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Severe Convective Weather Warning System

Zheng Dan

Southwest Jiaotong University Hope College, Chengdu 610000, China.

Abstract

Short-term nowcasting for severe convective weather is an urgent need for national disaster prevention and mitigation and refined weather forecasting. In order to effectively improve the use value of weather radar in Liangshan Prefecture and better serve government departments and the public, an early warning system based on radar-based data has been developed. The system is based on the ELM algorithm to achieve a business platform integrating monitoring, short-term forecasting, early warning and other functions. It can predict the occurrence of strong convective weather in the central and western parts of Liangshan Prefecture in the next hour, effectively improving the guiding role of short-term nowcasting. Artificial weather modification work has a very good auxiliary effect.

Keywords

Principal Component Analysis; ELM; SQLite; Early Warning.

1. Introduction

Although the new generation of weather radars are widely used in short-term weather forecasts and tracking observations of severe convective weather systems, the use of software technology to provide early warning and notification of weather radar echoes is not perfect. At present, the echo early warning work in the central and western parts of Liangshan Prefecture is carried out by the radar duty personnel through years of observation experience and the data analyzed by weather radar software to the state bureau meteorological station and the county bureaus by telephone. The weather radar echoes in the notification area are already in a relatively vigorous stage of development, and this notification mode can no longer effectively maximize the effects of weather radar in disaster prevention and mitigation. In order to better play the role of a new generation of weather radar "clairvoyance", combined with software engineering technology to build a diversified weather forecasting technology service means, effectively share, refine and scientific weather radar echo resources, improve disaster prevention, Disaster reduction work efficiency.

This article mainly introduces the early warning system of strong convective echoes in the central and western parts of Liangshan Prefecture, and realizes the one-hour warning release of the future strong convective echo weather in the central and western parts of Liangshan Prefecture, which can effectively improve the hail weather, heavy precipitation weather and the weather caused by the severe convective weather process. The accuracy of early warning and forecasting of thunderstorm weather is more conducive to the early preparation of shadow operations by the shadow department, improving the efficiency of disaster prevention and mitigation, and it also has a good auxiliary role in the forecast service of disastrous weather in the central, northern and central eastern parts of Liangshan Prefecture.

2. Data

From the weather radar application experience over the years, it is found that due to geographical factors, the continuous detection area of the weather radar is the central and western part of Liangshan

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Prefecture (Yanyuan, Muli, Mianning, Xichang). These areas can realize the weather radar precipitation mode 2 (Radar 9). Layer scan mode) full tracking and early warning. When strong convective echoes appear in the western and northwestern parts of Liangshan Prefecture, in the next 2-3 hours, the subsequent development of the echoes will directly affect the weather conditions in the central, northern and northeastern parts of Liangshan Prefecture, and even the subsequent regions. There will be greater hail weather and short-term heavy precipitation weather. Finding the special threshold area for weather radar echoes in the central and western parts of Liangshan Prefecture and comparing it with the previous weather fact database, can predict and analyze the probability of hail weather and heavy rainfall in the central and western parts of Liangshan Prefecture, the northwestern area and even in the area affected by the echoes. Early warning of the occurrence of severe weather.

The data in this paper are collected from the radar data of the weather process in the central and western part of Liangshan Prefecture, Xichang from 2005 to 2015. Through collating and analyzing the data of weather conditions and lightning location in central and western Liangshan Prefecture from 2005 to 2015, the time of occurrence of the severe convective weather process is determined, and the intensity of the strong convective weather process is determined quantitatively according to the rainfall intensity in the process and the number of lightning occurrences nearby. The intensity of convective weather. Sort and collect the radar-based data (about 10 time-times) 1 hour before the start of each strong convective weather process, and select the maximum echo height, maximum echo intensity, and maximum echo intensity near the place where the strong convection occurs from each time-based data. The center of strong echo and the moving speed of echo.

3. Key technologies

3.1 Principal component analysis method

In order to improve the accuracy of precipitation prediction, it is necessary to determine the radar factors that are closely related to precipitation. However, since the radar base data contains many categories, the factor selection of the input model is also the key. In the variable selection process, the principal component analysis method (Principle Components Analysis, PCA) combined with practical application experience can be used to evaluate the relevant input variables of the model, and finally determine the echo intensity, echo height, Echo velocity and echo azimuth are used as input factors, and salt source precipitation after 1 hour is used as output factors to establish and verify the model [1-2].

