Situation-Aware Stop Signal

Critical Design Review

Group 3

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Rethinking traffic control at small intersections

Project Description

A device that uses sensors to track cars from 20+ meters away to control traffic and prevent accidents

Influenced by technology found in existing traffic lights and autonomous cars

Focused towards small intersections that are currently controlled by stop signs

Objectives

Marketing Objectives

Accuracy

Self-sustainment

Efficiency

Low cost

Technical Objectives

Prevent

Protect

Schedule

Motivation

- Protecting the lives of the drivers that cross our roads – our families, our friends, and our neighbors
- "1/3 of all intersection crashes in the United States, and more than 40% of the fatal ones, occur at intersections controlled by stop signs." (Insurance Institute for Highway Safety)

We believe that **advances in technology**, now made more affordable through manufacturing improvements, present **an opportunity to revolutionize the way we advise, warn, and alert drivers** on the small roads of our community.

Team Organization

Name	Function
Jonathan Ling	Power
Annabelle Phinney	PCB
Trent Sellers	Embedded Software
Joseph Walters	Embedded Software/Embedded Hardware

Key Requirements Overview

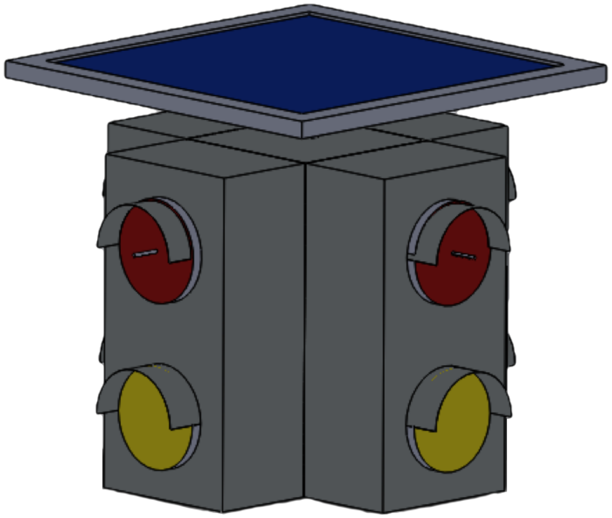
Design Requirements	Operational Requirements	Power Requirements	Safety Requirements
One centralized unit	IP52 weather resistant	Solar panel shall output greater than 6V and 40W	Abide by road sign laws specified in the Manual for Uniform Traffic Control Devices (MUTCD)
Visible during the day and night	Maintain operability between 0°C and 60°C	Battery shall hold enough power for minimum of 2 days of operation	Detect vehicles that are traveling up to 45 mph
Shall be operable 24/7	Detect an oncoming vehicle within 20 meters		
	Responsive in real-time operation		

Engineering Requirement Targets

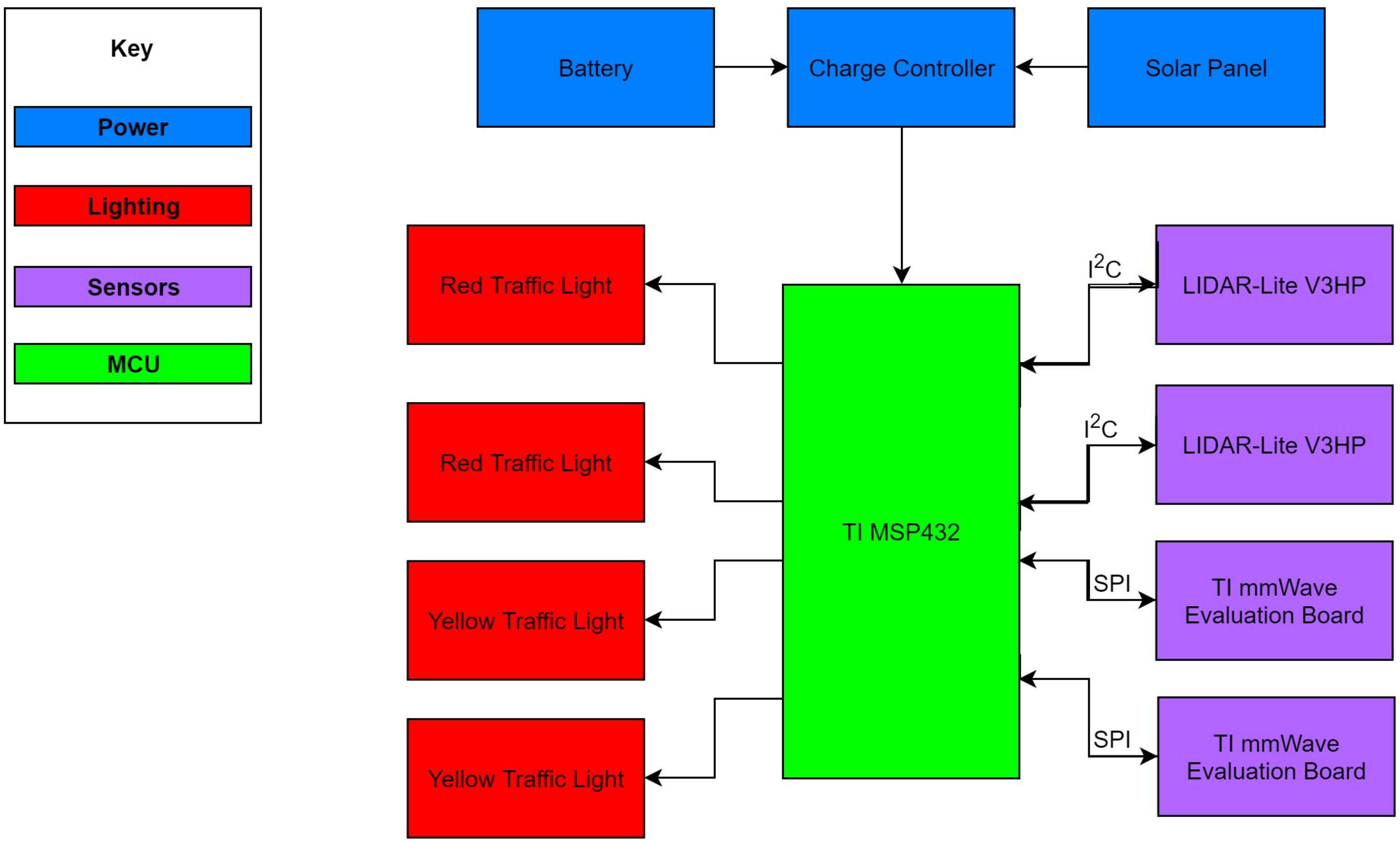
Target	Verification	Units (if applicable)
Obedience to Traffic Law	Complies with USDOT MUTCD rules and regulations	
Power Consumption	< 20	Watts
Self-Sustained Solar Power (generated)	0.48	kWh/day
Sensor Accuracy	90	% within 25 feet
Cost	< 1800	$US
Modular Structure (installation)	< 30	minutes

Concept of Operation

- A new way of controlling and organizing traffic
- Uses LiDAR and RADAR to detect cars
- Detects when it is safe for a car to cross an intersection
- Schedules right-of-way
- Recognizes possible threats – gives no one the right-of-way



Block Diagram



Power Design

Solar Panel

- Low cost
- Monocrystalline - High efficiency
- Over 80W power supply
- 25 solar cells at 0.6V each
- 6A current supply
- 28 x 28 in.
- Mounted on a hinge to adjust to the optimum angle
- Solar tracking is a stretch goal

Solar Cell Selection

Product	SunPower C60	Seeed Studio POW92145O	Aoshiki Mini Solar Cell	SparkFun PRT-13784
Price	$97.50	$199.00	$39.50	$474.00
Power generated (625 sq. in)	80W	50W	66W	54W
Efficiency	22%	17%	17%	19%
Layout	Solar Cell	Solar Panel	Solar Cell	Solar Panel
Waterproof	No	Yes	No	Yes

Battery

- Lithium Ion
- High energy density
- High charge efficiency
- Fast charge time
- High thermal threshold
- Long discharge cycles
- Long lifespan
- 12V
- 20Ah

Battery Materials

Battery Type	Lead Acid	Nickel Cadmium	Lithium Ion
Price	$	$$	$$$
Cell voltage	2.0V	1.2V	3.7V
Life Cycles	200-300	1000	500-1000
Wh/kg	40	50	140
Charge Time (h)	8-16	1	2-4
Temp Range (F)	-4° - 122°	-4° - 140°	-4° - 149°

