Road Interference Mapper (The RIM)

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1 Introduction

1.1 Objective:

Roadway obstacles are often hard to spot when a driver is focused on other aspects of driving. During rush hour in the city, when you're stuck in bumper to bumper traffic, it is nearly impossible to avoid all hazards on the road. Finding and removing every roadside obstacle promptly is just not possible. Debris and potholes can remain on the road for weeks, months, or even years. The result of a direct collision with one of these obstacles usually just results in a bump or possibly a flat tire. However, in the worst case, it can cause cars to veer off course, causing accidents.

To prevent car accidents on the road, we propose a product that will allow drivers to share information regarding roadway interferences such as potholes and debris. By constantly sensing the average distance to the road underneath a car using ultrasonic sensors, any deviation in this distance within a certain threshold would signify the presence of potholes or debris. A microcontroller will continuously process the distance data and, upon detection of an obstacle, send a signal to a smartphone app notifying the app of a detected interference. The smartphone app would then mark the location of the obstruction on a map using the location capabilities of the smartphone. All users using this app would be able to see every marked obstruction on their map and would be able to look out for and avoid the obstacle. Because of the limited reading rate of ultrasonic sensors, our solution will only detect debris and potholes when the user is driving under 22mph, as is the case during rush hour traffic in the city.

1.2 Background:

Other applications aim to detect potholes and debris, however, these applications utilize the sensors of a smartphone such as the accelerometer and the gyroscope to detect the impact with an obstacle. This method can only detect obstacles that were hit. Our solution will utilize an array of sensors to detect roadside obstacles. This will allow for more accurate results and more importantly, our solution will detect obstacles, such as potholes, that a driver may have driven over without collision.

1.3 High-level requirements list:

- Appropriate power must be supplied to processing modules
- Sensors must be able to detect potholes and debris without interfering with each other
- Data must be communicated between devices

