Automated Rail Switching System with Real-Time Applications

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Abstract: The objective of this research is to design an automated railway track switching system for junction crossings. This system will be integrated with a centralized monitoring interface to improve safety monitoring, streamline railway scheduling, and provide flexible route management. The suggested concept seeks to simplify complexity and lower implementation costs. It is based on Arduino microcontroller technology. The technology makes sure that switches move precisely by using infrared sensors to detect train locations and a DC motor and a manually constructed linear actuator for gate control. Software that shows train locations in real time makes it easier to monitor and visualize the whole system and provides opportunities for statistical data collecting and analysis. This model is capable of handling several junction railway lines and the simultaneous passage of one or more trains along the route. It may be operated manually or automatically from a central control center.

Key words: Automated railway track, monitoring interface, Arduino, infrared sensor, DC motor.

1. INTRODUCTION

Over the past several decades, train travel has become one of the most effective and commonly employed ways of transportation all over the world. One of the most important factors in linking large populations is the railway network, which is predicted to increase by a factor of two during the next two years. On the other hand, the heavy dependence on human administration for train scheduling,
track changes, and monitoring has led to monetary losses, delays, and a variety of operational issues [1]. Significant difficulties and financial losses are caused by a number of factors, including obsolete operational procedures, disturbances to the timetable, overcrowding, and problems in the track that are not recognized. The process of manually changing tracks, which frequently involves the use of hand levers, is prone to communication problems and severe weather conditions, which can result in expensive diversions and the waste of additional resources. When the Christmas season is at its zenith, disturbances to the schedule that can continue for up to 18 hours make these problems much worse [2]. Tickets are increased without any improvements being made to the services or facilities in order to compensate for the financial losses that are incurred as a result of cancellations. In addition, the absence of real-time train location awareness makes it more difficult to conduct prompt rescue operations in the event of accidents, which ultimately leads to more collateral damage. As a consequence of this, several nations have implemented automated systems in order to handle these difficulties, a trend that is continuing to gather steam among them. In order to address these issues, the system that we have developed has a central monitoring interface in addition to an automatic track-changing mechanism that is based on centralized source and destination inputs [3]. This allows for accurate tracking of train locations. It is possible to considerably improve the efficiency of rail travel in terms of fuel consumption, costs, and time by utilizing established and adjustable routes.

The operation of the junction switch is dependent on the input of the specified route as well as the acquisition of real-time train location information through the use of infrared (IR) sensors. For example, Meyer et al.’s concept for route-based vehicle control and a smart railway control system that integrates GPS and GSM for location detection are two examples of automated vehicle control systems that have been investigated in previous research. The switching of train tracks and electronic monitoring are not included in these research, according to the findings [4]. In addition, although models of self-driving trains have been developed, the adoption of these models would need large overhauls in the railway industry. This would involve enormous financial expenditures and extended execution time-frames [5]. In a rail-track switching system, the junction-switch adjusts its position to guide the train to its destination and prevent collisions when multiple trains share a rail-track [6]. This technique uses sensors without central monitoring or manual control. Sensor failure might cause railway mismanagement and collateral and financial losses. Previous research demonstrated sensor-based track changing and collision avoidance algorithms without centralized surveillance and control [7]. Despite a GPS location tracking system [8], its influence on train velocity and incapacity to predict and mitigate natural calamities restrict it. Communication-based train control systems [9] require computer-based monitoring modules at specified sites to identify train movements. Our system design prioritizes variable route inputs, centralized control-based track changes with human and automatic control, and continuous central surveillance to monitor train locations. Centralized control makes railway data collecting for future improvements easier. Our prototype has 26 IR sensors along the rail-track to track train locations. The sensor alerts our Arduino microcontroller to train locations at crossings, preventing collisions [10]. The Arduino system monitors sensors and manages
DC motors to modify the junction-switch, using manual gears to convert rotational motion to linear motion. We present the track layout, including railway station and sensor sites, so we can watch several train movements at once.

2. IMPLEMENTATION

We will outline the suggested design and the step-by-step implementation process in this part, along with the component ratings. There are three components to the overall process:

1. Development of Hardware
2. Development of Software
3. Building Structures

Figure 1 shows the prototype railway model that was used to design the construction. Here, supposed stations are indicated by A, B, and C, while junction crossings are represented by J1 and J2. Probable track locations at J1 and J2, respectively, are indicated by L1, R1, L2, and R2.

![Prototype railway model](image)

**Figure 1.** Prototype railway model

A. Development of Hardware:
1) Power Supply: An AC to DC converter converts 220V, 50 Hz AC power into a 5V DC supply, sufficient for the IR sensors, Arduino MEGA, and Arduino DUE functions. A single 9-volt battery supplies the motor circuits.
2) IR Sensors: As shown in Figure 2, 26 IR sensors are positioned between two train sleepers in order to precisely determine the train’s position and provide data to the microcontroller.
3) Arduino: To identify IR sensor outputs and transmit data to the computer and motors, Arduino MEGA and Arduino DUE are utilized. Through a USB connection, Arduino DUE enables serial communication with the computer. In order to increase the amount of analog inputs available for getting
data from all IR sensors, two Arduinos are used.

