Toy Train Safety Control System

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1. Introduction

1.1 Objective

The toy train is a lot of fun for children and it decorates our Christmas tree at home. However, as many users complain, toy trains may be derailed and damaged by running too fast at the bend or hitting an obstacle on track, which creates inconvenience and even money loss for toy train users [1]. Therefore, we want to design a safety control system able to detect the bend and the hazard obstacle on track, and thus slow down or stop the train in order to prevent the potential derailment and damages to the train.

We will use the computer vision as our main method to solve this problem. Specifically, we will install a camera at the locomotive of the toy train, and transmit the downsampled images shot by the camera to the computing unit for image processing. The computing unit should recognize patterns such as the curvature of the track and the obstacle amidst the track. Based on the recognition, the computing unit should determine the action of the train (run normally, decelerate, or stop), and send out a command signal to the power control system on track. The power control system on track is a circuit that receives the command sent from the computer, and change the voltage supplied to the train according to the command to control the speed of the train.

1.2 Background

As we researched on how the derailment is caused and how to avoid the derailment, we found three suggestions given by National Model Railroad Association: 1) the scenery or remodeling is done at the area of derailment; for, example, an obstacle stucks at the track, and the solution to this issue is to check the track again and remove that obstacle; 2) the toy train itself has problems; the solution to this issue is to check the inner elements of the toy train, the engine, the wheel and etc; 3) the switch of the track is not smooth. The solution is to clean the frog and guide rails free of debris [2]. However, all these troubleshootings are based on the fact that the train has already derailed, people have to check the system and environment conditions of the train, and assume the operating system and environment of the train would not be changed after people fixed the problem or the train might derail again. Our concern is that the train cannot automatically respond to the environment and prevent itself from derailing. For example, Supposing that the train runs normally on the track but suddenly a gift box hanging in the Christmas tree falling onto the track, if the train cannot automatically respond to the environment changes, it may directly hit the gift box on track and damages may be caused.

Therefore, we plan to build a system which can detect the potential hazards in the environment as mentioned above. Our terminal goal is that the industry can add our safety control system to the model train production, so that the quality of the model train can be efficiently increased and consumers will be more satisfied with their consumption.

1.3 High-level Requirements

- The toy train can run smoothly on the track even if there are obstacles or a large curvature bend without derailment.
- The safety control system is able to detect the obstacle, and the toy train must stop before hitting an obstacle amidst the track. The train must stop within 5 seconds if the train is about to hit the obstacle in 5 seconds with its original speed.
- The safety control system is able to detect the bend of the track, and the toy train must slow down to a safe speed (below 0.5 times of its original speed) before going through the bend on track.

2. Design

2.1 Block Diagram

The toy train safety control system consists of three Modules: power control module, computing module, and camera and transmitting module. The Power control system has two sources of power supply; one is 5 volts DC voltage from the AC-DC convertor supplied to digital signal controller, and the other is 12 volts DC voltage also from the AC-DC convertor supplied to voltage transformer. These two convertors are bought from the market for safety concerns, and they are connected to 120 Volts AC power. This module receives the command from the computing unit. According to the commands received, it controls the voltage supplied to the DC motor, and starts or closes the braking system. The computing unit will process the image sent by the camera and wireless transmitting module. It will determine whether the train is about to hit the obstacle on track, go through the bend, or the train runs normally. Based on the judgement, the computer will send a signal corresponding to the running condition of the train to the power control system. The camera and transmitting module has a Li-Ion battery as its power supply. Because this module is attached to the train, it will run together with the train on the track. The camera shoots the picture of the front of the train. The microprocessor stores the frames in its flash memory, down samples the image, and transmit the image data to computing module through the wifi transmitter.

