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JOURNAL

PEER-REVIEWED PROCEEDINGS

OCTOBER 2026

TORONTO, CANADA

gccr.academy

DEVELOPMENT OF A MICROCONTROLLER-BASED SMART RAILWAY CROSSING MONITORING SYSTEM

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https://doi.org/10.5281/zenodo.23331806

Abstract. This paper proposes a microcontroller-based system that monitors train approaches, obstacle presence, barrier status, and power supply at a railway crossing. It substantiates the principles of combining sensor signals, event logging, and transmitting fault notifications to the operator. The study is based on conceptual design and computational evaluation; field trial results are not presented.

Keywords: railway crossing, microcontroller, sensor, smart monitoring, diagnostics, telemetry, safety.

Introduction. At railway and roadway intersections, hazards are not limited solely to approaching trains: vehicles stranded on the road, barrier mechanism failures, and power outages are also critical factors. An engineering guide on crossings indicates the necessity of selecting protective equipment appropriate to local traffic conditions [1]. Therefore, the monitoring system must log each event with a timestamp and device status.

The objective of the study is to develop an architecture combining local analytics and remote data exchange for the continuous technical condition monitoring of a railway crossing. A key feature of the proposal is the separate identification of sensor, communication, and power faults alongside traffic conditions. The system is designed as an overlay monitoring layer that does not independently control the existing signaling system.

Research Methodology and Scientific Basis. Systems analysis, state-machine modeling, and time-budgeting methods are applied. The evaluation of reliability, availability, maintainability, and safety (RAMS) throughout the lifecycle is covered in international railway standards [2, 3]. Software requirements, verification, and fault management are

addressed separately [4]. These documents serve as a methodological framework and do not imply certified compliance of the prototype with the standards.

System Architecture and Operating Algorithm. An ESP32 microcontroller can be selected for the laboratory prototype: its digital inputs, hardware timers, and communication capabilities are well suited for monitoring tasks [5]. Train data is obtained via an approved, galvanically isolated interface. In the bench model, train movement is simulated using two sensors whose triggering sequence determines the direction of travel. A radar or optical sensor is proposed for obstacle detection, and limit switches for the boom barrier.



Figure 1. Functional diagram of the proposed monitoring system

The program manages "normal," "train approaching," "crossing occupied," and "fault" states. If the signals do not match or the update timeout expires, the area is not considered clear; a "status unknown" message is displayed. If an open barrier and an approaching train are detected simultaneously, a priority alert is transmitted to the operator. When communication is lost, events are saved in local memory and transmitted sequentially upon reconnection.

Table 1. Monitoring channels and verification criteria

Channel	Monitored state	Verification criterion
Train signal	Approach and direction	Signal sequence
Obstacle sensor	Presence of an object in the area	Consistency with reference state
Barrier gate contact	Open or closed state	Contact and status consistency
Power and communication	Voltage, message freshness	Recording of interruption

The MQTT messaging protocol can be used for telemetry [6, 8]. Duplicate messages are distinguished by an event number; authentication and an encrypted connection are provided. A watchdog timer detects program freeze/hang [7]. The tasks of sensor reading, logging, and transmission should be scheduled so that communication processes do not interrupt monitoring [9].

Computational Estimation and Testing Program. The available warning time is evaluated using the relation T = L / v, where L is the distance from the detection point to the crossing, and v is the train speed. In a hypothetical example, if L = 800 meters and v = 80 kilometers/hour = 22.22 meters/second, then T ≈ 36 seconds. This value is not a regulatory requirement. The monitoring delay is the sum of sensor reading, filtering, processing, and message delivery times; local warnings must not wait for a network response.

Testing covers bidirectional train movement, obstacle appearance, contact loss, power failure, and communication recovery. The detection rate is calculated as the ratio of correctly identified hazardous events to all benchmark hazardous events. False alarms and peak latency values are measured separately. Measurements are not yet available; no specific percentage claims are made regarding accuracy or accident reduction.

Conclusion. The proposed architecture enables joint monitoring of crossing status, device failures, and message history. Practical effectiveness will be evaluated following laboratory and field tests. In the next phase, electromagnetic interference, weather conditions, backup power, and diagnostic coverage must be tested. Connection to actual signaling systems will be implemented based on risk analysis and the requirements of the authorized railway authority.

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