International Journal of Advances in Electrical Engineering

E-ISSN: 2708-4582
P-ISSN: 2708-4574
IJAEE 2024; 5(1): 116-121

www.electricaltechjournal.com
Received: 05-03-2024
Accepted: 06-04-2024

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Anomaly detection for electric energy consumption in smart farms

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DOI: https://doi.org/10.22271/27084574.2024.v5.i1b.62

Abstract
Electric energy prediction has been a subject of extensive research, spanning various methodologies including traditional statistical methods, conventional machine learning techniques, deep learning (DL) methods, and hybrid DL approaches. This article introduces Electricity Talk, an Internet of Things (IoT) platform tailored for smart farms. By amalgamating artificial intelligence (AI) mechanisms with farming IoT devices, Electricity Talk facilitates electric energy prediction and anomaly detection. The primary objective of this project is to develop Electricity Talk, an innovative IoT platform for smart farms. This platform aims to integrate AI mechanisms with farming IoT devices to enhance electric energy prediction accuracy and facilitate anomaly detection. Specifically, the project seeks to leverage additional information from IoT switch statuses within smart farms and employ a novel random walk model for post-processing to improve the performance of electric energy prediction.

Keywords: Electric energy prediction, deep learning (DL) methods, hybrid DL approaches, electricity talk, artificial intelligence (AI) mechanisms, farming IoT devices, anomaly detection

Introduction

The rapid evolution of technology has cemented the Internet of Things (IoT) as an indispensable part of modern agriculture, particularly in the management of energy resources. Smart farms, utilizing a plethora of IoT devices, generate vast amounts of data that, if analyzed and utilized properly, can transform the efficiency of farm operations. In this context, the prediction and management of electric energy consumption becomes a significant challenge, addressing both the sustainability and economic concerns in agricultural settings. This paper introduces Electricity Talk, an innovative IoT platform that leverages artificial intelligence (AI) to enhance electric energy prediction and accurately detect anomalies in energy consumption in smart farms. By integrating AI mechanisms with real-time data from IoT devices, Electricity Talk not only aims to optimize energy utilization but also ensures operational stability by promptly identifying and addressing abnormal energy patterns.

Through robust analysis and empirical testing, this research seeks to validate the effectiveness of Electricity Talk and explore the potential of AI and IoT integration in revolutionizing energy management strategies in agricultural environments. By improving predictive accuracy and anomaly detection capabilities, Electricity Talk aims to contribute significantly to the advancement of smart farming technologies.

Background

The concept of smart farming has evolved significantly with advancements in technology, particularly through the integration of IoT devices and AI applications. Smart farms utilize a network of sensors and devices that collect data continuously, enabling precise monitoring and management of farm resources. This data-driven approach not only enhances productivity but also improves the sustainability of farming operations by reducing waste and optimizing resource use.

Electric energy consumption is a critical area that has garnered focus in the context of smart farming. Reliable and efficient energy use is vital, given the increasing complexity of operations that include automated irrigation systems, climate control in greenhouses, and numerous other energy-intensive activities. Traditionally, the management of this substantial energy use relied on manual monitoring and basic automated systems, which were often In efficient and error-prone. In recent years, the evolution of AI and machine learning technologies has provided new opportunities to enhance energy management systems. These technologies can predict energy needs and detect anomalies in consumption patterns, facilitating preemptive management actions that avoid wastage and potential system failures. Therefore, understanding and optimizing electric energy consumption using advanced IoT and AI systems stands as a key area of interest, driving both economic benefits and sustainability for smart farms.

Objective

The primary objective of this study is to develop and validate Electricity Talk, an advanced IoT platform integrated with an AI mechanism, designed to enhance predictive capabilities and anomaly detection in electric energy consumption for smart farms. This study aims to:

1. Assess the efficiency and accuracy of Electricity Talk in predicting daily, hourly, and minute-level electric energy consumption using IoT-derived data alongside traditional consumption metrics.
2. Evaluate the capability of the integrated AI mechanism, AItalk, which utilizes a novel approach combining modified Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) models, in detecting anomalies in energy usage.
3. Compare the performance of Electricity Talk against traditional electric energy prediction models, highlighting the improvements made possible by incorporating real-time IoT switch status information.
4. Emonstrate the practical applicability and benefits of Electricity Talk in real farm settings, focusing on its impact on enhancing operational efficiency and reducing energy wastage.

