

VIET NAM NATIONAL UNIVERSITY, HA NOI
CENTRAL INSTITUTE FOR NATURAL RESOURCE AND ENVIRONMENTAL STUDIES

Proceedings of the International conference on OCCUPATIONAL SAFETY, HEALTH AND ENVIRONMENT

INTERNATIONAL CONFERENCE

The first Occupational Safety, Health and Environment (OSHE)

Hanoi, Vietnam October 24-26, 2024



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Application of the PSO-SVR artificial intelligence model to predict air temperature in the blasting coal longwall at NamMau coal mine

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Abstract: With the development of Vietnam's economy, the demand for coal energy is increasing. Meanwhile, the resource reserves in the shallow parts are diminishing, leading to increasing mining depths in coal mines. Therefore, deep mining activities cause an increase in air temperature in underground coal mines. This results in deteriorating microclimatic conditions, particularly with a tendency for temperatures in mining areas to rise and exceed 30°C. According to the QCVN01:2011/BCT standard, mine air temperature should not exceed 30°C. Thus, this becomes a major issue affecting not only the mining process but also negatively impacting workers' health. Therefore, it is essential to accurately forecast air temperature in blasting coal longwalls to optimize solutions for improving the thermal environment in current underground mines. In this study, the temperature in underground mining areas has been forecasted using artificial intelligence models based on SVR and the PSO optimization algorithm. The SVR model is designed to forecast temperature and the PSO optimization algorithm is used to optimize the parameters of the SVR model to improve the accuracy of the traditional SVR model. The results of the paper show that the developed models can forecast mine air temperature with high accuracy. Among them, the PSO-SVR model provides higher accuracy than the traditional SVR model (RMSE = 0.16, R^2 = 0.95, MAE = 0.12), while the traditional SVR model only offers accuracy levels of (RMSE = 0.22, R^2 = 0.91, MAE = 0.18).

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Keywords: Longwall coal blasting, underground mining, PSO-SVR model, mine air temperature.

1. Introduction

The Nam Mau coal mine is located approximately 25 km north of Uong Bi city. The mine is opened through a pair of inclined shafts at levels +125/-200. The primary coal extraction method involves drilling and blasting. Ventilation uses the exhaust ventilation method, with two main fan stations: the 2K56-N018 fan station located at level +210 and the FBCDZ-10-N03.5 fan station located at level +279, providing the required clean airflow to the consumption points. However, as mining operations go deeper, the microclimatic conditions at the Nam Mau coal mine become increasingly severe, affecting the workers. One of the most important parameters related to the underground mine's microclimate is temperature [1]. According to QCVN01:2011/BCT, the temperature in underground mines must not exceed 30°C[2]. This not only affects workers' concentration levels [3] but also poses a risk to occupational safety [4]. Therefore, many researchers have focused on developing models to forecast the temperature in

underground mines, with the aim of proposing optimal solutions to minimize the impact of temperature on workers. For example, a multivariate regression model has been used to predict temperature in the ventilation system [5]. Truong Tien Quan and his research team predicted the air temperature in coal faces using an Artificial Neural Network (ANN)[6]. Meanwhile, an initial model in the C++ programming language was also proposed for a deep gold mine[7]. The forecasting results of these models have not been highly accurate and have not been applied to all areas. In recent years, Artificial Intelligence (AI) has become more popular and widely applied in various engineering fields. Among these, the Support Vector Regression (SVR) model has been proven to be an effective tool for solving nonlinear regression problems. However, it has also been proven that the accuracy of the SVR model largely depends on the choice of the kernel function and three hyperparameters, including the kernel parameter, regularization constant, and the

epsilon-insensitive coefficient. Therefore, selecting the hyperparameters of SVR is a critical issue [8]. Currently, there are many popular optimization algorithms, with grid search and Genetic Algorithm (GA) [9] being the most common. However, these methods require a lot of time, space, and face various challenges in execution. Instead of using grid search and GA, Particle Swarm Optimization (PSO) is employed in this study. PSO is inspired by the social behavior of organisms such as bird flocks and fish schools. Due to its simplicity, fewer parameters, and ease of implementation [10], PSO has been successfully applied in various fields such as function optimization and neural network training. The purpose of this paper is to develop a PSO-SVR model to

predict the temperature in coal faces. PSO is used to optimize the three hyperparameters of SVR. The SVR model with optimized hyperparameters is trained and tested using a dataset of parameters that affect the temperature in underground Vietnamese mines, aiming to achieve high correlation between the measurements and predictions.