2 Design

2.1 Block Diagram:

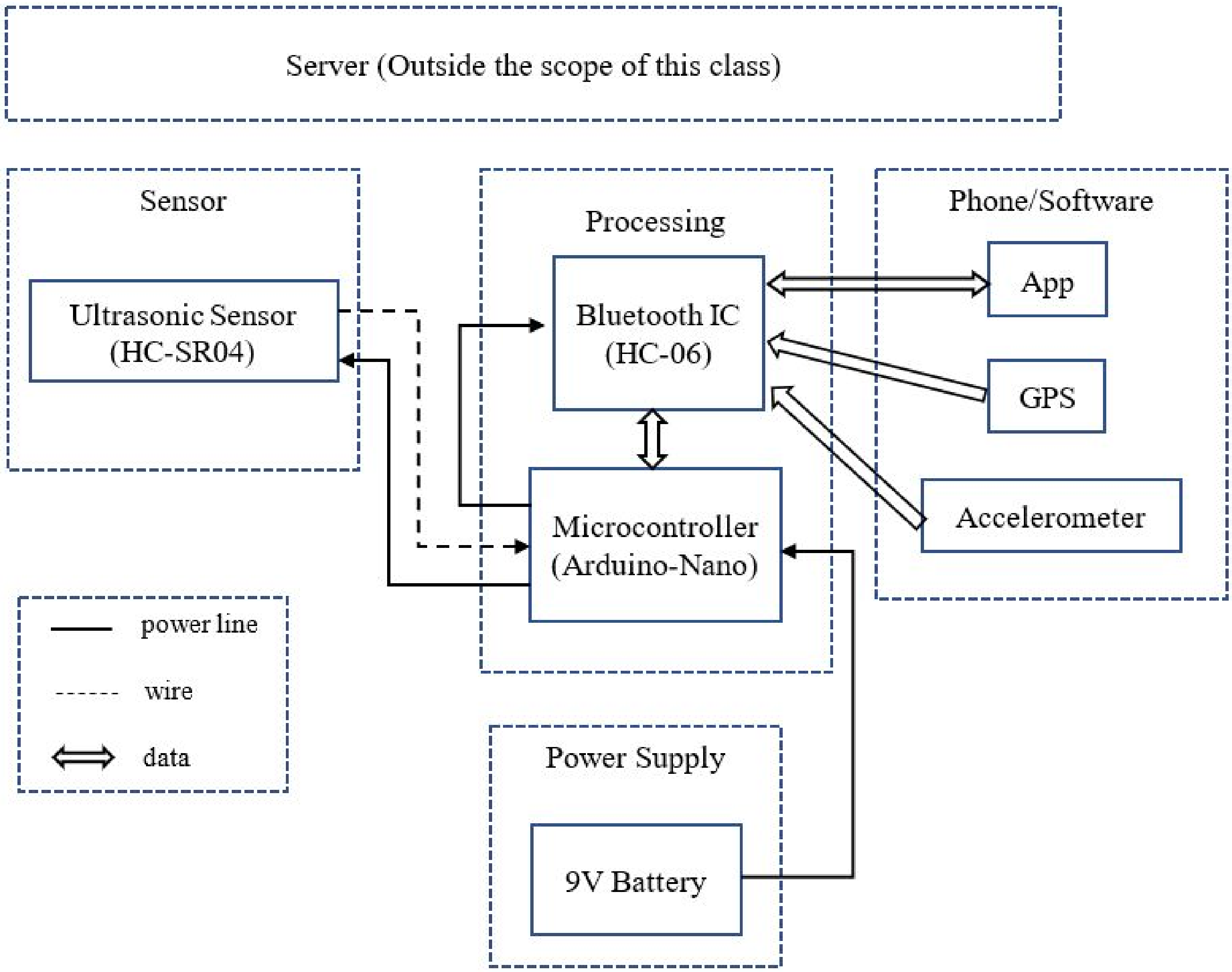


Figure 2.1

The RIM requires five main electrical components for operation as shown above in the Figure 2.1: 9V battery to supply power to a microcontroller (Arduino-nano) at all time, ultrasonic sensors to detect potholes and debris on roads at the speed within 20mph, microcontroller to power the ultrasonic sensors and Bluetooth IC at 5V, respectively and to process all data from the sensors and Bluetooth IC, Bluetooth IC as a bridge of data to process it between the microcontroller and phone, and phone/software to exchange data with Bluetooth, to detect any sudden bumps by using accelerometer and to mark the location of the potholes and debris for users.

The power supply system is on at all times to provide power to the microcontroller and the Bluetooth IC. However, the sensors will be turned on, when the app is turned on by the user. Therefore, the data from both the sensors and the phone will be delivered to the microcontroller, such as the time difference between when the trigger signal is sent out from the sensors and when the echo signal is received to the sensors. When the calculated distance between the sensors and the ground in the microcontroller is over a specified threshold, the signal via Bluetooth IC will be marked on the app at the location sent from the GPS. In addition to the data from the sensors, the accelerometer in the phone is used to detect any direct hit by the tires on the roads.

2.2 Physical Design:

For the purpose of demonstrating the functionality of The Rim on a remote controlled car pictured in Figure 2.3, we will arrange four ultrasonic sensor units vertically adjacent to each other as shown in Figure 2.2. The sensors will be mounted directly underneath the center of the toy car's body. When implemented on real cars, The Rim's sensors will be arranged horizontally as shown in figure 3.5.1 for reasons discussed in section 3.5, risk analysis.

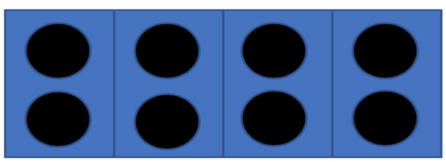


Figure 2.2

Figure 2.3

2.3 Power

A 9V battery directly supplies power to the microcontroller, which in turn supplies power to the bluetooth ic and ultrasonic sensors.

2.3.1 9V Battery

- A 9v battery with a polarized snap connector at the top connects to the microcontroller (Arduino Nano) through a battery clip with bare leads.

- *Requirements:*
    - V_{in} *pin on the microcontroller, chosen to be an Arduino Nano, must sink 7-12 V from the 9V battery source.*

2.3.2 Microcontroller

- The 3.3V and 5V output pin on the Arduino Nano supplies power to the bluetooth ic and ultrasonic sensors respectively.

- *Requirements:*
    - V_{cc} *on the bluetooth ic (HC-06) must sink 3.3V +/- 5%.*
    - V_{cc} *on the ultrasonic Sensors (HC-SR04) must sink 5V +/- 5%*

2.4 Sensors

Ultrasonic sensors measure the distance between the vehicle they are mounted underneath and the surface below it. These measurements are sent to the microcontroller from which the sensors also draw operating power.

2.4.1 Ultrasonic Sensors

- Ultrasonic sensors, chosen to be HC-SR04, send out trigger signals taking on the form of ultrasound(40khz) and receive echo signals. The sensors input the time the trigger signals are sent and the time the echo signal is received to the microprocessor.

