Heterogeneous **A**utomotive **R**esponse **A**pparatus **M**ade for **B**road **E**mergencies

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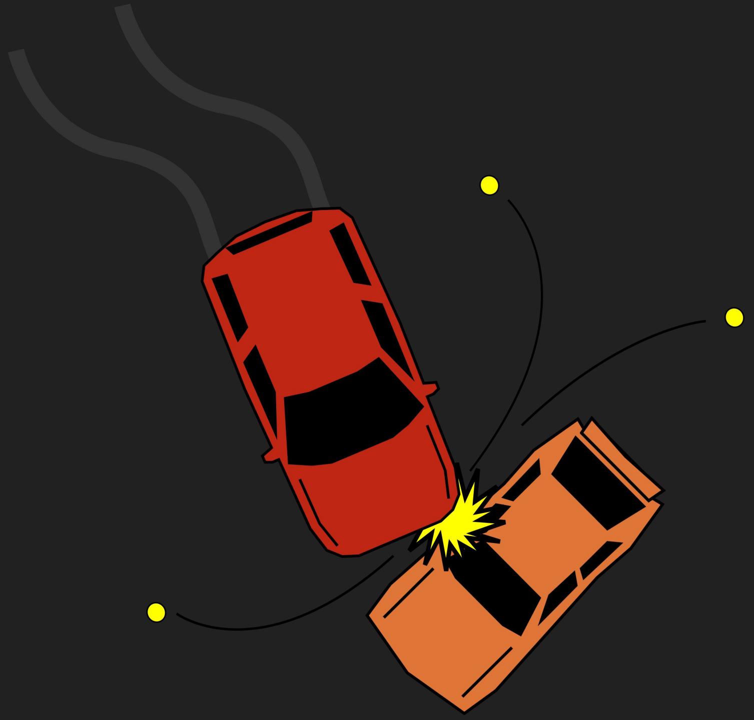
Motivation

- Statistics
  - 35,092 motor vehicle accident deaths in U.S. in 2015 (Source: NHTSA)
  - ~10.9 people per 100,000
- In the event of an accident the driver may be unable to access their phone, or they could be in a sparsely populated area
  - This will significantly delay emergency response times
- Reducing emergency response time will increase the driver's likelihood of survival



Project Goals

- Create a device that uses vehicle and IMU data to automatically determine whether the user has been in an accident
- Allow the device to work in all modern vehicles
- Gets power solely from the vehicle
- Have a mobile application that alerts the user when they have been in an accident

