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1 Introduction

1.1 Objective

The electric model train has captivated audiences for over a century, from its early days in toy store displays at the turn of the 20th century - capturing the imaginations of children for whom electricity in homes was still rare - to its growth as a popular hobby between the 1930s and 1950s [1]. Yet, there is still room for innovation in the modern era to improve the electric model train for future generations of children and even hobbyists. A major issue still confronting model trains is that of derailment. For instance, when the train’s speed is too great over a certain segment of the track, typically a corner, the train will often derail. Another instance of chaos arises from the accidental placement of another toy or an object in the path of the train, leading to collision, derailment, and possible damage to the train. We seek to reconcile this problem to better protect expensive model trains from accidental damage as well as serve as an educational toy for children to learn of simple sensor technology.

In order to combat derailment, we will employ two techniques - speed limit signs and obstacle detection. To stop a model train from moving too fast over a segment of track, a speed limit sign may be placed near the track to slow the train. Using an IR sensor on each sign and an IR LED on the train, the sensors will identify when the train passes the corresponding speed sign and communicate to a speed control unit that will adjust the voltage on the tracks to reach the proper speed. To achieve obstacle detection, two laser ToF sensors will be placed on the front of the train to locate oncoming objects as well as its distance from the train and communicate to the speed control unit if the train needs to be stopped. An additional third element of innovation on the electric model train will be path-mapping. Three RF receivers will be placed along the track in a triangular formation. They will all receive the same RF signal transmitted by the moving train and determine its distance from the train by analyzing the power of the signal. Using these distance measurements and the trilateration technique, the location of the train can be estimated, and the path it follows can be mapped out.

1.2 Background

According to the National Model Railroad Association (NMRA), the average age of its 19,000 members is currently 64, compared to an average age of 39 from four decades ago [2]. Over the past several decades, model train manufacturers have failed to capture the attention of the younger generation. In recent years, major manufacturers have begun to release newer products aimed towards selling to a younger market. Lionel released its new Mega Tracks set in 2016,
designed to appeal to kids with its more colorful and customizable tracks as well as spaceship theme [3]. This attempt by Lionel essentially alienates its existing customer base and divides its product base between child and adult demographics, in contrast to the traditional model train market from the mid-20th century.

If we can modify the existing model trains in order to appeal to a younger demographic, we may be able to create a product that would be desirable to both children and the existing hobbyist demographic. We look to add our sensors as an additional safety mechanism as well as to appeal to a younger audience. We also aim to achieve path-mapping and real-time location displaying of the train to create a more exciting interface for children. In the future, we would also look to provide more customizability to the tracks to allow for new track layouts for children to explore and map as well as a general broadening of a digital interface to the train to appeal to this tech-driven generation.

1.3 High-Level Requirements

- Train must detect obstacles on the track and halt motion 98% of the time.
- Train must detect speed limit signs and adjust speed accordingly 98% of the time.
- Train must map the track and estimate the position of the train with an accuracy of a 7.5 cm CEP radius.

2 Design

2.1 Block Diagram

The train system requires five main components to successfully accomplish all the high-level requirements: a power unit, a speed control unit, a speed detection unit, an obstacle detection unit and a track mapping unit as shown in Figure 1.

The power unit ensures that the entire train ecosystem is powered to perform the obstacle/speed detection and speed control, as well as providing the power to the tracks for train’s engine.

The speed control unit uses a full-bridge driver for the motor to allow a PWM input to vary the speed of the train as well as reverse the direction of the train. It receives data from both the obstacle detection and speed detection units. When the obstacle detection unit indicates an obstacle, the speed control unit will stop the train by turning off the output of the bridge to the motor. When the speed detection unit encounters a speed limit sign corresponding to a preset
speed, the speed control unit will adjust to that speed by altering the duty cycle of the PWM signal.

The speed detection unit uses an IR LED mounted on the train along with IR sensors on each speed limit sign. If a sign’s IR sensor sees the LED on the train, the speed detection unit sends the speed associated with the sign to the speed control unit and has the speed of the train adjusted accordingly.

The obstacle detection unit uses two laser time-of-flight (ToF) sensors on the train that can, respectively, see obstacles up to 20 cm ahead on the track and see obstacles 20-56 cm ahead on the track. When both ToF sensors see an object 20 cm ahead, the obstacle detection unit will send its detection to the speed control unit to stop the train before collision.

The track mapping unit uses an RF and ultrasonic transmitter located on the train as well as a single RF receiver and three ultrasonic receivers located around the track. In each time interval, the train will send out an RF and ultrasonic pulse. The RF receiver receives the RF pulse almost instantaneously (on the order of nanoseconds at the scale of the track) and begins timing. The ultrasonic pulse will travel to each of the beacons at the speed of sound. When the pulse is received at each beacon, the elapsed time is recorded for that beacon. Using the time and speed of sound, the distance of the train to the beacon is calculated. This data can be passed out to an external computer via USB connection, which can then map out the entire track, estimate the current position of the train, and display the map on the computer monitor. To map out the track, a trilateration algorithm is used.
In the figure above, we will be using the USB connection for prototyping with the microcontrollers. When we transfer the microcontrollers over to our finished PCBs we will be using a 9V battery with a voltage regulator as displayed for the case of the obstacle detection mini microcontroller.

2.2 Physical Design

The physical diagram of the train system includes the train engine (excluding attachable cars) and tracks, along with the five units listed in the block diagram as shown in Figure 2.

The train will carry the mini microcontroller, attached to the Bluetooth transmitter and two laser ToF sensors for obstacle detection and an IR LED for the speed detection unit. The two laser ToF sensors will be placed in front of the train at different angles to get the full view of what is beyond on the
The IR LED will be placed on the outer facing side of the train so that it can be detected by the IR sensors on the speed limit signs.

The speed limit signs will also be placed along the outside perimeter of the tracks. These will connect to the speed control microcontroller to communicate what speed limit the train has seen.

Three beacons with ultrasonic receivers will be placed in a triangular formation (for trilateration) around the tracks, along with one RF receiver. These will receive the signals from the RF and ultrasonic transmitter placed on the train. The three beacons are all connected to the track mapping microcontroller that will calculate and display the mapping of the track.

