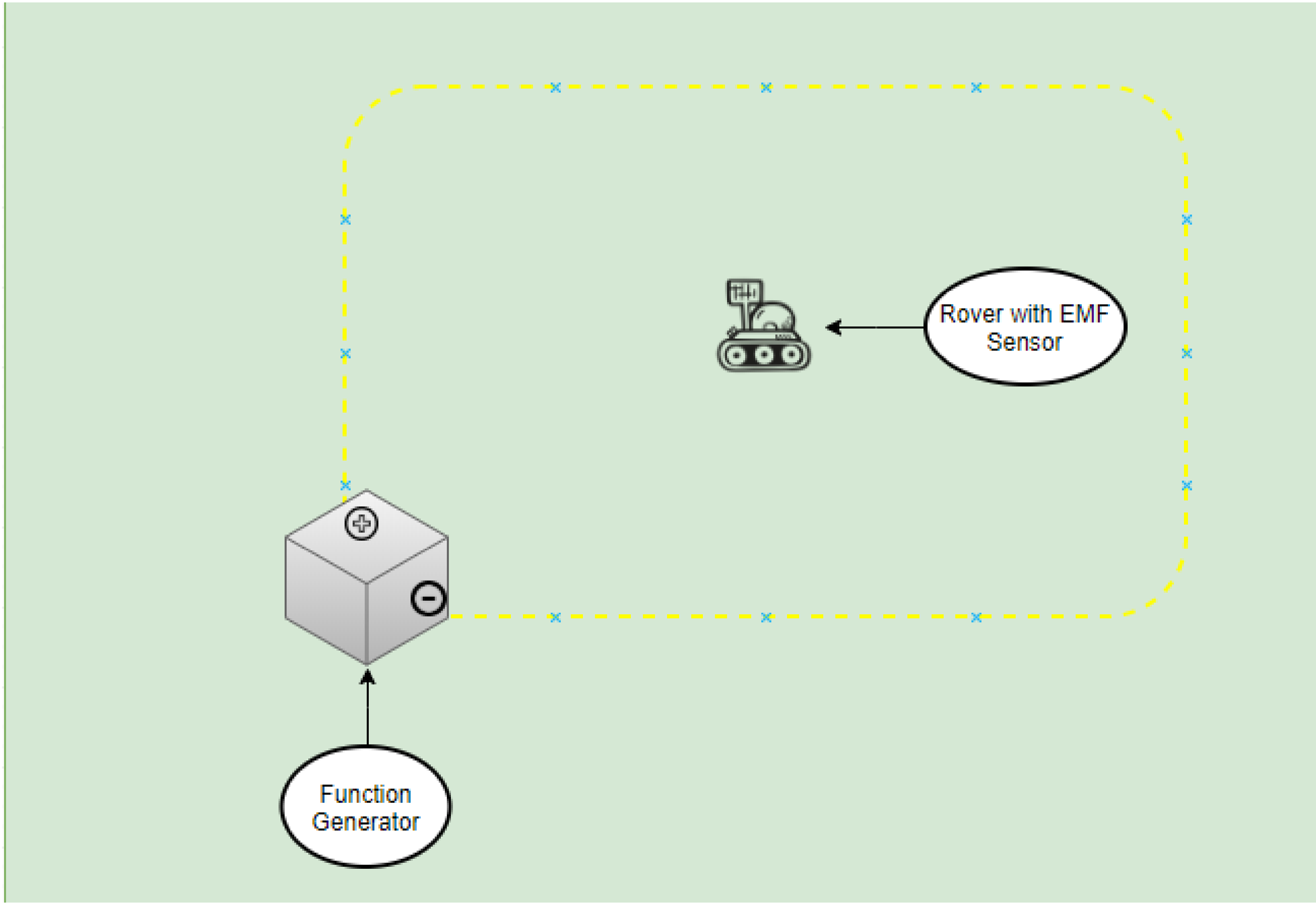
- Provide Low side computation for IMU, GPS, Perimeter Wire, and PWM Motors
- Publish and subscribe to ROS topics connected Odroid
- Support multiple forms of communication and signal I/O such as I2C, Serial, and Analog input.

	ATmega2560	ATmega328P	MSP432P401RIPZ	MSP4305529
Development Board	Arduino Mega2560	Arduino Uno	MSP432P401R SimpleLink	MSP-EXP4305529LP
Cost	~$12.00	~$2.00	~$8.00	~$7.00
Digital I/O	86	14	40	40
Analog input pins	16	6	8	8
Input Voltage	1.8 to 5.5	1.8 to 5.5	1.6 - 3.7	1.6 - 3.7
Clock Speed	16MHz	8MHz	48MHz	25MHz
Program Memory	256Kb	32Kb	96Kb	128Kb
I2C Support	YES	YES	YES	YES
Analog Input Support	YES	YES	YES	YES

Eduardo

Boundary Wire Subsystem

- Keep autonomous mower rover is operating with the specified 50x10 foot
- Ensure the safety of people and equipment.
- Composed of two pieces of equipment
  - Function Generator
  - Tank Circuit (EMF sensor)



Eduardo

Boundary Wire Subsystem

- Function Generator:
  - Driven by an NE555 timer integrated circuit
  - Create a functional square wave and output over 150ft
  - Output frequency target:
    - L = 30Khz
    - H = 43Khz
- Tank Circuit:
  - LC Circuit to for reading the frequency of the function generator
  - Calculated Resonance frequency:
    - ~34Khz
  - An Op-Amp LM324 will be used to amplify the signal gained from our circuit.

Eduardo

Perimeter Wire Part Selection

Item	Description
Perimeter Wire	100m Automower Boundary Wire 20AWG
Screw Terminals	3xED10561-ND, 125V, 6A, 1x02 2.54mm Screw Terminals
Timer	TI NE555P Timer
Op-Amps	TI LM324N
Resistors	4x1MΩ(1206), 4x10kΩ(1206), 1x3.3kΩ(1206), 1x12kΩ(1206), 1x47Ω(2W Axial-0.6)
Capacitors	2x22nF(1206), 1x100nF(50V 1206), 1x100nF(1206), 1x1µF(1206), 1x1.2nF(1206)
Inductors	2xRLB0914 Inductors 1mH
Housing	10x5cm Plastic Container

Eduardo

Boundary Wire Testing

1. Measurement of 150ft of Perimeter Wire.
2. Measurement of inductor to Perimeter wire to sense EMF field.

   Tank Circuit
   can approximately sense up to 8 inches from perimeter wire with correct isolation from subsystem

1

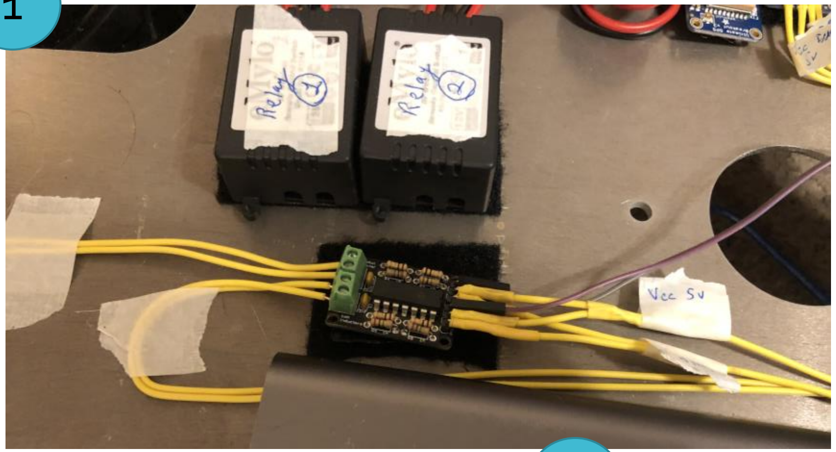
2

Eduardo

Tank Circuit Integration

1. Tank Circuit Secured on Rover using Velcro Pads.
2. Inductor sensors act like "Antlers" by staying low to the ground and detecting the magnetic field induced in the copper wire on the ground.