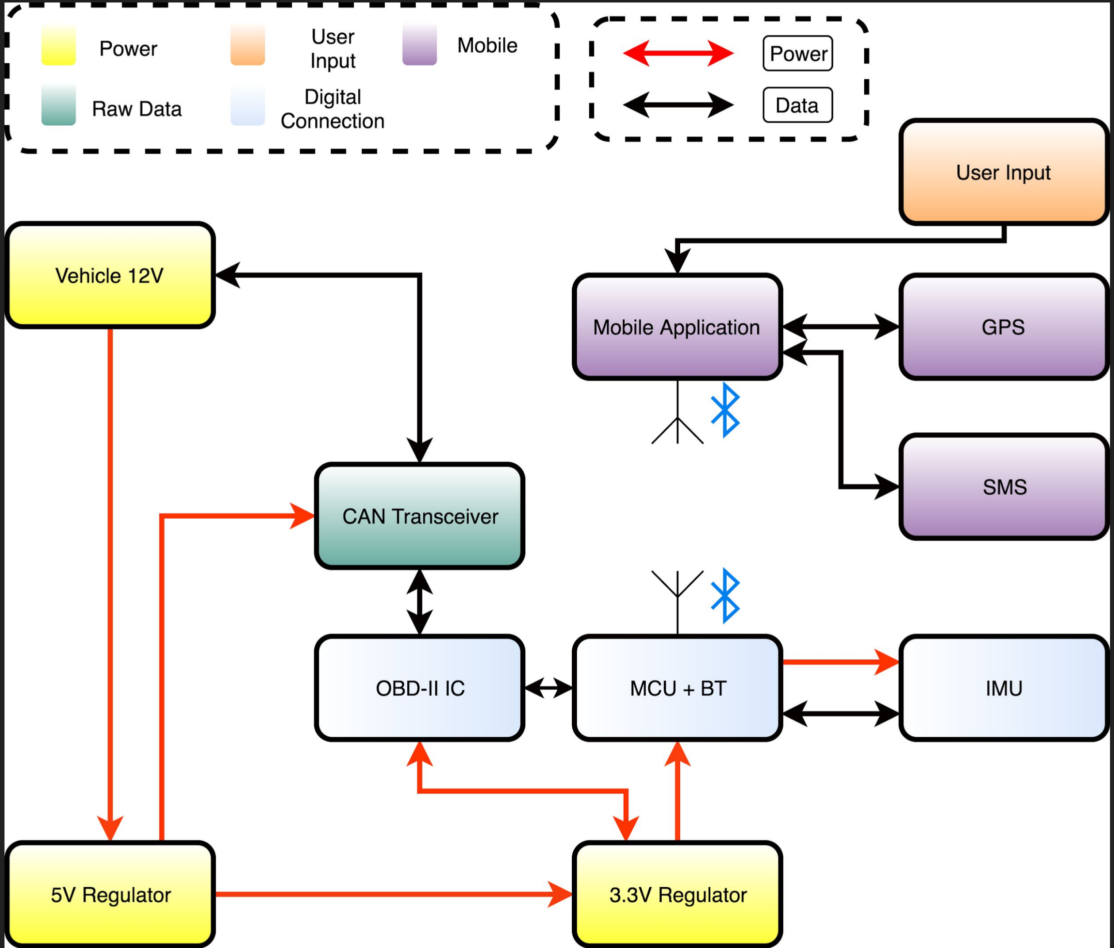
Requirements

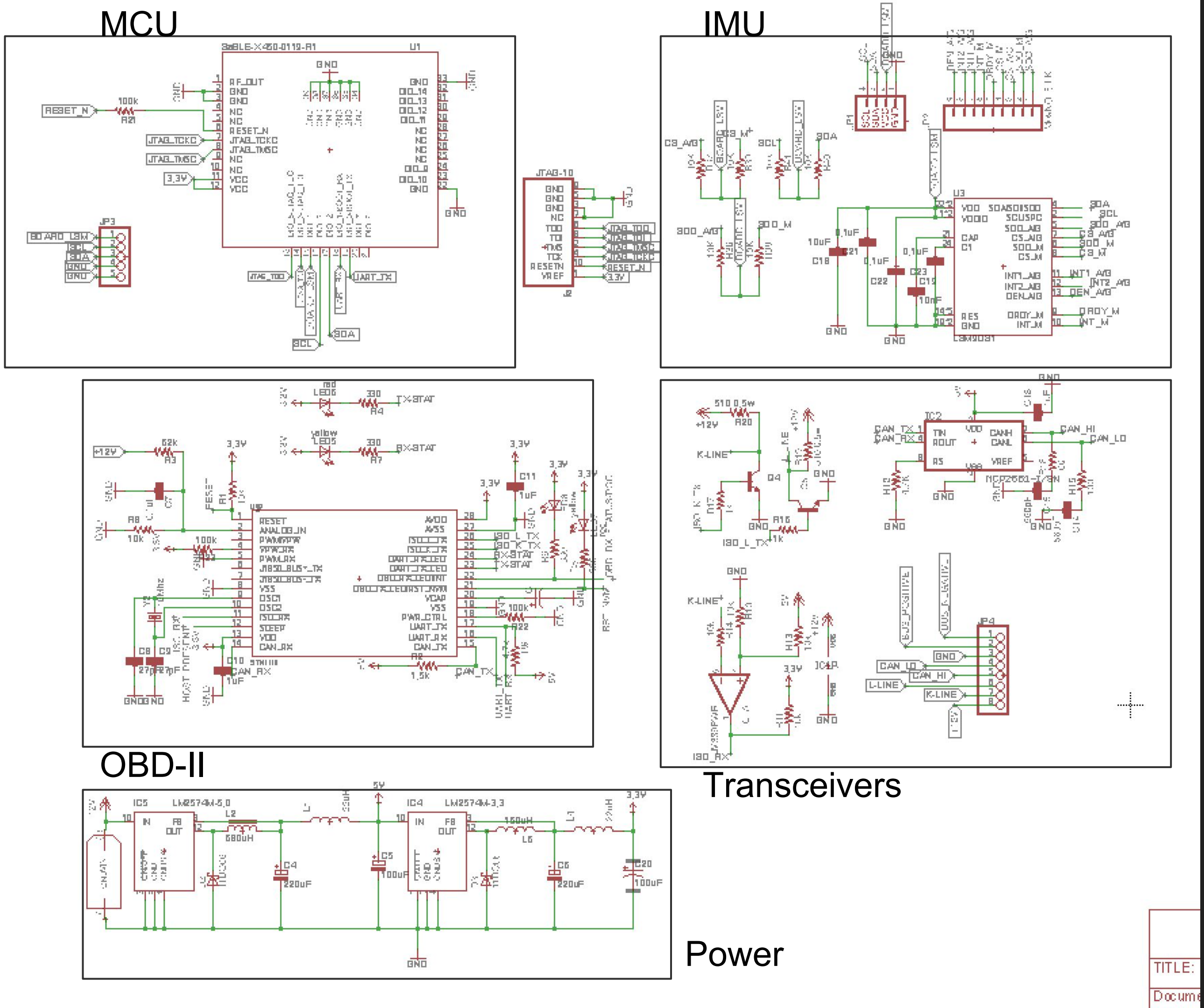
- Extract data available from OBD-II and accelerometer/gyroscope
  - Speed
  - Acceleration
  - Orientation
- Detect if the driver has been in an accident based on sensor and vehicle data
  - Acceleration data (Magnitude >= 0.65 g, x value >= 0.7 g)
  - Speed data (7.5 MPH / 1s)
  - Above values for testing purposes only
- Device must not obstruct the driver's footwell (10 in x 10 in x 5 in)
- Device must work on all vehicles created in 2007 and onward
- Main device must communicate with the mobile device wirelessly
- Mobile application needs to be **user-friendly** and have a low impact on overall system performance
- Must be cheaper than existing solutions on the market (Onstar, Automatic)

Specifications

Component	Parameter	Design Specification
Power Supply	Necessary Voltages	3.3v, 5v, 12v
Power Supply	Maximum Current Draw	150 mA
Mobile wireless link	Minimum distance	3 meters
GPS Link	Accuracy	10 meters
OBD-II	Protocols required	CAN (ISO11898)
Accelerometer	Sensitivity	~.08 mg/LSB
Gyroscope	Sensitivity	70 mdps/LSB
Microcontroller	Peripheral Samp. Rt.	10 samples / sec

Overall Block Diagram




MCU
IMU
OBD-II
Transceivers
Power
TITLE:

Power Delivery

- Draws 12V from OBD-II port on vehicle
- Needs to step down to 5V for CAN operation (Phased-out)
- Needs to step down from 5V to 3.3V for peripheral operation
    - MCU, OBD-II IC, Accelerometer/Gyroscope
- Needs to have a ripple voltage less than 150mV +/-
- Provide 125 mA to 3.3V power line
- Provide 75 mA to 5V power line

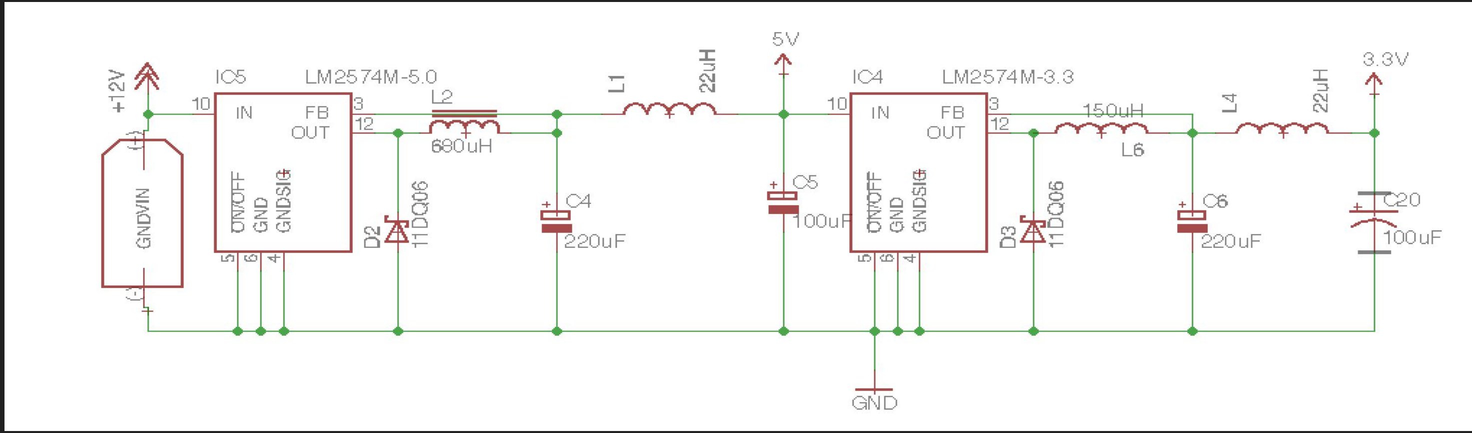
Power IC Decision

- Needs to be more efficient than standard products
  - Use of switching regulators bumps efficiency from 33% to 60%