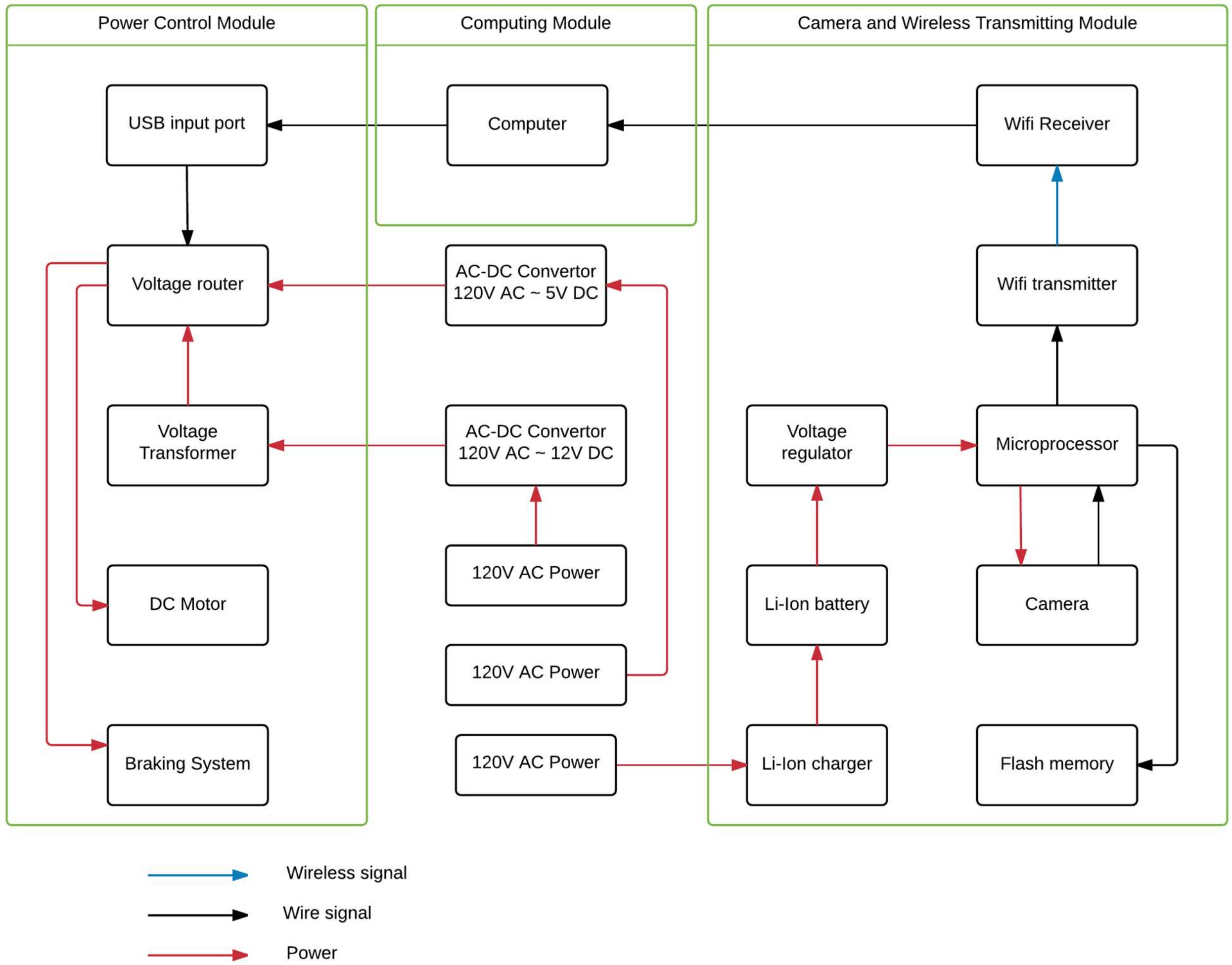

Figure 1. Block Diagram of Toy Train Safety Control System

2.2 Functional Overview

2.2.1 Motor Control Module

The motor control block basically consists of a voltage controlled voltage source, which delivers its output directly or indirectly to the motor. It controls the running speed of motor by managing the voltage drop across the motor, based on the input command signal from the microprocessor/computer. In addition, it should be able to initiate the motor or make the motor come to complete stop (with an electrical-mechanical braking system) once the corresponding command voltage signal from microprocessor is delivered to the motor control circuit. If necessary or specifically required by the motor, the motor control block will also provide a protection circuit for the motor, just in the case of a sudden short or excessive value of voltage attempted to be applied across the motor.