1



2

Eduardo

IMU -

FXAS21002C & FXOS8700

- Keep orientation and direction for rover
- Provide control for new heading position and directions for rover
- I2C communication with the microcontroller
- Powered using a 3.3v

Module Package	Sensors	Degrees of Freedom	ADC Resolution	Output Data Rate
FXOS8700	Accelerometer	3-Axis DOF	14-bit	1.563 to 800 Hz
	Magnetometer	3-Axis DOF	16-bit	1.563 to 800 Hz
FXAS21002C	Gyroscope	3-Axis DOF	16-bit	12.5 to 800 Hz

Features	FXAS21002C	FXOS8700
Supply DC Voltage	1.95 -3.6v	1.95 -3.6v
Scale Ranges	±2g /±4g /±8g	±250 /500 /1000/2000°/s
Current Draw	240µA- 80µA	2.7mA
Temperature Range	-40° to +85°C	-40° to +85°C

Eduardo

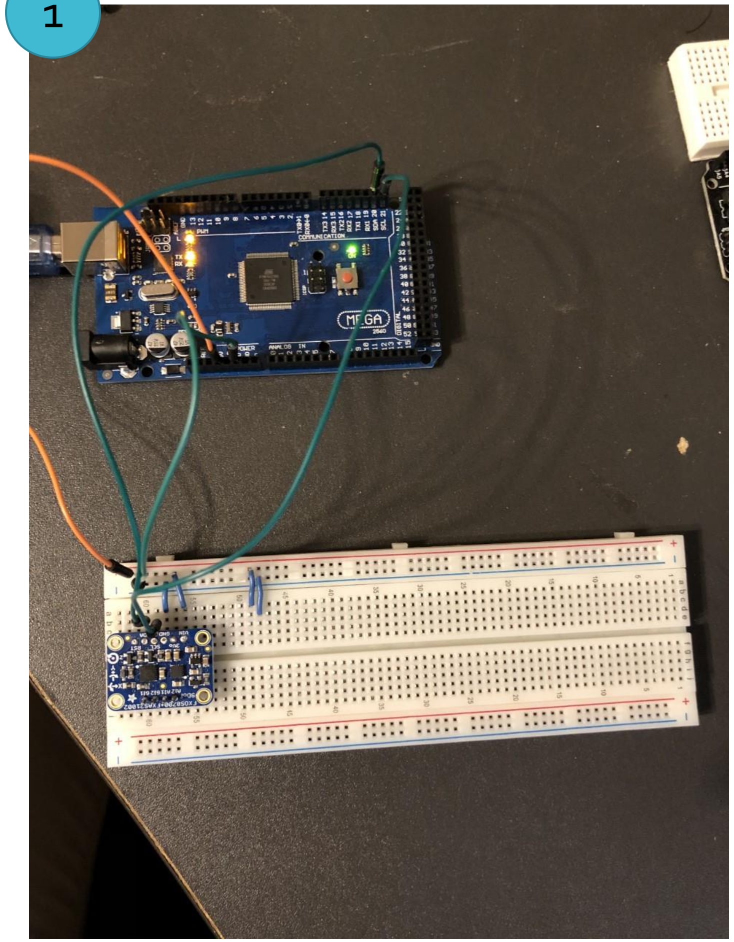
IMU Testing

1. Arduino Mega2560 connected via I2C bus connection

2. Linux Terminal echoing ROS topic that is publishing Pitch, Yaw, and Heading.

3. Software tool used to calibrate IMU for sensor fusion

1



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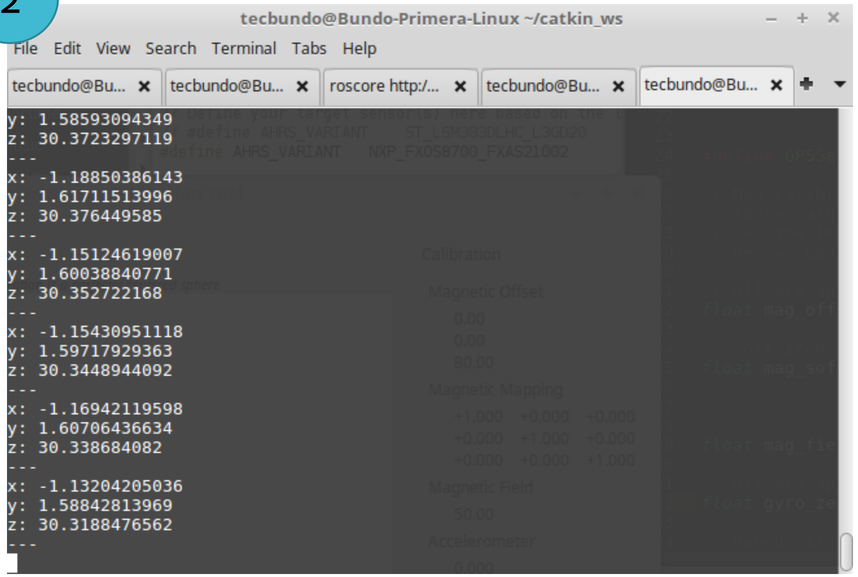

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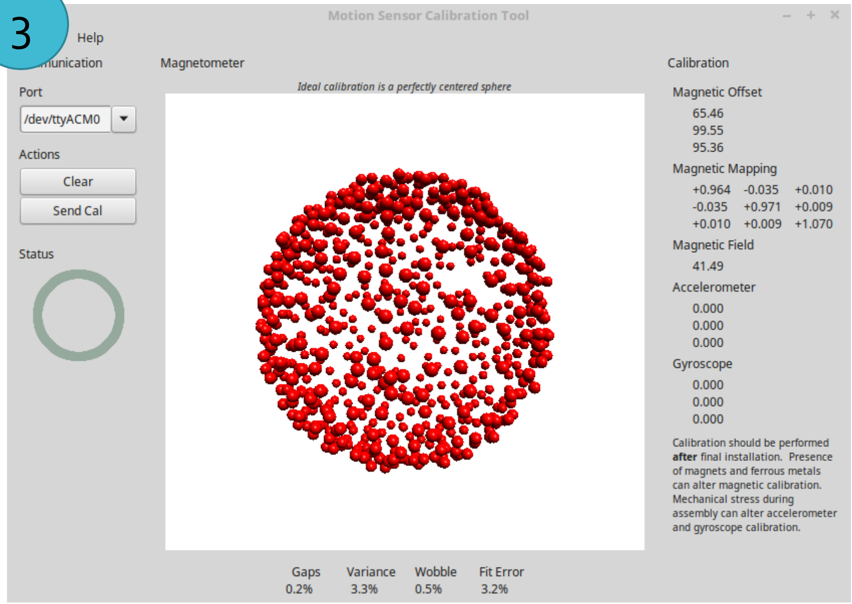
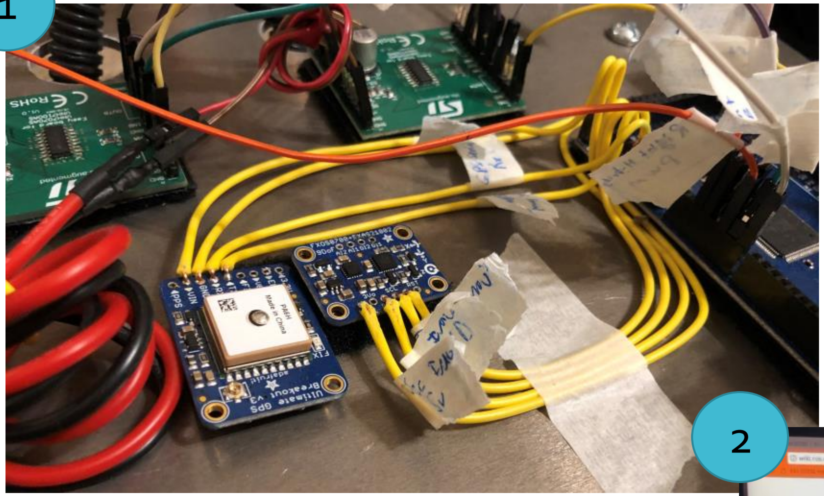


Eduardo

IMU Integration

1. The IMU is placed and secured near with Velcro near the center of the rover. Wire leads come out of the digital I/O and into the Arduino Mega.
2. Microcontroller connected to IMU displaying Roll, Pitch, and Yaw.

1



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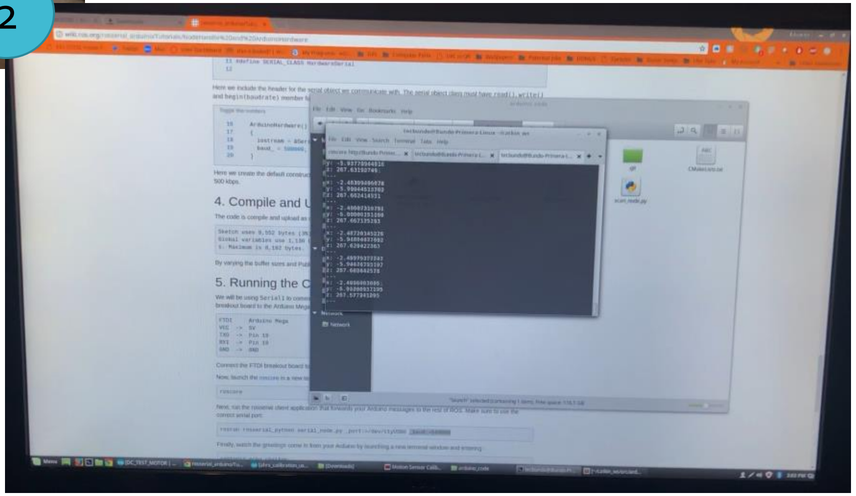
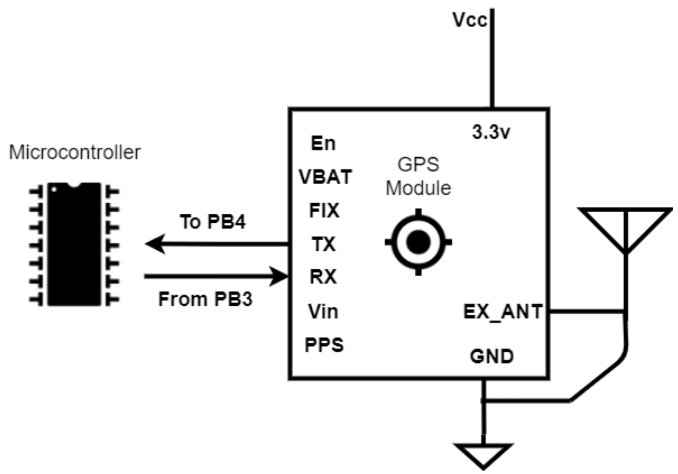


