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Research Article

Evolution Of a Web-Based Mining Engineering Toolkit Toward an IoT-Enabled Smart Mining Platform

Mritunjay Kumar *

Research Scholar, Department of Mining Engineering, NITK Surathkal

Corresponding Author: * Mritunjay Kumar

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Abstract

The mining industry is increasingly adopting digital technologies to enhance operational efficiency, safety, and decision-making. Web-based engineering platforms have emerged as accessible tools that allow mining professionals and researchers to perform calculations, analyse operational parameters, and manage engineering information through online interfaces. However, most existing web platforms operate primarily as static calculation tools that rely on manually entered data. The integration of Internet of Things technologies offers an opportunity to transform these platforms into dynamic smart mining systems capable of real-time monitoring and automated data analysis. This study presents a case study on the conceptual evolution of a web-based mining engineering toolkit toward an IoT-enabled smart mining platform. The research examines how sensor networks, communication infrastructure, data processing systems, and web interfaces can be integrated to support continuous monitoring of mining operations. Potential applications include environmental monitoring, equipment condition monitoring, production analysis, and geotechnical observation. The proposed framework demonstrates how web-based mining tools can be expanded to support real-time operational awareness and data-driven decision making. The findings highlight the potential of integrating IoT technologies with web platforms to support the development of digital mining ecosystems.

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1. INTRODUCTION

Mining operations involve complex processes that require continuous monitoring of environmental conditions, equipment performance, and production activities. Traditionally, mining engineers have relied on manual data collection and standalone software tools to evaluate operational parameters. While these approaches provide essential analytical capability, they often lack real time data integration and centralized accessibility, which can limit the efficiency of operational decision making [1-3].

The emergence of web-based engineering platforms has improved accessibility to mining analysis tools. These platforms allow engineers and researchers to perform calculations related to blasting design, ventilation planning, geotechnical stability, and productivity estimation through online interfaces [4,5]. Because these tools operate on web servers, users can access them from different locations without installing specialized software [6]. Such systems have contributed to the digitization of engineering workflows and have simplified the use of analytical models in mining practice [7,8]. In recent years, web platforms providing mining engineering utilities have become increasingly relevant for education, research, and industry applications as they enable collaborative access to computational tools and data resources [9].

Despite these advantages, most web-based mining platforms operate using manually entered data. Engineers must input parameters obtained from field measurements, reports, or monitoring systems [10]. This approach limits the capability of the platform to represent real time mine conditions and restricts its usefulness for operational monitoring [11]. Modern mining environments require continuous monitoring of environmental and operational parameters to ensure safe and efficient operations [12]. As mining operations become more complex and data intensive, there is an increasing demand for automated monitoring systems that can collect and process operational information in real time [13].

The Internet of Things provides a technological framework that allows sensors and devices to communicate through networks and transmit data to centralized systems [14]. IoT technologies enable distributed sensors to collect environmental and operational information and transmit these data through communication networks for analysis and visualization [15]. In the mining context, IoT sensors can measure parameters such as gas concentration, temperature, humidity, equipment vibration, and ground movement [16,17]. These sensors can generate continuous streams of operational data that provide insight into mine conditions and equipment performance [18].

Recent studies have highlighted the importance of digital technologies in transforming traditional mining operations into smart mining systems [19,20]. IoT based monitoring systems have been used in mining applications for environmental monitoring, equipment condition monitoring, and worker safety management [21,22]. For example, gas monitoring sensors can detect hazardous gas concentrations in underground mines, while vibration sensors can monitor equipment performance to detect early signs of mechanical failure [23,24]. Similarly, geotechnical sensors can measure ground displacement and stress variations to assess rock mass stability [25].

Integrating IoT technologies with digital platforms also supports the development of data driven mining systems capable of real time monitoring and predictive analysis [26]. When sensor generated data are combined with analytical tools available through web-based platforms, engineers can evaluate operational conditions more accurately and respond quickly to changing my environments [27]. Such integration can improve operational efficiency, enhance safety management, and enable predictive maintenance strategies for mining equipment [28].

The development of web-based mining engineering toolkits provides an opportunity to combine analytical tools with real time monitoring capabilities. Platforms that provide mining related computational utilities can serve as centralized interfaces where sensor data and engineering analysis tools are integrated within a unified system [29]. By incorporating IoT generated data streams into such platforms, it becomes possible to transform conventional web-based engineering tools into smart mining systems capable of supporting real time decision making [30].