- Requirement:
    - *The distance between the ground and the underside of the vehicle the sensors are mounted underneath must be between 2cm-400cm.*

2.5 Processing Unit

The processing unit performs the required calculations, using the distance sensor data, to determine whether or not an interference is detected. This unit consists of an Arduino Nano to make the calculations and a Bluetooth IC chip to transmit the data.

2.5.1 Microcontroller

- The microcontroller, an Arduino Nano, will handle the reception of the ultrasonic sensor signals, as well as the calculation to determine whether there is an obstacle at the current position. The Arduino will send and receive the required signals to and from the ultrasonic sensors to measure the current distance to the road. The Arduino will also send power to each of the sensors. This will allow the Arduino to depower the sensors when the smartphone app is not in use. After the Arduino detects an obstacle in the road, it will send a signal to the smartphone app signifying a road interference at the current position. The Arduino will send this signal through an offboard bluetooth IC chip. The Arduino will also receive signals from the smartphone app through the offboard bluetooth IC chip to put the Arduino to sleep or wake it up. Upon being put to sleep, the Arduino will cut off power to the ultrasonic sensors and enter a low power state. In this state, the Arduino will wait for another signal from the smartphone app to wake up.

- Requirements:
    - *The Arduino must detect at least 90% of road interferences using the collected distance sensor data.*
    - *The Arduino must power each ultrasonic sensor at 5V +/- 5% when the smartphone app is running and not supply power to each ultrasonic sensor when the app is not running*

2.5.2 Bluetooth IC

- The HC-06 Bluetooth chip will allow the Arduino Nano and the smartphone app to communicate. The Bluetooth chip will send a signal to the smartphone app from the Arduino upon the detection of a roadside obstacle. The Bluetooth chip will also receive a signal from the smartphone app and transmit it to the Arduino to wake up or put the Arduino to sleep depending on if the smartphone app is open.

- Requirements:
    - *The bluetooth chip will receive all signals from the Arduino Nano and send them to the smartphone app within 2 seconds +/- 5%.*
    - *The bluetooth chip will receive all signals from the smartphone app and send them to the Arduino Nano within 2 seconds +/- 5%.*

2.6 Smartphone

The smartphone will receive data from the microcontroller and bluetooth chip to mark the location of each obstacle using the smartphone's GPS capabilities. The app will also use the smartphone accelerometer to detect sudden bumps to detect interferences that hit a tire.

2.6.1 Smartphone App

- The smartphone app will act as an interface for which the user can see all the potholes and debris detected by the system. The smartphone app will send and receive data to and from the Bluetooth IC chip and microcontroller. The smartphone app will send a signal to wake up and put the microcontroller to sleep depending on whether or not the app is open. When the app is not open, the microcontroller will enter a low power mode to conserve battery life. The app will also receive a signal from the microcontroller when an obstacle is detected. Upon receiving this signal, the smartphone app will mark the location of the obstacle, using GPS capabilities of the smartphone and the current location, on an on-screen graphical user interface.

- The smartphone app will also utilize the accelerometer to detect any potholes or debris that may pass the array of sensors. Whenever a tire makes contact with a pothole, there should be a bump or sudden change in speed. The smartphone app will constantly monitor the speed and acceleration of the car using the accelerometer. Upon the detection of a sudden change in speed, the smartphone app will mark the location of the obstacle on the user interface. This will be done in the same way obstacles detected from the sensor array are marked.

- Requirements:
    - *The smartphone app will process signals and mark the locations of interferences within 5 seconds +/- 5% of receiving the signal.*

    - *The smartphone app will mark the current location on a user interface upon the reception of the "obstacle detected" signal from the Microcontroller. The marked location will be within 5cm +/- 5% of the actual interference.*

    - *The smartphone app will monitor the accelerometer data and mark the current location on a user interface upon a rapid change in speed or Acceleration with at least a 90% accuracy.*

2.6.2 Smartphone GPS

- The smartphone app will make use of the GPS chip to mark the location of each roadside interference detected. As this chip is integrated into the smartphone, we will not be directly working with it much.
- Requirements:
  - The GPS coordinates will be within 5cm +/- 5% of the true location.

2.6.3 Smartphone Accelerometer

- The smartphone app will use the accelerometer to detect sudden bumps and changes in speed. This will allow the smartphone app to detect road interference that are directly hit by the tires of the vehicle while passing around the array of ultrasonic sensors. As this component is also integrated into the smartphone, we will not be directly working with it much.
- Requirements:
  - The accelerometer will detect true interferences with at least a 90% accuracy.

