

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

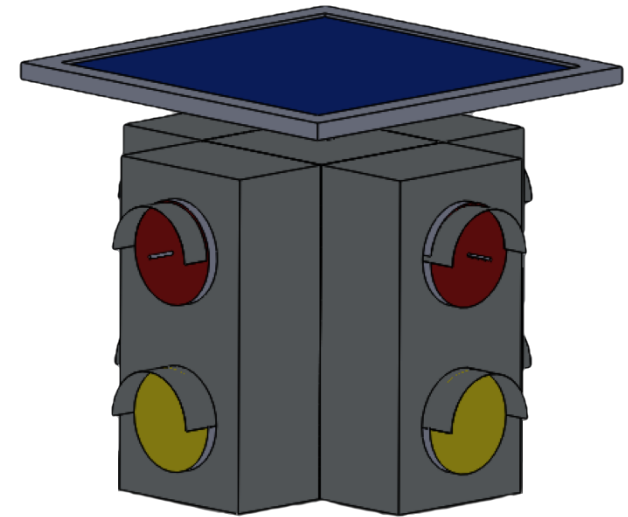
Design Requirements	Operational Requirements	Power Requirements	Safety Requirements
One centralized unit	IP52 weather resistant	Solar panel shall output greater than 6V and 40W	Abide by road sign laws specified in the Manual for Uniform Traffic Control Devices (MUTCD)
Visible during the day and night	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

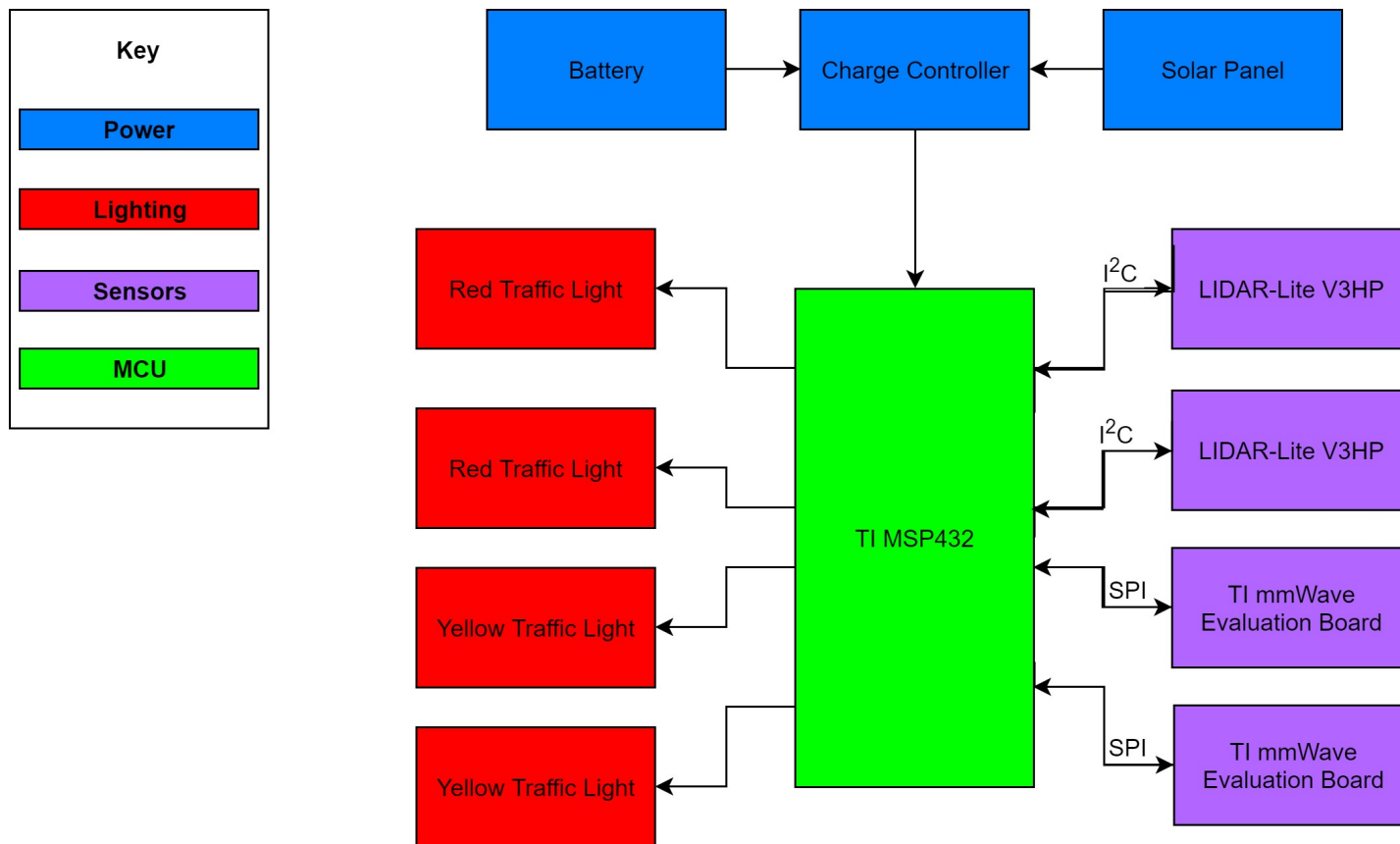
Target	Verification	Units (if applicable)
Obedience to Traffic Law	Complies with USDOT MUTCD rules and regulations	
Power Consumption	< 20	Watts
Self-Sustained Solar Power (generated)	0.48	kWh/day
Sensor Accuracy	90	% within 25 feet
Cost	< 1800	\$US
Modular Structure (installation)	< 30	minutes

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

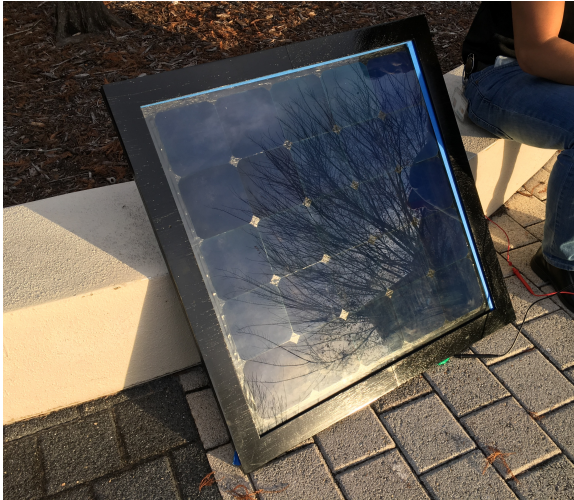


Block Diagram



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	Seed Studio POW921450	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