Eduardo

GPS -MTK3339

- Provide Users approximation status on the field
- Low powered to be operable after main batteries are depleted
- Closed off the shelf Antenna provides 28dB gain drawing around 10mA from the GPS module

Features	MTK339
Cold Start	34 sec
Vcc	3.3v
Satellites	22
Dimensions	16x16x5mm
Velocity Accuracy	±0.1m/s
Update Rate	1 to 10Hz
Acquisition Sensitivity	-145dBm
Operating Current	20-25mA
Tracking sensitivity	-165dBm

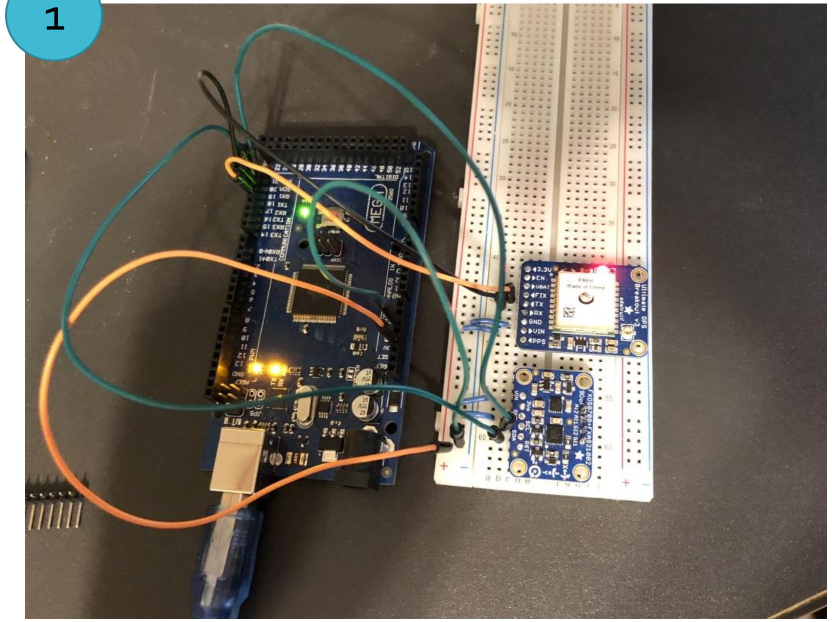


Eduardo

GPS Testing

1. Connection of GPS to Arduino Mega2560 through a hardware Serial connection
2. Linux Terminal echoing ROS topic that is publishing GPS coordinates and fix status.
3. GPS Antenna

1



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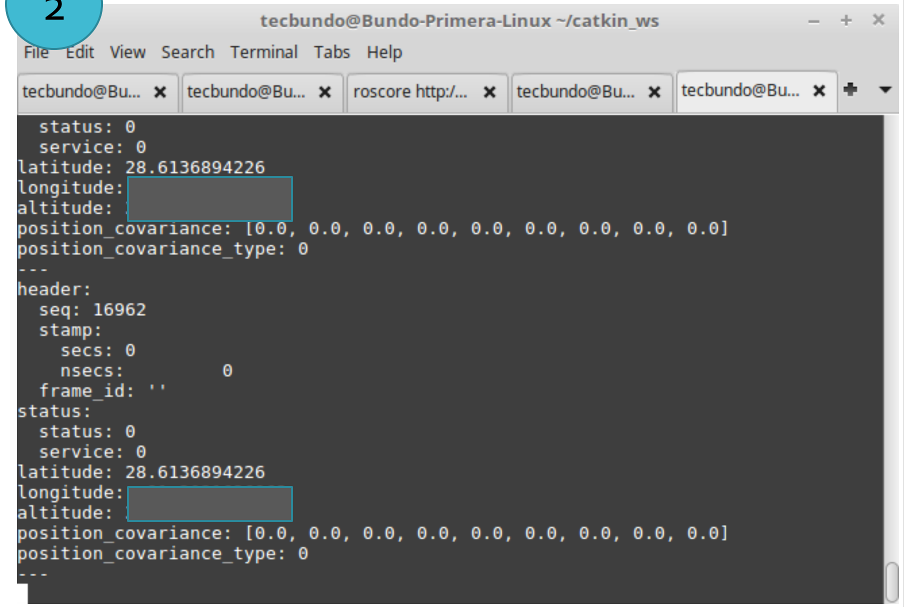

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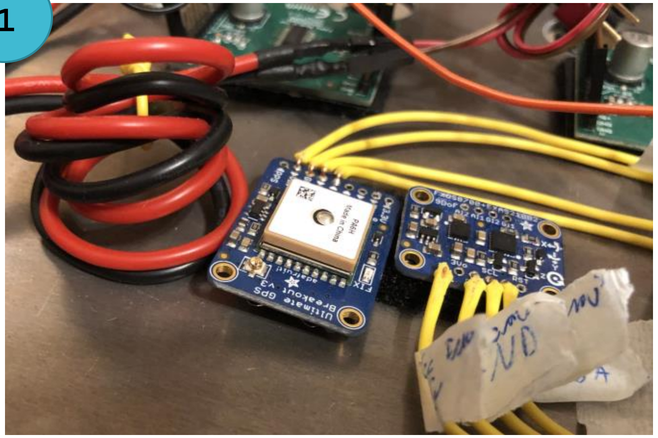
Eduardo

GPS Integration

1. GPS Module without SMA adapter to large Antenna
2. GPS Module with SMA adapter
3. GPS connected to Antenna and placed on chassis

1



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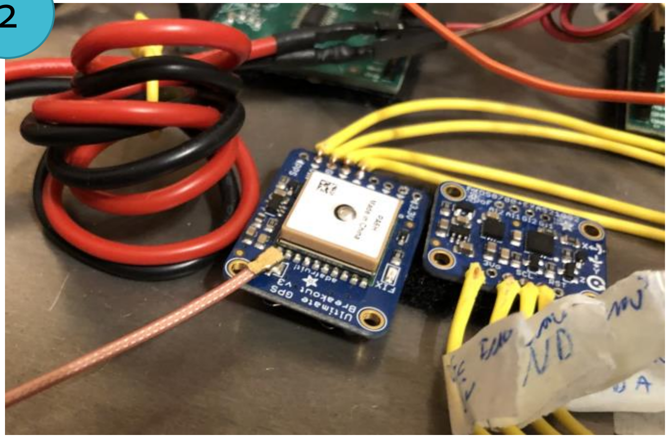

