Spring 2024

Simple Transit Braking System

Joshua Forde , '24

Simple Transit Braking System

Joshua Forde

Swarthmore College | Engineering Department

May 2024

1 Abstract

A prototype of an automatic braking system for a locomotive was designed and implemented for the purpose of adding an emergency fail safe for trains nationwide. An ultrasonic sensor detected environmental conditions in front of the train, while a connected relay communicated with a servo powered brake to change brake position. An O scale model train was mounted with an onboard sensor, microcontroller, and servo-powered brake to test the effectiveness of an automatic braking system for locomotives. A rubber-like material was used as the brake pad to slow and ideally stop the train on command. Arduino IDE was used to program the microcontroller with a state system that was used to switch between states that controlled the position of the brake. This project was successful at stopping the model train under low speed conditions and slowing the train under medium to high speed conditions. A realistic extension to actual locomotives is discussed in the Conclusion section.

Table of Contents

2 Introduction

In order to improve performance, safety is paramount. For that reason, I decided to design an automatic braking system for a locomotive in order to facilitate automatic braking in emergency situations. Throughout the report, trains and locomotives will be used interchangeably.

Speed and safety are two things that we want to characterize the modes of transportation that we use daily. Freight Trains carry 61 tons of goods per American annually in the United States [1]. Passenger Trains carry millions of people per day and Amtrak stops in 46 states across the United States and Canada [2]. This process of transporting goods or people from one location to another is made possible by the train braking system. The braking system is responsible for slowing the train during motion and stopping the train entirely.

1 Motivation

As a born and raised New Yorker, I used subway locomotives several times weekly to get from destination to destination. I was interested in improving the performance of the train so that collectively better train service could be achieved. I looked into communications-based train control which uses telecommunications between the train and track equipment to better manage train traffic and therefore increase throughput of trains. I looked into magnetic levitation as a system of rail transport which uses electromagnets to levitate the train, rather than rolling on wheels which removes rolling resistance. After looking into different areas where I could improve performance, I decided to pivot toward improving safety after learning more about recent train derailments, such as the Ohio Derailment on February 3, 2023. While an improved braking system may or may not have changed the outcome of these various incidents, I found working on brakes to be a good start toward improving the safety aboard trains. From there, I decided based on my background in programming microcontrollers and my knowledge of mechanics to design a prototype of an automatic braking system for a locomotive.

2 Benefits of an Automating Braking System

Similarly to self-driving cars, sensors on the car are sensitive enough to detect an obstacle in the way faster and more reliably than a human. Unlike self-driving cars, trains are not subject to human traffic errors and congestion. So in the event of a needed sudden stop, an automatic system can assist the train operator to stop when an obstacle is in the way.

3 Project Obstacles and Goals

The project is a minimum viable product of an automatic braking system. Naturally, the main objective of the system is to control the activation and retracting of the brakes, to detect foreign objects in the path of the train, and to stop the train while in motion.This will allow moving vehicles to start reducing speed and braking when the path ahead of it is not clear for movement. This is achieved by brake design around the physical constraints of the train itself, such as the space on the train itself to attach the brake, and having a servo to move the brake pad. The major obstacles to this project was testing the effectiveness of the brake and making sure that the train stopped within a 5 second period upon detecting an object.

3 Theory

3 Brake Theory

A brake is a mechanical device that inhibits motion by absorbing energy from a moving system [4]. The brakes are responsible for three major functions: enabling deceleration, controlling acceleration, and holding the vehicle stationary. While similar to a road vehicle, this system becomes more complex due to pulling multiple linked carriages and the ability to control the motion of these carriages as well. Important factors that govern the braking action in all vehicle braking systems are pressure, surface area in contact, amount of heat generation and braking material. To preserve human life and physical resources, some elementary requirements of a brake must be followed. The brake must be strong enough to stop the vehicle during an emergency within the shortest possible distance. There should be no skidding during brake application and the driver must have proper control over the vehicle during an emergency. Effectiveness of brakes should remain constant even on prolonged application or during descending on a down gradient. Brakes must keep the vehicle in a stationary position even when the driver is not present.

