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Energy Optimization In Iot Systems Through Blockchain Integration

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Abstract

The accelerated proliferation of the Internet of Things (IoT) across industrial domains has elevated the need for secure and intelligent energy management frameworks. This study proposes an IoT architecture enhanced with blockchain for dynamic industrial energy optimization, supported by deep learning methodologies. Environmental and operational parameters such as temperature, electricity usage, and humidity are collected using sensors. These values are validated using SHA-256 hashing and securely stored on a decentralized Ethereum blockchain. A Deep

Neural Network (DNN) model analyzes the processed data to identify trends and predict energy consumption behavior. Results are showcased via an interactive dashboard developed using React, enabling operators to proactively manage energy usage and detect anomalies. The integration of blockchain with AI ensures a transparent, scalable, and tamper-resistant solution for industrial energy monitoring. Experimentation confirms enhanced security, real-time anomaly detection, and reduced inefficiencies, establishing this approach as a resilient model for smart industry applications. Keywords: Blockchain, IoT, Deep Neural Network, Industrial Energy Monitoring, Data Integrity, Real-Time Analytics, Energy Forecasting.

1. INTRODUCTION

The objective of this project is to develop a secure and AI- based energy efficiency system tailored for industrial applications. It unifies sensor networks, blockchain mechanisms, and deep learning techniques to capture, store, analyze, and visualize energy data in real time. Its core aim is to empower industries with precise insights into energy utilization patterns to enhance efficiency and reduce unnecessary usage.

The architecture initiates with real-time data acquisition, leveraging sensors that monitor temperature, humidity, and electrical usage in industrial environments. The acquired raw data is protected using SHA-256 hashing and logged onto a blockchain ledger. This ensures immutability, thus safeguarding data from unauthorized tampering.

After being securely stored, the data undergoes a preprocessing phase, which includes noise removal, handling missing values, and normalization. This step is critical to preparing clean datasets that serve as the foundation for effective AI-based predictions.

Next, a Neural Network model processes the refined data to uncover complex dependencies between the observed parameters. This enables forecasting of energy patterns and highlights inefficient zones in the process, supporting smarter decision-making.

These analytical outputs are then rendered via a React- powered dashboard. The UI displays comprehensive graphs and trends, making it easy for users to monitor energy consumption patterns and detect irregularities. With the support of blockchain validation, all visualized data remains authentic and tamper-proof.

Overall, this initiative combines data collection, blockchain-secured storage, and deep learning analysis with interactive visualization. It offers industries a robust platform for secure energy monitoring and optimization, supporting sustainability and cost-efficiency goals.

2. LITERATURE REVIEW

This section explores prior work relevant to blockchain- enabled energy optimization in IoT systems. A review of multiple frameworks and methodologies reveals the growing potential and the key challenges in combining blockchain and AI for energy applications.

One study examined the role of blockchain in enhancing energy efficiency across IoT environments, focusing on the core blockchain principles—decentralization, consensus, and cryptographic security—and how they promote data transparency and reliability. It concluded that hybrid blockchain frameworks can offer improved energy efficiency in such contexts.

Another paper discussed secure computation offloading in blockchain-driven IoT, with emphasis on Intelligent Reflecting Surfaces (IRS) and Mobile Edge Computing (MEC). It proposed a Gas-oriented offloading strategy to reduce energy usage and improve resource allocation under fluctuating network conditions.

A novel trust-free system for private data usage using smart contracts and trusted execution environments was presented. It enabled transparent data sharing with fine- grained access controls while minimizing blockchain overhead.

In another study, a permissioned blockchain model was introduced to manage IoT resource access in semi-trusted environments. The architecture ensured robust security by maintaining data integrity and confidentiality.

A comprehensive survey on blockchain-enabled federated learning for Internet of Vehicles (IoVs) addressed privacy challenges and future development opportunities in this emerging area.

The DNNOff framework proposed an offloading strategy for DNN-based IoT applications, resulting in significant performance improvements across multiple neural models.

A two-layer blockchain infrastructure combined with a new consensus algorithm, DR-BFT, was outlined, designed for efficient and secure data validation in edge computing environments.

A forward-thinking approach to smart city applications using NFT-backed blockchain was presented, offering novel authentication methods for IoT devices in fog computing networks.

