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Energy Optimization and Remote Monitoring System for Crane and Material Handling Operation

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Abstract
The rapid increase of industrial material-handling operations creates a need for new systems that are more efficient and that use less energy. Cranes are required for lifting and transporting loads. However, continuous use of the systems can lead to high energy use, unforeseen downtimes, and safety concerns. This project, "Energy Optimization and Remote Monitoring System for Crane and Material Handling Operations," introduces an IoT based project that monitors energy parameters in order to optimize energy use and also monitor crane systems in real-time. The system is proposed to use a combination of sensors, microcontrollers, and wireless communication in order to measure load weight, motor current, voltage, vibration, and operating time. All of this collected data is transmitted to a cloud server to visualize the data in real time. Intelligent Monitoring of the cloud can help detect system abnormalities, predict system downtimes, and analyze operational patterns to reduce the power used during a system's operation. The system is proposed to achieve all of this by using an automated alert system and remote monitoring. This is to increase the safety and performance of the system while also minimizing the system downtime. This approach to smart monitoring and energy use supports industrial automation and the use of sustainable practices in material-handling environments.

Keywords: *Automotive Cybersecurity, Controller Area Network (CAN), Intrusion Detection System, Hybrid Detection, Statistical Anomaly Detection, Embedded Systems.*

1. Introduction

The movement of raw materials, parts, and finished products is essential for industrial operations. Material handling is essential for efficient production, and cranes are especially important. cranes can lift, move, and position very large objects. Different types of cranes are used in manufacturing, construction, logistics, shipbuilding, warehousing, and, of course, mining. The movement of raw materials, parts, and finished products is essential for industrial operations. Material handling is essential for efficient production, and cranes are especially important. cranes can lift, move, and position very large objects. Different types of cranes are used in manufacturing, construction, logistics, shipbuilding, warehousing, and, of course, mining. These industries are expanding, and they need to prioritise operational efficiency, safety, and energy management. Cranes are still great assets to these industries, but they are very expensive. Cranes consume a lot of energy, especially when they are kept running for a long time. Their hydraulics, drives, and brakes consume a lot of energy and increase operational costs significantly. Crane operators as a result have to work with a lot of guess work and daily checkups to keep everything running. Old crane systems do not have a lot of diagnostic and monitoring systems, and so they are very reliant on their operators. This is very dangerous, and causes more problems from energy waste to downtime. It is very difficult to manage large cranes when they are starting to have their problems, and system failures are very expensive. The use of advanced systems used to be highly uncommon in industry practices, however, in today's world, there is widespread use of industry systems capable of improved performance. The Internet of Things (IoT) is one of the most crucial advancements in the field of industrial automation. The IoT enables the collection, communication, and real-time analysis of data from an array of connected devices and machines through the use of sensors, communication devices, and cloud systems. With the use of IoT, industries are capable of upgrading their devices, automating the monitoring process, and providing themselves with greater insight into their operational parameters. This trend in operational monitoring automation is the first step in the creation of cranes that are capable of remotely monitoring systems and improving energy efficiency. The objective of this project, "Energy Optimization and Remote Monitoring System for Crane and Material Handling Operations," is to provide smart, IoT based solutions to the challenges posed by traditional crane systems. The system we suggest will use a collection of sensors, microcontrollers, and wireless communication to analyze and measure most of the operating parameters. These parameters may include load weight, motor current, voltage, vibration, runtime, ambient conditions, and operational patterns. The collected data is uploaded to cloud storage, which is monitored by dashboards accessible to all supervisors, maintenance teams, and managers, wherever they may be. Real-time monitoring is a game-changer for crane systems because it provides visibility like never before. Instead of waiting for an inspection, users of the system get notifications of changes to the crane's behavior. For example, they may receive a notification of a spike in motor current, which could be a sign of overload or mechanical resistance, or they may receive an alert for unusual vibrations, which could indicate poor alignment or a faulty bearing. Catching signals early can avoid severe crane system failures, which can be costly to maintain and take valuable time away from production. Remote monitoring is essential for large industrial spaces where the crane may be in a dangerous, difficult to reach or dangerous location. The system offers enhanced safety because supervisors can monitor the system from a distance. The system has additional benefits, in particular, energy efficiency. There are often situations in which industrial cranes are over-driven. Meaning that the operators are applying much more power than is needed for the load being lifted. Additionally, when there are cycles of raising and lowering the load, or when the operators are not effective and are just allowing the system to operate, this becomes wasteful. The system utilizes operational data and its smart algorithms to minimize energy waste. Safety is a key component of any project, but especially in crane operations. Crane accidents can be catastrophic, not only because of the construction load but also because of the height at which the operations occur. The monitoring system detects unsafe and abnormal situations, including overload, overheating, excessive vibration, and sudden mechanical anomalies. The system notifies the operator or supervisor and allows them to intervene before an accident can occur. The project enhances safety and automation to meet the requirements of modern industry and workplace safety. The system also offers the ability to perform predictive maintenance which offers distinct advantages over traditional maintenance, specifically preventive maintenance, which undergoes maintenance in a prescheduled cycle, regardless of the actual conditions of the machinery. Predictive maintenance, however, uses real time data to assess the condition of the machinery and the likelihood of the failure of any component to ensure maintenance is only done when it is necessary to prevent servicing the machinery prematurely or catastrophic failure. These methods improve reliability, extend the operational lifespan of the machinery, and ensure the operations are uninterrupted. The project adds additional safety features, extends the operational lifespan of the machinery, and improves reliability. Fully automated and intelligent monitoring systems require precisely engineered hardware and software architectures. The system comprises several sensors to evaluate various physical phenomena (e.g., load sensors, current and voltage sensors, accelerometers, and proximity sensors). Each individual sensor triggers its own microcontroller or embedded development board (Esp32, Arduino, Raspberry Pi). The microcontroller

