Directional Driver Hazard Advisory System

ECE 445 Design Document

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1 Introduction

1.1 Objective

Even with self-driving cars on the horizon, there is still more that we can do to make driving safer with technology for human operators. In the United States, there were 35,092 fatalities and 2.44 million injuries from motor vehicle accidents in 2015 [1]. This makes it one of the leading causes of death in the United States [2]. With some of the top causes of most accidents being distracted driving, reckless driving, and hazardous conditions on the road [3], a driver can benefit from increased awareness and information about the road and nearby drivers.

Our project aims to augment driver awareness of the road by using motion data from sensors within a car to detect and directionally communicate hazards to nearby cars. This information will propagate from car to car using IR transmitters and receivers to keep drivers informed of potential advisories through audio cues. Some hazards, like rapid deceleration or hard swerves could be automatically detected which would send a propagating notification backwards to advise other drivers. In addition to those automatically detected, the passenger will be able to put up advisories for less immediate hazards, such as road obstructions, stopped cars, or accidents.

1.2 Background

Currently most new vehicles on the road today already come equipped with additional sensors to attempt to keep the driver more alert and aware of unsafe driver behavior or road conditions. Sensors like blind spot sensors, lane departure sensors [4] and backup cameras greatly help driver awareness, but are limited to the immediate area around the car. Given that hazards that can be detected by one car can affect several behind it, our system aims to propagate and share information to ensure all drivers are aware.

Other technologies that work to provide a similar sharing of information are mobile apps like Waze and CB radio (an old-school approach). Our system differentiates itself in that it will respond to hazards automatically, unlike Waze which is meant to be used by a passenger who manually enters it. Also, our system is directional, meaning a notification will be propagated directionally as to only notify drivers who would be affected by that notification. It is also worth noting that because every system can communicate with any another system independently, it requires no internet connection or backend system to operate.

1.3 High-Level Requirements

- System must be able to transmit/receive full messages in daylight over IR in a straight line at ranges of at least 100ft up to 300ft.
- System must be able to detect sudden/severe deceleration at a rate of at least 100Hz. (With a range of -60 ft/s^2 to 60 ft/s^2 [5] at a resolution of 0.1 ft/s^2)
- System must be able to notify user of a received message through output from the speaker/screen within 200± 50ms of message validation.

2 Design

We decided to compartmentalize our project into functional components (As seen below in Figure 1). Each block represents an individual function, contributing in a different way to the goal of the project. The Input block represents the two user inputs to our system: passenger button inputs, and IMU readings. The output block represents the two ways in which we will communicate with the driver and passenger: the speaker and LCD. The communication block represents communication between devices. Each component is controlled by a microcontroller. Finally, the power block provides suitable power to each block.