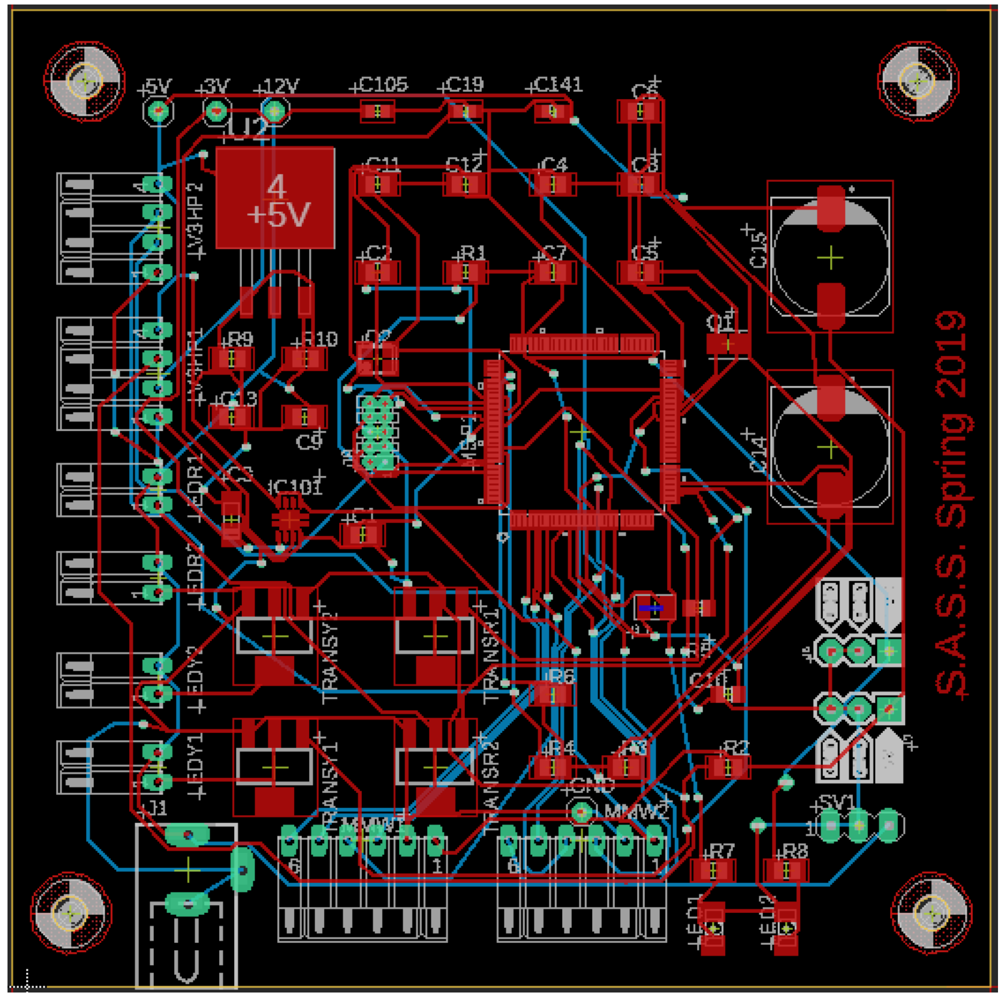
Charge Controller

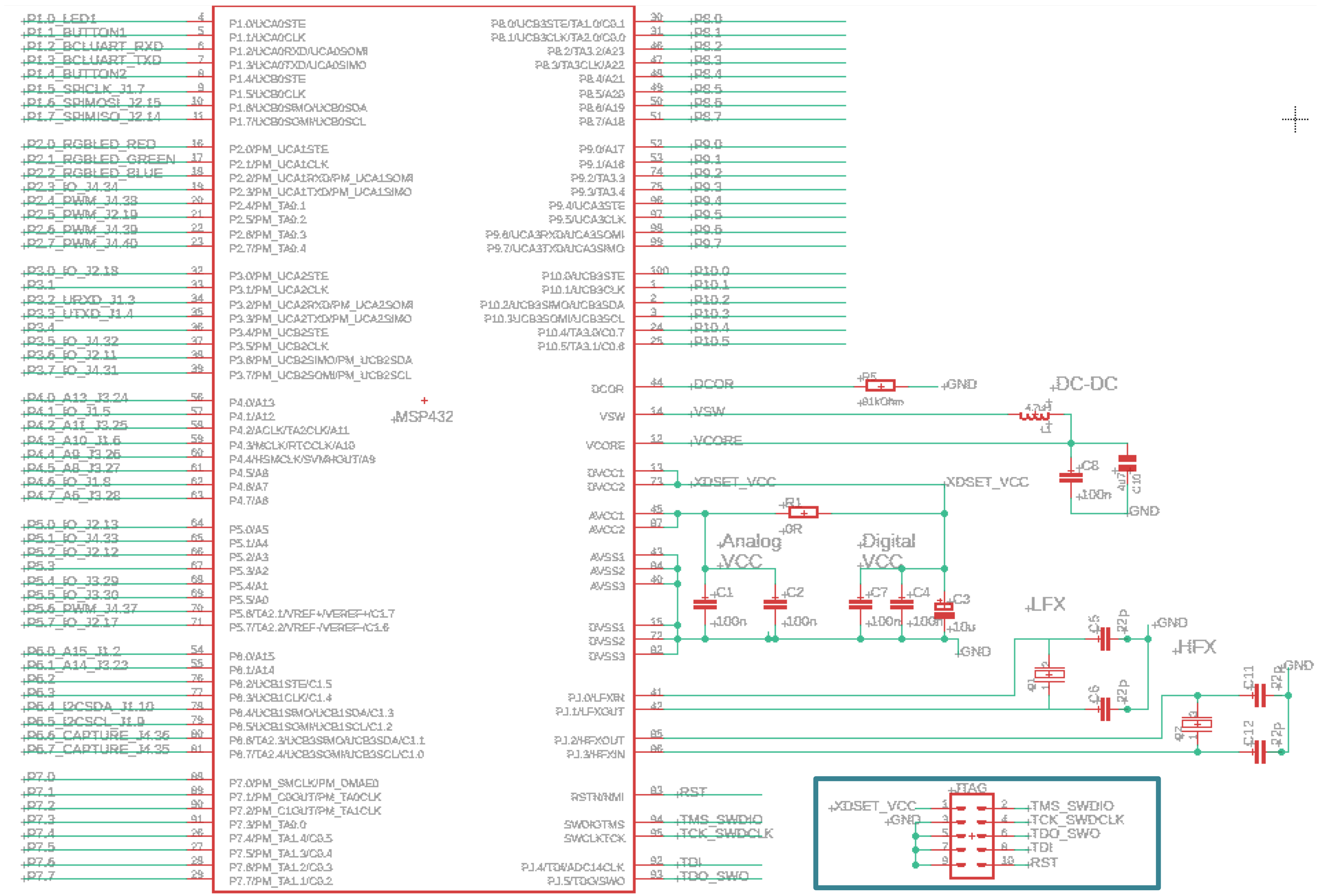
- MPPT - Maximum Power Point Tracking
- Highest efficiency ~ 99%
- Extends battery life
- Converts excessive voltage into additional current
- More expensive
- More parts than a 1-stage controller or PWM charge controller

Hardware Design

PCB Layout

- 85mm x 85mm
- Two layer PCB used to lower cost
- Used larger components for quick prototyping
- Large space between components
- Connectors placed on sides for easy access and secure connection