By achieving these objectives, this research seeks to push the boundaries of current agricultural practices, making them more sustainable and economically viable through technological innovation

Scope and Limitations

This study focuses on the application of the Electricity Talk platform in the context of smart farming, specifically tailored to predict electric energy consumption and detect anomalies using IoT and AI technologies. The study encompasses the development and testing of the AI mechanism, AI talk, which is integrated within the Electricity Talk platform and assesses its performance using data from real-world smart farm setups.

However, the study is not without limitations. Firstly, the performance results obtained are highly dependent on the quality and granularity of the data collected from the IoT devices. Any disruptions in data collection or inherent inaccuracies in sensor readings may affect the outcome of the predictions and anomaly detection.

Additionally, while the study aims to showcase the general applicability of the Electricity Talk system, the specific models and techniques developed may not directly transfer to other types of farms or agricultural environments without modifications and further testing. The computational resources required for processing and the technical expertise needed to maintain the AI models may also pose limitations for smaller or resource-constrained farm operations.

Finally, the scope of this study is confined to electric energy consumption within smart farms. Consequently, the generalizability of the findings to other sectors or different types of energy management systems outside agriculture may be limited. Further studies would be required to adapt and verify the effectiveness of the Electricity Talk platform in other contexts.

Traditional methods in enery prediction

Traditional methods in electric energy prediction primarily hinged on statistical approaches. These methods, including linear regression, time-series forecasting, and autoregressive integrated moving average (ARIMA) models, have been extensively used due to their simplicity and effectiveness in handling linear patterns in energy consumption data. Linear regression models predict future values based solely on historical consumption trends, making assumptions of linearity between variables.

Time-series forecasting, tailored for handling data that change over time, is fundamental in energy prediction, as energy consumption is intrinsically sequential and time-variant. Methods such as ARIMA and its variants, which account for trends and seasonality in historical data, have dominated this domain. These models, which adjust themselves based on the errors in their forecasted and actual values, have provided fairly reliable forecasts by capturing linear dependencies.

Despite their initial effectiveness, these traditional methods face significant challenges in adapting to the nonlinear and complex patterns in energy usage, especially with the advent of smart technologies in farming. Their primary limitation lies in their inherent assumption of linearity and their inability to incorporate multiple, diverse data sources which is often necessary for accurate predictions in scenarios involving complex interactions of multiple variables, as found in smart farms. These constraints have necessitated the exploration and adoption of more sophisticated, machine learning-based methods in recent years.

Evolution into machine learning and deep learning

As the limitations of traditional statistical methods became evident, particularly in handling complex and nonlinear data patterns in smart environments, there arose a shift towards machine learning and later, deep learning techniques, which offer greater flexibility and accuracy in predictions.

Machine learning methods, unlike their traditional counterparts, do not explicitly assume linearity and are better suited to adapt to changes and recognize patterns in large datasets. Techniques such as support vector machines, decision trees, and ensemble methods like random forests and gradient boosting machines have been employed to predict energy consumption, focusing on feature-driven models that utilize historical data patterns more comprehensively.

Deep learning, an extension of machine learning, employs artificial neural networks with multiple layers (hence 'deep') to perform more abstract and complex pattern recognition. Neural networks, particularly CNNs and LSTMs, have proven effective in capturing temporal sequences and spatial correlations, which are critical in predicting energy usage patterns. CNNs excel in handling data with grid-like topology (e.g., time- series data arranged in sliding windows), whereas LSTMs are specifically designed to address problems requiring learning from long-term dependencies, making them ideal for sequential prediction tasks seen in electric energy consumption.

The evolution to these advanced computational methods has enabled researchers and practitioners to tackle the increased variability and complexities of energy management in smart farms, incorporating various influencing factors beyond straightforward consumption patterns. The ability of deep learning to integrate diverse data types and large volumes of information has set the stage for more dynamic, efficient, and predictive energy management systems. These systems can now adaptively learn from real-time data, significantly improving predictive accuracy and operational efficiency in smart farming contexts.

Integration of Iot in energy prediction

The integration of the Internet of Things (IoT) in energy prediction marks a transformative advancement in managing and optimizing energy consumption, particularly in the agricultural sector. IoT technology enables the seamless collection and transmission of data from a myriad of devices across a farm, ranging from soil moisture sensors to weather stations and energy meters. This wealth of data provides a granular view of the farm's operational status in real time, facilitating more precise and dynamic energy management.

By harnessing IoT, predictive models can incorporate variables that were previously difficult to measure or predict, such as environmental changes, equipment performance, and real-time energy consumption patterns. This capability not only enhances the accuracy of predictive models but also allows for the automation of energy management processes. For instance, IoT platforms can dynamically adjust energy usage based on predictive data, leading to optimized energy consumption and reduced operational costs.