PCA takes the simplified matrix as the input of the model to reflect the effective information of the original variables to the greatest extent, so as to achieve the effect of deleting redundant variables and compressing data. The main analysis steps are:

3.1.1 Data standardization

The results of PCA are affected by the dimension, and the data of each variable should be standardized first [3], and the radar factors that affect precipitation are assumed to be composed of X=[X1,X2,……,Xn], and the original data are standardized:

$$x_i = (X_i - \bar{X}_i)/S_i$$

3.1.2 Calculate the correlation coefficient matrix

Use the standardized x=[x1, x2,……, xn] to calculate the correlation coefficient matrix of the sample $R=[r_1,r_2,……,r_n]$.

$$r_{ij} = \sum_{k=1}^{n}(x_{ki} - \bar{x}_i)(x_{kj} - \bar{x}_j) \Big/ \sqrt{\sum_{k=1}^{n}(x_{ki} - \bar{x}_i)^2 \sum_{k=1}^{n}(x_{kj} - \bar{x}_j)^2}$$

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3.1.3 Calculate eigenvalues and eigenvectors

According to the $|\lambda I - R| = 0$ calculation of eigenvalues $\lambda_1, \lambda_2, , \cdots, , \lambda_n$ and corresponding eigenvectors e_i (i=1,2,...,n). The new variable after dimensionality reduction can be obtained by the $Z = [e_1, e_2, \cdots, e_n]^T X$ linear transformation of, that is, p principal components are extracted.

3.1.4 Find the contribution rate and cumulative contribution rate of each principal component

Calculate the contribution rate of the k-th principal component:

$$p_k = \lambda_k / \sum_{i=1}^{n} \lambda_i$$

The cumulative contribution rate of the first p principal components:

$$P_p = \sum_{i=1}^{s} \lambda_i / \sum_{i=1}^{n} \lambda_i$$

The larger the cumulative contribution rate, the smaller the information loss of the data. Usually, the first p variables of Pp $\in$ [80%, 95%] are selected as the input variables of the model.

3.2 ELM model

Extreme learning machine is a new type of single hidden forward neural network with excellent performance. Compared with traditional neural networks, this learning algorithm has simple structure, fast learning rate and good generalization performance. It has the advantages of overcoming traditional gradient algorithms. The advantages of local minima, over-fitting and inappropriate selection of learning rate.

The network of the ELM model has three layers [4-5]. The connection weight ai and the threshold di between the input layer and the hidden layer are randomly generated (no need to adjust during the training process), and the weight coefficient matrix β from the hidden layer to the output layer needs to be trained. . ELM has randomly generated weight coefficients a and d before training, and β can be calculated after determining the number of neurons in the hidden layer and the activation function. The ELM algorithm flow is as follows:

(1) According to N different training samples, first determine the excitation function g(x) and the number of hidden neurons L;

(2) Randomly generate input weight matrix α and hidden layer bias matrix d;

(3) Find the hidden layer output matrix based on the known quantity.

$$H = \begin{bmatrix} g(a_1 x_1 + d_1) & L & g(a_k x_1 + d_k) \\ M & O & M \\ g(a_1 x_N) & L & g(a_k x_N + d_k) \end{bmatrix}_{N \times k}$$

(4) Calculate the connection weight β from $\hat{\beta} = H^+ Y$, H+ is the generalized inverse matrix of the hidden layer output matrix H.

Compared with traditional training methods, the extreme learning machine has the following advantages: (a) Simple structure, few parameters, and easy adjustment: There is no output layer bias, no need to set the learning rate, only the output weight is determined, and the amount of calculation is small; (b) Fast learning rate: The training speed of ELM is 2 to 3 times that of the traditional SLFN algorithm; (c) Good generalization performance: It can minimize the promotion error, and has strong scalability and adaptability. These advantages can effectively avoid problems such as the difficulty of determining the network structure in the traditional neural network model.

3.3 Choice of database platform

Using software engineering technology, the forecast conclusions of strong convective weather and strong teams for the next 10 times are generated according to the forecast model, written into the

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background database, and real-time display, alarm and historical forecast query functions are realized in the visual interface [6-7]. The data processing capability of the database is essential to the stability of the entire platform.

In the field of meteorology, databases include Oracle, SQL Server, and SQLite databases. The data processing capabilities of the database are critical to the stability of the entire early warning platform. Considering that SQLite is an open source embedded relational database, it is portable, easy to use, small, efficient and reliable. SQLite is embedded in the applications that use it, and they share the same process space instead of a separate process [8]. In order to ensure the possible data platform migration needs in the future, the design platform adopts the SQLite database system.