The speed control microcontroller next to the track has a Bluetooth receiver to get stopping signals from the train when an obstacle is detected as well as connections to the speed limit signs. The microcontroller then sends the speed selection, by varying the duty cycle, to the motor bridge driver which is connected to the track’s power terminals.
2.3 Power Unit

The power supply is essential for controlling the train’s speed, detecting obstacles, and mapping out the track. A 9V alkaline battery with a voltage regulator will be used to power the mini microcontroller, RF transmitter, and ultrasonic transmitter on the train. A connection to a laptop via USB will power the track mapping unit and speed control unit microcontrollers. A 16V wall supply will supply power to the motor bridge driver of the speed control unit which is ultimately used to power the tracks. The Bluetooth transmitter and receiver, the IR sensors, the laser ToF sensors, the RF receiver, the ultrasonic receivers, and the IC used in the motor bridge driver will all be supplied with power by the microcontroller with which they connect to.

2.3.1 9V Alkaline Battery + Voltage Regulator

One 9V battery will supply power to the mini microcontroller, in the obstacle detection unit, and the RF and ultrasonic transmitter, in the track mapping unit, all of which will be placed on the train. The mini microcontroller we plan on using, the Arduino Pro Mini, has a built-in voltage regulator of 5V. The alkaline battery must provide 0.2-0.6mA at 1.8-5.5VDC for the mini microcontroller. The RF transmitter requires approximately 9V at 8 mA to operate. The capacity of this battery is 500mAh.

2.3.2 USB Power

Most microcontrollers can be powered with the provided USB cable that comes with its packaging. This is the manufacturer’s recommended power supply method, because it provides the most consistent voltage power. Any fluctuations in power to the microcontroller would hinder its high performance. The USB power will either provide power via a computer connection or an adapter.

2.3.3 Wall Supply

The provided wall supply unit with the train comes with a 16 V DC output rated for up to 1000 mA. This unit will supply the motor bridge driver in the speed controller unit which will then power the tracks of the train. The resistance of the tracks and the track-train wheel connection has been measured to be around 60Ω. Thus, we need the wall supply to be able to supply around 0.267 A at 16 V during train operation.

2.4 Speed Control Unit

The speed control unit is responsible for adjusting the speed of the train by varying the duty cycle of a PWM signal powering the train tracks. This unit consists of a microcontroller that
communicates with a Bluetooth receiver and IR sensors to determine what speed the train should be operating. In addition, the motor bridge driver is used to supply the tracks with power. Once the required speed for the train is determined from the data the microcontroller receives, it selects the correct duty cycle of a PWM signal that controls the transistors of the bridge. A 16 V wall supply supplies the bridge and a PWM signal from the microcontroller controls the bridge such that a 16 V PWM signal controls the motor. By varying the duty cycle, we vary the speed of the train.

2.4.1 Microcontroller

The microcontroller communicates with the IR sensors of the speed detection unit (placed along the track) and the Bluetooth receiver.

The IR sensors are placed on speed limit signs around the track. When the train passes by the sign, the IR sensor detects the IR LED on the train to determine that the train has passed it. The sign then relays this information to the microcontroller and based on which pin it is communicating on, the microcontroller determines which speed limit sign the train has just passed and thus what speed it needs to adjust to. The microcontroller calculates the duty cycle for that speed and begins outputting a PWM signal to an enable signal in the motor bridge driver circuit. Input pins to the motor bridge driver circuit allow the microcontroller to select which direction the train should move.

The Bluetooth receiver communicates with the Bluetooth transmitter of the obstacle detection unit to determine if an obstacle has been detected. When the transmitter relays that an obstacle has been detected, the Bluetooth will communicate this over serial UART to the microcontroller which changes the input pins of the motor bridge driver circuit to disable the bridge and thus stop the train. We need the delay in Bluetooth communication and UART to be low enough that we can detect obstacles in time. Constraints on the delay are discussed later in this document.

The combination of the input and enable pins to the motor bridge driver determines whether the train brakes or if it moves and the speed/direction with which it moves.

2.4.2 Bluetooth Receiver

This Bluetooth module receives the 'halt' signal from the train when the obstacle detection unit detects an obstacle on the tracks. It then relays this message to the speed control microcontroller via serial UART so that it can stop the train.
During our tolerance analysis later in this document, we calculated the delay from various serial communications during the braking process as 17 ms (excluding a 6 ms delay from the Bluetooth). With an additional 33 ms from measuring and an overall timing budget of 100 ms as discussed in the tolerance analysis, our Bluetooth module must have a latency of less than 50 ms. Typical Bluetooth modules have a latency of 100 ms, while Bluetooth low energy (BLE) modules have a latency of 6 ms [4]. For this reason, we selected the HM-10 BLE module for receiver and transmitter.

2.4.3 Motor Bridge Driver Circuit

The motor bridge driver circuit consists of the L298 IC and the motor of the train, as well as some diodes and capacitors to ensure proper functioning of the full-bridge of the L298. See Figure 10 for the schematic.

The L298 is a dual full-bridge driver. It contains a power supply pin rated for up to 50 V. It also has two inputs pins and an enable pin for controlling the motor. When the enable pin is high, the motor can receive current. Setting one of the inputs high and the other low determines if the motor operates in the forward direction or the reverse direction. When both input pins are set high or low, a fast motor stop occurs - braking the motor. When the enable pin is set low, a free running motor stop occurs.

In our design, we will use one of the full-bridges of the L298. We will place a 16 V supply on the power supply pin (V\text{cc}) to drive the motor. We control the enable pin with a PWM output pin from a microcontroller to control the speed of the motor. We control the input pins from a microcontroller to set the direction of the train’s motion. We also use both input pins set to low in order to brake the train when we need to halt motion.

2.4.4 Train Tracks

The train tracks allow the train to run. Voltage will be supplied to one rail and ground will be connected to the other (there are two terminals on the side of the starter track to clip power and ground). This will allow current to flow through the motors on the train via the metal wheels. The train is purchased from a common model train manufacturer that has performed verifications for powering the model train.