2.2.1.1 Command recognizer

The command recognizer functions as the interface between the computer (the actual controller of train motion) and the motor. It recognizes the input command from computer/microprocessor, and pass it to the subsequent motor control circuit in DC voltage format.

2.2.1.2 Voltage Transformer

The voltage transformer is essentially a set of voltage amplifiers, taking in different small input voltages from command recognizer and output the correspond voltages of 0V, 5V or 12V (depends on value of voltage passed by digital signal controller), which eventually drives the motor.

2.2.1.3 DC Motor

The DC motor directly connects to the wheel, taking in a certain value of DC voltage to operate. It is supposed to be run with rated voltage which is 12V, but may be subject to voltage that is below the rated voltage.

2.2.1.4 Braking System

The braking system functions on the wheel of the train, which consists of an electromagnetic relay and a braking pad, powered by DC voltage. Depending on whether the input voltage is on or off, the braking system will be either braking the wheel or doing nothing.

2.2.2 Computing Module

This module receives images sent from the camera and transmitting module. To detect whether there is a potential hazard in front of the train, the computer will use the segmentation process to recognize our wanted patterns, the curvature of the track and the obstacle. Specifically, the image shot from the camera at the locomotive should be divided into two regions, the region between the track, and the background. As the assumption we made, there will be some color contrasts between the track and its background. Then we can threshold the grey level and divide the pixels into groups, and then recognize the patterns.

Specifically, we mainly want to distinguish the track from the environment in the picture. Because the track is a consistent line without much of color changing, we can utilize this feature to recognize the track. First, we will find the histogram of the picture. As we assumed, the environment is mainly light colored, so the color of the dark track will concentrate on a certain spectrum of the histogram. Then, the second step is to recognize this specific spectrum. Because the track lies mainly in the middle at the bottom of the image, we can find the relatively dark area at the middle bottom of the image. calculate the mean grey level, and standard variance of these dark pixels. Then, from the bottom to the top of the image, put the pixel which has grey level lies in [mean - 2 * sd, mean + 2 * sd] into the track recognized region. Then, the track can be fully recognized. With the same idea, after the track is recognized, we can recognize the colored obstacle in the middle of the track.

2.2.3 Transmitting and control unit

A control unit with input taken from a camera of pictures of the current train track, down samples it by approximately 10 times lower to meet the requirement of the processing speed of the recognition program (about 2 fps) of the computing microprocessor and then transmit a control signal through Wifi to the power control unit.

2.2.3.1 Camera

This part will be purchased online and connected to our circuit on the train to take the pictures of the track. In our design, we plan to use CMUcam5 Pixy but only use the most basic function of the camera, taking pictures. CMUcam5 Pixy is a very powerful camera with a programmable chip that can detect certain object and interact with the outside microprocessor but we will just use the function of the camera and do the detection on our own.

2.2.3.2 Microprocessor

Implemented on the train to take input images and downsample the images to a lower rate. We plan to use Raspberry Pi 3 purchased at the machine shop. This microprocessor is responsible for communicate with camera and wireless module and send images to be processed. Some pre-processing such as increase the contrast of images from the camera, or increase the brightness of the images might take place before transmission.

2.2.3.3 Wireless transmitter

The wireless transmitter is implemented on the train to receive data downsampled by the microprocessor and transmit data to the wireless receiver connected to the computing microprocessor.

2.2.3.4 Wireless receiver

The wireless receiver is implemented beside the computing unit to receive images transmitted from camera.