1 Mechanical Brake

Mechanical braking systems use either wheel tread brakes, axle-mounted disc brakes or wheel-mounted disc brakes as basic braking devices [4]. When the brake is activated, the mechanism of the brake uses a brake shoe to apply a frictional force onto the wheel or disc itself. The applied pressure is adjusted to regulate the breaking force. Wheel tread brakes are devices that apply friction directly to the wheel tread, creating a sliding effect. High speed trains use axle or wheel-mounted brakes over the wheel tread, because using the wheel-tread in high speed conditions may damage the wheel. Axle-mounted disc brakes are used primarily on trailer carriages due to these brakes requiring sufficient space. Wheel mounted disc brakes are used on motor carriages since it requires accommodating the motor and being more compact than an axle brake. “In both systems, compressed air or oil is applied to a brake cylinder that pushes the brake lining against the disc. Brake discs are dead weight that are useful only during braking, therefore operators can install lighter discs” [3]. Materials commonly used for brakes are carbon/carbon-composites and aluminum-composites due to their light weight.

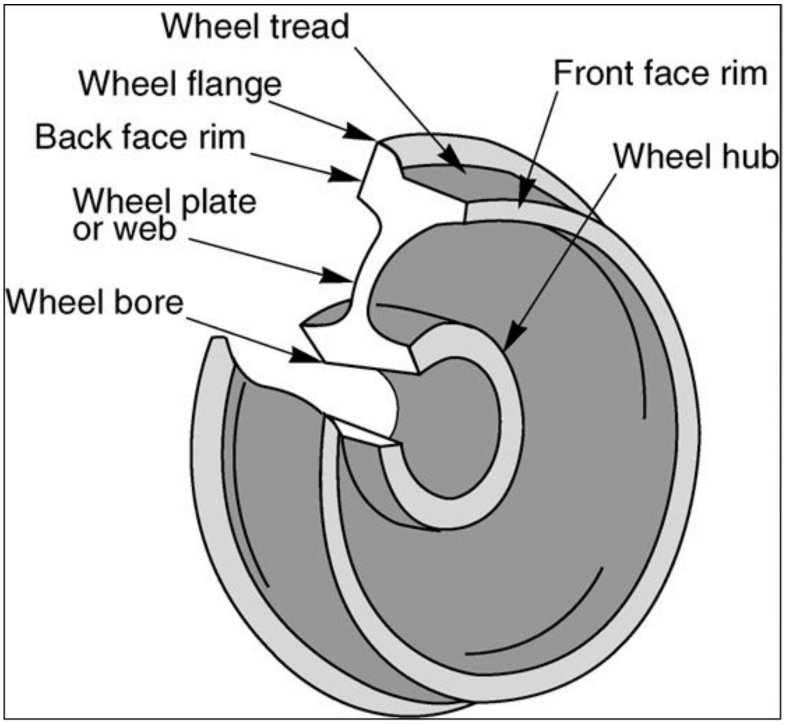

Figure 1. Locomotive Wheel [5]