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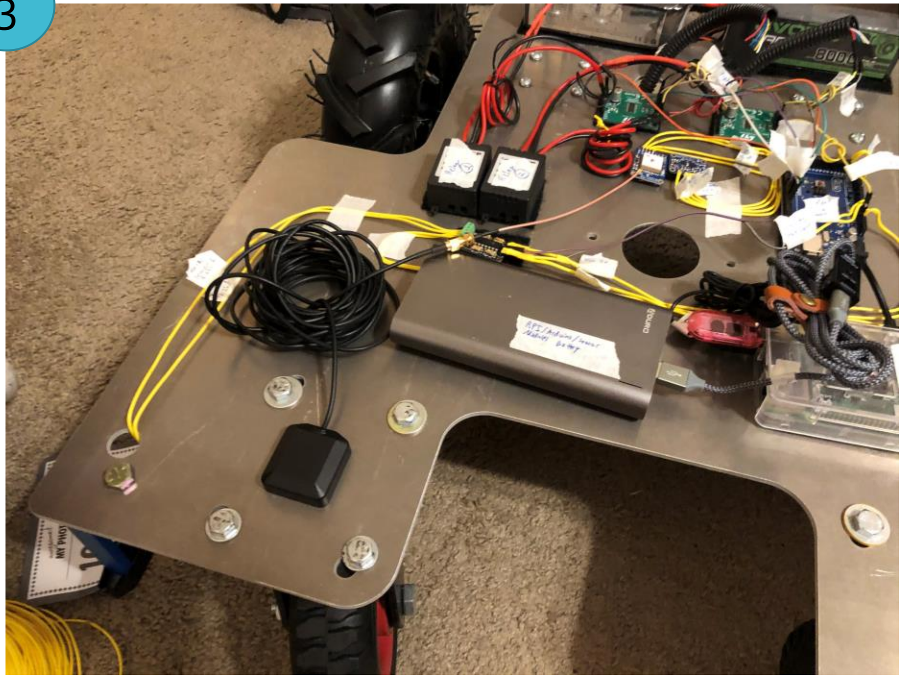
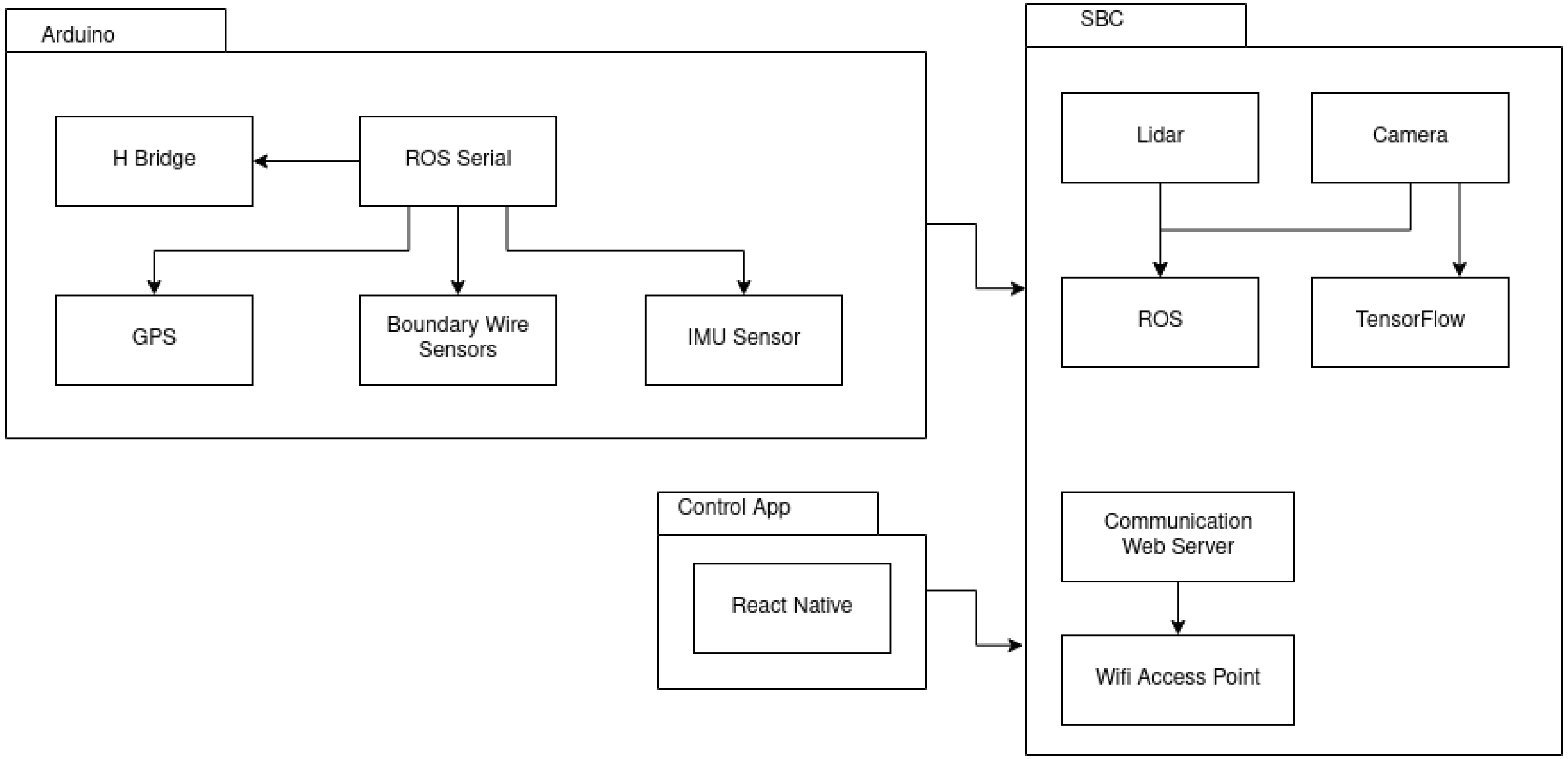


Eduardo

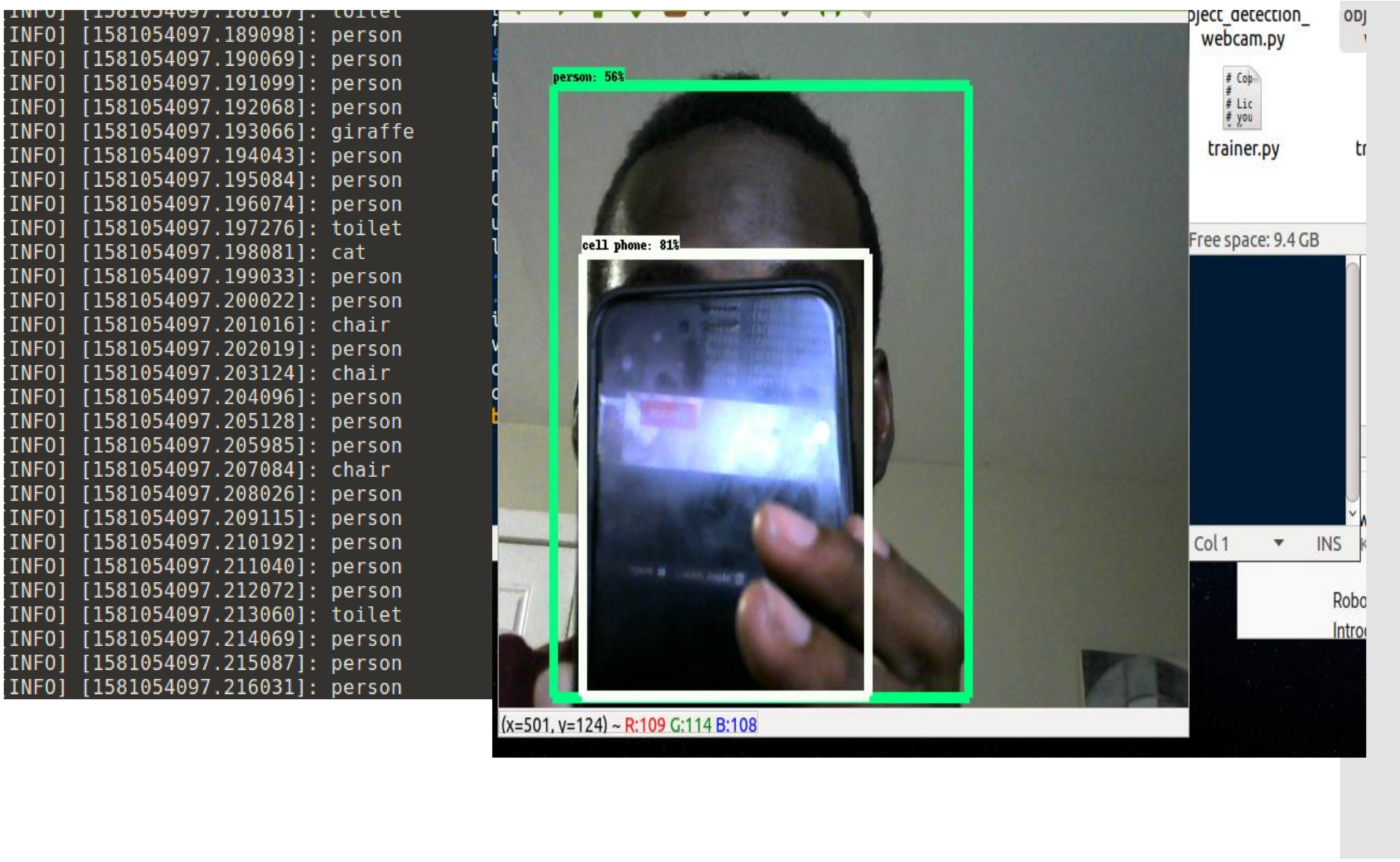
Software Block Diagram



Davis

Object Detection (Cam)

- Camera used for Computer Vision
- Python running on the Odroid SBC
- Single Shot Multibox Detector (SSD) with MobileNet
- COCO Dataset
- Using Tensor flow API and OpenCV
- Fast and reliable



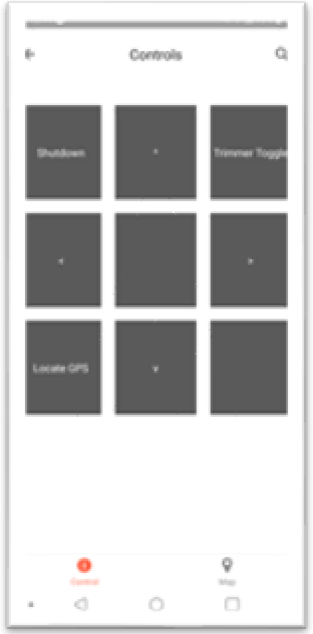
Tensor Flow API

- The model has been trained on the MS COCO dataset (Common Objects in Context).