The integration of IoT technologies with web platforms is therefore an important step toward digital transformation in the mining industry [31]. Digital mining systems that combine sensor networks, data analytics, and web-based interfaces can improve operational awareness and enable remote monitoring of mining environments [32]. These systems also support the long-term goal of developing autonomous and intelligent mining operations [33].

In this context, the present study examines the conceptual evolution of a web-based mining engineering toolkit toward an IoT enabled smart mining platform. The study explores how sensor networks, communication systems, data processing infrastructure, and web interfaces can be integrated to support continuous monitoring and analysis of mining operations[34,35]. The framework demonstrates how web platforms that provide mining engineering tools can be expanded to support real time monitoring and decision support applications in modern mining environments[36,37].

2. METHODOLOGY

This study adopted a conceptual system design methodology to examine how Internet of Things technologies can be integrated with a web-based mining engineering toolkit in order to support smart mining applications. The methodological framework focused on evaluating the architecture required to combine sensor-based monitoring systems with online engineering tools available through a centralized web platform. The approach was structured into three main stages. The first stage involved examining the functional structure of a web-based mining engineering toolkit and identifying the types of engineering tools typically provided to users through such platforms. The second stage focused on analyzing the operational architecture of IoT monitoring systems used in mining environments. The third stage involved developing an integrated framework that connects IoT data acquisition systems with web based analytical tools and visualization dashboards.

Web based mining engineering platforms provide computational tools that assist engineers in performing calculations related to mining operations. These platforms allow users to access engineering utilities through an online interface without requiring installation of specialized software. A web-based mining toolkit typically provides modules for engineering calculations such as blasting design estimation, ventilation analysis, geotechnical parameter evaluation, and production related computations. Platforms such as MiningToolkit.in demonstrate how engineering tools can be organized into a centralized web interface that allows engineers, researchers, and students to access multiple mining related utilities from a single location. Although these tools provide useful analytical functionality, they generally rely on manually entered data. Integrating IoT monitoring systems with such platforms can enable real time data acquisition and automated analysis.

The conceptual architecture used in this study is composed of four functional layers that represent the main components required to implement an IoT enabled mining platform. These layers include the sensor layer, the communication layer, the data processing layer, and the web interface layer. Each layer performs a specific role within the system while interacting with other layers to support the overall monitoring and analysis process.

2.1 Sensor Layer

The sensor layer represents the physical interface between the mining environment and the digital platform. Sensors installed within mining operations collect information related to environmental conditions, equipment performance, and operational parameters. These sensors generate continuous data streams that reflect the real time conditions of the mine.

Several types of sensors can be deployed depending on the operational requirements of the mining site. Environmental monitoring sensors are commonly used to measure gas concentration, temperature, humidity, and dust levels. Equipment monitoring sensors measure vibration, mechanical load, and operational temperature of mining machinery. Location based sensors can also be used to track the movement of vehicles and personnel within the mine.

The typical sensors used within the proposed system architecture are presented in Table 1.

Table 1: The sensors used within the proposed system architecture

Sensor type	Parameter measured	Mining application
Methane gas sensor	Methane concentration	Underground mine safety monitoring
Carbon monoxide sensor	CO concentration	Ventilation and hazard detection
Temperature sensor	Ambient temperature	Environmental monitoring
Humidity sensor	Relative humidity	Ventilation analysis
Vibration sensor	Equipment vibration	Machinery condition monitoring
Dust sensor	Particulate concentration	Occupational health monitoring

These sensors generate data that provides valuable insight into the operational condition of the mining environment. The collected data must then be transmitted to a central system where they can be analysed and visualised through web-based interfaces.

2.2 Communication Layer

The communication layer is responsible for transmitting data generated by sensors to centralised processing systems. Reliable communication is essential in mining environments because sensors may be located in remote underground locations or across large surface mining areas.

Both wireless and wired communication technologies can be used to transmit sensor data depending on the characteristics of the mining operation. Short range wireless networks can be used to connect sensors located within a limited area. Long range communication systems can be used to transmit data across larger distances or between underground and surface infrastructure. Several communication technologies suitable for mining applications are summarised in Table 2.