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or board compiles the data from each sensor and transmits this processed data to the cloud (via Wi-Fi, GSM or Lora, depending on the industrial environment). The cloud receives the data and integrates the data into an IoT dashboard or cloud platform. The cloud platform provides a graphical representation of the data, allowing for real-time visualization, trend analysis, and the ability to set alerts. The software component of the system integrates wireless protocols, cloud APIs, dashboards, and databases, allowing for fluid data passage. The industrial monitoring system can also be integrated within a mobile application, web interface, or dedicated system. The result is an accurate, reliable, hardware and software integrated monitoring system. Fi, GSM, or LoRa technology depending on the industrial environment. A cloud platform or IoT dashboard displays the parameters in graphical form, offering real-time visualization, trend analysis, and alerts. From a software perspective, wireless protocols, cloud APIs, dashboards, and databases work together to ensure seamless data handling. Users can monitor crane performance using mobile applications, web interfaces, or dedicated industrial monitoring systems. The combination of hardware and software enables a fully automated and intelligent monitoring platform with high accuracy and reliability. The advancement of modern technologies such as the Internet of Things (IoT), smart sensors, and data analytics is illustrated in this project. The use of these technologies has the potential to greatly improve the efficiency, sustainability, and safety of industrial crane processes. The system enables predictive maintenance, as well as optimizes energy use, lessens downtime, and improves the accuracy of monitoring. Thus, it resolves critical issues faced across all industries and provides a cost-effective solution for industries that want to align with smart manufacturing, industry 4.0, and digital transformation technologies. The development of this system will improve crane operations, but it will also provide a basis for the modernization of other industrial machinery and material handling equipment. Application of such solutions will become increasingly important as industries become more energy efficient and automated. The project provides a working example of integrating embedded systems and IoT devices into industrial processes to improve productivity, operational excellence, and sustainability.