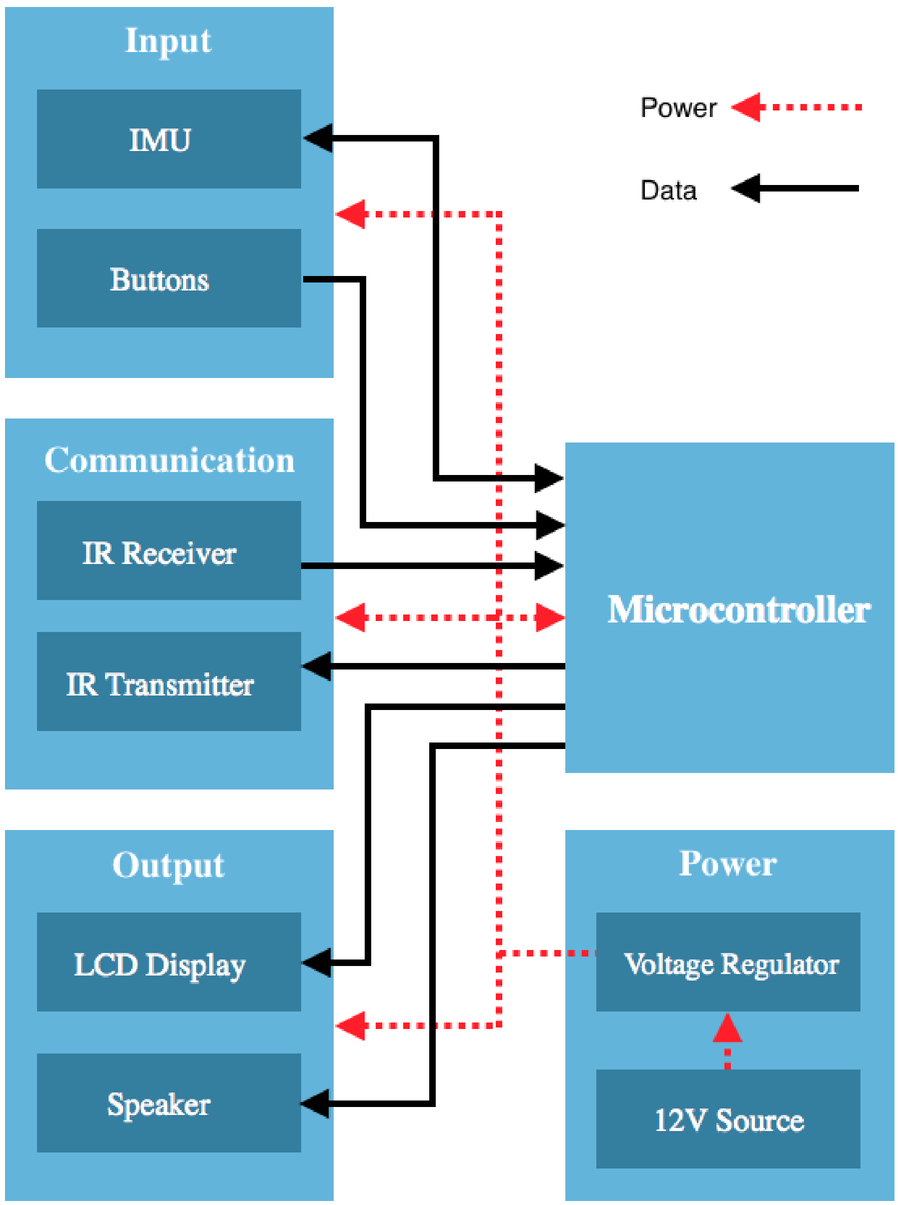

Figure 1: Block Diagram

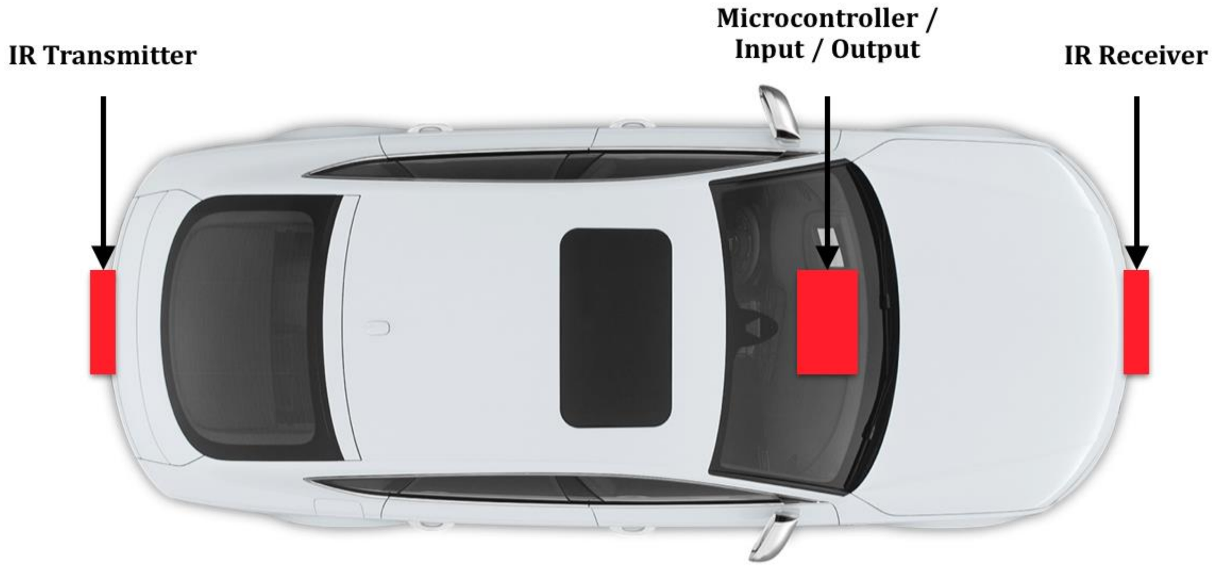

Figure 2: Overall Physical Design

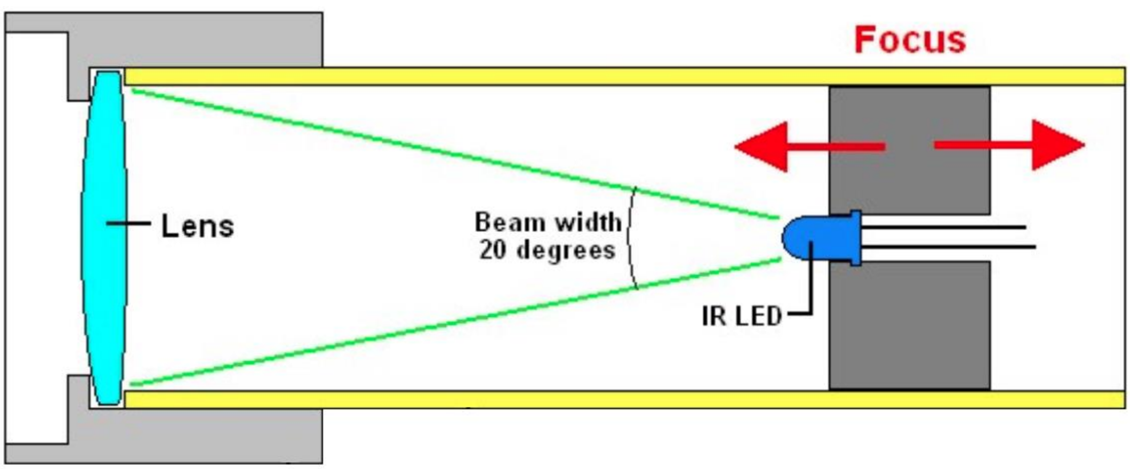

Figure 3: Transmitter Physical Design (from web)[8]

2.1 Communication

For communication between the cars, we have chosen to use IR (Infrared radiation) to limit communication to the car in front or behind the sender. This section is split into 2 main components of the **IR Receiver** and the **IR Transmitter** used to communicate between them. Each car will have 5 IR receivers in the front of the car to receive messages, and an IR Transmitter in the rear of the car (see figure 2) to send messages.

2.1.1 IR Receiver – Vishay Semiconductor TSOP38338

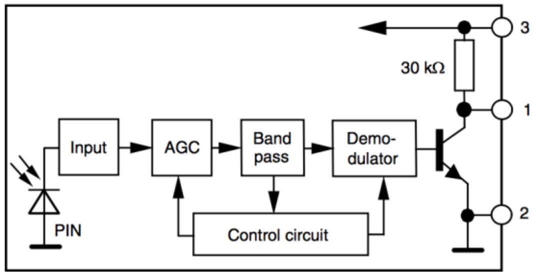

Figure 4: TSOP38338 Schematic (from manufacturer datasheet)[13]

We will have 5 IR Receivers mounted near the front of the car for an optimal view of the car directly in front of the user's car. Each will be connected to the microcontroller through a single input pin to relay message data, and will be powered with 3.3V from the Voltage Regulator. Current is estimated at ~0.45mA for each IR receiver.