Table 2: Communication technologies suitable for mining applications

Communication technology	Characteristics	Typical application
WiFi network	High data transfer rate	Surface mining operations
LoRa communication	Long-range low-power communication	Remote sensor networks
ZigBee network	Low-power short-range communication	Underground sensor clusters
Cellular network	Wide area communication	Remote surface mines

The communication layer collects data from multiple sensors and transmits the information to centralized servers where it can be processed and stored. This stage forms the link between the physical monitoring infrastructure and the digital data processing system.

2.3 Data Processing Layer

The data processing layer represents the computational component of the integrated system. Incoming sensor data are stored within centralised databases and processed using analytical algorithms. The processing system may include local servers or cloud-based infrastructure depending on the scale of the monitoring system. Data processing involves several tasks including data filtering, storage, analysis, and interpretation.

Raw sensor data may contain noise or redundant information that must be processed before meaningful insights can be generated. Analytical models can be used to identify patterns within the data and detect abnormal conditions. The types of analytical functions performed within the data processing layer are summarised in Table 3.

Table 3: Analytical functions performed within the data processing layer

Processing function	Description	Mining relevance
Data storage	Recording sensor data in databases	Historical data analysis
Data filtering	Removal of noise and invalid readings	Improved data reliability
Pattern analysis	Identifying trends in sensor data	Operational optimization
Alert generation	Detection of abnormal conditions	Safety monitoring

The processed information generated in this layer can then be integrated with analytical tools available on the web platform. For example, environmental sensor data can be used to support ventilation calculations, while equipment performance data can be used to evaluate production efficiency.

2.4 Web Interface Layer

The final layer of the system architecture is the web interface layer that provides users with access to information generated by the integrated system. The web platform serves as the central interface where engineers can access engineering tools, monitoring dashboards, and analytical modules.

The web interface allows users to visualise operational data through charts, tables, and interactive dashboards. Real-time sensor data can be displayed alongside engineering calculation tools to provide a comprehensive understanding of mining operations. Web-based platforms such as MiningToolkit.in illustrate how multiple mining engineering tools can be integrated into a single online interface that supports both analysis and monitoring functions. The key modules that can be implemented within the web interface layer are summarised in Table 4.

Table 4: The key modules that are implemented within the web interface layer

Web module	Function	Benefit
Environmental monitoring dashboard	Displays real time gas and environmental conditions	Improved mine safety
Equipment monitoring module	Displays equipment condition data	Preventive maintenance
Engineering calculation tools	Provides mining engineering calculators	Decision support
Production monitoring dashboard	Displays operational performance indicators	Productivity analysis

The integration of these modules enables the platform to function not only as an engineering calculation toolkit but also as a comprehensive monitoring and analysis system. By combining sensor-based monitoring with web-based engineering tools, the platform can support a wide range of mining applications including safety management, operational planning, and equipment monitoring.

The proposed methodology therefore demonstrates how a conventional web-based mining engineering toolkit can evolve into a smart mining platform through the integration of IoT technologies. This architecture allows real time data collected from mining environments to be integrated with analytical tools available on the platform, thereby enhancing the overall capability of the system.

3. RESULTS

The conceptual framework developed in this study demonstrates that integrating Internet of Things technologies with web-based mining engineering platforms can significantly enhance their functional capabilities. The proposed system Architecture allows continuous acquisition of operational data from mining environments while preserving the analytical capabilities of online engineering tools. Through the integration of sensor networks and web-based interfaces, the platform is capable of transforming traditional engineering calculation tools into a dynamic monitoring and decision support system.

One of the primary outcomes of the proposed framework is the ability to visualize environmental conditions within mining environments in real time. Sensors installed in underground workings can continuously measure parameters such as methane concentration, carbon monoxide levels, temperature, and humidity. These measurements are transmitted through communication networks to centralized servers where they are processed and displayed through graphical dashboards on the web platform. Engineers can therefore observe environmental conditions through interactive visualization tools rather than relying solely on periodic measurements. The environmental monitoring capability of the integrated system is summarized in Table 5.

Table 5: Environmental monitoring capability of the integrated system

Monitoring parameter	Sensor type	Information provided through web platform
Methane concentration	Methane gas sensor	Real time gas monitoring dashboard
Carbon monoxide level	CO sensor	Hazard detection and ventilation assessment
Temperature	Temperature sensor	Thermal conditions of working areas
Humidity	Humidity sensor	Environmental condition monitoring

Another important result of the integration is the ability to monitor the operational condition of mining equipment. Sensors attached to mining machinery can measure vibration, temperature, mechanical load, and operational cycles. These measurements provide insight into the health and performance of equipment used in mining operations. When sensor data are transmitted to the web platform, analytical modules can evaluate patterns in equipment performance and identify abnormal operating conditions that may indicate mechanical wear or potential failure.