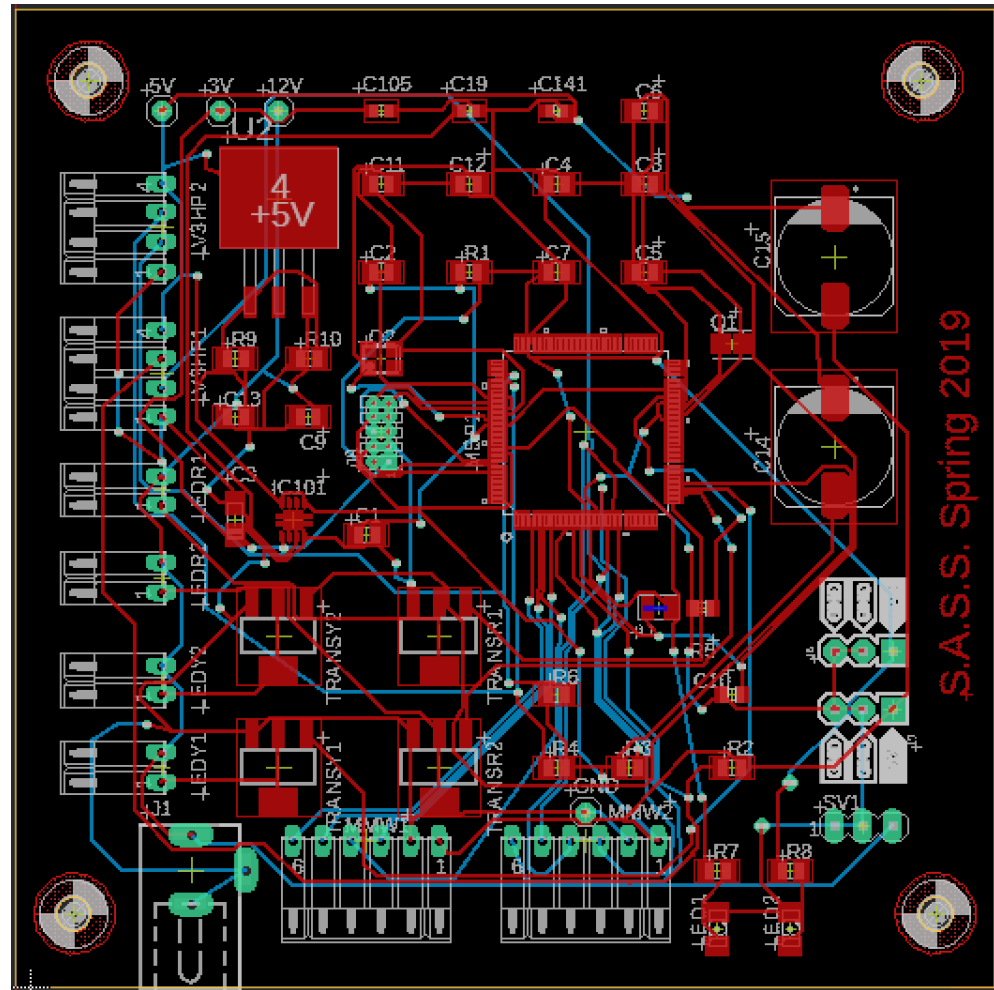


- MPPT - Maximum Power Point Tracking
- Highest efficiency ~ 99%
- Extends battery life
- Converts excessive voltage into additional current
- More expensive
- More parts than a 1-stage controller or PWM charge controller

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



+P1.0_LED1	4
+P1.1_BUTTON1	5
+P1.2_BCUART_RXD	6
+P1.3_BCUART_TXD	7
+P1.4_BUTTON2	8
+P1.5_SPICLK_11.7	9
+P1.6_SPIMOSI_12.15	10
+P1.7_SPIMISO_12.14	11
+P2.0_RGBLED_RED	16
+P2.1_RGBLED_GREEN	17
+P2.2_RGBLED_BLUE	18
+P2.3_IO_14.34	19
+P2.4_PWM_14.38	20
+P2.5_PWM_12.10	21
+P2.6_PWM_14.39	22
+P2.7_PWM_14.40	23
+P3.0_IO_12.18	32
+P3.1	33
+P3.2_UFXD_11.3	34
+P3.3_UFXD_11.4	35
+P3.4	36
+P3.5_IO_14.32	37
+P3.6_IO_12.11	38
+P3.7_IO_14.31	39
+P4.0_A13_13.24	56
+P4.1_IO_11.5	57
+P4.2_A11_13.25	58
+P4.3_A10_11.6	59
+P4.4_A9_13.26	60
+P4.5_A8_13.27	61
+P4.6_IO_11.8	62
+P4.7_A5_13.28	63
+P5.0_IO_12.13	64
+P5.1_IO_14.33	65
+P5.2_IO_12.12	66
+P5.3	67
+P5.4_IO_13.29	68
+P5.5_IO_13.30	69
+P5.6_PWM_14.37	70
+P5.7_IO_12.17	71
+P6.0_A15_11.2	54
+P6.1_A14_13.23	55
+P6.2	76
+P6.3	77
+P6.4_I2CSDA_11.10	78
+P6.5_I2CSCL_11.9	79
+P6.6_CAPTURE_14.36	80
+P6.7_CAPTURE_14.35	81
+P7.0	88
+P7.1	89
+P7.2	90
+P7.3	91
+P7.4	26
+P7.5	27
+P7.6	28
+P7.7	29

P1.0/PCA0STE
P1.1/PCA0CLK
P1.2/UCARXD/UCARXSOMI
P1.3/UCARXD/UCARXSIMO
P1.4/UCB0STE
P1.5/UCB0CLK
P1.6/UCB0SOMI/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_UCB2SOMI/PM_UCB2SDA
P3.7/PM_UCB2SOMI/PM_UCB2SCL

P4.0/A13
P4.1/A12
P4.2/ACLK/TA2CLK/A11
P4.3/ACLK/RTCLK/A10
P4.4/HSMCLK/SVMAHOUT/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/TA2.1VREF+VREF+HC1.7
P5.7/TA2.2VREF+VREF+HC1.6

P6.0/A15
P6.1/A14
P6.2/UCB1STE/C1.5
P6.3/UCB1CLK/C1.4
P6.4/UCB1SOMI/UCB1SDA/C1.3
P6.5/UCB1SOMI/UCB1SCL/C1.2
P6.6/TA2.3/UCB3SOMI/UCB3SDA/C1.1
P6.7/TA2.4/UCB3SOMI/UCB3SCL/C1.0

