PREDICTING RESIDENTIAL ELECTRICITY CONSUMPTION USING CNN-BILSTM-SA NEURAL NETWORKS

ABSTRACT

- The project investigates household electricity consumption patterns to optimize power generation, ensure stable supply, and develop effective energy-saving strategies.
- A CNN-BiLSTM-SA model is proposed, integrating CNN for feature extraction, BiLSTM for capturing long-term dependencies, and a Self-Attention mechanism for focusing on critical data features.
- The Maximal Information Coefficient (MIC) method is employed to evaluate the Spearman Rank and eliminate highly correlated features, ensuring optimal input data for accurate forecasting.
- The dataset utilized for this project is the Electricity Consumption dataset from the UCI repository, which includes measurements from three sub-meters.
- The model's efficiency is assessed using metrics such as R^2 score, RMSE, and MAE, ensuring reliable predictions for residential electricity consumption.
- To enhance efficiency, BiLSTM is replaced with BiGRU, which reduces computational complexity while maintaining predictive accuracy, making it suitable for large-scale electricity consumption forecasting.

INTRODUCTION

- The modern world faces a dual challenge in the energy sector: the increasing scarcity of global energy resources and the growing need for a stable power supply. Rapid industrialization and urbanization have further intensified energy consumption, making sustainable power management a critical concern.
- The global energy crisis highlights the urgency of adopting effective energy management strategies. Developing innovative solutions is essential to addressing rising energy demands and ensuring long-term sustainability.
- Household electricity usage constitutes a significant portion of global energy consumption, driven by the increasing use of home appliances, changing lifestyle patterns, and economic advancements.
- Understanding household energy consumption is crucial for optimizing power generation and distribution, ensuring a reliable power supply, and enabling energy-saving strategies tailored to individual usage patterns.
- Precise electricity consumption predictions help balance supply and demand, reducing power outages and improving overall energy sector efficiency. Analyzing household energy usage is both an economic necessity and a strategic priority for sustainable power management.

OBJECTIVE

- The objective is to develop an advanced deep learning model that accurately predicts residential electricity consumption by analyzing household energy usage patterns.
- The goal is to implement a CNN-BiLSTM-SA model, where CNN extracts temporal features, BiLSTM captures long-term dependencies, and the Self-Attention mechanism focuses on critical data features. As an extension, BiLSTM is replaced with BiGRU to enhance processing speed and efficiency.
- The aim is to predict continuous numerical values representing future electricity consumption levels rather than discrete classes, enabling better understanding of usage trends and optimizing power distribution.
- The objective is to evaluate the model's performance using R^2 score, RMSE (Root Mean Square Error), and MAE (Mean Absolute Error) to assess forecasting precision and efficiency.
- The goal is to benefit utility providers, policymakers, and households by enabling efficient energy management, reducing power outages, and supporting personalized energy-saving strategies.

PROBLEM STATEMENT

- The global energy sector faces a critical challenge due to the increasing scarcity of energy resources and the growing demand for a stable power supply, exacerbated by industrialization and urbanization.
- Conventional electricity consumption prediction models struggle to capture the complex spatial and temporal dependencies in household energy usage, leading to inaccurate demand forecasts and inefficient energy management.
- Existing systems fail to provide user-specific consumption analysis, making it difficult to implement targeted energy-saving strategies and optimize household electricity usage.
- Inaccurate electricity demand predictions lead to supply-demand imbalances, increasing the risk of power outages and reducing overall energy sector efficiency.
- To enhance prediction accuracy and efficiency, there is a need for an advanced hybrid deep learning model .