The integration of equipment monitoring data with analytical tools available on web-based mining platforms provides engineers with additional decision support capabilities. Platforms such as MiningToolkit.in demonstrate how engineering tools can be organized within a centralized interface, and the addition of IoT generated equipment data can further enhance the value of such systems by connecting real time operational information with engineering calculations. The equipment monitoring functions supported by the proposed framework are summarised in Table 6.

Table 6: Monitoring functions supported by the proposed framework

Equipment parameter	Sensor type	Operational insight
Machine vibration	Vibration sensor	Detection of mechanical imbalance
Operating temperature	Thermal sensor	Equipment overheating monitoring
Load measurement	Load sensor	Performance and utilization analysis
Operating cycle count	Motion sensor	Production cycle monitoring

Production monitoring also becomes more efficient through the integration of IoT devices with web-based analytical platforms. Sensors installed on mining equipment can record operational cycles, load capacity, and equipment utilisation rates. These data can be processed and displayed through web dashboards that provides a clear overview of production performance. Engineers can use this information to identify inefficiencies in operational processes and evaluate productivity trends over time. Production-related monitoring functions supported by the proposed system are presented in Table 7.

Table 7: Production-related monitoring functions supported by the proposed system

Production parameter	Data source	Analytical use
Equipment utilization	Equipment sensors	Productivity analysis
Load capacity	Load sensors	Haulage performance evaluation
Operational cycles	Motion sensors	Process efficiency analysis
Idle time	Equipment status data	Operational optimization

The integrated platform also supports geotechnical monitoring applications. Sensors such as extensometers, displacement sensors, and stress monitoring devices can provide continuous information about ground movement and rock mass behaviour. When these data are transmitted to the web platform, engineers can combine them with geotechnical analysis tools available on The platform to assess ground stability conditions more effectively. This integration allows engineering calculations to be supported by real-time field data rather than relying solely on manual observations. The geotechnical monitoring capabilities supported by the framework are summarised in Table 8.

Table 8: The geotechnical monitoring capabilities supported by the framework

Geotechnical parameter	Sensor type	Engineering application
Ground displacement	Extensometer	Monitoring deformation in underground openings
Rock stress	Stress sensor	Evaluation of rock mass stability
Roof movement	Displacement sensor	Roof stability monitoring
Structural deformation	Strain sensor	Ground support assessment

Overall, the results of the conceptual framework demonstrate that integrating IoT technologies with web-based mining engineering platforms enables continuous monitoring of environmental conditions, equipment performance, production activities, and geotechnical stability. These capabilities significantly expand the functionality of web-based engineering toolkits and contribute to the development of intelligent mining systems.

4. DISCUSSION

The integration of Internet of Things technologies with web-based mining engineering platforms represents an important step toward the development of digital mining systems. By combining sensor networks with analytical web tools, mining engineers can obtain a more comprehensive understanding of operational conditions within mining environments. This integration transforms conventional web-based engineering toolkits into dynamic platforms capable of supporting both analytical calculations and real time monitoring.

One of the most significant advantages of the integrated system is improved situational awareness. Traditional monitoring methods often rely on periodic measurements or manual inspection of equipment and environmental conditions. In contrast, IoT based monitoring systems provide continuous streams of data that allow engineers to observe operational conditions in real time. This capability enhances the ability to detect hazardous situations such as gas accumulation, excessive temperature, or abnormal equipment vibration before they develop into critical safety incidents.

Another important advantage of the integrated platform is improved operational efficiency. Data collected from sensors can be analyzed to identify inefficiencies in equipment utilization or production processes. By examining patterns in operational data, engineers can optimize equipment scheduling, improve production planning, and reduce idle time. When these analytical capabilities are integrated into web-based platforms that already provide engineering calculation tools, the platform becomes a comprehensive decision support system for mining operations.

Predictive maintenance represents another key benefit of integrating IoT technologies with web platforms. Continuous monitoring of equipment conditions allows early detection of mechanical problems before they result in system failure. Vibration patterns, temperature variations, and load measurements can be analyzed to identify signs of equipment wear or malfunction. Maintenance teams can therefore schedule repairs before major breakdowns occur, reducing operational downtime and maintenance costs.