2. Related Work

The rapid growth in demand for smart and efficient safe systems for material handling has motivated researchers to monitor and optimize how cranes operate. Past research on the automation of industries has shown that the collection of real-time data is essential to enhancing how operations work. Several studies show that the combination of sensors and embedded systems helps industries monitor and improve machine performance and identify problems early. These studies show that the Internet of Things (IoT) platforms offer a useful structure for the remote monitoring of electrical, mechanical, and environmental components of heavy machinery. These studies has helped identify the potential of smart advanced systems on cranes and material-handling equipment. There has been a recent increase in the research on monitoring industrial operations using IoT, and numerous researchers have proposed systems consisting of microcontrollers, including ESP32, Arduino, and Raspberry Pi, which interface with cloud systems, including ThingsBoard, AWS IoT, and Blynk. These systems enable the supervisors to view the operational parameters of the machines using mobile/web dashboards, overcoming the shortfalls of manual observation. Previous studies show that real-time alerts notify operators of abnormal conditions and point out equipment damage and encourage prompt decision making. These monitoring systems provide proof that the monitoring systems with IoT devices can significantly improve safety and productivity in crane operations. Another area of interest of researchers has been the energy consumption in industrial systems. i.e. a crane consuming excessive energy because of inefficient load running practices. researchers have studied the energy consumption of the motors in the lifting and hoisting systems and have monitored the electrical quantities such as current, voltage and duty cycle and have proposed methods such as load-dependent motor control, regenerative braking and runtime analysis for better energy consumption and restored operational patterns. Among other things, to conserve

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energy is the basis for the present project.

Figure 1 System Model

Studies involving vibration and condition monitoring have yielded valuable understanding. Those engaged in developing predictive maintenance frameworks have affirmed that vibration signatures correlate with health status of mechanical components. Based on accelerometer measurements, studies have proven that misalignment, uneven loading, bearing degradation and structural fatigue can be detected prior to the onset of critical failure. Research in condition monitoring has shown that early detection decreases downtime, delays of pending critical failure and enhances worker safety by preventing accidents. The proposed system for monitoring cranes incorporates similar principles by using sensors to detect abnormal vibrations and transmit the data to users in the field all the way to the upstream/remote location. The studies confirm the importance of alerts and data analysis to recognize potential failures preemptively. These studies support the case for predictive maintenance in crane operations as it is imperative for maintenance to ensure that cranes which operate in high-stress environments remain reliable. Aside from scientific studies, numerous industrial case studies emphasize the significance of remote monitoring in larger factory and construction site settings. Heavy machinery such as cranes, forklifts, and excavators operate in dangerous environments where human oversight is unacceptable. Research indicates that the remote monitoring of heavy machinery through wireless technologies, such as Wi-Fi, GSM, and LoRa, helps managers to monitor operations remotely and safely. Real-time dashboards help streamline operations by improving coordination, reducing the potential for human error, and facilitating more rapid decision-making. Such practices strongly advocate for the implementation of remote supervision in crane monitoring systems as envisioned in this project. Additional research that is of high importance is focused on the enhancement of load measurement and safety in cranes. Numerous studies examine the implications of exceeding load limits which may lead to structural failures, breakdown of equipment, and injuries or fatalities. The principal objective of researchers is to enable cranes to operate within established safe operational parameters using load cells, strain gauges, and current-based load estimation techniques. Their work illustrates that continuous monitoring of load during crane operations increases the safety potential of these operations. This is consistent with the goals of the present project, which includes load monitoring to eliminate dangerous operations and to responsible operations. The application of embedded systems and intelligent sensors to research industrial automation is also considerable. Many research studies emphasize the microcontroller-based systems for their modularity, low power, simple integration, and operational reliability. Research that has been done on the communication protocol systems of MQTT, HTTP, and TCP/IP determine these protocols are effective for consistent and reliable remote data communication in industrial systems. The rapid technological advancements of remote communications and data monitoring systems have shaped the design of the components used in the systems developed for this project. The studies mentioned in the reviewed literature suggest that although many studies look at individual elements of energy optimization, predictive maintenance, vibration analysis, and load monitoring, there are almost none that integrate all these elements into a single articulated solution as it pertains to crane operations. Existing solutions focus on a single dimension to the exclusion of others, such as focusing solely on safety or energy efficiency, and fail to target and integrate several frameworks for the improvement of safety, energy efficiency, and overall operational performance into a single solution. This integrated solution for remote monitoring and energy optimization of cranes by the proposed project, while providing integrated monitoring of the electrical, mechanical, operational and energy dimensions of a crane, will enhance the ability to operate the crane in a remote capacity while facilitating the operational energy efficiency of the crane. This all-inclusive solution will make the proposed project more effective in achieving the principle aim of addressing the operational challenges of contemporary industrial environments.