LITERATURE SURVEY

TITLE	AUTHORS	METHODOLOGY	DRAWBACKS	RESULTS	LINK
Avoiding Overconfidence in Predictions of Residential Energy Demand through Identification of the Persistence Forecast Effect	H.B.Akyol, C.Preist, and D.Schien	This study defines the Persistence Forecast Effect and proposes the 1-Step-Shifting method to detect its presence. It analyzes the effect's relationship to data irregularity using real-world electricity consumption data.	The 1-Step-Shifting method might not fully address all types of irregularities in data. Its effectiveness could be limited by the complexity of data and the forecasting techniques used.	The Persistence Forecast Effect can lead to overconfidence in predictions. The proposed method effectively detects this issue, improving prediction robustness and highlighting the importance of statistical regularity in forecasting.	https://ieeexplore.ieee.org/abstract/document/9855657

LITERATURE SURVEY

TITLE	AUTHORS	METHODOLOGY	DRAWBACKS	RESULTS	LINK
Hybrid Machine Learning Model for Electricity Consumption Prediction Using Random Forest and Artificial Neural Networks	W. Kesornsit and Y. Sirisathitkul	A hybrid machine learning model integrates dimensionality reduction and feature selection algorithms (PCA, SWR, RF) with a backpropagation neural network (BPNN) to predict electricity consumption in Thailand using real-world datasets.	The model's accuracy depends on the quality of data and feature selection. It may face challenges in adapting to highly dynamic or unpredictable consumption patterns due to reliance on historical data.	The hybrid model of RF and BPNN outperforms other predictive models for electricity consumption, offering a robust tool for energy demand planning and management through accurate prediction of consumption patterns.	https://onlinelibrary.wiley.com/doi/full/10.1155/2022/1562942

LITERATURE SURVEY

TITLE	AUTHORS	METHODOLOGY	DRAWBACKS	RESULTS	LINK
Forecasting Electricity Demand In Ghana With The Sarima Model	P. Y. A. Andoh, C. K. K. Sekyere, L. D. Mensah, and D. E. K. Dzebre	Time series data from the Western Regions of Ghana was analyzed using the SARIMA model to forecast electricity demand. The study employed data from the ECG regional headquarters for accurate predictions.	The SARIMA model may not fully account for external factors affecting energy demand, such as sudden policy changes or economic shifts, potentially reducing its forecasting accuracy for unpredictable scenarios.	The SARIMA model effectively forecasts electricity demand, aiding in future consumption predictions and investment in alternative power sources, contributing to the development of energy policies for the region's growing needs.	https://yrpipku.com/journal/index.php/jaets/article/view/288

LITERATURE SURVEY

TITLE	AUTHORS	METHODOLOGY	DRAWBACKS	RESULTS	LINK
Prediction of domestic power peak demand and consumption using supervised machine learning with smart meter dataset	R. Geetha, K. Ramyadevi, and M. Balasubramanian	A random forest supervised learning model is employed to forecast power consumption and peak demand using a smart meter dataset collected across various seasons, achieving high accuracy and stability in predictions.	The model's performance may be sensitive to the quality and completeness of the dataset, and it may struggle to generalize under unforeseen variables like sudden shifts in consumption patterns or emerging technologies.	The random forest model offers superior accuracy, stability, and generalization in forecasting domestic power consumption and peak demand, outperforming existing models and providing valuable insights for energy planning and management.	https://link.springer.com/article/10.1007/s11042-021-10696-4

LITERATURE SURVEY

TITLE	AUTHORS	METHODOLOGY	DRAWBACKS	RESULTS	LINK
Forecasting week-ahead hourly electricity prices in Belgium with statistical and machine learning methods	E. Spiliotis, H. Doukas, V. Assimakopoulos, and F. Petropoulos	This study compares neural networks, random forest, and traditional statistical methods for forecasting electricity prices in Belgium. The forecasting models incorporate external variables like weather, consumption, and seasonal factors.	While machine learning methods outperform statistical approaches, their complexity may hinder interpretability. Additionally, external variables, though beneficial, may introduce noise if not accurately captured, limiting model robustness in certain conditions.	Machine learning methods, particularly neural networks and random forest, offer more accurate and less biased forecasts for electricity prices, especially when external variables are included, with combined forecasts further enhancing performance.	https://www.sciencedirect.com/science/article/abs/pii/B9780128218389000050