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P1.1_BUTTON1
P1.2_BCLUART_RXD
P1.3_BCLUART_TXD
P1.4_BUTTON2
P1.5_SPICLK_J1.7
P1.6_SPIMOSI_J2.15
P1.7_SPIMISO_J2.14
P2.0_RGBLED_RED
P2.1_RGBLED_GREEN
P2.2_RGBLED_BLUE
P2.3_IO_J4.34
P2.4_PWM_J4.38
P2.5_PWM_J2.19
P2.6_PWM_J4.39
P2.7_PWM_J4.40
P3.0_IO_J2.18
P3.1
P3.2_URXD_J1.3
P3.3_UTXD_J1.4
P3.4
P3.5_IO_J4.32
P3.6_IO_J2.11
P3.7_IO_J4.31
P4.0_A13_J3.24
P4.1_IO_J1.5
P4.2_A11_J3.25
P4.3_A10_J1.6
P4.4_A9_J3.26
P4.5_A8_J3.27
P4.6_IO_J1.8
P4.7_A6_J3.28
P5.0_IO_J2.13
P5.1_IO_J4.33
P5.2_IO_J2.12
P5.3
P5.4_IO_J3.29
P5.5_IO_J3.30
P5.6_PWM_J4.37
P5.7_IO_J2.17
P6.0_A15_J1.2
P6.1_A14_J3.23
P6.2
P6.3
P6.4_I2CSDA_J1.10
P6.5_I2CSCL_J1.9
P6.6_CAPTURE_J4.36
P6.7_CAPTURE_J4.35
P7.0
P7.1
P7.2
P7.3
P7.4
P7.5
P7.6
P7.7
MSP432
P1.0/UCA0STE
P1.1/UCA0CLK
P1.2/UCA0RXD/UCA0SOMI
P1.3/UCA0TXD/UCA0SIMO
P1.4/UCB0STE
P1.5/UCB0CLK
P1.6/UCB0SIMO/UCB0SDA
P1.7/UCB0SOMI/UCB0SCL
P2.0/PM_UCA1STE
P2.1/PM_UCA1CLK
P2.2/PM_UCA1RXD/PM_UCA1SOMI
P2.3/PM_UCA1TXD/PM_UCA1SIMO
P2.4/PM_TA0.1
P2.5/PM_TA0.2
P2.6/PM_TA0.3
P2.7/PM_TA0.4
P3.0/PM_UCA2STE
P3.1/PM_UCA2CLK
P3.2/PM_UCA2RXD/PM_UCA2SOMI
P3.3/PM_UCA2TXD/PM_UCA2SIMO
P3.4/PM_UCB2STE
P3.5/PM_UCB2CLK
P3.6/PM_UCB2SIMO/PM_UCB2SDA
P3.7/PM_UCB2SOMI/PM_UCB2SCL
P4.0/A13
P4.1/A12
P4.2/ACLK/TA2CLK/A11
P4.3/MCLK/RTCCLK/A10
P4.4/HSMCLK/SVMHOUT/A9
P4.5/A8
P4.6/A7
P4.7/A6
P5.0/A5
P5.1/A4
P5.2/A3
P5.3/A2
P5.4/A1
P5.5/A0
P5.6/TA2.1/VREF+/VEREF+/C1.7
P5.7/TA2.2/VREF-/VEREF-/C1.6
P6.0/A15
P6.1/A14
P6.2/UCB1STE/C1.5
P6.3/UCB1CLK/C1.4
P6.4/UCB1SIMO/UCB1SDA/C1.3
P6.5/UCB1SOMI/UCB1SCL/C1.2
P6.6/TA2.3/UCB3SIMO/UCB3SDA/C1.1
P6.7/TA2.4/UCB3SOMI/UCB3SCL/C1.0
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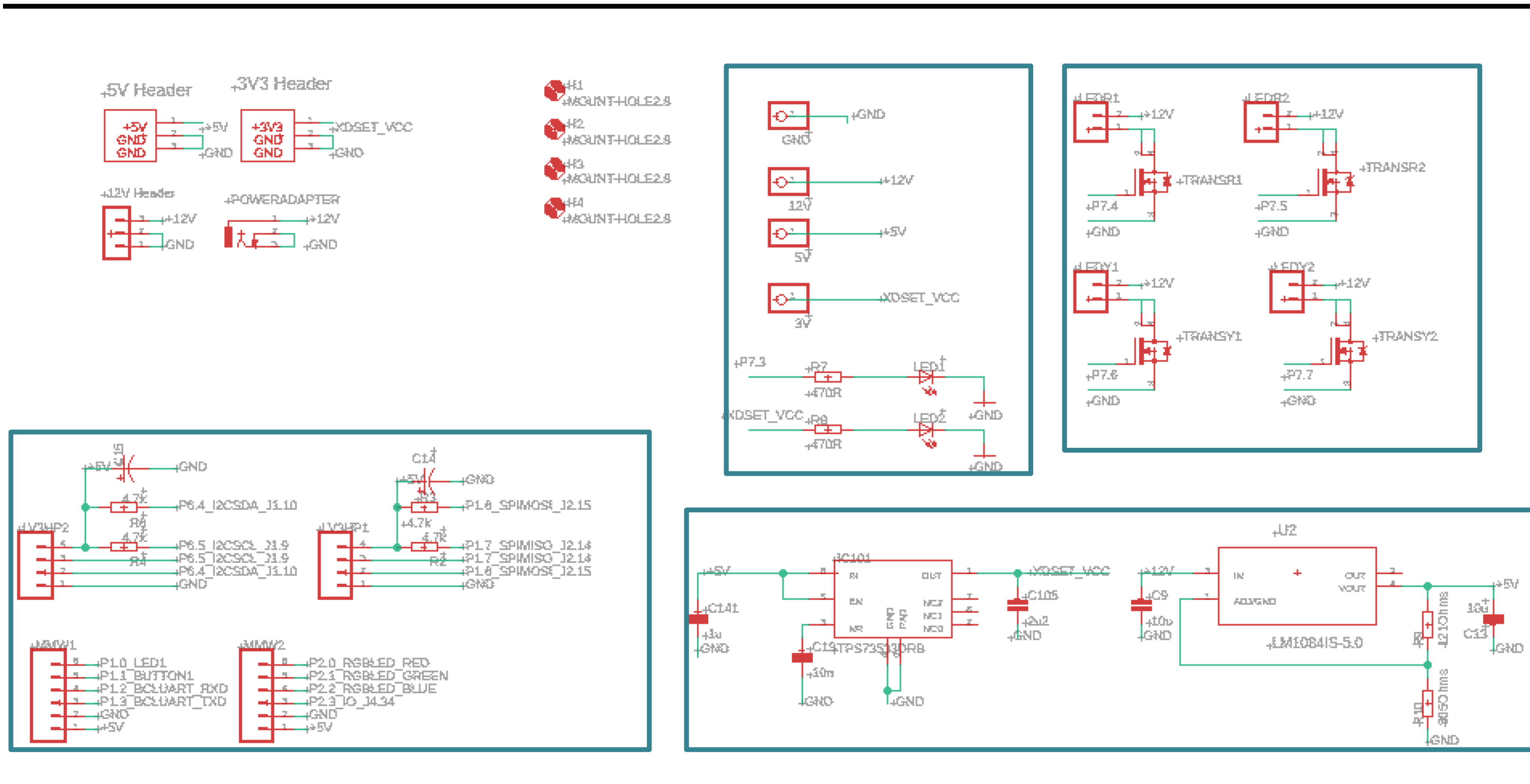
P7.2/PM_C1OUT/PM_TA1CLK
P7.3/PM_TA0.0
P7.4/PM_TA1.4/C0.5
P7.5/PM_TA1.3/C0.4
P7.6/PM_TA1.2/C0.3
P7.7/PM_TA1.1/C0.2
P8.0/UCB3STE/TA1.0/C0.1
P8.1/UCB3CLK/TA2.0/C0.0
P8.2/TA3.2/A23
P8.3/TA3CLK/A22
P8.4/A21
P8.5/A20
P8.6/A19
P8.7/A18
P9.0/A17
P9.1/A16
P9.2/TA3.3
P9.3/TA3.4
P9.4/UCA3STE
P9.5/UCA3CLK
P9.6/UCA3RXD/UCA3SOMI
P9.7/UCA3TXD/UCA3SIMO
P10.0/UCB3STE
P10.1/UCB3CLK
P10.2/UCB3SIMO/UCB3SDA
P10.3/UCB3SOMI/UCB3SCL
P10.4/TA3.0/C0.7
P10.5/TA3.1/C0.6
DCOR
VSW
VCORE
DVCC1
DVCC2
AVCC1
AVCC2
AVSS1
AVSS2
AVSS3
DVSS1
DVSS2
DVSS3
PJ.0/LFXIN
PJ.1/LFXOUT
PJ.2/HFXOUT
PJ.3/HFXIN
RSTN/NMI
SWDIOTMS
SWCLKTCK
PJ.4/TDI/ADC14CLK
PJ.5/TDO/SWO
P8.0
P8.1
P8.2
P8.3
P8.4
P8.5
P8.6
P8.7
P9.0
P9.1
P9.2
P9.3
P9.4
P9.5
P9.6
P9.7
P10.0
P10.1
P10.2
P10.3
P10.4
P10.5
DCOR
R5
91kOhm
GND
DC-DC
VSW
4.7uH
L1
VCORE
C8
100n
4u7
C10
GND
XDSET_VCC
XDSET_VCC
R1
0R
Analog
VCC
Digital
VCC
C1
100n
C2
100n
C7
100n
C4
100n
C3
10u
GND
LFX
C5
22p
GND
Q1
C6
22p
HFX
GND
C11
22p
Q2
C12
22p
RST
TMS_SWDIO
TCK_SWDCLK
TDI
TDO_SWO
JTAG
XDSET_VCC
GND
TMS_SWDIO
TCK_SWDCLK
TDO_SWO
TDI
RST


