Railway level crossing warning design in rural area using ultrasonic sensor and wireless communication

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Abstract. Collisions between train and roadway user in a level crossing in a rural area are the most railway accidents. A warning device for the level crossing is required to avoid the accident between roadway users and the train in the level crossing. The system shall independent from the existing railway system so that no disruption on the traffic of the train. This paper present a level crossing devices system based on ultrasonic sensors and wireless communication. Master control will display the result of detection using buzzer alarm, warning lamp, and train passage direction. Train passage warning with direction helps the roadway user to get a better awareness of incoming train and eliminate assumption of train passage direction. Especially in double track railway in a rural area, in case dual train enter the level crossing from left and right direction, the roadway users sometimes only aware on the first train passage and ignoring the second train and lead to the accident.

1. Introduction

Railway level crossings are often defined as any location where a public or private roadway, footpath (or both) crosses a railway track [1]. Railway crossing accidents rate increases every year as the roadway user grow rapidly. There are two types of level crossing: manned and unmanned [2]. There are 3,907 railway level crossings in Java island. Around 70% are illegal crossing unmanned without barrier, warning alert, traffic light or any warning system. Due to the large expanse of housing in rural area, there are more illegal level crossings opened to link the new area with surround area. This roadway usually developed by a private company who responsible for the housing area.

The railway operator and roadway authority are not responsible for this illegal level crossing. The roadway users have to take full responsibility for their safety at the level crossing due to very minimum protection. There are some marking boards installed at the level crossing as warning devices. However, this device is not sufficient to give the roadway users a significant warning as this is passive warning equipment.

This paper introduces a warning system for the level crossing based on ultrasonic sensor and wireless communication devices. The system proposed used a non-contact train detection and wireless devices so that no impact on the existing railway control and interlocking system, hence this warning system is not part of the railway traffic system.
2. Method

A master control device is placed at the level crossing. This device receives the train detection from remote detector devices on both side of train traffic direction as well as receive train detection from local detector device. Result of each detection then calculated by master control to display alert and warning indication. Display alert and warning indication which is proposed in this paper are: sounding alarm; Red/Flashing Yellow Traffic light; and Train traffic direction. Block diagram of the proposed system is shown in figure 1.

![Figure 1. Overall block diagram.](image)

Train detections are located in specified location, between 1 to 1.5 km apart from the level crossing in both side of (PM 10 2011 section 5.1.4). The sensor must be placed out of danger zone i.e. 3 meters away from railway path, as shown in Figure 2. The ultrasonic sensor shall have capability to detect the object, in this case is train car, at minimum distance 3 meter. Result of detection then sent to master control using FM transmitter. A simple protocol for wireless communication shall be implemented to ensure that only the valid data to be processed by master control. Remote device block diagram is shown in figure 2.

![Figure 2. Remote device.](image)
Master control consists of local train detection and wireless receiver device, and the display and warning devices. Once a valid data received from one of remote devices, master control will generate output to display red light lamp, output sounding alarm, display arrow direction, and estimated time of train arrival at level crossing. Arrow direction will be displayed based on identification of remote device as defined in the communication protocol. The output is held until the local detector detect that the train has passed the level crossing. Master control diagram block is shown in figure 3.

![Diagram of Master Control Device](image)

**Figure 3.** Master control device.

The red light and audible alarm will alert the roadway users that the train is approaching the level crossing. Arrow indication and estimated time will help to inform from which direction the train is coming and time estimation for train reaching the level crossing. In Indonesia, red light and audible alarm are typically warning devices installed in most of level crossing in Indonesia. The arrow indication has been installed in few level crossing locations.

Typical behavior is impatiently crossing once the train passes the level crossing [3]. In case double train coming from both directions, the user typically aware on first train. He/she will cross once the first train passes the level crossing while the second train is approaching from another direction. The arrow indication will give indication so that the roadway user has more awareness of train approaching.

3. **Results and discussion**

An Arduino Uno board that has ATMega2560 microcontroller forms data processing of the system. This board has been chosen for value effectiveness. It has a complete integrated development environment for easy prototyping and has complete pin input/output for multipurpose function such as UART and I2C.

Ultrasonic sensor module HS-SR04 has been chosen for the prototype. This module has a simple interface to the microcontroller board and has the capacity to detect in range up to 5 meters. Time difference between transmitted wave and reflected wave then produced by the module as a pulse width [4]. This pulse then calculated by microcontroller to calculate the distance to the object. This module can detect the moving object. A train traveling in the rural area has speed between 45 km/h to 90 km/h. It has been tested that the module can detect the object at 102 km/h. As the module only detect the object, not measure the distance, this module is working at 3.5 meters from railway path. Detection processing time required to state train exist or not is about 0.2s.
Wireless module E10-433MD is a transceiver module which used as transmitter at remote devices and receiver at master control device. This module has working frequency at 433MHz and has capability distance up to 2km with data-rate up to 1kbps. This module use SPI interface to send to/receive from microcontroller. The remote device located at 1.5 km from master control which located at level crossing, within the capability of the transceiver module. Detection data is packaged using simple protocol:

**Table 1. Simple protocol.**

| Preamble | ID | STX | “OCC” | ETX | Checksum |
|----------|----|-----|-------|-----|----------|
| 5 byte:  | 1 byte: | 1 byte: | 3 byte: | 1 byte: | 1 byte: |
| "UUUUU" | 'L' = Left emote remote | ‘0x02’ | "OCC” mean occupied | ‘0x03’ | XOR result of ID up to ETX |

Total 12 bytes per transmission is sent to master control device in every 3 seconds. Once the train has been passed the detection, remote device send “CLR” status instead of “OCC”. This “CLR” status is sent every 10 seconds for system healthy check. Delay transfer between transmitter and receiver is about 0.2s.

Master control device receives any state from left and right remote devices. The microcontroller checks the incoming validity through checksum calculation. As the result, remote device state then stores in internal memory. “OCC” state then trigger the output drivers. This output kept until local detection made to state that the train has left the section so the master control shall clear all the output. Total processing time is about 0.8s. total time processing since train first detected by remote device to the output is about 0.2 + 0.2 + 0.8 = 1.2 seconds.

Output interface done using solid-state relay to switch on/off the audible alarm, warning red-light, and left/right arrow. Experiment result is shown in following figure.

**Figure 4.** First stage: train first detection from left to right.

**Figure 5.** Second stage: train arriving at level crossing.
Figure 6. Third stage: train leaving the section, system ready for next train detection.

With maximum train speed at 90 km/h, total travel time between remote devices to level crossing is 60 seconds. Whereas 1.2 second of processing time make the output warning alert are driven 58.8 seconds before train arriving at level crossing. This value is higher than service break time which is 45 seconds [1].

Remote device is battery powered system due to the location are un-powered area. This design make system availability low in case of battery is empty. Total power consumption for the remote device is ultrasonic module + Arduino board + transceiver module = 20mA + 40mA + 80mA = 140mA. Standard alkaline battery with capacity of 2700mAh will keep the system works around 19 hours.

Master control device is located at level crossing. It is assumed that along the roadway, the line power is existing as part of power system to supply the resident area.

4. Conclusion
The idea can be enforced in large scale to facilitate higher safety standard for railway level crossing. Low power consumption devices shall be chosen for remote devices. An alternate power source such as solar panel to be considered to make system has higher availability. The 433MHz free frequency leads to collision frequency in use by other systems. Communication protocols to be improved such as two-way communication for transmission acknowledgement.

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