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Research Article

Development of a solar radiation prediction model using Fine Gaussian SVM in machine learning

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Abstract **–** The global transition toward renewable and clean energy sources is imperative for sustainable development and for reducing the adverse environmental effects associated with fossil fuel use. Among renewable options, solar energy is one of the most promising due to its abundance, scalability, and minimal environmental impact. Effective utilization of solar energy in each region requires a comprehensive understanding of solar radiation components, particularly diffuse radiation, which significantly influences the performance of solar energy systems. Moreover, accurate estimation of solar radiation is essential for climate change research, a critical area of global scientific inquiry. Currently, satellite-based solar radiation forecasting systems offer high spatial and temporal resolution data, including global, direct, and diffuse radiation components, making them valuable tools for the planning and optimization of solar power systems. In this study, satellite-based forecasting models were utilized to estimate diffuse solar radiation for the selected region. To enhance prediction accuracy, a Fine Gaussian Support Vector Machine (SVM) algorithm was employed to model solar irradiance based on key meteorological and geographical inputs. Additionally, the Ångström coefficients were determined using MATLAB to support the development of the predictive model. The performance of the proposed model was evaluated using various statistical error metrics, including root mean square error (RMSE), mean absolute error (MAE), and coefficient of determination (R^2). The results indicate that the Fine Gaussian SVM model provides highly accurate predictions of diffuse solar radiation, demonstrating its effectiveness for solar resource assessment and planning.

Keywords – Solar Energy, Solar Radiation, Statistical Error Tests, Fine Gaussian SVM.

I. INTRODUCTION

The growing energy demand driven by population growth, depletion of fossil fuel resources, and technological advancement has intensified the need for alternative energy sources. Among them, the Sun stands as the primary and most abundant source of energy on Earth. Solar energy is transmitted through space as electromagnetic radiation, and the amount that reaches the Earth's surface depends on factors such as the Earth's geometry, extra-atmospheric solar radiation, and atmospheric conditions. For accurate analysis and design of solar energy systems in any location, precise estimation of global solar radiation and its components is essential. Global solar radiation at the Earth's surface comprises two key ingredients: direct and diffuse radiation, both of which can be measured as outlined in [1]. Solar energy technologies represent renewable, clean, and locally available sources of energy, making them a crucial element in the transition toward sustainable energy systems. Turkey, located within the medium solar belt, receives approximately 2,640 hours of sunshine annually, with an average daily solar energy density of 3.6 kWh/m². The country's total gross solar energy potential is estimated at 8.8 million tons of oil equivalent (MTEP). Regional variations exist, with the highest annual total solar radiation observed in Southeast Anatolia—reaching up to 1,460 kWh/m² over 2,999 hours—and the lowest in the Black Sea region, with 1,120 kWh/m² over 1,971 hours annually [2]. Given the limited availability of solar radiation data from weather stations, the use of solar radiation models has become a common approach for estimating the required data in such cases. Empirical models are widely employed to predict global solar radiation by incorporating various meteorological and geographical parameters. These parameters typically include extraterrestrial radiation, sunshine duration, air temperature, soil temperature, relative humidity, number of wet days, altitude, latitude, longitude, total precipitation, cloud cover, and evaporation, as discussed in [3]–[5].

In this study, a predictive model for estimating solar radiation was developed using the Fine Gaussian Support Vector Machine (SVM) algorithm. The city of Adana, located in southern Turkey, was selected as the study area due to its high solar energy potential. The geographical characteristics of the region, including latitude, longitude, and elevation, are presented in Table 1. Hourly wind speed data for one year were obtained from the Turkish State Meteorological Service. These data, along with other relevant meteorological parameters, were used as inputs to train and validate the Fine Gaussian SVM model for accurate solar radiation estimation.

Table 1. Geographical coordinates of the study area

Variable	Value
Latitude	36,99 ° N
Longitude	35,33 ° E
The level of the sea	28 m
Measurement height	10 m

II. MATERIALS AND METHOD

A. *The Fine Gaussian SVM*

Support Vector Machines (SVMs) are commonly used to tackle binary classification tasks across a wide range of research domains, such as natural language processing, speech and speaker recognition, and computer vision. They function by determining the optimal hyperplane within the feature space that best separates data points from different classes, effectively serving as a decision boundary. The Fine Gaussian SVM is a variant of the SVM that uses the radial basis function (RBF) kernel, also known as the Gaussian kernel. The term *"fine"* refers to the use of a small kernel scale (σ), which enables the model to capture fine-grained patterns in the data by allowing more flexibility in the decision boundary.