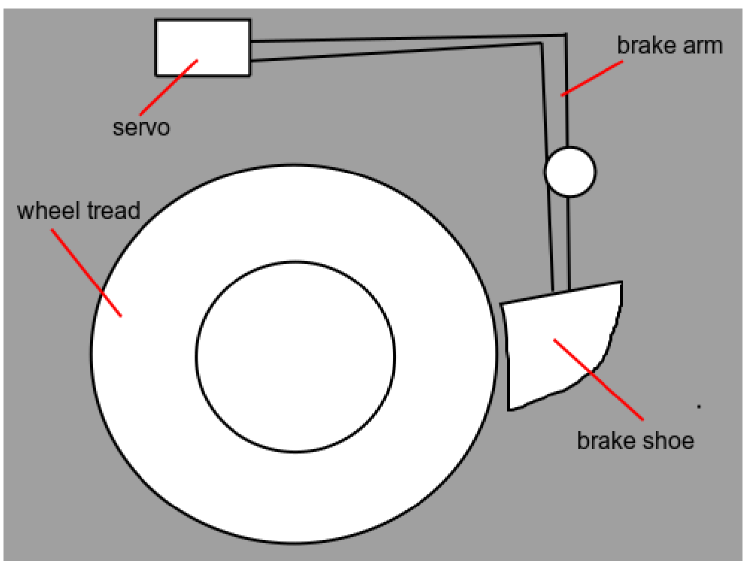

Figure 2. Wheel and Brake Diagram

4 Sensor Theory

An HC-SR04 Ultrasonic Module Distance Measuring Transducer Sensor was used to measure the distance between where the sensor was mounted and a foreign object. The sensor was controlled using code in Arduino IDE. The sensor detects distances between 2cm and 250cm. The detection is done in three steps First, the ultrasound transmitter, which is the trig pin, emits a high-frequency sound at 40 kHz. The sound travels through the air. If it finds an object, it bounces back to the module. The ultrasound receiver, which is the echo pin, receives the reflected sound or echo. Knowing the time when the receiver gets an echo signal, one can calculate the distance from an object to the receiver using the speed of sound in air. The distance to an object is equal to half the speed of sound in the air multiplied by time.

Figure 3. Locomotive Wheel [5]

3 Design

1 Modeling a Locomotive and Environment

The Locomotive was modeled by a O Scale Model Train and corresponding train tracks. O Scale was useful in order to have a model large enough to make modifications on and attach peripherals to it. A MRC Tech II transformer was wired to the tracks in order to supply DC power to the rails so that the wheels could conduct the electricity in the rails. From the wheels, the DC power is wired internally to the motor which turns the (piece connected to the wheels) which moves the wheels. The transformer had a knob that regulates the power nominally in divisions of ten, from 0 to 100.

Figure 4. The Locomotive on The Track

2 Structure

The automatic brake system had some criteria. In order for the system to be viable, the system must be able to detect sudden changes in the environment. In realistic conditions, a foreign object such as a tree could block the tracks ahead of the train, necessitating a stop. A condition I set was for the system to react within 10-15 seconds as to give the train ample time to stop. Using an Arduino Uno R3, I set specific instructions to occur when a condition was met, such as an object detected.

3 Brake Design and Spatial Constraints

Based on the basic requirements for any brake, I set some criteria for the brake. The brake must be able to slow and optimally stop the train within the shortest distance possible. In addition, the brake must activate within 10-15 seconds and cause little to no skidding. While in operation, the brake must be strong enough to hold the train in place such that it does not move. Lastly, the material of the brake shoe must not damage the wheel with use. A servo motor was chosen to assist in moving the brake arm into position due to its compatibility with arduinos. Attached to the arm on the servo motor was the brake shoe. Moving the brake shoe with the servo arm allowed the brake shoe to be forced into the wheel tread.

The O Scale Model Train initially had aesthetic pieces that were removed or altered for the purpose of obtaining more space to mount the servo above the wheels. Since the drive rod and crank turned the wheels, the servo was mounted above the wheel that had the crank to reduce and nullify the effect of the crank on the motion of the wheels. Having the servo above the wheel also reduced the distance the arm would have to move to force the brake pad into the wheel.

