SATELLITE: *Speed Adjusting, Track Exploring, Load Locating, Intelligent Train Engine*

Team 23 — John Ryan, Emily Alessio, Quinn Lertratanakul
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TA: Zipeng (Bird) Wang

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 IR LEDs on the sign and IR sensors on the train, the train will identify the speed and communicate back to a control unit that will adjust the voltage on the tracks to reach the proper speed. To achieve obstacle detection, an ultrasonic rangefinder will be placed on the front of the train to locate objects in front of the train as well as their distances and communicate to a control unit if the train needs to be stopped. An additional third element of innovation on the electric model train will be a path-mapping element. Three beacons will be placed and communicate with the train using RF and ultrasonic pulses in order to determine the distance of the train to each beacon. Using these distance measurements and a trilateration technique, the location of the train and its path will 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.

2 Design

The train system requires four main components to successfully accomplish all the high-level requirements: a power supply, a train sensing unit, a track control unit, and an RF module. The power unit provides power to the other units when the train system is being operated. The train sensing unit detects any obstacles and speed indicators along the track and communicates the information for the track control unit to regulate the speed of the train. This unit also collects data that will be used by the track control unit to map out the track and determine the train’s location. The track control unit contains the speed indicating LEDs and a microcontroller that regulates the speed on the tracks. Lastly, the RF module provides communication between the beacons and the microcontroller that controls the train’s movement.

Figure 2 below shows the physical design of the train system. The three beacons will be placed inside the track so that only one ultrasonic sensor needs to be placed on the train (on the inner side). Using the difference in travel time of RF and ultrasonic signals from the beacons to the train, the distance from each beacon will be determined. The track microcontroller and switching unit (left side) will connect to the track to adjust the speed of the train. The train will hold the ultrasonic sensor in the front to detect obstacles, the ultrasonic and IR detectors on the inner side, and the train microcontroller and RF transmitter on top.