4) Matrix Keypad: Information about the source and destination stations is submitted using a 4x4 matrix keypad, which is essential for figuring out the train’s travel path.

5) LCD Module: The names of the source and destination stations are shown on a 16x2 LCD module that is incorporated to display the output from the 4x4 matrix keypad.

6) L293D Motor Driver: This motor driver is used to drive the motors. It can provide an output current between 600mA and 1A, which is appropriate for the DC motors that are used in our system.

![Figure 2. IR sensor along the track](image)

**B. Development of Software:**

1) Computer Interface: Using Unreal Engine 4, our team has created a real-time C++ computer interface software. This software, which works with Microsoft Windows operating systems, looks for serial data (bytes) that the microcontroller sends over the USB port on the computer. When the received byte is compared to the predefined values linked to every infrared sensor, the software shows the associated active sensor on screen. Furthermore, the microcontroller enables it to interpret keypad inputs and display the relevant station names.

2) IR Sensor: The IR sensors are interfaced with using Arduino MEGA and Arduino DUE boards. Using the Arduino Integrated Development Environment (IDE), we uploaded the required scripts. The Proteus Design Suite was used to simulate the circuit in order to validate the circuitry prior to real hardware construction.

**C. Building Structures:**

1) Chassis: Beneath the rail-track is a lightweight 5-mm thin plastic wood chassis that is used to ease the passage of numerous connecting cables. This material, which forms the basis of the entire
construction, was selected due to its simplicity of drilling and mobility.

2) Motor: To operate a linear actuator, each of the two junctions has a 12-volt DC motor that is set to rotate in both directions as needed.

3) Linear Actuator: We used sturdy plastic to create a tiny, handcrafted linear actuator for our model of a miniature train track. The actuator has the ability to respond to motor rotation by pushing or pulling the junction-switch.

D. Rating of Components: We followed the recommended voltage and current specifications for every component to guarantee the secure operation of our automated railway system. The elements that make up our architecture are listed in the table below along with their corresponding ratings. The comprehensive details are shown in Table 1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>9V</td>
</tr>
<tr>
<td>AC-DC converter</td>
<td>220V 50 Hz to 5V</td>
</tr>
<tr>
<td>IR Sensor</td>
<td>5V</td>
</tr>
<tr>
<td>Arduino MEGA 2560</td>
<td>5V</td>
</tr>
<tr>
<td>Arduino DUE</td>
<td>5V</td>
</tr>
<tr>
<td>4x4 Matrix Keypad</td>
<td>5V</td>
</tr>
<tr>
<td>16x2 LCD Module</td>
<td>5V</td>
</tr>
<tr>
<td>L293D Motor Driver</td>
<td>5V</td>
</tr>
<tr>
<td>DC Motor</td>
<td>12V, 1A, 300 rpm</td>
</tr>
</tbody>
</table>

3. METHODOLOGY

A. Module for the Selection of Routes:
A feature that enables users to pick the beginning point and destination station of the train is incorporated into our suggested system. This feature makes it possible for users to facilitate variable route inputs. This capability allows for route modifications to be made based on passenger demand during peak seasons or hours. Additionally, it allows for the tracking of the train’s movement and the selection of appropriate motors for switching the junction switch of the rail line. The matrix keypad is employed for this purpose, and it is through this keypad that information regarding the source and destination is inputted. Following that, the information is sent to the central monitoring unit through the use of Arduino.

B. Module for Monitoring the Position of Trains:
The fundamental component of the position tracking device contains infrared (IR) sensors, strategically positioned at regular intervals along the model rail-track, as depicted in Figure 2. To function, these sensors send out infrared waves and then detect the signals that are reflected back to them. The output of a sensor remains low when it does not identify any obstacles, which indicates that there is
no presence of a train. On the other hand, the output will change to high once a train passes over the sensor of the sensor. Continuously sent to the microcontrollers are the readings that are obtained from each of the 26 infrared sensors. Additionally, these readings are connected to the computer interface program using Arduino DUE through the use of USB connection in real time.

**C. Rail-Line Switching Module:**
The motor input pin that is responsible for regulating the movement of the junction switch is triggered when it is determined that the IR sensor that is located closest to a junction has produced a high output. Through this action, the linear actuator is prompted to move the junction switch in the forward direction, which makes the change in its position easier to accomplish. After that, the motor input is transferred in the opposite direction when the final bogie of the train passes the sensor that is located in front of the junction. Before the actuator moves it back to its default position in the other direction, there is a little delay that is inserted to guarantee that the junction flows through without any obstructions. The second junction (J2) and the switching unit that it contains are depicted in Figure 3 of our model. The essential track positions that correspond to the input source and destination stations, as well as the direction of the train (clockwise or counterclockwise), are outlined in Table II. In order to keep things simple in our prototype, we have only examined the movement of the train position in a clockwise direction.

