Prediction of Explosion Power of Fuel Air Mixture in Coal Mine by Improved BP Neural Network

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Abstract. In order to improve the feasibility and accuracy of predicting the explosion power of fuel air mixture, a method of BP neural network prediction is proposed by combining factor analysis method with BP neural network. Using factor analysis method, the original data of 9 fuel air mixture explosion power factors were processed by dimensionality reduction data, 2 common factors were obtained, and 2 common factors were substituted for 9 fuel air mixtures as input layer parameters of BP neural network. A prediction model of coal and gas outburst with the combination of factor analysis method and BP Neural network is established to predict the explosion power of fuel air mixture. The prediction model of the explosion power of the fuel air mixture is selected to verify the improved BP neural network prediction models, and the final results are as follows: The relative error range of four prediction samples is 0.16%-7.58%, all less than 10%. The improved BP neural network prediction method is used to solve the problem of the traditional BP neural network because of the excessive number of input layer parameters, low data processing efficiency, slow iteration rate and low precision, which provides a new research way for predicting the explosion power of fuel air mixture.

1. Introduction
In recent years, in China's petroleum, chemical, coal and other industrial fields, the safety accidents caused by the explosion of combustible dust, combustible gas and air to form a fuel-air mixture have increased year by year. In particular, as the mining industry gradually enters deep mining, due to the particularity of its working environment and conditions, once the fuel-air mixture explosion occurs, it will have extremely adverse effects on personnel safety and local economic and social development. In order to effectively prevent the explosion of fuel-air mixture, domestic and foreign scholars have carried out research on such explosive characteristics, explosive power and explosion mechanism. Among them, Zhang Yan and other studies used optical methods to measure the dust concentration in dust explosion experiments [1]. Zhang Qi et al. studied the effect of blowing pressure and dust concentration on the optimal ignition delay time of dust explosion in closed containers [2-4]. Cao Weiguo et al. carried out an experimental study on the influence of different ignition quality on dust explosion characteristics in a closed container [5]. Engler is the first scholar at home and abroad to study the explosion characteristics of fuel-air mixture. He studied and proposed the gas-dust explosion characteristics [6]. Fan Baolong et al. conducted a study on the main influence parameters of methane-pulverized coal-
air mixture explosion through self-built explosion experimental platform [7]. Tan Yumei et al. studied and proposed the explosion characteristics of propylene oxide vapor-aluminum powder-air mixture [8]. Bai Chunhua et al. obtained the explosion law of gas-coal-air mixture in different concentrations through numerical simulation software [9]. At present, many domestic researches on fuel-air mixture are still in their infancy, especially for the prediction of explosive power of fuel-air mixture. Scholars have proposed a method based on neural network to predict the explosive power of fuel-air mixture. However, this method has certain limitations in verification research, because the prediction method involves more prediction indicators, resulting in low accuracy, slow convergence efficiency and poor reliability. The factor analysis method can simplify the relationship between the mutual predictive indicators and obtain the main influence factor, that is, the common factor, so that a larger number of common factors can be replaced by a smaller number of common factors. Based on the principle of factor analysis, this paper proposes a method for predicting the explosive power of coal-fired fuel-air mixture by combining factor analysis and BP neural network method. The common factor obtained by the factor analysis method is replaced by the common factor as BP. The input layer parameters of the neural network structure reduce the number of input layer parameters of the BP neural network, simplify the structure of the BP neural network, and improve the efficiency of iteration and operation.

In this paper, liquid propylene oxide and solid metal aluminium powder are selected to form a liquid-solid mixed fuel. The detonation condition is a small dose unconstrained space [10]. Based on the original data of the main influencing factors related to the explosive power of fuel-air mixture, combined with the method of predicting the explosive power of coal-fired fuel-air mixture based on factor analysis and BP neural network, the coal mine based on factor analysis and BP neural network was tested. The practicability and predictive accuracy of the fuel-air mixture explosion power prediction method.

2. Factor Analysis and Principle of BP Neural Network

2.1. Factor Analysis

Factor analysis is a method of replacing a large number of indicators or inter-relationships between elements by a few major factors. In the factor analysis method, several variables with relatively large correlations are represented by the same main factor, and a few major factors are used to represent most of the information in the original data, thereby simplifying the structure and improving the operation efficiency, but Does not affect the accuracy of the final result.