2.5 Speed Detection Unit

The speed detection unit consists of three IR sensors, each placed on a speed limit sign, and an IR LED, which is placed on the train. Each sensor is placed on a speed limit sign along the perimeter of the track. When a sensor detects IR light from the LED, the microcontroller in the
speed control unit will determine which IR sensor is detecting the LED and change speed of the train by changing the duty cycle of the PWM enable signal controlling the motor bridge driver that powers the tracks. Figure 11 shows the schematic of the unit.

2.5.1 IR LED

The IR LED is used as part of the speed limit sign detection system. The light will shine continuously from its place on the outer facing side of the train, and an IR sensor along the track will only detect it when the train passes it. The sensors will in turn send a signal to the speed control unit microcontroller to change the speed. The LED will be powered with the 5V output of the mini microcontroller of the obstacle detection unit, pulled down with resistors to provide 3V.

2.5.2 IR Sensor

The IR sensor is used to detect the IR LED on the train as it passes by. Each sensor will be placed on a speed limit sign. When a sensor detects the LED, it will send a signal along a wire to the speed control unit microcontroller. The microcontroller will have an input pin for each of the three speed limit signs so it can easily determine which speed the train must adjust to.

2.6 Obstacle Detection Unit

This unit contains two laser ToF (VL53L0X) sensors to detect obstacles ahead on the track, a mini microcontroller to process the output of the ToF sensors, and a Bluetooth transmitter to relay the stop signal back to the speed control unit. See Figure 12 for the schematic.

Based on our speed and stopping distance measurements, at maximum speed the train will take about 14 cm to stop. As such we must design the detection system to be able to detect an object at least 14 cm ahead on the track. We choose to design it so that the unit can detect an object more than 14 cm ahead on the track so that any latency in communication and range measurement is accounted for as well. In our chosen design, the obstacle detection unit is able to detect an object up to 20 cm away.

2.6.1 Mini Microcontroller

This microcontroller will be located on top of the train. It will take the data from the laser ToF sensors and, if an obstacle is detected, it will transmit a 'halt' signal to the Bluetooth module which will notify the speed control unit microcontroller to halt motion.

Refer to Figure 8 on how the mini microcontroller will collect data from the laser ToF sensors, make sense of the data, and transmit a 'halt' signal via the Bluetooth transmitter if an object is
detected. It first waits to receive a start signal from the Bluetooth module that is connected by serial ports. After it is able to communicate and send data to the Bluetooth module, the microcontroller acts as the master in the I2C connect and sends the start signal to the two laser ToF sensors, which are the slaves in the connection. The master will continue to generate clock pulses at a regular interval and send that data to the SDA pin. The slaves will continue to send data to the SCL pin until all the data frames have been sent. Once all the data frames have been received by the master, the master will send a stop signal to the slaves and send the meaningful data of objects being detected by the two ToF lasers to the Bluetooth module via the serial port. Once all the data has been sent via the serial port, the microcontroller sends a stop signal to the serial port.

2.6.2 Laser ToF Sensor

We two laser time-of-flight (VL53L0X) sensors, each with a field of view (FOV) of 25 degrees, will be used on the front of the train. The range measurement time of these sensors is typically 33 ms. One will be installed at the center pointing directly ahead so that the center of its beam is always tangent to the circular train track. The other will be placed at an angle of 25 degrees away from the center of the first sensor - pointing towards the center of the track. See Figure 3 for a visual of the two lasers and their FOVs with respect to the train track, created in Geogebra. The two chord lengths displayed demonstrate the maximum distance away an object can be detected on the tracks for each sensor. Thus with these sensors, we will be able to see objects from about 20 cm to 56 cm ahead on the track as displayed.

![Figure 3: Two laser ToF sensor FOV on track](image)

When both sensors detect an object 20 cm away, we will be able to determine that an object is on the track, eliminating the issue of objects near the track accidentally triggering the brake.
mechanism. If both sensors see an object 20 cm away, the obstacle detection unit microcontroller will determine that there is an obstacle on the track and will begin communication with the speed control unit to stop the train.

If we need to increase accuracy, we will add additional programming to the microcontroller such that for an object to trigger obstacle detection it will need to have been seen by the off-center sensor for at least 15 measurements. This is calculated as follows: the off-center sensor (FOV displayed in blue in Figure 3) will be able to see from about 20 cm away to about 56 cm away. That is a range of 36 cm. At our maximum speed, 60 cm/s, this will take 0.6 seconds to traverse. At a typical range measurement time of 33 ms, approximately 18 range measurements will have been taken in this span. We lower this number to 15 in case there are any errors in the previous calculation or during measurement so that we do not set too strict a requirement and thus never detect obstacles. Now, the off-center sensor will have to have taken at least 15 measurements that were in the 20 to 56 cm range before the center sensor detects an object 20 cm away. If the center sensor detects a 20 cm distance and the off-center sensor has taken 15 consecutive measurements of objects in the 20 to 56 cm range and also sees an object approximately 20 cm away, we will define that as obstacle detection.

2.6.3 Bluetooth Transmitter

This component will transmit the 'halt' signal to the Bluetooth receiver in the speed control unit whenever the mini microcontroller receives data of an obstacle being detected on the track. As discussed with the Bluetooth receiver section, the latency of this process must be less than 50 ms and will be verified the same as before.

2.7 Track Mapping Unit

The track mapping unit consists of one RF transmitter on the train along with one ultrasonic transmitter designed with a conical aluminum acoustic reflector on top such that it can cover 360 degrees and up to 1 m in range (see Figure 13 for the schematic). In addition, there are three ultrasonic receivers arranged outside the track to act as the centers of circles for trilateration calculations along with one RF receiver. The train will transmit a RF and ultrasonic pulse simultaneously. The RF signal will be received almost instantaneously and will signal the microcontroller to begin measuring the time it takes for the ultrasonic signal to reach each ultrasonic receiver, from which the estimated distance (radius of the circle) can be calculated and used to perform trilateration to position the train. Only one RF receiver was chosen to simplify design as the timing difference to receive the RF signal at each ultrasonic receiver will be negligible at the scale of our project.
As shown in Figure 4, the estimated position of the train would be at point B, the single intersection of all three circles.