Variable	Linear Regulator	Switching Regulator
Family Name	LE33CZ-TR	LM2574HV
Vin min.	4.3V	4V
Vin max.	18V	40V
Efficiency	27.5%	72%
Cost	$0.66	$2.76
Complexity	Low	High

Power Circuitry

- Series connection implemented to retain “continuous” operation
  - Continuous operation range (0.1A to 0.5A)
- Low-pass filter implemented to reduce output ripple.
  - Decreases line voltage slightly due to DCR



OBD-II Communication

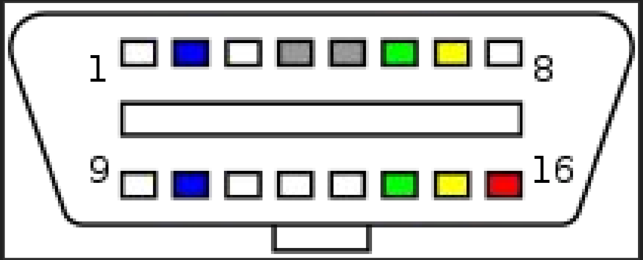
- Every vehicle made after 1996 has OBD-II port
  - Standardized data port
- Allows us to get data from vehicle
  - Speed
  - Engine RPM
  - Throttle position
- Not able to get Airbag codes
  - Proprietary
- Multiple Protocols
  - CAN, J1850, ISO-9141

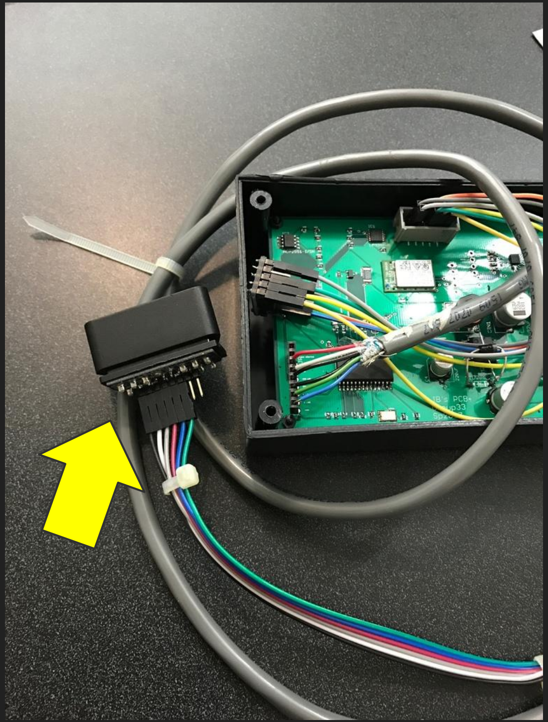
OBD-II IC Choice

Product	ELM327 v1.4	STN1110
Architecture	8-bit	16-bit
Processing speed	4 MIPS	40 MIPS
FLASH (ROM)	32 KB	128 KB
RAM	1.5 KB	8 KB
Supports all OBD-II protocols	Yes	Yes
Supported UART baud rates	9600 bps to 500 kbps	38 bps to 10 Mbps
Price each, for 1000 units	$24	$10
Development Board available?	No	Yes

OBD-II Header

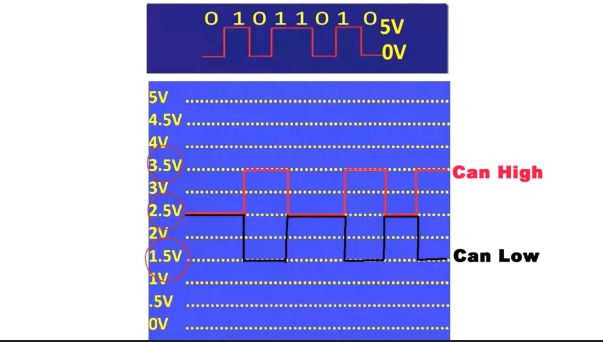
- Pin 5 - Signal Ground
- Pin 6 - High Level CAN Bus Line
- Pin 14 - Low Level CAN Bus Line
- Pin 7 - K-Line (ISO-9141)
- Pin 15 - L-Line (ISO-9141)
- Pin 16 - Vehicle battery voltage (12V)

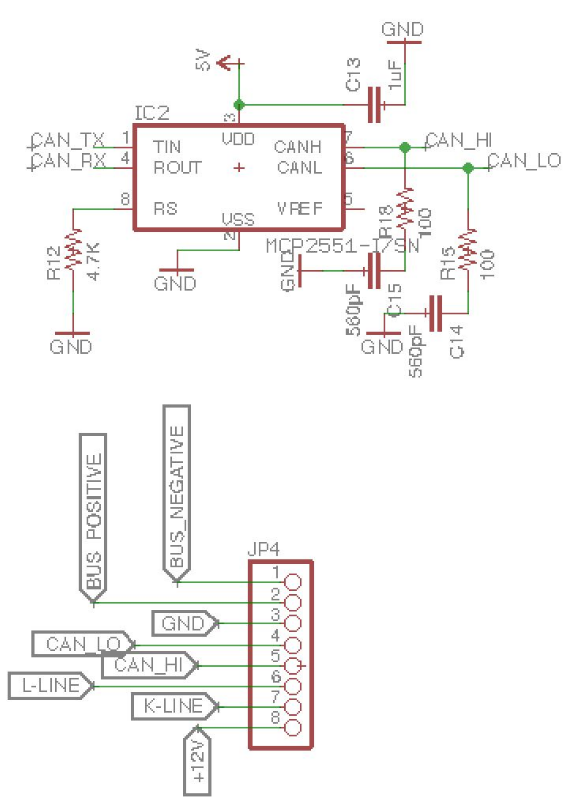




OBD II (CAN) Transceiver

- CAN variants are used in modern vehicles
  - ISO 15765-4 and SAE J2284
- Standardized for use in vehicles after 2007
- Uses the CAN-High and CAN-Low pins from the OBD-II connection for data transmission