Moreover, IoT enables predictive systems to be more responsive to anomalies in energy usage, which could indicate equipment malfunctions or inefficiencies. By providing immediate alerts and insights, IoT-driven systems help farm managers to take swift corrective actions, thereby minimizing downtime and improving the sustainability of operations.

Overall, the integration of IoT into energy prediction represents a pivotal shift towards more intelligent, data-driven, and efficient energy management strategies in smart farms. This not only contributes to economic benefits but also enhances the sustainability of agricultural practices by ensuring energy is used judiciously and effectively

Overview of electricity talk platform

Electricity Talk, the innovative platform discussed in this paper, encapsulates the integration of IoT and advanced AI technologies to revolutionize electric energy prediction and anomaly detection in smart farms. The core of Electricity Talk lies in its dual capabilities of predictive accuracy and real-time anomaly detection, brought about by its unique AI mechanism known as AI talk, which incorporates a modified Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) models.

This platform is not merely an analytical tool but a comprehensive IoT system that connects various farm sensors and devices through a centralized server. It collects high-frequency data from these IoT devices, which include information not only on power consumption but also on operational status and environmental conditions. By processing this diverse data, Electricity Talk can predict power consumption patterns and promptly detect deviations that might signify operational anomalies.

One of the significant innovations of Electricity Talk is its ability to utilize the switch status information from farming appliances provided by IoT devices in real-time. This data inputs into the AItalk mechanism substantially enrich the predictive model, allowing for enhancements in the accuracy and responsiveness of the system. The improvement is quantifiable; through the implementation of Electricity Talk, the Mean Absolute Percentage Error (MAPE) is significantly reduced, achieving a new level of precision in predictive analytics in agriculture.

Practically, this platform is designed to be user-friendly and easily integrable into existing farm infrastructures. It supports decision-makers in farm management by providing actionable insights and detailed reports on energy consumption trends and anomaly alerts, thereby facilitating more informed decisions regarding energy use and operational practices. Altogether, Electricity Talk exemplifies the potential of IoT and AI to create smarter, more efficient agricultural systems.

AI mechanism: AL talk description

The AI mechanism central to the Electricity Talk platform is AI talk, a sophisticated model that integrates modified Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) architectures. This combination leverages the strengths of both neural network types to enhance the prediction and anomaly detection capabilities in energy consumption on smart farms.

AI talk's CNN component is tailored to process spatial data inputs, which in the context of Electricity Talk, involves the analysis of patterns from multidimensional sensor data across the farm. This functionality is crucial for detecting correlations and interactions between various data points that affect energy usage, such as temperature variations, equipment status, and operational schedules.

Conversely, the LSTM component of AI talk excels in handling time-series data, making it ideal for predicting energy consumption over time. LSTM networks are adept at learning long-term dependencies, allowing AI talk to remember information for prolonged periods, which is integral in understanding ongoing trends in energy usage and identifying long-term anomalies that might not be immediately apparent.

Together, the integrated CNN-LSTM architecture provides a robust framework that not only predicts future energy needs based on historical and real-time data but also rapidly detects anomalies that deviate from established consumption patterns. This dual capability makes AItalk a powerful tool in ensuring operational efficiency and sustainability in smart farming operations. Additionally, the adaptability of AItalk allows for continual learning and improvement as more data is gathered, thus progressively enhancing its predictive accuracy and anomaly detection precision.