Figure 4: Trilateration [5]

The coordinates of point B is calculated with the following formulas for the three circles, with P1 starting at (0, 0):

\[ r_1^2 = x^2 + y^2 \]  
\[ r_2^2 = (x - d)^2 + y^2 \]  
\[ r_3^2 = (x - i)^2 + (y - j)^2 \]

Solving the three equations above we obtained the following x- and y-coordinates of the intersection of the three circles

\[ x = \frac{r_1^2 - r_2^2 + d^2}{2d} \]  
\[ y = \frac{r_1^2 - r_1^2 + r_3^2}{2j} - jx \]

We defined the requirement on the accuracy of our trilateration system to be a 7.5 cm CEP radius. An example of CEP is shown in Figure 5 below:
A CEP ring of radius 7.5 cm is defined as follows. Assuming some collection of position measurements, then for a plot of the offset of each measurement from the mean value, 50% of the points would fall within the 7.5 cm ring.

We calculated a suitable radius of 7.5 cm as follows. The RF pulse travels at the speed of light over a maximum distance of 1 m, taking about 3.33 ns. The RF receiver communicates at a data rate of 4800 bps, taking about 0.21 ms to communicate a bit indicating reception. The ultrasonic receivers simply set a microcontroller pin to high, taking a maximum of 62.5 ns for a 16 MHz microcontroller to notice. Over this period of time, the ultrasonic pulses will be traveling at the speed of sound which adds an error of about 7.1 cm. The maximum time the ultrasonic pulse will take to reach the train is about 2.9 ms at a 1 m separation. The train will be moving at maximum of 60 cm/s which will add an error of only about .18 cm. Thus, the total error could be on the order of 7.28 cm but we will adjust this to 7.5 cm to define our CEP ring.
2.7.1 Microcontroller

This microcontroller will be placed on the side of the tracks. It will receive an RF pulse from the RF transmitter on the train to signal the start of timing. As each of the three ultrasonic receivers detect the paired ultrasonic pulse, they will communicate the reception to the microcontroller which will record the time for each ultrasonic receiver. The microcontroller will then use that timing data to calculate the distance of each receiver from the train and thus position of the train via the trilateration method. A USB connection to a laptop will power this microcontroller and will also allow the microcontroller to send information to display the map of the track and the train’s position on the laptop’s monitor.

Refer to Figure 9 on how the RF and ultrasonic receivers will collect data. First the microcontroller will connect to the RF and ultrasonic receiver through its serial pins by sending and receiving the start signal. When data is received from any of the serial ports, the microcontroller will identify which port it is from. The signal from the RF receiver must arrive before that any ultrasonic receiver; otherwise, that data is neglected. The time the data from the RF receiver is received by the microcontroller is stored as the ‘start time.’ The time the data from each ultrasonic receiver is received by the microcontroller is stored as individual ‘end time’ variables. Once the microcontroller receives a stop signal from a serial port, it sends a stop signal back and the difference between the ‘start time’ and each ‘end time’ is sent to the computer to calculate the distance and perform trilateration to position the train.

2.7.2 RF Transmitter

The RF transmitter, placed on top of the train, will act as a beacon by transmitting short pulses at 434 MHz. The RF receiver will detect this signal within nanoseconds and will send a signal to the microcontroller to begin to time the ultrasonic signal as the first step in trilateration. We will make a simple helical wire antenna to solder to the PCB at a point coupled to ground. We chose this antenna design to begin with due to its small size but can also experiment with air-core loaded coil or various monopole configurations. This frequency range is noisy and power may be lost through the trace between the chip and antenna, but our requirement should still be satisfied since we are only using the transmitter as a beacon. If needed, we will experiment with matching networks and length adjustment.

2.7.3 RF Receiver

One RF receiver will be placed on a beacon alongside one of the ultrasonic receivers. This will detect the pulses sent by the RF transmitter. Once the receiver detects a pulse, it will send a signal to the microcontroller to begin to measure the time it takes for the ultrasonic signal to reach each of the ultrasonic detectors. Only one RF receiver is necessary since the scale of the
track is small enough that any difference in receiver timing would be negligible. This receiver will be placed near the microcontroller so that the 5V output may be used as power through a breakout board. It will use the same antenna as described above for the transmitter.

2.7.4 Ultrasonic Transmitter and Amplifier Circuit

An ultrasonic rangefinder will be used solely as a transmitter on top of the train. To do this, a logical high signal will be applied to the trigger pin and the echo pin will be ignored. Since the beam of the rangefinder is only 15 degrees, we will build and place a cone-shaped acoustic reflector above the transmitter. As long as the diameter of the cone is the same size or larger than the diameter of the transmitter, the sound will be reflected out at least 1m to the ultrasonic receivers.

2.7.5 Ultrasonic Receiver

Three ultrasonic receivers will be arranged around the outside of the track. Once the microcontroller receives the RF “start” signal it will begin measuring the time it takes for each ultrasonic receiver to detect the signal. Knowing the speed of sound, it can then calculate the distance from beacon to train and perform trilateration calculations. We will also use ultrasonic rangefinders for these components and read from the echo pin while ignoring the trigger pin. The piezoelectric nature of the receiver will produce the output voltage.

2.8 Tolerance Analysis

Our measured maximum stopping distance is around 14 cm, so we wish to be able to detect objects at least this far away on the track. We also need to take care so that we only detect objects on the track and not off to the side.

To do so, we first consider the case where we place one laser ToF sensor (or any arbitrary distance sensor for that matter) at the front of the train in the center of the train. This sensor will have some field of view (FOV) which will determine a cone in which the sensor can see. In our 2D case, this will simply be some angle. Based on our positioning of the sensor at the front and center of the train, the center line of this FOV angle should be approximately tangent to the circle defined by the track. Thus, half of the FOV angle will be viewing the curved portion of the track in front of the train while the other half looks outward from the track. It is the former half-angle which we are concerned with in determining the distance an object can be detected away on the track.

An example of this can be seen in Figure 6 below, created with Geogebra, which has values for the specific case of our chosen laser ToF sensor. However, we will see that the following
argument works for any sensor with an arbitrary FOV angle and helps place a requirement on our chosen sensor. In the figure, line BD represents the tangent and the angle $\angle EBF$ represents the FOV (25° in our case) and is labeled as such. The angle $\angle CBF$ represents half the FOV as discussed above and is labeled $\theta$. The circle has a radius of 45.72 cm to represent our track.