2. Study Area and Data Used

2.1. Study Area

The study area encompasses all long coal faces that use blasting technology supported by XDY, ZH and GK supports, with the explosive type being AH1, and an extraction output of 150 to 250 tons per year. The blasted coal face is illustrated in Figure 1.

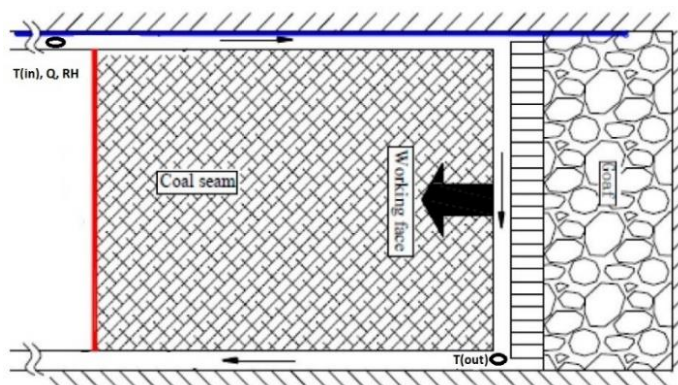


Figure1. Longwall area



2.2. The Data Used is Described as Follows

The research team collected data from sensor devices as well as actual measurements at the mine. The data was gathered from the coal faces and includes the following

parameters: input temperature in the coal face area, average air humidity, mining depth, length of the mining area, capacity of the mining equipment, airflow through the mining area, and output temperature of the coal face, as shown in Table 1.

Table 1: Summary of the Data Used in This Study

Parameter	Min.	Mean	Max.	Std
T(in)	24.6	27.09	28.4	0.73
RH	80	89.5	94.0	2.6
Q	5.4	7.23	9.18	0.84
P	115.5	129,2	140.0	10.11
A	416	564.24	698.0	78.78
D	30	40.55	50.0	7.59
L	172.54	250.53	364.0	51.91
T(out)	25.4	28.67	30	0.78

From Table 1, it can be observed that the input temperature in the coal face area T(in) ranges from 24,6°C to 28,4°C, the air humidity in the coal face RH ranges from 80% to 94%, the airflow provided to the coal face Q ranges from 5,4 to 9,18 m³/s, and the power of the electrical equipment in the coal face area P ranges from 115,5 to 140

kW. The extraction output ranges from 416 to 698 tons, the mining depth ranges from 30 to 50 m, and the length of the mining area L ranges from 172,54 to 364 m. The output temperature of the coal face area T(out) ranges from 25,4 to 30°C. The frequency distribution of the dataset in this study is shown in Figure 2.