PID Codes

- Used to get data from OBD-II port
- Able to get various types of data
  - Speed
  - Throttle Position
  - Engine RPM

Code	Purpose	Bytes of data returned
01 00	PIDs Supported	4
01 03	Fuel System Status	2
01 0D	Vehicle Speed (kmh)	1
01 0C	Engine RPM	2
01 11	Throttle Position	1

Accelerometer / Gyroscope

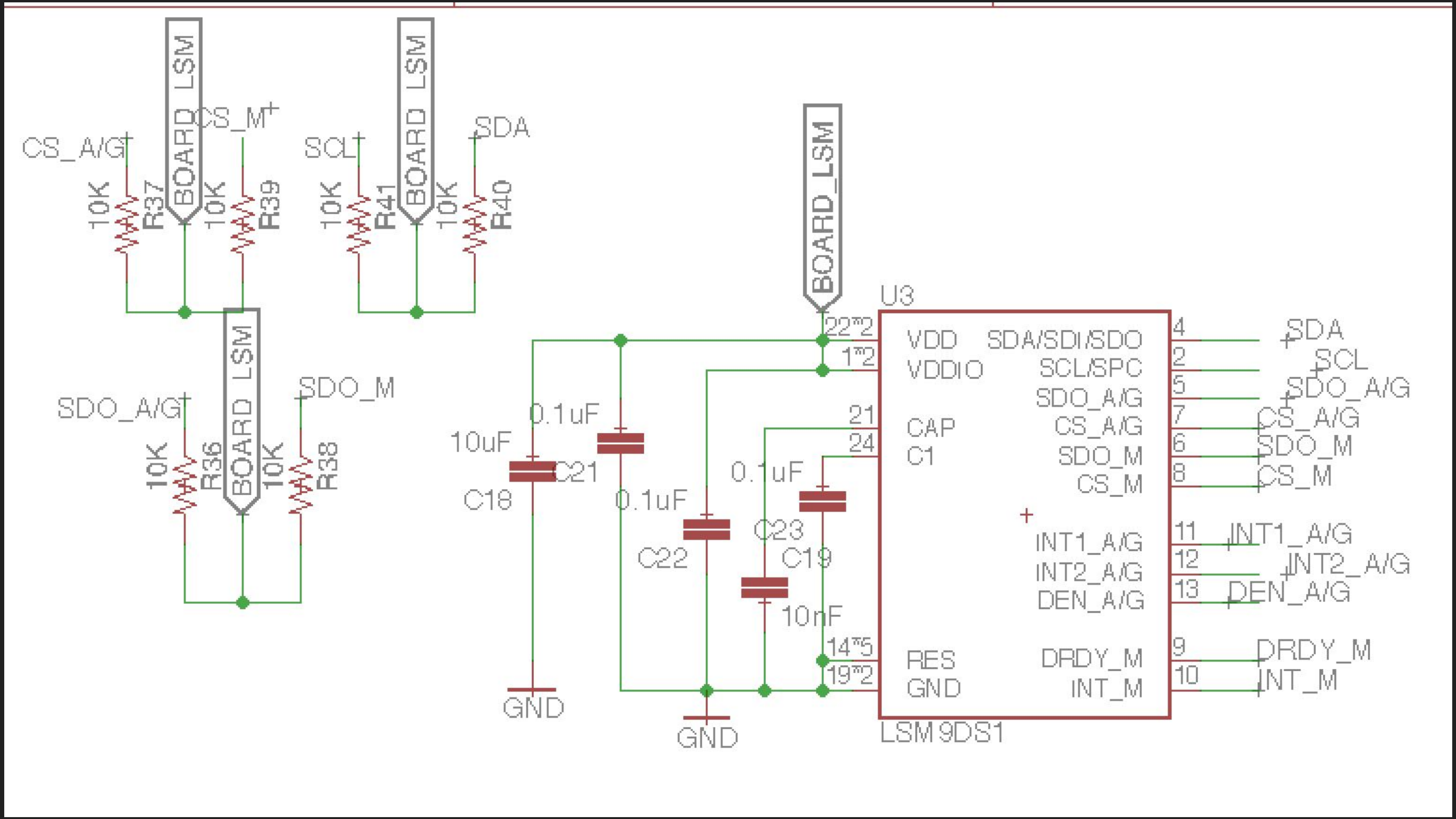
- Need to detect acceleration/deceleration of the vehicle
  - Hard braking
  - Sharp turns
- Need to detect changes in orientation
  - Flip, T-bone
- Allows for introspection into the motion / orientation of the vehicle

Accelerometer / Gyroscope Decision

- Ended up going with LSM9DS1
  - Lower power than predecessor
  - Cheapest Alternative
  - Development board is available
  - User-friendly libraries available

Product	LSM9DS1	LSM9DS0	MPU-9250
Manufacturer	ST Microelectronics	ST Microelectronics	Invensense
Price per unit	$6.40	$7.35	$9.41
Current Draw	4.0 mA	6.1 mA	3.7 mA
Operating Voltage	1.9 - 3.6v	2.4 - 3.6v	2.4 - 3.6v
Development Board Available	Yes	Yes	Yes
Gyroscope Accuracy	8.75mdps/LSB	8.75mdps/LSB	7.63mdps/LSB
Accelerometer Accuracy	0.061mg/LSB	0.061mg/LSB	0.061mg/LSB
Gyroscope Max	2000dps	2000dps	2000dps
Accelerometer Max	16g	16g	16g
Communication Protocol	I2C, SPI	I2C, SPI	I2C, SPI
Package Size	LGA(3.5x3x1mm)	LGA(4x4x1mm)	QFN(3x3x1mm)

Accelerometer / Gyroscope Schematic



Mobile Wireless Connectivity

- Main module needs to connect wirelessly to Android device
- Modern devices implement both Wi-Fi and Bluetooth
- Wi-fi is much more difficult to implement
- Bluetooth implementation is simpler and more secure