5V Header
3V3 Header
+5V
GND
GND
+3V3
GND
GND
XDSET_VCC
12V Header
POWERADAPTER
+12V
H1 MOUNT-HOLE2.8
H2 MOUNT-HOLE2.8
H3 MOUNT-HOLE2.8
H4 MOUNT-HOLE2.8
12V
5V
3V
P7.3
R7
470R
LED1
R8
LED2
LEDR1
LEDR2
TRANSR1
TRANSR2
P7.4
P7.5
LEDY1
LEDY2
TRANSY1
TRANSY2
P7.6
P7.7
C15
C14
4.7k
R6
R4
R3
R2
LV3HP2
LV3HP1
P6.4_I2CSDA_J1.10
P6.5_I2CSCL_J1.9
P1.6_SPIMOSI_J2.15
P1.7_SPIMISO_J2.14
MMW1
MMW2
P1.0_LED1
P1.1_BUTTON1
P1.2_BCLUART_RXD
P1.3_BCLUART_TXD
P2.0_RGBLED_RED
P2.1_RGBLED_GREEN
P2.2_RGBLED_BLUE
P2.3_IO_J4.34
IC101
IN
EN
NR
OUT
NC
C141
1u
C19
10n
TPS73533DRB
C105
2u2
C9
10u
U2
ADJ/GND
VOUT
LM1084IS-5.0
121Ohms
R9
R10
365Ohms
10u
C13

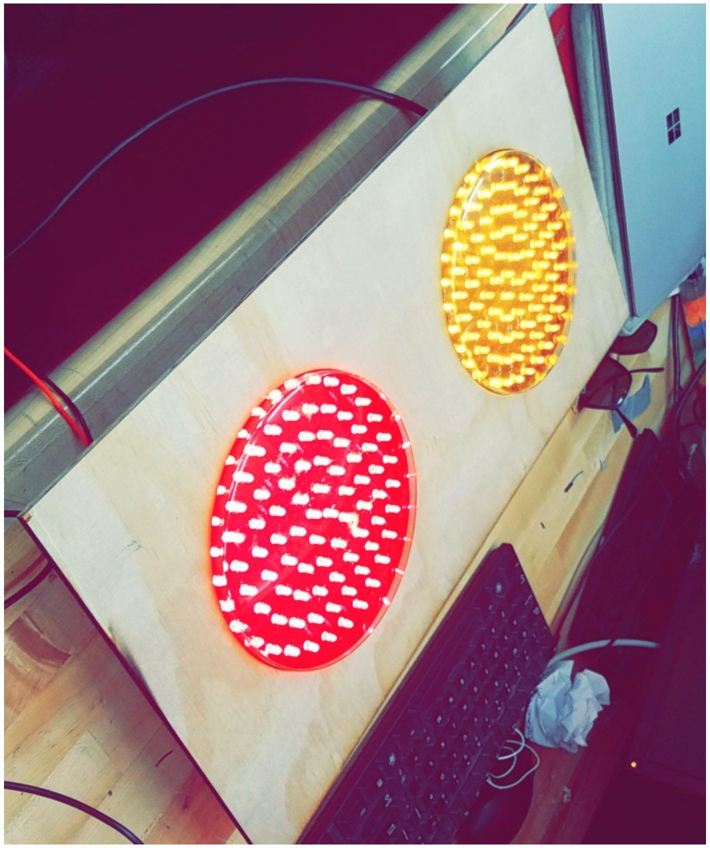
Light Selection

- Efficiency
- Environmentally Friendly
- Lower Power Requirements
- Cost

Bulb Style	Incandescent	CFL	LED
Price	$	$$	$$$
Lumen/Watt	14.3	57.14	80
Lifespan(h)	5,000	10,000	50,000-100,000

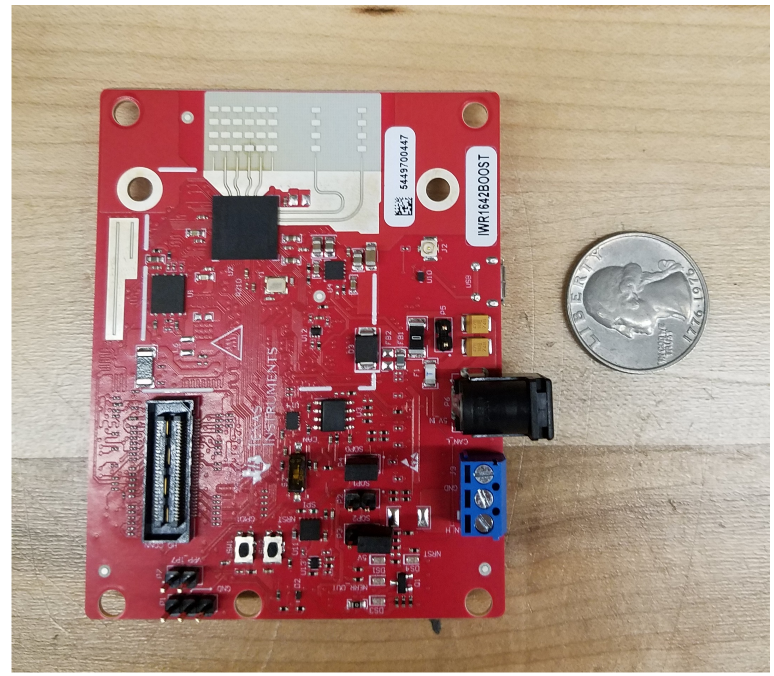
Light Selection

- Standard 01 from Section 4D.07 of the MUTCD states that there shall be two nominal diameter sizes for vehicular signal indications: 8 inches and 12 inches
- According to Section 4.1 of the ITE, the minimum lumen requirement for 8 inch bulbs is 10 lumens for a red LED and 45 lumens for a yellow LED
- Red and yellow are easily understood by drivers
- Safety



Sensors and Gathering Data (RADAR)

- These sensors transmit radio waves, then use the reflections from these radio waves to detect nearby objects
- Higher frequency with a smaller radio wave size(100MHz to 1THz)
- Larger bandwidth which decreases the sensitivity as well as the sensor's signal-to-noise ratio (SNR)
- Can compute and interpret data on its own using the IWR1642 MCU



Sensors and Data Gathering (RADAR)

Product	Hyperikon Microwave Motion Sensor	IWR1642 Evaluation Module	TIDEP-0090	IWR1642AQAGABLR (MCU)
Size (m)	0.07x0.06	0.01x0.01	0.01x0.01	0.01x0.001
Cost ($)	38.95	310.48	300	33.91
Range (m)	16	70	70	N/A
Beam width (degrees)	360	Approximately less than 90	Not specified	N/A
Power (W)	1.5	2	2	0.06

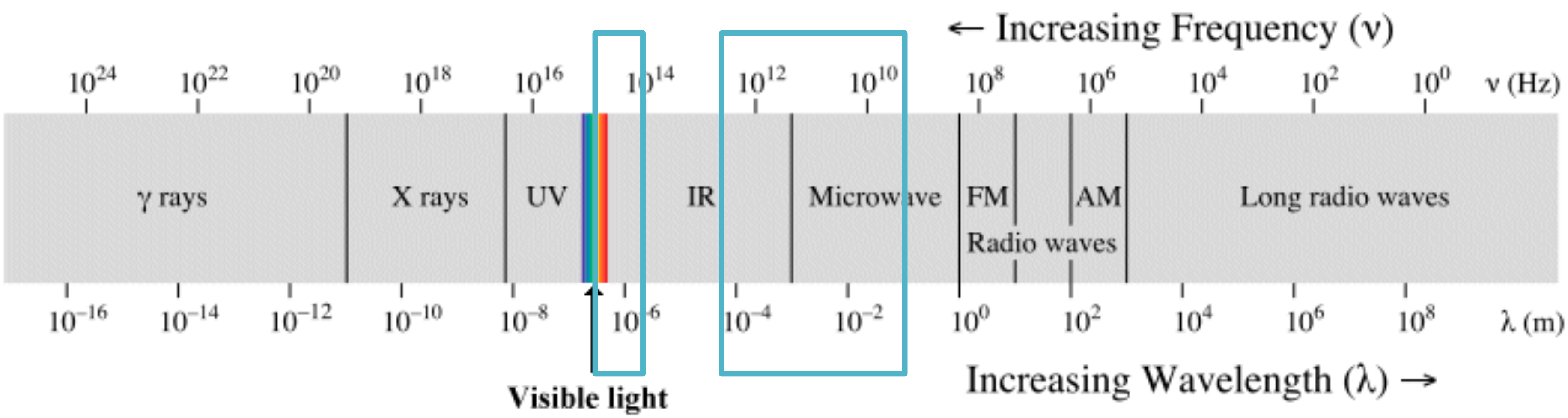
Sensors and Data Gathering (LiDAR)