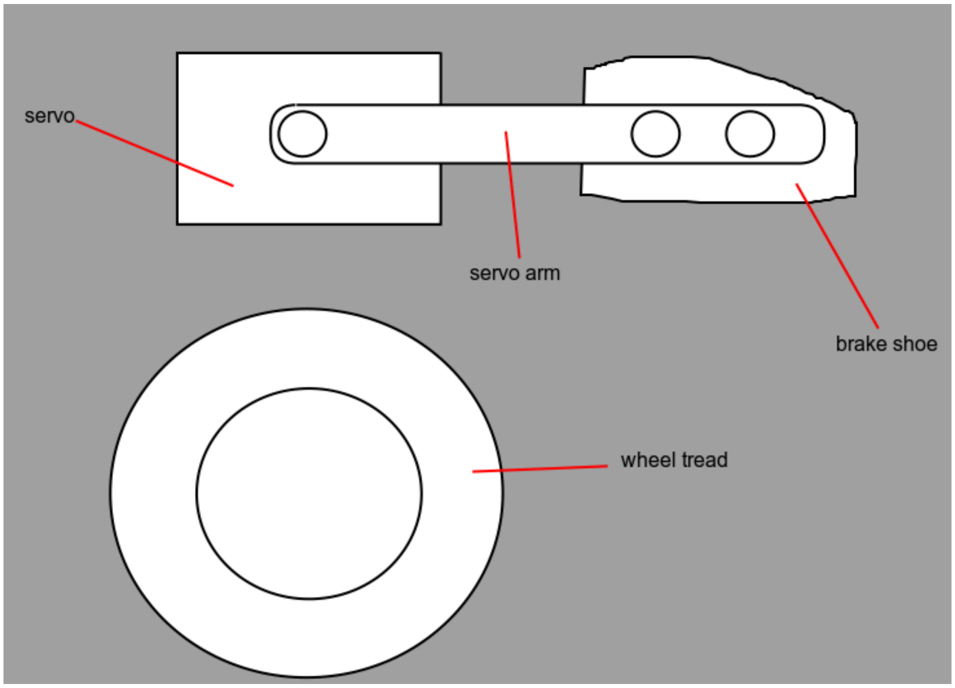

Figure 5. First Model of the Brake

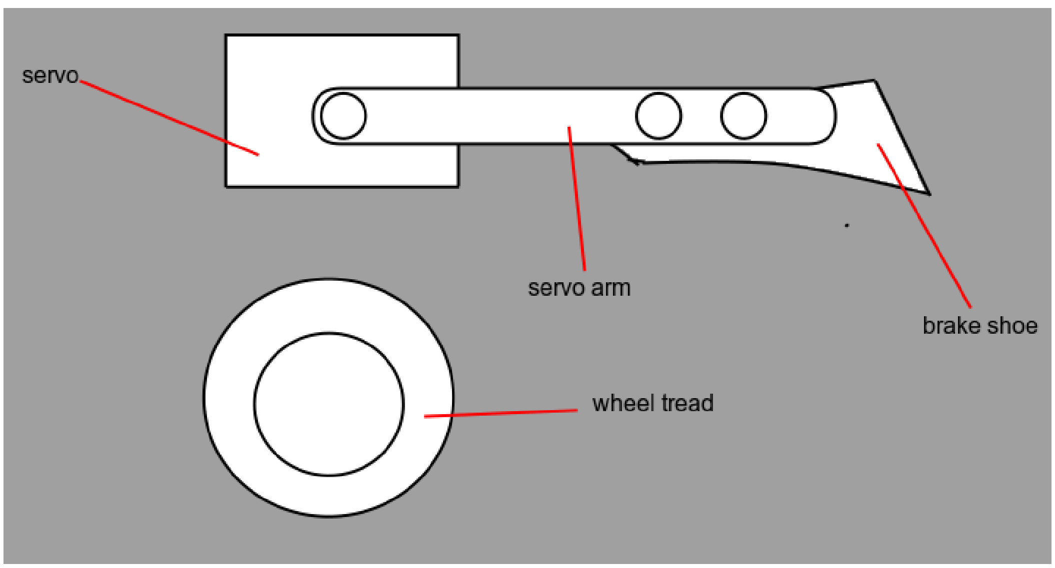

Figure 6. Second Model with Improved Brake shoe

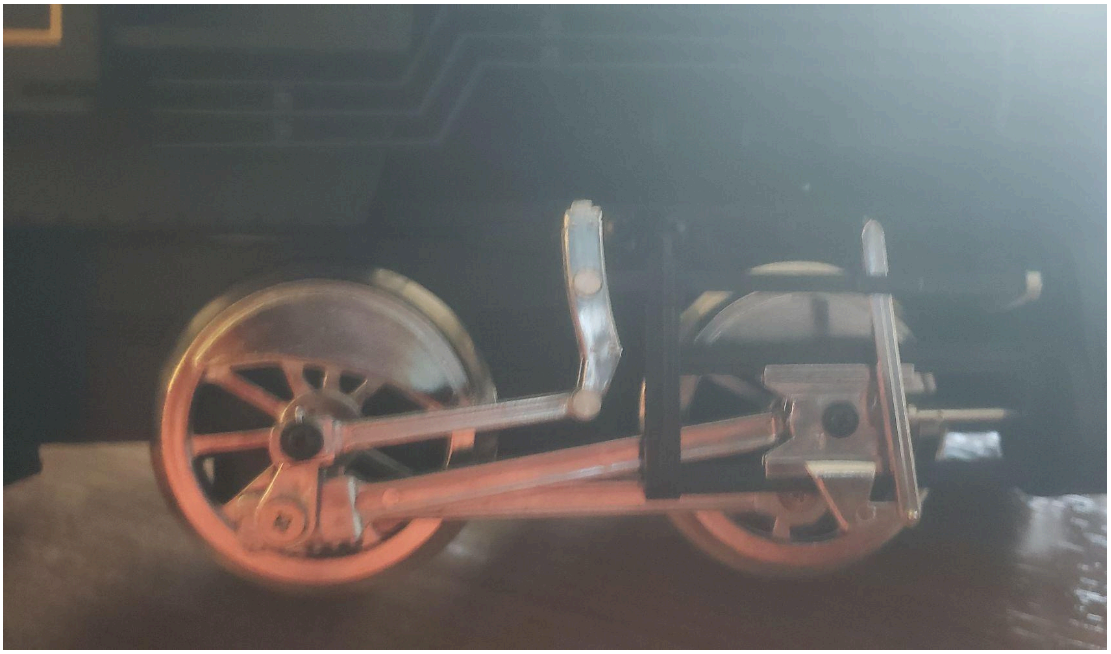

Figure 7. Close Up of The Wheel before Modification

4 Monitoring Sensor System

Mounted on the train, an Arduino UltraSonic Sensor was used to send out a signal periodically in front of it to detect the distance of the sensor from an object in the distance. Using this distance, the arduino relayed a signal containing desired servo arm position (out of 180 degrees) to the servo motor.

4 Implementation

1 Structure

