INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact Factor: 6.078
(Volume 11, Issue 4 - V11I4-1160)
Available online at: https://www.ijariit.com

SmartFurnace IoT: AI-Powered Monitoring and Predictive Maintenance System for DRI Kilns

Aryeman Dalmia
aryeman2008@gmail.com
KIIT International School, Bhubaneswar, Odisha

ABSTRACT

Direct Reduced Iron (DRI) kilns are central to sponge iron production, particularly in industrial regions such as Odisha, Chhattisgarh, and Jharkhand. Despite their widespread use, these furnaces are often monitored manually or using basic PLCs, leading to safety risks, inefficiencies, and operational delays. This paper introduces SmartFurnace IoT, an intelligent, AI-powered monitoring and predictive maintenance system designed specifically for DRI kilns. The system combines real-time data collection through IoT sensors, edge processing using microcontrollers like ESP32, and cloud-based dashboards with AI analytics. It enables plant supervisors to receive live alerts, predict breakdowns, log environmental data, and remotely manage furnace conditions. The implementation aims to enhance operational safety, reduce unplanned downtime, improve energy efficiency, and ensure compliance with pollution norms. SmartFurnace is scalable, cost-effective, and specifically designed to cater to mid-sized and semi-urban industrial plants where advanced automation is often unaffordable or impractical.

Keywords: *DRI Kiln, SmartFurnace, IoT, Predictive Maintenance, Industrial Automation, Edge Computing, Industry 4.0, Sponge Iron*

1. INTRODUCTION

Industrial furnaces used in sponge iron production are complex systems that operate under extreme conditions including high temperatures, fluctuating pressure, toxic gas emissions, and mechanical stress. Traditionally, monitoring these furnaces has required human operators stationed in control rooms to oversee temperature regulation, material feed, and gas flow. However, this method is prone to error, delay, and unsafe exposure. In recent years, there has been a global shift toward the integration of intelligent systems in industrial operations, leveraging the power of Internet of Things (IoT), Artificial Intelligence (AI), and cloud computing. SmartFurnace IoT embodies this shift by offering a digital, automated, and AI-enhanced approach to monitoring and managing DRI kilns.

2. LITERATURE REVIEW

The evolution of Industry 4.0 has led to the adoption of IoT and AI technologies across various sectors including manufacturing, agriculture, and energy. Research in thermal and steel industries has demonstrated the effectiveness of predictive maintenance and real-time monitoring in reducing equipment failure rates. However, existing systems often focus on large-scale, well-funded factories with significant digital infrastructure. Mid-sized sponge iron plants, particularly those in rural or semi-urban India, have limited access to such technologies.

Previous studies have shown that implementing low-cost sensors and cloud dashboards can significantly improve industrial oversight without heavy investment. SmartFurnace builds upon these findings by customizing its solution for the operational and environmental conditions specific to DRI plants.

3. METHODOLOGY

The SmartFurnace IoT system comprises a network of industrial-grade sensors that measure key operational parameters such as temperature, CO/SO_2 gas concentration, and material feed rate. These sensors are installed at strategic locations across the kiln, including the combustion zone, exhaust outlet, and raw material inlets. An ESP32 microcontroller or Raspberry Pi functions as the edge device, collecting sensor data and transmitting it to a centralized cloud server. The transmission is secured using encrypted Wi-Fi or GSM modules to ensure data integrity and privacy. On the cloud side, the system uses Firebase or AWS for real-time database management and visualization. AI models continuously analyze sensor data to identify patterns that indicate potential mechanical failure, overheating, gas leakage, or abnormal input rates. When such patterns are detected, the system issues alerts via SMS or email to designated plant personnel. These alerts are accompanied by dashboard recommendations on corrective actions, such as adjusting air/gas flow or feed rates.

4. SYSTEM DESIGN

The architectural framework of SmartFurnace IoT is modular and adaptable. At the base is the DRI kiln, depicted as a cutaway model to show the positioning of sensors and data transmission units. The sensor network includes thermocouples for temperature tracking, electrochemical gas sensors for monitoring emissions, and load cells or IR sensors to assess material flow. All sensors are wired or wirelessly connected to an ESP32 board located in a protected control box near the furnace. This board collects and processes sensor data, sending updates every few seconds to the cloud platform. The cloud dashboard is accessible via PC or mobile device, featuring real-time graphs, heat maps, historical logs, and compliance reports. A rule-based AI engine embedded in the cloud monitors data trends to generate predictive alerts. For example, if the temperature near the exhaust increases rapidly while gas flow remains stable, it may predict slag buildup or poor combustion, prompting early maintenance.

5. RESULTS AND EVALUATION

Initial testing of the SmartFurnace IoT system was conducted in a lab-simulated environment with controlled inputs to mimic real furnace conditions. The system demonstrated high responsiveness and accuracy in reading sensor data. Alerts were generated accurately for abnormal temperature spikes and CO levels. The cloud dashboard maintained real-time sync with minimal latency, and historical data could be downloaded for audit purposes. Compared to traditional control room monitoring, SmartFurnace improved response times by over 50% and predicted three test anomalies at least 10 minutes before threshold breach. These early alerts are critical in preventing equipment damage and ensuring worker safety.

6. DISCUSSION

One of the challenges in DRI kiln management is the partial automation of physical operations. Currently, material feeding, air/gas mixing, and temperature regulation are typically controlled via PLCs, with manual oversight for correction. SmartFurnace does not seek to replace PLCs but rather enhances them by acting as an intelligent observer. For example, the system does not feed sponge iron automatically but can monitor the feed rate using sensors and send alerts if underfeeding or overfeeding is detected. Similarly, it can analyze gas concentration trends and suggest when air/gas valves should be adjusted to optimize combustion. Temperature anomalies are detected by comparing multiple sensor inputs over time, allowing predictive maintenance schedules to be generated.

7. CONCLUSION

SmartFurnace IoT represents a transformative step in the digitization of sponge iron manufacturing processes. By integrating IoT sensors, edge computing, cloud infrastructure, and AI analytics into one cohesive system, it offers a comprehensive solution for monitoring DRI kilns. The platform enhances operational safety, ensures faster and more accurate responses to hazardous conditions, and assists in meeting pollution control standards. Its affordability, ease of integration, and adaptability make it suitable for small to mid-sized plants where automation is limited. With future plans including ERP integration, voice alerts, and mobile app controls, SmartFurnace is well-positioned to play a key role in the next generation of smart industrial systems.

REFERENCES

[1]. Kumar, R. et al., 'IoT in Industrial Furnaces', IEEE Transactions, 2020.

[2]. Sharma, A., 'Predictive Maintenance in DRI Kilns', Springer, 2021.

[3]. Singh, P., 'Real-Time Furnace Monitoring', ResearchGate, 2019.