Experimental setup and result

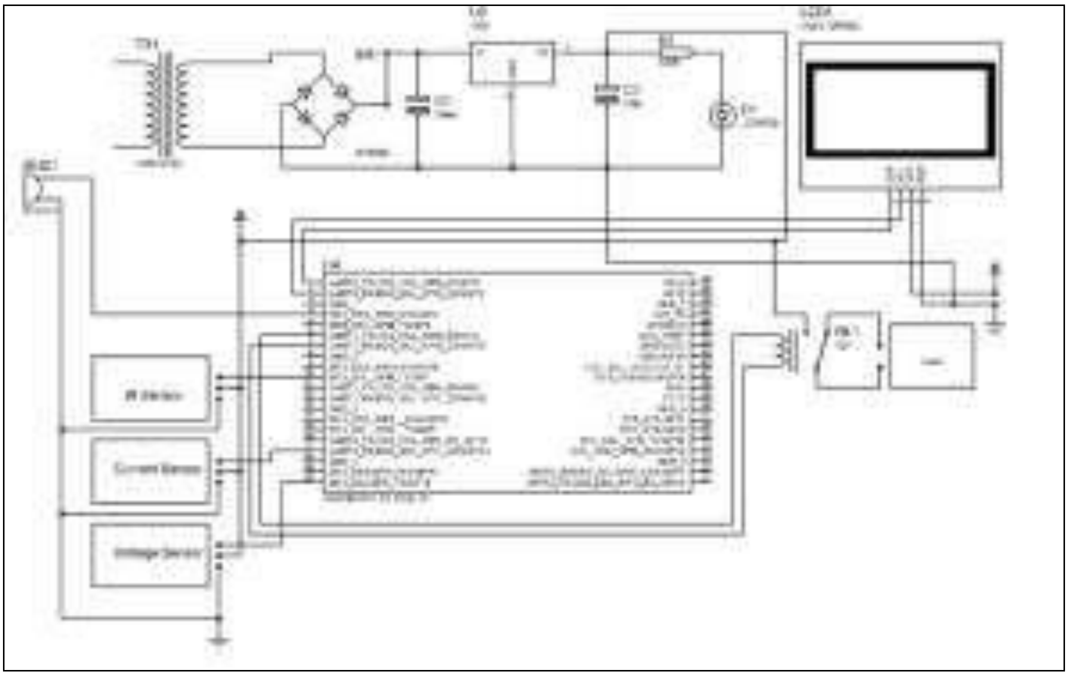

Fig 1: Schematic diagram of proposed system

To validate the efficacy of the Electricity Talk platform powered by AItalk, a rigorous experimental setup was employed, utilizing datasets from multiple smart farm environments. The primary datasets used in this study were the UCI Machine Learning Repository dataset and the Bao farm dataset. These datasets comprise diverse parameters, including but not limited to temperature, humidity, equipment status, and actual energy consumption rates recorded over different intervals.

The experimental design followed a structured approach: initially, baseline prediction models of energy consumption using only historical energy data were established. Subsequently, the AI talk mechanism was integrated, utilizing additional inputs from IoT devices, particularly switches and operational status data. The performance of both setups was then meticulously compared to gauge the improvements afforded by the inclusion of IoT data.

Fig 2: Hardware Implementation of project

The results of these experiments were evaluated using standardized performance metrics, notably the Mean Absolute Percentage Error (MAPE), precision, and recall rates. These metrics served to quantify the accuracy of energy predictions and the effectiveness of anomaly detection within the operational parameters of smart farming.

Fig 3: Execution of project

Substantial improvements were noted across all measured parameters when employing the AItalk mechanism. The model not only demonstrated heightened predictive accuracy but also showcased superior anomaly detection capabilities, as evidenced by the empirical results detailed in the subsequent sections. These enhanced outcomes underscore the potential of integrating AI and IoT technologies in optimizing energy management and operational efficiency in smart farming contexts.

Comparision of results

The experimental results highlight the significant enhancements achieved by the Electricity Talk platform compared to traditional prediction methods. Initially, using traditional predictive models, the MAPE scores for daily, hourly, and minute-wise predictions were 35.95%, 21.43%, and 2.334%, respectively. However, once the AItalk mechanism was integrated with additional IoT switch data, a marked improvement was noted.

Specifically, with AI talk, the MAPE for daily predictions improved by 22% to 28.05%, highlighting increased prediction reliability over longer periods. More dramatic was the improvement in the hourly predictions, where the MAPE improved by 51%, descending to 10.30%. The minute-wise predictions, critical for real-time operational adjustments, showed a 34.5% improvement, bringing the MAPE down to 1.532%.

These results underscore the enhanced capability of Electricity Talk in handling complex, dynamic data flows typical of smart farming environments, thus supporting more accurate and timely decisions in energy management. The use of real-time data from IoT devices substantially contributes to these advancements, offering a clear benefit over traditional prediction models that rely solely on historical data.

Analysis of result

The dramatic improvements in predictive accuracy and anomaly detection as demonstrated by the decreased MAPE values and enhanced precision and recall rates confirm the hypothesis that integrating IoT data significantly augments the performance of energy prediction models in smart farming environments. The integration of real-time operational data (like switch statuses) allows for a more nuanced understanding of energy requirements and irregularities, leading to these improvements.