- A dataset of 300k images of 90 most found commonly objects:
    1. Dogs
    2. Cats
    3. Laptops
    4. Teddy bear
    5. Chair
    6. Phones
    7. And others

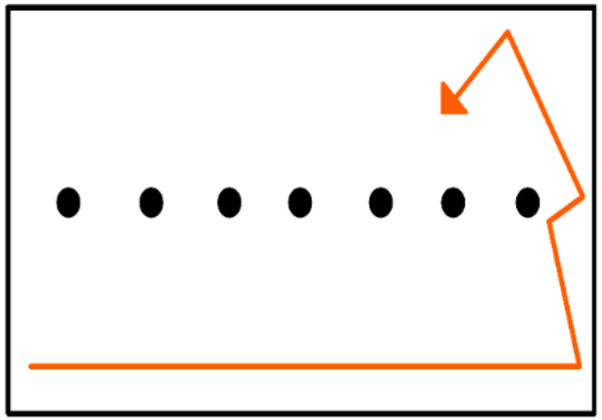
Mobile App and Connection

- In lieu of a wireless data internet connection such as LTE, the rover will have a wifi access point built in, and all outside connection will go through that.
- This limits us in range, but it will still be useable for our requirements
- The mobile app (written in React Native) will communicate over a simple REST api to the main ROS node, and allow a user to perform basic functions such as starting and stopping the rover



Davis

Navigation Algorithm



- Two obstacle detections:
  1. Boundary wire (edge)
  2. Lidar (detect object within a distance and FOV)

- Third input of human detection (shut off)

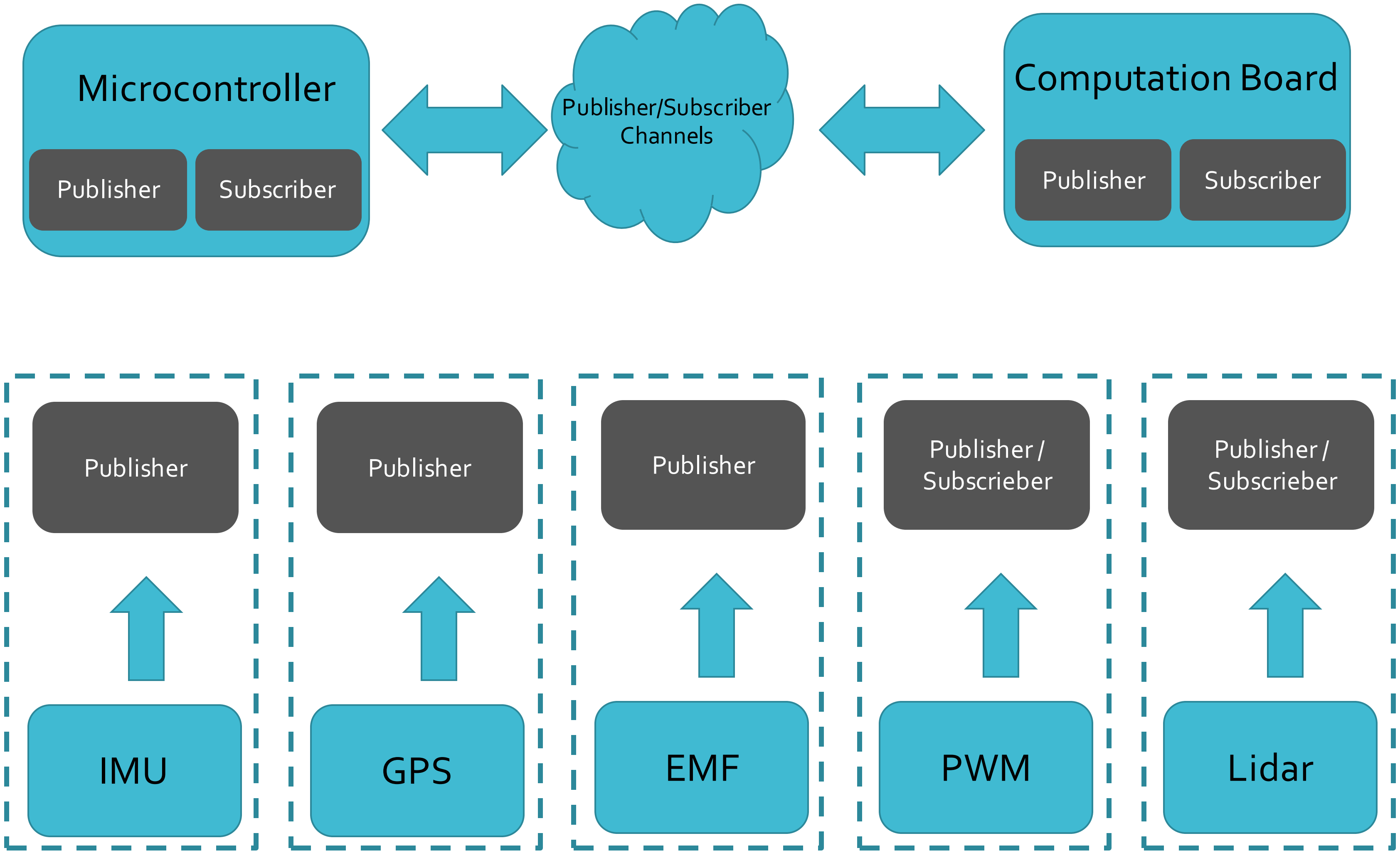
ROS / Software

- ROS stands for Robot Operating System

- ROS is a set of software libraries and tools that help you build robot applications
- ROS is open-source and can be installed in many operating systems, but it has fast performance in Linux which makes the best OS for ROS.
- Main programming language used are C++ and Python

Jordan

ROS Publisher/ Subscriber nodes



Jordan

ODROID-XU4 (Initial Choice)

- A powerful Single Board Computer and energy efficient hardware.

- The ODROID-XU4 supports running various versions of Linux including:
  1. Ubuntu 16.4 and
  2. Android 4.4 KitKat and 5.0 Lollipop.

Size	83 x 58 x 22 mm approx.(including cooling fan)
RAM	2Gbyte LPDDR3 RAM PoP stacked
CPU	Samsung Exynos 5 Octa 5422 (4x up to 2.1 GHz + 4x up to 1.4 GHz)
Storage	Supports eMMC5.0 HS400 and/orMicro SD
GPU	Mali-T628 MP6
Video	Full HD
USB	2xUSB3 1xUSB2
Power source	5V/4A
Storage types	Micro SD EMMc Sata(optional)
Network Connectivity	Gigabit Ethernet
CPU Instruction set	ARMv7-A
GPIO	24 Pins
Display Port	HDMI 1.4a

Jordan

Switched to Raspberry PI 4

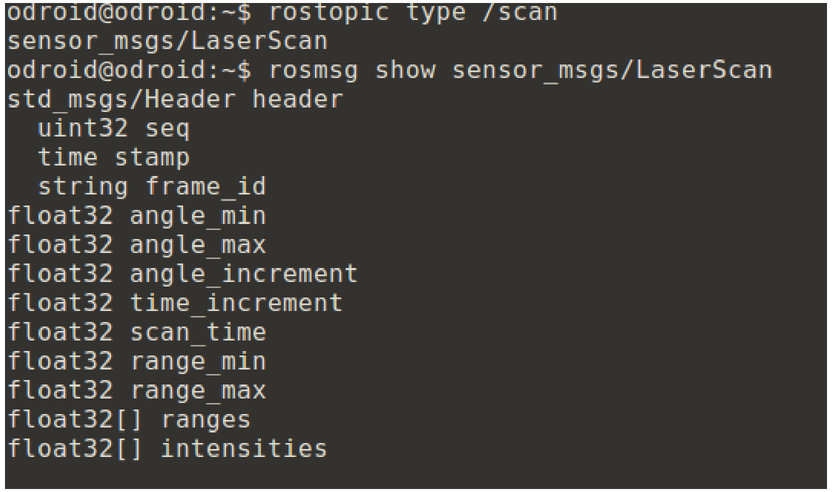
- A powerful and very popular Single Board Computer and energy efficient hardware.
- The Raspberry PI 4 supports running various versions of Linux including:
  1. Raspbian
  2. Ubuntu 16.4 and
  3. Snappy Ubuntu Core
  4. Risc OS
  5. Windows10 Iot Core