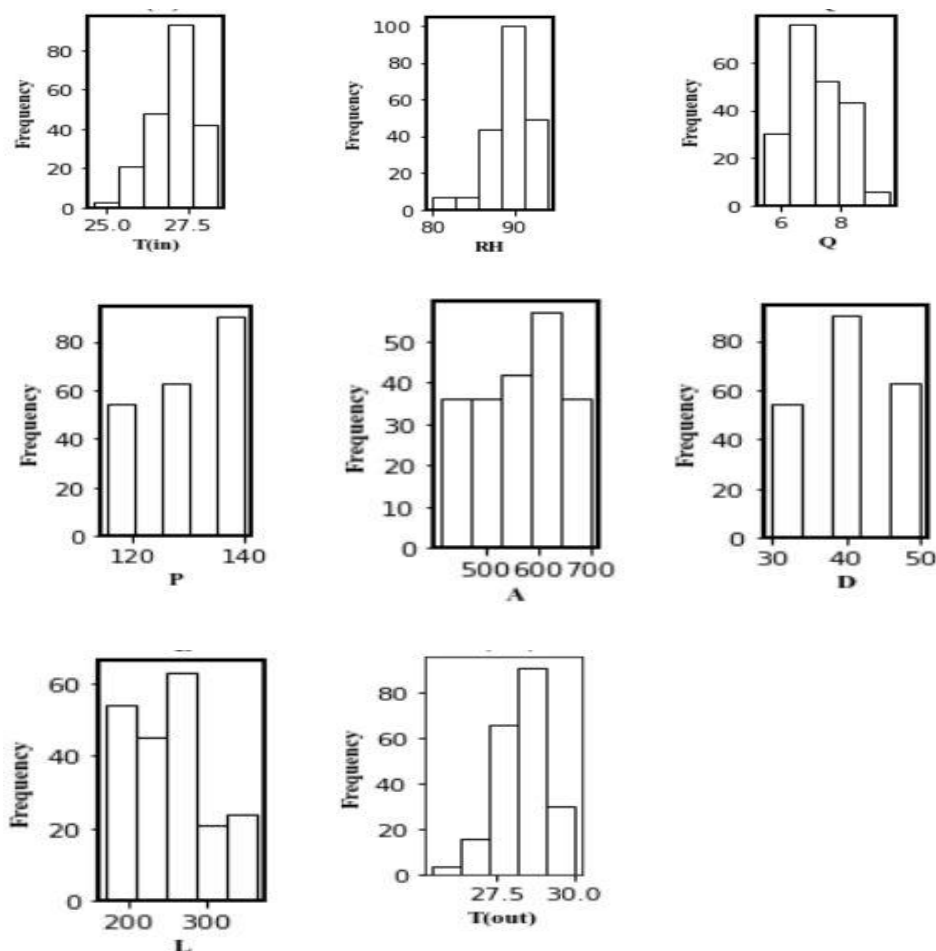


Figure 2. The frequency distribution of the dataset in this study

3. PSO-SVR Algorithm

The paper utilizes two algorithms: Support Vector Regression (SVR) and Particle Swarm Optimization (PSO). In this context, SVR is used to predict the temperature in the coal faces, while PSO is employed to optimize the parameters of SVR.

3.1 Support Vector Regression

Support Vector Regression (SVR) is a machine learning algorithm based on the principle of minimizing structural risk to improve generalization capability on a limited number of samples, as proposed by Cortes and Vapnik [11]. SVR can address both classification

and regression problems. For regression tasks, SVR relies on a subset of training data to build the predictive model. The goal of the SVR model is to estimate the function $f(x)$ with a deviation no greater than epsilon for all output values. However, the accuracy of the prediction results depends on the parameters of the SVR model, including the penalty parameter, the epsilon-insensitive loss coefficient, the kernel function, and the kernel parameters.

Penalty Parameter (C): The penalty parameter is used to represent the error margin and determine the complexity of the SVR model, which is controlled by the number of support vectors. A small penalty parameter means there is a relatively large margin, resulting in a relatively simple model.

Epsilon-Insensitive Loss Coefficient (ϵ): The epsilon-insensitive loss coefficient is used to measure the error margin of each data sample. It also controls the complexity of the model. A larger value for this parameter results in fewer support vectors and a simpler SVR model.

Kernel Function: The original feature space is mapped to a new feature space through the kernel function. Different kernel functions can produce different SVR models with varying regression functions, so changing the kernel function can lead to significant differences in the prediction results of the SVR model

Linear Kernel Function

Polynomial Kernel Function

Radial Basis Function Kernel

Here, r , d , γ , and σ are kernel parameters that can be adjusted for optimal predictive models. In summary, the selection of the penalty parameter, epsilon-insensitive loss coefficient, kernel function, and kernel parameters largely determines the quality of the SVR model, and these parameters depend on the specific data. Therefore, the PSO algorithm is used to optimize the parameters of the SVR model to minimize the prediction error of the SVR model. As a result, the SVR model for predicting the temperature in the coal face will be more accurate.

3.2. Particle Swarm Optimization Algorithm

Particle Swarm Optimization

(PSO) was proposed by Dr. Eberhart and Kennedy in 1995 [12], with the aim of simulating the foraging behavior of bird species. In the PSO description, each bird is considered a particle, and each particle represents a potential solution at its location. In each iteration, a particle adjusts its position and velocity based on its individual optimal position, the global optimal position, and its previous position. The algorithm continues to iterate until a predefined termination condition is met. We define the position of a particle at time t as $X_i(t)$. The position of particle i is represented in Equation (4) $X_i(t)$: represents a multidimensional vector, and the number of dimensions depends on the number of parameters that need to be optimized. The velocity $V_i(t+1)$ is represented in Equation (5)

$$V_i(t+1) = \omega V_i(t) + c_1 r_1(t)[pbest - X_i(t)] + c_2 r_2(t)[gbest - X_i(t)] \quad (5)$$

$V_i(t+1)$ can be initialized to 0 or a random value within a given range. ω is the inertia coefficient that describes the particle's ability to maintain its momentum. c_1 and c_2 are learning coefficients, usually

equal to 2, while $r_1(t)$ and $r_2(t)$ are random values in the range from 0 to 1. Additionally, $pbest$ represents the best position of a particle, and $gbest$ represents the best position of all particles

$$P = (C, \gamma, \delta)$$

In this paper, the data samples are divided into two parts: one part constitutes 80% of the dataset for training, and the remaining part makes up 20% for testing. The prediction error of the testing data can characterize the generalization capability of the SVR model. Therefore, we use the root mean square error (RMSE) as the fitness function to evaluate the quality of the particles. RMSE is represented in Equation (6)

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - pre_i)^2} \quad (6)$$

In the above equation, y_i represents the measured value, pre_i represents the predicted value from the SVR model, and nnn is the number of testing data samples. A smaller RMSE indicates better fitness.

