iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** III **Month of publication:** March 2026

DOI: https://doi.org/10.22214/ijraset.2026.77919

Smart Railway Wagon Monitoring using PLC and Automation

Prof. Akshay P. Pundkar[1], Saurabh V. Solao[2], Atharv A. Uttarwar[3], Devanshu R. Shishte[4], Devang G. Tekade[5], Akshay D. Bhoyar[6]
[1]Professor, Department of Electrical Engineering, Amravati, M.S, India
[2, 3, 4, 5, 6, 7]UG Students, Department of Electrical Engineering, Amravati, M.S, India
P. R. Pote Patil College of Engineering & Management, Amravati, M.S, India

Abstract: Railway transportation plays a crucial role in freight movement, but the manual monitoring of wagon conditions leads to higher labour requirements, longer maintenance times, and increased operational costs. Frequent inspections are necessary to track parameters such as load status, temperature, vibrations, smoke detection, and overall wagon health, which is timeconsuming and inefficient. To address these challenges, this project proposes a Smart Railway Wagon based on Programmable Logic Controller (PLC).In the proposed system, various sensors—including load, temperature, vibration, smoke,and GPS modules—are installed on the wagon to continuously monitor its operational conditions. The PLC acts as the central controller, processing real-time data from these sensors and automatically triggering alerts or actuators when abnormal conditions are detected. Through an IoTenabled communication module, the data is transmitted to a SCADA system or cloud dashboard, enabling remote monitoring and predictive maintenance from a central control room.By automating the monitoring process, the system significantly reduces the dependency omanual labour, minimizes maintenance m time, and enhances safety and operational efficiency.This integration of PLC-based automation with IoT and SCADA ensures real-time monitoring, faster decision-making, and better resource management, making it a robust and scalable solution for modern railway operations.
Keywords: Ladder logic, PLC, Smart Automation, Real time control, Sensors and Actuators, HMI, Network communication, Automation System.

I. INTRODUCTION

Railway freight plays a crucial role in national logistics, but conventional wagons are still largely “dumb” assets with limited real-time information about their health, loading, and operating conditions. Failures such as abnormal vibration, overheating of bearings, brake issues, or overloading are often detected late, leading to safety risks, unplanned maintenance, and delays. At the same time, modern electrified rail systems and digital communication technologies create a suitable platform for implementing smart, condition-based monitoring on wagons.

In this context, Programmable Logic Controllers (PLCs) and industrial automation techniques offer a robust way to continuously monitor critical parameters using sensors distributed on the wagon and along the train. A PLC can collect data from temperature, vibration, load, and position sensors, execute ladder-logic based decision rules, and trigger alarms, logging, or control actions in real time. By combining PLC-based automation with structured data acquisition, the “Smart Railway Wagon Monitoring” concept aims to enhance safety, reduce downtime, and support predictive maintenance in freight operations.The proposed project focuses on designing a PLC-centric monitoring architecture for wagons, integrating appropriate sensors, signal conditioning, communication, and visualization mechanisms. The work targets low-cost, scalable implementation suitable for Indian freight operations, while remaining compatible with existing electrified infrastructure and standards.

II. LITERATURE SURVEY

Early work on railway electrification mainly concentrated on supplying reliable traction and auxiliary power to coaches through overhead equipment, transformers, rectifiers, and distribution boards. These systems improved energy efficiency and reduced emissions, but supervision of wagon-level parameters remained limited to periodic inspections and basic signaling. Recent studies on freight electrification highlight the growing use of power electronics, regenerative braking, and smart monitoring to optimize energy usage and system reliability. In parallel, industrial automation literature documents the evolution from relay-based control to PLC-based systems and ladder logic as the dominant programming paradigm for real-time control. Authors describe PLCs as robust, modular controllers that interface with a wide range of sensors and actuators, support deterministic scan cycles, and integrate with

SCADA and IIoT platforms. Research on Industry 4.0 emphasizes networking PLCs, using protocols such as Modbus, Profibus, and Ethernet-based solutions, and leveraging PLC data for predictive maintenance and advanced analytics.