Product	Slamtec RPLIDAR A3 360° Laser Scanner	LIDAR-Lite v3HP	TF02 - LiDAR Rangefinder	TF MINI MICRO LIDAR MODULE
Cost ($)	599	158	99	49
Rate (Hz)	16000	270	100	100
Range (m)	25	40	22	3-7
Power Required (W)	0.12	0.675	0.6	0.12
Size (in)	3.0 x 1.6 x 3.0	0.8 x 1.9 x 1.6	2.7 x 1.8 x 1.0	1.7 x 0.6 x 0.6

Sensors and Data Gathering (LiDAR)

- Our LiDAR sensor is a ”Time-of-Flight” sensor.
- Near infrared light
- Narrow field of view (<cm)
- High accuracy (cm)

Light Wave Spectrum

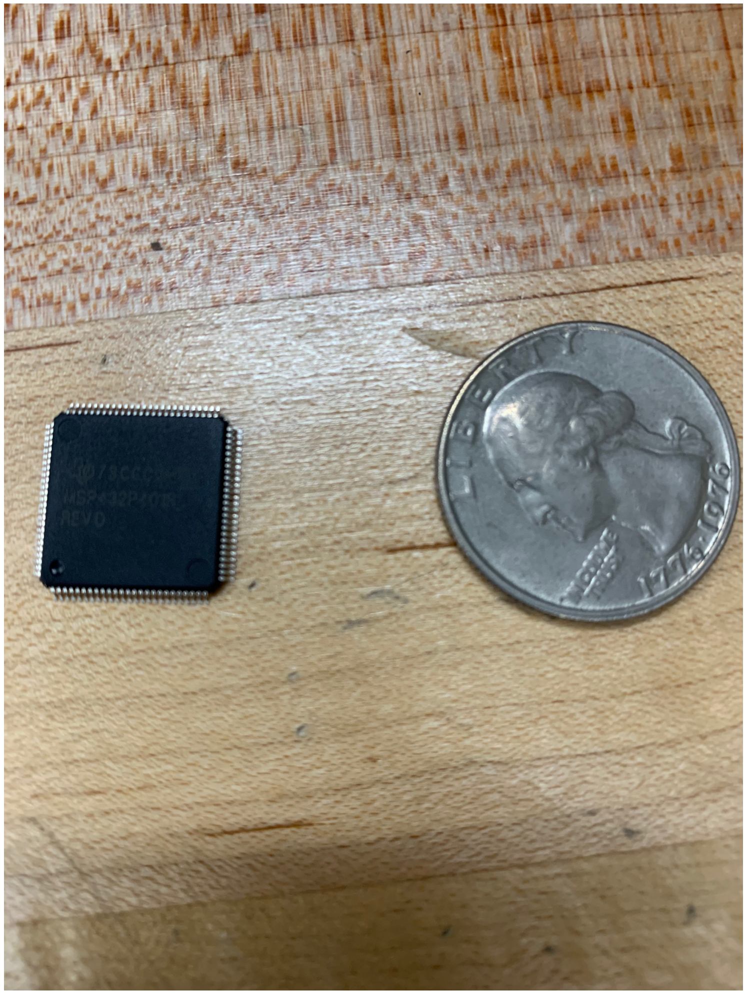


Microcontroller

Processor	MSP430G2553	MSP432P401R	ATmega328P	ATmega2560
Processor Speed	16MHz	48MHz	48MHz	48MHz
Flash Mem.	16KB	256KB	32KB	256KB
RAM	512B	64KB	2KB	8KB
Voltage Rating	5V	1.62V - 3.7V	5V - 12V	5V - 12V
No. GPIO	15	48	15	58
RTOS	2	3	0	0
LPM	Yes	Yes	No	No
Price	$2.20	$6.08	$1.28	$4.32

MSP432

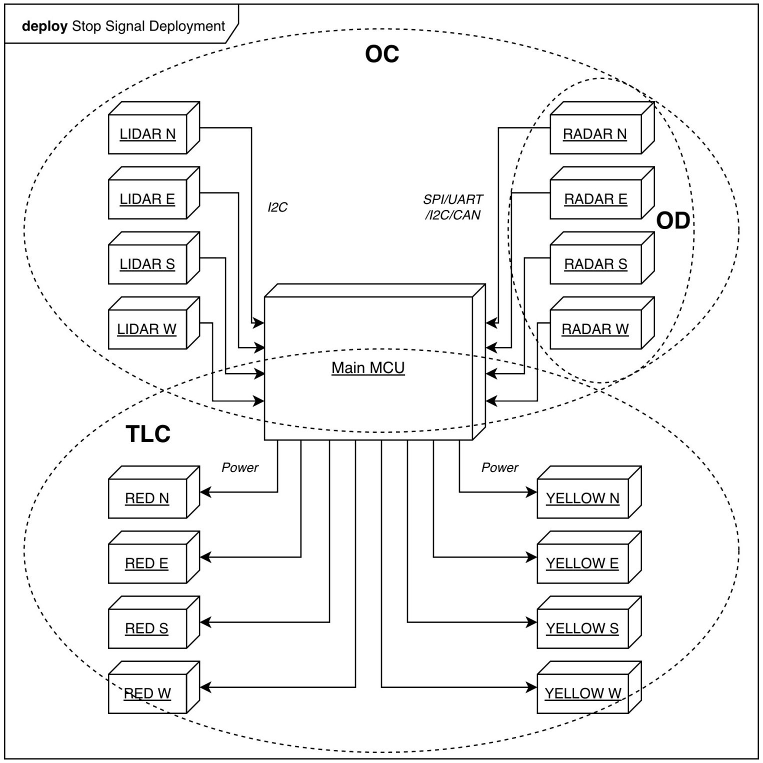
- Low Power : High Performance
- 48MHz allows for fast processing of real-time data
- Granular control over microcontroller
- More memory compared to ATMega2560
- Supports TI-RTOS
- Supports C/C++
- Supports POSIX threading



Software Design

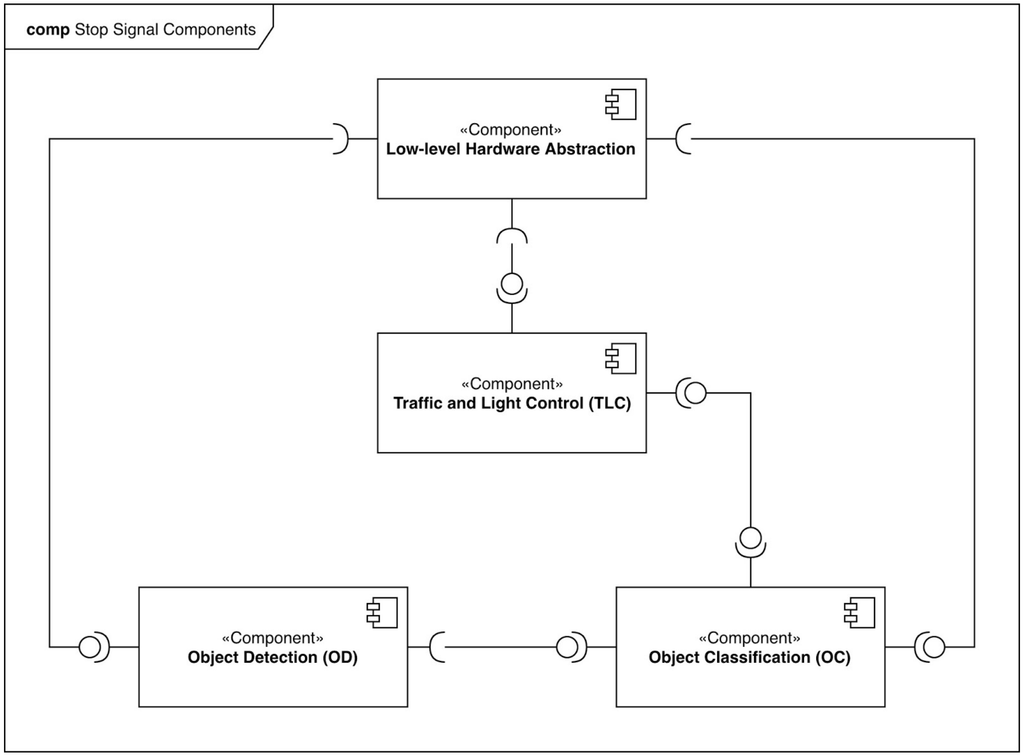
Stop Signal Software

- Written in **C++**
- Managed by **TI-RTOS**
- 4 manageable components:
- Low-level Hardware Abstraction (**LLHA**)
- Object Detection (**OD**)
- Object Classification (**OC**)
- Traffic and Light Control (**TLC**)



