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Smart Hot Axle Box Detection and Cooling System Using IoT for Indian Railway

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***Abstract*— The performance & safety of railway operations are critically dependent on the condition of key components, such as axle boxes. Overheating & mechanical failures in axle boxes can lead to serious accidents, costly maintenance & operational disruptions. This paper presents the design & implementation of a "Smart Hot Axle Box Detection & Cooling System" aimed at improving the safety, reliability & efficiency of Indian Railways.**

The proposed system integrates a real-time monitoring platform that uses temperature sensors for continuously assessing the health of axle boxes. An IoT-based data acquisition system is employed to collect & transmit sensor data on the cloud for real-time monitoring. Furthermore, the system incorporates an automatic cooling mechanism that activates upon detection of elevated temperatures, effectively preventing damage & enhancing the overall operational lifespan of railway assets.

The proposed solution not only reduces the risk of axle box failure but also minimizes maintenance costs & improves the operational efficiency of the railway network.

Keywords: Axle box, IoT, Cooling system, Smart Detection, Indian Railway.

I. INTRODUCTION

Indian Railways is a vital transportation network, offering an efficient and reliable solution for long-distance travel of both passengers and goods. It connects cities, towns, and remote areas, making it an essential part of India's economic infrastructure and providing an affordable means of travel for millions across the country.

The Indian Railway Network, the largest in the world, faces numerous safety concerns, with hot axle failures and brake binding being major contributors to accidents. A hot axle refers to the overheating of the axle box, typically caused by friction or inadequate lubrication of the bearings. When this occurs, it can compromise the performance of the train, potentially leading to severe mechanical failures or even derailments. Timely detection and management of hot axle conditions are essential to prevent such incidents and ensure the safe and smooth operation of the railway system.

This research develops an IoT-based sensor system for early detection and cooling of hot axles in railway wagons. The system continuously monitors axle temperature and, when overheating is detected, activates cooling mechanisms and alerts railway operators for quick action. This proactive approach improves safety, reduces accident risks, and enhances maintenance efficiency.

The Smart Hot Axle Box Detection and Cooling System using IoT provides real-time monitoring of key parameters, particularly the temperature of axle boxes in railway wagons. This system continuously collects temperature data and transmits it to railway authorities, allowing them to monitor the condition of the axles remotely. When overheating is detected, the system can trigger an automatic cooling mechanism and alert operators, enabling quick intervention. This real-time monitoring ensures that potential issues are addressed promptly, enhancing safety, preventing accidents, and improving the overall reliability of the Indian Railway system.

II. THE PROPOSED SYSTEM

This flowchart represents a temperature monitoring and control system using an ESP32 microcontroller. The process begins with a temperature sensor detecting the current temperature. The ESP32 then compares the recorded temperature against a predefined threshold. If the temperature exceeds the threshold, the cooling system is activated to prevent overheating. Otherwise, the data is uploaded to the cloud via Wi-Fi for further analysis. The system also logs temperature data for analytics, helping in performance monitoring.

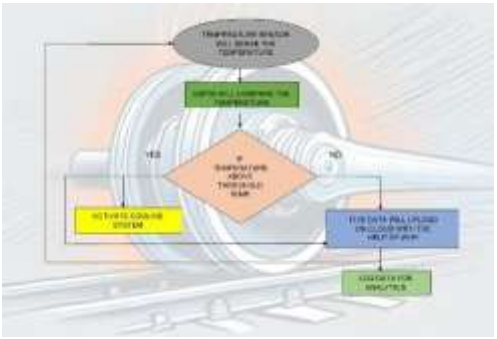

Fig. 1. Flow Chart of Proposed System.

The proposed system illustrates an automated temperature monitoring and cooling system utilizing an ESP32 microcontroller and cloud-based data analytics. The process starts with a temperature sensor detecting the surrounding temperature. The ESP32 then processes and compares this temperature against a predefined threshold. If the temperature surpasses the threshold, the system activates a cooling mechanism to regulate the temperature. If the temperature remains within the acceptable range, the data is transmitted to the cloud using Wi-Fi. The uploaded data is further logged and analyzed for trends, predictive maintenance, and optimization of system performance. This setup is ideal for industrial applications, IoT-based smart cooling systems, and remote monitoring, ensuring efficiency, safety, and data-driven decision-making.

A. *Electronic Sensors used for Proposed system.*

MLX90614 Sensor:-

Fig. 2. *MLX90614 temperature sensor*

The MLX90614 is a non-contact infrared temperature sensor manufactured by Melexis. The MLX90614 is an infrared (IR) temperature sensor designed for non-contact temperature measurement. It is widely used in medical, industrial, and consumer applications for detecting surface temperatures of objects or human body temperature without physical contact.

The MLX90614 sensor detects infrared radiation emitted by an object and converts it into an electrical signal. The built-in signal processing unit then converts the analog signal into a digital value, which can be read via I²C communication

Here are the key features:

1. Accuracy: ±0.5°C (in the range of 0°C to 50°C).

2. Wide temperature range:

Object temperature: -70°C to +380°C

Ambient temperature: -40°C to +125°C

3. Non-contact measurement: Uses infrared thermopile technology

4. Digital output: Communicates via I²C (Inter-Integrated Circuit) and PWM (Pulse Width Modulation).

5. Factory calibrated: No external calibration is needed.

6. Low power consumption: Ideal for battery-operated devices.

7. Built-in Signal Processing: Includes a 16-bit ADC and a Digital Signal Processor (DSP) for accurate temperature conversion.)

- *ESP32 :-*

Fig. 3. ESP32.

ESP32 in Fig 3.is a cost friendly dual-core circuit .It is low power system with both Wi-Fi and Bluetooth inbuilt on it .It consists of 30 pins with one of Vin and a 3.3v input pin and also two ground pins.

A. The features of ESP32 ARE:

It has ultra-low power which means it cons coprocessor memory of 320 Ki BRAM and 448 Ki BRAM which are Wireless.

B. Technical Specification

- Wi-Fi-802.11b/g/n
- Bluetooth-v4.2BR/EDR and BLE(shares the radio with Wi-Fi)
- 34×programmable GPIOs
- 12-bit SARADC upto18 channels
- 2×8-bitDA

- *CJMCU TCA9548A I2C multiplexer*

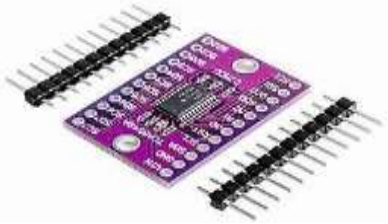

Fig 4. CJMCU TCA9548A I2C multiplexer

the CJMCU TCA9548A is an I²C multiplexer module that allows multiple devices with the same I²C address to operate on a single I²C bus.

1. 8-Channel I²C Switching: Controls up to 8 independent I²C devices on different channels.
2. I²C Address Expansion: Avoids conflicts when using multiple devices with the same address.
3. Data Transfer Rate: Supports standard I2C speeds of 100kHz (Standard mode), 400kHz (Fast mode), and up to 1MHz (Fast mode+), which ensures it can operate efficiently in various scenarios.
4. Bidirectional Communication: Supports two-way data transfer between the microcontroller and I²C device
5. Supports Multiple Addresses: Base address 0x70 (configurable from 0x70 to 0x77 via A0-A2 pins.

The CJMCU TCA9548A I²C multiplexer enables multiple temperature sensors (MLX90614) to monitor railway axle boxes, preventing I²C address conflicts. It transmits real-time data to IoT platforms for overheating alerts and automated cooling activation.

- *Heavy duty Water-pump*

Fig.5. Heavy duty Water-pump

1. Voltage: 12V DC (direct current)
2. Current: Usually ranges from 1A to 10A, depending on the power and size of the pump. Smaller pumps may draw less, while larger or more powerful pumps draw more.
3. Efficient Cooling Mechanism – When IoT sensors detect excessive axle box temperatures, the water pump is activated to spray cooling fluid, preventing bearing failure

- *Relay (JQC3F-05VDC-C)*

Fig 6. Relay (JQC3F-05VDC-C)

1. Type: Electromagnetic relay
2. Configuration: SPDT (Single Pole Double Throw) meaning it has one common (COM), one normally open (NO), and one normally closed (NC) contact.
3. Type of Mounting: Through-hole (PCB mount).

- *LCD display 16*2*

Fig 7. LCD display 16*2

1. Character Set: ASCII characters (and some additional special symbols depending on the controller)
2. Backlight Control: Depending on the model, it can either be always on or controllable via a pin (using PWM for brightness control in some cases)
3. I2C (uses SDA and SCL for communication, saving pins on the microcontroller).
4. I2C Address**:** Typically 0x27 (sometimes 0x3F, depending on the module).

- *Cooling :ECO2 antifreezing coolant*

The ECO2 coolant is a vegetable-based, environmentally friendly The coolant circulates through the copper tube, absorbing heat and maintaining optimal temperatures by efficiently transferring thermal energy away from the system.

1. Environmentally Friendly: Biodegradable, non-toxic, and made from renewable vegetable sources.
2. Thermal Performance: Protects down to -50°C, miscible with water for efficient cooling.
3. Corrosion & Fouling Protection: Contains inhibitors to prevent corrosion and biological growth.
4. Physical Properties: Density: 1.02 - 1.26 g/cm³, pH: 7.5 - 10.5, Boiling Point: >100°C.
5. Freezing Protection: Available in concentrations for varying frost protection, down to -35°C.

6. Shelf Life: 3 years, stored in sealed containers away from sunlight.

- *SMPS*

Fig 8.SMPS

1. Typically 100-240V AC (Universal input), allowing the power supply to operate across different regions.
2. Power Factor Correction (PFC): Some models feature PFC to improve efficiency and reduce electrical noise.
3. Automatically shuts down or limits current to prevent damage in case of a short circuit.

III. RESULT

The output of this system includes efficient temperature regulation, real-time monitoring, and data-driven insights. When the temperature exceeds the predefined threshold, the system activates the cooling mechanism to maintain optimal conditions. If the temperature remains within the safe range, the data is uploaded to the cloud via Wi-Fi for further analysis. Additionally, all temperature readings are logged for analytics, enabling predictive maintenance and performance optimization. This allows users to remotely monitor temperature trends, make informed decisions, and improve system efficiency. Ultimately, the system ensures safety, prevents overheating, and enhances overall operational reliability.

Fig.9. Real time temperature sensors display

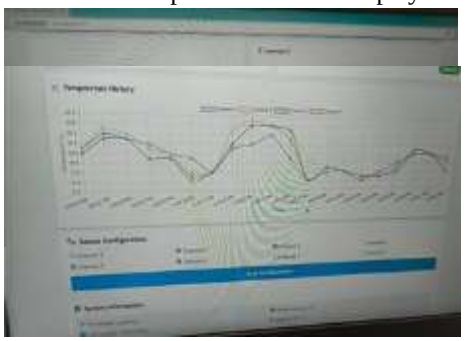

Fig 10. Real time temperature graph

IV. FUTURE SCOPE

Cross-Industry Adaptations The future scope for the Smart Hot Axle Box Detection and Cooling System Using IoT lies in the integration of cutting-edge technologies to revolutionize railway safety and efficiency. It can be used in various sectors, after required customization the system can be tailored to other transportation sectors such as freight trucks or even aircraft landing gear, where the axle box analogous (like wheel bearings) also face overheating issues. Other than that it also be used in Mining, heavy equipment such as Monitoring Drills and Excavators works under extreme hot condition leads to frequent overheating; by changing cooling system it is also use full for Data Centres where the Server and Storage Units get overheated and may leads to system failure by using HAVC Cooling System in this module it can be used in Data Centres also.

V. CONCLUSION

The Smart Hot Axle Box Detection and Cooling System using IoT offers a transformative solution for Indian Railways, enhancing safety and operational efficiency. By enabling real-time temperature monitoring and automated cooling, the system significantly reduces the risk of derailments caused by overheating. Its predictive maintenance features ensure timely interventions, while continuous data logging provides insights for better asset management. With a focus on sustainability and improved passenger safety, this innovative system positions Indian Railways for a modernized future, fostering greater reliability and trust in rail transport.

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