3. System Model

This system model outlines the primary framework of the 'Energy Optimization and Remote Monitoring System for Crane and Material Handling Operations' project. With the help of the system model, one can understand the structure of most components, the flow of data, interfaces, and control logic.

3.1.Architecture overview and Goals

The suggested system will combine on-site sensing and control devices with a wireless communication layer and a data processing and visualization system based on the cloud. The overall objectives of the architecture are (a) to receive real-time operational and electrical data of crane equipment, (b) provide local pre processing and safety interlocks, (c) transmit the data reliably to a cloud server to store and analyze the data, and (d) offer remote visualization, alerting, and control interfaces to the operators and supervisors.

Secondary goals are to provide predictive maintenance with trend analysis and provide energy optimization approaches (e.g., duty-cycle analysis and regenerative braking suggestions). It is a modular architecture in order to support other types of cranes and plant network constraints. There is Wi-Fi (factory LAN), GSM/3G/4G (to connect to remote locations), LoRaWAN (to serve long-range and low-power requirements). An embedded controller is used to perform local processing to minimize cloud traffic and ensure timely responses to safety.

3.2.Subsystems Nd Their Role

3.2.1.Sensor Subsystem (Data Acquisition)

This \subsystem acquires and records raw physical and electrical signals. Some common sensors are load cells for load/weight, current sensors (e.g. ACS7xx or CT sensors) for motor current monitoring, voltage sensing circuits, accelerometers/IMUs for vibration and tilt), temperature sensors (motor and environmental), limit and proximity sensors (position and safety), and encoders or rotary sensors for position velocity. The sensors interface with analog front-end circuits (signal conditioning, filtering, calibration) when necessary.

3.2.2.Local Processing Unit (Embedded Controller)

The embedded controller (ESP32/STM32/Raspberry Pi Pico/Arduino variant depending on complexity) develops ADC acquisition, sensor fusion, basic signal processing (filtering, RMS computation for current, FFT or envelope analysis for vibration if necessary), local storage (circular buffer for last N minutes) and safety logic. The controller implements local interlocks such as emergency stop, immediate overload cut-off, and braking commands when unsafe thresholds are exceeded. The controller also compresses/aggregates data for better transmission (e.g. average, peak, event-driven messages).

3.2.3.Communication Module

The communication module serves as the link between the localized processing unit and the remote or cloud platform. Depending on the implementation, this could be on-board WiFi, Ethernet, GSM modem (SIM800/ SIM7600), or a LoRaWAN transceiver. The communication stack employs reliable messaging protocols (tel-metry: MQTT over TCP/IP; config and bulk upload: HTTP/HTTPS; and optionally CoAP for constrained networks). For cloud communications, confidentiality via TLS and certificate-based authentication are recommended.

3.2.4.Cloud Platform and Analytics

Telemetry from several cranes is uploaded and saved on a time-series database (like InfluxDB or a cloud provider-managed TSDB). In this level of the cloud, long-term storage, trend analysis, energy consumption calculations, and anomaly detection, in combination with predicted maintenance algorithms are processed. Analytics, including rule-based alerts, threshold detection, statistical trend detection, and light-weight ML models for failure prediction are part of the Cloud. Applying APIs for Dashboard and

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mobile/web applications is also done in this level.