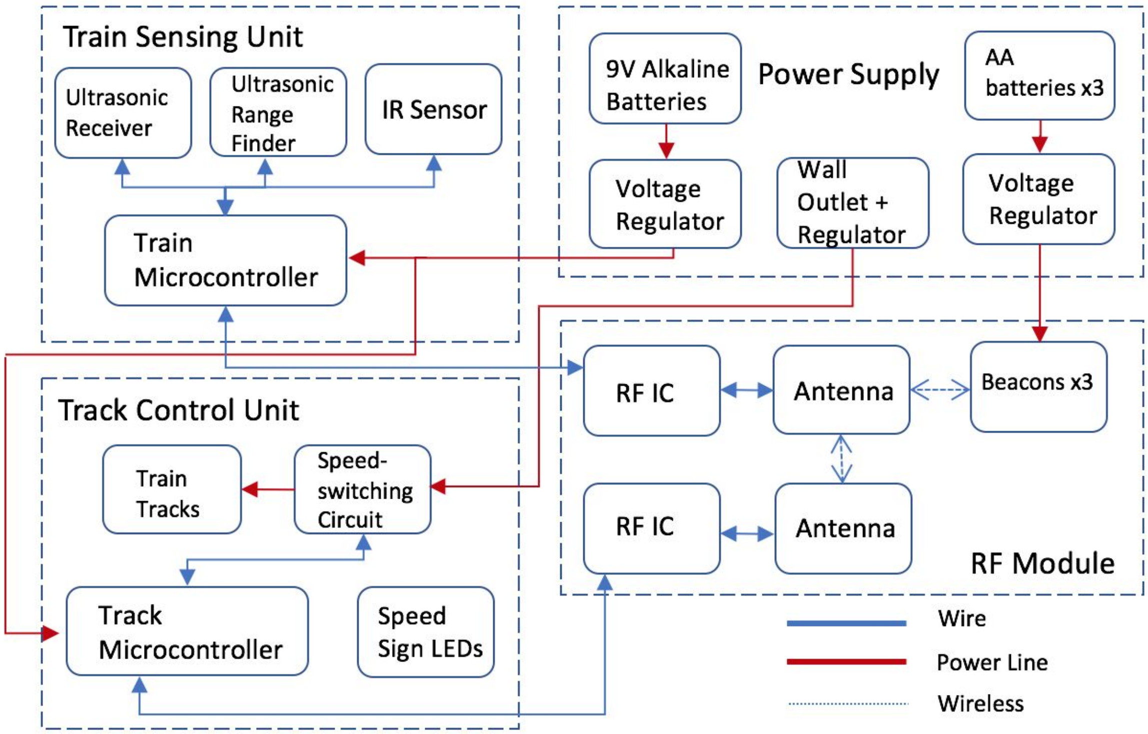

Figure 1: Block Diagram

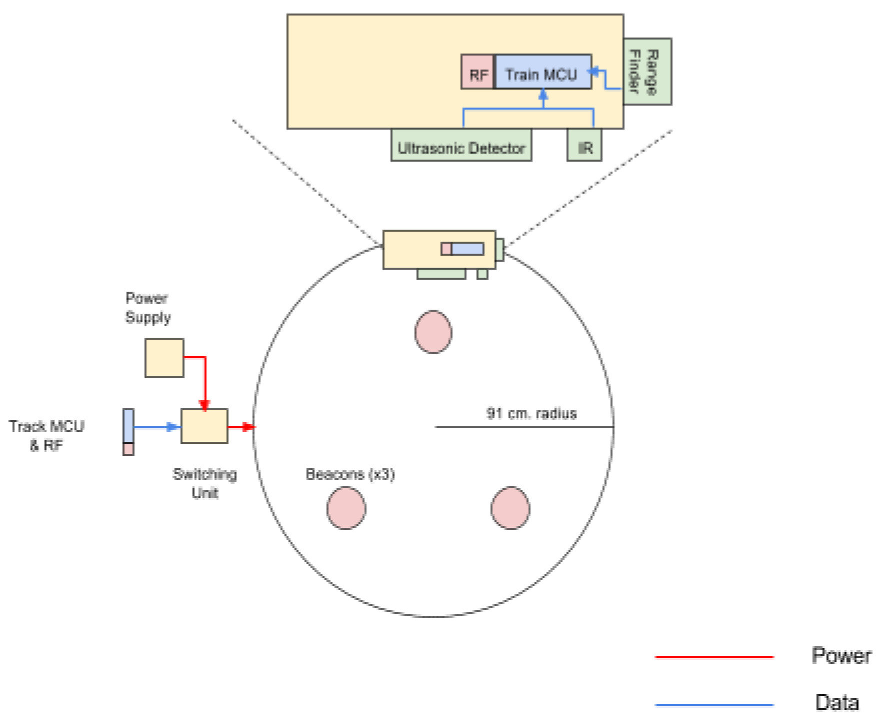

Figure 2: Physical Diagram

2.1 Power Supply

The power supply is essential for controlling the train's speed and for mapping out the track. A 9 V alkaline battery will be used to power each of the microcontrollers, the AA alkaline battery packs will power each of the beacons and the regulated voltage from the wall outlet will input into the speed-switching circuit for voltage division.

2.1.1 Alkaline Batteries and Voltage Regulator

Three AA (1.5 V) batteries will be used to power each beacon, and a 9 V battery will be used to power each microcontroller. We need three AA batteries for each beacon because it requires 4.2-4.8 V to be powered. A 9 V battery is sufficient for each microcontroller because each requires a 8.7-9.3 V input.

Requirement 1: The battery packs for the beacons must provide 12-13 mA at 4.2-4.8 V.
Requirement 2: The batteries for the microcontrollers must provide between 8.7-9.3 V.

2.1.2 Wall Outlet and Regulator

The wall outlet will provide a 16 V power source (after it is stepped down from the original 120 V) to the speed-switching circuit.

Requirement: The voltage regulated wall outlet must provide 16V +/- 5% from a 120 V source.