These ideas are directly relevant to turning railway wagons into smart, connected assets .Sensor and data acquisition literature provides a strong foundation for selecting and integrating suitable sensing elements. Standard texts and DAQ design guides detail sensor types (temperature, strain, acceleration, proximity), performance metrics (sensitivity, range, accuracy, linearity), and the role of signal conditioning and ADCs in high-quality data collection.

Recent works highlight wireless and IoT-enabled sensors, low-power operation, and edge processing, which are attractive for rolling stock applications where wiring and power are constrained. Overall, prior research shows mature building blocks—electrified power supply systems, PLC-based control, and advanced sensor/DAQ technologies—but there is a specific gap in integrated, wagon-level smart monitoring architectures tailored for freight operations in developing railway networks. The present project positions itself in this gap by proposing and demonstrating a PLC-driven monitoring solution focused on wagon health, load, and environmental parameters.

III. METHODOLOGY

The methodology for the “Smart Railway Wagon Monitoring Using PLC and Automation” project begins with a detailed requirement analysis. Key parameters to be monitored include axle-box temperature, wagon body vibration, load distribution, brake status, and basic environmental data such as ambient temperature or humidity. For each parameter, permissible thresholds and alarm levels are defined based on standards or engineering judgement. This step also considers constraints such as available power on the wagon, communication distance, environmental conditions, and cost.

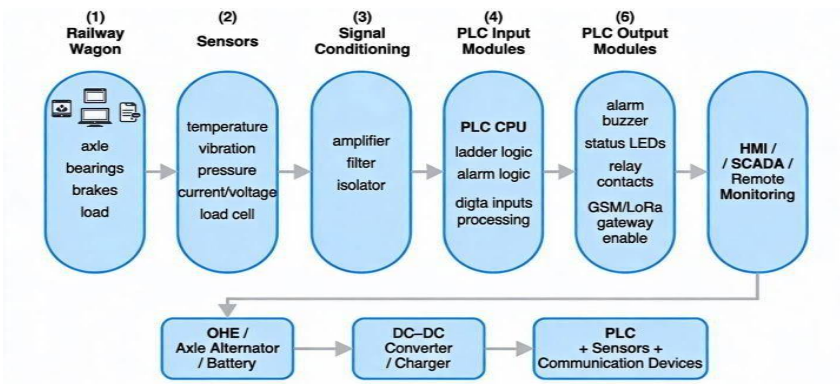


Fig 3.1: Smart railway wagon monitoring using PLC and Automation

Next, suitable sensors are selected and grouped into a data acquisition layer. For example, temperature sensors can be mounted near bearings, accelerometers on the wagon frame, and strain or load sensors on the suspension or bogie elements. These sensors feed into signal-conditioning modules that provide amplification, isolation, filtering, and level shifting to match the PLC input specifications.depending on the PLC model, analog inputs may be wired directly, or interfaced through external DAQ modules with ADCs.