The arduino and the relay were mounted on the right side of the train. The battery pack for the arduino mounted on the back of the train in the cab. The sensor, wired into a breadboard, was mounted to the front of the train in a similar manner, and held in position using a clamp. Screws and metal plates found in the machine shop were used to fasten and hold these components into place on a flat surface. The servo was mounted using a little arm that was fastened above the wheels. The brake shoe was cut out of rubber found in the machine shop.

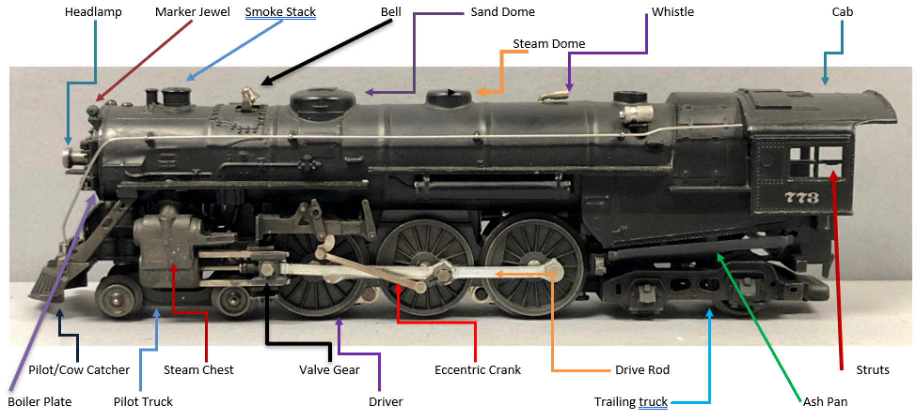

Figure 8. Locomotive Anatomy [6]