![Figure 6: Laser ToF sensor FOV around corner](image)

We see that $\theta$ intersects the circle at point D, which is the farthest away we can detect an object on the track. The chord length DB is the distance measurement the laser would make if it were to see an object at that position. In our measurements, we essentially measured a chord length as representative of our stopping distance so we can do our calculations based upon these chord lengths.

To find the chord length we wish to find the size of a central angle $\alpha$ defined by the center of the circle and points B and D. From there, we can calculate the length of chord DB as

$$Chord\ Length = 2R \sin(\alpha/2)$$

where $\alpha$ is defined in degrees and $R$ in cm. When we draw out the lines AB and AD, we know that they are radii, so we see that we form an isosceles triangle where the chord DB is the base. As such, we know that the base angles will be congruent. One base angle is displayed in Figure 6 labeled $\beta$, defined by the angle $\angle DBA$ which forms between the radius and the chord. We note that $\theta$ and $\beta$ sum to the angle defined by $\angle CBA$ between the tangent line and the radius. But we
know this angle is simply $90^\circ$ since the radius will be perpendicular to the tangent line at the point the tangent line intersects. Thus, we can take the difference between $\theta$ and $\beta$ and find that the base angle of the isosceles triangle is

$$\beta = 90 - \theta \quad \text{Eq. 2}$$

where $\theta$ and $\beta$ are in degrees. Since the base angles are the same, we can now find the central angle as

$$\alpha = 180 - 2(90 - \theta) = 20 = \text{FOV} \quad \text{Eq. 3}$$

Thus, the central angle will always be equivalent to the FOV of the sensor since $\theta$ is half the FOV. Now using Eq. 1 and setting the chord length to 14 cm, we can determine the minimum FOV we need from a sensor:

$$\text{FOV} = 2 \sin^{-1}\left(\frac{\text{Chord Length}}{2R}\right) = 2 \sin^{-1}\left(\frac{14}{45.72}\right) = 17.66^\circ$$

Thus, we require a sensor with at least a $17.66^\circ$ FOV. In our design, we choose to use a sensor with a $25^\circ$ FOV.

Our next requirement of the sensor is that it has a fast range measurement time - the time it takes to make each distance measurement. First, since all range measurements will take some finite time, we need to increase our FOV so that we have time to make a measurement, see that the object is 14 cm away, and then stop (with a maximum stopping distance of 14 cm in this case). As a result, our requirement on measurement time and FOV can be a little flexible as we can play around with both (increasing FOV to compensate increasing measurement time). After analysis of the measurement time of several viable sensors, we may choose a maximum of 100 ms for the measurement time as a amount typical of some ultrasonic sensors. Using our approximate maximum speed, 60 cm/s, we can calculate how far the train will move while a measurement is being made, the product of speed and time, as 6 cm. Thus, we need to increase our FOV so that we can see up to 20 cm away on the track. We do this by choosing a FOV of $25^\circ$ as our minimum allowed FOV.

Now, we need to include some time for the sensor to detect the object and communicate this all the way back to the speed control unit. We will start with the fact that the communication will take some finite time. Thus, we must choose a sensor with a measurement time below 100 ms and incorporate a communication delay into the previous 100 ms requirement such that the maximum distance the train can move during this process (range measurement, communication,
and stopping) is still 20 cm. We choose a laser ToF sensor with a 33 ms range measurement
time, leaving 67 ms for the delay.

If we were to pick arbitrary range measurement times and communication latencies, then we
could calculate \( \varepsilon \), the maximum allowable communication latency, by the equation:

\[
(Speed \ of \ Train)(Range \ Measurement \ Time + \varepsilon) + Stopping \ Distance \leq Obstacle \ Detection \ Distance \quad \text{Eq. 4a}
\]

The first term on the left measures how far the train will travel before the brakes are applied and
the second term is how long it takes for the train to stop after this fact, which has been measured
to be a maximum of 14 cm. The obstacle detection distance is the maximum distance with which
we can identify an object on the tracks, which has been set to 20 cm by the previous 100 ms
latency assumption. But we could incorporate the Eq. 1 as the right side of this equation as well,
to see that we have 3 variables we can control. Rearranging to solve for \( \varepsilon \),

\[
\varepsilon = \frac{(Obstacle \ Detection \ Distance - Stopping \ Distance)}{Speed \ of \ Train} - Ranging \ Latency \quad \text{Eq. 4b}
\]

Plugging in our known values,

\[
\varepsilon = \frac{(20 - 14)}{60} - 0.033 = 0.067 \text{ s} = 67 \text{ ms}
\]

Again, our maximum allowable latency is 67 ms for our chosen design.

We can now calculate the expected maximal communication latency in our design. In the case of
the laser ToF sensors, each range measurement will be communicated over a 400 kHz I2C line as
a 200 bit value giving a transmission time of 0.5 ms. In the case of our Bluetooth to
microcontroller lines, these will communicate over a serial UART at a 9600 bps baud rate. Since
we only need to send a ‘halt’ or ‘start’ signal via Bluetooth, we will only require a byte of data to
be sent. Referring to Figure 7 for a BLE packet description, we see that by sending 1 byte of data
we will require 10 bytes minimum or 80 bits. At 9600 bps, this will take 8.3 ms.
Going through the entire process from obstacle detection to braking, we will identify the areas in which will contribute to this communication latency:

1. Communication of range data back to obstacle detection microcontroller via I2C line (< 0.5 ms)
2. Identification of obstacle by microcontroller (nanoseconds - 16 MHz clock)
3. Communication from microcontroller to Bluetooth transmitter to send out detection message (< 8.3 ms)
4. Reception of message at the Bluetooth receiver of the speed control unit (100 ms BT vs. 6 ms BLE)
5. Communication of the message from the Bluetooth receiver to the speed control microcontroller (< 8.3 ms)
6. Identification of obstacle detection message and changing inputs to motor bridge driver by microcontroller (nanoseconds - 16 MHz clock)
7. Communication of brake inputs to the motor bridge driver (nanoseconds - 16 MHz clock)
8. Turning off the bridge (nanoseconds - TTL)

We ignore the steps that should take on the order of nanoseconds. The remaining communication latency is around 23 ms, which is less than the maximum 67 ms latency.

