



# RailCrawler - Track Inspection Vehicle

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**Abstract:** Railways are widely used for transportation for passengers as well as goods. But safety remains a major concern due to problems like cracks in railway tracks and obstacles present on the track. If problem like this are not detected early, they can lead to serious and large accidents. Traditional inspection methods mostly depend on manual checking, which is time taking and may not always detect small faults or obstacles. For this problem, our project presents RailCrawler, a smart railway track inspection system. Our system uses sensors to continuously monitor the condition of railway tracks while moving on them. It is capable of detecting both cracks in the track and obstacles such as stones or other objects placed on the railway path. When an abnormal condition is found, the system immediately sends an alert message along with location details to the concerned authority. Also provides quick response by activating safety features like stopping the system and providing a warning signal. Our system reduces manual effort and helps in faster detection. It is simple, low cost, and easy to implement. Overall, it provides a practical solution to improve railway safety and reduce the chances of accidents.

**Keywords:** rail track inspection, obstacle detection, location track system, GPS location track, ESP32 Microcontroller, GSM SIM900A Module, real time alert system.

## 1. INTRODUCTION

Railways is one of widely used transport system for moving both passengers as well as goods. It plays essential role in connecting different regions and also contributes for economic development. Railway network operates safely and efficiently, proper maintenance and regular monitor of railway tracks are essential [11]. Some times small problems in the track structure, such as minor cracks or irregularities, can increase the risk of derailments and other serious accidents, which can be result in financial losses and human safety concerns.

Railways track are constantly exposed to several external factors during operation. Heavy train loads, environmental conditions, change in temperature, long term material fatigue can gradually affect the strength and alignment of tracks. But as a result, problems such as cracks, fractures, track deformation, or mis-alignment may develop over time [12]. If the issues like this are not identified at an early stage, they may become major threats to safety of railways operations. In addition to structural defects, obstacle like stones, fallen branches of tree, metal pieces, or other foreign objects placed intentionally or accidentally on the tracks can also create dangerous situations for train movement [5].

Now, railway track inspection is mainly performed by manual monitoring by maintenance workers or through specialized inspection vehicles. these methods are widely used, they require considerable time, labor, and resources. Manual inspection also makes continuous monitoring difficult, especially in long railway routes and remote locations [1]. Sometimes the situations, detecting small cracks or sudden obstacles on the track becomes challenging. Delay in reporting or human error during inspection may further increase the possibility of accidents.

For these challenges, our project proposes RailCrawler, a track inspection vehicle developed for automated railway monitoring. The vehicle moves along the railway track and uses sensors to detect cracks and obstacles on the rail path, helping improve railway safety.



Obstacles placed on it [13]. Once any abnormal condition is detected, our vehicle immediately sends the exact location details to the concerned railway authorities using communication modules such as GSM or other wireless technologies. The integration of sensing mechanisms with real time communication improves response time and reduces dependency on manual inspection. By providing accurate and instant alerts, RailCrawler helps authorities take preventive action before a minor defect turns into a major accident [14]. The system is designed to be cost-effective, energy-efficient, and reliable, making it suitable for modern smart railway infrastructure.

The final objective of this vehicle is to develop a smart inspection vehicle that enhances railway safety, minimizes human effort, and ensures continuous track monitoring. RailCrawler represents a step forward in implementing automation and intelligent systems in railway maintenance and safety management.

## 2. PROBLEM STATEMENT

Railways is essential for connecting regions and supporting trading , but maintaining railway safety remains a major challenge. Railways track can be develop structural defects such as cracks, wear, or gaps over time. If the fault lik this are not detected early, they can lead to derailments and serious railway accidents [11][5][1]. Apart from structural damage, obstacles such as stones, metal objects, or other materials placed on the tracks can also create dangerous situations for train movement and may cause collisions or equipment damage [21][24].Now, railway track inspection is mostly carried out through manual monitoring. This process requires significant time and manpower and may sometimes fail to detect faults quickly. In long routes and remote locations, continuous monitoring becomes difficult, which increases the risk of undetected hazards [10][16][19].