4. Results and Discussion

4.1. Performance metrics for evaluating models

To evaluate the performance of forecasting models, performance indicators are used, including root-mean-square error (RMSE), coefficient of determination (R^2), and mean absolute error (MAE), which are calculated using Eqs. (7-9), respectively.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \quad (7)$$

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (8)$$

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \quad (9)$$

Where:

Y_i : the actual value of sample i ; the corresponding predicted value, $\bar{y}$: the mean of the actual values, n : the total number of samples.

4.2. Evaluating forecasting models

Based on traditional SVR forecasting models with different kernel functions and the developed

PSO-SVR model, experimental datasets were used to evaluate the performance of the models according to the formulas above. For Support Vector Regression with a linear kernel (SVR-L), the penalty coefficient C is used to improve model accuracy. The polynomial kernel model (SVR-P) adjusts the penalty coefficient C and the degree, while the RBF kernel model (SVR-RBF) adjusts the parameters C and γ . The PSO-SVR model optimizes three parameters: C , γ , and ϵ . To enhance model accuracy and avoid overfitting, ten-fold cross-validation with three repetitions was used during model development. RMSE was used to optimize the models by minimizing its value. The resulting optimal parameters were as follows: (SVR-L) with $C = 891.15$; (SVR-P) with $C = 1.67$, degree = 2; (SVR-RBF) with $C = 1000$, $\gamma = 0.1$; (PSO-SVR) with $C = 35.45$, $\gamma = 0.3$, $\epsilon = 0.08$.