According to these results, we need a sensor with a FOV of at least 25 degrees and range measurement time of below 77 ms assuming a 23 ms communication latency. However, we can tweak the design by varying these values such that they always satisfy Eq. 4a.

In our design, we have chosen sensors that give a 25 degree FOV and range measurement time of 33 ms with a communication setup that should give up to 23 ms delay. As discussed, with this
setup only 100 ms are allowed for the measurement and communication of an object in order to stop in time. Thus, we are 44 ms below budget. This allows for a 79% tolerance on our overall range measurement and communication time delay.

2.9 Software Flowcharts

![Flowchart of Obstacle Detection Microcontroller](image)

Figure 8: Flowchart of Obstacle Detection Microcontroller
Figure 9: Flowchart of Track Mapping Microcontroller
2.10 Schematics and Simulations

Figure 10: Motor Bridge Driver Unit

Figure 11: Three IR sensors surround an IR LED (Speed Detection Unit Schematic)
Figure 12: Obstacle Detection Unit Schematic

Figure 13: Track Mapping Unit Schematic
### 2.11 Requirement and Verification Table

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
<th>Points (50 total)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Unit</strong></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Voltage Regulator</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 1. The output of the voltage regulator must provide 0.4mA +/- 0.2mA at 5V to the mini microcontroller for 830 hours. | 1. Connect a 12.5kΩ resistor from Vdd to ground.  
2. Break the circuit to measure the current with a multimeter. Ensure that the pin current never deviates from the desired range to verify that the battery is delivering the correct current | |
| 2. The output of the voltage regulator must provide 8mA +/- 0.5mA at 9V to the RF transmitter for 62 hours. | 2. Use a multimeter to measure the current through the RF transmitter by breaking the circuit between the transmitter and the voltage regulator after every 30 minutes of operation for a total of 2 hours.  
Assuming linear decay, find the average rate of decay and project into 62 hours to ensure that the current remains in the desired range. | |
| **Speed Control Unit** | | |
| Microcontroller | | 2 |
| 1. Accept real-time data from the IR sensors. | | |
| 2. Relay data from the Bluetooth module at 9600 baud. | 1. Reading data from one sensor at a time, use the built-in LED on the board to flash when a change in signal occurs. Visually confirm this happens when the IR LED on the train passes in front of the correct sensor.  
2. Start a timer and send 50 packets to the Bluetooth module. Stop the | |
<table>
<thead>
<tr>
<th>Bluetooth Receiver</th>
<th>Motor Bridge Driver Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Receive the correct signal to the Bluetooth receiver with 95% accuracy.</td>
<td>1. Upon obstacle detection, the train should brake by supplying 0V to the tracks.</td>
</tr>
<tr>
<td>2. Latency must be below 50 ms - no longer than 50 ms can elapse between the obstacle detection microcontroller sending ‘halt’ and the speed control microcontroller detecting ‘halt.’</td>
<td></td>
</tr>
</tbody>
</table>

- **Bluetooth Receiver**
  - **1.** Receive the correct signal to the Bluetooth receiver with 95% accuracy.
  
  - **2.** Latency must be below 50 ms - no longer than 50 ms can elapse between the obstacle detection microcontroller sending ‘halt’ and the speed control microcontroller detecting ‘halt.’

- **Motor Bridge Driver Circuit**
  - **1.** Upon obstacle detection, the train should brake by supplying 0V to the tracks.

<table>
<thead>
<tr>
<th>Bluetooth Receiver</th>
<th>Motor Bridge Driver Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Connect Bluetooth module with MCU. Pair the master Bluetooth (receiver) with the slave (transmitter).</td>
<td>1. Use an oscilloscope to measure the voltage applied to the train tracks.</td>
</tr>
<tr>
<td>b. Use transmitter to send one packet to receiver and check if the correct value is received. Repeat this 20 times and check for the correct value at least 19 times.</td>
<td>b. Begin powering the train at any</td>
</tr>
<tr>
<td>2. Connect Bluetooth module with MCU. Pair the master Bluetooth (receiver) with the slave (transmitter).</td>
<td></td>
</tr>
</tbody>
</table>
2. When the speed limit sign senses the train passing, the motor bridge driver should alter the duty cycle so that the train travels at the given speed of the sign.

duty cycle.
c. Place an obstacle on the tracks. If the obstacle detection unit is not yet verified, manually set the input pins of the driver to 00 or 11 to brake.
d. Check that the train brakes properly by measuring 0 V across the tracks.

2. a. Use an oscilloscope to measure the voltage applied to the train tracks.
b. Begin running the train at a 100% duty cycle.
c. Time how long the train takes to traverse 1 circumference of the track. Divide the circumference (287 cm) by the measured time to get the speed. It should be around 60 cm/s.
d. Place a speed limit sign near the track. If the speed detection system is unverified, manually lower the duty cycle.
e. After the train passes the speed limit sign or after changing the duty cycle, confirm that the voltage signal on the oscilloscope has changed its duty cycle.
f. Repeat step 2c. This time the speed should be near the speed corresponding to that speed limit sign.
g. Repeat process 49 times. The proper speed should be met 49 out of 50 times.