The specific principle and calculation process are as follows [11]:

Based on the data information contained in the original data, the total factor matrix $X$ is established:

$$X=(X_{ij})_{N \times p}$$

$N$ is the number of groups of data matrices and $p$ is the number of influencing factors.

Correlation matrix $R$:

$$R=(r_{ij})_{p \times p}$$

$r_{ij}$ is the correlation coefficient of the factor $i$ to $j$.

Calculate the factor load matrix $A$:

$$A=(a_1, a_2, \ldots, a_q)=(a_{ij})_{p \times p}$$

Establish a factor score model $X=AF+\varepsilon$:

$$X_i=a_1F_1+a_2F_2+\cdots+a_qF_q+\varepsilon_i$$

The expression of the common factor matrix $F$:
\[ F = B F + \varepsilon \]  

(5)

2.2. BP Neural Network
At present, the most widely used artificial neural network models and algorithms are multi-layer feedforward networks and error back propagation learning algorithms, namely BP neural network algorithms.

The BP neural network model structure is composed of three parts: input layer, hidden layer and output layer. According to relevant theoretical research, BP neural network with an implicit layer can approximate any nonlinear function with arbitrary precision [12]. The learning algorithm of BP neural network is to input the original sample data into BP neural network, and the actual output of BP neural network is obtained through BP neural network algorithm. If the obtained relative error between actual output and expected output cannot meet the error precision requirements Then, the error is propagated backward from the output layer, thereby adjusting the weights and thresholds in the BP neural network model structure, and then the original sample data is re-inputted into the BP neural network for operation, so that the actual output and the expected output of the BP neural network are The relative error is gradually reduced until the target error accuracy requirement is met.

3. Application of Factor Analysis and BP Neural Network in Explosive Power of Fuel-air Mixture

3.1. Fuel and Air Mixture Explosion Power Main Influence Factor Data Acquisition
This paper selects the main influencing factors of the explosive power of fuel air mixture: liquid propylene oxide mass percentage \( C_{PO} \), solid metal aluminum powder mass percentage \( C_{Al} \), mixed fuel oxygen balance \( OB \), center charge quality \( m_c \), specific dose \( r \), high \( h \), ambient temperature \( T_0 \), humidity \( H_0 \), air pressure \( P_0 \), the original data of each influencing factor are shown in Table 1 [10].

| Sample | \( C_{PO} \)/% | \( C_{Al} \)/% | \( OB \)/(g·g\(^{-1}\)) | \( m_c \)/g | \( r \)/% | \( h \)/m | \( T_0 \)/\(^\circ\)C | \( H_0 \)/% | \( P_0 \)/atm | \( P \)/MPa | \( T \)/K | \( Q_V \)/(m\(^3\)·kg\(^{-1}\)) | \( V \)/(m\(^3\)·kg\(^{-1}\)) | \( F \times 10^5 \)/(N·kg\(^{-1}\)) |
|--------|--------------|--------------|-----------------|---------|--------|------|----------|--------|---------|--------|-------|----------------|----------------|----------------|
| 1      | 100          | 0            | -33.25          | 12      | 12     | 1.9  | 26.75    | 74     | 1.01    | 1.14   | 1805.7| 1.59            | 0.99            | 6.99            |
| 2      | 98           | 2            | -32.99          | 12      | 12     | 1.9  | 26.15    | 68     | 1.17    | 1.16   | 1871.4| 1.71            | 0.99            | 7.50            |
| 3      | 96           | 4            | -32.38          | 12      | 12     | 1.9  | 25.35    | 71     | 1.23    | 1.19   | 1945.8| 1.79            | 0.99            | 8.06            |
| 4      | 94           | 6            | -31.77          | 12      | 12     | 1.8  | 27.41    | 63     | 1.42    | 1.21   | 2015.1| 1.91            | 0.99            | 8.63            |
| 5      | 92           | 8            | -31.16          | 12      | 12     | 1.8  | 23.58    | 60     | 0.98    | 1.25   | 2085.4| 1.98            | 0.99            | 9.14            |
| 6      | 90           | 10           | -30.55          | 11      | 11     | 1.7  | 22.14    | 65     | 0.89    | 1.28   | 2157.1| 2.10            | 0.99            | 9.75            |
| 7      | 80           | 20           | -27.25          | 11      | 11     | 1.6  | 28.16    | 69     | 1.53    | 1.42   | 2512.2| 2.61            | 0.99            | 12.58           |
| 8      | 60           | 40           | -21.05          | 11      | 11     | 1.6  | 23.57    | 70     | 1.07    | 1.55   | 3074.4| 3.63            | 0.99            | 16.92           |
| 9      | 50           | 50           | -17.99          | 10      | 10     | 1.5  | 21.19    | 59     | 0.95    | 1.56   | 3286.1| 4.14            | 0.99            | 18.22           |
| 10     | 34           | 66           | -13.37          | 10      | 10     | 1.5  | 20.23    | 67     | 0.83    | 1.53   | 3537.5| 4.95            | 0.97            | 18.77           |
| 11     | 20           | 80           | -8.84           | 11      | 11     | 1.7  | 25.42    | 66     | 1.12    | 1.47   | 3714.1| 5.77            | 0.93            | 18.02           |
| 12     | 10           | 90           | -5.79           | 12      | 12     | 1.8  | 27.11    | 72     | 1.29    | 1.40   | 3801.2| 6.31            | 0.89            | 16.91           |
| 13     | 0            | 100          | -2.74           | 12      | 12     | 1.9  | 28.55    | 80     | 1.51    | 1.31   | 3801.3| 6.53            | 0.88            | 15.43           |
| 14     | 49           | 51           | -17.95          | 10      | 10     | 1.6  | 24.84    | 68     | 1.47    | 1.56   | 3286.1| 4.14            | 0.98            | 18.30           |
| 15     | 35           | 65           | -13.38          | 10      | 10     | 1.6  | 25.42    | 66     | 1.03    | 1.52   | 3518.8| 4.91            | 0.98            | 18.90           |
| 16     | 19           | 81           | -8.80           | 10      | 10     | 1.6  | 25.89    | 67     | 1.38    | 1.46   | 3714.3| 5.77            | 0.93            | 18.00           |
| 17     | 11           | 89           | -6.35           | 10      | 10     | 1.6  | 24.68    | 68     | 1.12    | 1.41   | 3801.6| 6.31            | 0.89            | 17.01           |