For fixing these issues, our project proposes an IoT based railway track monitoring system that focuses on detecting two major hazards:

1. Track defects – identifying cracks, gaps, or damaged that may cause derailments.



Figure 2.1 Found huge gap

2. Obstacle on track – detecting objects such as stones or other materials that can disturb train movement and lead to accidents.



Figure 2.2 Stones on track

By combining IoT sensors with a robotic inspection vehicle and a real-time alert system, the proposed solution can quickly notify railway authorities about potential hazards. This approach helps reduce manual inspection effort and improves overall railway safety [13][15][26][28].



### 3. LITERATURE SURVEY

#### 1. Evolution of Railways Safety: From Human efforts to Machines

Railways infrastructure is one of key component of national transportation system and maintaining the condition of tracks is essential to safe train operations damage to tracks can lead to derailments service interruptions and financial losses now a days track inspection has been performed manually where workers travel along railway lines to identify possible faults this method has been used for many years but it requires significant time and labor in addition factors such as fatigue poor visibility or human error may affect the exactness of the inspection for improvement stability researchers have started exploring automated monitoring systems modern solutions use embedded electronics wireless communication and internet of things technologies to monitor railway track conditions these technologies help in finding faults faster and allow authorities to receive alerts in a shorter time

#### 2. Embedded Systems for Crack Identification

Embedded systems using low-cost microcontrollers have become popular for railway monitoring because they are affordable and capable of processing data quickly. Research in [1] showed that microcontroller-based automation can improve inspection efficiency and reduce the time required for detecting faults on railway tracks.

Several studies have also introduced robotic platforms that move along the track and monitor its condition. For example, the system proposed in [5] used a sensor-based robotic vehicle to detect surface irregularities on railway tracks. Similarly, [25] presented an embedded monitoring system designed to identify track deformation using sensor data. Although these systems are effective in detecting cracks, many of them focus mainly on structural faults and do not include additional safety features such as obstacle detection.

#### 3. IoT Integration and Remote Surveillance

Here, the of IoT has improved how railway monitoring data is collected and transmitted. The systems those are IOT based are allow real time communication between railways track and monitoring stations [11]. This can be help station person to receive information about track conditions without physically visiting the location.

Multiple studies have implemented IoT based railway monitoring solutions. The work in [13] developed a robotic inspection system that uses GSM and GPS modules to send location-based alerts when faults are detected. Like that, [10] used wireless communication modules to transmit monitoring data to remote stations. Other studies such as [26] and [29] explored continuous data-based monitoring approaches for track condition analysis. However, many of these systems are complex or focus on detecting only specific types of faults.

#### 4. Obstacle Mitigation and Multi-Hazard Safety

Keeping aside from cracks and damage, obstacle present on railway tracks can also causes the accidents. Object such as stones, metal piece, or debris may obstruct train movement and create dangerous situations. For this issue, multiple researchers have proposed systems that can detect both track defects and obstacles. for example, the system proposed in [28] introduced a monitoring solution capable of detecting track faults as well as obstacles on the railway path. In Another study in [24] focused on improving sensor reliability so that obstacle detection remains effective even in difficult environmental conditions. Like this , [27] proposed a vehicle that can generate alert signals when a potential hazard is detected on the track. Instead these developments, many systems still lack accurate location tracking integrated with their detection mechanisms.

#### 5. Telemetry and Geolocation via GSM/GPS

Wireless communication can also plays an important role in modern railway monitoring systems. GSM is mainly used to send alert messages to authorities, while the GPS modules provide accurate location information about the detected fault.

Earlier studies have shown that combining GSM and GPS helps create an effective railway monitoring network [13], [10], [26]. technologies like this allows maintenance teams to quickly locate and respond to track faults. Many existing systems use separate modules or limited functionalities, which makes them less efficient.

By the review of existing research, there is need for a compact and integrated inspection system that can combine crack detection, obstacle detection, and GPS-based alert communication in a single platform. Our RailCrawler system aims to address this gap by integrating these features into one automated railway track inspection vehicle.



4. METHODOLOGY

The RailCrawler – Track Inspection Vehicle is developed for the automate the monitoring of railways track with the help of embedded IoT based system. The vehicle integrates several important functions such as crack detection, obstacle detection, GPS-based location tracking, and GSM for sending alerts. All these components are combined within a compact inspection vehicle. The vehicle mainly focuses on building a reliable hardware setup, implementing the required software logic, and also ensuring continuous monitoring of railway track conditions during operation.