<table>
<thead>
<tr>
<th>Speed Detection Unit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IR LED and IR Sensors</strong></td>
<td></td>
</tr>
<tr>
<td>1. Each sensor must detect the IR LED on the train passing by with 98% accuracy.</td>
<td>1. Drive the train by each sensor 50 times and verify that the sensor outputs changes at least 49 times.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Obstacle Detection Unit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini Microcontroller</td>
<td>Laser ToF Rangefinder</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>1. Accept real-time data from each laser ToF sensor.</td>
<td>1. Change the ranges of the object each laser ToF sensor is detecting and see the response of the change by lighting the built-in LED on the board when an object is stationary. This should be done when the laser ToF sensors on the train are also stationary. Each laser ToF sensor should be tested individually.</td>
</tr>
<tr>
<td>2. Relay data to the Bluetooth module at 9600 baud.</td>
<td>2. Start a timer and send 50 packets to the Bluetooth module. Stop the timer when all 50 packets are sent back in response from the Bluetooth module. Divide the time in half and divide 50*number of bits per packet by the halved time.</td>
</tr>
<tr>
<td>3. Provide 98-102 mA at 3V to the IR LED for continuous light.</td>
<td>3. Use a multimeter to measure the current through the LED by breaking the circuit between the LED and the microcontroller.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Laser ToF Rangefinder</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Must have a FOV of at least 25° (at an absolute minimum, must be at least 17.66°).</td>
<td>1.</td>
</tr>
<tr>
<td>2. Must have a range measurement time of less than 77 ms.</td>
<td>a. Place an object 1 m in directly in front of the center of the sensor, with no other objects closer to the sensor.</td>
</tr>
<tr>
<td></td>
<td>b. Use sensor to take a measurement of the distance.</td>
</tr>
<tr>
<td></td>
<td>c. Repeat steps 1a-b but move the object 10 cm each time in the horizontal direction only until 50 cm is reached.</td>
</tr>
<tr>
<td></td>
<td>d. The object should no longer be detected at 50 cm. Test the object at around 46.63 cm or just below to see that it is detected.</td>
</tr>
</tbody>
</table>

2. Place an object 0.5 m in front of the sensor and run for 5 seconds and collect the sensor measurements. |
3. Move the object away after 5
<table>
<thead>
<tr>
<th>3. Detect obstacles 20 cm ahead on the track with 98% accuracy.</th>
<th>seconds and disable data collection.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Ignore obstacles on the side of the track with 98% accuracy.</td>
<td>c. Check to see that there are at least 64 measurements of 0.5 m.</td>
</tr>
<tr>
<td></td>
<td>d. Repeat 49 times and ensure this is met 49 out of 50 times.</td>
</tr>
</tbody>
</table>

| 3. Place an obstacle at least 20 cm in front of the train 50 times and verify that both laser ToF sensor detect the object at least 49 times. |
| 4. Place obstacles inside and outside the track at 10, 30, 50, 70, and 90 degrees away from the train at distances of 10, 20, 30, 40, and 50 cm and ensure that at least 98 out of 100 are ignored (not detected) by one or both of the laser ToF sensor. |

<table>
<thead>
<tr>
<th>Bluetooth Transmitter</th>
<th>1. Transmit the correct signal to the Bluetooth receiver with 95% accuracy.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Latency must be below 50 ms - no longer than 50 ms can elapse between the obstacle detection microcontroller sending ‘halt’ and the speed control microcontroller detecting ‘halt.’</td>
<td></td>
</tr>
</tbody>
</table>

| 1. Connect Bluetooth module with MCU. Pair the master Bluetooth (receiver) with the slave (transmitter). |
| 2. Use transmitter to send one packet to receiver and check if the correct value is received. Repeat this 20 times and check for the correct value at least 19 times. |

| 2. Connect Bluetooth module with MCU. Pair the master Bluetooth (receiver) with the slave (transmitter). |
| 3. Separate the transmitter and receiver by 1 m. |
| 4. Have the transmitter send one packet and begin timing on the MCU as it does. |
| 5. Upon reception at the receiver, have the receiver send a packet in response. |
| 6. End timing once the transmitter | 5 |
has received the response packet.
f. Divide the round trip time by 2 to get the latency.
g. Repeat steps 2c-f 49 times and ensure that the latency doesn’t go above 50 ms for 49 of them.

<table>
<thead>
<tr>
<th>Track Mapping Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Microcontroller</strong></td>
</tr>
<tr>
<td>1. Transmit data at 10KB/s to computer via USB connection.</td>
</tr>
<tr>
<td>2. Retrieve data from the RX pin before each of the digital echo pins from the ultrasonic receivers 99% of the time.</td>
</tr>
<tr>
<td><strong>RF Transmitter and Receiver</strong></td>
</tr>
<tr>
<td>1. Transmit and receive signals at 434 MHz with designed antennas.</td>
</tr>
<tr>
<td>2. Refer to Figure 9 on the process of data retrieval, and keep track of how many data packets from the ultrasonic receivers are neglected because they arrived before the RF receiver packets.</td>
</tr>
</tbody>
</table>

| **Ultrasonic Transmitter and Receiver** |
| 1. The receivers must be able to detect the transmitted ultrasonic signal from 5-95cm away. |
| 2. Repeat for the other two ultrasonic receivers. |
3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

<table>
<thead>
<tr>
<th>Name</th>
<th>Hourly Rate</th>
<th>Total Hours</th>
<th>Total = Hourly Rate x 2.5 x Total Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinn Lertratanakul</td>
<td>$30.00</td>
<td>175</td>
<td>$13,125</td>
</tr>
<tr>
<td>Emily Alessio</td>
<td>$30.00</td>
<td>175</td>
<td>$13,125</td>
</tr>
<tr>
<td>John Ryan</td>
<td>$30.00</td>
<td>175</td>
<td>$13,125</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>525</td>
<td><strong>$39,375</strong></td>
</tr>
</tbody>
</table>