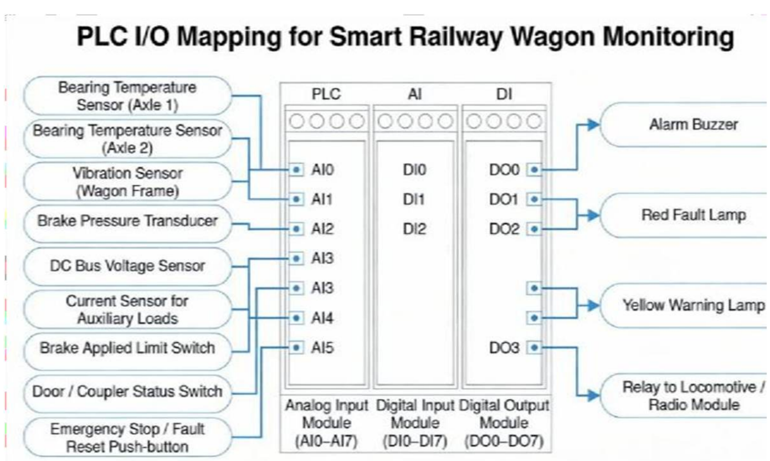


Fig 3.2 : PLC I/O mapping block diagram

The core of the system is the PLC, programmed using ladder logic. Inputs are mapped to specific addresses, and the program is structured into modular rungs for functions such as sensor acquisition, limit checking, alarm generation, data logging, and communication. Timers and counters are used for functions like averaging over time, debouncing noisy signals, or counting threshold exceedances. The PLC scan cycle continuously reads sensor values, evaluates conditions, and sets output bits that drive alarm indicators, relays, or communication flags. Communication and visualization form the upper layer. The PLC can be linked to a small HMI panel mounted in the locomotive or control cabin to display live data and alerts. For advanced setups, the PLC communicates over a wired or wireless industrial protocol to a central SCADA or remote server, enabling fleet-wide monitoring and logging. During development, the ladder logic is first tested in simulation, then validated using hardware-in-the-loop arrangements and finally on the physical prototype wagon model or test rig. Testing scenarios include normal running, over-temperature, excessive vibration, sensor failure, and communication loss, to ensure safe and predictable responses.

In this project, the ladder logic for wagon monitoring is divided into a few clear functional blocks so that each part of the program has a specific job. First, there is a basic "run" section and a common fault latch. A RUN contact, which can come from a key switch or an internal start command, turns on a SYSTEM_ENABLE coil. When this coil is energised, all the monitoring rungs are allowed to work. If RUN is turned off, the program immediately forces all alarms and outputs into a safe condition, so the system never remains active by mistake.Right after that, there is a global fault latch rung. Here all the main trip signals – bearing trips for axle 1 and 2 (BRG1_TRIP, BRG2_TRIP), vibration trip (VIB_TRIP), brake pressure trip (BRK_TRIP) and power trip (PWR_TRIP) – are connected in parallel and used to energise a coil called FAULT_LATCH. As soon as any one of these trips becomes true, the latch turns on and then holds itself through a sealing contact on the same rung.