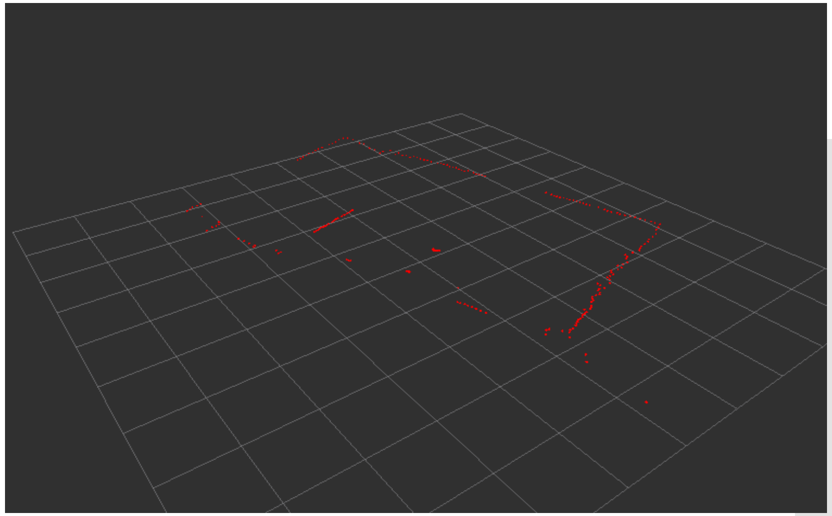
Feature	Pi 3 Model B+ (Predecessor*)	Pi 4 Model B
CPU	1.4GHz quad-core 64-bit ARM Cortex-A53	1.5GHz quad-core 64-bit ARM Cortex-A72 (**~3X better performance**)
RAM	1GB	1GB, 2GB, or 4GB
USB ports	4x USB 2.0	2X USB 3.0, 2X USB 2.0
Ethernet	Gigabit (max. throughput 300 Mbps)	Gigabit (full throughput)
Bluetooth	4.2, BLE	5.0, BLE
HDMI	Single HDMI	Dual HDMI, with 4K output

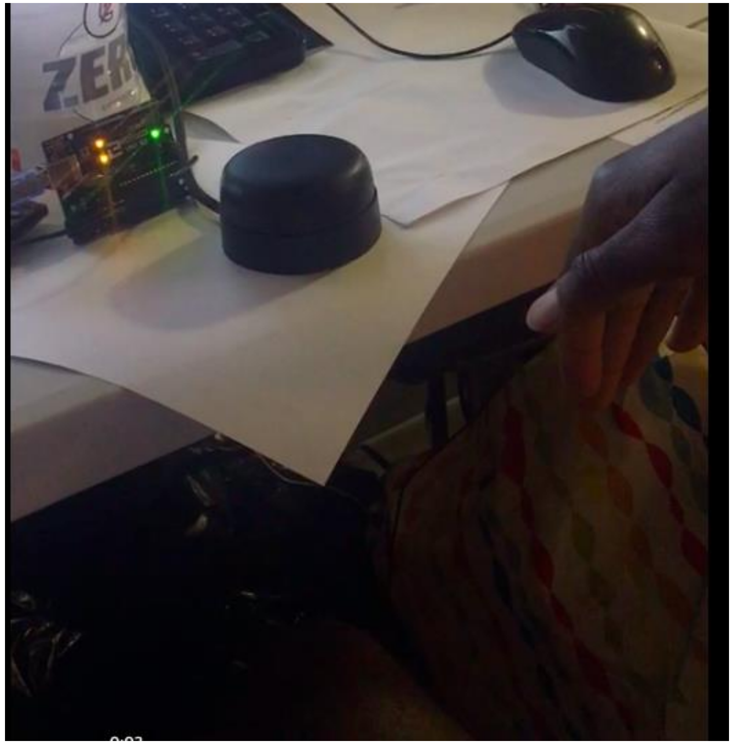
Jordan

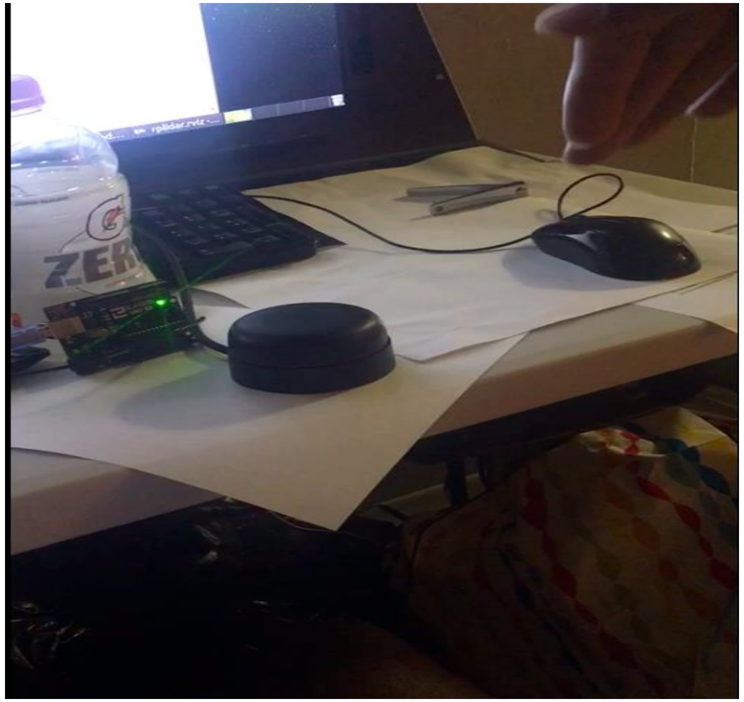
Object Detection(Lidar)

- Lidar scans its environment and collect data
- The data collected is broadcasted on /scan topic
- Lidar can be used to detect object which is why we used as part of our object detection components
- Very accurate and fast









Jordan

ROS/Code

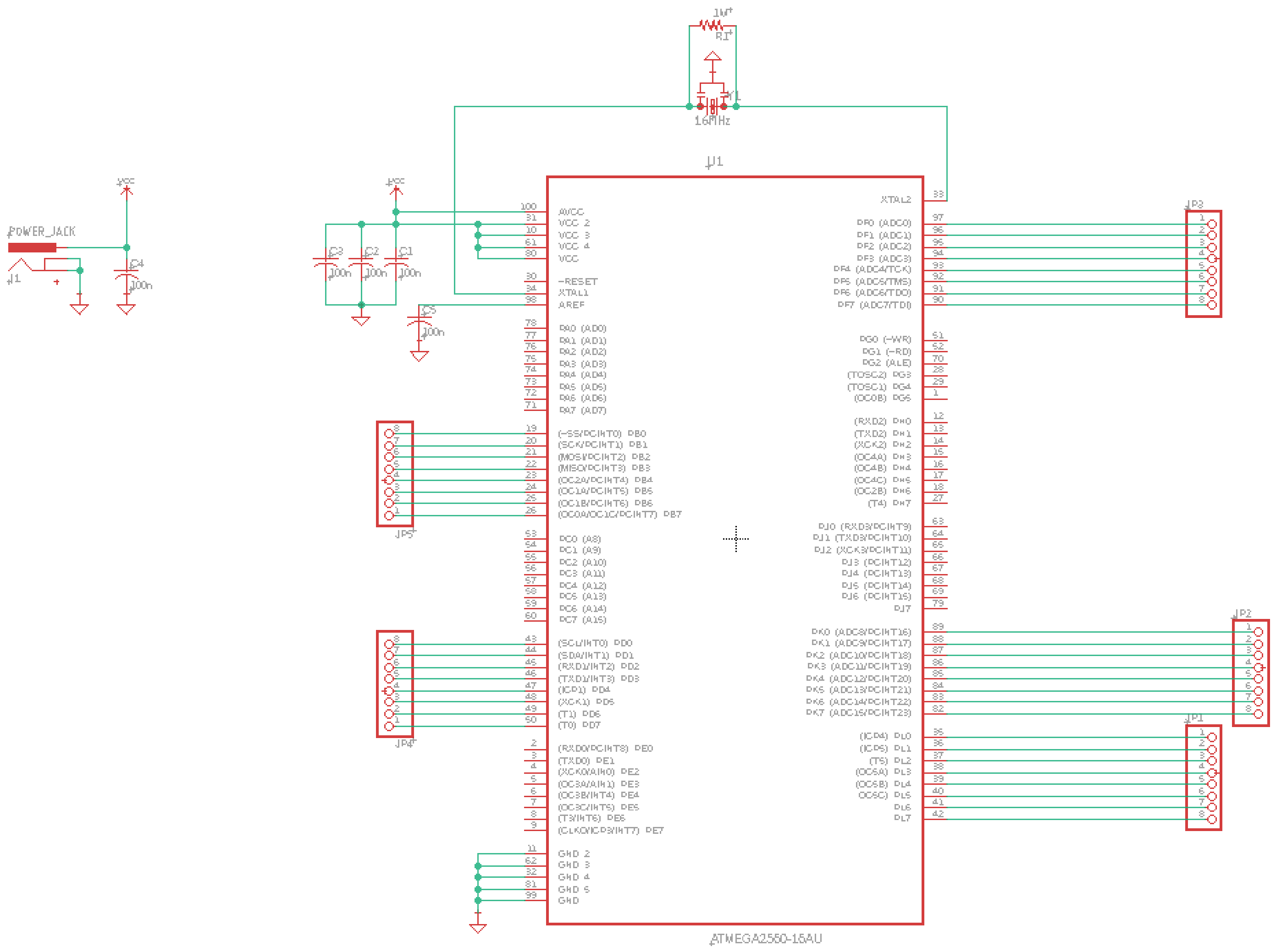
```
def gobackwards():
    velocity_publisher = rospy.Publisher('/cmd_vel', Twist, queue_size=10)
    vel_msg = Twist()
    speed = 1
    vel_msg.linear.x = -1
    #Since we are moving just in x-axis
    vel_msg.linear.y = 0
    vel_msg.linear.z = 0
    vel_msg.angular.x = 0
    vel_msg.angular.y = 0
    vel_msg.angular.z = 0
    velocity_publisher.publish(vel_msg)
```

```
def move():
    pub = rospy.Publisher('/cmd_vel', Twist, queue_size=10)
    #print "talker function"
    vel_msg = Twist()
    vel_msg.linear.x = 1
    vel_msg.linear.y = 0
    vel_msg.linear.z = 0
    vel_msg.angular.x = 0
    vel_msg.angular.y = 0
    vel_msg.angular.z = 0
    pub.publish(vel_msg)
    rospy.loginfo(vel_msg)
```

```
def callback(data):
    global x
    pub = rospy.Publisher('/cmd_vel', Twist, queue_size=10)
    #print "talker function"
    vel_msg = Twist()
    #vel_msg.linear.x = 0
    vel_msg.linear.y = 0
    vel_msg.linear.z = 0
    vel_msg.angular.x = 0
    vel_msg.angular.y = 0
    vel_msg.angular.z = 0
    for i in range(0,359):
        if (i>270 or (i<90 and i>0)) and data.ranges[i]<1:
            #x = True
            vel_msg.linear.x = 0
            rospy.loginfo(vel_msg)
            pub.publish(vel_msg)
            time.sleep(12)
```