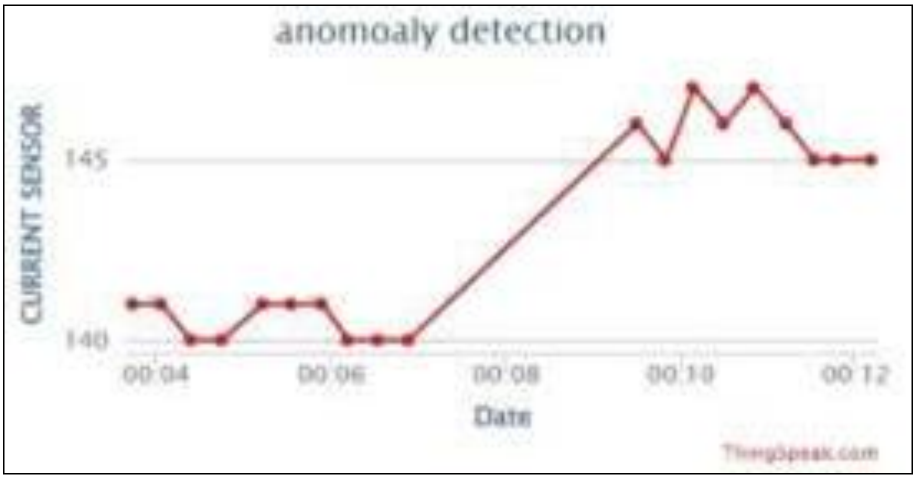

Fig 4: Graph-1 from Things speak (current)

Furthermore, the near-perfect recall rates signify that almost all energy consumption anomalies were detected by the Electricity Talk platform, indicating a high level of sensitivity in the anomaly detection algorithm. The precision rates being greater than 0.994 suggest that the instances flagged as anomalies were truly anomalous, thus minimizing the risk of false positives—an essential factor in operational settings where response actions based on inaccurate predictions can lead to unnecessary expenses or resource wastage.

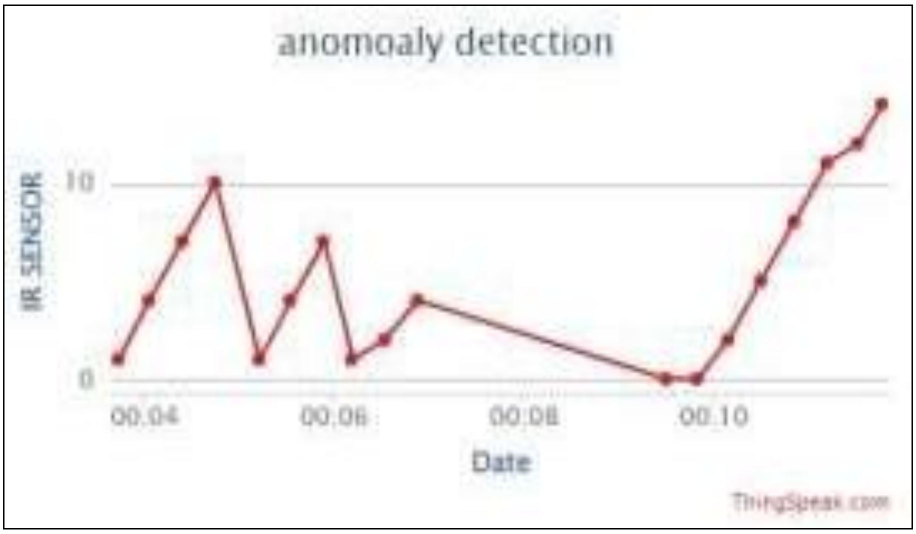

Fig 5: Graph-2 from Thing speak (No. of units comsumed)

This analysis illustrates not only the technical feasibility but also the practical advantages of employing sophisticated AI tools in conjunction with IoT infrastructure for managing energy in agriculturally intensive settings. The outcomes strongly advocate for the adoption of such hybrid AI-IoT systems, potentially setting a new standard for energy management practices in the sector.

Conclusion

This paper proposed Electricity Talk, an IoT platform that integrates the AI mechanism called AItalk with IoT devices for enhanced electric energy prediction and anomaly detection in smart farms. The integration of real-time farming appliance switch information as extra features significantly improved the accuracy of electric energy predictions and enhanced anomaly detection capabilities. Results showed a considerable improvement in MAPE scores across various prediction intervals-daily, hourly, and minute-wise-demonstrating the superiority of Electricity Talk over traditional models.

The precision and recall metrics further validate the robustness of our system in operational environments, with near-perfect detection and minimal false positives. These achievements illustrate the potential of IoT and AI to revolutionize energy management in agricultural settings, setting a benchmark for future developments in smart farming technologies

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