3.1.2 Parts

<table>
<thead>
<tr>
<th>Item</th>
<th>Part Number</th>
<th>Manufacturer</th>
<th>Q</th>
<th>Unit Price</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HO Train Set</td>
<td>00692</td>
<td>Bachmann</td>
<td>1</td>
<td>$79.99</td>
<td>$79.99</td>
</tr>
<tr>
<td>Arduino Uno Rev3</td>
<td>ATmega328P</td>
<td>Adafruit</td>
<td>2</td>
<td>$24.95</td>
<td>$49.90</td>
</tr>
<tr>
<td>Arduino Pro Mini</td>
<td>ATmega328</td>
<td>Adafruit</td>
<td>1</td>
<td>$9.95</td>
<td>$9.95</td>
</tr>
<tr>
<td>Bluetooth LE Module</td>
<td>HM-10</td>
<td>Qunqi</td>
<td>2</td>
<td>$14.99</td>
<td>$29.98</td>
</tr>
<tr>
<td>IR Sensor</td>
<td>TSOP38238</td>
<td>Vishay Semiconductors</td>
<td>3</td>
<td>$1.95</td>
<td>$5.85</td>
</tr>
<tr>
<td>IR LED</td>
<td>ILED-8</td>
<td>Ledtech</td>
<td>1</td>
<td>$0.25</td>
<td>$0.25</td>
</tr>
<tr>
<td>RF Transmitter</td>
<td>RF Link Transmitter - 434MHz</td>
<td>Wenshing</td>
<td>1</td>
<td>$3.95</td>
<td>$3.95</td>
</tr>
<tr>
<td>RF Receiver</td>
<td>RF Link Receiver - 4800bps (434MHz)</td>
<td>Wenshing</td>
<td>1</td>
<td>$4.95</td>
<td>$4.95</td>
</tr>
<tr>
<td>Ultrasonic Rangefinder (x5)</td>
<td>HC-SR04</td>
<td>Elegoo</td>
<td>1</td>
<td>$9.99</td>
<td>$9.99</td>
</tr>
</tbody>
</table>
Laser ToF Sensor  | VL53L0X   | Adafruit | 2  | $14.95  | $29.90  
4.7kΩ resistor  | 4116R-2-472-ND | Bourns | 2  | $0.28   | $0.56   
Motor Bridge Driver  | L298  | STMicroelectronics | 1  | $2.95   | $2.95   
1Ω resistor  | L25J1RO  | Ohmite | 1  | $2.90   | $2.90   
100 nF capacitor  | FG26C0G2A104JRT06 | TDK | 1  | $1.39   | $1.39   
Diode  | 1N4933  | Vishay Semiconductor Diodes Division | 4  | $0.26   | $1.04   
PCBs  | PCBway | 3  | $10     | $30     
**Total**  |  |  |  | **$263.64**  

3.1.3 Grand Total

<table>
<thead>
<tr>
<th>Section</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$39,375</td>
</tr>
<tr>
<td>Parts</td>
<td>$244.88</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>$39,619.88</strong></td>
</tr>
</tbody>
</table>

3.2 Schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Task</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/26/17</td>
<td>Present Design Review</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Order IR sensors, ultrasonic components</td>
<td>Emily</td>
</tr>
<tr>
<td></td>
<td>Order microcontrollers, RF components</td>
<td>Quinn</td>
</tr>
<tr>
<td></td>
<td>Order remaining components</td>
<td>John</td>
</tr>
<tr>
<td>3/5/17</td>
<td>Test ultrasonic devices and gather baseline data. Design and make antennas; test RF communication.</td>
<td>Emily</td>
</tr>
<tr>
<td></td>
<td>Test IR sensors and LED detection accuracy. Order signs from</td>
<td>Quinn</td>
</tr>
<tr>
<td>Date</td>
<td>Task Description</td>
<td>Assignee</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td></td>
<td>Test laser ToF sensor and gather baseline data. Breadboard and test full-bridge rectifier circuit for speed control.</td>
<td></td>
</tr>
<tr>
<td>3/12/17</td>
<td>Breadboard, then submit PCB design for track mapping microcontroller.</td>
<td>Emily</td>
</tr>
<tr>
<td>3/12/17</td>
<td>Breadboard, then submit PCB design for speed adjustment microcontroller.</td>
<td>Quinn</td>
</tr>
<tr>
<td>3/12/17</td>
<td>Breadboard, then submit PCB design for train microcontroller.</td>
<td>John</td>
</tr>
<tr>
<td>3/19/17</td>
<td>Spring Break</td>
<td>All</td>
</tr>
<tr>
<td>3/26/17</td>
<td>Unit test track mapping function.</td>
<td>Emily</td>
</tr>
<tr>
<td>3/26/17</td>
<td>Unit test speed adjustment function.</td>
<td>Quinn</td>
</tr>
<tr>
<td>3/26/17</td>
<td>Unit test obstacle detection function.</td>
<td>John</td>
</tr>
<tr>
<td>4/2/17</td>
<td>Submit any PCB design revisions</td>
<td>Emily</td>
</tr>
<tr>
<td>4/2/17</td>
<td>Create display for track map.</td>
<td>Quinn</td>
</tr>
<tr>
<td>4/2/17</td>
<td>Measure and test delays and errors in trilateration data, begin working on alternative solutions if error too great.</td>
<td>John</td>
</tr>
<tr>
<td>4/9/17</td>
<td>Prepare mock demo</td>
<td>All</td>
</tr>
<tr>
<td>4/9/17</td>
<td>Debug track mapping unit.</td>
<td>Emily</td>
</tr>
<tr>
<td>4/9/17</td>
<td>Debug speed adjustment unit.</td>
<td>Quinn</td>
</tr>
<tr>
<td>4/9/17</td>
<td>Debug obstacle detection unit.</td>
<td>John</td>
</tr>
<tr>
<td>4/16/17</td>
<td>Mock demo (4/19)</td>
<td>All</td>
</tr>
<tr>
<td>4/23/17</td>
<td>Final demonstration</td>
<td>ALL</td>
</tr>
<tr>
<td>4/23/17</td>
<td>Mock presentation</td>
<td>ALL</td>
</tr>
<tr>
<td>4/23/17</td>
<td>Write final paper</td>
<td>ALL</td>
</tr>
</tbody>
</table>
4 Ethics and Safety

One safety concern in this project is the use of alkaline batteries. These common, household batteries are relatively safe, but pose the risk of leaking acidic liquids, gels or pastes [8]. This risk is increased under high temperatures or pressure, so we will ensure that the batteries remain at a temperature less than 50 degrees Celsius and place no objects on top of them. We will also check for leaks at the beginning of every development session and properly dispose of any leaky batteries. The laser rangefinder does not pose a safety risk since it is a Class 1 laser. As members of the IEEE community, we “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” [9].

Since the time frame of the project is short, we may face obstacles that will hinder our progress. Regardless of such obstacles, we abide to be “to be honest and realistic in stating claims or estimates based on available data” and “to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others” [9]. In return for the help from our classmates, teaching assistants, and professors, we will “assist colleagues and co-workers in their professional development” and “support them in following [the IEEE Code of Ethics]” [9].

This toy train project does not pose any other ethical concerns, because the final product will simply be a hobbyist toy. The scale of this project is too small to consider applications in larger fields, in which there would be moral dilemmas that arise from a toy enjoyed by many individuals around the world.
5 Citations