When a dataset is not linearly separable, Support Vector Machines (SVMs) utilize various kernel functions to transform the data into a higher-dimensional space, where a clear decision boundary (optimal hyperplane) can be established between different classes. These kernel functions essentially act as similarity measures between feature vectors $'x'$ and their corresponding class labels $'y'$. Among them, Gaussian kernels well-suited for handling time-series data. The Gaussian kernel is mathematically defined as shown in the equation below [6].

$$K(x_i, x_j) = \exp\left(\frac{-1}{2\sigma^2} \|x_i - x\_j\|^2\right)$$

Let x represent a data point, and i and j denote the indices of the features in the dataset, while σ stands for the standard deviation. For all classification experiments, the parameters γ and C are fixed at 1 and 0.01, respectively.

In this research, Fine Gaussian SVM was employed to predict solar radiation using input features like sunshine duration, temperature, and various other meteorological factors. Its strength in modeling nonlinear patterns made it well-suited for capturing the intricate relationships that affect solar radiation fluctuations.

B. *Performance Measurements*

The performance of the Fine Gaussian SVM is evaluated using three statistical performance indicators such as Sum of Squared Relative Errors (SSRE), Coefficient of Determination (R^2), and the t-statistic (t-stat)

SSRE quantifies the total squared error between predicted and actual values, relative to the actual values. It's especially useful for regression tasks like predicting solar radiation. Its expression given by:

$$SSRE = \sum_{1}^{n} \left(\frac{y_i - \widehat{y_i}}{y_i}\right)^2$$

where y_i, $\widehat{y_i}$, and *n* are actual value, predicted value by Fine Gaussian SVM, number of data points, respectively.

R^2 measures how much variance in the dependent variable (e.g., solar radiation) is explained by the independent variables (e.g., sunshine, temperature) via the model. It is calculated by:

$$R^2 = 1 - \frac{\sum_1^n (y_i - \widehat{y_i})^2}{\sum_1^n (y_i - \bar{y})^2}$$

where $\bar{y}$ is mean actual value. Values range from 0 to 1, where 1 means perfect prediction.

The t-statistic tests whether a model's parameter (or feature contribution) is significantly different from zero, often used in regression. It is calculated as follows:

$$t = \frac{\widehat{\beta_J}}{SE\ (\widehat{\beta_J})}$$

Where $\widehat{\beta_J}$ is estimated coefficient and $SE\ (\widehat{\beta_J})$ is standard error of the coefficient.

III. RESULTS AND DISCUSSION

In this study, one year of sunshine duration data and monthly average daily solar radiation on a horizontal surface were utilized for the selected region. The measured solar radiation data were obtained from the General Directorate of State Meteorology. The performance of the developed model is illustrated in Figure 1, which presents a graphical comparison of observed and estimated solar radiation values.

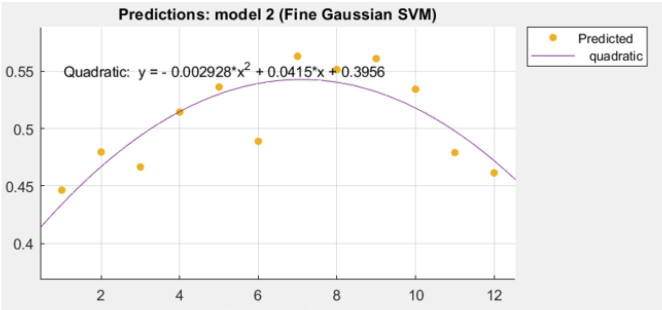

Fig. 1 The graph of the developed model by using Fine Gaussian SVM

Three different statistical error analysis tests were employed to evaluate the accuracy and reliability of the newly developed model. The results indicate a high level of agreement between the estimated and observed values. The model's performance metrics are as follows:

- **Sum of Squared Relative Errors (SSRE):** 0.46757
- **Coefficient of Determination (R^2):** 0.98975
- **t-statistic (t-stat):** 4.024

These results demonstrate that the model provides highly accurate predictions of solar radiation for the selected region.

IV. CONCLUSION

In this study, a novel approach was implemented to estimate solar radiation for the selected region using satellite-based data. The model's performance was assessed using three distinct statistical error metrics, demonstrating high predictive accuracy. The findings suggest that accurate satellite-based forecasting methods can effectively estimate both global and diffuse solar radiation across the country. The developed model contributes to the growing body of literature and offers a valuable tool for assessing regional solar energy potential. As the accurate determination of solar radiation remains a critical focus in renewable energy research, this study provides a foundation for future work aimed at optimizing solar resource assessment and planning.

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