OBSTACLE DETECTING AND DERAILMENT AVOIDING MODEL TRAIN

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1 Introduction

1.1 Objective

While model trains have become more and more advanced over the last few decades, they are still entirely controlled by a human operator. While on a small scale this is fine, the more complex the system, the less feasible this becomes. Our aim was to give each locomotive some ability to respond to the track on its own by detecting obstacles and reacting to programmable beacons placed on the track. A variety of sensors are placed on the locomotive, such as a time of flight sensor to detect obstacles and an IR beacon receiver to adjust speed on different parts of the track such as curves. We essentially want the train to "read" the track as it goes along and avert any potential problems.

1.2 Background

The root of this problem is that currently all functions of a model train system must be controlled by the human operator. A lapse in attention could result in a derailment which detracts from the enjoyment of the model. We believe that by putting some of that work on the locomotive itself with a microcontroller and some sensors, we will reduce the failure rate of the train and increase its overall aesthetic appeal. The point of these models is to be fun and our goal is to make them more fun and realistic.

1.3 High-Level Requirements

- Must be able to operate indefinitely on existing methods of track power, both analog (DC) and bipolar Digital Command Control (DCC).
- Must be able to detect oncoming obstacles on the track and stop to avoid derailment or damage.
- Must be able to read speed limit beacons and adjust its speed accordingly.

2 Design

Our solution consists of two independent circuits: the beacon board and the locomotive board. The beacons are individual tiny PCB's on the track that constantly send out a signal and are read as the train passes over them. The locomotive board is on the train and is responsible for motor control and input from the sensors.

2.1 Rail Power

2.1.1 Power Supply

A power supply is needed to provide power via the rails to the motor, the microcontrollers, and the sensors. The rail power can be sourced from a bench DC power supply or an off-the-shelf transformer. It will power the entire system track system and any trains on the tracks.

Requirement 1: Must have a maximum voltage of ±18V for DC and ±27V for DCC[1]
Requirement 2: Must not fall below ±12V at a current of 1.8A[2]
Requirement 3: Must be able to supply a minimum current of 1.8A

2.2 Beacon Block Diagram

The beacon consists of a simple power system and control system. The power system will take the variable voltage coming off the rails, rectify it, and then regulate it down to a voltage that the control block can use. In the control system, the microcontroller will control the IR LED to emit a 38 kHz signal of a unique ID value programmed to each board. The beacon block diagram is shown in Figure 1.

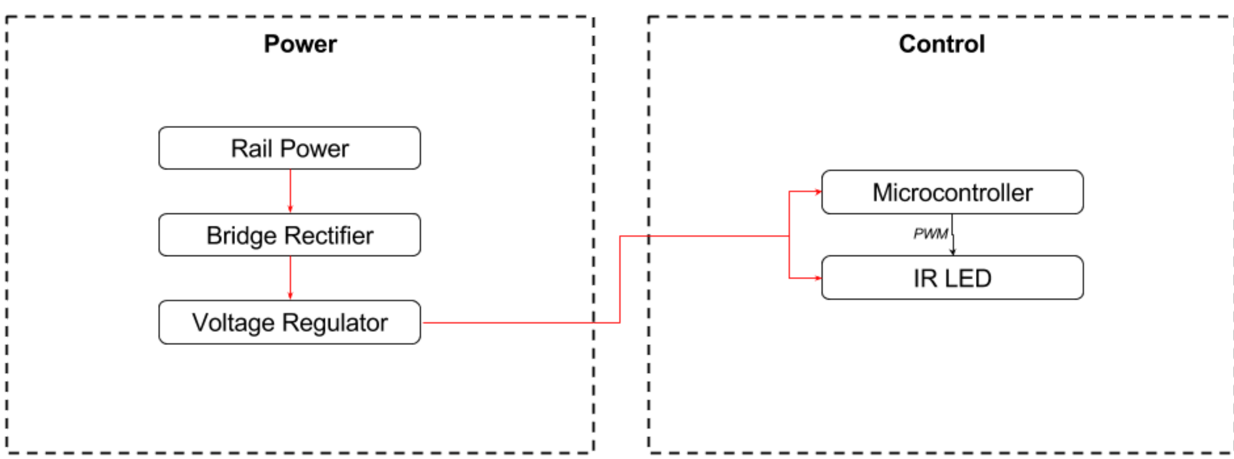

Figure 1: Beacon Block Diagram

2.3 Beacon Power

2.3.1 Full Bridge Rectifier

The full-bridge rectifier will rectify arbitrary polarity power signals from the rails before they are routed to the motor driver.