Literature Review / Research Gap

To overcome the limitations identified in the literature survey, this project incorporates a **hybrid deep learning model (CNN-BiLSTM-SA)** to capture complex spatial and temporal dependencies, improving predictive accuracy compared to traditional methods. It employs **Maximal Information Coefficient (MIC)** for optimal feature selection, eliminating highly correlated features to enhance forecasting performance. Additionally, to reduce computational complexity, **BiLSTM is replaced with BiGRU**, which simplifies the structure while maintaining accuracy. A **Flask-based front-end** with **user authentication** is also integrated, ensuring secure access and a user-friendly platform for electricity consumption analysis.

EXISTING SYSTEM

The existing electricity consumption forecasting systems primarily rely on historical data and statistical techniques to analyze usage patterns. However, they often struggle to capture complex, non-linear relationships and seasonal variations effectively. Traditional machine learning models, such as regression and decision trees, do not efficiently leverage temporal dependencies, while hybrid approaches combining multiple ML techniques fail to fully utilize advanced architectures like CNNs and LSTMs. Although RNN and LSTM models have been used for time-series forecasting, they lack comprehensive feature extraction and self-attention mechanisms, limiting their accuracy. Additionally, statistical methods like ARIMA face challenges in long-term forecasting and adapting to dynamic electricity consumption patterns.

Disadvantages of the Existing System:

- Existing models fail to capture intricate spatial and temporal dependencies, leading to inaccurate predictions.
- Many traditional models cannot dynamically adjust to evolving household electricity consumption behaviors.
- The absence of advanced feature extraction techniques, such as CNN and self-attention, results in lower forecast accuracy.
- RNN and LSTM models require high computational resources, making them less efficient for large-scale, high-frequency electricity consumption data.

PROPOSED SYSTEM

The proposed system introduces a hybrid deep learning model, CNN-BiLSTM-SA, for accurately predicting residential electricity consumption. It integrates CNN to extract temporal features, BiLSTM to capture long-term dependencies, and Self-Attention (SA) to focus on critical data features, enhancing predictive accuracy. Additionally, the system employs the Maximal Information Coefficient (MIC) for feature selection, eliminating highly correlated features to ensure optimal input data for forecasting. This combined approach effectively analyzes complex spatial and temporal consumption patterns, making it more efficient than traditional methods.

Advantages of the Proposed System

- The integration of CNN, BiLSTM, and Self-Attention improves the model's ability to capture spatial and temporal dependencies, leading to more precise electricity consumption forecasts.
- The use of the Maximal Information Coefficient (MIC) ensures that only the most relevant features are considered, reducing noise and improving forecasting efficiency.
- The model dynamically learns evolving household electricity usage trends, making it more adaptable to compared to traditional methods.
- The hybrid deep learning architecture allows for faster and more efficient processing of large-scale electricity consumption data while maintaining high predictive accuracy.

EXTENSION / NOVELTY

As an extension, the **Bidirectional Long Short-Term Memory (BiLSTM)** component is replaced with a **Bidirectional Gated Recurrent Unit (BiGRU)** to enhance processing speed and efficiency while maintaining predictive accuracy. Unlike BiLSTM, which has **three gates (input, forget, and output)**, BiGRU simplifies the structure with only **two gates—update and reset**—reducing computational complexity while effectively capturing long-term dependencies in electricity consumption data. The update gate determines how much past information should be retained, while the reset gate controls how much past information should be forgotten, enabling faster convergence and reduced memory usage.

Additionally, a **front-end interface is developed using the Flask framework** for user testing, providing a seamless interaction platform. The interface incorporates **user authentication mechanisms**, ensuring secure access and personalized electricity consumption forecasts.