2.2.3.4 Power supply

Since all the on-train hardwares require a relatively low voltage to work, we would use rechargeable Li-ion batteries to supply power. To be more specific, we plan to use 18650 3.7V

5000mAh Rechargeable Li-ion Batteries and a voltage regulator to stabilize the output voltage to 5V and 6-10V.

2.3 Block Requirement

2.3.1 Motor Control Module

Requirement 1: The command recognizer circuit should be able to recognize and greatly recover the command signals sent from computer (expected to cover above 90% command signal bandwidth).

Requirement 2: The voltage transformer combined with voltage regulators should be able to offer the motor a steady DC voltage within the 2% error tolerance range of motor.

Requirement 3: The self-made electrical-mechanical braking system should be able to respond shortly after the power is on (we can probably increase the voltage supplied to it) and be powerful enough to brake the train within 1.5s when needed.

Requirement 4: The DC motor needs to be able to run under the rated operating voltage (about 12V) for some time.

2.3.2 Computing Module

Requirement 1: The computer is able to operate C program consistently.

Requirement 2: The computer has powerful enough computability. We expect it to have at least 1 GHz CPU speed and 128 MB RAM.

Requirement 3: The computer has at least two USB 2.0 or USB 2.0 above ports.

Requirement 4: The algorithm can finish process each image in 0.5 seconds at most.

Requirement 5: Because the track is black, the environment around the track must be other lighter colors for the algorithm to recognize the pattern of the track.

Requirement 6: The obstacle should be put at a distance that the train runs at least 5 seconds with its normal speed to complete for the computer to recognize.

Requirement 7: The color of the obstacle cannot be any color similar to the colors of the track and the objects amidst the track but not obstacles for the computer to recognize.

Requirement 9: The obstacle should be large enough that the computer can recognize.

2.3.3 Camera and Transmitting Module

2.2.3.1 Camera

Requirement 1: Work properly under the correct voltage of 6-10V.

Requirement 2: Maintain at least 20 fps

Requirement 3: Capable of taking processable images above 300 Standard Maintained Illuminance(lux)

Requirement 4: Capable of taking images with resolution of at least 640x480

Requirement 5: The camera should run under light illumination environment.

2.2.3.2 Microprocessor

Requirement 1: Work properly under the correct voltage of 2.5A@5V

Requirement 2: It is able to down sample the frame rate to approximately 2-5 fps

Requirement 3: Clear up its buffer with at least 5MB used for store input images every 5 seconds

2.2.3.3 Wireless transmitter

Requirement 1: Capable of transmitting data above 500 Kb/s

Requirement 2: Capable of transmitting data within 5 meter omni-directional

2.2.3.4 Wireless receiver

Requirement 1: Capable of receiving data over 500 Kb/s

Requirement 2: Capable of receiving data within 5 meter omni-directional

2.2.3.4 Power supply

Requirement 1: Capable of providing 5V and 6-10V

Requirement 2: Capable of powering the camera, microprocessor and wireless transmitter for at least 10 minutes.

2.4 Risk Analysis

The braking system, which basically consists of an electromagnetic relay combined with a brake block, may pose great possibility of failure to our project's functionality. As for a self-made electromagnetic relay, it may look like below:

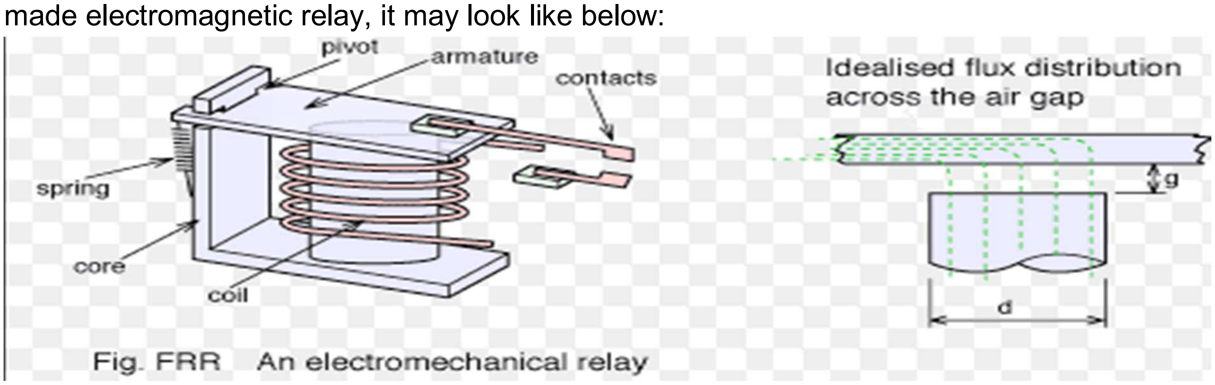

Figure 2. Self-made electromechanical relay prototype [9]

To let the electromechanical relay reach our expectation, it requires careful calculations and cautious selection of magnetic materials. Whether the relay is able to provide magnetic field that is strong enough to pull the contacts up depends on several elements: The voltage offered at the input portal, the spring constant, how we wind up the iron core, and etc. If the concise calculation about several parameters (such as the spring constant and number of winding rounds) is not performed under extreme care, the relay may drop the contact at any time, therefore causing unexpected brake.

The wireless communication module responsible for transmitting images taken by the camera can also be risky. We plan to use wifi as our transmission method but a lot of wifi chips need to connect to a router instead of directly communicating with each other. As a result, we need to put more effort and researches to design this module so that we can use wifi to directly communication between two chips.

The computability of the computer to implement the algorithm we choose is a crucial determinant of the success of our project. We propose that the computer has to finish processing each image within 0.5 seconds. Even though we researched that thresholding a 1024x1024 pixels image only took 0.03 seconds [7], however, the computability difference of different computers is apparent. Also, this step is only to threshold the grey level of the image. After the threshold, we will have to implement the algorithm described in 2.2.2, which takes a longer time. Therefore, there is a risk that the computability cannot satisfy our requirement. Under such a condition, we can use a more power computer or slow down the normal speed of the train in order to enrich the processing time as a remedy.

3. Ethics and Safety

There are several potential safety hazards in our project. The first safety issue we have thought of is the usage of a AC-DC converter to convert the existing 120V to a smaller voltage for our use, the circuit might heat up and burn if some of the connections of our circuit are broken. Considering the 1st rule of IEEE code of ethics, "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" [8], we will do our best to avoid causing unsafe factors. We will check all the connections between AC-DC convertor and our circuits before turning on the operation.

Second, the motor running condition also arouses safety issues. The motor is supposed to run with the rated voltage. However, it is possible that the DC voltage supplied to the motor is not perfect and may not be stable over a long period of time. As a result, there might be some time that the motor will be expected to run with a voltage under or above the rated voltage. This may cause potential damage to the motor, resulting in a crash-down of motor after a long time of usage or testing. Just like we state above, we will do our best to avoid these hazards considering the 1st rule of IEEE code of ethics [8]. To avoid this happening, we would explore how the motor of the toy train works, including output power under rated voltage and lower voltage than the rated voltage. Based on the output power, we will threshold the minimum and maximum voltage supplied to the motor. We would do some experiments to fully justify what we found on the internet about the characteristics of the motor and during this process, the motor would suffer from a risk of heating up as well because the main goal of our project is to brake the train so if we can't control the power of the motor, part of the energy that should have transformed to dynamic energy would be transformed to thermal energy. we would do lots of researches online for instructions to build up the hardware frame that takes images taken by the camera and transmit it to the other microprocessor so it would be very important to keep academic integrity and put everything we cited clearly in reference.

Third, the Li-Ion battery stores a large amount of energy. If it is overcharged or operated in wrong condition, it may explode. Considering the 1st rule of IEEE code of ethics [8], we would try our best to avoid this happening by strictly operating the regulatory standard. We will charge the Li-Ion battery with the nominal voltage of 3.2~3.65 volts [10]. We will clean the contacts of the Li-Ion battery before usage [11].

References

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