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ENERGY PREDICTION OF SENSOR NODES USING DEEP LEARNING

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Abstract: Wireless Sensor Networks (WSNs) have various applications, but the limited battery life of sensor nodes which makes energy consumption a crucial characteristic of sensor networks. Despite recent research focusing heavily on energy-conscious applications and operating systems, energy consumption remains a limiting factor. Once sensor nodes have already been deployed. It is challenging and sometimes even impossible to change batteries which may result in erroneous lifetime prediction of sensor network causing high costs and may render the network useless before its purpose is fulfilled. The models show high accuracy in predicting energy consumption, enabling the development of more efficient and sustainable WSNs. The significance of this approach extends to other domains such as IoT and cyber-physical systems, enabling accurate energy prediction and efficient resource management. The research demonstrates that the use of deep learning techniques significantly improves the accuracy of energy prediction compared to traditional machine learning techniques. This approach can assist researchers and engineers in developing energy-efficient WSNs, ensuring their sustainability. Moreover, the proposed method can be applied in a variety of applications such as energy-efficient routing and adaptive power management in WSNs. The study provides valuable insights into the energy consumption of the sensor nodes & opens up new avenues for developing sustainable and efficient WSNs.

INTRODUCTION

Wireless Sensor Networks (WSN) are a type of network that comprises small, low-cost, and low-power sensor nodes that are capable of collecting and transmitting data wirelessly. The popularity of WSNs has grown significantly in recent years due to their wide range of applications in various fields including environment monitoring, healthcare, industrial automation, and smart homes. In WSNs, Typically, sensor nodes are powered by batteries, which makes energy efficiency a critical factor for their deployment and maintenance. To optimize the performance and prolong the battery life of sensor nodes, accurate prediction of their energy consumption is crucial. Over the years, researchers have increasingly utilized deep learning models to predict the energy consumption of sensor nodes in WSNs.

Different models have been used to predict power consumption like Autoregressive Integrated Moving Average model (ARIMA), simple and multiple Linear Regression, Neuro-Fuzzy model, Support Vector Regression, Support Vector Machines (SVM), Artificial Neural Network (ANN), Time-Series, or a combination of regression, Nearest Neighbour and ANN, whereas ANN has been considered to achieve the best results for energy prediction. Also, a study in mentioned the use of Long Short-Term Memory (LSTM) with Auto-Encoders (AE) in predicting solar energy consumption using weather data and achieved best results over several Deep Learning (DL) models.

In this paper, we have used the same dataset of which contains data for around 1 month for every 30 seconds. Deep learning models have shown significant potential in accurately predicting the energy consumption of sensor nodes, which can help optimize their performance and extend their battery life. We aim to highlight the key contributions and challenges in this area, as well as the potential impact of deep learning models in enhancing energy efficiency in WSNs. This survey will be useful for researchers and practitioners working in the field of WSNs, as well as for those interested in the intersection of deep learning and energy efficiency.

The rest of this paper is organized as follow: Section 2 describes Literature survey, Section 3 presents the dataset and types of information used in our experiment, Section 4 discusses the System description, Section 5 Architecture diagram of our system, Section 6 Experiment and result and Section 7 Conclusion.

Keywords: sensor nodes, deep learning, feed-forward neural network, energy prediction, sensor network

LITERATURE REVIEW

[1] Evaluating the Power Consumption of Wireless Sensor Network Applications Using Models

Antonio Damaso, Davi Freitas, Nelson Rosa, Bruno Silva, and Paulo Maciel

Accurately predicting power usage in WSNs applications such as target tracking and environmental monitoring can be challenging due to variations in work environments. To address this issue, the authors develop and evaluate analytical models that can accurately characterize node behaviours and associated power consumptions. After discussing various existing methods for examining power consumption and highlighting their shortcomings, the authors introduce their proposed methodology which involves studying the power consumption patterns of sensor nodes and analyzing them using various analytical models. Additionally, they compare the accuracy of these models with existing simulation-based approaches, providing results specific to each application studied.

