FORECASTING SOLAR RADIATION IN BRAZILIAN CITIES USING A UNIFIED MULTILAYER PERCEPTRON MODEL

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Abstract: This comprehensive study investigates the utility of a unified Multilayer Perceptron (MLP) for 1-hour solar radiation forecasting in four significant Brazilian cities: Brasília, Salvador, Manaus, and Porto Alegre. The study's diverse geographical locations ensure a comprehensive evaluation of the MLP model's predictive performance under varying climatic conditions. The unified MLP model exhibited successful performance across all cities, showcasing its adaptability and versatility, with an average MAE of 174.59, Pearson correlation above 0.92, and R^2 above 0.8. These results offer valuable insights for integrating advanced AI techniques into renewable energy applications, contributing to the sustainable development of solar energy systems.

Keywords: MLP, Brazil, Radiation, Solar, AI.

PREVISÃO DE RADIAÇÃO SOLAR EM CIDADES BRASILEIRAS UTILIZANDO UM MODELO UNIFICADO DE PERCEPTRON MULTICAMADAS

Resumo: Este estudo investiga a utilidade de um Perceptron Multicamadas (MLP) unificado para previsão de radiação solar de 1 hora em quatro importantes cidades brasileiras: Brasília, Salvador, Manaus e Porto Alegre. As diversas localizações geográficas do estudo garantem uma avaliação abrangente do desempenho preditivo do modelo MLP sob condições climáticas variadas. O modelo MLP unificado apresentou desempenho bem-sucedido em todas as cidades, destacando sua adaptabilidade e versatilidade, com um erro médio absoluto de 174,59, correlação de Pearson acima de 0,92 e R^2 acima de 0,8. Esses resultados oferecem informações valiosas para a integração de técnicas avançadas de IA em aplicações de energia renovável, contribuindo para o desenvolvimento sustentável de energia solar.

Palavras-chave: MLP, Brasil, Radiação, Solar, IA.

1. INTRODUCTION

The geographical location and extensive sunlight make Brazil a prominent player in the generation of solar energy [1]. However, the chief component, solar radiation, exhibits high variability and is largely dependent on weather conditions, [2] leading to a demand for accurate predictions to enhance the efficiency of solar energy systems [3].

The emergence of AI technologies, specifically deep learning, provides powerful tools for environmental predictions [4]. The Multilayer Perceptron (MLP), a feedforward artificial neural network, has been appreciated for its capabilities in pattern recognition and data interpretation [5]. This study leverages a unified MLP model to predict solar radiation in four distinct Brazilian cities, using weather forecast data spanning more than two decades.

Considering Brazil's geographical diversity, the adaptability of a unified model is of paramount importance. With this study, we examine the potential of a single MLP model to generalize and accurately predict solar radiation across diverse climates and multiple seasons. Brazil's climate varies significantly from equatorial in the north (Manaus) [6] to subtropical in the south (Porto Alegre) [7], while Brasília has a tropical climate [8], and Salvador experiences a humid tropical climate [9]. This study's findings will further help optimize the use of solar energy in these cities, contributing significantly to Brazil's renewable energy sector.

