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A Study on Intelligent Level Crossing Safety Control System

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Abstract. Statistical data show that losses caused by railway transportation system accidents are far more severe than those incurred by highway accidents, and most of the railway accidents occur at level crossings. It is necessary and urgent to design a reliable railway crossing security system to effectively reduce the number of accidents. Through the deployment of sensors, this paper discusses how to construct an intelligent level crossing control system to reduce the loss of life and property caused by such accidents. Remote monitoring with single-chip safety control system gives real-time alarm of people or vehicles trapped at the railroad crossing. Furthermore, immediate notifications can be given to train drivers so that necessary measures can be taken in advance. With the assistance of security personnel stationed at level crossings, this intelligent level crossing safety system is expected to significantly reduce accidents.

Keywords: level crossing, sensors, single-chip safety control system

1 Introduction

Since 1960s, many countries have implemented Intelligent Transportation System (ITS) that combines electronics, communication, information, vehicle locating, navigation, and control technologies to enhance road safety. ITS takes into account many factors such as people, vehicles, weather, time, and road conditions. At the beginning of development, the focus was on highway transportation. But recently Japan, Europe, and China actively expand ITS application to railway transportation and promote research on Intelligent Railway Transportation System (IRTS) [1].

On the other hand, level crossing is the flaw of railway safety. According to the statistical data compiled by Taiwan Railway Administration (TRA), during 2005 and 2007, on the average, 25.6 level crossing accidents occurred per year, and the analysis of accidents revealed several major causes. First of all, ignorance of the Stop sign, which caused 43% of the accidents. This is followed by security gate trespassing (26.2%), careless driving (22.3%), and vehicle failures (1.6%) [2].

When people or vehicles are passing a level crossing, an accident may occur and it is impossible to make a prediction given all the possibilities. If train drivers only rely on their eyes or warning signals given off by detecting devices, there is no enough time to react when an obstacle appears at a level crossing which results in accidents [3]. To overcome the deficiency, high technology products play an important role. For instance, live videos and digital signal processing were introduced in hope of curbing the occurrence of accidents [4]. In order to reduce property loss and casualties from level crossing accidents, developing effective accident prediction models which have capability to provide useful information of accident frequency and severity given a vector of covariate [5] is necessary.

Despite of this, relate to road transportation, railway transportation is more concerned with safety, punctuality and reliability. Therefore, the ultimate goal is to enhance security and reduce the possibilities of accidents [6]. For the purpose of establishing a level crossing safety control system, issues involving

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component and system design need to be addressed [7]. The objective is to achieve high reliability and minimize misjudgment.

Our design uses composite sensing mechanisms to detect and identify potential hazards, as shown in Fig. 1. First, two pairs of infrared sensors installed at a distance of about 750 and 1,500 meters from the level crossing are used as detecting approaching trains. Second, high above the level crossing a live video camera is installed with image processing to recognize pedestrians or vehicles near or on the tracks, together with alarming horns and backend system to inform the train to slow down or trigger emergency braking. Third, an intelligent traffic light manipulation scheme is designed to direct vehicles away from the level crossing after it is shut down.