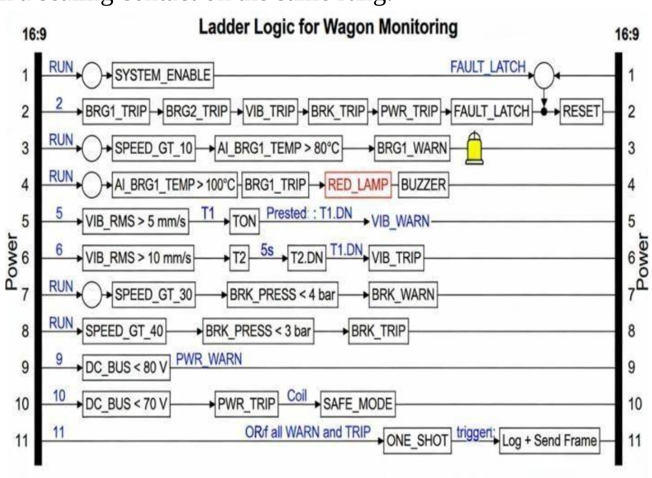


Fig 3.3: Ladder logic diagram for wagon monitoring

Even if the original trip bit goes back to zero for some reason, the latched fault remains stored. At the beginning of this rung there is a normally-closed RESET contact; the operator has to press the reset push-button deliberately to clear the latch after the fault has been checked and rectified.For bearing temperature, a separate set of rungs looks after each axle. For axle 1, the temperature signal AI_BRG1_TEMP is read on an analogue input and compared with two levels. In the warning rung, the PLC checks that the wagon speed is above a small limit (for example SPEED_GT_10) and that the temperature is higher than 80 °C. When both conditions are satisfied, the BRG1_WARN bit is set. This bit turns on a yellow "bearing hot" lamp and is also used to generate a warning entry for communication or data logging. In the next rung, the same input is compared with a higher trip value, such as 100 °C. If this value is crossed, BRG1_TRIP becomes true. This trip signal goes to the global FAULT_LATCH, and at the same time it activates the red fault lamp and the buzzer. Exactly the same logic is used for axle 2, with its own channel and flags (BRG2_WARN, BRG2_TRIP) Vibration is handled with a bit more filtering to avoid reacting to momentary shocks. The PLC takes the RMS vibration valueVIB_RMS from the accelerometer and compares it with a first limit, for example 5 mm/s. When this condition is true, a timer T1 (type TON) starts counting for about 5 seconds. Only if the vibration stays above the limit for the whole timer period does T1 finish and set its done bit (T1.DN), which then sets VIB_WARN. This warning bit can drive a lamp and create a log entry, but it only appears when the vibration is genuinely high for some time, not just for one sample. Another rung repeats the same idea with a higher limit, say 10 mm/s, and a second timer T2. If VIB_RMS is above this higher level long enough, T2.DN sets VIB_TRIP.

This trip bit goes into the FAULT_LATCH logic so that continuous, strong vibration always produces a latched fault.Brake safety is checked using both speed and pressure together. In the warning rung, the program looks for a situation where the train speed is above a medium level (for example SPEED_GT_30) while the brake pipe pressure has fallen below a warning value such as 4 bar. If both conditions are present at the same time, BRK_WARN is set. This means the braking system may not be working at full strength and should be inspected, but it is not yet an emergency. The trip rung is more strict: it checks if the speed is higher again (for example SPEED_GT_40) and the brake pressure has dropped below 3 bar.

When this happens, BRK_TRIP is set and sent to the FAULT_LATCH. In this way, dangerous combinations of high speed and very low pressure are always treated as serious faults, not just warnings.The DC supply to the PLC and sensors is checked in another small group of rungs. The measured DC_BUS voltage is first compared with a warning level, such as 80 V. If the bus voltage goes below this value, the PWR_WARN bit turns on. This tells the operator that the power source is getting weak, but the system can still run for some time. A second rung watches a lower, critical level, for example 70 V. If the voltage falls below this limit, PWR_TRIP is set and a SAFE_MODE coil can also be energised. SAFE_MODE is used in other parts of the program to switch off non-essential loads, freeze some functions and make sure important data are stored safely before the power drops too far.Finally, there is a communication and reporting section which connects the internal status bits to the outside world.

All the main warning and trip bits – such as BRG1_WARN, VIB_WARN, BRK_WARN, BRG1_TRIP, VIB_TRIP, BRK_TRIP and PWR_TRIP– are combined using OR logic and then passed through a one-shot (rising edge) function. Whenever one of these bits changes from 0 to 1, the one-shot produces a short pulse. That pulse is used to trigger a function block which records the event with a time stamp, wagon ID, current speed and measured values, and then sends this information to the HMI, SCADA system or remote monitoring centre through the communication module. Because of this, the same ladder logic that drives local lamps and buzzers also keeps a clear event history and supports remote monitoring and analysis of the wagon's condition over time.

IV. APPLICATION

The primary application of the proposed system is continuous health monitoring of freight wagons during operation. By observing axle-box temperature and vibration signatures, the PLC can detect early symptoms of bearing failure, wheel defects, or track irregularities, and raise warnings before a serious incident occurs. This supports condition-based maintenance, reducing the risk of derailments and extending component life. Another key application is real-time loading supervision. Load or strain sensors can help identify over-loaded or asymmetrically loaded wagons, which affect braking performance, stability, and infrastructure stress. When thresholds are exceeded, the PLC can log the event and alert operators, allowing corrective action at the next suitable location. Over time, such data also helps optimize loading practices and improve safety. The system can also integrate with existing electrified coach infrastructure for power and communication, and feed information to centralized railway control systems. In an advanced deployment, aggregated wagon data can be used by railway planners for predictive maintenance scheduling, asset tracking, and energy optimization across the fleet. The same architecture can be extended to passenger coaches for monitoring HVAC, doors, and safety systems, showing the flexibility of PLC-based smart monitoring in rail applications.