![Figure 3. Track changing motor with linear actuator](image)

**D. Central Monitoring Unit:** The Central Monitoring Unit accomplishes the objective of observing the location of trains in real time from a centralized office. Additionally, it provides human control of the mechanism that changes the track. The application that we have developed is quite lightweight and functions with a click-to-run feature. It was developed using Unreal Engine 4. Instead of using frame-ticking subroutines, we have built trigger-based subroutines that are reliant on the serial data that is
being received. With regard to the program interface, each circle that is presented corresponds to an infrared sensor. In the event that the output of any sensor remains high, the circle that corresponds to that sensor will become red, showing the position of the train at the moment; otherwise, it will remain blue. As seen in Figure 4, a red circle represents the current location of the train as it travels towards its destination, while the remaining 25 circles continue to be blue. It is possible for the application to identify many trains at the same time, resulting in the display of multiple red circles on the screen. Using the data that is input from the keypad, it is also able to identify the names of the stations that are the source and the destination.

### Table 2. Desired Track Position

<table>
<thead>
<tr>
<th>Source</th>
<th>Destination</th>
<th>Clockwise</th>
<th>Anti-clockwise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>J1</td>
<td>J2</td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>L1</td>
<td>L2</td>
</tr>
<tr>
<td>A</td>
<td>C</td>
<td>L1</td>
<td>a</td>
</tr>
<tr>
<td>B</td>
<td>C</td>
<td>R1</td>
<td>a</td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>R1</td>
<td>R2</td>
</tr>
<tr>
<td>C</td>
<td>A</td>
<td>a</td>
<td>R2</td>
</tr>
<tr>
<td>C</td>
<td>B</td>
<td>a</td>
<td>L2</td>
</tr>
</tbody>
</table>

**Figure 4.** Computer interface showing real-time train location. (a) A red circle is showing current position. (b) As the train is moving, colors of all the circles are also updated according to new position of the train.

**E. Flowchart:**
Figure 5 is a flowchart that depicts the whole switching mechanism of any junction that is running in automated mode.

![Flowchart of the overall system](image)

**Figure 5.** Flowchart of the overall system.

4. RESULTS, ANALYSIS and IMPLEMENTATION

Ten operating cycles were completed by the full arrangement, using 26 sets of IR sensors. 21 of these sensors, on average, were able to quickly and reliably determine the train’s location and show it on the computer interface in real time. The DC motors successfully altered the track, demonstrating a reaction time of around 0.5 seconds after the IR sensors sent out data. The computer’s input data was effectively saved. Table III provides an overview of accuracy percentages. A range of sensors, including grafting sensors, linear displacement sensors, and capacitive transducers, may be systematically positioned at regular intervals along the railway rails in order to link the railway infrastructure with central monitoring offices. When passenger trains are near junction switches, these sensors are used to determine their location and direction. Position sensors can also be used to detect anomalies in the railroad tracks, including fishplate displacement, slipper displacement, or spike and bolt malfunctions. However, to guarantee optimal operation, ongoing monitoring and required system updates are essential. This gadget works in unison with our automated system, acting independently according to the movement and direction of trains as well as the source and destination stations. In order to handle any problems or faults with the automated railway system, manual control stays in standby mode. By using position sensors, exact information about the train’s position, speed, and state can be collected. This makes it easier to determine the train’s planned times of arrival and departure. With this improvement, travelers may plan their trips more effectively and save a significant amount of time.
Table 3. Accuracy of different segments

<table>
<thead>
<tr>
<th>Specification</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR Sensor</td>
<td>80.7</td>
</tr>
<tr>
<td>Motor</td>
<td>100</td>
</tr>
<tr>
<td>Interface</td>
<td>100</td>
</tr>
<tr>
<td>Data</td>
<td>100</td>
</tr>
</tbody>
</table>

5. CONCLUSION AND FUTURESCOPE

In conclusion, we have developed a prototype system that is capable of changing tracks automatically based on the direction and position of the train, and it also has the capability of being controlled manually from a central office located in the same location. Additionally, our system has a real-time computer interface that is able to continually monitor the location and movement of the trains that are moving down the tracks. Additionally, our system is equipped with an appropriate data management procedure that contains the capability to record and show the planned holding and destination stations of a train. The goal of our design is to create a concept that, if properly implemented, has the potential to bring about a significant transformation in the existing railway system. This transformation might result in increased efficiency, increased profits, and most importantly, the provision of a railway transportation system that is both cost-effective and economical. To reduce the likelihood of accidents and incidents occurring on train tracks, effective management of railway traffic is of the utmost importance. In order to ensure the safety of drivers and passengers, a strong traffic system that makes use of position sensors can efficiently restrict vehicle paths when a train is in the vicinity. Additionally, the development of mobile applications that are coupled with global positioning systems (GPS) and central interface systems can give passengers information about the locations and timetables of their specific trains. This all-encompassing system is flexible enough to accommodate and accommodate a variety of forms of transportation, including land railroads, and it has the ability to be modified to accommodate mass rapid transit systems like metros and subways. Installing position sensor systems that may inform users to keep a safe distance from active rails and show which tracks are active will help reduce the number of incidents involving trains running over each other.

References