2.1.2 IR Transmitter – Vishay Semiconductor TSAL6100

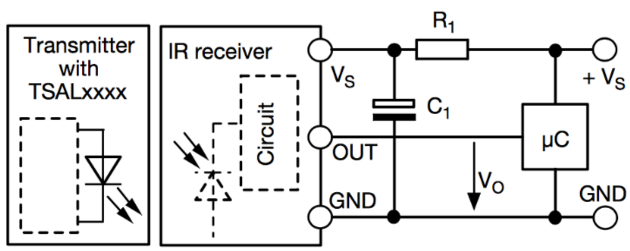

Figure 5: TSOP38338 Recommended Circuit (from manufacturer datasheet)[13]

The IR Transmitter will be mounted in the rear of the car to be able to propagate messages backwards and is a high-power IR LED. It will be powered with 3.3V and controlled by a MOSFET which is being controlled by the microcontroller (Required current is too high to directly output from the microcontroller). We will use an asymmetric double-convex lens to narrow the LEDs beam for better range (see figure 6). The lens will be roughly 2" in diameter. Without the lens, IR range will be roughly 30-40ft. With the lens we should be able to get at least 100ft, and up to 600ft[8]. The package will consist of a PVC pipe with the lens at one end and the LED at the other. Our carrier frequency will be between 30 to 40 kHz and has transmission rate of a 1 or 0 being 1800 microseconds and 1200 microseconds respectively (figure 7). We also transmit a header to identify the start of the message which has a transmission rate of 3ms (For more detail on message protocol, refer to Section 2.8). Current is estimated at ~100mA for the Transmitter.

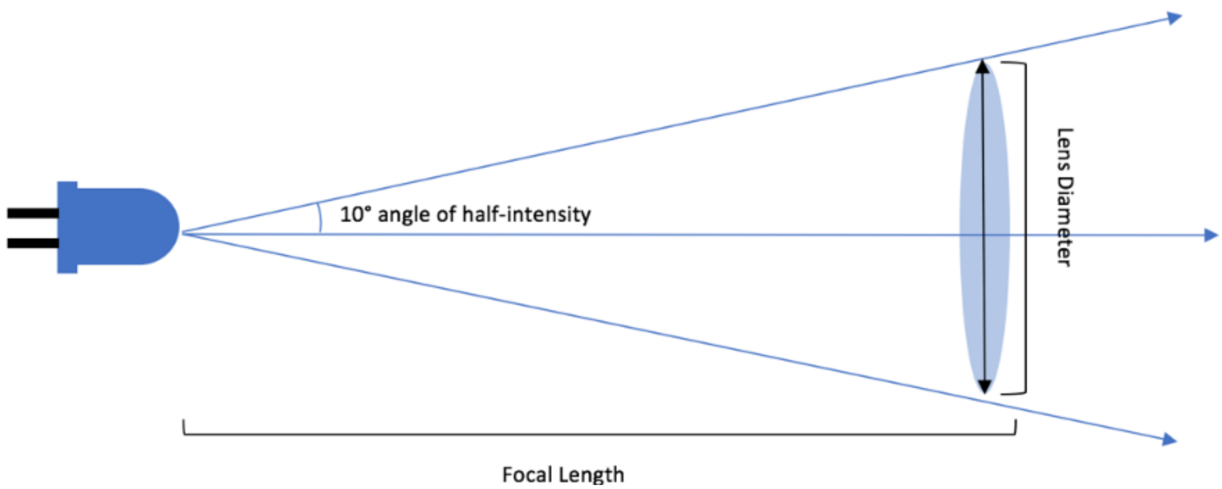

Figure 6: Lens

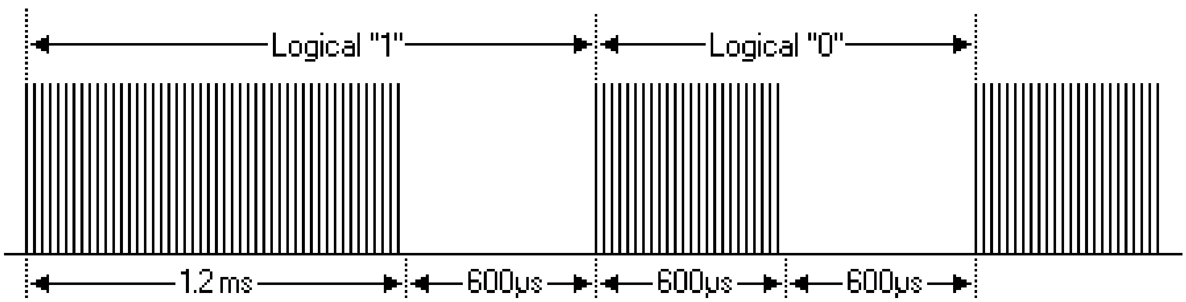

Figure 7: Modulated Signal (from web) [9]

2.1.3 Requirements and Verification

Part	Requirement	Verification	Points
IR Transmitter/ Receiver	*Must be able to correctly receive a message from 0-100ft during daylight and night with good visibility and with optics.*	A. Place IR Receiver and lens assembly exactly 100ft downrange from IR Transmitter (Once at night and once during the day). B. Send message with random data. C. Ensure message was received correctly.	6
	Must be able to correctly receive a message from 0-30ft during daylight and night with good visibility and without optics.	A. Place IR Receiver and lens assembly exactly 30ft downrange from IR Transmitter (Once at night and once during the day). B. Send message with random data. C. Ensure message was received correctly.	4
	Must maintain at most a 47% packet loss rate at a 16-bit message size.	A. Place IR Receiver exactly 100ft downrange from IR Transmitter. B. Send 50 messages with predefined data. C. Ensure at least 53% of the messages were received by comparing sent and received.	2
	Must have a field of view between 25° and 180°.	A. Place IR Receiver exactly 10ft downrange from IR Transmitter. B. Move the IR Transmitter 2.22ft in a perpendicular direction, creating a ~12.5°angle. C. Send a message and ensure that it was received.	2
	Must be able to transmit one message of size 16 bits in under 50ms	A. Write program to transmit/receive 1000 messages. B. Run program and use profiling tool on the receiving side to time how long it takes.	2
		Total	16

2.2 Input

2.2.1 User Input Buttons – 4 Pin DIP Micro PCB tactile Push Button

A strip of roughly 5 buttons will be needed, each with a message mapped to it, so that the user can put up less immediate advisories. These will either be wired directly to the microcontroller or to a binary encoder if we are short on pins. We do not need any sort of hardware debouncing, any debouncing should be able to be done in software.

2.2.2 Inertial Measurement Unit (IMU) - XYG-Module IMU MPU9255 BMP280

An IMU will be used to detect rapid deceleration to trigger automatic messages. The IMU will be powered by the 3.3V source and wired to the microcontroller using 2 pins for I2C. Current is estimated at ~10mA for the IMU. Figure 8 shows our IMU in our schematic, for the full schematic see section 2.6.