P7.0/PM_SMCLK/PM_OMAED
P7.1/PM_C8OUT/PM_TA0CLK
P7.2/PM_C1OUT/PM_TA1CLK
P7.3/PM_TA0.0
P7.4/PM_TA1.4/C8.5
P7.5/PM_TA1.3/C8.4
P7.6/PM_TA1.2/C8.3
P7.7/PM_TA1.1/C8.2

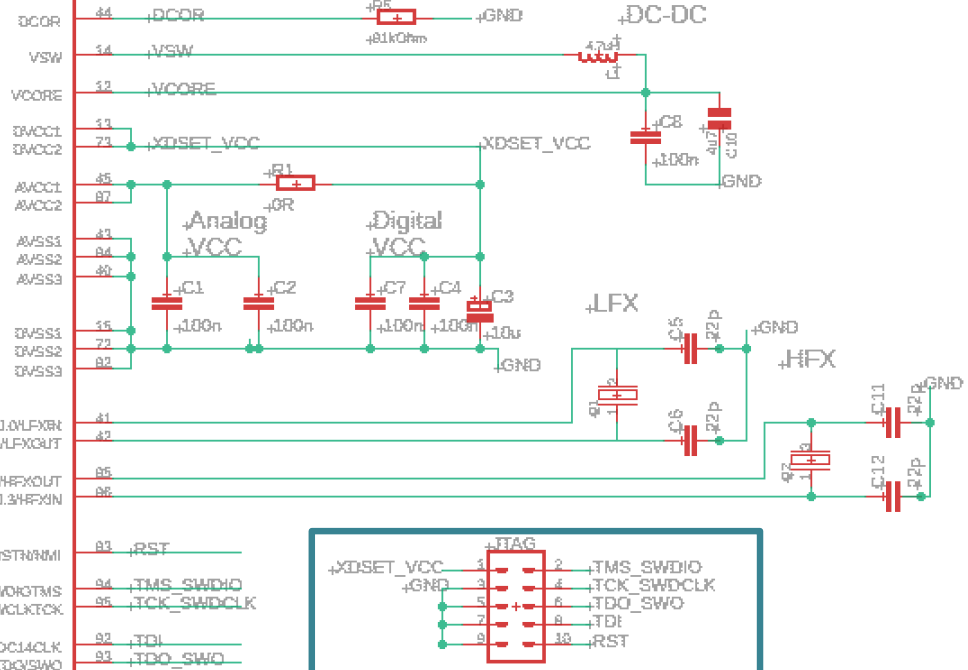
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P8.1/UCB3CLK/TA2.0/C8.0
P8.2/TA3.2/A2.3
P8.3/TA3CLK/A2.2
P8.4/A2.1
P8.5/A2.0
P8.6/A1.9
P8.7/A1.8

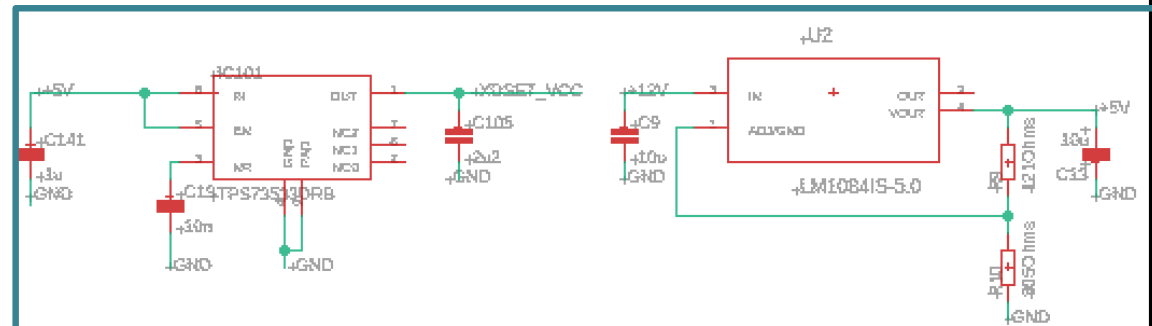
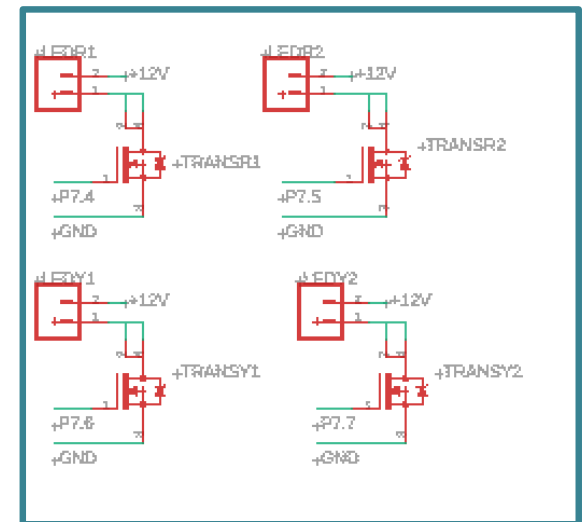
P9.0/A1.7
P9.1/A1.6
P9.2/TA3.3
P9.3/TA3.4
P9.4/UCB3STE
P9.5/UCB3CLK
P9.6/UCB3RXD/UCB3SOMI
P9.7/UCB3TXD/UCB3SIMO

P10.0/UCB3STE
P10.1/UCB3CLK
P10.2/UCB3SOMI/UCB3SDA
P10.3/UCB3SOMI/UCB3SCL
P10.4/TA3.8/C0.7
P10.5/TA3.1/C0.6

30	+P8.0
31	+P8.1
46	+P8.2
47	+P8.3
48	+P8.4
49	+P8.5
50	+P8.6
51	+P8.7
52	+P9.0
53	+P9.1
74	+P9.2
75	+P9.3
96	+P9.4
97	+P9.5
98	+P9.6
99	+P9.7