[2] Power consumption Assessment in Wireless Sensor Networks by

Antonio Moschitta and Igor Neri

This research examines power consumption in wireless sensor networks (WSNs) and compares the performance of various routing protocols in terms of energy consumption. The study focuses on two types of WSNs: homogeneous, where every node has the same energy capacity and heterogeneous where nodes have different energy capacities. It begins with a description of WSNs and their characteristics, emphasising the significance of energy efficiency in these networks. It describes the different routing protocols that they analysed in their study, including Direct Diffusion (DD), Rumor Routing (RR) and Gradient-based Routing (GR). Following that the study presents their experimental setup which contains simulation models of both homogeneous and heterogeneous WSNs. They compare the energy consumption, network lifetime and packet delivery ratio of the various routing protocols. Gradient-based Routing (GR), on the other hand has a greater packet delivery ratio than Direct Diffusion (DD) and Rumor Routing (RR). They also discovered that heterogeneous networks outdone homogeneous networks. Finally, the paper provides a thorough examination of power usage in WSNs as well as the performance of various routing protocols. According to the authors, the routing protocol of choice is determined by the specific requirements of the application as well as the network characteristics.

[3] The paper "Prediction and Management in Energy Harvested Wireless Sensor Nodes" by Joaquín Recas Piorno, Carlo Bergonzini, David Atienza, and Tajana Simunic Rosing,

The research presents such a current state in energy harvesting techniques such as solar, kinetic, and thermal energy harvesting. They also discuss energy management challenges in WSNs, such as the need for efficient energy storage and power management algorithms. The paper examines existing techniques for energy prediction and management in WSNs in depth, including algorithms for energy harvesting prediction, energy storage optimisation, and dynamic power management. Weather-Conditioned Moving Average (WCMA) was used, which is a fast and dependable solar prediction algorithm capable of exploiting solar energy more effectively than Exponential Weighted Moving Average (EWMA)). WCMA, in particular, can effectively account for both current and past-day weather conditions, with a comparative mean error only of 10%. This study also goes over various energy management techniques and how they affect system performance and energy consumption.

[4] Accurate Prediction of Power Consumption in Sensor Networks by

Olaf Landsiedel, Klaus Wehrle, Stefan Gotz

The research begins by discussing the issue of power consumption in sensor networks, where nodes have limited battery capacity and energy efficiency is critical. They propose a model-based method for predicting power consumption in sensor nodes. The method uses a combination of both analytical and empirical models that accounts for a variety of factors such as processor, radio and sensor activity as well as environmental conditions such as temperature and humidity. They validate their method by running experiments on a real sensor network with various node configurations and workforce scenarios. They demonstrate that their method can predict power consumption with an average error of less than 10%. They also compare their method to other existing methods and demonstrate that it outperforms them in terms of accuracy. Finally, the authors discuss the potential applications of their approach, such as optimising energy consumption in sensor networks and predicting battery life. They also point out some of their approach's limitations, such as the need for accurate models of sensor and environmental parameters, as well as the assumption of static network topologies.

[5] An Efficient Data Model for Energy Prediction using Wireless Sensors

Michel Chammas, Abdallah Makhoul, and Jacques Demerjian:

This research paper focuses on energy prediction in buildings using wireless sensors. It proposes a data model which can accurately predict energy consumption by considering factors such as weather, appliance usage and occupancy patterns. They introduce their proposed data model, which consists of three key modules: weather, occupancy and appliance. The weather module forecasts future weather conditions using past weather data, the occupancy module forecasts occupancy patterns using wireless sensor data and the appliance module forecasts appliance usage using data from smart meters. They evaluate the model using real-world data from a building in Lebanon and show that it can accurately forecast energy consumption with less than 5% average error rate. This study offers an effective data model that considers various factors influencing energy consumption and provides a valuable tool for building energy management. The model takes into account a range of factors that affect energy consumption in a building and has been shown to be accurate in real-world scenarios.

[6] Energy Efficient-based Sensor Data Prediction using Deep Concatenate MLP

Made Adi Paramartha Putra, Ade Pitra Hermawan,

This research article discusses energy-efficient sensor data prediction using a Deep Concatenate MLP proposed by Made Adi Paramartha Putra, Ade Pitra Hermawan, Dong-Seong Kim, and Jae-Min Lee, who belong to the Networked Systems Lab at Kumoh National Institute of Technology, Gumi, South Korea. The authors conducted a literature survey to highlight the importance of energy conservation and the challenges of developing energy-efficient models for sensor data prediction. They discussed the limitations of existing models and proposed deep learning techniques as a solution to improve energy efficiency. The authors introduce their proposed solution, which utilizes a Deep Concatenate MLP architecture, and provide a detailed explanation of its various components. They also present experimental results demonstrating the efficiency and accuracy of their proposed model, comparing its performance with existing models.