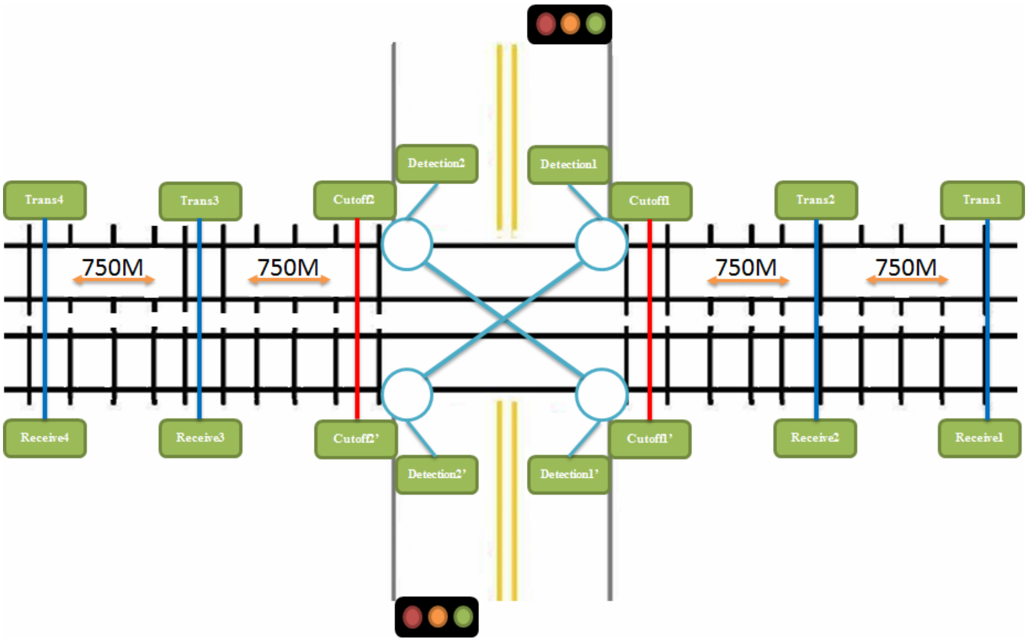

Fig. 1. Deployment of sensors in the level crossing safety control system

The following section describes the system model, circuit simulation, and designing process of the intelligent level crossing safety control system. Section III will present the prototype system software and hardware. Finally, Section IV draws the conclusion and points to future direction of system development.

2 Level Crossing Safety Control System

2.1 System Model

In Taiwan, level crossing safety system is designed to meet the requirement of the Taroko Express, the currently fastest train on the tracks. The level crossing alarm must be triggered at least 45 seconds prior to a train passing the level crossing.

The velocity of Taroko Express is 130 km/h or 36.1 meters per second and can travel a distance of 1,625 meters in 45 seconds. Under dry condition, the coefficients of friction between rails and steel wheels are from 0.25 to 0.3. The maximum deceleration exerted by the braking system in case of emergency is 4.32 km/h/s. Hence, from braking to a full stop requires 30 seconds. According to Newton's law of motion, with a equal to –4.32 km/h/s=–1.2 m/s2, the braking distance S of the Taroko Express is

$$V_0^2 + 2aS = 0\,,\; S = 588 \text{ m}. \quad \textbf{(1)}$$

Under wet condition, the coefficients of friction between rails and steel wheels fall from 0.27 to approximately 0.19. As a result, the maximum deceleration value is

$$a = -1.2 \times \frac{0.19}{0.27} = -0.84\mathrm{m/s^2}. \quad \textbf{(2)}$$

Newton's equation of motion, with the substitution of rainy day deceleration value of a, gives the braking distance as

$$S = \frac{(36.1\mathrm{m/s})^2}{2 \times 0.84\mathrm{m/s^2}} = 775\mathrm{m}. \quad \textbf{(3)}$$

Although the braking distance of Taroko Express is very long, there is only one safety warning device, the manual operating emergency button at the level crossing. When vehicles are trapped at the level crossing because of unexpected vehicle malfunctioning or traffic jam, the driver is supposed to get out of the vehicle and press the emergency button to warn the approaching train. But it has been found that in a lot of incidents people got caught in great panic and forgot to press the emergency button at the first moment. After the driver finds there is no way to move the vehicle away, it is too late and an accident is inevitable.

After alarms are activated, Taroko Express will arrive at a level crossing in 45 seconds and take 588 meters to brake to stop under good weather condition. This allows only 28 seconds to take necessary actions - pressing the button and making the train stop right before the level crossing. The reaction time is further reduced to 23 seconds under bad weather condition. In case the emergency button is pressed, the train driver who has to decide whether to start the braking to slow down the train will received a signal. To increase reaction time, a safety control system is designed to automatically detect obstacles in the level crossing area. Simultaneously, alert signal is transmitted to the auto-braking system on the train to avoid accidents caused by improper or untimely human operation.