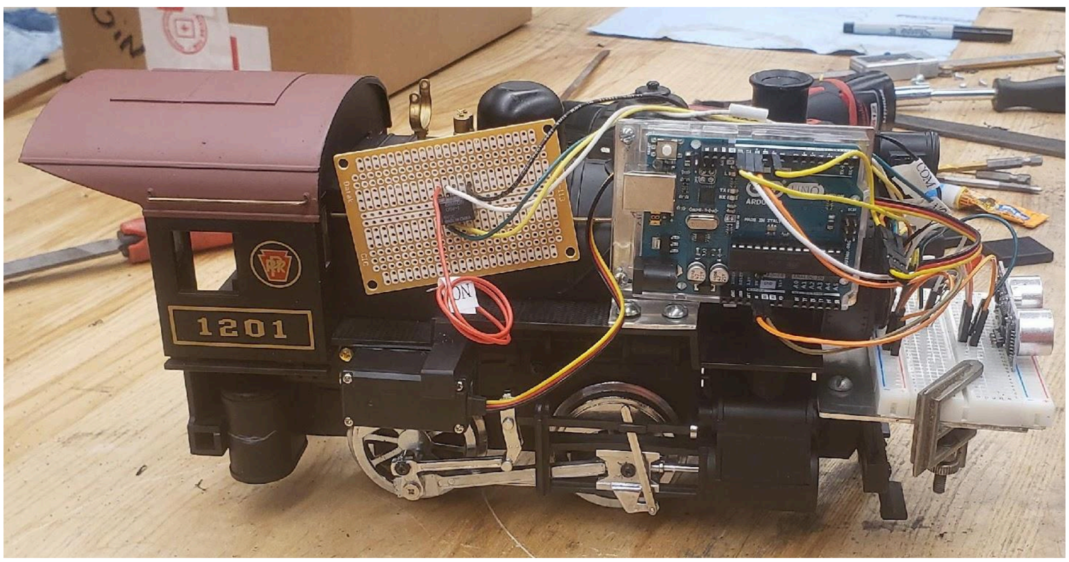

Figure 9. The Modified Locomotive

2 Onboard Sensor System

The sensor sent out a pulse out in front of it and had a receptor to catch any return signal from an object in the distance. The code used to program the sensor detected the distance and returned the distance as a float on the console. If an object was detected within 20 mm or 2 cm, then an LED would be flashed on, to visibly show that an object has been detected. Additionally, the arduino would relay a signal to the servo to change the position of the servo arm to 20 degrees. If an object was not detected within 20 mm, then the LED would be off and the servo position to 180 degrees.