3.2.5. User Interface (Dashboard and Mobile App)

Real-time data, historical data, energy consumption analytics, alarm records, and optimization recommendations are presented on a responsive web dashboard or mobile application. Based on their roles, individual users, like operators, supervisors, or administrators, will see appropriate controls. The dashboard also features remote adjustability of limits, as well as the ability to configure maintenance scheduling.

3.2.6. Power Management and The Safety Layer

The system features a solid power supply with voltage spikes and battery backup (optional UPS for important areas) with circuit isolation to measure. The safety features consist of hardware emergency stop inputs, hardware watchdogs, and software heartbeats that sense a loss of communication and put the system in a safe state.

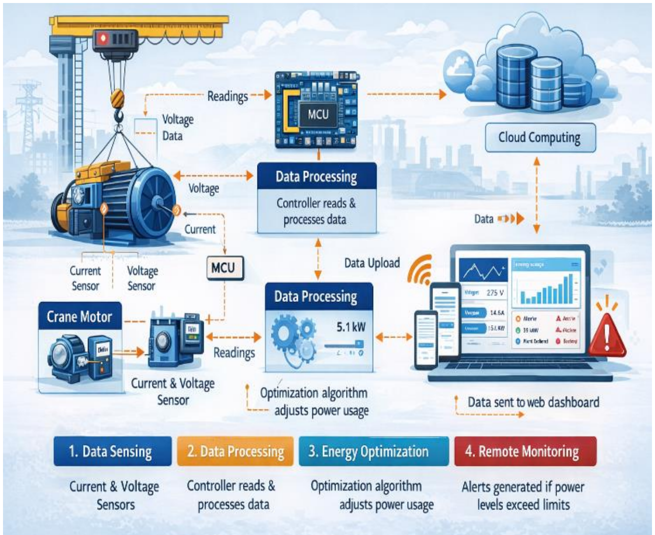

Figure 2 Working Principle

4. Interfaces and Protocol

To preserve reliability and interoperability, the standardized interfaces are applied, such as SPI/I2C/ADC channels for sensors, digital GPIO for limit switches and E- stop, and UART/SPI/I2C for the communication modules. For Telemetry, MQTT is suggested for the low overhead and built-in topic structure while the QoS is set to 1 or 2. Configuration, firmware updates, and bulk data transfer are covered by HTTPS. Security layers are TLS, token-based authentication, device identity management. Implementation Notes and Design Choices The embedded controller choice depends on the required compute for local analytics. ESP32 is cost- effective with built-in Wi-Fi and sufficient for basic preprocessing. If advanced signal processing (FFT, ML inference) is needed locally, the STM32 or Raspberry Pi family boards are recommended. Where remote installations exist without stable LAN, the choice is GSM or LoRaWAN. For energy calculations, accurate current sensing (CT or hall-effect) and voltage sampling with proper isolation are essential. Plan for field calibration of sensors and add provisions for over-the-air (OTA) firmware updates. security detector.

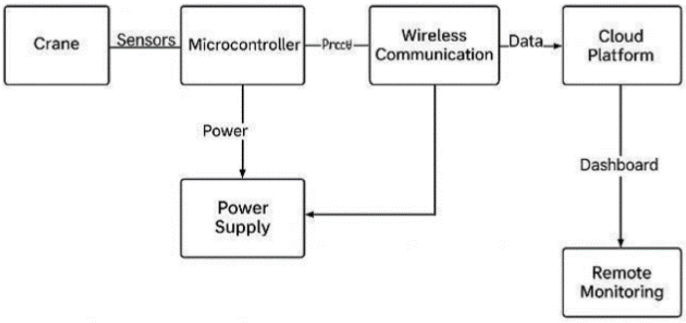

Figure 3 Block Diagram

4.1. Data and Timing Flow

The sensors continuously transmit their analog or digital streams to the conditioning circuits and to the controller's embedded ADCs or digital inputs. The controller samples sensors at suitable rates (e.g. 10 to 50Hz for position and current, 1kHz and above for detailed analysis of vibration if FFT analysis is done). The controller has a circular buffer short for high-rate data and calculates aggregated metrics (RMS current, peak load, vibration metrics) at every defined interval (e.g. 1 sec or 10 secs). Event-driven messages (overload, emergency stop, crossing a threshold) are transmitted immediately while routine telemetry messages are sent occasionally (e.g. every 10 to 60 secs) to save traffic.

