Reactor Power Generation Prediction using SVR based on Cherenkov Effect

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1. Introduction

Nuclear power generation is a critical source of energy in many countries, and its efficient and stable operation is essential for safety and cost-effectiveness. Therefore, accurate prediction of nuclear power generation is of utmost importance. The Cherenkov phenomenon, characterized by an emerald blue glow observed in nuclear reactors generating power or storing spent fuel rods, arises from high-speed electrons colliding with dielectric media like water molecules at velocities exceeding the speed of light, generating a characteristic wavelength. Interestingly, the intensity of this blue light is directly proportional to the reactor's power output, thus establishing a linear relationship between the two parameters [1]. Leveraging this relationship, we have devised an innovative algorithm employing regression artificial intelligence techniques to predict reactor power using RGB color system values, as well as HSV and YUV color system values, extracted from video data of the HANARO reactor.

2. Methods and Results

The present section delineates the stepwise procedure employed to estimate the power of a nuclear reactor by leveraging the Cherenkov effect and artificial intelligence. The algorithm incorporates diverse stages, such as extracting color features, creating a database, training the support vector regression model, and ultimately predicting the reactor's power output.

2.1 Color Feature Extraction

To extract color features, we initially acquire images of the HANARO reactor with a resolution of 1920 x 1080 pixels, and the video is split into frames captured at a rate of 1 FPS. Each frame is processed by applying Eq. 1 to its RGB values, where pixels with blue values above a certain threshold are retained, and those below the threshold are set to 0.

$$\sum_{0}^{1920}\sum_{0}^{1080} P(r,g,b) = \begin{cases} P(r,g,b) & P(b) > T \\ P(0,0,0) & P(b) < T \end{cases} \qquad (1)$$

The retained pixels with the blue values above the threshold are then subjected to a summation of their R, G, and B values, which are averaged to generate a single feature value. This average value, which serves as input to the SVR, is derived by computing the average of the three R, G, and B values.

2.2 Database Construction

To facilitate our analysis, we built a comprehensive database incorporating RGB values, extracted as described in Section 2.1, as the 3-channel input data, and Power, denoting the power output of the reactor at each instance, as the 1-channel output data for the SVR. Additionally, we constructed similar databases using the HSV and YUV color systems, following the same method applied for extracting RGB data.

Figure 1 illustrates the variation in RGB values corresponding to the input factors utilized in the database, while Figure 2 depicts the distribution of Power values in the dataset.

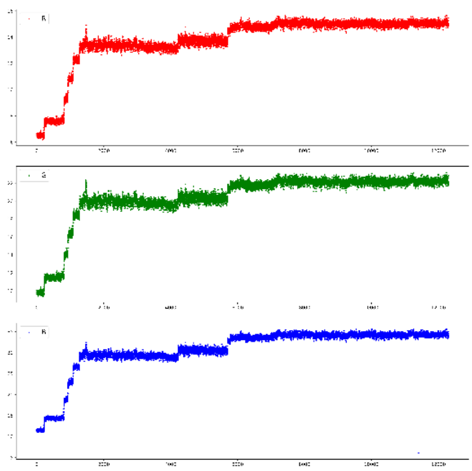

Fig. 1. Plot of RGB values over time.

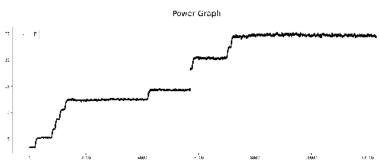

Fig. 2. Plot of Power values over time.

2.2 support vector regression

Support Vector Regression (SVR) is a variant of Support Vector Machine (SVM) that is used in regression analysis to predict continuous values. SVR is typically applied to high-dimensional data and offers significant advantages in regression analysis [2-3].

The objective of SVR is to find the hyperplane that best represents the input data. Unlike SVM, which is used to classify input data, SVR uses the hyperplane to predict input data. SVR finds a hyperplane that minimizes the difference between the actual value and the predicted value of the input data. To prevent overfitting, SVR typically includes a regularization term in the optimization problem. The regularization term limits the complexity of the hyperplane and reduces the complexity of the model. SVR is commonly used in various fields for regression analysis, especially in time-series data analysis. SVR performs well in processing high-dimensional data and has the ability to handle nonlinear problems [4].

The algorithm utilized a Support Vector Regression Model that employs 3 channels of inputs and 1 channel of output. The model was configured with a linear kernel, a penalty parameter of 1, and an epsilon value of 0.1. For the purpose of training and testing the model, 80% of the entire dataset was allocated for training, while the remaining 20% was used for testing.

2.3 Result

The algorithm employed SVR to input the RGB value of the video and predict the corresponding power output, which was then compared with the actual power output. Furthermore, the power output of the reactor was predicted by inputting HSV and YUV values, which are alternative color systems to RGB. The results of the Support Vector Regression test indicated that the mean error rates were 6.37% when RGB values were used, 3.15% when HSV values were used, and 6.27% when YUV values were used, as indicated in Table 1. Figure 3 illustrates the predicted power output through the SVR algorithm.

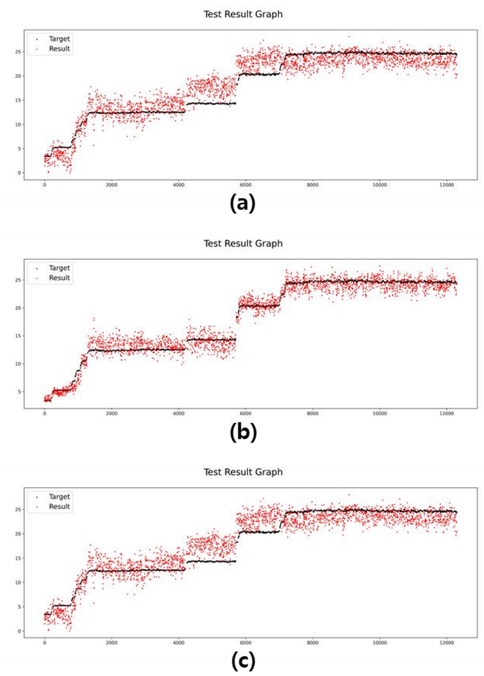

Fig. 3. Support Vector Regression result plot (a) RGB (b) HSV (c) YUV

Table I: Mean error rate of Support Vector Regression

	RGB	HSV	YUV
Error(%)	6.37	3.15	6.27

The findings of our study demonstrate a relatively high error rate in predicting the output of a simple reactor using SVR. As our research advances, it would be more advantageous to utilize Long Short-Term Memory (LSTM) [5] or Transformer [6] algorithms, which forecast output based on time series data, to enhance prediction accuracy.

3. Conclusions

Prediction of reactor power based on the Cherenkov effect using artificial intelligence can serve as a valuable tool for nuclear power plant operators to gain insights into the reactor's condition. This system is expected to complement existing methods, enabling more precise and accurate reactor power predictions.

ACKNOWLEDGMENTS

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