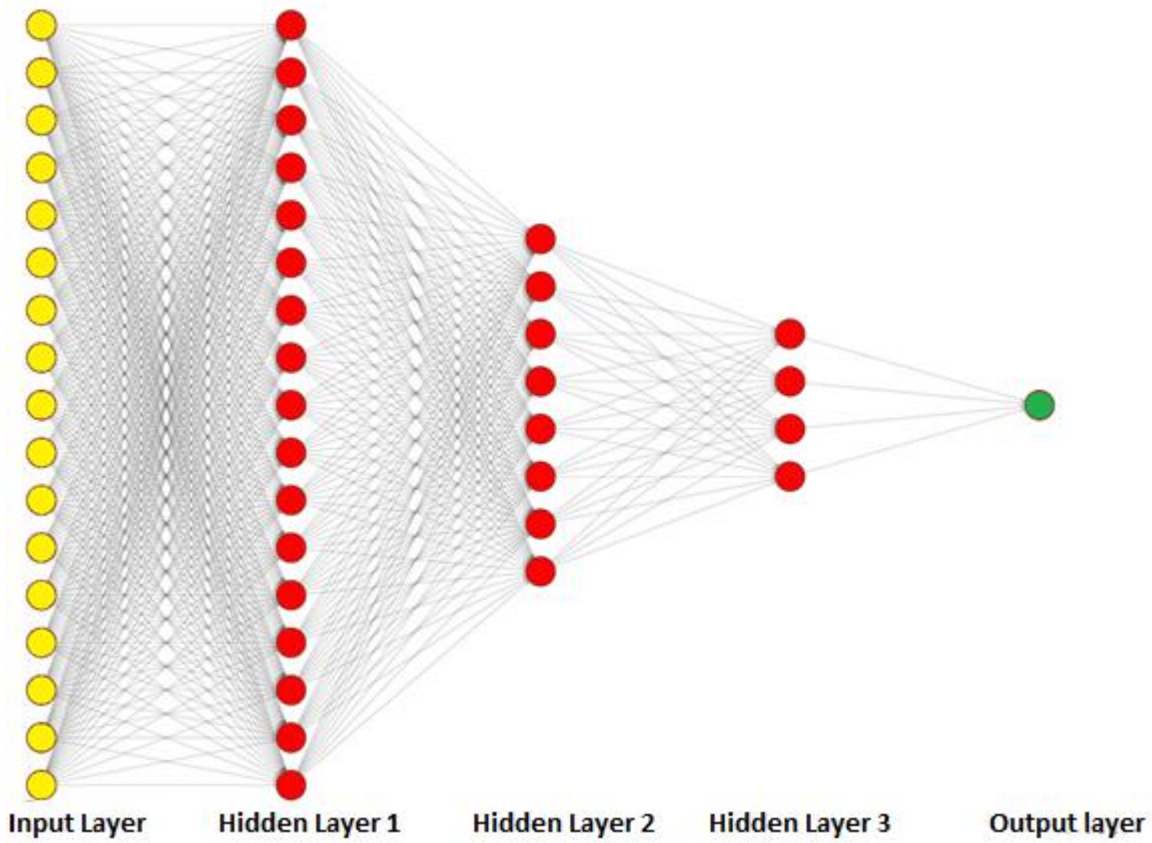
2. METHODOLOGY

The research adhered to a systematic process involving data collection from INMET stations (*Instituto Nacional de Meteorologia*), pre-processing, model development, training, and evaluation [10]. We compiled data sets from Brasilia, Salvador, Manaus, and Porto Alegre from 2000 to 2021, containing variables like temperature, humidity, total precipitation, atmospheric pressure, wind speed, latitude, longitude, and altitude, along with corresponding solar radiation.

The data pre-processing phase involved crucial steps of data cleaning, normalization, and partitioning to prepare the data for the MLP model. MLP's ability to detect patterns in high-dimensional data renders it an apt candidate for predicting solar radiation from weather forecast data [11].

We built a unified MLP model using Python and TensorFlow, a renowned machine learning library [12]. This model has 17 inputs, 3 hidden layers (17,8,4 neurons respectively) and 1 output layer with 1 single neuron (Figure 1). The model was trained using data from 2000 to 2021 and then tested on data from 2022 to 2023. A separate validation subset was used to guard against overfitting, a common pitfall in machine learning applications.

Figure 1. MLP Model Layers



Performance evaluation of the model was done using Mean Absolute Error (MAE), a popular metric in regression problems, to quantify the model's accuracy [13]. The use of the MAE loss provides a straightforward interpretation of the model's performance, as it represents the average magnitude of prediction errors.

3. RESULTS AND DISCUSSION

The unified MLP model yielded satisfactory results, predicting solar radiation for all four Brazilian cities. It surpassed traditional machine learning models, such as Linear Regression and Polynomial Regression, in performance [14]. However, the model's performance was heavily influenced by the quality and volume of the input data, underlining the importance of enhancing data collection and pre-processing techniques [15].