V. ADVANTAGES AND DISADVANTAGES

A PLC-based smart wagon monitoring system offersseveral technical and operational advantages. PLCs are designed for harsh industrial environments, providing high reliability, deterministic control, and ease of maintenance compared to custom electronic controllers. Ladder logic is intuitive for electrical and maintenance staff, which simplifies troubleshooting and future modifications. The modular nature of PLC hardware and I/O allows the monitoring system to be scaled to different wagon types with minimal redesign. From an operational perspective, continuous monitoring enhances safety, enables predictive maintenance, and reduces unplanned downtime. Early detection of abnormal temperature or vibration can prevent catastrophic failures and costly disruptions to traffic.Data collected over time supports better asset management decisions, such as optimizing maintenance intervals, identifying recurring problem routes, or validating design changes.

However, there are also limitations and disadvantages. Implementing PLC hardware, sensors, wiring, and communication equipment on every wagon increases initial capital cost and adds weight and space requirements, which are already constrained in rolling stock. Reliable power supply on wagons, especially in purely freight formations, can be challenging and may demand batteries or energy harvesting arrangements that require regular maintenance. The system also introduces complexity in terms of cybersecurity, software updates, and the need for trained personnel to manage PLC programming and diagnostics. If not designed carefully, large ladder programs can be hard to maintain, and integration with existing railway signaling and IT systems can be non-trivial.

VI. IMPLICATIONS

The successful deployment of smart wagon monitoring using PLC and automation has important implications for railway safety, economics, and technology adoption. On the safety side, continuous condition monitoring reduces the probability of mechanical failures that could lead to derailments, cargo damage, or track accidents, thereby protecting passengers, staff, and goods. Automated alarms and data logs also support transparent incident investigations and compliance with safety regulations. Economically, shifting from time-based to condition-based maintenance can lower lifecycle costs. Maintenance resources can be focused on wagons and components that show signs of degradation, while healthy assets remain in service longer, improving fleet utilization.

In the long term, this can reduce spare-part inventory, workshop congestion, and train cancellations. For a large network, even small improvements in availability and reliability translate into significant financial and service-quality benefits. Technologically, the project aligns railway operations with broader Industry 4.0 and smart infrastructure trends.

Integrating PLC-based monitoring with SCADA and IoT platforms helps create a cyber-physical system where physical wagon conditions are continuously reflected in digital models and dashboards. This encourages the development of advanced analytics, machine-learning-based failure prediction, and eventually more automated traffic management. It also demands upskilling of railway engineers in automation, data analytics, and cybersecurity, influencing workforce development and training priorities.

VII. LIMITATIONS AND FUTURE SCOPE

Despite its benefits, the proposed system faces several practical limitations. Rolling stock operates in a harsh environment with vibration, temperature extremes, dust, moisture, and electromagnetic interference, which can affect sensor accuracy and electronic reliability. Maintaining calibration of multiple sensors across a large fleet is a non-trivial task. Power availability on wagons, particularly in long freight trains, is another constraint; relying solely on batteries requires robust charging strategies and adds maintenance overhead. Scalability is also a concern. Equipping thousands of wagons with PLCs, sensors, and communication links requires significant capital investment and standardization of interfaces and data formats. Interoperability with existing signaling, monitoring, and IT systems must be carefully managed to avoid data silos and integration issues. Furthermore, network-connected PLCs introduce cybersecurity risks that must be mitigated through secure architectures, access control, and regular updates.

Future work can explore several directions. One promising area is the use of low-power smart sensors with onboard processing and energy harvesting, reducing dependency on centralized power sources and wiring. Edge computing monitoring kits that can be adapted to different wagon designs, enabling faster deployment at scale. In the longer term, smart wagon monitoring can be integrated with broader initiatives in high-speed freight corridors, green logistics, and fully digital railways, contributing to safer and more sustainable transport networks.