PCB Schematic

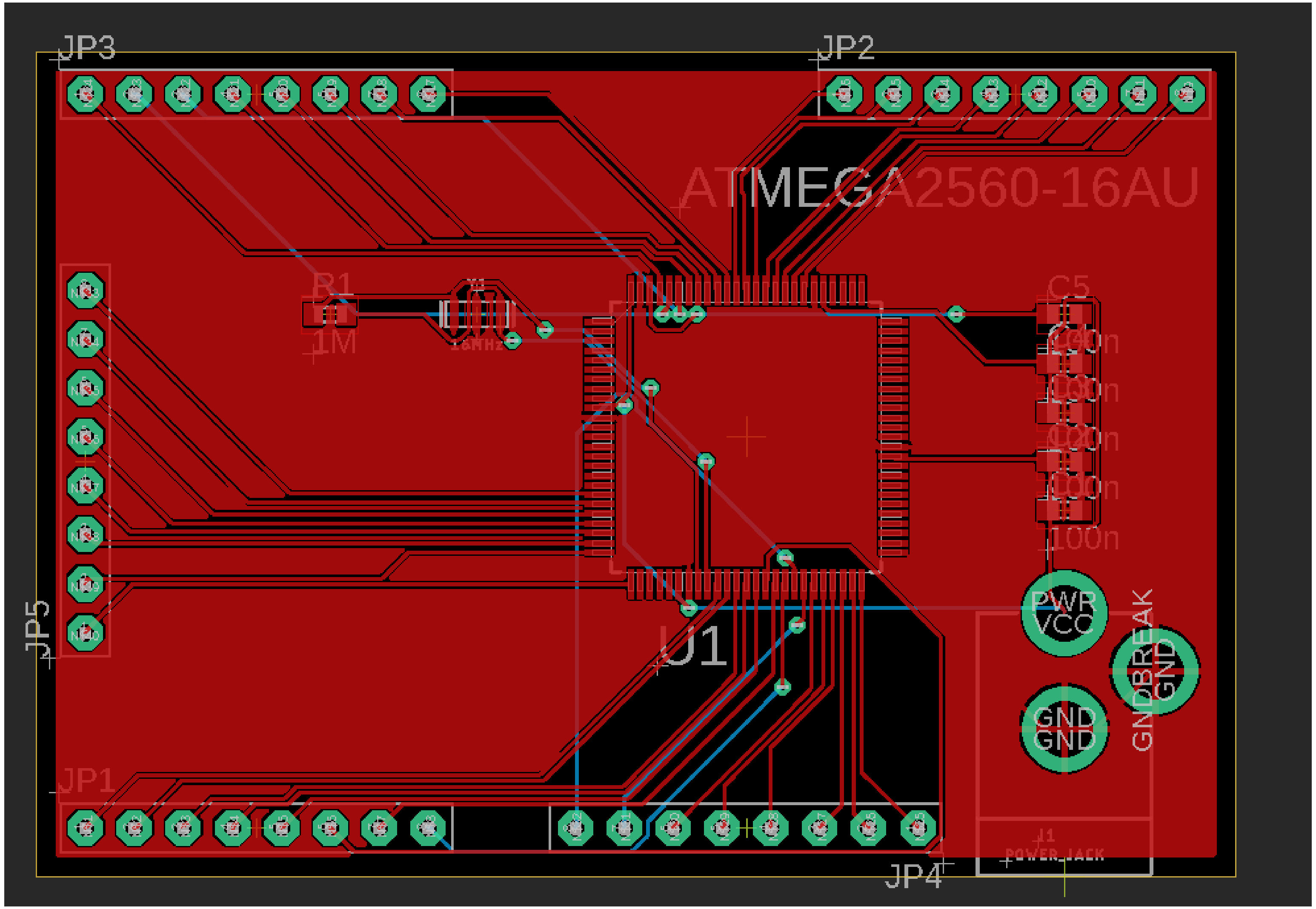
- Bare bones because most of the components and sensors are separate discrete parts
- made in Eagle



Jonathan

Printed Circuit Board v1.0

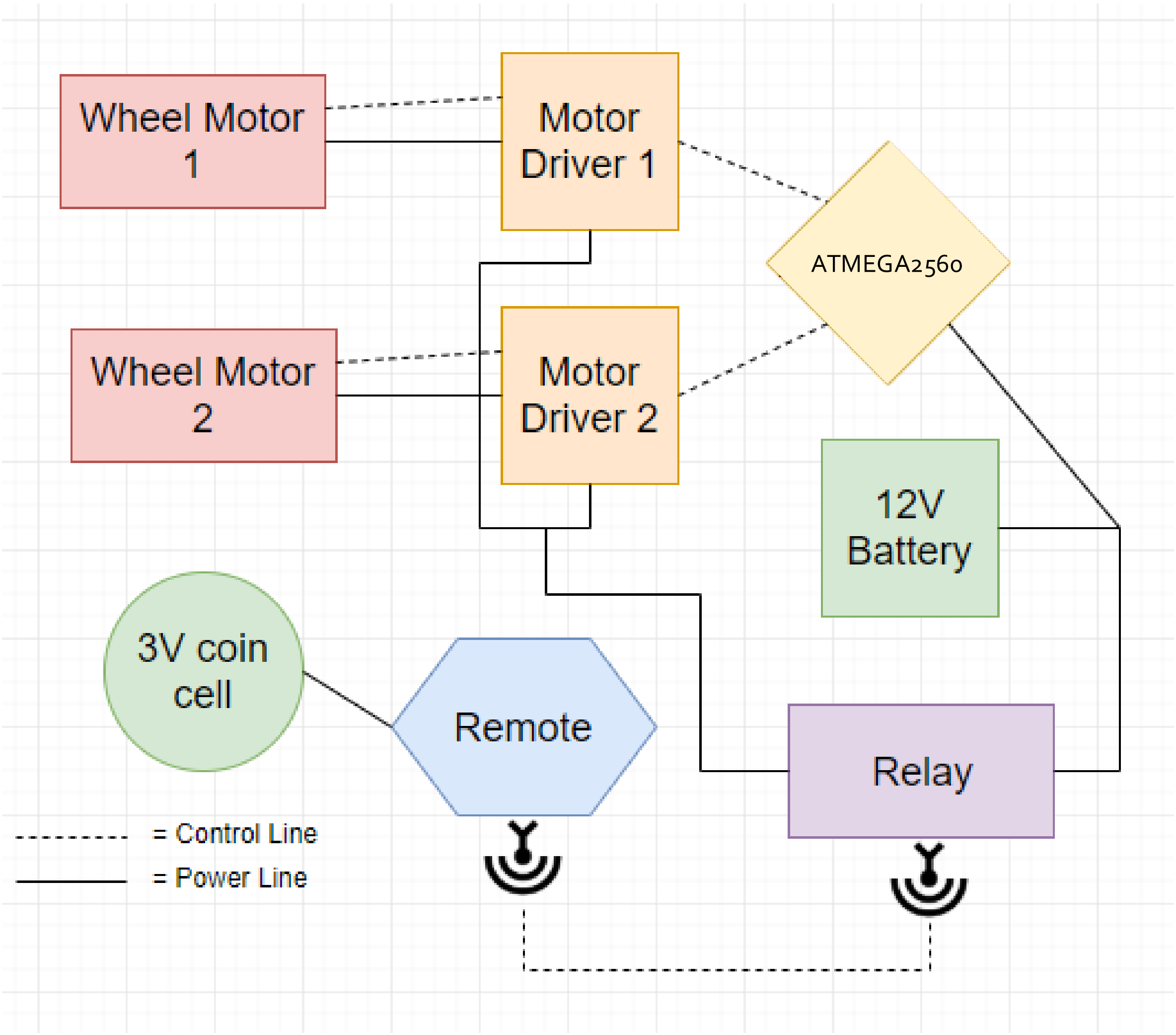
- Dimensions: 2.5"x2"
- Layers: 2
- Vias used to connect top and bottom layers as well as GND
- Pin headers for easy testing, experimenting, and debugging