3.2. Analysis of Factors Affecting the Explosive Power of Air Mixture
The factor analysis function of the SPSS software is used to preprocess the raw data related to the main factors affecting the explosive power of the fuel-air mixture. Based on the raw data in Table 1, a 17 x
14 matrix database was created. The BP neural network input layer parameters are selected as liquid propylene oxide mass percentage CPO, solid metal aluminum powder mass percentage CAl, mixed fuel oxygen balance OB, central charge quality mc, specific dose r, high h, environment Temperature T0, humidity H0, pressure P0, using the factor analysis method to reduce the dimensionality of the above input layer parameters, the common factor is replaced by the original input layer parameters as the new input layer parameters of BP neural network. The calculation process is as follows:

Data preprocessing. The SPSS software calculates the variance contribution rate and cumulative contribution rate of each component (Table 2), the correlation matrix of each factor (Table 3), and the component matrix (Table 4). The factor with the cumulative percentage of the previous q eigenvalues greater than or equal to 80% is selected as the common factor. According to the results of Table 2, two common factors are selected.

The SPSS software performs operations to obtain a component score coefficient matrix table (Table 5) and a common factor matrix table (Table 6).

### Table 2. Variance Contribution Rate of Each Component and Cumulative Contribution Rate Table

| Ingredient | Initial Eigenvalue | Extract Square Sum Loading | Rotation Square Sum Loading |
|------------|--------------------|----------------------------|-----------------------------|
|            | Total              | Variance %                 | Grand Total %               | Total              | Variance %                 | Grand Total %               |
| 1          | 4.2891             | 47.6605                    | 47.6607                     | 4.2897             | 47.6609                    | 47.6601                     | 3.8687             | 42.9762                    | 42.9766                     |
| 2          | 3.0705             | 34.1140                    | 81.7745                     | 3.0704             | 34.1145                    | 81.7740                     | 3.4921             | 38.7984                    | 81.7745                     |
| 3          | 0.8896             | 9.8791                     | 91.6544                     |                   |                            |                             |                   |                            |                             |
| 4          | 0.3943             | 4.3765                     | 96.0305                     |                   |                            |                             |                   |                            |                             |
| 5          | 0.1897             | 2.0976                     | 98.1273                     |                   |                            |                             |                   |                            |                             |
| 6          | 0.1294             | 1.4347                     | 99.5615                     |                   |                            |                             |                   |                            |                             |
| 7          | 0.0305             | 0.3314                     | 99.8926                     |                   |                            |                             |                   |                            |                             |
| 8          | 0.0106             | 0.1082                     | 100.0000                    |                   |                            |                             |                   |                            |                             |
| 9          | -6.878E-19         | -7.642E-18                 | 100.0000                    |                   |                            |                             |                   |                            |                             |