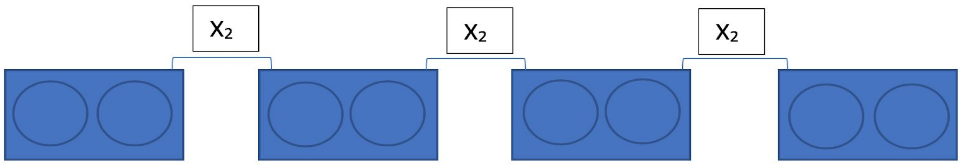
2.7 Risk Analysis:

The operation of The RIM depends on the accuracy of its ultrasonic sensors which are affected by the sensors' spread and sampling frequency. For the purpose of classroom demonstration, these risks are nullified due to the limited speed and low elevation of the toy car we will demonstrate with.

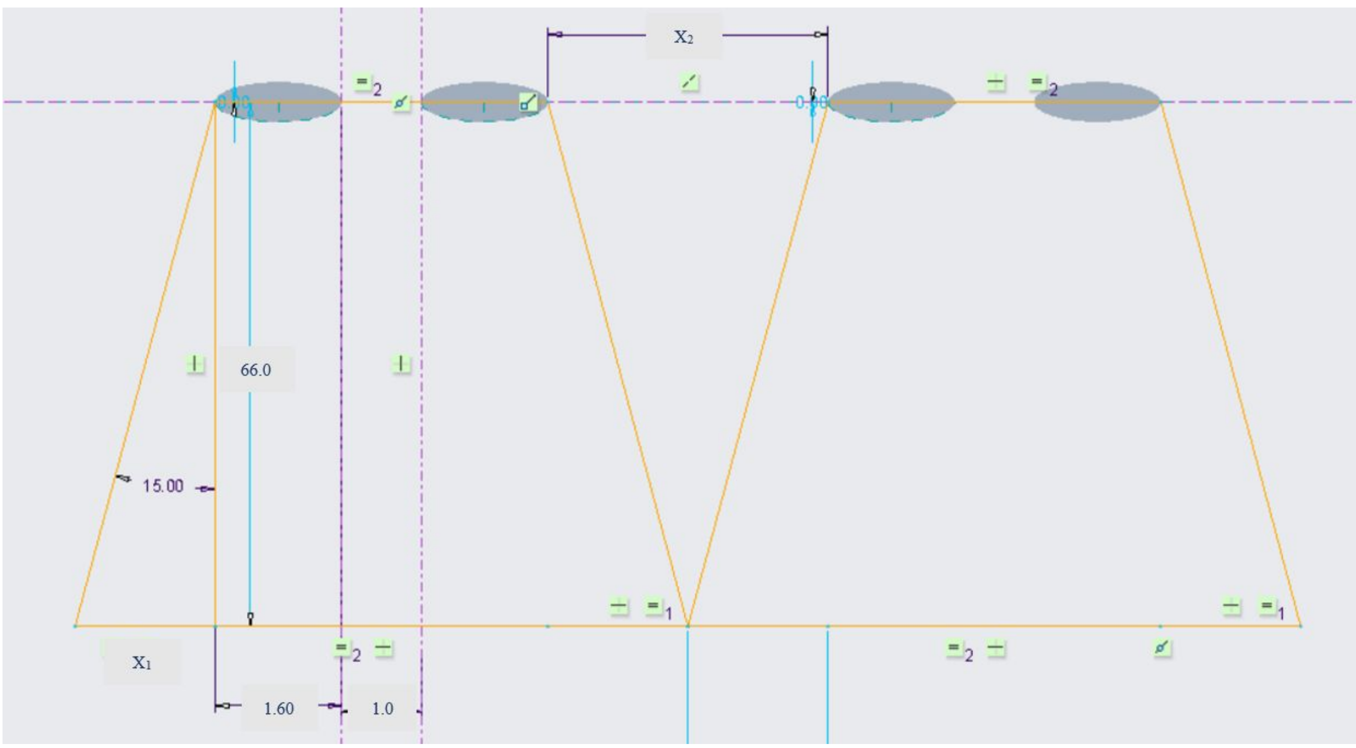
2.7.1 Sensor Spread:

- The Arduino Nano only has 8 analog input pins which implies we can only use up to 4 ultrasonic sensor units. The HC-SR04 ultrasonic sensor unit has two ultrasonic sensors each with a 15 degrees spread; depending on the distance between the ground and the bottom of the vehicle the sensors are mounted on, each ultrasonic sensor unit will only get ground-distance reading on a finite area of the ground. If the superposition of these 4 areas do not cover the entire width of the vehicle between its wheels, interferences the vehicle drives over might go undetected if they are underneath a "blind spot".