Requirement 1: Must be able to rectify at least a voltage of ±30V
Requirement 2: Must be able to supply a minimum current of 1.8A

2.3.2 Voltage Regulator

The voltage regulator IC will take an input from the rectified rail power and bring the voltage down to 2.8V needed for the MCU and its peripherals.

Requirement 1: Must output a voltage of 2.8V±0.2V at a minimum of 200mA
Requirement 2: Must operate from an input voltage of 4.4-27V

2.4 Beacon Control

The beacon control unit consists of a microcontroller and an IR LED. The microcontroller will modulate the LED so as to broadcast an ID that is unique to that particular beacon. The locomotive control unit will read this ID via its IR receiver.

2.4.1 Microcontroller

The microcontroller used will be an ATtiny45 8-bit AVR processor. It will control the IR LED and continuously broadcast its unique ID.

Requirement 1: Must be able to blink the IR LED at a frequency of at least 38kHz
Requirement 2: Must be able to be powered at 2.7-5.5V drawing no more than 10mA

2.4.2 IR LED

The 940nm IR LED will be used to broadcast a unique ID that the receiver on the locomotive can read. It will use the standard 38 kHz modulation format used by many televisions and other consumer devices.

Requirement 1: Must draw no more than 150mA continuously
Requirement 2: Must have a forward voltage of at most 2.8V

2.5 Locomotive Block Diagram

The locomotive unit consists of four blocks. The power system will take the rail voltage and rectify it for the motor controller. If plugged in over USB the voltage switcher will just use its 5V and regulate it down to 2.8V for the control unit and sensor unit. If power is coming from the rail, the voltage switcher will select the rectified power to be regulated down to 2.8V instead. The locomotive block diagram is shown in Figure 2.