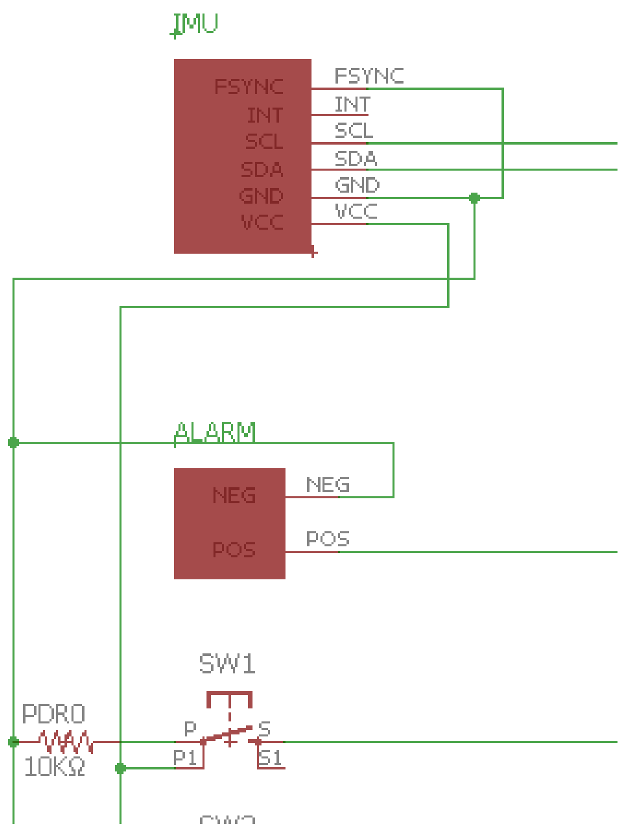

Figure 8: Close-up IMU In Our Schematic

2.2.3 Requirements and Verification

Part	Requirement	Verification	Points
User Input Buttons	*Must be a momentary button and be a tactile button so the User knows it is pushed.*	A. Press button. B. Should feel a sharp, tactile click. C. Check continuity of electrical path through button (there should be continuity). D. Release button. E. Check continuity of electrical path through button (there should be no continuity).	1
IMU	*Must be able to measure acceleration/deceleration from +60 ft/s² to -60 ft/s² in X and Y axes.*	A. Connect IMU to MCU. B. Start measurement of acceleration in all axes. C. Move MCU 1ft in less than 120 ms. D. Verify that the acceleration reading is over 60ft/s² E. Move MCU 1ft in less than 240 ms. F. Verify that the acceleration reading is over 30ft/s² G. Repeat for each axis.	1
	Must be able to measure at a resolution of 0.1 ft/s² [5] and maintain a sample rate of 100Hz.	A. Connect IMU to MCU. B. Start measurement of acceleration in all axes. C. Leave IMU static. D. Compare accuracy of measurement of gravitational acceleration to 32.2ft/s². E. Verify that at least 100 distinct samples were collected in 1 second.	1
	Must be able to communicate on I2C interface and draw less than 10mA at 3.3V.	A. Connect to I2C driver. B. Connect ammeter. C. Start measurement. D. Measure current. E. Place IMU on surface parallel to ground, do not move IMU. F. Verify that one axis of data reads gravitational acceleration and that the others read 0.	1
		Total	4

2.3 Microcontroller – Atmega1284

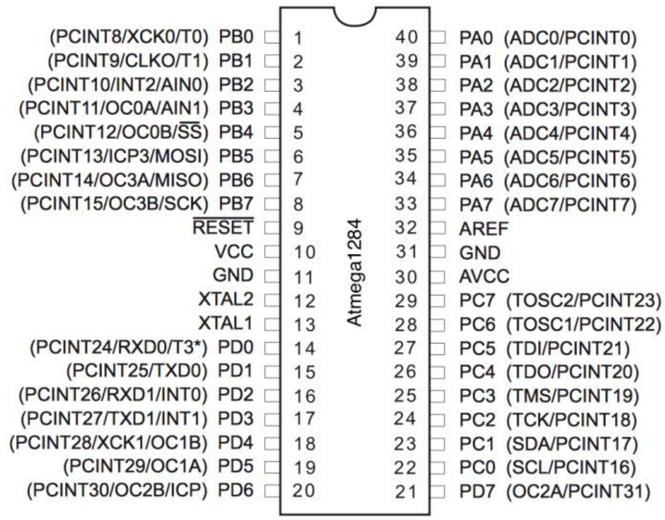

Figure 9: Atmega1284 Pins (from manufacturer datasheet)[12]

A low power microcontroller will be needed to control the screen, send and receive messages, play audio cues, and interface with the IMU. We chose the Atmega1284 because it is well documented, has an operating voltage of 1.8-5.5V, has sufficient I/O pins, and has sufficient timers and PWM hardware for driving the LED and speaker. Current is estimated at ~100mA for the microcontroller.

Part	Requirement	Verification	Points
Microcontroller	*Must have sufficient IO pins to talk to 5 IR receivers, 1 LED, an I2C bus (2 pins), 5 buttons (3 pins), speaker (1 pin), and display (5 pins) (16 total). Must have PWM for at least 2 pins.*	A. Verify that MCU has at least 16 I/O pins. B. Drive each pin high and low and read from each pin. C. Write high and low to each pin and verify output using a multimeter. D. Verify that MCU has at least two PWM capable pins.	1
	Must work with a 3.3V power source and consume less than 100mA.	A. Connect MCU to 3.3V source and ammeter. B. Measure current. C. Load MCU with program. A. Verify output of program.	1
		Total	2

2.4 Output

2.4.1 LCD Display - Nokia 5110 Graphic LCD 84x48

For low priority advisories (ones that do not have a dedicated sound cue), a small (~1-2 inch) display will be used to display them to the driver. Messages will be pre-determined and stored on the microcontroller. Current is estimated at ~500mA for the LCD and backlight.

2.4.2 Speaker - Large Piezo 3KHz Alarm

A speaker will be used to provide sound cues during a hazardous situation. It will be driven by the microcontroller, which will play a fixed single tone which will be specified by the microcontroller (No storage necessary). For urgent messages, we will play a repeating tone for a second and for less urgent messages we will play a single tone. Figure 10 shows the LCD controller in our schematic. See section 2.6 for our full schematic.