VIII. SMALL CASE STUDY

In this case study, imagine a loaded freight wagon running steadily at around 70 km/h on a mainline route. At the starting moment [t_0], all conditions are healthy: the bearing temperature on axle 1 is about 60 °C, vibration levels are within normal limits, and the brake pipe pressure is around 5 bar. Inside the PLC, all warning and trip bits are in the reset state, so only the green “Healthy” indication is active on the HMI and wagon status panel.After some distance, the bearing on axle 1 starts to lose lubrication and internal friction slowly increases. Because of this, the PLC begins to see a gradual rise in the analog input AI_BRG1_TEMP. When the measured value crosses the predefined warning limit of 80 °C while the train is still moving above 10 km/h, the comparison block in the ladder logic sets the BRG1_WARN bit. The yellow “Bearing Hot” lamp on the wagon turns on, and the PLC logs an event with a time stamp, current train speed and wagon identification number.This warning does not require an immediate emergency stop, so the driver or control centre operator only gets a caution message on the HMI/SCADA screen. The train is allowed to continue up to the next planned halt or suitable loop line, as the bearing is still within a safe but abnormal temperature range. However, maintenance staff are informed in advance that this particular wagon needs attention at the next yard, so they can prepare tools and spares in time.If the defect is not addressed and friction keeps increasing, the bearing temperature may eventually reach or exceed the critical trip level of 100 °C. When AI_BRG1_TEMP crosses this threshold, the PLC’s comparison logic sets BRG1_TRIP. This signal goes into the global FAULT_LATCH rung, which energizes the fault latch coil. Immediately, the red fault lamp and audible buzzer are activated on the wagon or in the locomotive cab, and the communication module sends a high-priority alarm frame to the driver’s HMI and to the remote control centre.To prevent unsafe operation, the ladder logic is designed so that no one can simply clear the alarm at high speed. A reset command is only accepted when the train speed falls below a safe limit, for example 20 km/h, and an operator deliberately presses the fault reset push-button after acknowledging the alarm.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue III Mar 2026- Available at www.ijraset.com

This interlock ensures that the system cannot be overridden casually while the train is still moving fast with a potentially dangerous bearing condition.Once the train reaches the scheduled halt or maintenance location, engineers physically inspect axle 1 and usually find signs of overheating, such as discoloured grease or damage to the bearing surfaces. The damaged bearing is replaced or repaired before the wagon is allowed back into service. Later, engineers can review the logged temperature and speed trends from the PLC or SCADA system, which clearly show the gradual rise from normal to warning and finally to trip level. This information helps them refine maintenance schedules, lubrication practices and possibly the warning/trip thresholds, reducing the chance of similar failures in the future.

IX. CASE STUDY OUTPUT

Bearing Failure Progression Here the simulated output data from our case study scenario ,generated from the PLC ladder logic progression over 60 min. Key events match exactly : BRG1 WARN trigger at ~7.3 min (82.1 degree celcius) BRG1 TRIP at ~12.1 min (100.8)

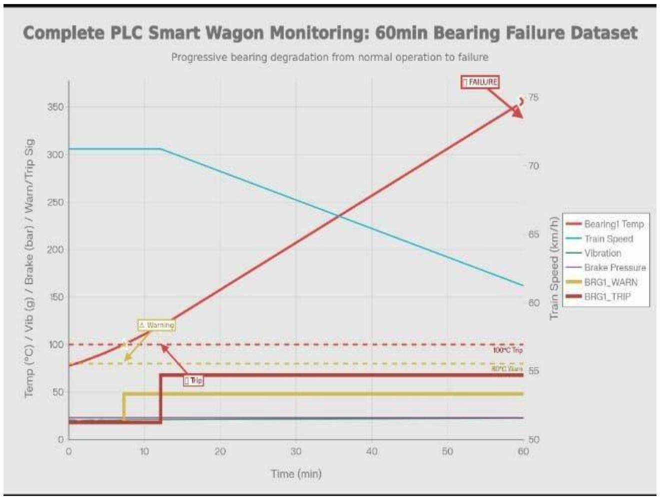


Fig 8.1: 60 min Bearing Failure Dataset

Full 60 min dataset: Bearing temp nonlinear rise,speed drop,status prgession Complete 60-min Monitoring DatasetCaption: Bearing temperature rises nonlinearly from 60°C (healthy) → 82.1°C (t=7.27min, WARNING) → 100.8°C (t=12.12min, TRIP). Train speed steady at 70km/h, brake pressure stable ~5 bar. Status progression: Green → Yellow → Red