Technology		Wi-fi		Bluetooth Low Energy	
Factor	**Weight**	**Raw**	**Weighted**	**Raw**	**Weighted**
Ease of Implementation	8	3	24	8	64
Cost	3	5	15	5	15
Performance	5	2	10	5	25
IC size	2	5	10	5	10
Inherent Security	4	1	4	5	20
Total Score:			63		**134**

Microcontroller

- Two possible design patterns
  - Bluetooth and MCU are separated into different ICs
  - **Bluetooth and MCU on same SoC**
- Most secure Bluetooth LE solutions are present on SoCs (ex. TI CC2640)
- Went with the latter due to ease of implementation and consolidation of development environments

	Mode	Integrated Processor	Flash	RAM	Current Consumption BLE (RX/TX)	Average Current 1 sec / 4sec connection interval
TI CC2540/CC2541	Single Mode v4.0	8051	128kB/256kB	8kB	17.9mA / 18.2mA to 14.7mA / 14.3mA	24uA / 6.8uA
Texas Instruments CC256x	Dual Mode Classic + BLE/ANT	No - External	None	None	-	-
Texas Instruments CC26xx	Single Mode BLE v4.1	Cortex-M3	128kB	20kB	5.9mA	-
Nordic Semiconductor nRF51822	Single Mode v4.1 / ANT	Cortex-M0	128kB / 256kB	16kB / 32kB	9.7mA / 8mA	15.5uA / 5.6uA
Nordic Semiconductor nRF8001	Single Mode v4.0	None	None	None	14.6mA/12.7mA	-
Dialog Semiconductor DA14580	Single Mode BLE v4.1	Cortex-M0	32kB OTP	42kB + 8kB	4.9mA / 4.9mA	-
Cypress Semiconductor PSoC 4 BLE / PRoC BLE	Single Mode BLE v4.1	Cortex-M0	128kB / 256kB	16kB / 32kB	15.6mA / 16.4mA	18.9uA / 6.2uA
CSR CSR101x	Single Mode BLE v4.1	16-bit RISC	64kB	64kB	16mA	28uA / 10.8uA

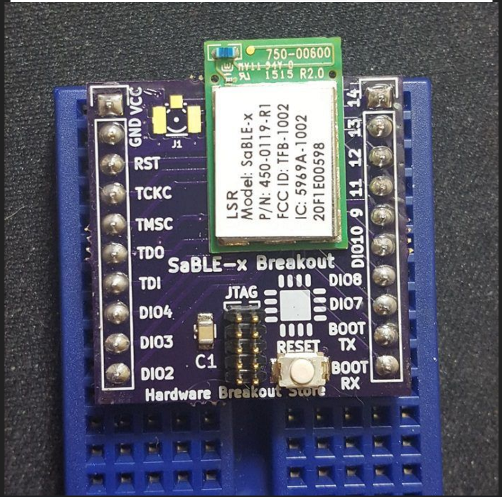
Microcontroller Decision

Chose the **TI CC2640** due to familiarity with development environment, affordable development kit, internal security, plentiful documentation, and the inclusion of a real-time operating system

Products:	TI CC2640	Nordic NRF51882	TI CC2540	Dialog DA14580
Rewritable Flash?	Yes	Yes	Yes	No
Integrated Processor	Cortex M3, dedicated Cortex M0 for Bluetooth	Cortex M0	8051	Cortex M0
Flash Size	128 KB	128 KB / 256 KB	128 KB / 256 KB	32KB OTP
RAM	20 KB	16 KB / 32 KB	8 KB	42 KB + 8 KB
Current Consumption	5.9 mA	9.7 mA	18.2 mA	4.9 mA

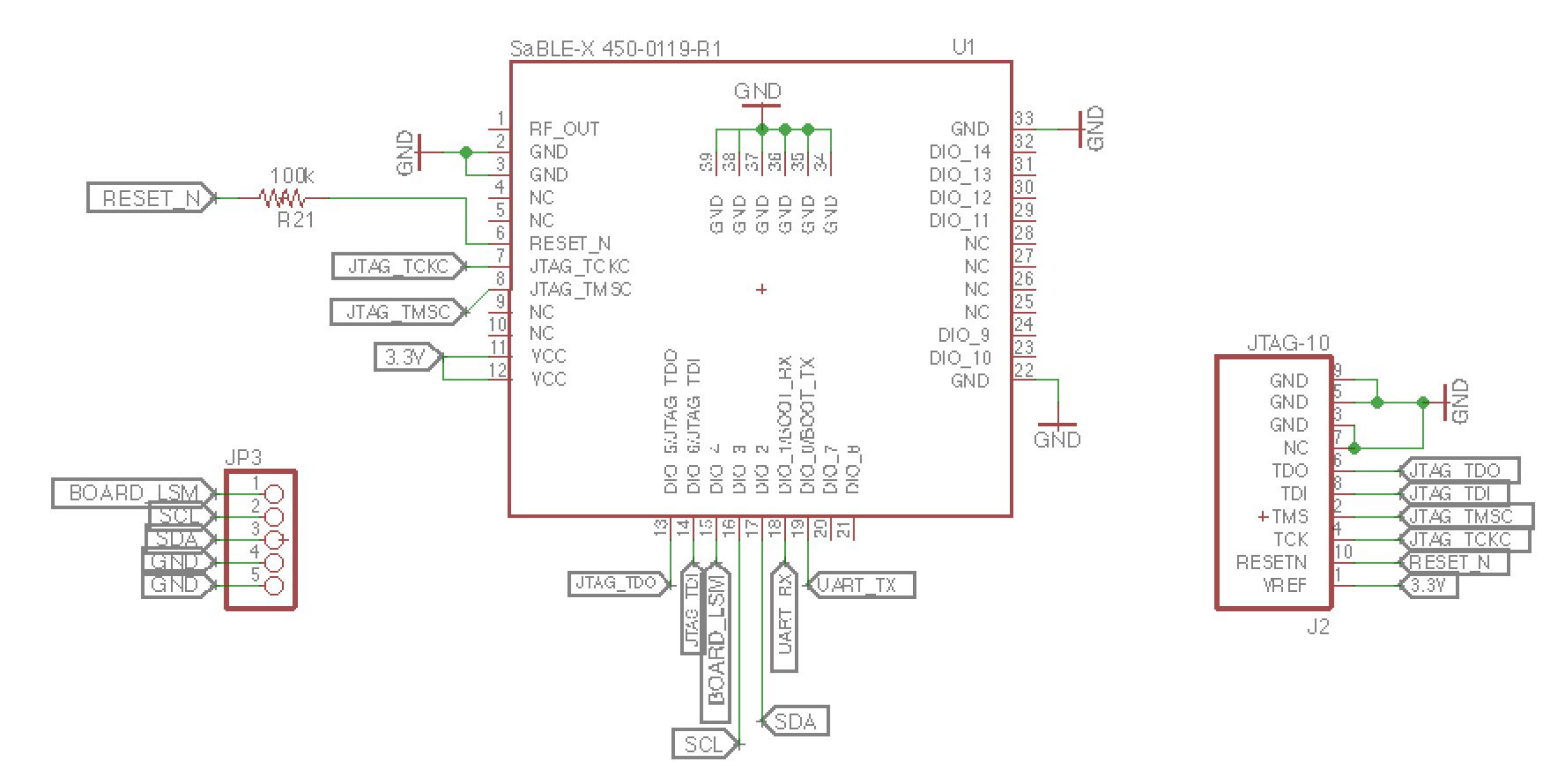
Third-party Implementation: LSR SaBLE-X SoC