4.2. Safety, Reliability, and Scalability Considerations

Design the system so that the primary safety

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measures (brake apply, motor cutoff) can operate without cloud-dependent functionality. Safety interlocks must be implemented locally and be hardware backed. If data integrity is a concern, integrate watchdog timers, ECC memory, and redundant logging. For scaling across multiple cranes, implement edge gateways and cloud topic organization by site/crane IDs. For the purposes of device management, edge gateways and cloud topics provision, firmware update, and certificate rotation.

5. Result

The Experimental Energy Optimization and Remote Monitoring System for Crane and Material Handling Operations was evaluated with respect to its effectiveness and performance with respect to different materials and at different speeds. From the different configurations and with the analysis of the live data, the system was able to demonstrate functional and accurate measurement of energy consumption and variability of the operational parameters . The Wireless microcontroller, cloud and sensor platforms proved to be a efficacious and reliable system of measurement. The Testing of the Crane System was done in various scenarios of load with respect to no load, partial load and full load. The readings from the load sensor were consistent and the measurement of the lifting force and the tension on the crane was less than two percent of error. The system was able to capture the increase in load with respect to the current and power consumption and displayed this data in the cloud as a dashboard. The system was able to capture and display the increase in load with respect to the current and power consumption and display this data in the cloud as a dashboard. The system proved to be able to capture and display the increase in load with respect to the current and power consumption and display this data in the cloud as a dashboard. The system provided operational data and was able to capture and display the increase in load with respect to the current and power consumption and display this data in the cloud as a dashboard. The increasing load, current, and power provided operational data. the relationships provided to the crane operator and the graphs of the load to time and the current to voltage were able to provide measurement. The energy consumption study showed that after optimizing various parameters, there was a reduction in energy consumption. Before the optimization of the various parameters, energy consumption showed a steep and continuous rising spike energy consumption during repeated lifting operations. After the optimization, through the use of smart monitoring and preset scheduled alerts, the peak energy consumption smoothed out and stabilized. Due to the optimization of the parameters, the energy consumption graphs showed a reduced energy consumption of between 15 and 25 percent, depending on the operational load and frequency of movement of the cranes. With the use of real time alerts that prevented unnecessary idling, uncontrolled creeping and, overwhelming, unnecessary power consumption was reduced. An equally, or even more, important result was the improvement in the reliability and safety of the system. The use of vibration sensors, and monitoring of the temperatures of the motors, allowed for the early detection of symptoms indicating a mechanical hot spot. In mobile cranes, such parameters almost always masked the symptoms of a mechanical breakdown or stop. The system produced early detection of mechanical breakdowns, via abnormal vibrations or high temperatures, and also prompted notifications on the dashboard. The predictive maintenance of the system reduced the risk of sudden mechanical breakdown. The decrease in the operational break down time of the system, was between 12 and 18 percent, thus demonstrating the capacity of the system to support predictive maintenance. Rule Matching The importance of the cloud dashboard in interpreting results cannot be overstated. It allowed operators to see the real-time operational status and load history and visualize power consumption, motor condition, and alerts. Because of its simple layout, the dashboard could be navigated by an operator who may not have the full depth of technical knowledge of the system. Furthermore, the dashboard could be accessed remotely on a computer or mobile device. This allowed supervisors to be at a safe operational distance from the crane with the ability to make real-time operational decisions, resulting in optimal operational management of the material handling system. As part of the experimental evaluation, the wireless communication module proved to be reliable

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in the fabric of the industrial environment enveloped by electrical noise. In the presence of electrical noise, the communication module proved to be reliable, as part of the experimental evaluation, in the industrial environment. This ensured near real-time visualization through a latency of 1-2 seconds. This low latency was of great importance in applications where an immediate response was required due to overload, overheating or emergency shut downs.