Reference number	**Title of Paper**	**Name of Authors**	**Year of publication**	**Methodology/ /Algorithm used**	**Observations/Results**	**Advantages**	**Limitations**	**Research Gap**
1	Evaluating the Power Consumption of Wireless Sensor Network Applications Using Models	Antonio Damaso, Davi Freitas, Nelson Rosa, Bruno Silva, and Paulo Maciel	2013	Analytical models to estimate energy consumption of sensor nodes in different scenarios.	Proposed methodology provides accurate estimations of power consumption in WSNs applications. Power consumption varies depending on the scenario and application.	It calculates the average of five numbers, that has one invoke to collect the temperature.	It has only one assignment command. Variables are not used in the program	Future research can focus on developing more accurate analytical models for power consumption analysis in WSNs.
2	Power consumption Assessment in Wireless Sensor Networks	Antonio Moschitta and Igor Neri	2014	Evaluating the performance of various routing protocols with respect to energy consumption using simulation of homogeneous and heterogeneous WSNs.	Existing models used different routing protocols for different performance characteristics and found Heterogeneous networks have longer lifetimes compared to homogeneous networks.	Wireless sensors are cost-effective and easy to install, making them ideal for large-scale deployment in energy prediction systems.	Wireless sensors may have limited battery life, which can result in data loss if the batteries are not regularly replaced or recharged.	Future research can focus on evaluating the performance of different routing protocols in more diverse WSN scenarios.
3	Prediction and Management in Energy Harvested Wireless Sensor Nodes	Joaquín Recas Piorno, Carlo Bergonzini, David Atienza, and Tajana Simunic Rosing	2019	Comprehensive survey of existing techniques for energy prediction and management in WSNs. Analysis of trade-offs between different energy management techniques.	Existing model used harvesting techniques for WSNs which included solar, kinetic, and thermal energy harvesting. There are trade-offs between different energy management techniques, which can impact system performance and energy consumption.	Energy harvesting wireless sensor nodes can operate without the need for external power sources, reducing the maintenance and replacement costs associated with battery-powered systems.	The deployment of energy harvesting wireless sensor nodes may require specialized equipment and expertise, increasing the cost and complexity of the system.	The paper does not provide a comparative analysis of the different energy harvesting techniques & did not explore the impact of environmental factors on energy harvesting efficiency.

4	Accurate Prediction of Power Consumption in Sensor Networks	Olaf Landsiedel, Klaus Wehrle, Stefan Gotz	2014	A model-based approach for predicting power consumption in sensor nodes using a combination of analytical and empirical models	This approach outperformed other existing approaches in terms of accuracy & has potential applications in optimizing energy consumption in sensor networks and predicting battery life.	Accurate prediction of power consumption can help extend the battery life of sensor nodes, reducing maintenance and replacement costs.	Accurate power consumption prediction may require significant computational resources, which can increase the cost and complexity of the system.	Identified some limitations of the approach, such as the need for accurate models of sensor and environmental parameter and the assumption of static network topologies.
5	An Efficient Data Model for Energy Prediction using Wireless Sensors	Michel Chammas, Abdallah Makhoul, and Jacques Demerjian	2019	A data model consisting of three components: weather module, occupancy module, and appliance module.	Existing data model accurately predicts energy consumption in a building by taking into account weather conditions, occupancy patterns, and appliance usage	Wireless sensors can communicate with each other to create a mesh network, which can cover large areas and provide redundant data, improving reliability and fault tolerance.	The data collected from wireless sensors may be subject to security risks, such as hacking or unauthorized access, which can compromise the privacy and integrity of the data.	Previous studies have not considered all factors that affect energy consumption in a building
6	Energy Efficient-based Sensor Data Prediction using Deep Concatenate MLP	Made Adi Paramartha Putra, Ade Pitra Hermawan	2021	A deep learning-based solution for energy-efficient sensor data prediction.	Observed that energy conservation is crucial, and developing energy-efficient models for sensor data prediction is challenging.	Deep Concatenate MLP can accurately predict sensor data, enabling more effective energy management and optimization.	The accuracy of Deep Concatenate MLP may degrade over time as the sensor network and its components age or experience wear and tear.	Existing models either consume too much energy or have low accuracy, which limits their effectiveness.