100	+P10.0
1	+P10.1
2	+P10.2
3	+P10.3
24	+P10.4
25	+P10.5





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

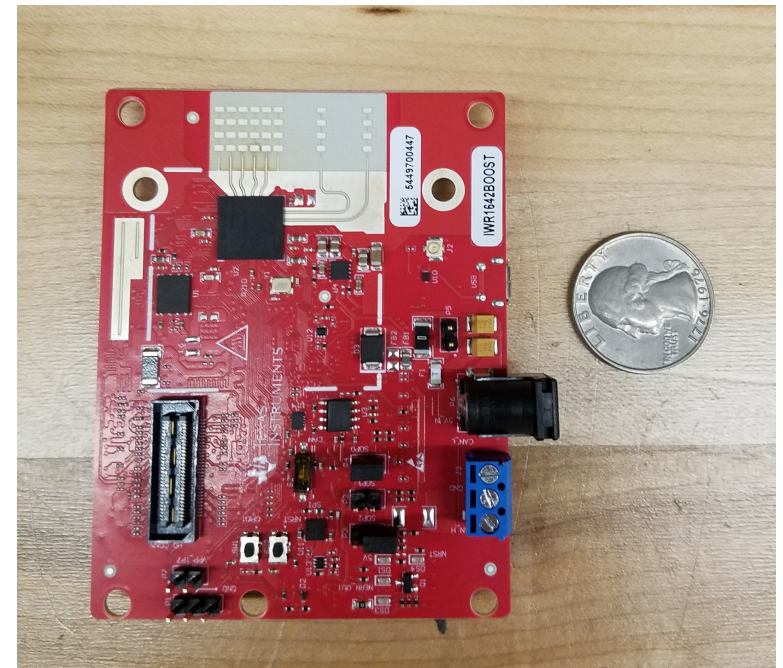
Light Selection

- 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)

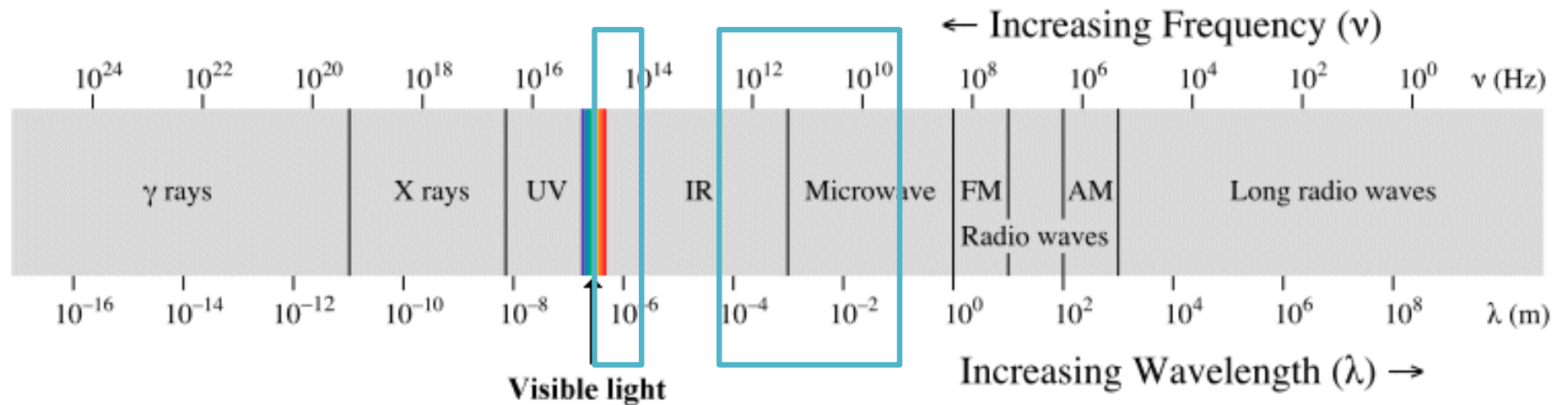
Product	Slamtec RPLIDAR A3 360° Laser Scanner	LIDAR-Lite v3HP	TF02 - LiDAR Rangefinder	TF MINI MICRO LIDAR MODULE
Cost (\$)	599	158	99	49
Rate (Hz)	16000	270	100	100
Range (m)	25	40	22	3-7
Power Required (W)	0.12	0.675	0.6	0.12
Size (in)	3.0 x 1.6 x 3.0	0.8 x 1.9 x 1.6	2.7 x 1.8 x 1.0	1.7 x 0.6 x 0.6