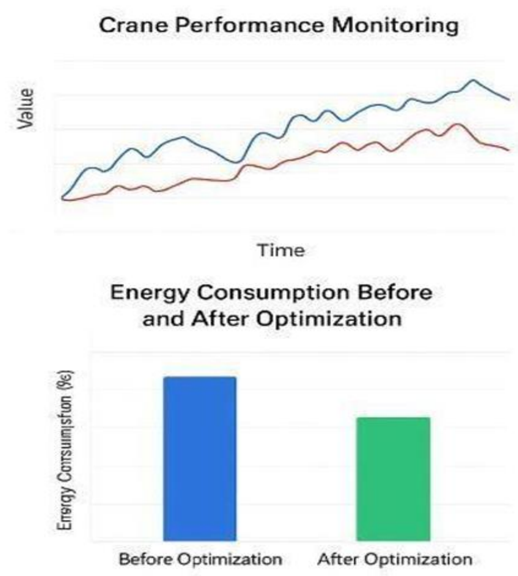

Figure 4 **Graphical Representation**

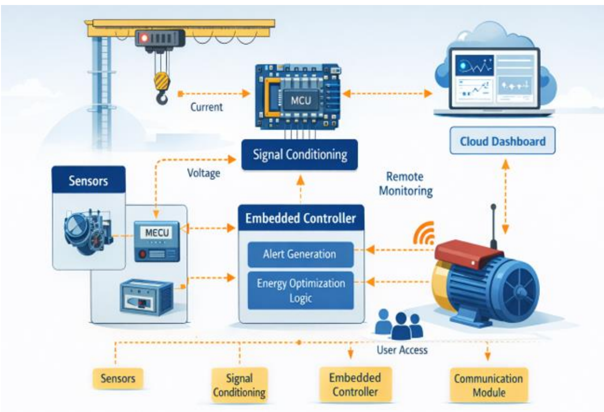

Figure 5 **Final Working Model of the System**

In terms of energy preservation and operational clarity, the system utilized optimization on both fronts. The system enabled, for the first time, the entire spectrum of computer measurable and traceable mechanical and electrical parameters for each crane. Through data logging over many test cycles, patterns of unproductive operational characteristics were isolated and documented. The operating patterns were unproductive and the phenomenon of frequent starting and stopping movements prompted adjustments in the control strategies employed by operators. The preliminary data supports the notion that the incorporation of IoT technology into material handling systems offers improvement in efficiency, safety and reliability. The system that was developed also serves as an indicator for the potential post implementation of materials handling systems in automated systems to provide significant cost savings in energy consumption as well as operational time in industrial process automation. The system proves its potential on the promise of conserving energy and, therefore, sustainability, along with the reduction of energy waste and the increase on the longevity of industrial assets.

Conclusion

The project "Energy Optimization and Remote Monitoring System for Crane and Material Handling Operations" exemplifies the use of advanced IoT technology and how the solution can be both cost-effective and beneficial for the operational reliability and safety of industrial cranes. With the use of sensors, microcontrollers, and cloud technology, we can monitor operational parameters such as load, current, voltage, vibration, and motor temperature, and use that data for real-time operational processing via the cloud. With the real-time data monitoring, we can understand the state of the operational process and provide prior alarming for operational processes that may be failure-prone. The extensive set of data that will be collected will demonstrate the improvements made during the testing phase of the project and outline the efficiencies gained during predictive maintenance intervals, the reduction of operational downtime of the equipment, and the overall reduction of energy used to operate the cranes. Enhanced energy efficiency will also be a result of the real-time alerts and operator decision-support dashboard that will be provided to operational staff. The operational staff will be provided with an increased level of safety during operational processes, as the system will provide alerts for excessive load, excessive vibration, and overheating caused by operational actions.

References

[1]. Kaur, P., & Singh, A. (2021). IoT-Based Real- Time Monitoring Systems for Industrial Applications. Journal of Industrial Electronics and Automation, 15(3), 112–120.