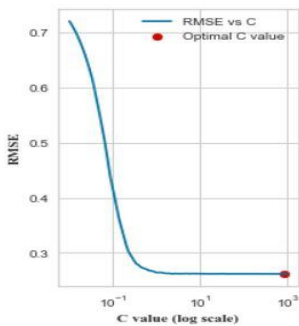


Figure 3. Model performance on training data for the SVR-L model

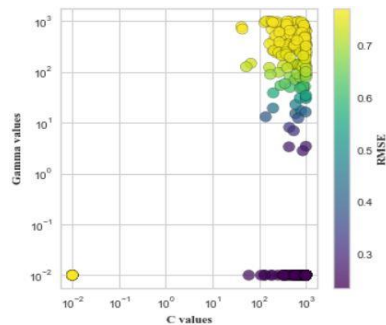


Figure 4. Model performance on training data for the SVR-P model

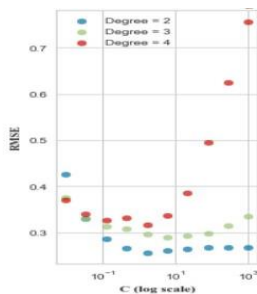


Figure 5. Model performance on training data for the SVR-RBF model

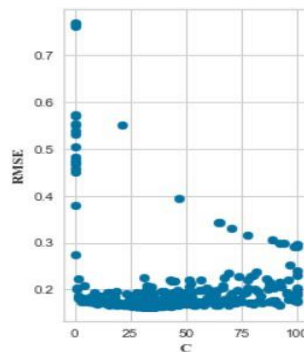


Figure 6. Model performance on training data for the PSO-SVR model

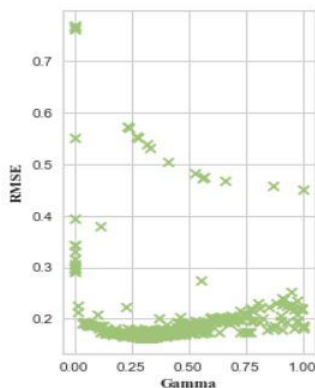


Figure 7. Model performance on training data for the PSO-SVR model

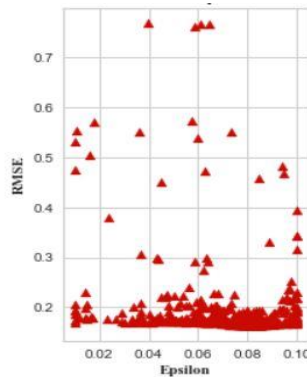


Figure 8. Model performance on training data for the PSO-SVR model



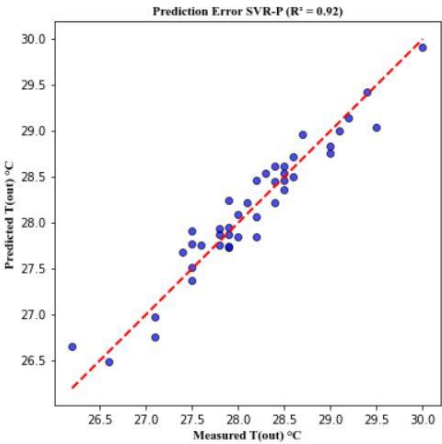
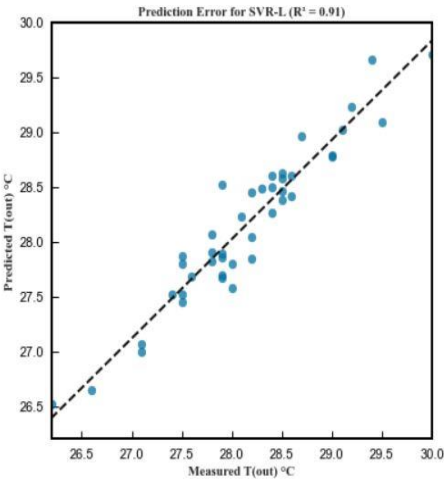
Accordingly, RMSE, R^2 , and MAE are calculated on both the training and testing datasets.

Table 2. Performance of forecasting models on the training and testing datasets

Model	Training datasets			Testing datasets		
	R2	RMSE	MAE	R2	RMSE	MAE
SVR-L	0.9	0.24	0.2	0.91	0.22	0.18
SVR-P	0.92	0.22	0.17	0.92	0.2	0.17
SVR-RBF	0.93	0.21	0.17	0.93	0.19	0.15
PSO-SVR	0.95	0.18	0.14	0.95	0.16	0.12

From Table 2, we can see that all four developed models perform well in predicting the temperature at the Nam Mau coal mine drilling and blasting sites. Among them, the PSO-SVR model provides the best forecasting results with $R^2=0.95$,

RMSE = 0.16, and MAE = 0.12, while the traditional SVR(L) model gives the lowest results with $R^2=0.91$, RMSE = 0.22, and MAE = 0.18 on the testing dataset. Figure 9 illustrates the forecasting results of the models



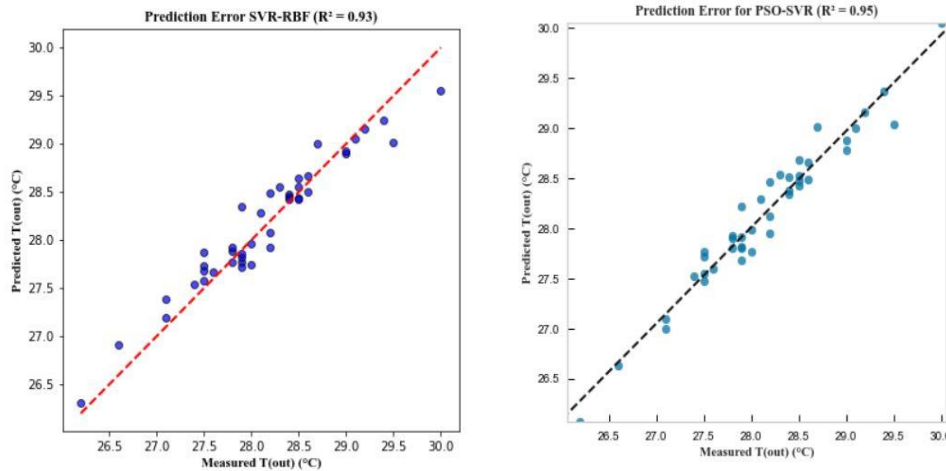


Figure 9. The relationship between measured and predicted values of the predictive models on testing datasets

5. Conclusion

Currently, as mining operations go deeper, the air temperature in underground mines is increasing, which affects the health of workers and compromises safety in production. It is a fundamental parameter for forecasting and controlling microclimates in underground mines. Accurate temperature forecasting is crucial for production safety and optimizing measures to protect workers.

(1) The temperature in mining faces numerous influencing factors, and the relationships between them are nonlinear and complex. The SVR method can better handle these

nonlinear relationships.

(2) The kernel functions and parameters of traditional SVR models significantly impact the accuracy of SVR. Through evolutionary algorithms, optimal values for kernel functions can be achieved for the SVR model.

(3) PSO is the most dominant evolutionary algorithm when combined with the SVR model for predicting underground mining temperatures, yielding more accurate results than traditional SVR models. This should be recognized as a powerful technique for accurate temperature forecasting.

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