### Table 3. Related Matrix Table

| Correlation Matrix | $C_{PO} \quad C_{Al} \quad OB \quad m_c \quad r \quad h \quad T_0 \quad H_0 \quad P_0$ |
|--------------------|-----------------------------------------------|
| $C_{PO}$           | 1.0000                                        |
| $C_{Al}$           | -1.0000                                       |
| $OB$               | -0.834                                        |
| $m_c$              | 0.457                                         |
| $r$                | 0.453                                         |
| $h$                | 0.371                                         |
| $T_0$              | -0.041                                        |
| $H_0$              | -0.277                                        |
| $P_0$              | -0.170                                        |
| $C_{PO}$           | -1.0000                                       |
| $C_{Al}$           | 0.834                                         |
| $OB$               | -0.435                                        |
| $m_c$              | -0.457                                        |
| $r$                | -0.453                                        |
| $h$                | -0.371                                        |
| $T_0$              | 0.520                                         |
| $H_0$              | 0.351                                         |
| $P_0$              | 0.170                                         |
| $OB$               | -0.435                                        |
| $m_c$              | 1.0000                                        |
| $r$                | -0.453                                        |
| $h$                | -0.371                                        |
| $T_0$              | 0.979                                         |
| $H_0$              | 0.947                                         |
| $P_0$              | 0.496                                         |
| $m_c$              | -0.453                                        |
| $r$                | 1.0000                                        |
| $h$                | 0.947                                         |
| $T_0$              | 0.520                                         |
| $H_0$              | 0.947                                         |
| $P_0$              | 0.496                                         |
| $r$                | -0.453                                        |
| $h$                | 1.0000                                        |
| $T_0$              | 0.979                                         |
| $H_0$              | 0.947                                         |
| $P_0$              | 0.496                                         |
| $h$                | -0.371                                        |
| $T_0$              | 0.520                                         |
| $H_0$              | 0.520                                         |
| $P_0$              | 0.520                                         |
| $T_0$              | -0.041                                        |
| $H_0$              | -0.277                                        |
| $P_0$              | -0.170                                        |
| $H_0$              | 0.351                                         |
| $P_0$              | 0.170                                         |
| $P_0$              | 0.351                                         |
| $P_0$              | 0.170                                         |
### Table 4. Composition Matrix Table

| Component Matrixa | 1       | 2       |
|-------------------|---------|---------|
| \( C_{PO} \)      | 0.9275  | -0.0806 |
| \( C_{O} \)       | -0.9274 | 0.0802  |
| \( OB \)          | -0.9295 | 0.1631  |
| \( m_c \)         | 0.6332  | 0.7044  |
| \( r \)           | 0.6413  | 0.7048  |
| \( h \)           | 0.5714  | 0.7587  |
| \( T_0 \)         | -0.0715 | 0.8984  |
| \( H_0 \)         | -0.2298 | 0.7703  |
| \( P_0 \)         | -0.3037 | 0.6982  |

### Table 5. Matrix of Component Score Coefficients

| Component Score Coefficient Matrix | 1       | 2       |
|-----------------------------------|---------|---------|
| \( C_{PO} \)                     | 0.2492  | -0.0642 |
| \( C_{O} \)                      | -0.2493 | 0.0641  |
| \( OB \)                         | -0.2544 | 0.0894  |
| \( m_c \)                        | 0.1375  | 0.1795  |
| \( r \)                          | 0.1392  | 0.1796  |
| \( h \)                          | 0.1181  | 0.1977  |
| \( T_0 \)                        | -0.0583 | 0.2678  |
| \( H_0 \)                        | -0.0958 | 0.2362  |
| \( P_0 \)                        | -0.1112 | 0.2183  |