Deployment Diagram

Stop Signal Software



Component Diagram

Low-Level Hardware Abstraction (LLHA)

- With TI-RTOS we can abstract the hardware as needed
- This ultimately simplifies our job as the project grows
- Custom API Calls:
- I^2C (LIDAR-Lite v3HP)
- SPI (mmWave)
- Back-Channel UART (Debug & Logging)

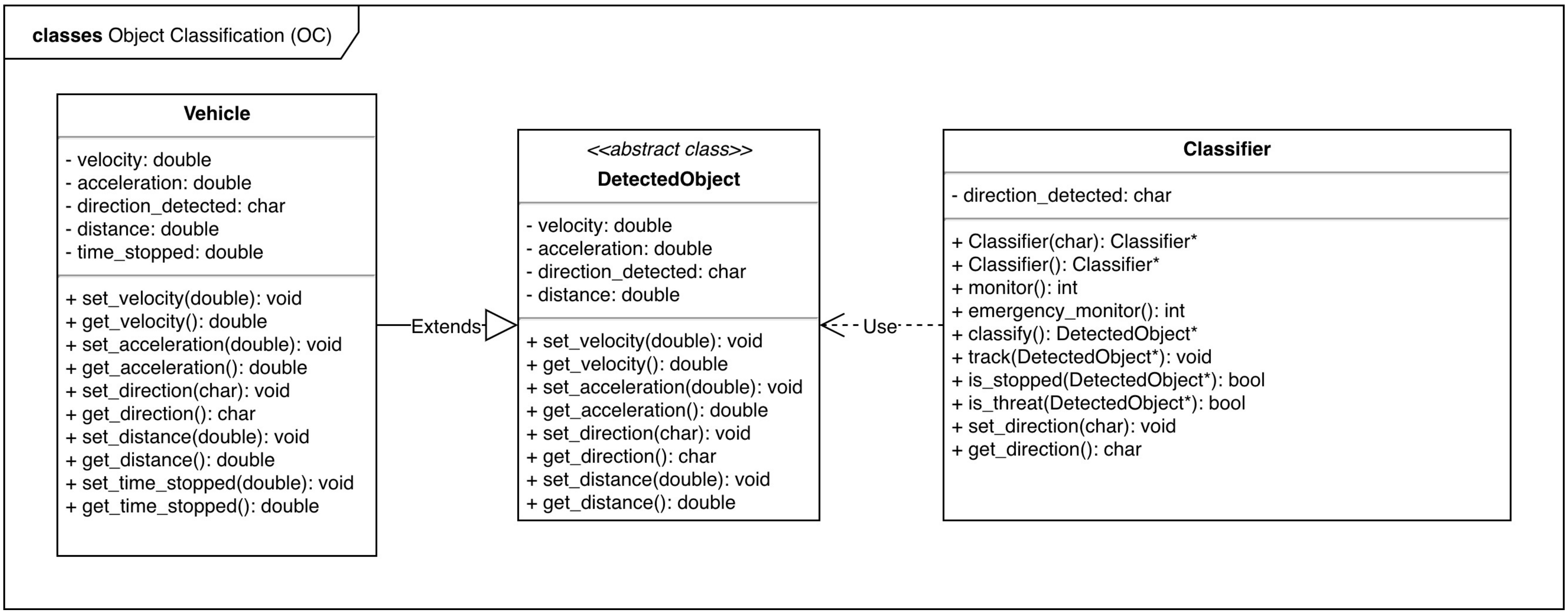
Object Detection (OD)

- Uses RADAR to detect objects
- Using that information, the system can:
- Wake up out of low-power mode
- Spawn threads to handle LiDAR
- Activate LiDAR sensors and enter into Object Classification using sensor fusion

Object Classification (OC)

- Uses RADAR and LiDAR to determine:
  - Object's speed
  - Object's acceleration
  - Distance to object
- Using that information, the system can:
  - Track up to 1 vehicle per side
  - Determine if vehicle is able to stop in a timely manner
  - Classify the object as a vehicle/bicyclist/etc.

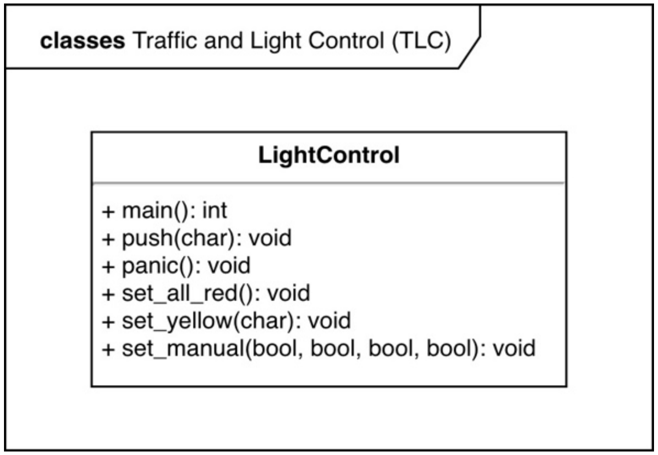
Object Classification (OC)



Object Classification Class Diagram

Traffic and Light Control (TLC)

- This module directly interfaces with the LLHA module
- Performs simple scheduling when vehicles enter the intersection
- Implements a simple FIFO queue to allow for fair scheduling



Traffic and Light Control Class Diagram

Software – Sensor Fusion

- Double redundancy
- Verification of real-time data
- Data analysis to ensure sensor accuracy

Operating System Selection

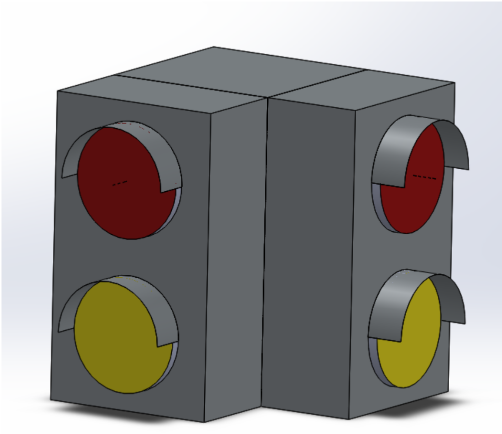
Product	FreeRTOS	Zephyr™	eCos	TI-RTOS
Distribution Type	Open Source	Open Source	Open Source	Open Source
License	MIT	Apache 2.0	GPL	BSD
Years in Development	15+	20+	20	20
Average Kernel Size (KB)	6-12	8	1	Unspecified
Easily Scalable	Yes	Yes	Yes	Yes
Implements Power Management	Yes	Yes	Yes	Yes
Compatibility	Various platforms supported	Various platforms supported	Various platforms supported	Limited to TI platforms