The integration of smart grid technologies with blockchain was explored to facilitate secure, transparent energy exchanges, though issues of standardization and interoperability remain.

Lastly, an energy-aware consensus protocol was proposed for edge-integrated IoT blockchains, reporting reduced energy and memory usage compared to previous approaches.

3. PROPOSED WORK

The increasing demand for energy-efficient solutions in industrial settings has inspired the development of a secure, AI-powered optimization framework. This system overcomes the shortcomings of traditional energy monitoring by integrating blockchain technology, machine learning, and live sensor data acquisition.

The process starts with sensor deployment, where temperature, humidity, and electrical sensors capture energy-related metrics in real time. These data points reflect operational fluctuations and are vital in identifying consumption behavior. Instead of relying on centralized storage, this system utilizes a decentralized blockchain network, applying the SHA-256 algorithm to hash and store each reading securely. This immutable ledger ensures the authenticity and integrity of recorded data.

Once recorded, the sensor data is processed through a cleaning and normalization pipeline. This ensures that the dataset is consistent, noise-free, and suitable for machine learning. The processed data is then fed into a Deep Neural Network (DNN) designed to identify complex nonlinear relationships across variables. The model evaluates historical energy use, forecasts future trends, and uncovers inefficiencies that would otherwise go unnoticed.

To provide actionable insights, the system incorporates a React-based interface that acts as a live dashboard. The application allows users to:

- Track real-time sensor metrics via interactive visualizations.
- Receive AI-powered alerts on abnormal energy patterns.
- Review energy trends for strategic decision-making.

Scalability is another key advantage. The blockchain design supports the seamless addition of sensors and broader system integration. The AI model continuously retrains with new data, enhancing prediction accuracy as environments change.

By merging blockchain, AI, and live analytics, the system offers a forward-looking solution for secure, scalable, and sustainable industrial energy optimization.

4. METHODOLOGY

This project is structured around four major components: sensor-based data collection, preprocessing and hashing, deep learning analysis, and interactive visualization.

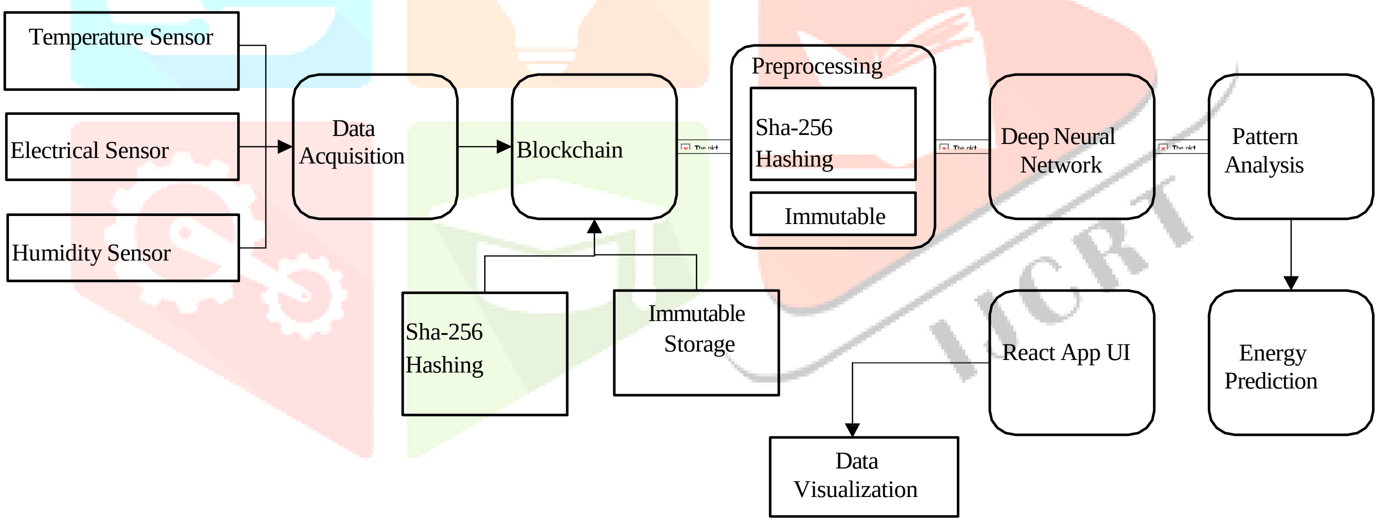
4.1 Dataset Collection

A diverse dataset is generated using IoT-enabled sensors positioned across an industrial layout. These sensors record critical variables including temperature, electrical load, and humidity. Each entry is timestamped to allow chronological trend analysis.