Advantages Of Extension / Novelty

- The replacement of **BiLSTM with BiGRU** reduces computational complexity, as BiGRU has only two gates (update and reset), making it faster and more efficient.
- BiGRU requires fewer parameters compared to BiLSTM, leading to reduced memory usage and better scalability for large electricity consumption datasets.
- While simplifying the architecture, BiGRU retains the ability to capture long-term dependencies, ensuring that predictive accuracy is maintained or even improved.
- The **Flask-based front-end interface** provides a simple and accessible platform for users to upload datasets, view predictions, and analyze electricity consumption trends without requiring in-depth technical knowledge.
- **User authentication** ensures that only authorized users can access and utilize the system, protecting sensitive electricity consumption data from unauthorized access.

REQUIREMENTS

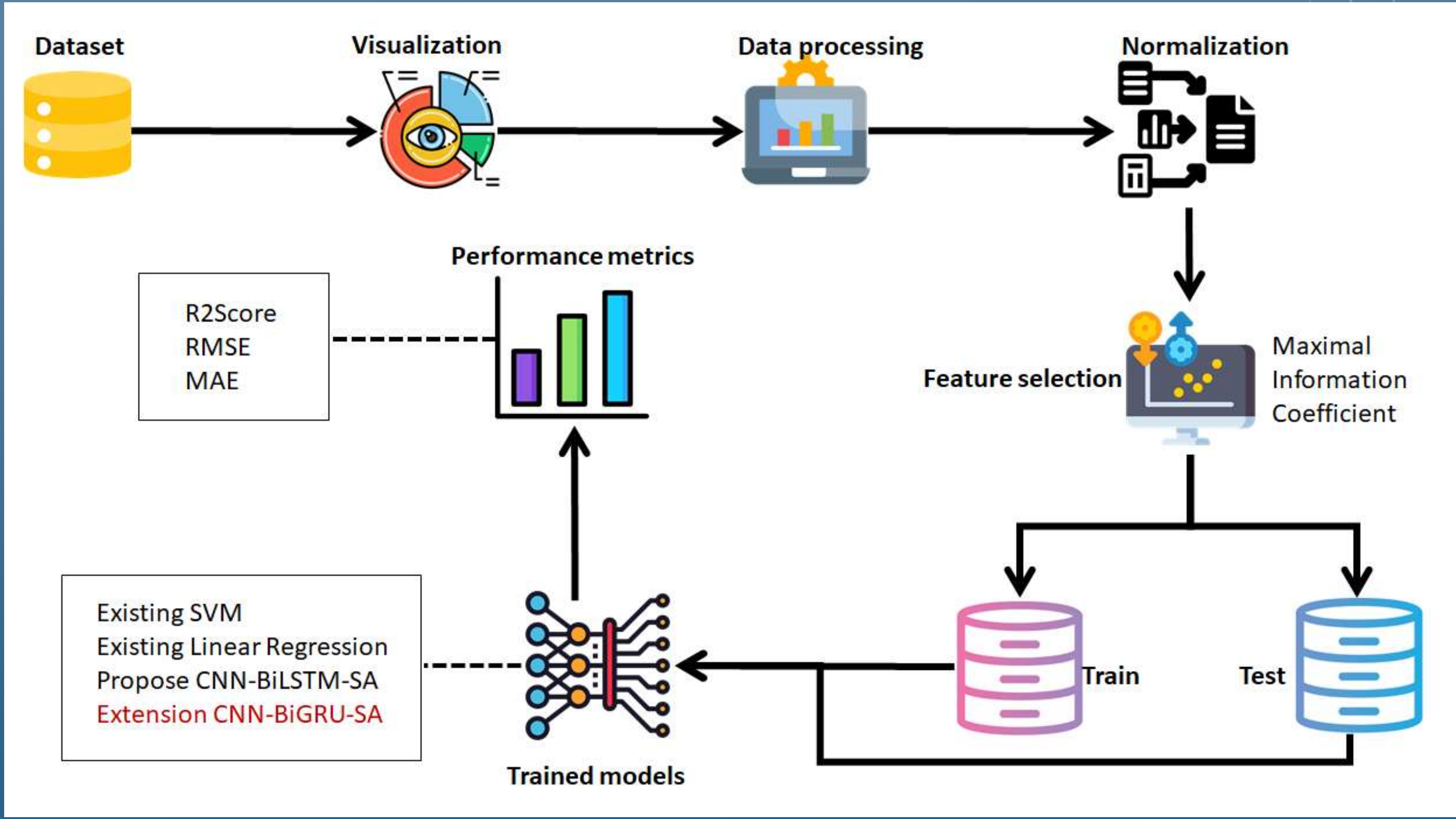
SOFTWARE REQUIREMENTS

1. Software: Anaconda
2. Primary language: Python
3. Frontend framework: Flask
4. Back-end framework: Jupyter notebook
5. Database: Sqlite3
6. Front-end technologies: HTML, CSS, javascript and bootstrap4

HARDWARE REQUIREMENTS

1. Operating system: windows only
2. Processor: i5 and above
3. Ram: 8 GB and above
4. Hard disk: 25 GB in local drive

SYSTEM ARCHITECTURE



DATASET

Dataset Link: https://archive.ics.uci.edu/dataset/235/individual+household+electric+power+consumption

	Date	Time	Global_active_power	Global_reactive_power	Voltage	Global_intensity	Sub_metering_1	Sub_metering_2	Sub_metering_3
0	16/12/2006	17:24:00	4.216	0.418	234.84	18.4	0.0	1.0	17.0
1	16/12/2006	17:25:00	5.360	0.436	233.63	23.0	0.0	1.0	16.0
2	16/12/2006	17:26:00	5.374	0.498	233.29	23.0	0.0	2.0	17.0
3	16/12/2006	17:27:00	5.388	0.502	233.74	23.0	0.0	1.0	17.0
4	16/12/2006	17:28:00	3.666	0.528	235.68	15.8	0.0	1.0	17.0
...	...	...	...	...	...	...	...	...	...
9995	23/12/2006	15:59:00	4.958	0.664	241.34	20.6	0.0	0.0	17.0
9996	23/12/2006	16:00:00	4.954	0.666	241.50	20.6	0.0	0.0	18.0
9997	23/12/2006	16:01:00	4.932	0.658	240.80	20.6	0.0	0.0	18.0
9998	23/12/2006	16:02:00	4.926	0.660	240.77	20.6	0.0	0.0	18.0