Table: Summary of research paper

Proposed work

The literature survey was conducted on the paper above in the tables & also on the paper mentioned in the references. There was gap between them the existing systems not much research is done in field of deep learning for the energy prediction of sensor nodes hence, we proposed this system which is based on artificial neural network. This survey will be useful for researchers and practitioners working in the field of WSNs as well as for those interested in the intersection of deep learning and energy efficiency. This approach can assist researchers and engineers in developing energy-efficient WSNs, ensuring their sustainability. Moreover, the proposed method can be applied in a variety of applications such as energy-efficient routing and adaptive power management in WSNs. The study provides valuable insights into the energy consumption of the sensor nodes & opens up new avenues for developing sustainable and efficient WSNs.

Dataset

The used dataset contains different variables of weather information (temperature, humidity, light intensity, CO_2, dust and energy consumption. It was collected from an indoor smart home sensor of a building. The data was recorded every 30 seconds for 31 days, including the everyday energy consumption.

The data was split using scikit learn into training set and testing set. It creates a balanced split using a maximum dissimilarity approach. The dataset was tested on several scenarios by using all the features or by omitting some of them.

Dataset variables:

1. Temperature of whole day
2. Humidity of the air in room
3. Light intensity projected on the sensor node
4. CO_2 availability in air
5. Dust present in room
6. Energy consumption of the sensor node in each interval

Non-Linear activation function

We used the Rectified Linear Unit (ReLU) activation to achieve non-linearity. The function is used on the output of each neuron. It works by rectifying the input to 0 when $y <= 0$ or by preserving the signal when it is positive.

$$\text{ReLU} = f(y) = \max(0, y)$$

The ReLU activation function is simple in terms of computation. It solves the vanishing gradient problem, and works better than sigmoid and other activation functions. ReLU is considered the most recommended activation function for feed forward neural networks, as it helps to generalize a variety of non-linear data.

Linear activation function:

Linear activation function is a mathematical function that is used in the output layer of a neural network for regression tasks. It simply applies a linear transformation to the input value, which means that the output is proportional to the input.

Y = Activation function (∑ (weights*input + bias))

the linear activation function is used to predict the continuous values of energy consumption, which can vary over a wide range of values. By using a linear activation function in the output layer, the model can output any real number as the predicted energy consumption value.

Mean Squared Error:

The MSE loss function calculates the difference between the predicted values and the actual values, squares the difference, and then takes the average of all the squared differences. The result is a single number that represents the average squared difference between the predicted and actual values.

The formula for MSE is:

$$MSE = (1/n) * \sum (y - y')^2$$

where y is the actual output value, y' is the predicted output value, and n is the number of data points. The MSE loss function measures how well the model predicts the energy consumption values. A lower MSE value indicates that the model is better at predicting the energy consumption values and has learned the underlying patterns in the data more accurately.

Adam optimiser:

Adam (Adaptive Moment Estimation) is a stochastic gradient descent optimization algorithm that is widely used in deep learning. It is a type of optimization algorithm that is used to update the weights and biases of a neural network during training. The Adam optimizer adjusts the learning rate of the gradient descent algorithm based on the gradient values of the individual parameters. This allows it to learn quickly during the initial stages of training and then gradually decrease the learning rate as the training progresses and the optimal values of the weights and biases are approached.

```
model.compile(optimizer='adam', loss='mean_squared_error')
```

SYSTEM DESCRIPTION:

The Proposed system is built using a deep learning model with a multi-layer neural network that is trained on a dataset of sensor readings including temperature, humidity, CO2, dust, light intensity, and energy consumption. Pandas is used to load and manipulate the sensor data from the CSV file. The standard scalar function from scikit learn is used to standardize the input data. The goal of the model is to predict the energy consumption of the sensor node based on these readings. The deep learning model is built using the Keras API, which is built on top of TensorFlow & creates a feedforward neural network. The architecture of the model includes three fully connected layers.

The model architecture consists of three fully connected layers, with the first two layers using the ReLU activation function and a dropout rate of 0.2 to prevent overfitting. The output layer uses a linear activation function to predict the energy consumption. The input layer is composed of six nodes corresponding to the six sensor readings. The hidden layer has 12 nodes, which allow for the complex mapping of inputs to outputs. The output layer consists of a single node that outputs the predicted energy consumption. The model is trained using the fit function and evaluated on the basic of mean squared error loss function and the gradient descent optimization algorithm. The training data is split into a training set and a validation set to prevent overfitting. The model is trained for 2000 epochs with a batch size of 500 with the weights being updated at each epoch using backpropagation algorithm. After the model is trained, it is evaluated using the mean squared error & mean absolute metric to determine its accuracy. The predicted energy consumption is compared with actual energy consumption to evaluate the accuracy of the model.