2.2 Control System Design and Simulation

The development of the level crossing safety control system uses chipset and circuit assembly in its composition. It also employs computer simulation in design, debug and inspection to ensure robustness. At first, AVR ATmega16 was used in simulation as the microcontroller because of its availability. Eventually, Microchip PIC24FJ256GB106 was chosen for use in the final system. The two are pin-compatible. However, there exist some differences between the two. During the hardware design phase, we defined the I/O pins that were shared by the two chips. Later, during the software design phase, the same parameters and variables were used. As a result, only minor problems were encountered in the transition from simulation to actual implementation.

Proteus [8] was employed to simulate circuit behavior based on actual wiring diagram, as shown Fig. 2. Furthermore, Proteus code was used to test the circuit for function correctness. The main program of AVR ATmega16 chipset was written in C language, but the I/O hardware control code was written in assembly language. As mentioned above, to facilitate the implementation and debugging of the PIC24FJ256GB106 chipset, the same variables were defined in simulation and actual implementation. In addition, operation of the level crossing security gates is coordinated with the sensors that detect train movement. In the prototype model, stepper motors were used to control the security gates.

2.3 Intelligent Traffic Light Signal Control

Severe accidents often happens in front of level crossing, e.g. the intersection of Fu-Hsing Rd and Yi-Hsing Rd in Yi-Lan County which is shown in Fig. 3(a); therefore, the research expects to use this intersection as a simulation demonstration example to help solving traffic problems.

After the train approaching detection alarm is alerted, the priority is to guide vehicles off the level crossing red zone. Intelligent traffic light signal control is shown in Fig. 3(b). The red arrows mean to forbid vehicles coming through level crossing by red traffic lights, and the green arrows mean to guide vehicles away from level crossing by green traffic lights.

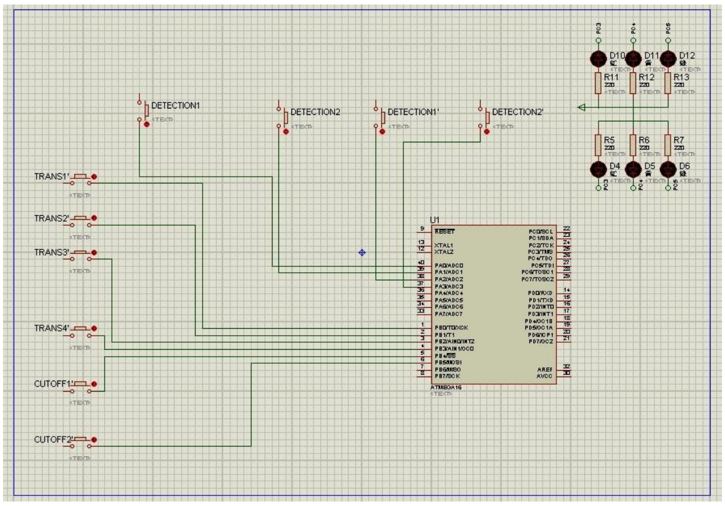

Fig. 2. Proteus simulation of the system

Fig. 3(a) Intersection of level crossing Map (taken from Google Earth)