- Using a third-party implementation
    - Efficient on space
    - Has certified pre-routed antenna
    - Has all I/O broken out already
- Eliminates unnecessary points of failure
- Few (unofficial) development boards available
    - HardwareBreakout



Manufacturer	LSR
SoC Used	TI CC2640
Price	$16.52
RAM	20 KB
Flash	128 KB

Microcontroller Schematic



Microcontroller Software - Real-time OS

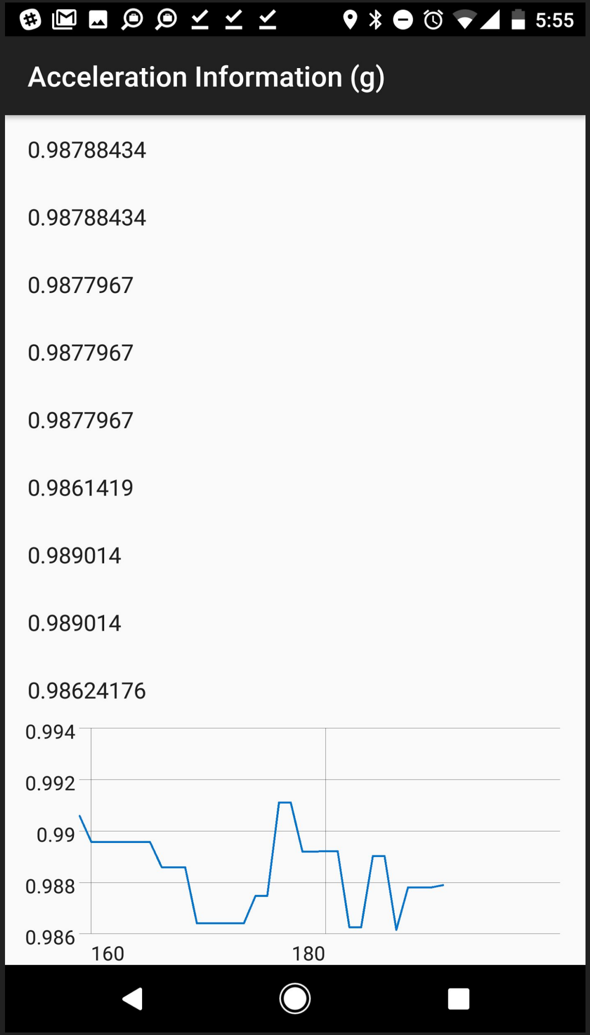
- TI CC2640 necessitates use of RTOS (Real-time Operating System)
  - TI-RTOS
- Benefits
  - Less manual memory management
  - Ability to have multiple tasks
  - Exposes API for Bluetooth
- Drawbacks
  - No widespread use, so less support
  - Steep learning curve
  - Code-size is larger than expected
  - No third-party libraries written

Microcontroller Software - Execution Flow

Mobile Application

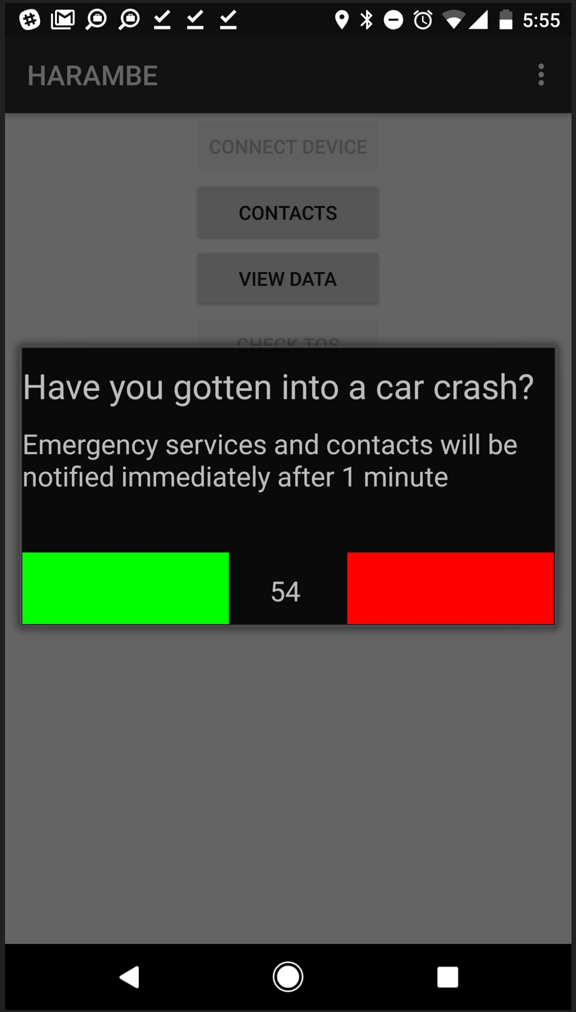
Mobile Application

- Connect to the main device using Bluetooth
- Always running in the background while the car is running
- Obtain real-time data from OBD-II and LSM