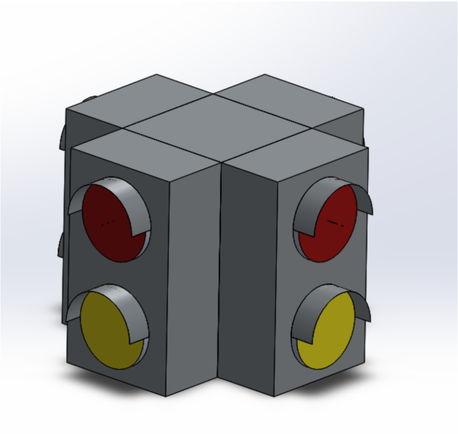
Programming Language Selection

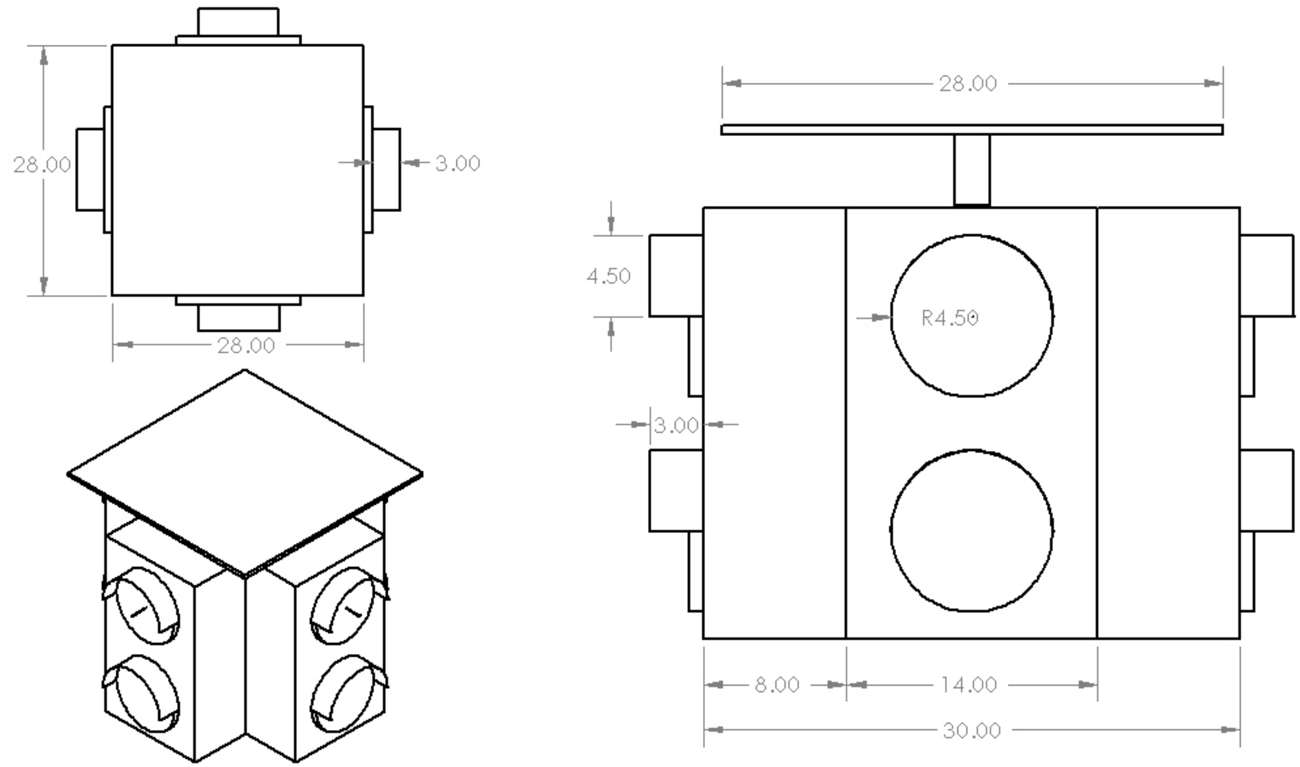
Product	C	C++	Cython*	Assembly
Speed	2	3	5	1
Libraries	4	1	2	5
Hardware Access	2	3	5	1
Zephyr Compatibility*	Yes	Yes	No	Yes
Objected Oriented	No	Yes	Yes	No
Multithreaded	Not standard	Standard post C++	Yes, but not C standard	No
Personal Knowledge on Language	1	5	2	4

Mechanical Design

- Modular design – helps achieve low cost
- Modeled after traditional traffic lights
- Prototype designed for quick replication and assembly
- Prototyped for a 2-way stop
- 3-way and 4-way stop is our current stretch goal







UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	Jon Ling	11/25/2018
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Acrylic	COMMENTS:		
FINISH Black			
DO NOT SCALE DRAWING			

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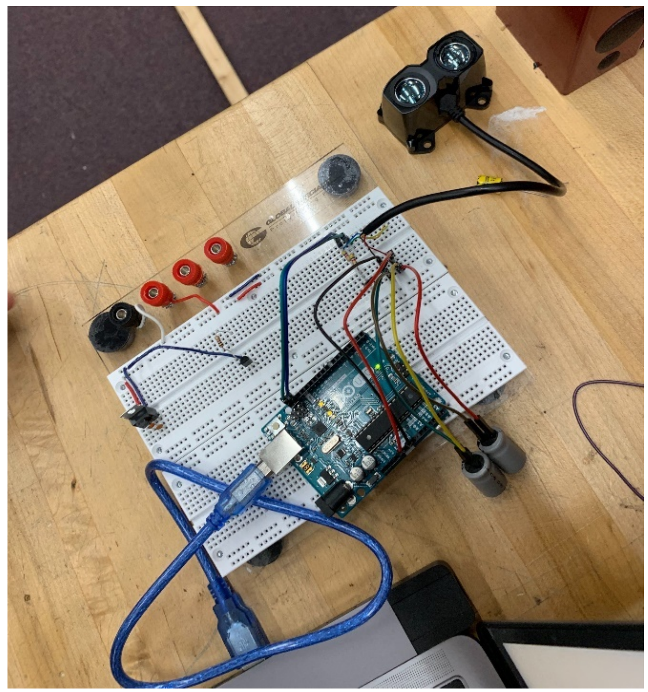
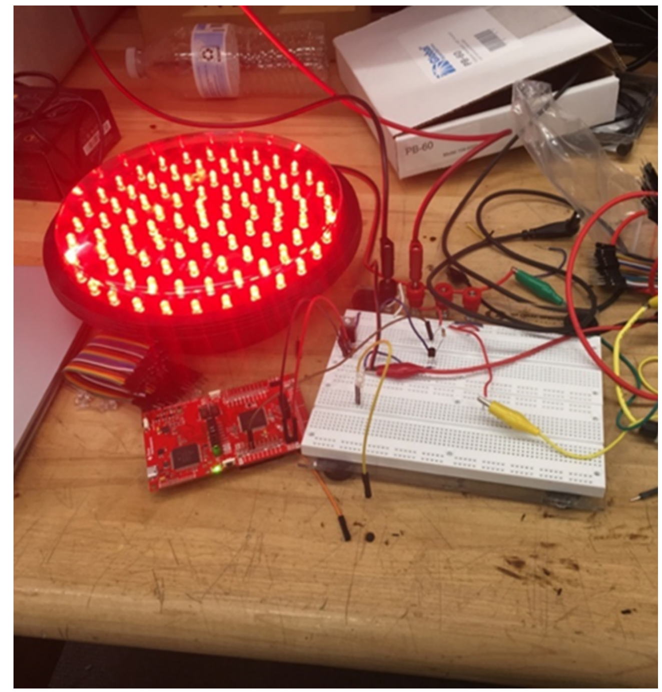
SIZE	DWG. NO.	REV
A	S.A.S.S	