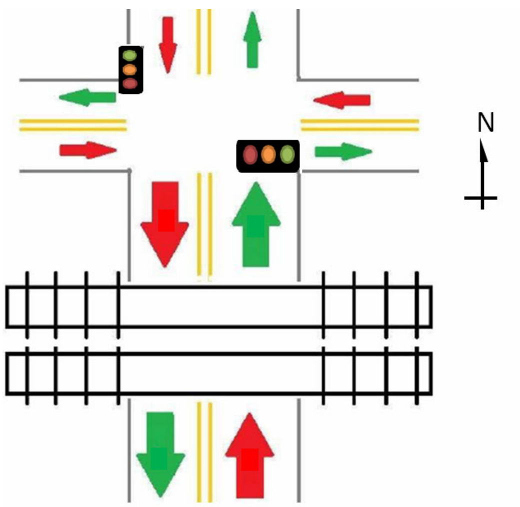

Fig. 3(b) Intelligent traffic light control

The operation of the traffic light control mechanism can be divided into two modes. In the normal operation mode, the state transition diagram is shown in Fig. 4(a). M1 is the initial state of the traffic lights in all directions with the all-red lights. After a period of t1=5 seconds, the control system switches to state M2 in which light-north-south (LNS) and light-south-north (LSN) changes to green, and light-west-east (LWE) and light-east-west (LEW) remain red. After duration of t2=60 seconds, the state changes to M3 in which the NS direction green ends, LNS and LSN change to yellow and last for t3=5 seconds. Subsequently, state M4 enters and all lights will be red for t4=5 seconds. When the state is M5, LNS and LSN remain red; LWE and LEW changes to green for t5=60 seconds. Finally, state M6 reaches, and LWE and LEW changes to yellow and last for t6=5 seconds. It then makes a transition back to state M1.

For the interrupt mode, the state graph is shown in Fig. 4(b). When sensors detect a train at a distance of 1,500 meters away, an interrupt signal I is generated and level crossing alarms alerts. Then the traffic light control system switches to state M'1 or M"1, depending on the current state of the traffic light system. If some lights are green in the state M2 or M5, the interrupt state will be M'1: only green lights change to yellow, others remain red; if lights are red or yellow in the state M1, M3, M4 or M6, the interrupt state will be M"1: all lights change to red.

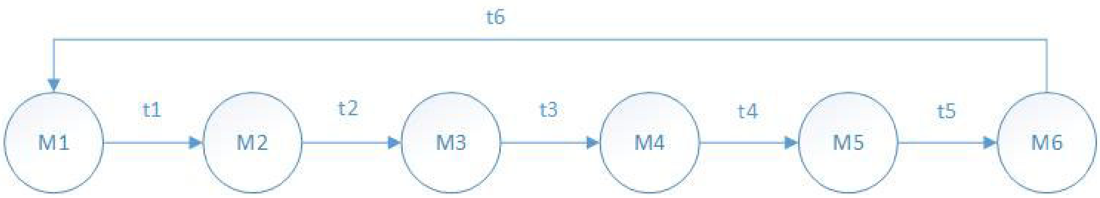

Fig. 4(a) Normal traffic light flow chart

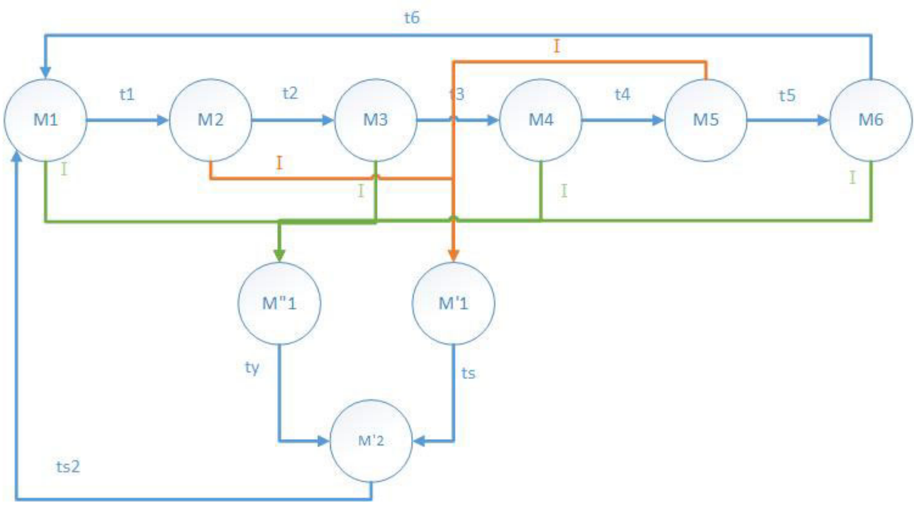

Fig. 4(b) Interrupt traffic light flow chart

After switching to state M'1, yellow lights remain for tS=5 seconds, then switching to state M'2: only the LSN changes to green to lead vehicle away, other lights are red to stop vehicles entering. Since states M1, M3, M4 and M6 lights are not green, the next state M"1 with all lights will be red for tY =5 seconds then switch to state M'2. The state M'2 continue for a time tS2 that is decided by the time of train entirely passing level crossing. After the train passes through level crossing, traffic lights return to initial state M1.