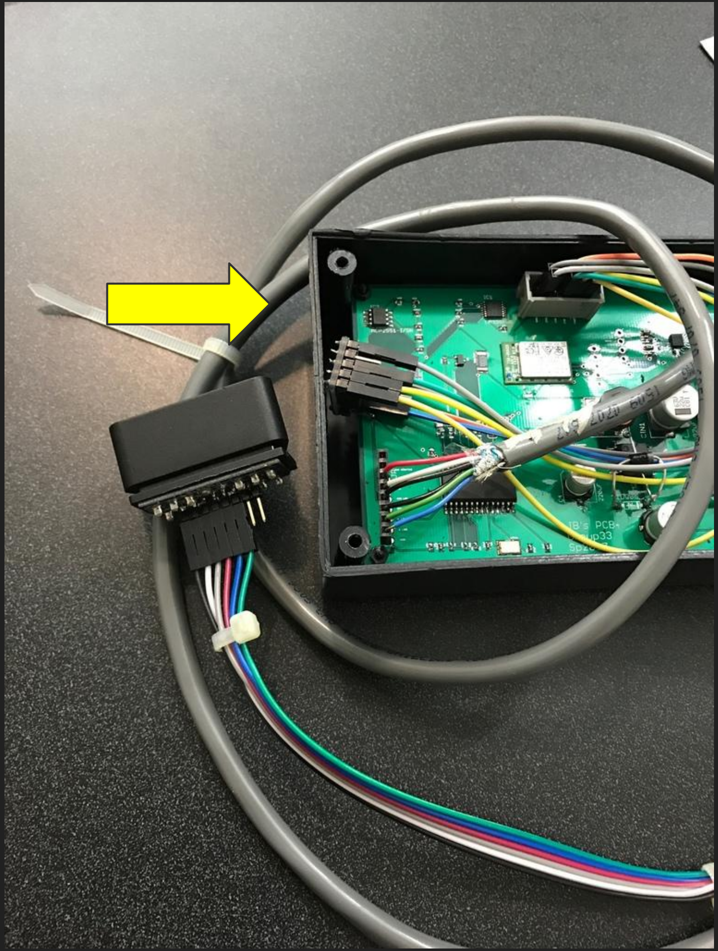
Mobile Application

- Prompt the user when they get into an accident
- Make it as annoying as possible
  - Must respond within 1 minute
- Sends message to custom contacts
- Calls emergency services (911)



Enclosure

- Plastic Box: 5” X 4” X 3” in
- Velcro at the bottom of the box and safety belt to secure the box
- Secure Velcro to wire and route the cable underneath the driver seat
- Wire 16 AWG, 4 ft long (can be placed in anywhere that is safe in the car)



Challenges Faced

- ISO-9141 difficult to implement
  - Issue with transistor
  - No vehicles to test it on
  - Ended up scrapping it
- Android activity concurrency
  - Initial issues with timing
  - Gained experience with multithreading in Android applications
  - Allows the application to stay active in the background