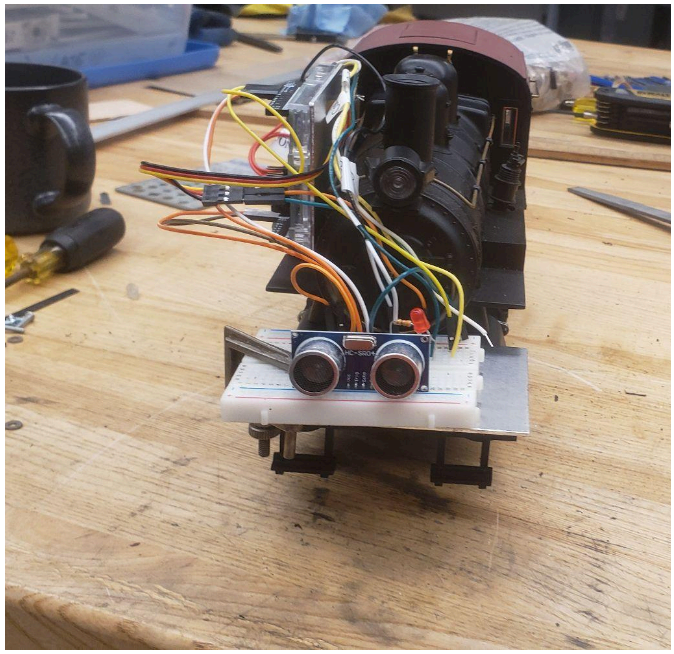

Figure 10. The Modified Locomotive Front View with Sensor

3 Clutch Braking Models

The initial design of the brake shoe was a triangular wedge. After testing and finding out that the triangular wedge lacked contact area with the wheel, a revision was made to make the shoe more curved along the side that interacted with the wheel. This increased the contact area and therefore increased the braking force on the wheels.

Figure 11.Close Up on Model 1

Figure 12. Close on Model 2

5 Results and Discussion

1 Sensing and Response

The sensor detected an object in front of it within an average of 5.7 seconds. Within the time the sensor detected an object, there was a quarter second delay between the detection and the brake activation. The rubber material used for the brake shoe applied friction onto the wheel without permanent distortion to the brake shoe itself or damage to the wheel and it maintained its effectiveness after 25 trials, with no distortion or wear.

2 Limitations of Current Model (Power Woes)

In testing, the train was limited to low power use to prevent excessive wear on the wheels and to preserve the material. The range of transformer nominal power settings used was 0-50 out 0-100. Due to the inherent limitation of wheel-tread brakes, using the current system as is for higher speeds was not viable. An extension to using disc-brakes to apply the frictional force can be considered to handle higher speed situations. Using the first model of the brake shoe, the train only stopped reliably, within 5-7 seconds, 7 times in 25 trials. In the other trials, the train continued moving forward but significantly slower. With higher power settings, the effectiveness of the brake lowered. While the activation time stayed the same, the speed reduction was noticeably lower. After the revisions to the brake shoe, the number of successful stops in 25 trials were 21, with the train only slightly irking forward. In the 4 trials where the train did not stop, there was still a noticeable speed reduction.

3 Future Work

Considering that the crank was still turning the wheels while the brake was activated, the brake likely had to work harder to stop the train from moving. Given extra time, I would have rewired the train motor to connect to the relay wired into the arduino so that the relay could regulate the power being supplied to the motor. Considering that the power to the motor is supplied directly from the rails, a switch would have to be created to create a short circuit when the brake is activated so the motor stops turning the crank on the wheels. This would leave the frictional force to only have to counter the residual momentum left in the wheels while it was previously accelerating.

6 Conclusion

During this project, I made a proof-of-concept prototype of an automatic braking system for a locomotive. The braking system was successful at stopping under optimal conditions and slowing the locomotive otherwise. This ability to slow the locomotive even outside of optimal conditions is useful in emergency situations where a reduction in speed is the difference between saving more lives and not.

1 Impact of Automatic Braking

Automatic Emergency Braking (AEB) systems are already widely implemented. Research by IIHS during the period of 2010-215 found that vehicles equipped with AEB exhibited a 50 percent decrease of police-reported rear-end crashes relative to equivalent vehicles without an AEB system [6][7]. This data was over twenty-two states and in six makes, taking into account police-reported rear-end crashes with or without injury. A similar improvement could be made to safety when it comes to implementing these systems in large vehicles such as locomotives. In a proposed standard by NHTSA and FMCSA, the administrations estimated that a widespread implementation of AEB systems would prevent 19,118 crashes, saving lives and preventing injuries [8] .

2 Limitations of AEB

AEB does have its limitations [9]. Depending on ambient conditions such as rain, snow or ice, braking conditions will change. Also false alerts can happen due to reflections, road shadows, cars parked along the curve or even vehicles driving in the adjacent lane. This system also isn't guaranteed to stop or prevent accidents alone, as it requires human control to fully activate the braking in order to force a stop. Even though AEB is not a substitute for paying attention while operating a vehicle, it is helpful for assisting humans with slowing down in emergency situations and reducing the impact of a crash.