Table 7.1: Key Event Table.

Time (min)	Temp (°C)	Speed (km/h)	Status
0.00	60.0	70.0	Healthy
7.27	82.1	70.0	WARNING
12.12	100.8	70.0	TRIP
60.00	337.8	60.0	FAULT

Database CSV (Appendix)
Time_min,Bearing1_Temp_C,Train_Speed_kmh, Vibration_g,Brake_Pressure_bar
0.0,60.0,70.0,2.51,5.00
0.61,61.1,70.0,2.72,5.01
[...full 100 points available...] 60.0,337.8,60.0,4.68,4.96[code_file:1]

REFERENCES

[1] Historical Evolution of Industrial Systems Webb, J. W., & Reis, R. A. (2015). Programmable Logic Controllers: Principles and Applications (6th Edition). Pearson.https://www.pearson.com/store/p/programmable-logic-controllers-principles Gaines, L. M. (1997). History of PLCs. Control Engineering magazine.https://www.controleng.com/articles/history-of- plcs/

[2] Ladder Logic Programming Keating, C., & Brambley, M. (2010). Introduction to Ladder Logic Programming for PLCs.https://pdfs.semanticscholar.org/6d64/f2d1395f637250ff2a8a93e21717d59c6b12.pdf IEEE Instrumentation and Measurement Magazine. (2017). Ladder Logic:Understanding an Industrial Programming Language.https://ieeexplore.ieee.org/document/8241087

[3] Integration with Smart Automation Lee, J., Bagheri, B., & Kao, H. A. (2015). A CyberPhysical Systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 3, 18- 23. https://doi.org/10.1016/j.mfglet.2014.12.001

[4] Wang, S., Wan, J., Li, D., & Zhang, C. (2016). Implementing Smart Factory of Industrie 4.0: An Outlook. International Journal of Distributed Sensor Networks,vol 12, Article ID 3159805. https://doi.org/10.1155/2016/3159805

[5] Xu, L. D., He, W., & Li, S. (2014). Internet of Things in Industries: A Survey. IEEE Transactions on Industrial Informatics, 10(4), 2233-2243. https://doi.org/10.1109/TII.2014.23007531.

[6] IEEE and Elsevier journals on DAQ systems. https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119782698.

[7] D.Patranabis, "Sensors and Transducers", PHI Learning. https://link.springer.com/chapter/10.1007/978-3-03169421-9_4?utm_source .

[8] Jacob Fraden, "Handbook of Modern Sensors". https://next.gr/tutorials/sensors-andtransducers/transducers-and- sensorstutorial?utm_source .

[9] National Instruments, “DAQ System DesigGuide”. https://www.hbm.com/en/8038/seminar-daq- systemssensor-connection-amplifier-principles.