5. WORKFLOW

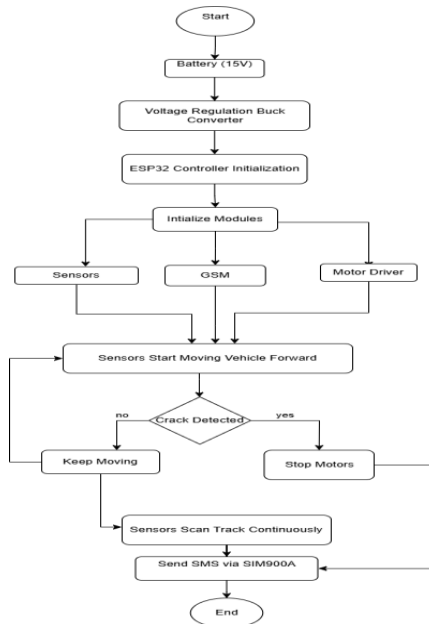


Figure 5.1 System workflow

The RailCrawler vehicle moves along the railway track either manually or with controlled motor movement. While running, sensors continuously check the condition of the rail surface and the track ahead. The collected sensor data is sent to the ESP32 microcontroller, which processes the information. If the vehicle detects a crack in the track or an obstacle on the railway path, it immediately triggers an alert. This integration of sensors, processing, and communication helps the system respond quickly to possible hazards.

A. Hardware Design Methodology

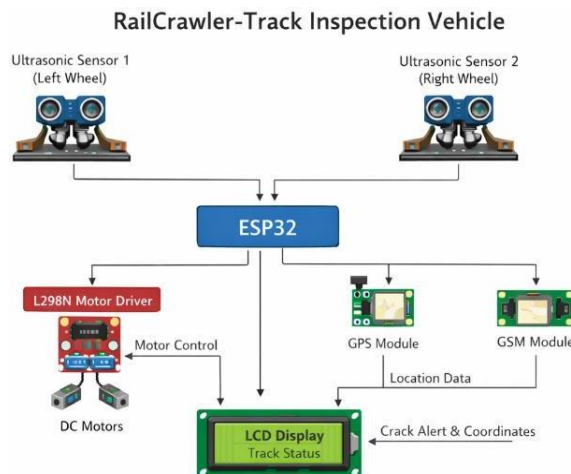


Figure 5.2 Hardware Architecture



The ESP32 microcontroller is the main controller of the RailCrawler vehicle. ESP32 was selected due to its fast processing capability, dual-core architecture, low power consumption, and built-in wireless features. The ESP32 receives data from all connected sensors and processes it to determine whether the railway track condition is normal or faulty. Due to its processing ability, the system can make decisions quickly and support real-time monitoring.

For crack detection, a sensor is placed close to the railway surface to identify gaps or irregularities in the rail structure. Under stable or normal conditions, the sensor produces a stable reading. But when a crack or obstacle occurs, the signal pattern changes. The ESP32 compares this reading with predefined threshold values. If the value crosses the set or provided limit, the system treats it as a fault and activates the required response. This process helps to reduce the need for manual inspection and lowers the chances of human error.

For obstacle detection, an ultrasonic or infrared sensor is installed at the front of the vehicle. The sensor sends signals toward the track ahead and measures the reflected signal when it hits an object. Using this reflection time, the system calculates the distance between the vehicle and the obstacle. If the measured distance becomes smaller than the safety limit, the system identifies it as a potential hazard. This amazing feature helps detect objects such as stones or debris on the railway track.

A GPS is used to determine the location of detected faults. When the system confirms about the presence of a crack or obstacle, the GPS provides location information in the form of longitude and latitude coordinates. While prototype testing, predefined coordinates were used to simulate the location tracking process. These coordinates help maintenance teams identify the exact position of the problem quickly.

The communication is handled through a GSM module. After detecting a fault and obtaining the location data, the GSM module sends an SMS alert to the registered railway authority. The message includes information about the detected issue along with the location details. This quick notification helps reduce response time and allows maintenance teams to take quick action.