Acknowledgements

I would like to acknowledge my advisor Professor Lynne Molter for advising me, helping me keep on track through weekly meetings, and guiding me from ideation of this project to product. I would like to acknowledge J. Johnson for his mechanical and machine shop expertise, mounting the parts onto the train and discussing surrounding material for the brake. I would like to acknowledge Edmound Jaoudi for his electrical and computer expertise, for the arduino, servo motor, relay, the wiring of it all, as well as starter code to help me get started. I would like to thank Catherine Burnet for ordering materials for my project.

7 Bibliography

1. “How Much Freight Ships by Rail In the US?,” *www.up.com*. https://www.up.com/customers/track-record/tr120120-freight-rail-how-much-ships-by-rail.htm

2. “Amtrak Routes & Stations,” *www.amtrak.com*. https://www.amtrak.com/train-routes

3. V. B. Bhandari, *Design of machine elements*. New Delhi: Tata Mcgraw-Hill, 2010.

4. Rakesh Chandmal Sharma, M. Dhingra, and R. K. Pathak, “Braking Systems in Railway Vehicles,” *International journal of engineering research and technology*, vol. 4, no. 1, Jan. 2015.

5. D. Joshi, Ed., Week 2 Railwheel and Track. 2020. Accessed: May 19, 2024. [Online]. Available: https://skill-lync.com/projects/week-2-railwheel-and-track-22

6. “Anatomy Of A Locomotive Properanatomy | Images and Photos finder,” aiophotoz.com. https://www.aiophotoz.com/photos/anatomy-of-a-locomotive-properanatomy.html (accessed May 19, 2024).

7. “AUTOMATIC EMERGENCY BRAKING PERFORMANCE IN THE CONTEXT OF COMMON CRASH SCENARIOS SEPTEMBER 2022 NewsRoom.AAA.com.” Available: https://newsroom.aaa.com/wp-content/uploads/2022/09/Research-Report-2022-AEB-Evaluation-FINAL-9-26-22-1.pdf

8. IIHS-HLDI, "IIHS eyes higher-speed test for automatic emergency braking," 5 May 2022. [Online]. Available: https://www.iihs.org/news/detail/iihs-eyes-higher-speed-test-for-automatic-emergency-braking. [Accessed 23 June 2022].

9. “NHTSA and FMCSA Propose New Safety Standard Requiring Automatic Emergency Braking Systems in Heavy Vehicles | NHTSA,” www.nhtsa.gov. https://www.nhtsa.gov/press-releases/heavy-vehicles-automatic-emergency-braking-proposed-rule

10. S. Fogel, “Automatic Emergency Braking: How Does Your Car Know When To Stop?,” SlashGear, May 01, 2024. https://www.slashgear.com/1570308/how-automatic-emergency-braking-works-explained/ (accessed May 19, 2024).

8 Appendices

1 Arduino Code

```
/*
 * System Control
 *
 * https://create.arduino.cc/projecthub/Isaac100/getting-started-with-the-hc-sr04-ultrasonic-sensor-036380
 *
 * based on HC_SR04 by Isaac100
 */
#include <Servo.h>

const int trigPin = 11;
const int echoPin = 12;

Servo myservo;  // create servo object to control a servo
int posin = 20;    // variable to store the servo position
int posout = 180;
int alarmdist = 20;   // variable to store the alarm distance

float duration, distance;

void setup() {
  myservo.attach(9);  // attaches the servo on pin 9 to the servo object
  pinMode(13, OUTPUT);    // sets the digital pin 13 as output
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  Serial.begin(9600);
}

void loop() {
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  duration = pulseIn(echoPin, HIGH);
  distance = (duration*.0343)/2;

    if (distance<alarmdist){
   myservo.write(posin);
   digitalWrite(13, HIGH); // sets the digital pin 13 on
   Serial.println("Stop!");
   } else {
   myservo.write(posout);
   digitalWrite(13, HIGH); // sets the digital pin 13 on
   Serial.println("Full Speed Ahead!");
   }

  Serial.print("Distance: ");
  Serial.println(distance);
```

```
delay(100);
```