To ensure data comprehensiveness, inputs are drawn from both embedded systems and industrial IoT platforms. This ensures the model captures dynamic energy behaviors across varied operational conditions.

4.2 Data Preprocessing

Before analysis, raw sensor readings undergo preprocessing. This phase includes:



- Data Cleaning: Elimination of faulty, redundant, or missing entries.
- Normalization: Standardization of values for consistent scale comparison.
- Noise Filtering: Techniques applied to minimize outliers caused by external interference.
- Feature Extraction: Isolating the most impactful parameters for model training.

All refined datasets are hashed using SHA-256 and stored on the Ethereum blockchain. This step guarantees data permanence and ensures no unauthorized modifications can be made.

4.3 Deep Learning Analysis

A Deep Neural Network (DNN) is implemented to perform predictive analytics. The model includes:

- Input Layer: Receives cleaned and formatted sensor input.
- Hidden Layers: Processes complex patterns through ReLU and Sigmoid activations.
- Output Layer: Provides predictions of energy usage and identifies anomalies.

The DNN is trained on historical data using backpropagation, optimizing weights to reduce error and improve prediction reliability over time.

4.4 Real-Time Data Visualization

A web-based application built in React serves as the system's visual interface. This dashboard delivers:

Real-time energy visualizations through interactive graphs.
- Alerts based on AI-detected deviations.
- Trend tracking over time to support energy strategy adjustments.

Conclusion:

This project introduces a novel strategy for managing industrial energy by combining real-time sensor data collection, blockchain-secured data storage, and deep learning-based analysis. The system seamlessly gathers readings from temperature, electrical, and humidity sensors, ensuring round-the-clock surveillance of key industrialparameters. By employing the SHA-256 cryptographic algorithm, the integrity and permanence of the collected data are secured via blockchain, effectively safeguarding it from unauthorized alterations.

A Deep Neural Network (DNN) is central to the system's intelligence, capable of detecting intricate, non-linear patterns within the data. It provides precise forecasts and exposes inefficiencies that may not be visible through conventional methods. The continuous learning mechanism further enhances the reliability of its predictions over time.

To make the analytical insights more accessible, a React- based web interface delivers interactive and real-time data visualizations. This bridge between technical analysis and user interaction enables operators to gain actionable insights and respond proactively to changes in energy usage.

By eliminating the need for centralized storage and manual intervention, this system enhances data security, reduces operational complexity, and supports more informed energy decisions. In essence, the project

empowers industries to adopt smarter, more sustainable practices, cutting operational costs while promoting efficient resource utilization. The convergence of AI, blockchain, and real-time monitoring sets a new standard for next-generation energy management systems.

5. Result and Discussions:

The system was tested using a simulated industrial IoT environment that replicated real-time data generation from temperature, electricity, and humidity sensors.

The blockchain module successfully used SHA-256 hashing to ensure that data written to the decentralized ledger remained immutable and traceable. A sample of sensor data transactions revealed complete transparency, including hash generation, block indexing, and smart contract interactions via MetaMask.

The Deep Neural Network model, trained on preprocessed inputs, delivered precise forecasts for energy usage. It was also able to detect anomalies in energy behavior, alerting potential inefficiencies and irregular trends.

Interactive results were visualized through the React web application, including:

- Add Unit Interface: Showed blockchain address assignments for multiple units.
- Save Data Module: Displayed JSON-format blockchain logs alongside live readings.
- Transaction Requests: MetaMask integration details confirmed transaction authenticity.
- Accounts Overview: Ganache interface tracked ETH balances, gas prices, and block activity.
- Efficiency Scores: Illustrated prediction trends using DNN outputs, labeling system performance as either "Danger" or "Good".