2.2 Train Sensing Unit

The sensors are located on the train and used for speed-adjustment, obstacle detection, and path mapping. We will use an IR sensor for detecting signals from IR LEDs on speed limit signs located around the track, an ultrasonic rangefinder for locating obstacles in front of the train, and an ultrasonic receiver for determining distances from the beacons using the speed of sound. All of the sensors are powered by the train microcontroller, which sends the sensor data over RF to the track control unit.

2.2.1 Train Microcontroller

This microcontroller will receive sensor data from the IR sensor, ultrasonic receiver, and ultrasonic rangefinder. It will communicate with an RF module to receive signals from the beacons and begin timing until it receives an ultrasonic signal. The difference in time calculated is the "time of flight." This microcontroller will then transmit an RF signal to the track microcontroller to communicate when a speed limit sign has been seen (and the given speed), an obstacle has been detected, or the time of flight from a given beacon to the train.

Requirement 1: Continuous communication with the ultrasonic range finder to provide < 500ms response to any obstructions on the track.
Requirement 2: Simultaneous communication between the RF module and ultrasonic receiver.

2.2.2 Ultrasonic Receiver

The ultrasonic receiver will determine if an ultrasonic pulse has been received from one of the three beacons. When the train receives an RF signal from a beacon, it will begin timing until it receives an ultrasonic pulse on one or more of the three receivers. Using this timing data and the speed of sound, the distance from that beacon will be determined.

Requirement: Receive ultrasonic signal from all beacons within a 140 cm radius.

2.2.3 Ultrasonic Rangefinder

The ultrasonic rangefinder will be placed on the front of the train, essentially consisting of an ultrasonic transmitter and receiver. The transmitter will output a pulse and measure the time of flight of its reflection to determine the distance to any object in front of the train’s path.

Requirement: Detect obstructions on the track within a 20 cm from the front area of the train.

2.2.4 IR Sensor

An IR sensor will be placed on the innermost side of the train. It will detect signals from IR LEDs on speed limit signs placed within the radius of the track. Depending on the signal transmitted from each of these signs, the sensor will be able to determine which speed limit it has read.

Requirement: Detect change in intensity from LEDs with 95% accuracy.

2.3 Track Control Unit

A track control unit will be used to control the speed of the train as well as computing the position data to an external monitor for displaying the mapping layout of the train tracks. A track microcontroller will be receiving sensing data through RF from the train sensing unit. Depending on the speed data received, the track microcontroller will switch the speed of the tracks using the speed-switching circuit drawing power from a wall plug source. IR LEDs will be placed along the track and coded for varying speeds for the train.

2.3.1 Track Microcontroller

This microcontroller will control the voltage supplied to the tracks and thus the speed of the train. Given speed/obstacle detection data from the train microcontroller, this microcontroller will adjust the voltage on the track using a switching unit (described below). Using time information from each beacon to the train and the speed of sound, this microcontroller will calculate the distance from the given beacon and communicate that data to a computer via a USB connection in order to map the path of the train.

Requirement 1: Control the speed of the tracks by transforming the output voltage between 12 and 20 V based on the input signals from the train microcontroller.
Requirement 2: Calculate the location of the train with 95% accuracy.

2.3.2 Speed-switching Circuit

This circuit, located between the wall power supply and the tracks, will adjust the voltage delivered to the tracks. The track microcontroller, using the speed limit signal from the train microcontroller, will choose which one of three output pins - corresponding to three set speeds - will be set to high. The switching circuit will use transistors and resistors to select which voltage will be supplied to the train tracks. If an output pin is set to high, it will close the corresponding transistors which will connect the 16 V DC from the wall adapter through a set series resistance to the track. The series resistance will determine the final voltage that is dropped across the track, thus determining the speed of the train. If the train is to be stopped, none of the corresponding output pins of the track microcontroller will be set to high and thus no switch will be closed so that no power is supplied to the tracks.

Requirement 1: Receive the speed limit signal from the track microcontroller and set the switches to “turn on” the resistive branch for the desired voltage (three choices) or “turn on” none of the branches to stop the train.