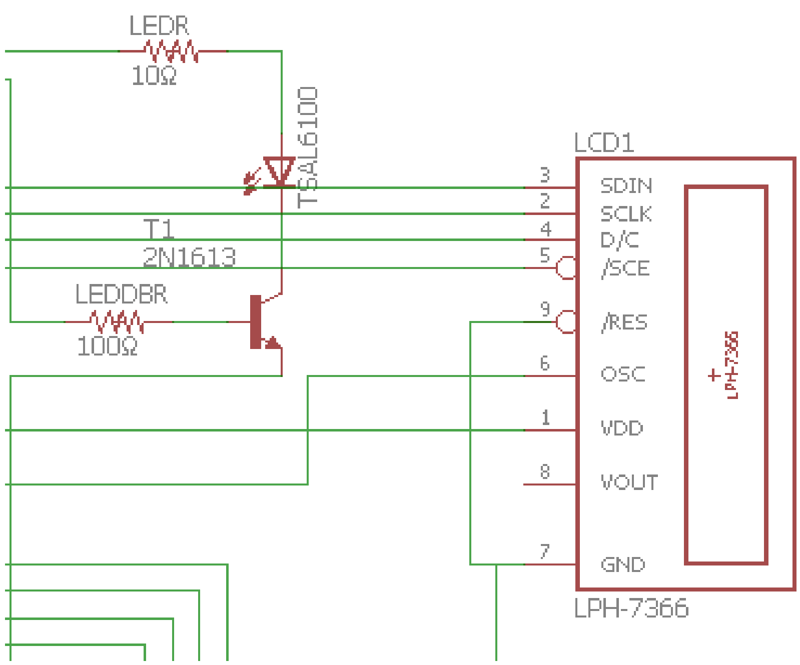

Figure 10: Close-up LCD In Our Schematic

2.4.3 Requirements and Verification

Part	Requirement	Verification	Points
LCD Display	*Must be larger than 1" and be able to display at least a 64*64 resolution black and white icon.*	A. Load icon onto display and verify that entire icon is visible B. Connect to controller and load driver. C. Load black and white image onto screen. D. Verify that there are black and white pixels.	3
	Must draw less than 500ma with a 3.3V source when display is on with backlight on.	A. Connect ammeter and measure current.	1
Speaker	*Must be at least 50-70 dB and be able to produce a tone at 3kHz.*	A. Connect to 12v source. B. Measure volume with decibel meter. C. Measure frequency of sound emitted with a spectrum analyzer.	1
	Must work with a 3.3V or 12V power source at less than 50mA.	A. Connect to 3.3v source. B. Connect ammeter C. Leave connected for 2 minutes. D. Verify that a tone is emitted and that the unit is not hot. A. Measure current.	1
		Total	6

2.5 Power

2.5.1 Power Source - ROHS Car Adapter Plug PRT-11474

The device will be powered from the car's 12V source, brought down to 3.3V. Our estimated maximum power consumption is 1A (500mA for the LCD and backlight, 10mA for the IMU, 50mA for the speaker, 10mA for each IR receiver, 100mA for each IR transmitter, 100mA for the microcontroller). Our power draw would be 3.3V*0.950A + 12V*50mA = 3.735±1W.

2.5.2 Voltage Regulators - Texas Instruments LM1086IT-3.3/NOPB

We will be using a linear regulator to bring down the 12V dc voltage from the source to 3.3V. Figure 11 shows the voltage regulator in our schematic, see section 2.6 for the full schematic.

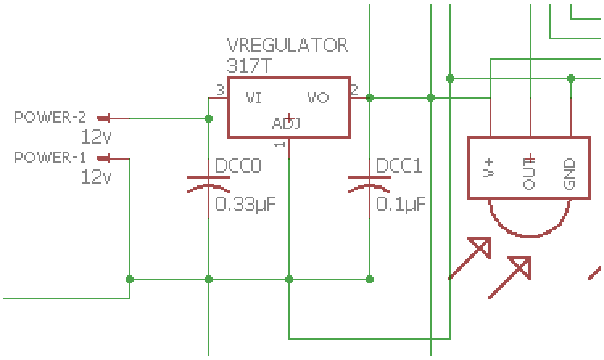

Figure 11: LCD In Our Schematic

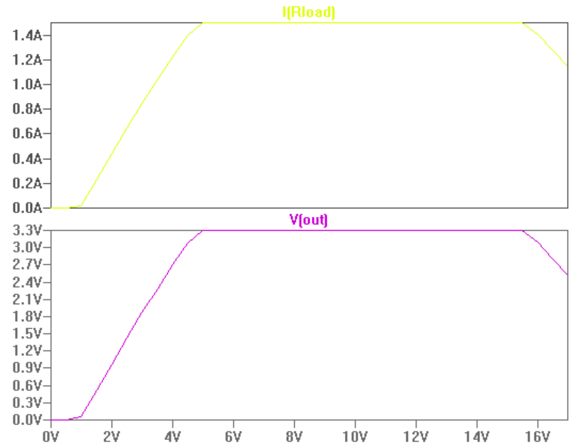

Figure 12: Voltage Regulator Simulation

2.5.3 Requirements and Verification

Part	Requirement	Verification	Points
Voltage Regulator	*Must be able to take an input of 12V±10% and output 3.3V±10% and must be able to output 0-1A.*	A. Connect to bench power supply and voltmeter. Vary input voltage and measure input and output voltages. B. Connect to bench power supply and wire a potentiometer in series. C. Connect ammeter. D. Turn potentiometer to maximum resistance. E. Lower resistance until the ammeter reads 1A.	1
Circuit Power Requirements	*Must draw less than 3.755±1W*	A. Connect circuit to power supply and ammeter. B. Start circuit operation. C. Measure current draw of circuit.	1
		Total	2