Furthermore, the model demonstrated a successful interpretation of diverse climatic patterns across the four cities, suggesting MLP's potential for predicting solar radiation across different geographical regions [16]. These findings can have meaningful implications for the adaptability of MLP models in varied environmental contexts and provide insights into the potential for scaling such models.

The study's results, indicating the efficiency of the MLP model, can be particularly useful for entities invested in harnessing solar energy. With improved forecasting of solar radiation, planning and resource allocation can be optimized, leading to improved output and cost-effectiveness.

Table 1. Metrics of all cities between 2022 and 2023

	MAE	MSE	NRMSE	Pearson	R2	Fac 2
Brasilia	171.5451	342.2257	0.0797	0.9520	0.9027	0.3867
Manaus	192.7395	379.0038	0.0975	0.9204	0.8130	0.3504
Salvador	171.8042	338.8286	0.0806	0.9494	0.8998	0.3874
Porto Alegre	162.2792	316.1087	0.0793	0.9520	0.9039	0.3545

In Figures 2-5, the solar radiation forecast for each of the four cities is visually represented in 3 different seasons for the years 2022 and 2023. The comparison of actual (orange) versus predicted (blue) values illustrates the MLP model's accuracy in capturing the temporal variations in solar radiation. The trend lines in these graphical representations indicate a close match between the MLP's predicted values and the actual data, supporting the effectiveness of our model.