2.3.3 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, which will allow current to flow through the engine on the train via the metal wheels and through the motors of the train.

Requirement: Accept voltage supplied by the speed-switching circuit on one rail in order to set the speed of the train.

2.3.4 Speed Sign LEDs

The speed signs will be used to automatically send signals to the train to adjust its speed. These signs will have IR LEDs which will shine in varying intensity correlated to speeds, to be detected by the IR sensors.

Requirement: Must have distinguishable intensities by 100 Lux or 0.5 V to be detected by the IR Sensor.

2.4 RF Module

2.4.1 Beacons (x3)

Each beacons will have and RF transmitter and an ultrasonic transmitter which will transmit simultaneously. The RF receiver on the train will receive the RF signal pulse instantaneously, which will alert the ultrasonic receivers to prepare to measure the time for the ultrasonic pulses to reach the train. The time for the sound to reach the ultrasonic receivers on the train will then be used to calculate the distance from the beacon to the train using the known speed of sound.

Requirement: Each beacon must transmit an RF signal and ultrasonic signal within 1 microsecond of each other when directed.

2.4.2 RF IC and Antenna (x2)

One wireless communication module will be on each microcontroller. The RF IC + Antenna, tentatively a Digi XBee 802.15.4, for the train microcontroller will receive the RF signals from the beacons and also transmit data to the stationary, track microcontroller. The RF IC + Antenna on the track microcontroller will receive the signals transmitted by the train microcontroller.

Requirement: Send and receive signals when a speed limit sign has been seen (and the given speed), an obstacle has been detected, or the time of flight from a given beacon to the train with 95% accuracy.

2.5 Risk Analysis

The trilateration technique provides the most risk for this project. Trilateration uses the measurement of distance to 3 stationary beacons as well as the geometry of circles and triangles to determine the location of an object. This technique is used in surveying and navigation, as well as GPS. However, it is not a perfect method. Knowing the center of three circles (beacon locations) and their radii (distance to train receiver) may yield two possible locations. This problem can be mitigated using probability and knowledge of previous locations, but there is still room for error when mapping out the track. The trilateration algorithm must also estimate timing through clocks, transmission, calculation, and other system components. We will measure the time it takes the data to transfer through each part of the system down to the microsecond several times, then include the estimations in the algorithm along with the speed of the train at any given time to calculate the delay in position determination.

Our specific approach will make use of RF and ultrasonic signals. Each beacon will emit an RF signal and an ultrasonic pulse simultaneously. The RF receiver on the train will receive the signal instantaneously, which will signal the ultrasonic receivers to prepare for the ultrasonic pulses. The time for the sound to reach the ultrasonic receivers on the train will then determine the distance from the beacon (radius of circle) using the known speed of sound. Several risks come with this approach. Since three beacons will transmit, there is a possibility that the signals will interfere. The train will require multiple receivers, and the RF and ultrasonic receivers must be paired together and positioned such that the timing measurements correlate to the correct beacons. The beacon transmissions can be staggered to help mitigate this problem. We require 90% accuracy when calculating positions so that any false positions can be corrected by looking for continuity in the path. Additionally, having the train travel over the tracks multiple times will increase the accuracy of the mapped track. This tolerance will ensure that the train accurately maps the track it travels on, as required.

3 Safety and Ethics

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 [4]. This risk is increased under high temperatures or pressure, so we will ensure that the batteries remain at room temperature 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 other type of battery used in this project is the coin cell battery. The biggest danger inherent to these small batteries is that children may swallow them due to their size and shiny appeal. As many as 3,400 children have swallowed buttons in the US in one year, some with permanent damage [5].To prevent this problem from occurring, the final market product should include a warning to adults regarding the dangers of swallowing coin cell batteries, as well as a list of symptoms and emergency action advice. Additionally, the train will have and LED to signify when a battery is missing. 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” [6].

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” [6]. 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]” [6].

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.

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