The integration of IoT monitoring systems with web-based engineering platforms also creates opportunities for advanced data analysis. Historical datasets generated by sensors can be used to develop predictive models that estimate future operational conditions. Machine learning techniques can be applied to these datasets to identify complex relationships between environmental factors, equipment performance, and production outcomes. Such capabilities can further enhance the decision-making capabilities of digital mining platforms.

Despite these advantages, several technical challenges must be addressed in order to implement IoT enabled mining platforms effectively. Communication networks in underground mines can be difficult to maintain due to the presence of rock formations, tunnel geometry, and environmental conditions that interfere with signal transmission. Reliable communication infrastructure is essential for ensuring that sensor data can be transmitted continuously to centralized servers.

Power supply for distributed sensors also represents a practical challenge. Sensors installed in remote or underground locations must operate for extended periods without frequent maintenance. Energy efficient sensor design and battery management strategies are therefore necessary to ensure reliable operation of monitoring systems.

Data security and system reliability are also critical considerations when implementing IoT based monitoring platforms. Mining operations involve sensitive operational information that must be protected from unauthorized access. Secure data transmission protocols and robust cybersecurity measures must therefore be incorporated into the platform architecture to ensure that operational data remain protected.

Overall, the integration of IoT technologies with web-based mining engineering platforms provides a promising pathway toward the development of intelligent mining systems. By combining real time sensor data with engineering analysis tools, platforms such as MiningToolkit.in can evolve beyond traditional calculation utilities and contribute to the broader digital transformation of mining operations.

5. CONCLUSION

This study examined the conceptual integration of Internet of Things technologies with a web-based mining engineering platform in order to support the development of intelligent digital mining systems. The proposed framework demonstrates how sensor networks, communication infrastructure, data processing systems, and web interfaces can be combined to create a unified platform capable of supporting both engineering analysis and real time operational monitoring. The integration of these components allows traditional web-based engineering toolkits to evolve from static calculation utilities into dynamic platforms that provide continuous insight into mining operations.

The results indicate that IoT enabled monitoring systems can significantly enhance the capabilities of web-based mining platforms. Environmental sensors can provide continuous information about gas concentrations, temperature, and humidity within mining environments, allowing engineers to monitor safety conditions in real time. Equipment monitoring sensors can detect abnormal vibration, temperature, and mechanical performance patterns, enabling early identification of potential equipment failures. Production related data collected from operational sensors can also support productivity analysis and operational optimization.

The integration of geotechnical monitoring data further extends the functionality of the platform by enabling engineers to evaluate ground stability conditions using real time measurements. When these monitoring capabilities are combined with analytical tools available through web-based mining engineering platforms, engineers are able to perform more accurate evaluations and make informed decisions based on current operational data.

Another important implication of this integration is the improvement of situational awareness and safety management within mining environments. Real time monitoring systems allow hazardous conditions to be detected quickly and provide engineers with immediate access to relevant information through web-based dashboards. Platforms such as MiningToolkit.in demonstrate how centralized web interfaces can organize engineering tools and operational data into accessible digital systems that support both analysis and monitoring functions.

Although the proposed framework highlights several advantages, successful implementation of IoT enabled mining platforms requires addressing practical challenges related to communication reliability, power supply for distributed sensors, and cybersecurity protection of operational data. Continued research and technological development in these areas will be necessary to ensure the reliability and scalability of smart mining platforms.

Overall, the integration of IoT technologies with web-based mining engineering toolkits represents a significant step toward the digital transformation of mining operations. By combining real time monitoring systems with accessible analytical tools, such platforms can contribute to safer, more efficient, and data driven mining practices in the future.

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About the corresponding author

Mritunjay Kumar is a mining engineering researcher specialising in rock mechanics, numerical modelling, and geotechnical analysis for safer and more sustainable mining operations. He holds a B. Tech in Mining Engineering from BIT Sindri, an M. Tech in Mining Engineering, and a PhD in Rock Mechanics from NIT Karnataka. He has academic experience as an Assistant Professor and Lecturer and has contributed to research in pillar design optimisation, rock temperature measurement, dragline planning, and sustainable mineral development. His technical interests include Rocscience software, RS2 modelling, mining informatics, and data-driven approaches for mine stability assessment.