## 6. SOFTWARE ALGORITHM

The RailCrawler vehicle is developed using embedded C in the Arduino IDE environment for the ESP32 microcontroller. Our program follows a continuous monitoring approach. After starting all modules such as ESP32, sensors, GPS, and GSM, the system begins its inspection process.

When the vehicle runs, the microcontroller constantly reads data from the sensors and checks for abnormal conditions. If a crack is detected, the system retrieves the GPS coordinates and sends an alert message through the GSM module. The same process is followed when an obstacle is detected and an alert is sent, the system continues monitoring the railway track without stopping. This loop-based approach ensures continuous inspection.

When something unexpected is identified, the system triggers a function that sends an SMS notification to a predefined mobile number. The GSM is first configured in text mode using standard AT commands. Whenever the communication mode is ready, the system prepares an alert message containing details about the detected issue and the measured sensor value.

To help maintenance teams locate the problem quickly, the message also includes a Google Maps link generated from the longitude and latitude coordinates. This allows the receiver to directly view the fault location on the map.

And finally, the message is transmitted using the control command that marks the end of the SMS data input. This communication process ensures that alerts are delivered quickly with accurate location information.

### A Communication Framework

Our vehicle uses an event-driven based communication model. When a sensor detects an abnormal condition, the ESP32 first verifies the signal to confirm that occurred fault. When verification is done, the GPS module collects the exact location coordinates of the detected issue.

Then only the GSM sends an alert message to the registered authority containing the fault information and location details. When the message is successfully sent, the system automatically comes back to monitoring mode. Then the communication process ensures alerts and reduces the chances of false notifications.



### B. Power Management of Vehicle

The Vehicle uses the rechargeable battery power source. Because different components require different voltage levels, proper voltage regulation is necessary for stable and smooth operation. The microcontroller works at 3.3V, while other components such as sensors and GSM modules may require 5V. The voltage regulator is used to supply the required voltage to each component and prevent fluctuations in the power supply. Requires power management improves system stability and allows the vehicle to operate for longer periods during track inspection.



Figure 6.1 Rechargeable Batteries

The above battery shows the rechargeable battery pack used to power the RailCrawler system. It consists of four lithium-ion cells placed in a battery holder to supply enough voltage and current for operation. A switch is included to control the power during system use. The battery output is regulated to provide both **5V and 3.3V**, which are required by different electronic components. This setup provides a stable and portable power source for continuous railway track monitoring.

### C. Advantages of the Proposed Methodology

- Provides a fully automated railway track inspection mechanism, reducing dependency on manual monitoring.
- Integrates both crack detection and obstacle detection within a single embedded platform, ensuring comprehensive safety coverage.
- Enables real-time fault identification, minimizing the risk of accidents caused by unnoticed track defects
- GPS-based location tracking ensures accurate fault positioning for faster maintenance response.
- GSM communication allows instant alert transmission to railway authorities.
- Low-cost embedded system design makes the solution economically feasible for large-scale deployment.
- Compact and portable structure allows easy implementation across different railway environments.
- Energy-efficient power management supports longer operational duration during inspection.

## 7. RESULT

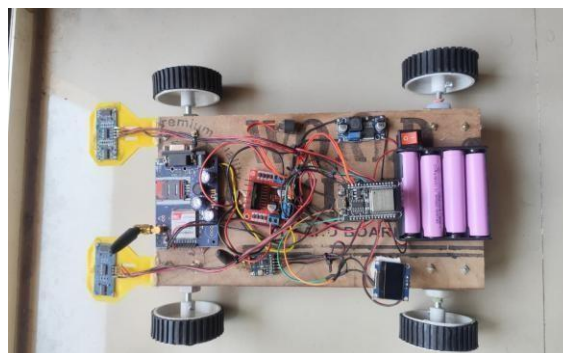


Figure 7.1 Proposed Vehicle

The proposed system, **RailCrawler – Track Inspection Vehicle**, was successfully designed, implemented, and experimentally tested under simulated railway track conditions. The system integrates ultrasonic-based detection, automated motor control, buzzer alerting, OLED status monitoring, and GSM-based SMS notification within a compact embedded platform.