Administrative Content

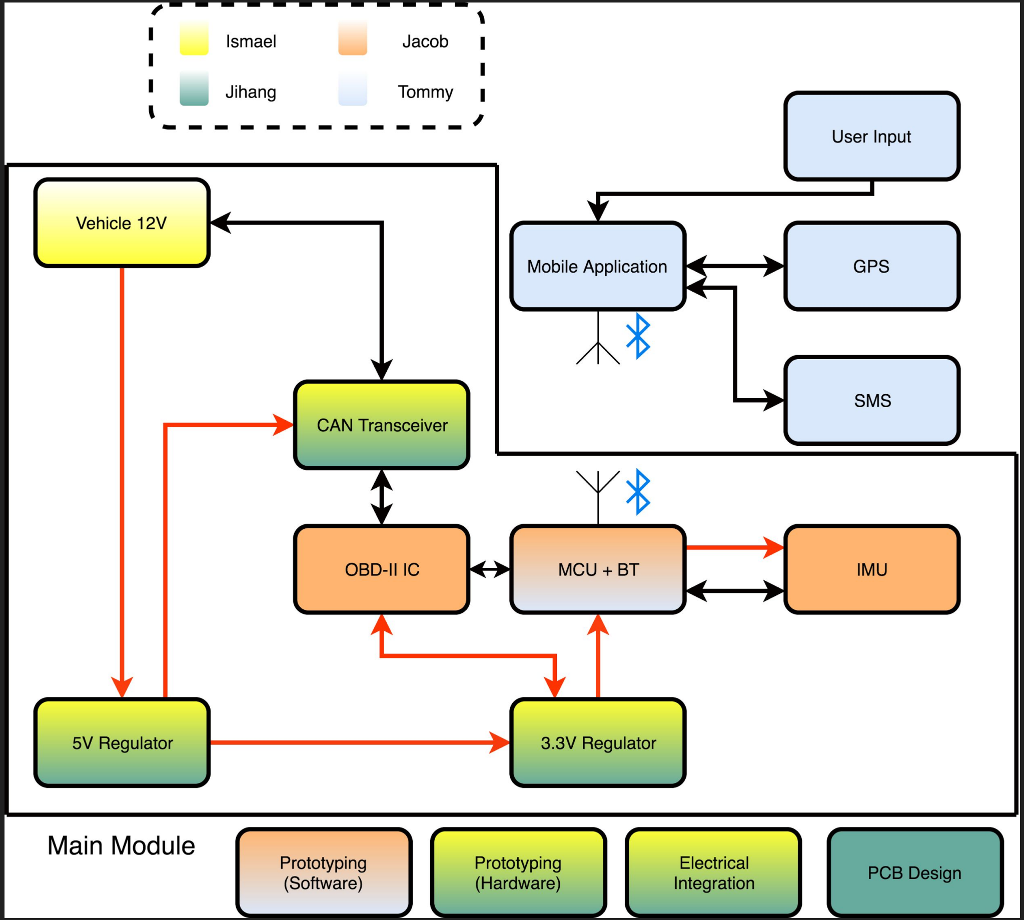
Bill of Materials

Product	Unit Cost	Quantity	Cost
OBD-II Header	$7.00	1	$7.00
8-POS Female	$0.89	1	$0.89
OBD-II Port			$7.89
LM2574 - 5.0V	$2.76	1	$2.76
LM2574 - 3.3V	$2.76	1	$2.76
680uH Ind.	$0.72	1	$0.72
150uH Ind.	$0.91	1	$0.91
22uH Ind.	$0.20	2	$0.40
22uF E.Cap.	$2.27	1	$2.27
220uF E.Cap.	$0.63	1	$0.63
220uF E.Cap.	$0.44	1	$0.44
100uF E.Cap.	$0.75	1	$0.75
100uF E.Cap.	$0.42	1	$0.42
POWER			$12.06
MCP2551	$1.05	1	$1.05
560pF	$0.10	2	$0.20
1uF	$0.11	1	$0.11
100 Ω	$0.12	2	$0.24
4.7 kΩ	$0.12	1	$0.12
CAN Transciever			$1.72
LM339PWR	$0.37	1	$0.37
10 kΩ	$0.12	4	$0.48
BJT (NPN)	$0.68	2	$1.36
510 Ω	$0.60	2	$1.20
1 kΩ	$0.12	2	$0.24
ISO Transciever			$3.65
STN1110	$9.99	1	$9.99
16MHz Crystal	$1.46	1	$1.46
LED Red	$0.54	2	$1.08
LED Yellow	$0.54	2	$1.08
10uF Tant	$0.73	1	$0.73
27pF	$0.10	2	$0.20
0.1uF	$0.10	1	$0.10
1uF	$0.10	2	$0.20
330 Ω	$0.10	4	$0.40
1.5 kΩ	$0.12	1	$0.12
4.7 kΩ	$0.12	1	$0.12
10 kΩ	$0.12	1	$0.12
62 kΩ	$0.10	1	$0.10
100 kΩ	$0.12	2	$0.24
STN1110			$15.94
SaBLE-X	$16.52	1	$16.52
Micro. Header	$1.58	1	$1.58
100 kΩ	$0.12	1	$0.12
Bluetooth Low Energy			$18.22
Lsm9ds1	$6.40	1	$6.40
10 nF	$0.10	1	$0.10
0.1 uF	$0.10	3	$0.30
10 uF	$0.26	1	$0.26
10 kΩ	$0.12	6	$0.72
Lsm9ds1			$7.78
PCBWay	$15.40	1	$15.40
Enclosure	$5.40	1	$5.40
Cable	$1.30	1	$1.30
Lsm9ds1			$22.10
TOTAL			$89.36

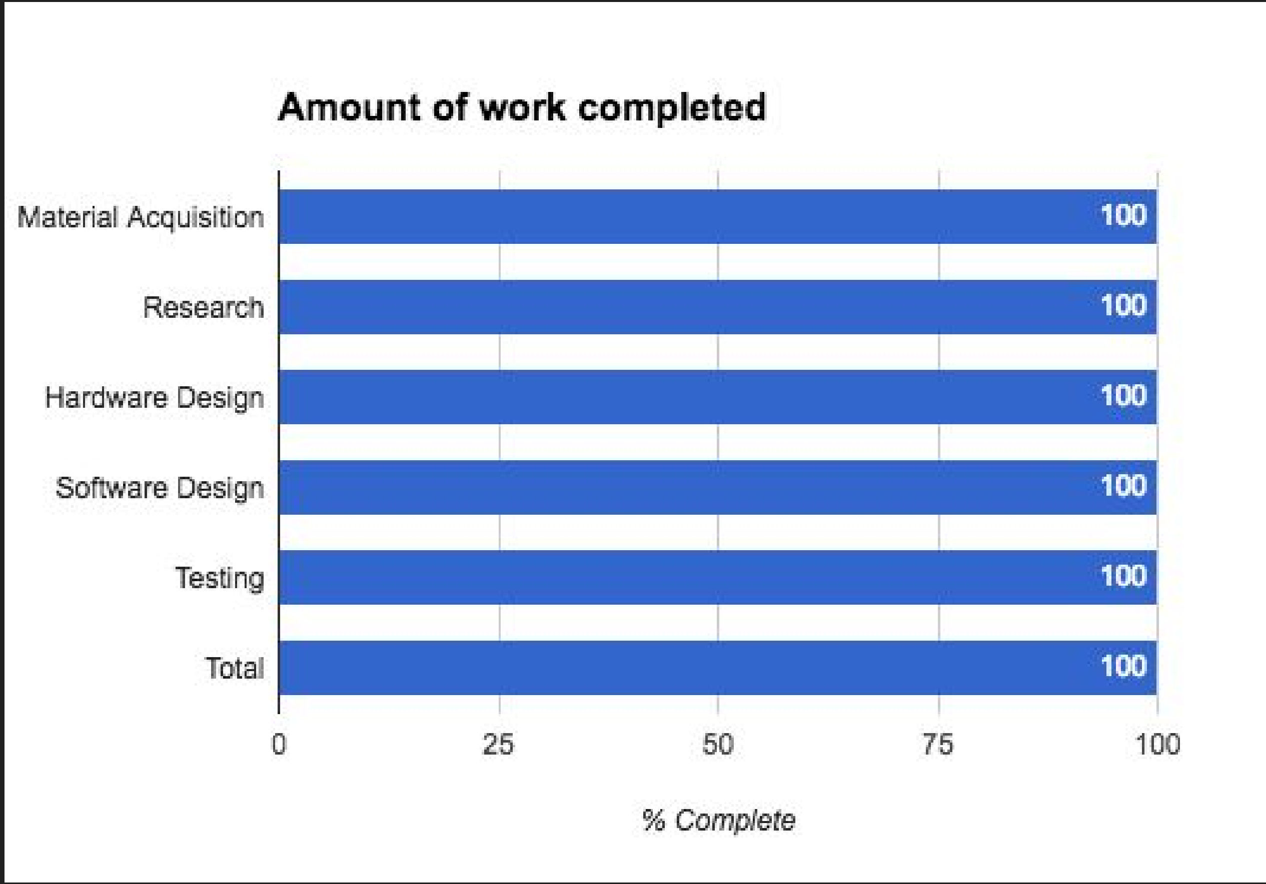
Overall Budget

Category	Expected Cost	Actual Cost
OBD-II Port	$20	$7.89
POWER	$15	$12.06
CAN Circuitry	$10	$1.72
ISO Circuitry	$5	$3.65
OBD-II IC	$20	$15.94
BLE / MCU	$30	$18.22
IMU	$10	$7.78
Prototyping Equipment (Digital)	$300	$240
Prototyping Equipment (Analog)	$100	$63.75
PCB Manufacturing	$100	$77
Total	$610	$448.01

Work Distribution



Overall Progress



Demo

Let's go outside!