9999	23/12/2006	16:03:00	4.658	0.660	240.81	19.6	0.0	0.0	17.0

CONCLUSION

- The project successfully develops a **hybrid deep learning model (CNN-BiLSTM-SA)** to predict residential electricity consumption with high accuracy by capturing complex spatial and temporal dependencies.
- The integration of **Maximal Information Coefficient (MIC)** ensures that only the most relevant features are selected, improving data quality and enhancing the forecasting performance.
- The extension, which replaces **BiLSTM with BiGRU**, achieves the **highest accuracy among all models**, offering faster processing, reduced computational complexity, and better performance for large-scale electricity consumption forecasting.
- A **Flask-based front-end** is developed to allow users to interact with the system, upload datasets, and visualize electricity consumption trends, improving accessibility and usability.
- By providing highly accurate consumption forecasts, the project supports **better energy management strategies**, helping utility providers and households optimize electricity usage, reduce costs, and improve sustainability.

FUTURE SCOPE

- The model can be extended to consider additional influencing factors like **weather conditions, electricity pricing, and socio-economic trends**, which can improve the reliability of predictions.
- Implementing the model on **larger and diverse datasets** from multiple geographic regions can enhance its adaptability and effectiveness in varying energy consumption patterns.
- The project can be transformed into a **cloud-based API service**, enabling energy providers, researchers, and consumers to access **real-time forecasting insights** and integrate them into smart grid management systems.
- The forecasting model can be further enhanced to provide **personalized energy-saving recommendations** for households, helping users optimize power usage and reduce electricity costs.
- The model can be integrated with **IoT-based smart home systems**, enabling automated control of appliances based on predicted electricity consumption patterns for improved energy efficiency.

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