2.6 Schematics

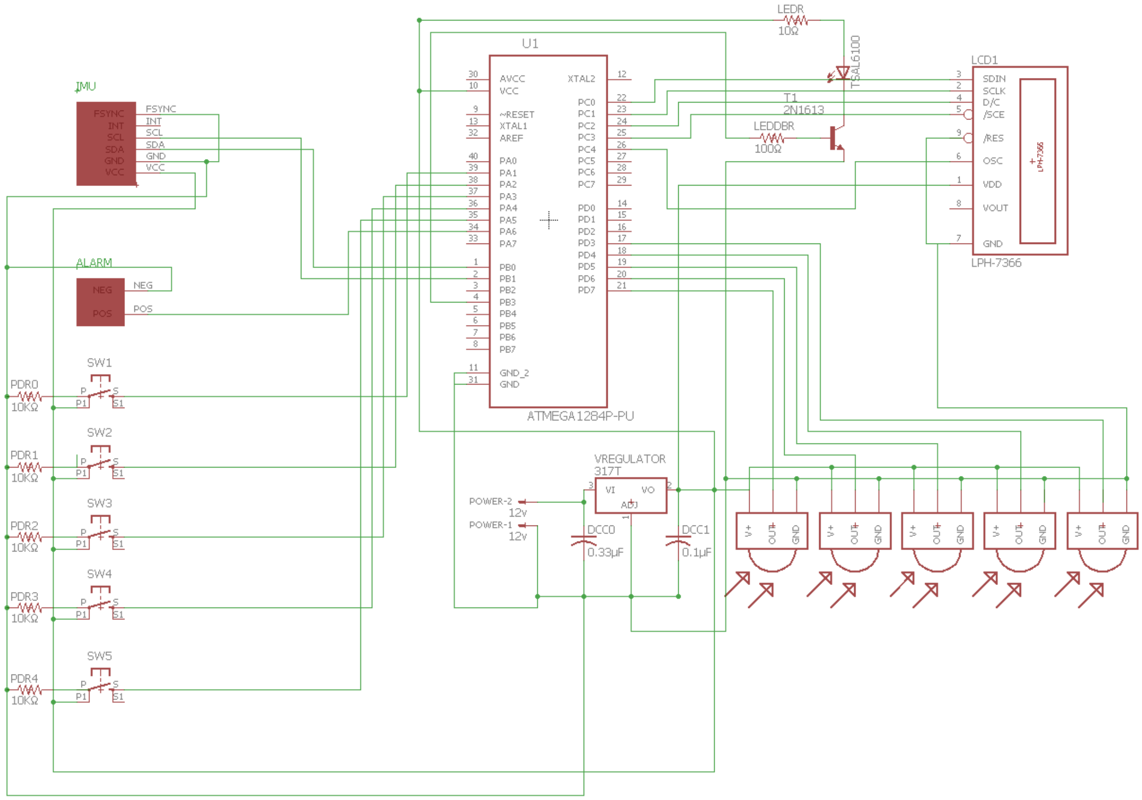

Figure 13: Circuit Schematic

2.7 Software

In addition to our hardware components, our project relies on two important software implementations. The **IR Message Protocol** which describes the way that the message data is formatted, sent, and propagated from IR Transmitter to receiver, and the **IMU Hazard Detection** algorithm which is focused on detection of dangerous braking patterns. These two components are described in more detail below.

2.7.1 IR Message Protocol

Our messaging protocol will be based around our messages which are going to be 16 bits wide. They will consist of 4 bits for a message_id, 4 bits for hops_to_live, and the remaining bits for the message data (See Figure 14).

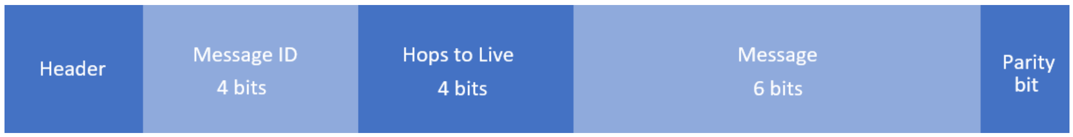

Figure 14: Message

Our send and receive protocol is then a simple at-least-once protocol. When a vehicle wants to alert other drivers of an advisory the transmitter will spam a message continuously for 3 seconds which allows us to combat the relatively high packet loss rate while also delivering vehicles who come into range of the transmitter while sending. We have set a reasonable packet loss rate of around 47%, at a worst case following distance of 100ft. Under worst case conditions, where a driver in front of you begins breaking hard, a car going 55mph, which is the speed limit on most US highways in urban environments, will travel 100ft in 1.24s. With a driver reaction time of 1s [10], that leaves us 0.24s to transmit our message for a driver to notice it before having driven 100ft. In 0.24s, with a message length of 50ms, we can send at most 4 full messages. Since we would like to successfully alert the driver at least 95% of the time, the chance of a message failing 4 times in a row must be less than 5%. With a packet loss rate of 47%, the chance of 4 messages in a row being lost is 4.9%. Additionally, we will include a parity bit. If there is an error, the data should be rejected.

After one of these messages is received, the receiver will check the message_id against a list of recent message_ids to not spam the user with the same message. The receiver will then deliver the message and check the hops_to_live parameter of the received message to see if it should be propagated backwards. If the hops_to_live is greater than 0, the message would be propagated with a decremented hops_to_live parameter. Currently we believe a default hops_to_live of 5 will notify all drivers who would need to immediately be informed of an upcoming advisory.

2.7.2 IMU Hazard Detection

Our IMU Hazard Detection algorithm uses the accelerometer data from the IMU in order to determine if an vehicle is braking at an unsafe rate. Firstly, we determined that we will sample the IMU at a rate of 100Hz (though our IMU is capable of sampling at

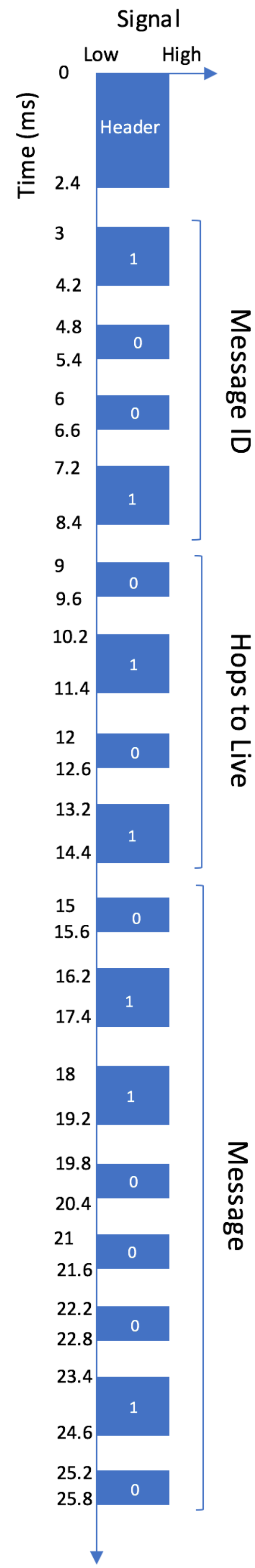

Figure 15: Message Signal

up to 32KHz) which is well within the range of being able to detect extreme decelerations. For example, with a vehicle going 65 mph or 29.057 m/s, an average driver can safely decelerate an automobile under reasonable conditions at a rate of 15 fps or 4.572 m/s^2[10]. Therefore, a full deceleration from 65 mph to full stop, takes 6.35 seconds. (See Eq. 5)

$$v_f = v_i + at \quad 0 = 29.0576 + (4.572)t \quad t = 6.35s$$

Equation 1

Because we will keep a will be keeping a time moving average of the last 10 readings which with a sampling of 100 Hz will be 100ms, and our system can react to hard breaking within 100ms. To determine this we will test that if at any point that average moved higher than our set safe braking threshold of 4.572 m/s^2 (See Eq. 6). Once we hit this threshold, the vehicle will send a message alerting other cars to brake immediately.

$$\frac{S_T + S_{T-1} + \cdots + S_{T-8} + S_{T-9}}{10} < 4.572\ m/s^2$$

Equation 2

2.7.3 Requirements and Verification

Part	Requirement	Verification	Point
IR Message Protocol	*Notifies user only once when receiving the same message more than once.*	A. Spam messages with varying message IDs. B. Verify that only one notification is made to the user for each message ID.	5
	In case of single flipped bit, data should be rejected.	A. Send messages with no error. B. Verify that message is accepted. C. Send messages with error. D. Verify that message is not accepted.	5
IMU Hazard Detection	*Data that crosses acceleration threshold triggers a message send event.*	A. Provide simulated IMU input that contains a fake hard braking event. B. Verify that the function that sends a message is called.	5
Buttons	*Pressing a button sends a message for the corresponding advisory.*	A. Press a button on one unit. B. Verify that the correct advisory is set on the other unit. C. Repeat for each button.	1
Display	*Displays a different icon for each advisory.*	A. Simulate receiving a message for each type of advisory.	4
		Total	20

2.8 Tolerance Analysis

An important tolerance to the success of our project is that of the positioning of the transmission LED relative to the lens. It is the riskiest part of our design because it could impact both the safety of drivers and the completion of our project. It is important that we are able to get this component of our design to work, given that the basic premise of our project involves communicating at following distances for cars. Pairing a suitable lens to our LED and positioning the LED well relative to the lens will allow us to communicate at greater distances. The lens's focal point needs to be chosen with respect to the lens's diameter as to maximize the amount of light captured from the LED. Our chosen LED has an angle of half intensity of 10°. Doing some geometry (see figure 6), we can see that the optimum focal point f for a lens of diameter D paired with our LED which has an angle of half intensity a is given by equation 3.

$$f(D, a) = \frac{D}{2\tan(a)}$$

Equation 3

We need to place our LED at the focal point of the lens to get the desired effect of bending a cone of light into a cylinder of light. Placing the LED as close to the focal point as possible (as in figure 16) is important. If the LED is too far from the lens, the light will be bent into a narrowing cone (as in figure 17), causing us to lose range. If the LED is too close to the lens (as in figure 18), the light will be bent into an expanding cone, causing us to lose range. If the LED is off-center, we will have parallax (as in figure 19), making it more difficult to aim and possibly preventing us from gathering as much light as we could, also causing us to lose range. We will take these tolerances into account when sourcing and building our transmitter assembly. We will purchase a lens with diameter and focal lengths optimized for our chosen LED. Additionally, we will precisely measure and cut the mounts for the LED in order to ensure that it is the correct distance from the lens and that it is centered with respect to the lens. In addition, a larger lens will necessitate a larger focal length for our LED, and a larger focal length will minimize the effect of parallax from the LED being off center relative to the lens. The trade-off here is that a larger lens will generate a larger cylinder of light, reducing the amount of light we can transmit in a given area.

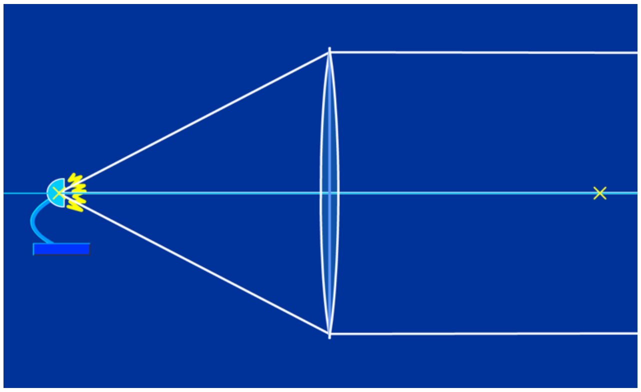

Figure 16: Ideal Positioning

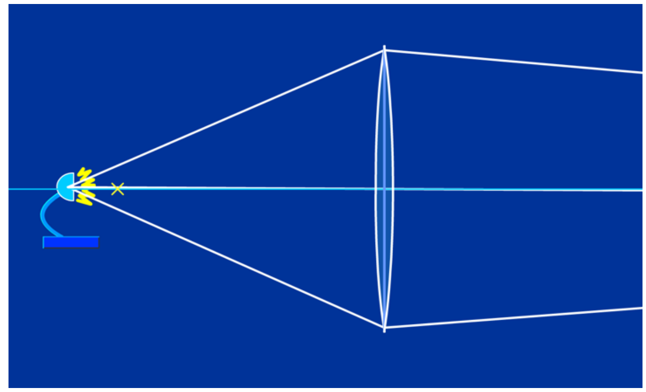

Figure 17: Too Far

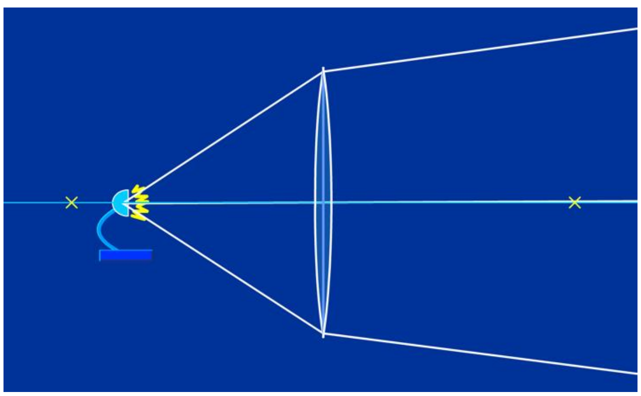

Figure 18: Too Close

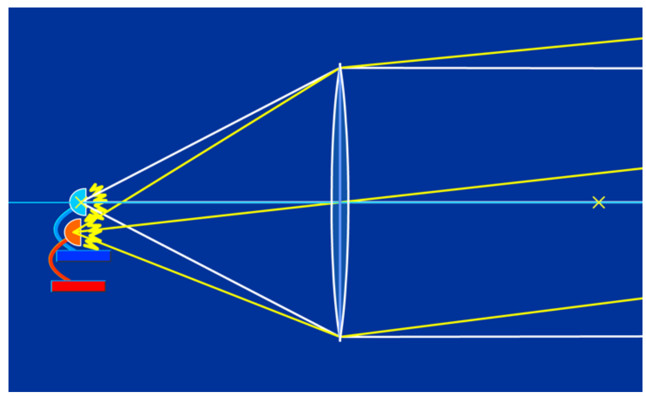

Figure 19: Parallax (Red) vs. Ideal (Blue)

3 Cost

Our cost firstly is defined by the cost of our hardware which is shown below. (Note: Total cost is cost per board, which we plan on designing two for them to communicate).

Part	Vendor	Quantity	Cost (Prototype)	Cost (Bulk)
IR Receiver Vishay Semiconductor TSOP38338	Digikey	5	$5.60	$2.05
IR Transmitter Vishay Semiconductor TSAL6100	Digikey	1	$0.57	$0.13
User Input Buttons 4Pin DIP Micro PCB tactile Push Button	Amazon	5	$5.29	$5.29
IMU XYG-Module Inertial Measurement Unit MPU9255	Amazon	1	$21.96	$21.96
Microcontroller Microchip Technology ATMEGA1284-PU	Digikey	1	$5.15	$4.27
LCD Display Nokia 5110 Graphic LCD 84x48	Sparkfun	1	$9.95	$8.96
Speaker Large Piezo 3KHz Alarm	Sparkfun	1	$2.95	$2.66
Voltage Regulator Texas Instruments LM1086IT-3.3/NOPB	Digikey	1	$1.67	$0.82
12V Power ROHS Car Adapter Plug PRT-11474	Sparkfun	1	$0.50	$0.50
Transistors STMicroelectronics STN3NF06L	Digikey	2	$0.43	$0.36
Resistors (x4 10K, x1 10. X1 100), Capacitors (.33µF, .1 µF)	Digikey	8	$0.05	$0.03
PCB 100x100mm 2 Layer	PCB Way	1	$10.00	$10.00
Total			$64.12	$57.03

Table 1: Hardware Costs

The second cost is our development cost, which we will estimate at $30 per hour, 10 hours per week, and 16 weeks of development each for the two members of our group. (See Eq. 4)

$$\frac{\$30}{hr} * \frac{10\,hr}{week} * 16\,weeks * 2 = \$9600$$

Equation 4

With our $9600 of development cost and 2 x $64.12 (the prototype cost of our board), we estimate our total cost to be $9728.24. (See Eq. 5)

$$\$9600 + (2 * \$64.12) = \$9728.24$$

Equation 5

4 Schedule

Week	Ben	Vasil
2/27/17	Acquire parts. Flash microcontroller so that we can start programming it.	Assemble prototype transmitter/receiver, power supply.
3/6/17	Program prototype IR transmitter/receiver using Arduino. Compile data on maximum transmission ranges.	Build transmitter and lens enclosure. Design initial board. Order board
3/13/17	Prototype user interface on breadboard. Debug first board design revision.	Prototype IMU algorithm on breadboard. Debug first board design revision.
3/20/17	Prototype display driver using breadboard.	Begin programming communication protocol and control logic.
3/27/17	Programming final display driver. Finish programming final communication protocol logic.	Finish programming communication protocol logic. Finalize board design, order board.
4/3/17	Begin programming user interface and final control logic.	Assemble final board, debug.
4/10/17	If bugs were found in final board design, fix and re-order board.	Conduct range vs. packet loss rate experiments
4/17/17	Design and model case for 3D printer.	Design and model mount for 3D printing.
4/24/17	Controlled testing outdoors, in conjunction with some in-vehicle testing.	Fix any bugs discovered during testing
5/1/17	Begin final report.	Prepare final presentation.

Table 2: Schedule

5 Ethics and Safety

The obvious main potential safety and ethical problem with our project is that our device is to be used while a user is operating a vehicle which can be problematic in the event of failure (either false positive or false negative feedback to the driver). We would like to avoid users to rely so heavily on our device that it puts them in dangerous situations, therefore we will add a disclaimer that informs the user to use our product as an aid, rather than rely on it solely and that users should make sure to assess the situation before taking action as a result of a message received.

This connects to another serious issue which is driver distraction. To mitigate this risk, our system will be designed in such a way to not add any user interaction more distracting then what is currently outfitted on a car dashboard. For the manual hazard entry, the buttons are placed so that only a passenger in the front seat can interact with it, preventing the driver from taking his/her eyes off the road or otherwise getting distracted. We will still give the driver some feedback in the form of audio cues in the event of an emergency, but the cues will conform to audio design patterns used in existing driver safety systems (such as blind spot sensors) in the event of an emergency.

Finally another potential risk factor is IR radiation. Though some IR sources such as IR lasers can cause damage to the eyes, we will be using IR LEDs which, per semiconductor manufacturer Vishay Intertechnology Inc., “nearly all LEDs are far below the Exempt limits” [6] so to mitigate this risk, we need to make sure the IR LEDs we purchase are safe.

Our safety risks and mitigations follow the IEEE code of ethics first point, “to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment” [7]. We believe that the benefits provided through increased driver awareness outweigh the potential risk of driver distraction given our distraction mitigation techniques.

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