SCALE: 1:16 WEIGHT: SHEET 1 OF 1

Prototyping

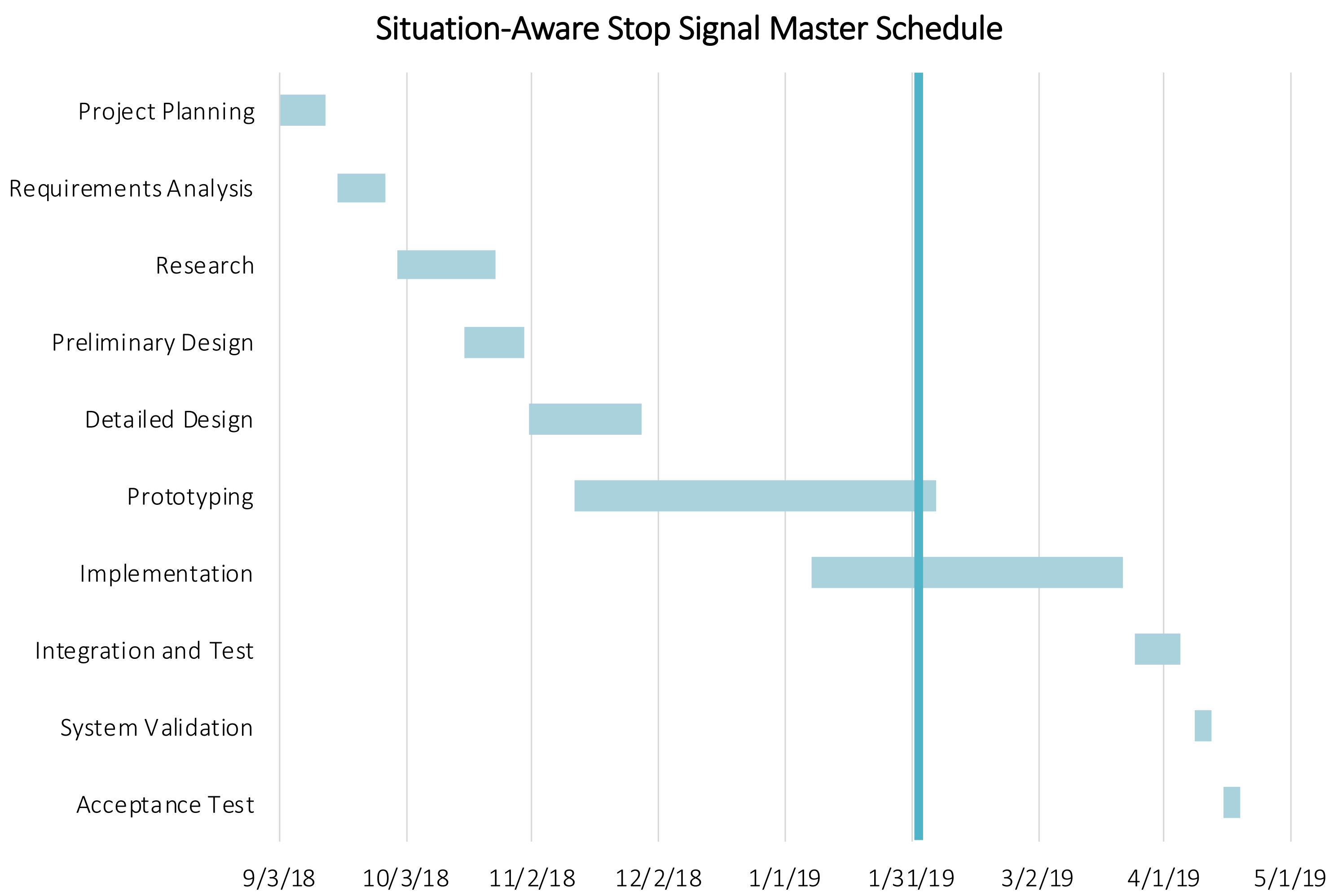
- Testing LiDAR with Arduino UNO and breadboard
- Used MSP432P401R Evaluation Board to test most components
- Tested, lights, software, and sensors with MSP432P401R before testing with PCB

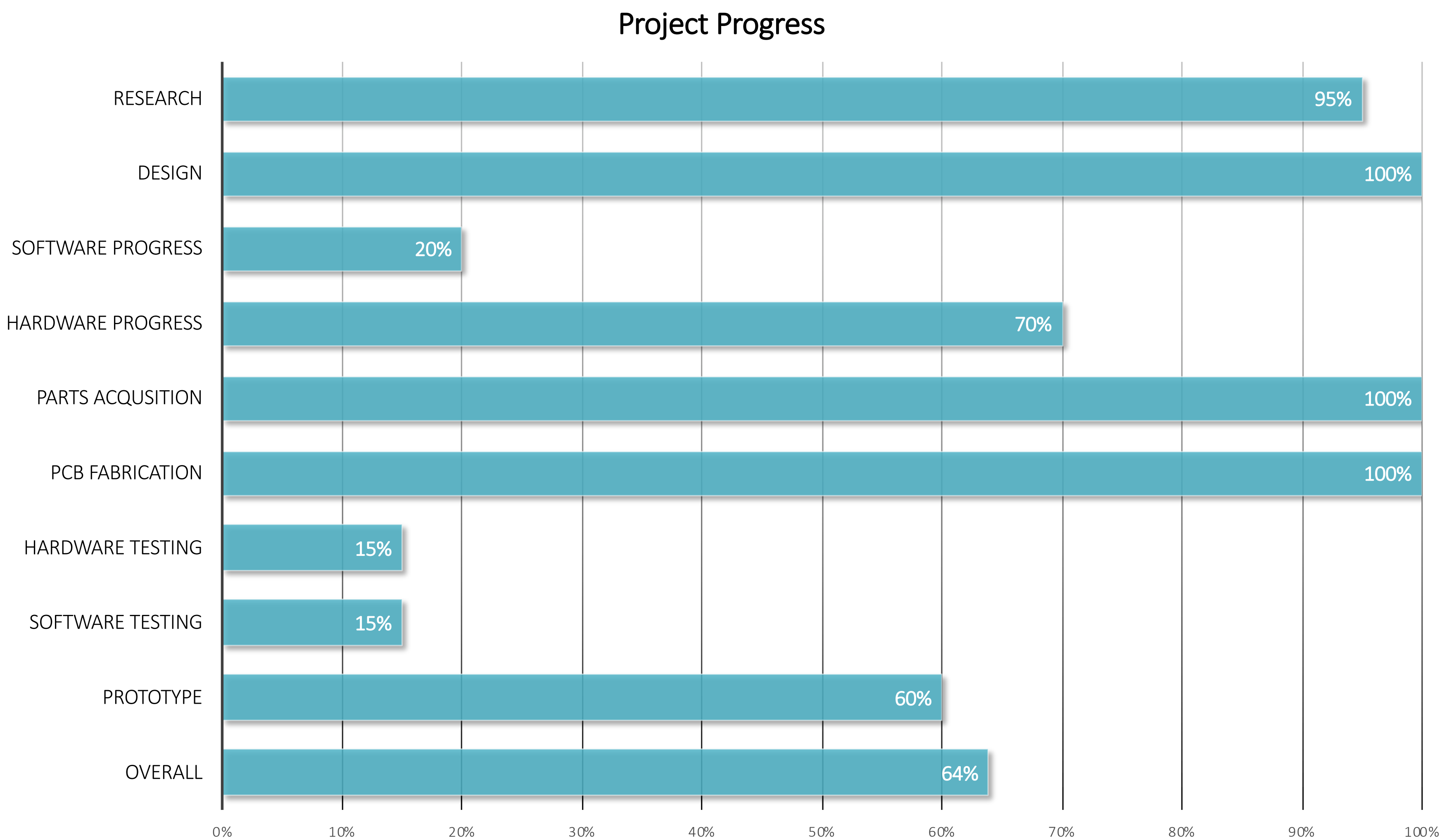




Budget

Product	Subsystem	Quantity	Unit Cost	Total Cost
Solar Cell	Power	28	$4.13	$115.64
Lithium Ion Battery	Power	1	$87.00	$87.00
MPPT Solar Charge Controller	Power	1	$69.45	$69.45
LED Traffic Light	Hardware	4	$42.75	$171.00
TI mmWave Evaluation Board	Hardware	2	$0.00	$0.00
Garmin LIDAR-Lite V3HP	Hardware	2	$149.99	$299.98
TI MSP432P401R	Hardware	1	$0.00	$0.00
PCB	Hardware	2	$20.00	$40.00
Minor Components	Hardware	1	$90.00	$90.00
Physical Building Material	Mechanical	1	$100.00	$100.00
Misc.	Misc.	1	$50.00	$50.00
Total				**$1033.07**


Situation-Aware Stop Signal Master Schedule
Project Planning
Requirements Analysis
Research
Preliminary Design
Detailed Design
Prototyping
Implementation
Integration and Test
System Validation
Acceptance Test
9/3/18
10/3/18
11/2/18
12/2/18
1/1/19
1/31/19
3/2/19
4/1/19
5/1/19


Project Progress
RESEARCH
DESIGN
SOFTWARE PROGRESS
HARDWARE PROGRESS
PARTS ACQUSITION
PCB FABRICATION
HARDWARE TESTING
SOFTWARE TESTING
PROTOTYPE
OVERALL
95%
100%
20%
70%
100%
100%
15%
15%
60%
64%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

Issues

- Creating custom libraries for mmWave RADAR module
- Creating custom libraries for LIDAR-Lite v3HP LiDAR module
- Triggering the lights using STN2NF10 MOSFETs

Questions

References

“Drivers Often Stop but Don't See.” *IIHS*, 2002, *www.iihs.org/iihs/sr/statusreport/article/37/9/4*.