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

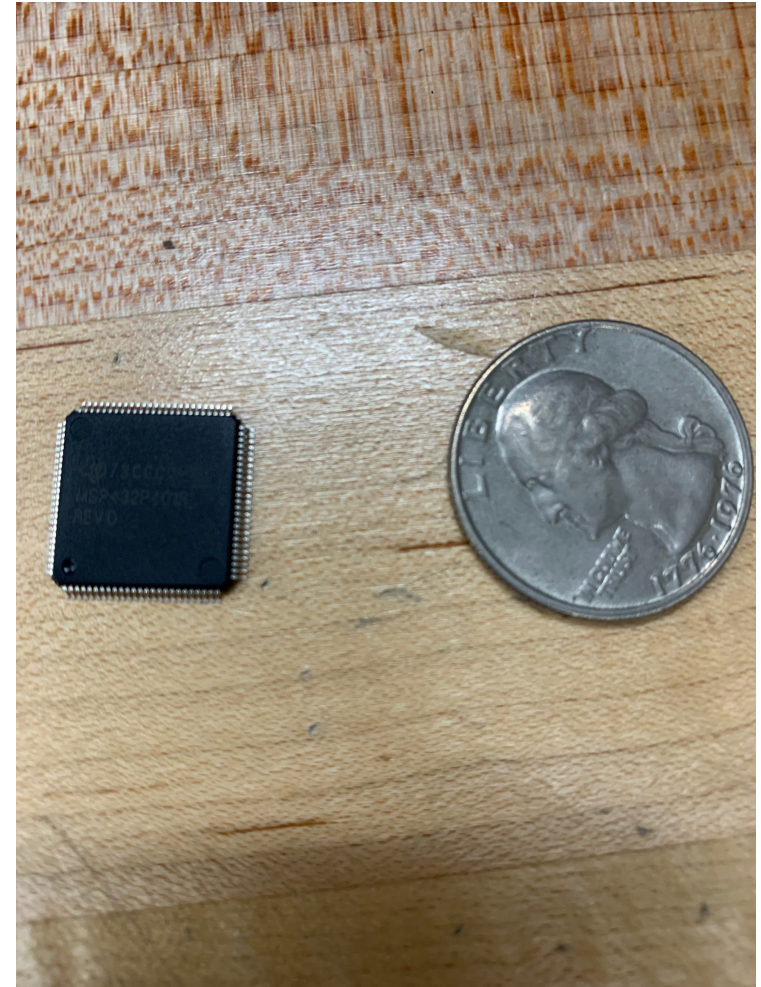


Microcontroller

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

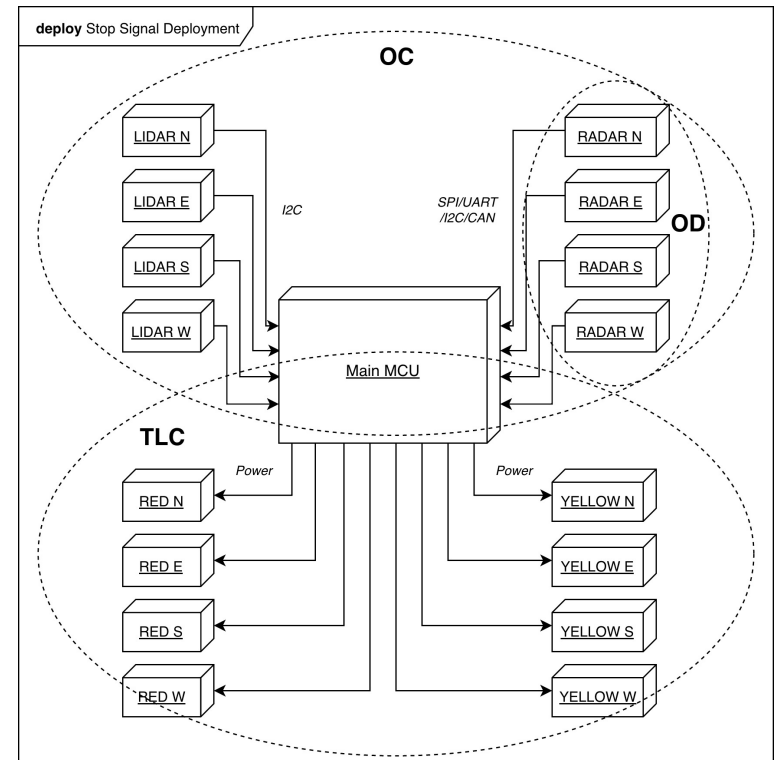
- Low Power : High Performance
- 48MHz allows for fast processing of real-time data
- Granular control over microcontroller
- More memory compared to ATmega2560
- Supports TI-RTOS
- Supports C/C++
- Supports POSIX threading



Software Design

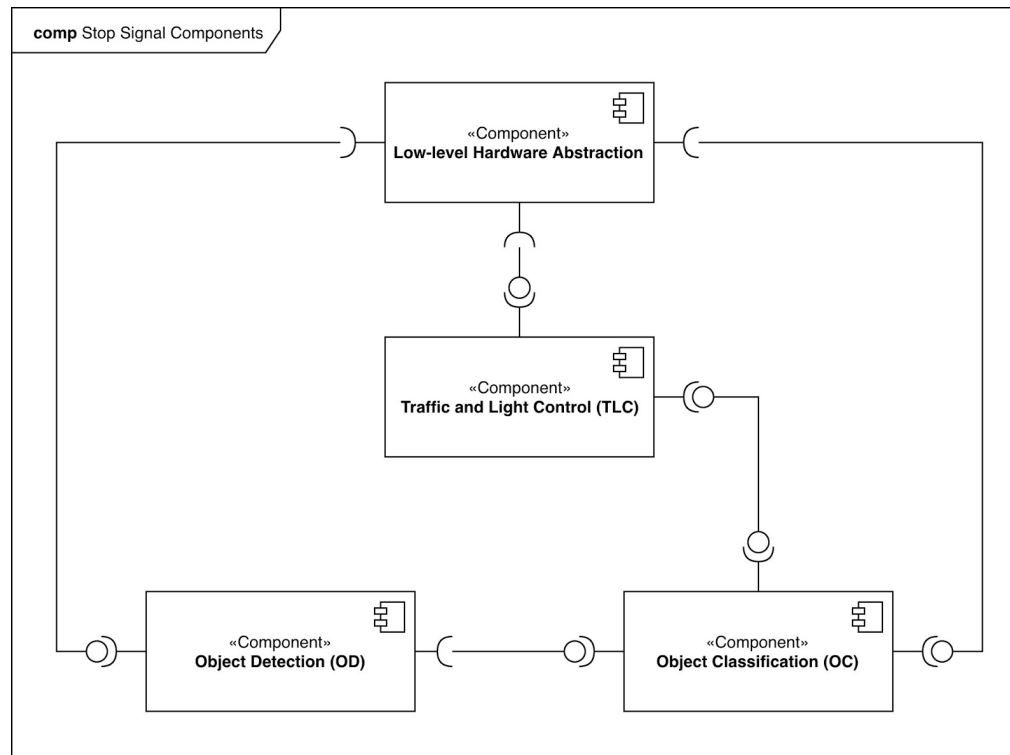
Stop Signal Software

- 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



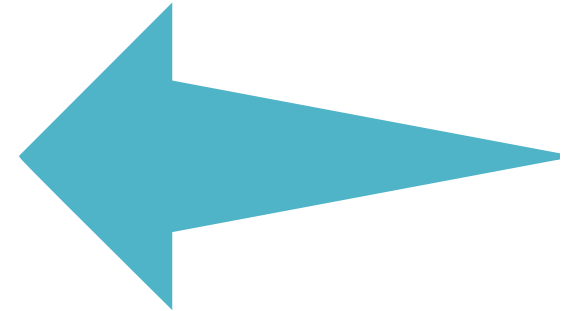
Component Diagram

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:
 - I²C (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