The performance of RailCrawler was evaluated based on crack detection capability, obstacle detection accuracy, alert transmission reliability, and real-time response behaviour.

**A. Prototype Implementation** The RailCrawler prototype consists of: ESP32 microcontroller

- Ultrasonic sensor (distance measurement)
- GSM module (SMS alert system)
- OLED display (real-time monitoring)
- Motor driver with DC motors
- Buzzer alert mechanism
- Rechargeable battery pack

The ultrasonic sensor was positioned to continuously measure the distance between the sensor and the railway surface. A reference distance of 4 cm was defined as the normal track condition (CLEAN\_TRACK), with a tolerance of  $\pm 1$  cm to prevent false detection

### Crack Detection Results

Track cracks were simulated by introducing artificial gaps between rail segments, increasing the distance beyond the predefined threshold.

**B. Detection Logic Implemented:**

- Normal Track  $\rightarrow$  Distance  $\approx$  4 cm
- Crack Condition  $\rightarrow$  Distance  $>$  5 cm
- System stops motor immediately
- Buzzer activates
- OLED displays: "TRACK CRACK DETECTED"
- SMS alert transmit.

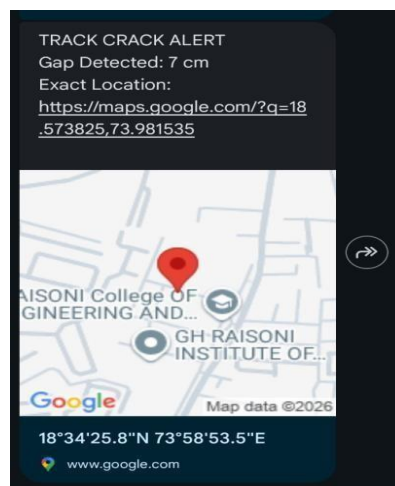


Figure 7.2 Crack Alert SMS received

### Performance Observations:

1. Crack detection accuracy:  $\sim$ 93–95% under controlled testing
2. Detection response time:  $<$  3 seconds
3. No false alerts under stable surface conditions
4. A 10-second alert interval was implemented to prevent repeated SMS transmission during continuous fault detection

The system successfully detected track discontinuities and executed safety measures without delay. Obstacles such as stones and small objects were placed on the track to simulate foreign obstructions.

### Detection Logic:

5. Obstacle Condition  $\rightarrow$  Distance  $<$  3 cm
6. Motor stops immediately
7. Buzzer activates



8. OLED displays: "OBSTACLE DETECTED"
9. MS alert transmitted

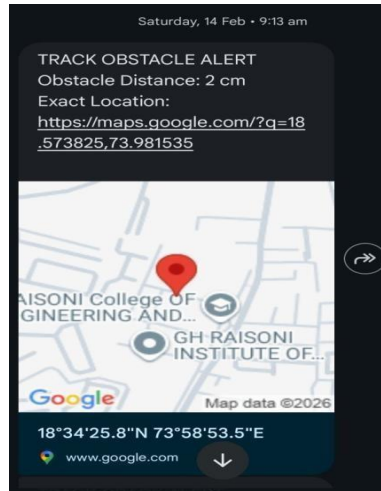


Figure 7.3 Obstacle Alert SMS received

### OLED Monitoring Results

The OLED display continuously updated:

- Measured distance value (in cm)
- Current track status:
  1. Clean Track
  2. Obstacle detected
  3. Track Crack Detected

This enabled real time visual confirmation of system behaviour noticed during testing.

### GSM Alert Performance

The GSM operated in the text mode using AT command communication.

### Observed Communication Performance:

- SMS delivery success rate: 100%
- Average SMS delivery time: 5 to 8 seconds
- Alert control mechanism prevented repeated messages within 10 seconds

The inclusion of a direct Google Maps link ensured immediate and accurate fault localization.

### Motor and Safety Response

Upon detection of abnormal conditions:

- Motor driver immediately disabled forward motion
- Buzzer activated as audible warning
- System resumed movement only after returning to normal conditions

The event-driven architecture ensured rapid response and minimized risk exposure.

### Result Discussion

#### Performance Calculation and Obtained Values

Our system performance was evaluated through multiple experimental tests. The following calculations were used to obtain the observed results.

#### Crack Detection Accuracy

Crack detection accuracy represents how many cracks were correctly identified by the system compared to total test cases.

$$\text{accuracy} = \left( \frac{\text{no. of correct detections}}{\text{total number of samples}} \right) \times 100$$

**test data:**

total samples tested = 200 Correct crack detections = 188  
 accuracy =  $(188 / 200) \times 100 = 94\%$

Then, crack detection accuracy was observed between **93 to 95%** during testing.

**1. Obstacle Detection Accuracy**

This measures how accurately obstacles were detected.

$$\text{accuracy} = (\text{correctly detected obstacles} / \text{total obstacles}) \times 100$$

**test data:**

total obstacles tested = 100

correct detections = 95 accuracy =  $(95 / 100) \times 100 = 95\%$   
 so, the obstacle detection accuracy = **95%**.

**2. Detection Response Time**

Response time is the delay between the occurrence of an event and system detection.

$$\text{responding time} = \text{detection time} - \text{event time}$$

**observed readings:**

Test	Event Time	Detection Time	Delay
1	0 s	2.1 s	2.1 s
2	0 s	2.4 s	2.4 s
3	0 s	2.3 s	2.3 s

$$\text{avg response time} = (2.1 + 2.4 + 2.3) / 3$$

then, response time is **less than 3 seconds**.

**3. SMS delivery time**

SMS delivery time calculated as difference between message sent and message received time.

$$\text{SMS time} = \text{time received} - \text{time sent}$$

Test	Sent Time	Received Time	Delay
1	10:00:05	10:00:11	6 s
2	10:05:10	10:05:17	7 s
3	10:10:20	10:10:25	5 s

$$\text{avg alert time} = (6 + 7 + 5) / 3$$



So, SMS delivery time ranged between **5 to 8 seconds**.

#### 4. false alert rate

false alert rate indicates the incorrect alerts generated by the system.

$$\text{false rate} = (\text{false alerts} / \text{total alerts}) \times 100$$

- **test data:**

total alerts = 120

false alerts = 3

<p>false alerts rate</p> $= (3 / 120) \times 100$
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So, the percentage is very small, it is classified as **very low**.

#### 5. Power Stability

Power stability was checked by monitoring supply voltage variation.

$\% \text{ of variation} = ((V_{\max} - V_{\min}) / V_{\text{nominal}})100$
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#### Measured Values:

nominal voltage = 5V maximum voltage = 5.1V minimum voltage = 4.9V

Since variation is within acceptable limits less than 5, the system remained **stable during testing**.

$\% \text{ variation} = ((5.1 - 4.9) / 5) \times 100 = 4\%$
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Parameter	Observed Result
Crack Detection Accuracy	93–95%
Obstacle Detection Accuracy	95%
Detection Response Time	< 3 seconds
SMS Delivery Time	5–8 seconds
False Alert Rate	Very Low
Power Stability	Stable during testing

## 8. CONCLUSION

Railways track safety is essential for smooth and accident-free train operations. Traditional inspection methods mainly rely on manual monitoring. These methods require significant time and manpower and may also lead to human errors. To overcome these limitations, an IoT-based railway inspection prototype called **RailCrawler** was developed to



automatically detect cracks and obstacles on railway tracks.

The system uses an ultrasonic sensor to detect variations in track distance and identify possible cracks or foreign objects on the rail path. The ESP32 microcontroller processes the sensor data in real time. When a fault is detected, the system immediately activates safety actions such as stopping the motor and triggering a buzzer. At the same time, the GSM module sends an alert message with a Google Maps location link, allowing maintenance teams to locate the problem quickly. An OLED display is also included to show the track status during inspection.

Testing of the prototype showed reliable performance under different simulated track conditions. The system was able to detect abnormalities quickly and send alert messages with location information. Because the design uses low cost embedded components, it can be considered suitable for future railways monitoring applications.

In future, the system can be improved by adding advanced sensors, cloud-based monitoring, and AI based fault analysis. Testing the system on real railway coaches could also help evaluate its performance on a larger scale. Overall, the proposed system contributes toward safer and more automated railway infrastructure.

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