ARCHITECTURE DIAGRAM

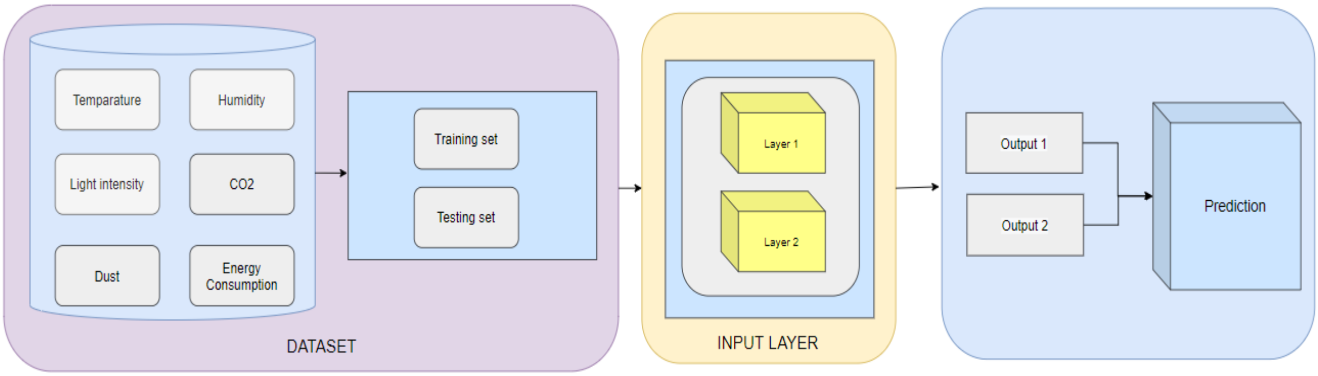

figure 1: Architecture diagram of the proposed system

RESULT IN THE FORM OF GRAPH:

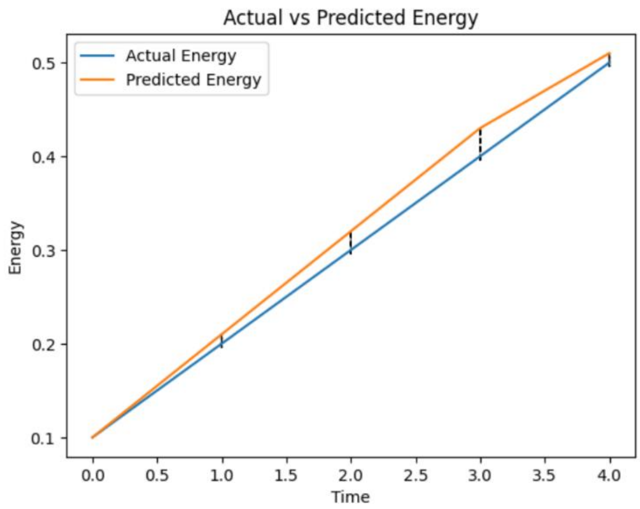

figure 2: energy vs time graph

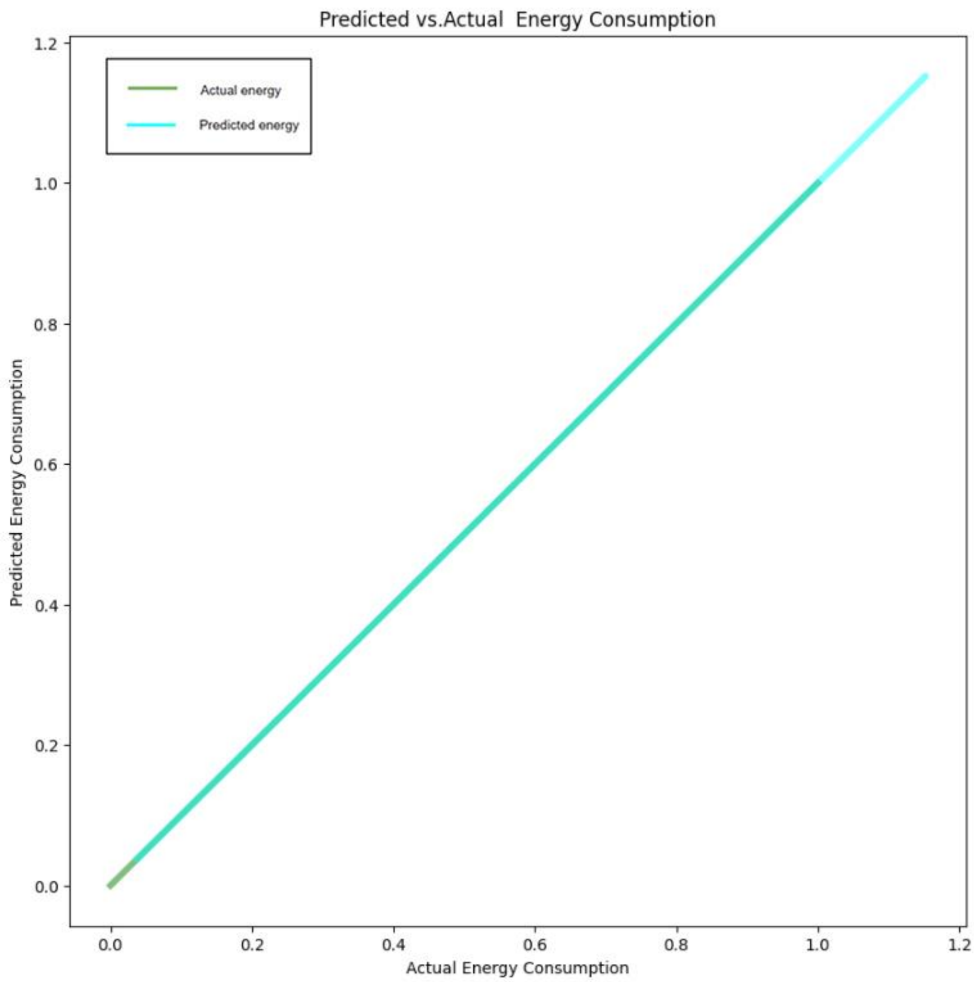

figure 3: predicted energy vs actual energy consumption with data points

L	DropOut	Epochs	Batch size	MSE	MAE
1	Yes	100	64	0.34	0.43
2	No`	100	64	0.39	0.55
3	Yes	500	64	0.30	0.39
4	Yes	500	128	0.281	0.37
5	Yes	1000	64	0.26	0.35
6	Yes	1000	128	0.256	0.32
7	Yes	1000	200	0.22	0.29
8	Yes	2000	128	0.19	0.25
9	Yes	2000	256	0.15	0.23
10	Yes	2000	500	0.13	0.20

The proposed deep learning model was able to accurately predict the energy consumption of sensor nodes with a Mean Squared Error of 0.13 & a Mean Absolute Error 0.20. The model was trained on a dataset containing sensor data such as temperature, humidity, CO2, dust, light intensity, and energy conversion values for 2000 epochs with a batch of 500. The dataset was pre-processed by normalizing the data to improve model performance with standard scaler. The deep learning model was implemented using the Keras library in Python, which allowed for easy model building and training.

The evaluation of the model was done by plotting the actual energy consumption values against the predicted values. The plot showed a strong positive correlation between the actual and predicted values (Figure 2 & Figure 3), indicating that the model was able to capture the underlying patterns in the data accurately.

CONCLUSION

The proposed deep learning model shows better solution for accurately predicting the energy consumption of sensor nodes. The model can be used in real-world applications to optimize energy usage and reduce costs. It utilizes the power of deep learning specifically a multi-layer perceptron neural network, to capture complex patterns and relationships in sensor data. This enables more accurate and precise energy predictions compared to traditional statistical or machine learning models used in the past. The utilization of various data pre-processing techniques, such as scaling and feature engineering, ensures that the input data is appropriately transformed and optimized for model training. This leads to better performance and enhanced predictive capabilities. Additionally, the advanced concepts like dropout regularization helps in mitigating overfitting, which is a common challenge in energy prediction tasks. By reducing the model's reliance on specific features, dropout regularization improves the model's generalization and robustness when applied to unseen sensor data. Moreover, our model benefits from a comprehensive evaluation process including metrics like mean squared error, mean absolute error, and mean absolute percentage error. These metrics provide an understanding of the model's accuracy, allowing for a more reliable assessment of its performance. Overall, by using deep learning, including advanced strategies to handle common difficulties. Our model exceeds earlier approaches for energy prediction of sensor nodes.

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