3 Result and Discussion

The prototype system is shown in Fig. 5. It was constructed with wiring between chipsets, sensors, security gate, and traffic lights. The picture also shows highway, railroad, level crossing and so on. More details of the hardware and software could be found in below paragraph.

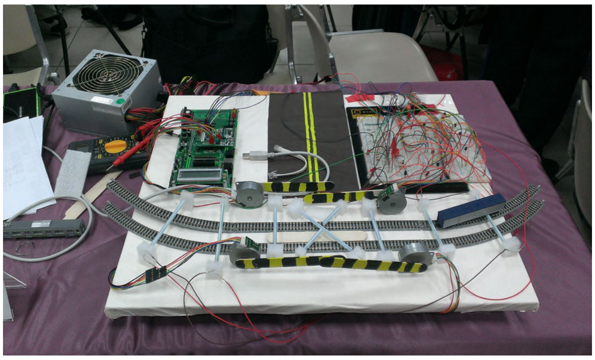

Fig. 5. System prototype

3.1 Hardware

The level-crossing safety control system is designed around the PIC24FJ256GB106 single-chip microcontroller and combines with sensors to detect one or multiple trains approaching a level crossing, alarms alert people and vehicles in the level crossing area, stepper motors to lift and shut down the security gate, and traffic lights to direct vehicles away from the red zone. In the prototype model, train motion detection was performed by infra-red sensors to determine whether a train is approaching or leaving, so the controller may take appropriate actions.

In order to shorten the warning process and help train drivers to make right decisions in time, the level-crossing safety control system will augment infrared sensors with video cameras to turn on vehicle image identification function. Other enhancements under consideration include better traffic light coordination and wireless remote control.

3.2 Software

As the previous description, the microcontroller applied with PIC24FJ256GB106 and the software is coded in C language in accord with the hardware design. The program is written in a modular fashion to facilitate maintenance and modification. Currently, major system functions such as train detection close to the level crossing, traffic signal control, and security gate control have been successfully implemented and tested. The code snippet for actions in response to train approaching, including control of the level crossing security gate activation and deactivation, which is shown in Fig. 6.

```
if (r1==0 && r2==0);
else if (r1==1 || r2==1)
 {  if (r1==1 && r2==1)  // Two-way train
        {  motor_down();
               Delay(60000);
               Delay(60000);
               If (r1==1 && r2==1) {  motor_up();   } }
               else if (r1==1 && r2==0)  //Train on right hand side
               {         motor_down();
                          Delay(60000);
                          Delay(60000);
                     If (r2==1)  { motor_up();  }      }
               else if (r1==0 && r2==1)  //Train on left hand side
               {          motor_down();
                          Delay(60000);
                          Delay(60000);
                          If (r1==1)   {   motor_up();    }          }
        }
```

Fig. 6. Code snippet of fence activation and deactivation control program

4 Conclusion

This study proposes a prototype of level crossing safety control system to alleviate collision accidents. The system combines single-chip hardware design applied with software coding. Based on the preliminary results, this single-chip microcontroller-based system is cheap, easy to install, and can inter-operate with existing safety system to help train drivers make the right decision. However, a level crossing safety system should make every effort to avoid any accident caused by system malfunction. Since live video cameras are already installed in major level crossings, future research will introduce image recognition capability to increase system reliability and make improvement in other aspects to reduce mis-judgment condition which caused by the environment such as unstable weather.

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