Figure 2. Brasilia - Station A001

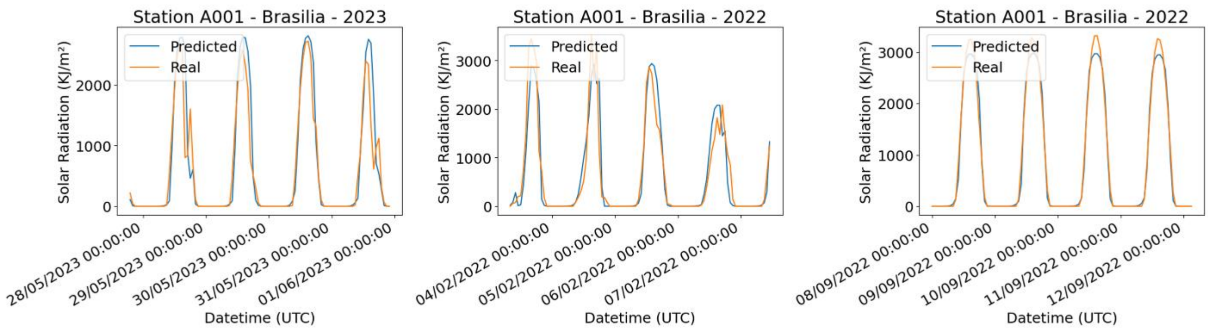


Figure 3. Manaus - Station A101

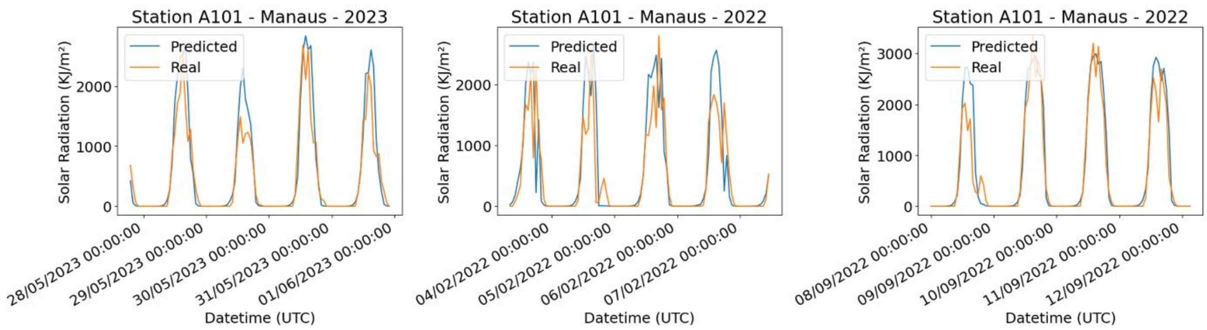


Figure 4. Salvador - Station A401

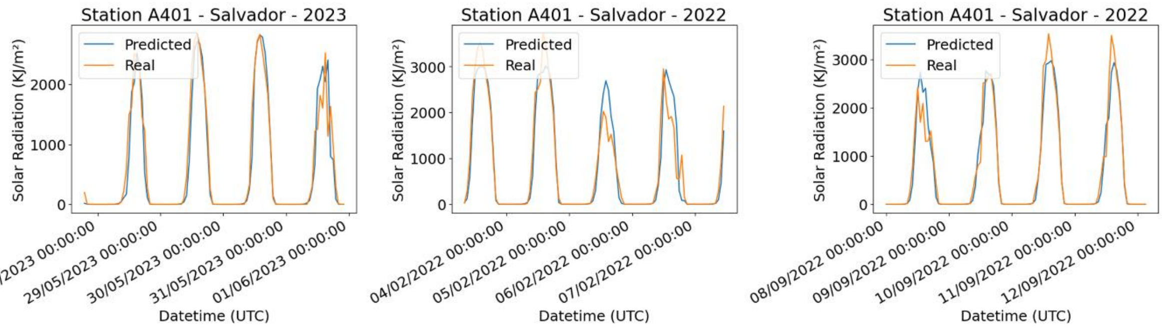
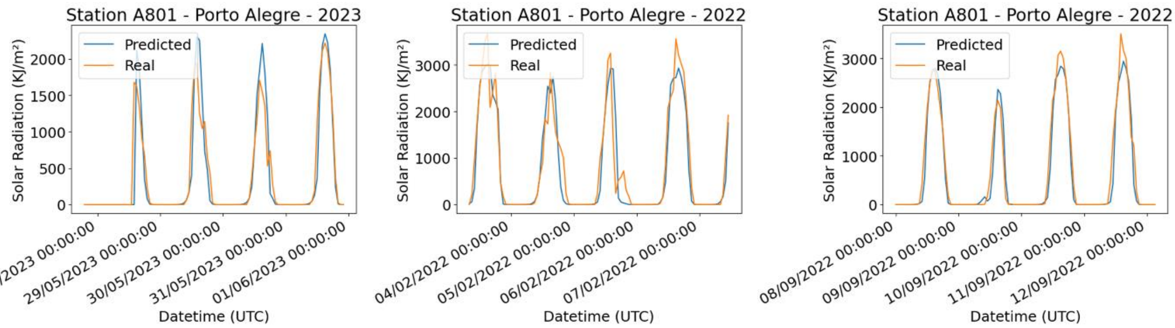


Figure 5. Porto Alegre - Station A801



The study's results, indicating the efficiency of the MLP model, can be particularly useful for entities invested in harnessing solar energy. With improved forecasting of solar radiation, planning and resource allocation can be optimized, leading to improved output and cost-effectiveness. Furthermore, the consistency of results across different cities and years bolsters the robustness of the MLP model in handling diverse and dynamic weather patterns.

4. CONCLUSION

This study's application of a unified Multilayer Perceptron to predict solar radiation 1 hour ahead across Brasilia, Salvador, Manaus, and Porto Alegre showcases the immense potential of AI, particularly deep learning models, in the renewable energy domain. Our research adds to the growing body of knowledge about AI's application in environmental modeling and lays the groundwork for future research, which could include integrating MLPs with other deep learning models for enhanced prediction accuracy.

On a practical level, implementing the MLP model in real time can significantly boost the efficiency of solar energy harvesting, thereby profoundly impacting the renewable energy sector in Brazil and around the globe [16]. Given the world's urgent need for reliable and sustainable energy sources, this study's findings could contribute significantly to the efforts to tap into the full potential of solar energy.

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