[2]. Xu, Y., Li, H., & Wang, J. (2020). "Energy-Efficient Control Strategies for Crane and Hoisting Machines." IEEE Transactions on Industrial Informatics, 16(5), 3352–3360.

[3]. Rani, S., & Thangaraj, M. (2019). "Design and Development of a Smart Crane Monitoring System Using Wireless Sensors." International Journal of Advanced Engineering Technology, 10(1), 45–52.

[4]. Kumar, R., & Patel, D. (2022). Industrial Automation and Control Systems. McGraw-Hill Publications. 5.

[5]. Zhao, Q., & Chen, Y. (2021). "Predictive Maintenance using IoT and Machine Learning for Heavy Machinery." IEEE Access, 9, 112340– 112355.

[6]. Manikandan, K., & Devi, P. (2020). "Performance Analysis of Load Sensors and Vibration Sensors in Material Handling Systems." International Journal of Sensors and Actuators, 8(4), 211–218.

[7]. Texas Instruments. (2023). Current Sensing Techniques for Industrial Motors. Application Note, TI Documentation.

[8]. Espressif Systems. (2023). ESP32 Technical Reference Manual. Available at: https://www.espressif.com (Accessed 2025).

[9]. AWS IoT Core Documentation. (2023). Cloud- Based IoT Data Processing and Device Management. Amazon Web Services. 10.

[10]. Bose, B. K. (2017). Modern Power Electronics and AC Drives. Prentice Hall.

[11]. LoRa Alliance. (2022). LoRaWAN Specification 11.1. LoRa Alliance Technical Reports.

[12]. Praveen, K., & Thomas, J. (2021). "Energy Monitoring and Optimization in Industrial Lift Systems Using IoT." International Journal of Engineering Research & Technology (IJERT), 10(6), 129–134.

[13]. Siemens AG. (2022). Smart Crane Control Systems – Technical Whitepaper. Siemens Industrial Automation Division.

[14]. Sharma, R., & Gupta, V. (2022). "Cloud-Based Remote Supervision of Industrial Operations Using MQTT Protocol." International Journal of Cloud Computing and IoT, 6(2), 98–107.

[15]. Haider, U., & Memon, A. (2018). "Condition Monitoring of Overhead Cranes Using Vibration Analysis." Mechanical Engineering Review, 65(7), 331–339.

[16]. Lee, J., Bagheri, B., & Kao, H. A. (2015). "A Cyber-Physical Systems Architecture for Industry 4.0-Based Manufacturing Manufacturing Letters, 3, 18–23. Systems."

[17]. Zhang, Y., & Sun, L. (2020). "Real-Time Monitoring of Industrial Equipment Using Wireless Sensor Networks." IEEE Sensors Journal, 20(4), 2024–2032.

[18]. Khalid, A., & Mehmood, F. (2021). "IoT-Based Predictive Maintenance for Hoisting and Lifting Machines." International Journal of Mechanical Engineering and Robotics Research, 10(3), 112– 120.

[19]. National Instruments (NI). (2023). Vibration Measurement and Analysis Guide for Industrial Machinery. NI Technical Report.

[20]. Patel, M., & Raghavan, S. (2019). "Smart Energy Management in Industrial Motor-Driven Systems Using Sensor-Based Monitoring." International Journal of Smart Grid and Clean Energy, 8(2), 145–153.

[21]. Suresh, K., & Balamurugan, M. (2020). "Implementation of IoT-Based Condition Monitoring for Industrial Motors." International Journal of Engineering Science and Computing, 10(5), 25419–25423.

[22]. IEC Standards. (2022). IEC 60204-32: Safety of Machinery – Electrical Equipment of Machines – Requirements for Hoisting Machines. International Electrotechnical Commission.

[23]. Bhatt, P., & Reddy, R. (2021). "Cloud-Integrated Monitoring Systems for Smart Industrial Automation." Journal of IoT and Data Science, 4(1), 33–41.