- The tolerance for the sensor's spread will vary depending on the model of the vehicle it is mounted on. Assuming an average road to sensor height of 66cm, a single HC-SR04 unit can cover a horizontal spread of about 39cm (see equation 3.5.2). Four of these units placed horizontally in series will cover a maximum horizontal spread of 1.5m assuming the sensor configuration shown in figure 3.5.1 Again assuming an average road to sensor height of 66cm, if the width of a vehicle is less than 158cm, the sensor's limited spread will not inhibit the functionality of The Rim. The total sensor spread, according to equation 3.5.4, is about 158cm.



Ultrasonic sensor configuration top view (Left 2 Sensors)
Figure 3.5.1



Ultrasonic sensor configuration side view (Left 2 sensors)
Figure 3.5.2

$$x_1 = sin(15) * \frac{66cm}{cos(15)} = 17.7cm$$ Equation 3.5.1

$$SensorUnit_{Spread} = (2 \cdot x_1) + (2 \cdot 1.6cm) + 1cm = 39.6cm$$ Equation 3.5.2

$$x_2 = 2 \cdot x_1 = 35.4cm$$ Equation 3.5.3

$$TotalSpread = 4 \cdot SensorUnit_{spread} = 4 \cdot 39.6cm = 158.4cm$$ Equation 3.5.4

2.7.2 Sensor Sampling Frequency:

- The HC-SR04 has a maximum sampling frequency of 40Hz.
- If we aim to obtain a ground-distance reading every 0.25m, an ultrasonic sensor sampling at 40hz will only be able to detect interferences under a car moving up to 10 m/s which is about 22mph. The proof is worked out in equation 3.5.4. If a car is moving less than 22mph, as is with the case of rush hour driving, the ultrasonic sensor's limited sampling frequency will not inhibit the functionality of The Rim.

$$\frac{40readings}{1second} \cdot \frac{0.25m}{1reading} = (\frac{10m}{s}) \cdot (\frac{2.237mph}{\frac{1m}{s}}) = 22mph$$

Equation 3.5.4

3. Ethics and Safety

There are a few potential safety issues with our project. The sensor mount could fall off of the vehicle and potentially damage the vehicle or other vehicles if it becomes completely unattached. Extensive stress testing and a strong adhesive or mountain apparatus will remedy this potential hazard.

Another potential hazard is that weather conditions such as rain could potentially damage circuits and sensors and cause shorts. This could lead to high temperatures, melting, and even fires in the circuits. To prevent this hazard, all of the electrical components will be enclosed in a robust weatherproof casing.

As with all batteries, the 9V battery used to power the system could overheat or melt due to an electrical short. Every component of the circuit will be extensively tested to ensure there are no potential shorts in the circuitry of the system.

As our system is a decentralized network, there will always be the possibility of persons attempting to maliciously falsify data. For example, one could place debris, detect it with our system, then remove the debris. This could be done numerous times to trick a user into avoiding that road, or even trick a user into driving erratically to avoid all of the false obstacles. This would go against #9 of the IEE code of ethics, "to avoid injuring others, their property, reputation, or employment by false or malicious action" [3]. We do not currently have a solution to this problem as we feel that limiting the system would significantly affect the performance. Also, the effect of malicious users should not be that great as our system is meant to increase the awareness of users rather than warn exactly where an obstacle may be. The purpose and effectiveness of our app will be stated upon opening the app in compliance with #3 of the IEEE code of ethics, "to be honest and realistic in stating claims or estimates based on available data;"[3].

Finally, our app could be a potential distraction for the driver and may cause accidents. To mitigate this, our app will remind the users to pay attention to their surroundings while using the app. This will dissuade users from putting too much focus on the app when driving.

Our solutions to potential safety and ethics concerns follow #1 of the IEEE code of ethics, “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment;” [3]. There are many potential risks in a product that is to be used while operating an automobile, but we feel that our mitigations allow the benefits to outweigh the potential problems with such a system.

4. References

[1]"Arduino Nano", *Store.arduino.cc*, 2019. [Online]. Available:https://store.arduino.cc/usa/arduino-nano. [Accessed: 19- Sep- 2019].

[2]*Cdn.sparkfun.com*, 2019. [Online]. Available: https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf. [Accessed: 19- Sep- 2019].

[3] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available:http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 29- Feb- 2016].

[4]*Olimex.com*, 2019. [Online]. Available: https://www.olimex.com/Products/Components/RF/BLUETOOTH-SERIAL-HC-06/resources/hc06.pdf. [Accessed: 19- Sep- 2019].