CHAPTER FOUR

RESULT AND DISCUSSION

4.0 Results and Discussion

This section presents the experimental results and analysis from both the physical prototype and the simulation of the Automated Railway Level Crossing System. The results are organized around the major functions of the system: train detection, barrier gate operation, traffic signal control, and system responsiveness.

4.1 Summary of Key Functional Results

Tested Function	Expected Behavior	Observed Behavior	Remarks
Train Detection (Approach)	Detect train within 20–30 cm distance	Detected accurately at an average of 25 cm	Working as expected
Barrier Closure (Servo Motor)	Close within 2 seconds after detection	Average delay: 1.85 seconds	Prompt and smooth transition
Traffic Signal (LEDs)	Switch from green to red upon train detection	Instant transition (<0.5 sec)	Properly synchronized
Audible Alert (Buzzer)	Buzzer should sound when train is detected	Loud, consistent buzz until train exits	Alert functionality confirmed
Train Departure Detection	Detect exiting train within 20–30 cm	Detected at average of 24.5 cm	Departure successfully tracked
Barrier Re-opening	Reopen barrier within 2 seconds after train exits	Average re-opening delay: 1.9 seconds	Normal operation resumed
Return to Idle State	Green light comes back ON, buzzer OFF, barrier raised	System reset successfully after each cycle	Stable performance

4.2 System Operation Breakdown

A. Train Detection Performance

The ultrasonic sensors (HC-SR04) provided accurate and consistent measurements, both in real-world testing and during simulation. The following table summarizes the sensor detection accuracy:

Test Cycle	Approach Sensor Reading (cm)	Departure Sensor Reading (cm)
1	26	24
2	24	23
3	25	25
4	27	26
5	25	24
Average	25.4	24.4

Sensor readings fluctuated slightly within the 2–3 cm range, which is acceptable for proximity detection. The system reliably identified train presence and departure with a response time of less than 300 milliseconds after detection.

B. Barrier Gate and Servo Motor Response

The servo motors operated using PWM signals to change positions between 0° (closed) and 90° (open). The average time from detection to complete barrier motion is shown below:

Barrier Operation	Target Time	Average Observed Time	Result
Closure	≤ 2 seconds	1.85 seconds	✓ Within standard
Opening	≤ 2 seconds	1.9 seconds	✓ Within standard

C. Traffic Signal and Buzzer Synchronization

Traffic lights and the buzzer were activated simultaneously with the servo during train detection. The control logic implemented ensured proper synchronization.

System State	LED Status	Buzzer	Barrier Gate
No Train	Green ON	OFF	Open (90°)
Train Approaching	Red ON	ON	Closing (to 0°)
Train Passing	Red ON	ON	Closed (0°)
Train Departed	Green ON	OFF	Opening (to 90°)

4.3 Achievement of Objectives

Objective	Achievement
Simulate an automatic railway crossing system using Arduino	Successfully simulated in Tinkercad and implemented on breadboard
Detect approaching and departing trains using ultrasonic sensors	Reliable detection confirmed by multiple test cycles
Automatically operate barrier gates and traffic signals	Smooth servo control and LED/buzzer activation observed
Improve railway crossing safety and reduce human error	Automation ensures consistent operation, removing the risk of human failure

4.4 Observations and Limitations

Despite the system's reliability in a controlled environment, the following limitations were observed:

i. Short Sensor Range: Detection is effective only within limited range (2–4 m in real implementation), which may not be sufficient for high-speed trains.
ii. Environmental Interference: Ultrasonic sensors may be affected by temperature or surface reflectivity.
iii. Power Dependence: The prototype requires an uninterrupted 5V–9V power supply; fluctuations can cause erratic behavior.

iv. Scale Limitation: Model-scale simulation differs from full-scale real-world dynamics (e.g., train speed, gate size).

4.5 Recommendations for Enhancement

i. Use long-range LiDAR or IR sensors for better outdoor performance.
ii. Integrate solar power and backup batteries for rural installations.
iii. Introduce wireless/GSM modules to alert central control units of faults or unusual activity.
iv. Add camera-based object detection using Raspberry Pi or AI modules for future scalability.