Jonathan

Wheel Motor Power System

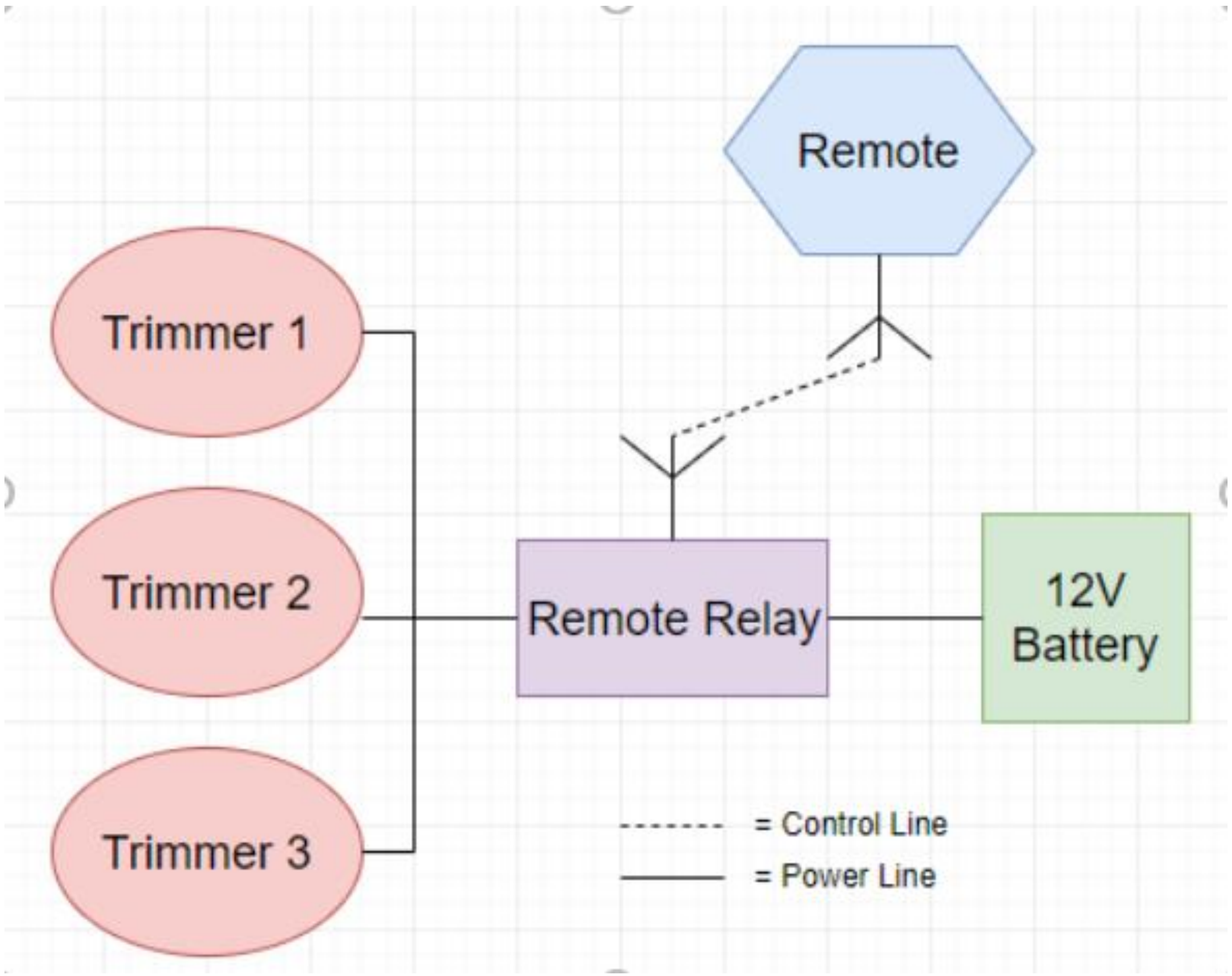
- 12V 15000mAh battery powering both wheel motors
- Remote relay to turn on and off wheel motors(kill switch)
- 3V coin cell battery to go into relay remote control



Jonathan

Trimmer Motor Power System

- 3 12V Lipo batteries rated for 8000mAh
- Remote relay to turn on and off trimmers (kill switch – on a different channel)



Jonathan

Financing

- Option to be personally financed
- Primarily financed by Duke Energy and Orange County Utility

- Total Budget provided by Duke Energy and OUC: $1500
- Total Budget currently used: approximately $1205/1500

Jonathan

Budget

Part	Price	Quantity	Total
Caster Wheel	$15.86	1	$15.86
Drive Wheels	$107.52	1	$107.52
Driving Motors	$84.33	2	$168.65
Trimming Motors	$13.58	2	$27.16
Trimmer Head	$17.69	1	$17.69
18V Ryobi 1.3Ah	$69.97	1	$69.97
18V Ryobi 4.0Ah	$119.00	1	$119.00
32 Qt latching box	$7.98	1	$7.98
Boundary Wire	$18.95	1	$18.95
GPS Module	$39.95	1	$39.95
SMA Adapter Cable	$3.95	1	$3.95
GPS Antenna	$14.95	1	$14.95
IMU Sensor	$14.95	1	$14.95
Lidar	$300	1	$300
Perimeter Wire Kit	$9.95	1	$9.95
Odroid XU4	$77.85	1	$77.85
Bearing Pillow	$15.95	1	$15.95
USB-Hub Adapter	$6.99	1	$6.99

Davis

Budget

Part	Price	Quantity	Total
Intel RealSense Camera	$175.99	1	$175.99
Wireless Relay	$28.69	1	$28.69
Ovonic 11.1V 8000mAh 3S 50C LiPo Battery	$87.99	1	$87.99
B3 RC LiPo 2S-3S Battery Balancer Charger 7.4-11.1V	$10.99	2	$21.98
5pcs Male T-Plug	$9.98	2	$19.96
Lipo Bag	$7.77	1	$7.77
Velcro Strips	$8.99	1	$8.99
Buck Converters (5pcs)	$26.59	1	$26.59
Wire loom	$11.99	1	$11.99
Wire	$15.99	1	$15.99
Connectors	$11.99	1	$11.99
Connectors (robust)	$10.99	1	$10.99
Wire (robust)	$16.89	1	$16.89

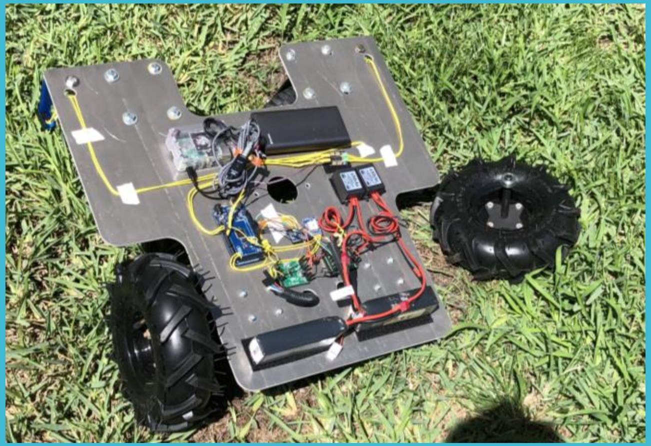
Davis

Budget

Department	Cost Estimate
Mechanical Engineering	$551.70
Electrical & Computer Engineering	$653.30
Total	$1205.00

- Had to re-order the ODROID due to a mix up in the UCF purchase process

Difficulties and Constraints



- Mechanical Engineering Department Order Process Errors/ Mistakes
- COVID-19 Uncertainties starting March 9th created issues for integration
- Integration of Mechanical and ECE Work hindered due to stay at home orders from UCF and the state of Florida
- Suppliers shut down for sourcing materials or slow

Jonathan

What we longed for…

- Mechanical Body integration with Top Cover finished
- Integration of LiDar and Camera on the Body
- Integration of the trimmer head to the base plate body
- Proper Navigational Autonomy directed through Single Board Computer
- Integrate more software safety features with sensor modules

Jonathan

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