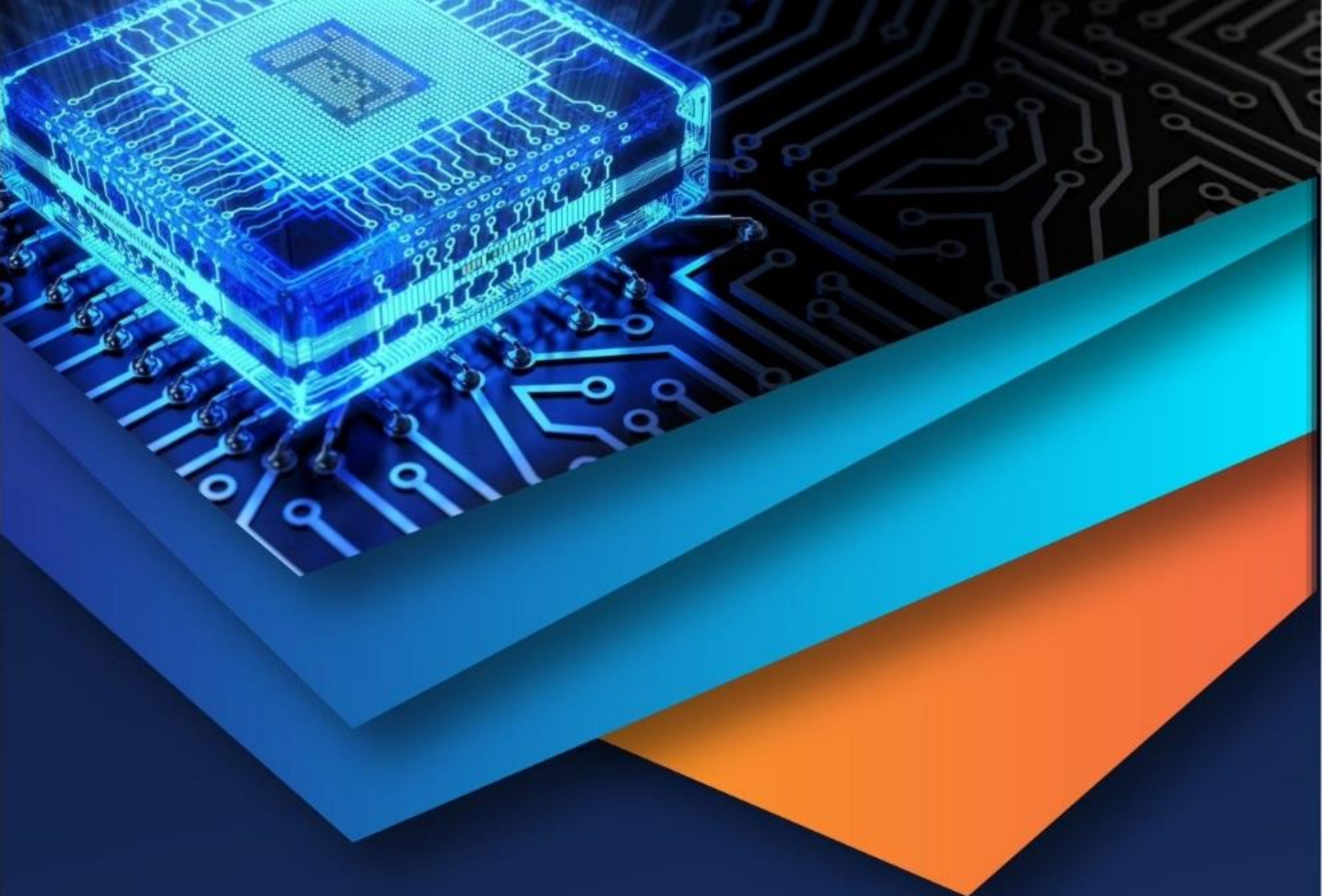
[10] Sensor datasheets and manufacturer whitepapers. https://www.reddit.com/r/engineering/comments/

[11] Railway Electrification (General Overview) https://en.wikipedia.org/wiki/Railway_electrificat ion

[12] Systems of Railway Electrification (Technical Document) https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004092006210179pavan_engg_electrical_traction_2.pdf

[13] Techno-economic Analysis of Freight Railway Electrification https://journals.sagepub.com/doi/full/10.1177/09 54409719867495

[14] Audit Report on Electrification Projects in Indian Railways https://cag.gov.in/uploads/download_audit_repor t/2017/Report_No.22_of_2017-Performance_audit_Union_Government_Electrificatio n_Projects_Reports_of_Indian_Railways.pdf



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL
IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY