A system of IoT devices to prevent underloading/overloading of railway wagons

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1 Abstract

Efficient cargo transportation via railway systems necessitates optimal loading of wagons to prevent both underloading, leading to inefficient resource utilization, and overloading, posing safety hazards and infrastructure strain. This research proposes an Internet of Things (IoT) integrated system tailored for monitoring and managing cargo loads in railway wagons. The system comprises smart sensors embedded within the wagons to collect real-time data on load capacities. Through continuous monitoring and analysis, the system dynamically regulates cargo allocation to prevent underloading and overloading instances. Moreover, it interfaces with a centralized control mechanism, enabling prompt interventions or adjustments to maintain load equilibrium. The IoT-based approach enhances operational efficiency, reduces maintenance costs, and ensures railway safety standards are met, thereby contributing to a more sustainable and optimized rail freight transportation network.

2 Executive Summary

India is the second-largest coal-producing nation in the world. Coal transported by railway in India reached 652.8 million metric tons in the fiscal year 2022. While transporting it through rail wagons, underloading and overloading can be a significant concern. For underloading, the government faces a loss of 500 crores yearly. Overloading can affect the fuel consumption, maintenance cost of the wagon, and damage to it. Also, there is a punitive charge of one lakh rupees per wagon for overloading as per subsection (1) read with clause(d) of sub-section (2) of section 87 of the Railways Act,1989, (24 of 1989). We are approaching this problem with the help of the Internet of Things (IoT) based hardware model. We are using load cells to measure the weight of the wagon at a particular loading station which will be isolated from the other tracks. The wagons will be stationary at this point for loading and the IoT will be implemented to check the data on intranet website or mobile application.

This IoT-based system presents a potential shift in quick measurements, offering a scalable and adaptable solution for the aforementioned problems. By enabling remote monitoring and control, the system introduces efficiencies that could revolutionize the traditional loading practices.

3 Literature survey

The investigation into optimizing railway wagon loads has been explored through diverse research endeavors. Wang et al. emphasized strain monitoring for identifying moving train loads on railway bridges, while Pau and Vestroni delved into weigh-in-motion techniques based on rail strain measurements. Their studies underscored the significance of real-time monitoring to comprehend load dynamics.[1]

Furthermore, Zhang et al.'s work on predicting coal self-ignition using machine learning highlighted the complexities inherent in weight prediction due to varying coal specificities. Understanding these nuances is crucial as it informs the challenges faced in accurately estimating cargo weights, particularly in the case of substances like coal with diverse specific gravities and air gap concerns.[2]

In a parallel vein, Hajializadeh et al. explored the development and testing of a Railway Bridge Weigh-in-Motion System, contributing valuable insights into the practical application of such systems.[3]

Drawing from these studies, a consensus emerges on the efficacy of weigh-in-motion concepts. However, your astute observation highlights an innovative approach: the simultaneous weighing of both empty and loaded wagons. This approach minimizes energy consumption and time while ensuring accurate measure-

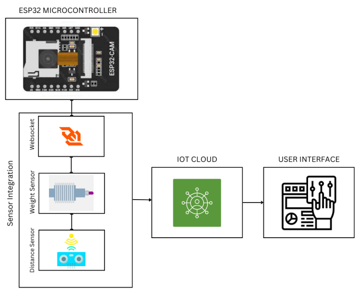

Figure 1: Block Diagram

ments, presenting a promising alternative to intricate weight prediction models. [4]

Building upon this, the proposal for an IoT-based system integrating simultaneous weighing methods for railway wagons signifies a forward-looking direction. This system, if developed, holds the potential to revolutionize cargo transportation efficiency and safety in railways by preventing underloading and overloading in real time.

4 Components, tools, frameworks and specifications

4.1 Hardware

1. Microcontroller:
   ESP32 board.
   This will serve as the central processing unit for data collection, processing, and connectivity.
   Power supply for the microcontroller

2. Load Cells (4)
   The transducers which convert force into a measurable electrical output for weight calculation.

3. HX711 amplifier
   A precision 24-bit analog-to-digital converter (ADC) that is designed for weighing scales and industrial control applications to interface directly with a bridge sensor.

4. Ultrasonic Sensor
   A an electronic device that measures the distance of a target object by emitting ultrasonic sound waves. This is used for counting the wagons.

5. Additional Components:
   Wiring and Breadboard To connect and prototype the components effectively.

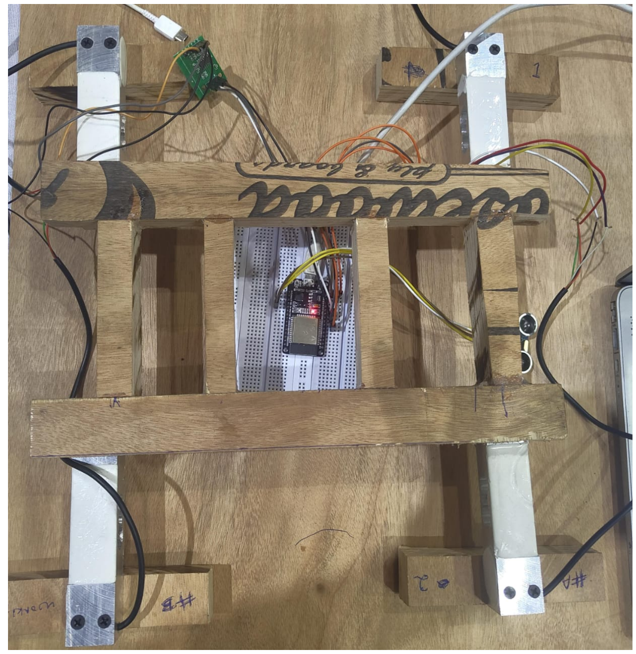

Figure 2: Circuit connection

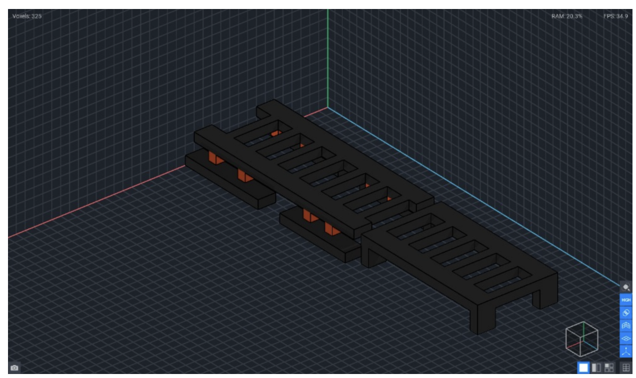

Figure 3: 3D Model

4.2 Software

1. IoT cloud interface (Websocket)

2. Programming environment (Arduino IDE for ESP32)

3. Simulation software (SCADA, Proteus, TinkerCAD)

4.2.1 Web Inetrface

1. Node JS for websocket

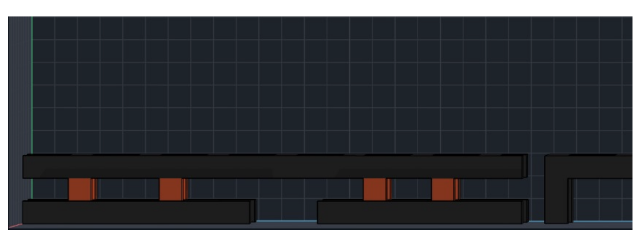

Figure 4: 3D Model

2. Mongo DB for database
3. React for front-end

4.3 Modelling

4.3.1 3D modelling

1. Fusion 360
2. Sandbox - VoxEdit

5 IoT based measurement

As shown in the block Diagram (Figure 1), This system uses a system of sensors interfaced with the ESP32 microcontroller to measure the parameters in order to prevent the wagon from overloading and underloading.

The aforementioned measurement can be done in real-time by making some isolated platforms where the wagon stops to get loaded with the coal. The weight of the empty wagon is measured on arrival. Then the system subtracts the weight of the empty wagon with the coal filled wagon to obtain the weight of the coal.

The isolation is done by making a small cut, which is of negligible size while the size of a freight train wheel is considered. The wagon is loaded and the weight incremented for each iota from the strokes of the excavators. The incremented weight is then and there updated in the web which can give an alert to the payloader once the weight reaches near the threshold. In this way, the system can address both the overloading and the underloading issues.

The simulation for the same is done using InTouch, a Supervisory Control and Data Acquisition and PLC software. The Simulation pictures are added below(Figure 3).

6 Components Description

6.1 HX711

The HX711 is a precision 24-bit analog-to-digital converter (ADC) specially designed for weigh scales and industrial control applications. It's a highly popular and versatile chip due to its ability to amplify and digitize small analog signals directly from a load cell, offering high resolution and accuracy in weight measurements.

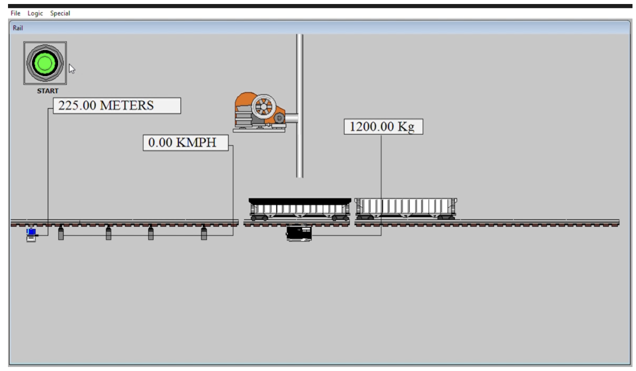

Figure 5: SCADA demonstration and simulation

Figure 6: Final Model

Key features of the HX711 include its differential input channels that allow direct connection to a load cell, built-in programmable gain amplifier (PGA) providing selectable gain levels (128 or 64), and the ability to interface with microcontrollers through a simple two-wire serial interface.

One of its standout functionalities is the ability to perform real-time data acquisition with low noise, enabling precise readings even in environments susceptible to electrical interference. Its low power consumption and ability to operate in low-voltage conditions make it suitable for various portable and battery-powered applications.

The HX711's simplicity in integration and usage has made it a go-to choice for DIY projects, especially those involving weight sensing or force measurements. Its compatibility with a wide range of microcontrollers and support from various libraries simplifies its implementation in different systems.

Pin #	Name	Function	Description
1	VSUP	Power	Regulator supply: 2.7 ~ 5.5V
2	BASE	Analog Output	Regulator control output（NC when not used）
3	AVDD	Power	Analog supply: 2.6 ~ 5.5V
4	VFB	Analog Input	Regulator control input（connect to AGND when not used）
5	AGND	Ground	Analog Ground
6	VBG	Analog Output	Reference bypass output
7	INA-	Analog Input	Channel A negative input
8	INA+	Analog Input	Channel A positive input
9	INB-	Analog Input	Channel B negative input
10	INB+	Analog Input	Channel B positive input
11	PD_SCK	Digital Input	Power down control (high active) and serial clock input
12	DOUT	Digital Output	Serial data output
13	XO	Digital I/O	Crystal I/O (NC when not used)
14	XI	Digital Input	Crystal I/O or external clock input, 0: use on-chip oscillator
15	RATE	Digital Input	Output data rate control, 0: 10Hz; 1: 80Hz
16	DVDD	Power	Digital supply: 2.6 ~ 5.5V

Figure 7: HX711 Specifications

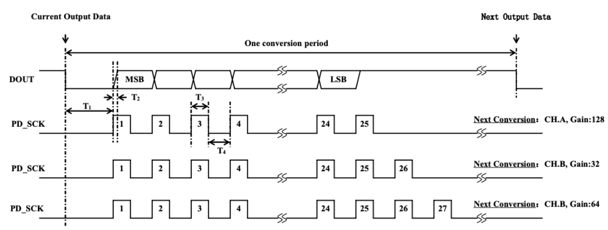

Figure 8: HX711 Timing Diagram

Overall, the HX711 is renowned for its accuracy, ease of use, and robust performance in converting analog signals from load cells into digital data, making it an integral component in many industrial and hobbyist weight measurement applications.

In conclusion, the HX711 module's affordability, reasonable accuracy, and ease of integration render it a valuable asset in applications where cost efficiency and basic environmental monitoring capabilities take precedence over precision.

6.2 Load Cell

A load cell is a transducer used to convert force or weight into an electrical signal. It's a vital component in weighing systems, industrial applications, and force measurement devices. These cells operate on the principle of strain gauge technology, where deformation or strain caused by force on the load cell produces a change in electrical resistance, subsequently converted into an output signal.

Load cells come in various types, including hydraulic, pneumatic, capacitive, and strain gauge load cells. Among these, strain gauge load cells are the most common due to their precision, reliability, and cost-effectiveness.

Strain gauge load cells typically consist of multiple strain gauges arranged in a Wheatstone bridge configuration. When force or weight is applied to the load cell, it deforms slightly, causing strain in the strain gauges. This strain alters their electrical resistance, resulting in an imbalance in the Wheatstone bridge and generating a proportional electrical output signal.

Load cells are available in different capacities to suit various applications, ranging from a few grams to several tons. They offer high accuracy, repeatability, and linearity in measuring forces or weights, making them indispensable in industries like manufacturing, aerospace, healthcare, and automotive.

Moreover, load cells exhibit characteristics such as high stiffness, minimal deflection, and robust construction, ensuring durability and reliability in harsh environments. They are often paired with signal conditioning electronics or instrumentation amplifiers to enhance signal quality and accuracy.

Overall, load cells serve as the foundation for accurate and precise weight or force measurements across a wide spectrum of industrial, commercial, and research applications, providing essential data for critical processes and systems.
Pin PDSCK and DOUT are used for data retrieval, input selection, gain selection and power down controls. When output data is not ready for retrieval, digital output pin DOUT is high. Serial clock input PDSCK should be low. When DOUT goes to low, it indicates data is ready for retrieval. By applying 25 27 positive clock pulses at the PD SCK pin, data is shifted out from the DOUT output pin. Each PDSCK pulse shifts out one bit, starting with the MSB bit first, until all 24 bits are shifted out. The 25th pulse at PDSCK input will pull DOUT pin back to high (Fig.3). Input and gain selection is controlled by the number of the input PDSCK pulses. PDSCK clock pulses should not be less than 25 or more than 27 within one conversion period, to avoid causing serial communication error.

6.2.1 Interfacing Load Cell with HX711

Interfacing a load cell with an HX711 amplifier involves connecting the load cell's wires—often color-coded for power and signal—to the corresponding pins on the HX711 module. Typically, the red and black wires from the load cell

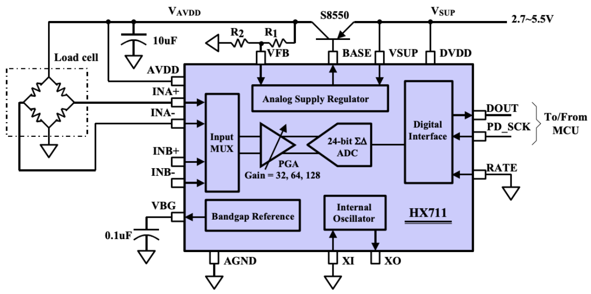

Figure 9: HX711 module Diagram

connect to power (usually +5V) and ground, while the white and green wires carry the differential signal output to the data (DT) pin on the HX711. Additionally, the clock (SCK) pin on the HX711 links to the microcontroller for communication. Through a two-wire serial interface, usually implemented via SPI, the HX711 communicates with the microcontroller, allowing it to read the digital output. Calibration is critical, achieved by recording known weights and their corresponding HX711 readings to establish a relationship between output and weight. Once calibrated, the microcontroller can accurately calculate weights based on the HX711's digital output, enabling precise weight measurements. There is no programming needed for the internal registers. All controls to the HX711 are through the pins.

6.3 Microcontroller

The ESP32 microcontroller serves as the linchpin in this project, providing indispensable capabilities for effective wagon weight monitoring. Its robust processing power, driven by a dual-core architecture and ample clock speed, facilitates real-time computations essential for precise weight measurements. Moreover, the ESP32's integrated Wi-Fi and Bluetooth functionalities enable seamless data transmission, allowing the microcontroller to relay wagon weight data to a web interface for remote monitoring. This connectivity also empowers the ESP32 to trigger alerts when weight thresholds are approached, ensuring proactive management of loading operations. With its versatility in interfacing with various sensors, including load cells, and its cost-effectiveness, the ESP32 emerges as a pivotal component, enabling efficient, accurate, and remotely accessible monitoring to prevent overloading and underloading of railway wagons.

7 Appendix

The initial approach was using AI and ML. The approach was highly inaccurate because of change in properties of each and every variety of coal. Then the mathematical approach using delaunay triangulation of coal using MATLAB was done. Volume calculation from 3D point cloud is widely used in engineering and applications. The existing methods either have large errors or are time-consuming. This paper focuses on the coal measurement. Based on the triangular mesh generated from the point cloud, each triangle is projected downward to the base plane to form a voxel. We derive the calculation formula of voxel by an integral method, which is more efficient than the method of decomposing voxel into tetrahedrons and more accurate than slicing methods. Furthermore, this paper proposes a Delaunay triangulation-driven volume calculation (DTVC) method. DTVC does not preserve the Delaunay triangles but directly calculates the volume in the process of triangulation. It saves memory and running time. Experimental results show that DTVC has achieved a good balance between error and efficiency. But it was completely theoritical and no chance of real-life implementation in near future. As the criteria expects us to present a hardware solution, The idea was finalised and the simulation of the model was done in SCADA. As the results were good, the implementation was started.

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