#### 3.3. BP Neural Network Prediction Model Based on Factor Analysis

Taking F1 and F2 in Table 6 as the input layer parameters of the BP neural network, the explosion pressure \( P \), the explosion temperature \( T \), the explosion heat \( Q_V \), the gas product volume \( V \), and the explosion power index \( F \) are five indicators for reflecting the explosive power of the fuel-air mixture. As an output layer parameter of the BP neural network. The number of hidden layer neurons calculated by the traditional formula of the hidden layer neurons \( l = \sqrt{mn} \) [13] and the empirical formula \( l = 2n + 1 \) [14] are substituted into the BP neural network prediction model, and the final result shows that when the hidden layer neurons are When the number is 5, the improved BP neural network has the best convergence effect and the highest accuracy, that is, the empirical formula is used to calculate the number of neurons in the hidden layer. Finally, the topology of the BP neural network model is determined to be 2-5-5.

The first 13 sets of data samples of the common factor are used as training samples, and the last 4 sets of data samples are used as prediction samples. BP neural network toolbox in Matlab software is used to create BP neural network. Two common factors are used as input layer parameters, and the explosion pressure \( P \), explosion temperature \( T \), explosion heat \( Q_V \), gas product volume \( V \), and explosion power index \( F \) are output. Layer parameters, tansig function and logsig function are used as transfer functions of hidden layer neurons and input layer neurons respectively. Purelin function and trainlm function are selected as output layer activation function and BP neural network training function respectively. The maximum number of training sessions for BP neural network is 100, the BP neural network training error is \( 1 \times 10^{-3} \), the BP neural network learning rate is 0.9, and the remaining BP neural network training parameters are default values. The last four sets of data samples were used as predictive
samples to test whether the trained BP neural network met the target requirements. The results are shown in Table 7. The final prediction results show that the relative error range of the improved BP neural network prediction is less than 10%, and the model is considered to be practical.

### Table 6. Common Factor Matrix Table

| F1       | F2       |
|----------|----------|
| 1.33872  | 0.71635  |
| 1.35477  | 0.52941  |
| 1.24724  | 0.65071  |
| 1.06395  | 0.48089  |
| 1.39416  | -0.51530 |
| 1.03833  | -0.94050 |
| -0.44623 | 0.60074  |
| 0.05113  | -0.40994 |
| -0.19230 | -1.76732 |
| -0.58095 | -1.52345 |
| -0.61044 | 0.11706  |
| -0.75376 | 1.23984  |
| -1.10585 | 2.27883  |
| -0.64475 | -0.27618 |
| -0.69432 | -0.65064 |
| -1.21842 | -0.11647 |
| -1.24128 | -0.41403 |

### Table 7. Comparison of Model Prediction Results

| Sample | P/MPa | T/K | QV/(mJ·kg⁻¹) | V/(m³·kg⁻¹) | F×10⁵/(N·kg⁻¹) |
|--------|-------|-----|--------------|-------------|----------------|
|        | eva.  | cal.| δ/%          | eva.        | cal.           | eva.          | cal.          | δ/%          |
| 14     | 1.563 | 1.561| 0.1          | 3.1         | 4.457          | 4.143         | 7.5           | 0.972        | 0.982        | 12.574       | 12.301       | 1.4          |
| 15     | 1.557 | 1.529| 1.8          | 3.511.8     | 4.887          | 4.908         | 0.4           | 0.967        | 0.975        | 18.750       | 19.903       | 0.8          |
| 16     | 1.492 | 1.465| 1.9          | 3.784.9     | 5.456          | 5.774         | 2             | 0.964        | 0.930        | 18.326       | 18.002       | 1.8          |
| 17     | 1.462 | 1.401| 4.3          | 3.929.4     | 6.311          | 5.955         | 5             | 0.958        | 0.894        | 18.101       | 17.014       | 6.3          |

Note: eva.—evaluation value; cal.—calculation value; δ—relative error, δ=(eva.-cal.)/cal.×100%.

### 4. Conclusion

1. Using the factor analysis method to reduce the input parameters of BP neural network, and replace the original data with a small number of common factors as the input layer parameters of BP neural network, thus constructing BP neural network based on factor analysis. The network prediction model provides a new idea and method for the prediction of coal mine fuel-air mixture explosion power.

2. Using the improved BP neural network prediction method to predict the explosive power of coal mine fuel-air mixture, the prediction result: the relative error range of the predicted samples is 0.16%-7.58%, both less than 10%, which proves that based on factor analysis and BP network, the network's coal mine fuel-air mixture explosion power prediction method is finally feasible and predicts better accuracy.
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