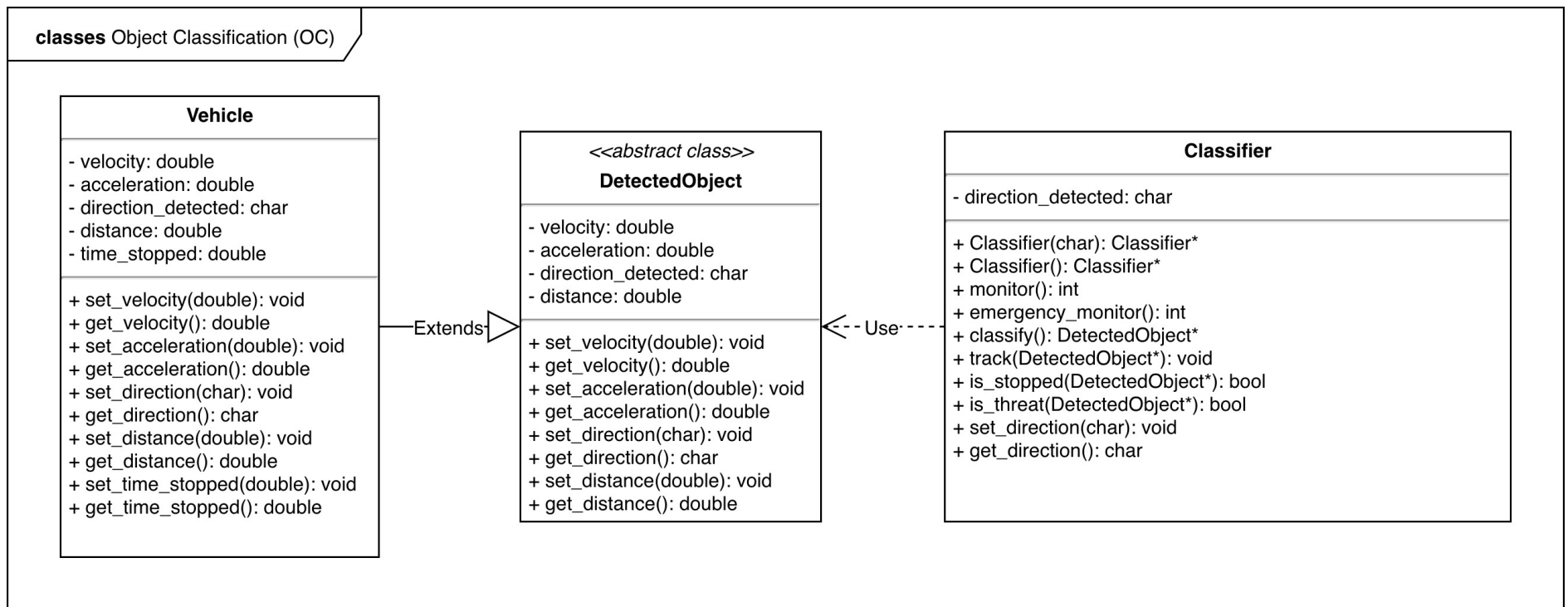


Object Classification (OC)

- 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.



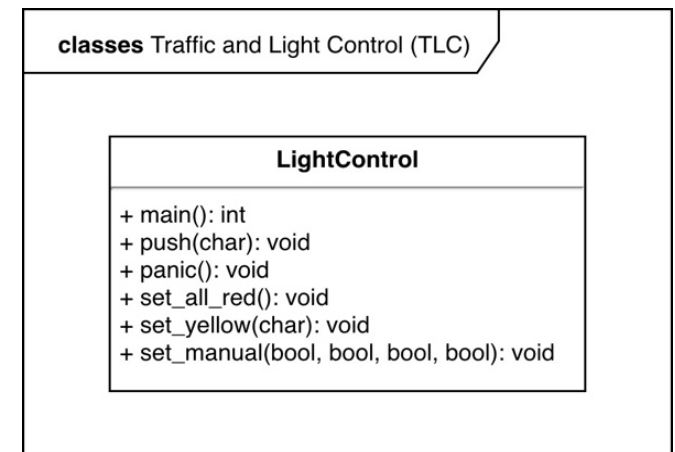
Object Classification (OC)



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

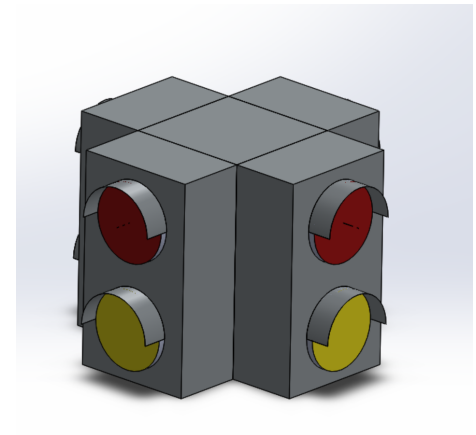
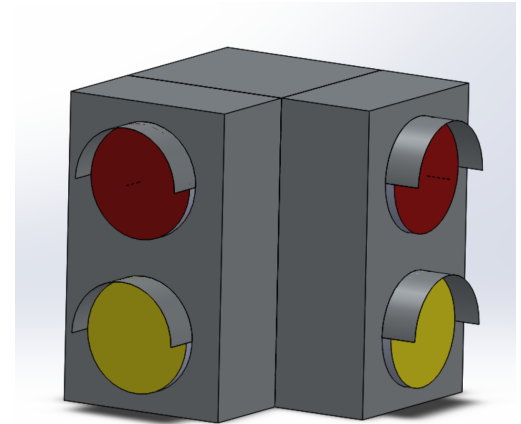
Product	FreeRTOS	Zephyr™	eCos	TI-RTOS
Distribution Type	Open Source	Open Source	Open Source	Open Source
License	MIT	Apache 2.0	GPL	BSD
Years in Development	15+	20+	20	20
Average Kernel Size (KB)	6-12	8	1	Unspecified
Easily Scalable	Yes	Yes	Yes	Yes
Implements Power Management	Yes	Yes	Yes	Yes
Compatibility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