These outcomes demonstrate the feasibility of combining deep learning and blockchain for real-time, secure, and scalable industrial energy monitoring. The system's success in early-stage simulation sets the foundation for broader deployment.The proposed system was evaluated in a simulated industrial IoT environment utilizing real- time sensor data from temperature, electrical, and humidity measurements. The system successfully implemented a blockchain-based data storage mechanism using the SHA-256 algorithm, ensuring data security and integrity. A trained Deep Neural Network (DNN) was employed for energy consumption predictions, leveraging preprocessed sensor data to identify inefficiencies and anomalies.

This represents the Add Unit interface of the Blockchain Industry Analysis web application is shown. The sidebar on the left provides navigation options, including Live, Predict, and Add Unit, with the current selection highlighting the Add Unit option. The central section contains a table that organizes information under the columns Unit Name, Name, and Address. Existing entries for units such as rajesh, and adhil are displayed alongside their respective blockchain addresses. On the right, a MetaMask pop-up window is visible, detailing the portfolio

The Saved Data section of the Blockchain Industry Analysis web application is illustrated. On the left side, live sensor data from the Boiler System, Cooling Tower, and Storage is displayed, showcasing real-time readings for temperature, pressure, and humidity. The right side features Saved Data represented in JSON format, providing detailed information regarding a blockchain transaction. This includes the transaction hash, block number, sender and receiver addresses, gas utilized, and the associated contract address. A notification at the bottom-right corner highlights the successful submission of sensor data to the blockchain, ensuring transparency and user confirmation.

This represents the Blockchain Industry Analysis web application interface is shown, featuring a MetaMask Transaction Request pop-up overlaid on the screen. On the left, live sensor data for the Boiler System, Cooling Tower, and Storage is displayed, providing real-time measurements such as temperature, pressure, and humidity. The center section shows an active loading spinner, indicating that an operation is in progress. The MetaMask pop-up highlights transaction details originating from http://localhost:3000 and interacting with the blockchain contract at address 0x38B1D...Added. Key transaction parameters such as network fee, transaction speed, maximum fee, and nonce are displayed. The pop- up includes Cancel and Confirm options at the bottom, enabling the user to proceed or abort the transaction.

This represents the Accounts interface of the Ganache blockchain development platform is depicted, with the workspace titled BLOCKCHAIN-INDUSTRY- ANALYSIS. The interface presents a detailed list of blockchain accounts, including their respective addresses, balances in ETH, transaction counts, and indices, enabling users to monitor account activity efficiently. At the top left, the mnemonic phrase used for account generation is displayed, providing a means to regenerate the same set of accounts if needed. Additional metadata is shown at the top, outlining critical blockchain parameters such as the current block number, gas price, gas limit, network ID, and the RPC server address. This comprehensive setup aids in simulating and testing blockchain transactions in a controlled environment.

This represents the system has generated a normalized score of 2.9 out of 10, indicating a critical performance concern. The overall efficiency trend is marked as Danger, reflecting a noticeable decline in system capability over time. As seen in the prediction graph, the efficiency starts at a low value, shows a minor improvement, and then steadily drops before a slight rise in the final prediction point. This pattern highlights an overall declining efficiency, which suggests that the system may face potential issues or failures if not addressed promptly. Immediate investigation and corrective actions are highly recommended.

This represents the system displays a normalized score of 5.2 out of 10, representing a moderate performance level. The efficiency status is categorized as Good, showing a positive growth pattern in the prediction trend. The graph reveals a consistent upward trajectory in efficiency values over the initial sequence points, reaching a peak before a slight dip toward the end. This indicates an improving efficiency, suggesting that the unit is performing well and progressing in a stable manner. Continued monitoring is advised to ensure sustained performance and to address minor variations early.

6. Limitation and Future Works:

A promising future enhancement for this project is the integration of predictive maintenance powered by artificial intelligence. Beyond analyzing energy efficiency, the deep neural network can be expanded to predict potential equipment failures by recognizing patterns in sensor data, such as unusual fluctuations in temperature, voltage spikes, or abnormal humidity levels. By training the model with historical data of machine breakdowns and maintenance logs, the system could forecast when a particular device is likely to fail or require servicing. This proactive approach would allow industries to schedule maintenance activities before a failure occurs, reducing unplanned downtime, minimizing repair costs, and extending the lifespan of critical machinery. The predictive maintenance insights could be seamlessly integrated into the React web app, alerting operators with real-time notifications and visualizing the health status of industrial equipment. This enhancement would strengthen the project's capabilities, moving from

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