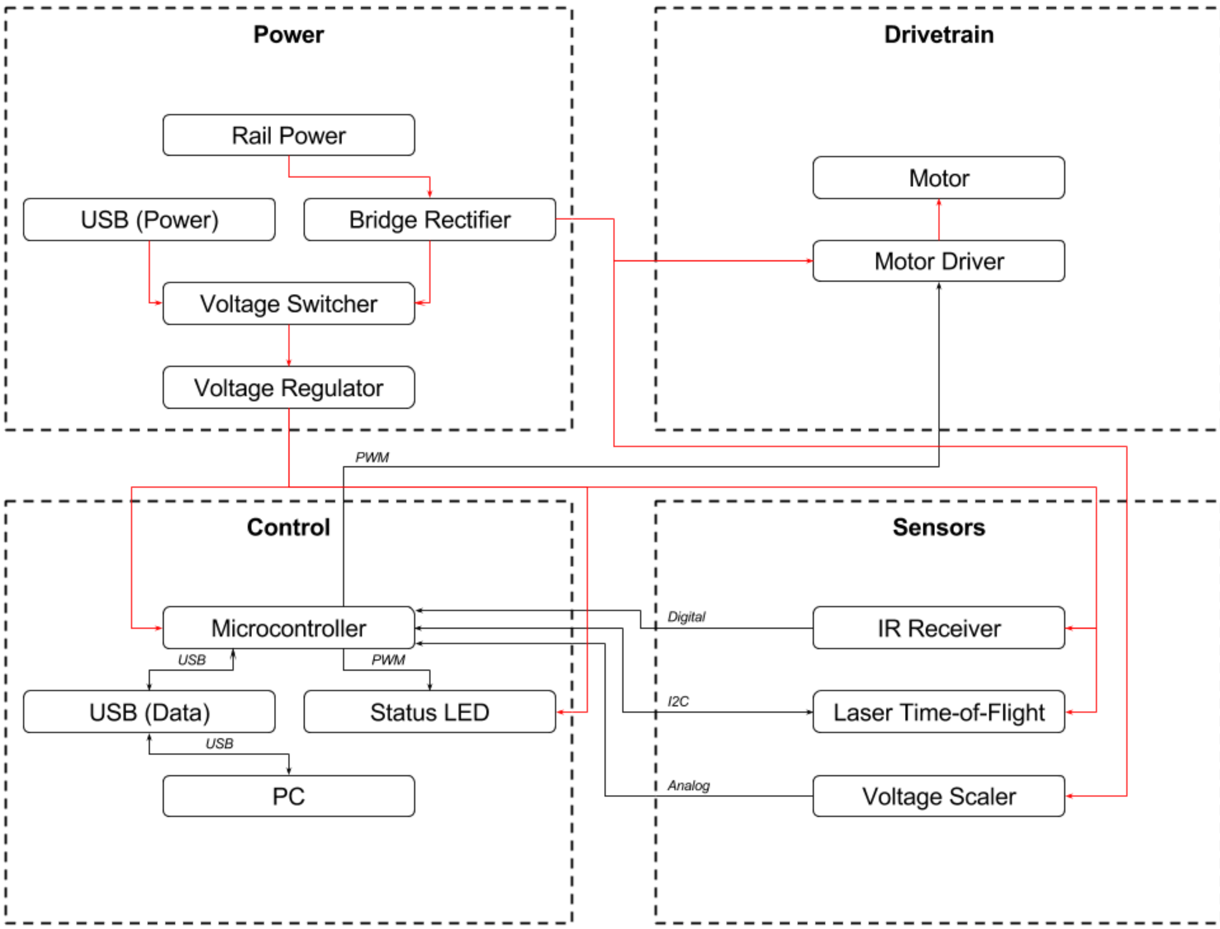

Figure 2: Locomotive Block Diagram

2.6 Locomotive Power

2.6.1 Full Bridge Rectifier

The full-bridge rectifier will rectify arbitrary polarity power signals from the rails before they are routed to the motor driver.

Requirement 1: Must be able to rectify at least a voltage of ±30V
Requirement 2: Must be able to supply a minimum current of 1.8A

2.6.2 USB (Power)

The microcontroller will be bus-powered when it is being programmed via USB.

Requirement 1: Must supply 4.4-5.2V at a minimum of 300mA[4]

2.6.3 Voltage Switcher

When the microcontroller on the locomotive board is being programmed, power will be sourced from the USB connection. Otherwise, the train will be powered by the bench power supply or transformer via the rails. The circuit will consist of one PFET and one NFET driven by USB voltage in order to switch between the two power sources.

Requirement 1: Must be able to be gate driven by a 4.4-5.25V source

2.6.4 Voltage Regulator

The voltage regulator IC will take an input from either the USB power source or the rectified rail power and bring the voltage down to 2.8V needed for the MCU and its peripherals.

Requirement 1: Must output a voltage of 2.8±0.2V at a minimum of 300mA
Requirement 2: Must operate from an input voltage of 4.4-27V

2.7 Locomotive Control

The locomotive control unit consists of a microcontroller, a status LED, and a USB data connection. If there is a USB connection the control unit will enter a programming mode, otherwise is will enter normal track operation. This will allow operators to map the beacon IDs to one of 128 different speeds limits[3], amongst other functions. The microcontroller receives input from the sensors and outputs a PWM signal to the drivetrain to control the speed.

2.7.1 Microcontroller

The microcontroller used will be an STM32F405 32-bit ARM processor. It will communicate with the sensors and control the motor. It will also store configuration data for the beacons.

Requirement 1: Must be able to read and write digital signals and PWM over the GPIO pins
Requirement 2: Must be able to communicate using the I^2C protocol
Requirement 3: Must be able to read an analog voltage signal of 0V-2.8±0.2V using the ADC
Requirement 4: Must be able to act as a USB Mass storage device when connected to a PC

Requirement 5: Must be able to be powered at 2.8±0.2V drawing no more than 240mA
Requirement 6: Must be able to store track configuration between power cycles

2.7.2 USB (Data)

The data pins of the USB port will be used to communicate with the PC and get the configuration data for the beacons.