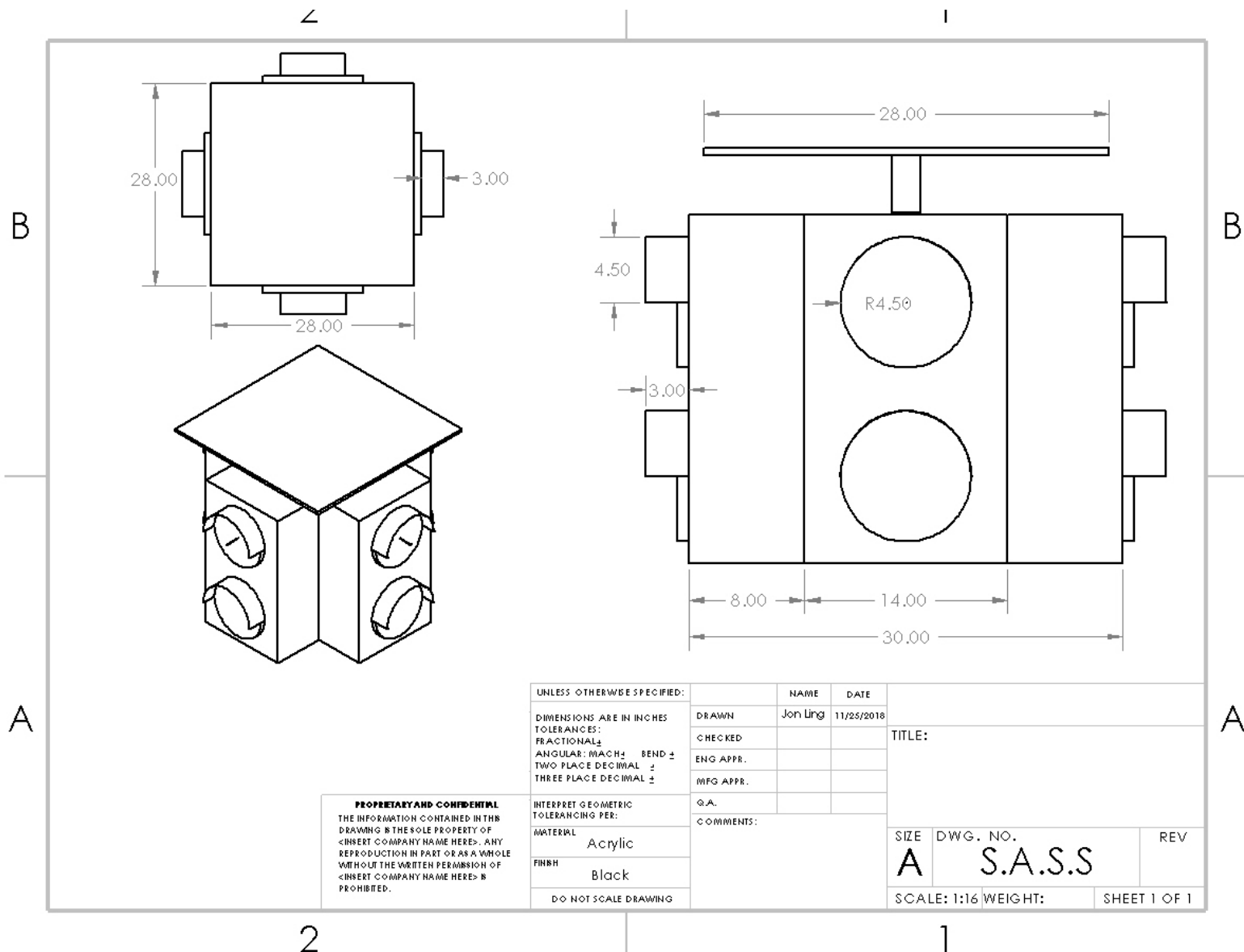
Programming Language Selection

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

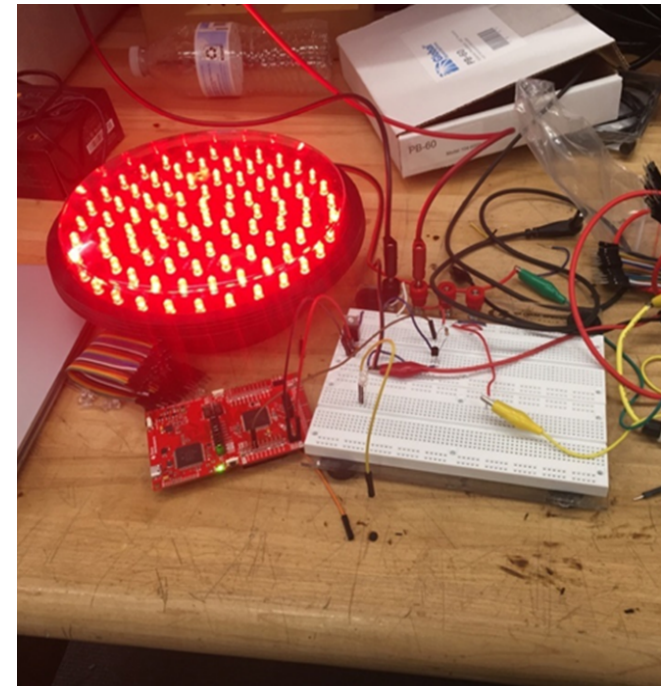
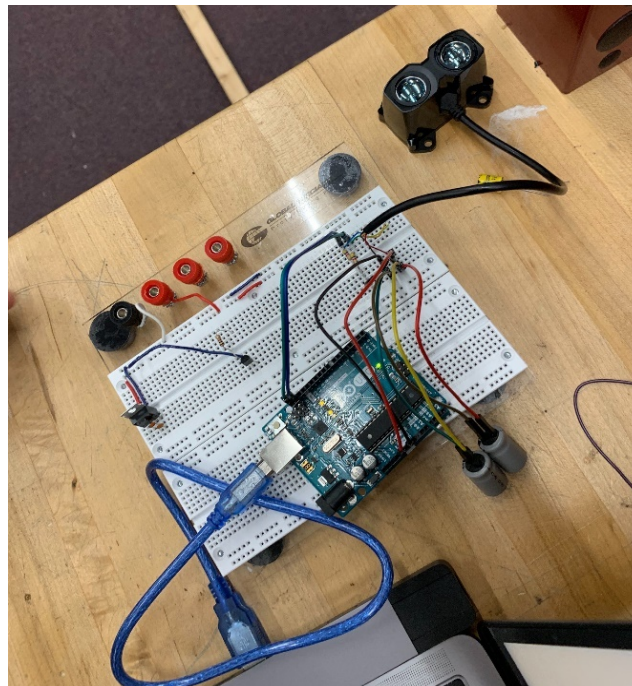
- Modular design – helps achieve low cost
- Modeled after traditional traffic lights
- Prototype designed for quick replication and assembly
- Prototyped for a 2-way stop
- 3-way and 4-way stop is our current stretch goal





Prototyping

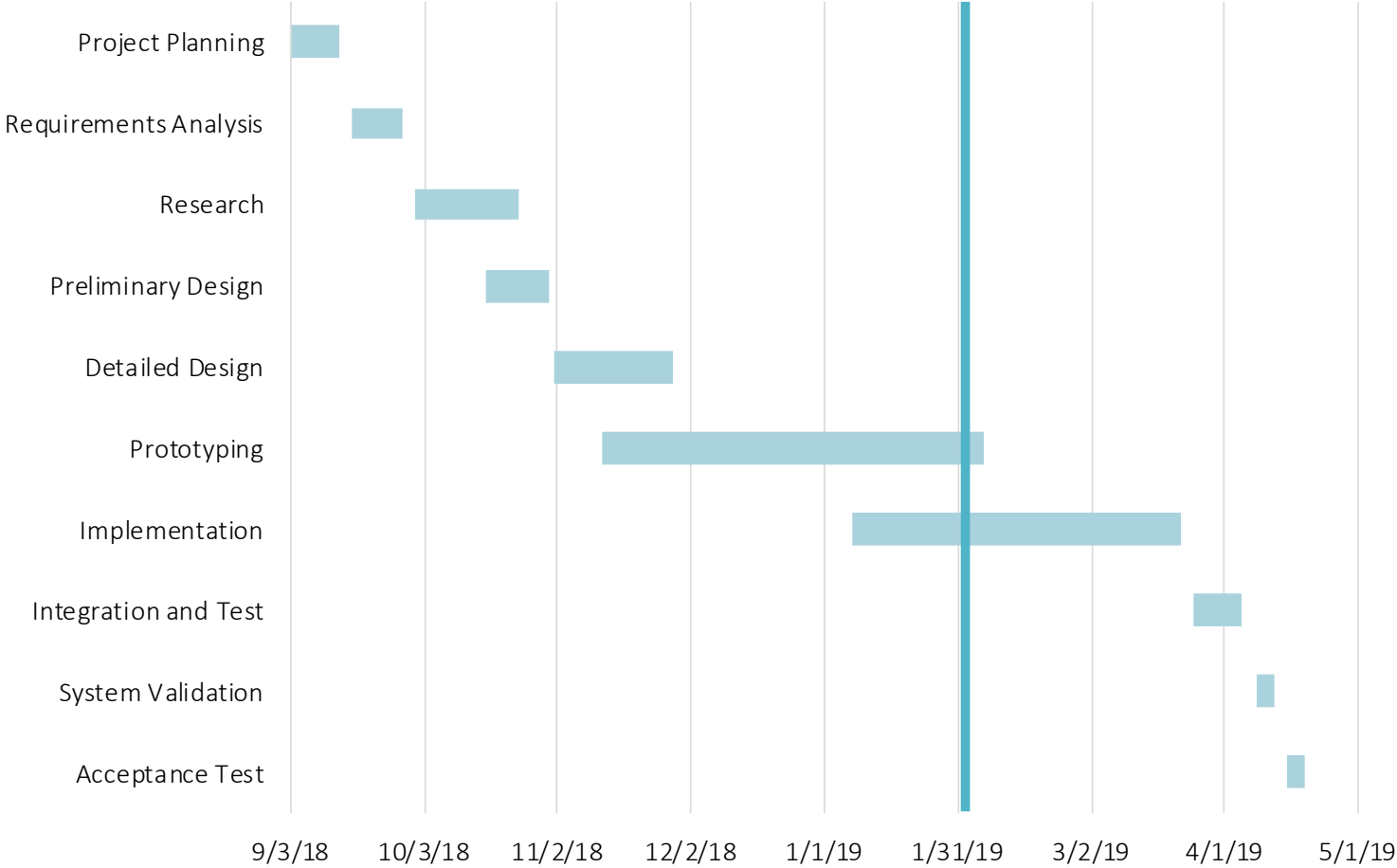
- Testing LiDAR with Arduino UNO and breadboard
- Used MSP432P401R Evaluation Board to test most components
- Tested, lights, software, and sensors with MSP432P401R before testing with PCB



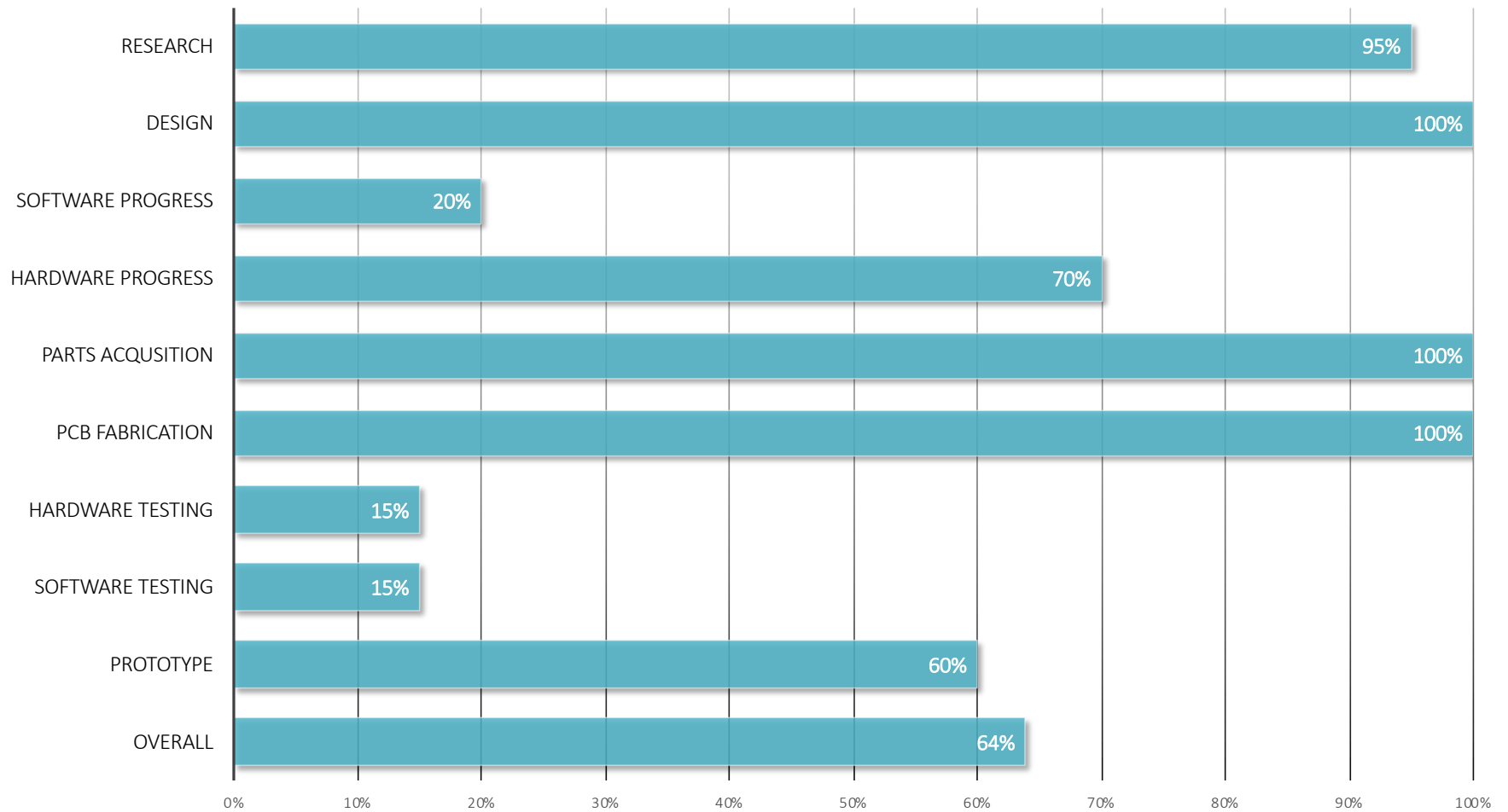
Budget

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 Progress



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.*