Requirement 1: Must be able to communicate as a USB mass storage class (MSC) device

2.7.3 Status LED

The status LED will indicate if the board is in programming mode (i.e. if it is connected over USB) or in track mode for normal operation. It can also be used to alert the user of a status code.

Requirement 1: Must draw no more than 20mA continuously
Requirement 2: Must have a forward voltage of at most 2.8V

2.7.4 PC

The PC will be used to assign a mapping of the beacon codes to a desired operation and to upload that data to the board over USB. The PC is mostly outside of the scope of this course

Requirement 1: Must be able to write to a USB mass storage device

2.8 Locomotive Sensors

The locomotive sensor unit consists of three sensors that detect obstacles on the track, read the IR beacons, and detect the rail voltage.

2.8.1 IR Receiver

The IR receiver will read the beacons as the train passes over them and the microcontroller will match the beacon ID to the predetermined mapping.

Requirement 1: Must be able to sense a 38kHz modulated 940nm IR beam
Requirement 2: Must output a demodulated digital signal

2.8.2 Laser Time-of-Flight Sensor

The optical time-of-flight distance sensor will be used to detect obstacles on the track and stop the train if it is about to hit something.

Requirement 1: Must be able to operate at 2.8±0.2V

Requirement 2: Must have a 16.5mm breadth of view at 100mm from the front of the train

2.8.3 Voltage Scaler

The voltage scaler will use a differential op amp to detect the voltage coming from the rail power in order to calculate the correct PWM signal to send to the motor driver.

Requirement 1: Must be able to scale a voltage range of 0-27V down to 0-2.8V

2.9 Locomotive Drivetrain

The locomotive drivetrain unit consists of the motor driver that will interface the PWM signal from the microcontroller with the rectified rail power and send that to the motor to control speed.

2.9.1 Motor

The train motor will be controlled by a motor driver in order to run at the correct speed. It will have the capability to run forward as well as backward to aid in braking.

Requirement 1: Must have a maximum voltage of at least 27V
Requirement 2: Must have a stall current of at most 1.5A

2.9.2 Motor Driver

The motor driver will be used to control the speed and direction of the DC train motor.

Requirement 1: Must have a minimum control voltage of at most 2.6V
Requirement 2: Must have a minimum control current of at most 25mA

2.10 Risk Analysis

The riskiest block that would impact our project the most in terms of time is the power block. Specifically, if our voltage regulator failed, it has the potential to burn out our microcontroller. Ordering a replacement microcontroller would take about a week to be shipped. Soldering it onto our PCB would also require time to ensure our connections are correct. We plan to mitigate this risk by ordering a backup microcontroller. Also if our voltage switcher fails to switch to USB power, the train would be rendered useless since it would not be reprogrammable.

3 Ethics and Safety

There are two potential safety concerns with our project, however we believe they are both within the acceptable tolerances for a general consumer product. The first of these is that the rails of the train track are electrically charged so one could potentially shock themselves.

However, we are not changing this characteristic in our design and therefore are not creating any additional safety hazards. This is a well understood risk of model trains so responsible usage dictates they should be kept out of reach of small children or pets. The second is that we are using a time-of-flight sensor that uses a laser. The laser used is Class 1, which means that it is safe for use under normal conditions and while operating within the manufacturer's specifications[5]. We fully intend on staying within those guidelines.

Our project does not introduce any major ethics concerns as we are only modifying a toy. In accordance with the IEEE code of ethics, we will only endeavor to take on technical tasks we feel we are qualified for and seek advice from our mentors for the skills we lack. We will seek feedback and criticism for our work and continuously work to correct our mistakes. We will strive for honesty and properly credit individual contributions to our project. Most importantly, we will support and encourage each other to follow this code of ethics.

References

[1] "Electrical Standards for Digital Command Control", *http://www.nmra.org*, 2006. [Online]. Available: http://www.nmra.org/sites/default/files/standards/sandrp/pdf/s-9.1_electrical_standards_2006.pdf. [Accessed: 08- Feb- 2017].

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