4. System design

4.1 System design ideas

The system is based on the Visual Studio 2013 compilation platform and is compiled by a mixture of C# and MATLAB. In the MATLAB environment, complete the establishment of the predictive model, and then use the controls provided by Visual Studio 2013 to implement the form involving layout and the function framework provided by .NET FrameWork to achieve login settings, real-time display, data storage and data query functions [9-10]. The overall functional block diagram of the system is as follows:

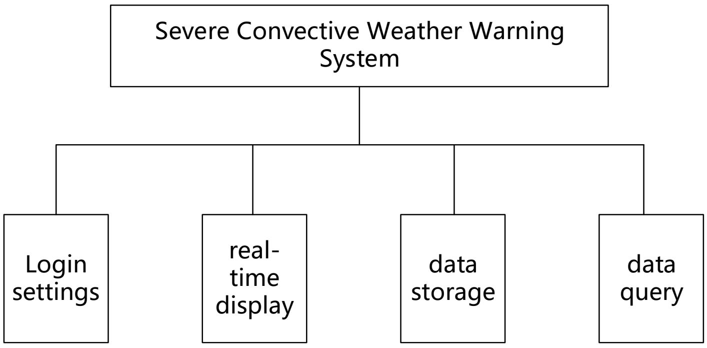

Figure 1. The overall function diagram of the system

(1) In the MATLAB environment, the extreme learning machine (ELM) is used to establish a strong convective weather prediction model, determine the 4 input variables of the ELM model, and output the precipitation at the time to be predicted to obtain the precipitation predicted by the strong convective weather Amount and rainfall type.

(2) C# calls the data in MATLAB and displays the prediction results on the visual interface.

(3) Data storage and query.

4.2 Design of predictive model

4.2.1 Data processing

According to business specifications, rules, etc., the data is screened, invalid samples are eliminated, and abnormal data is corrected to improve the accuracy and authenticity of the data. And normalize all the data to eliminate the difference in units and orders of magnitude between the dimensions, and avoid the phenomenon that some variables are submerged during the mapping.

4.2.2 Feature factor extraction

Since the radar base data contains many types of data, there are many factors that can be selected. In this study, the principal component analysis (PCA) method combined with practical application experience was used to evaluate the relevant input variables of the model, and finally determined for 1 hour The previous echo intensity, echo height, echo speed, and echo azimuth are used as input factors, and the salt source precipitation after 1 hour is used as output factors to establish and verify the prediction model.

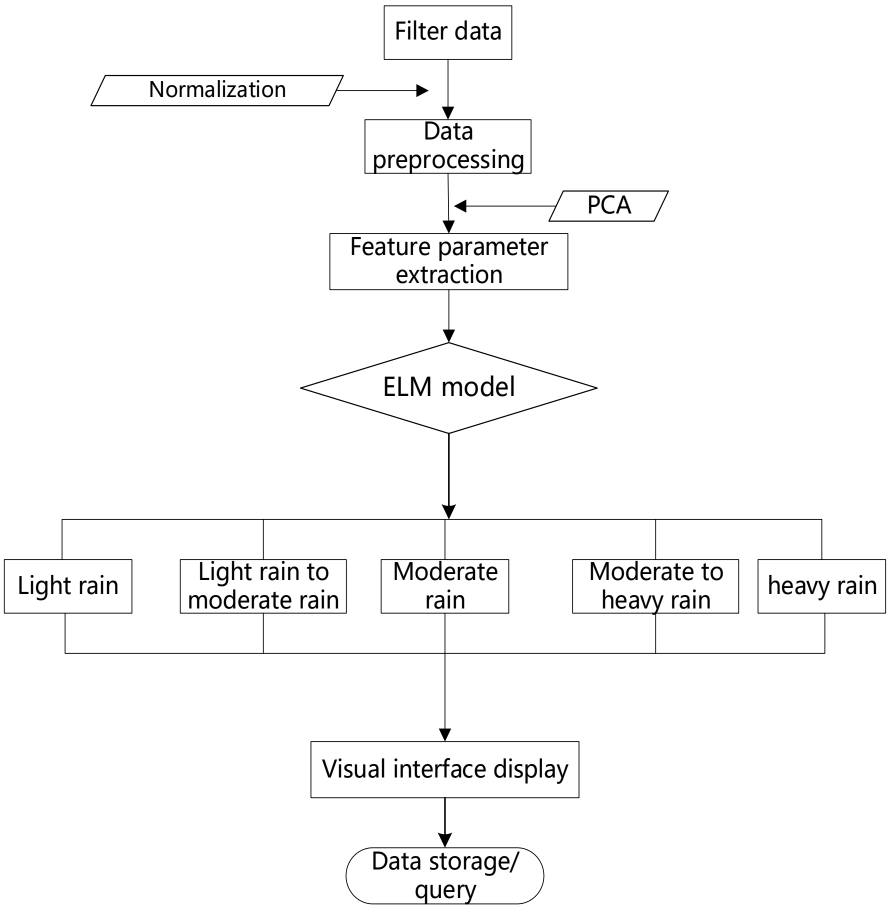

Figure 2. Flow chart of forecasting model

4.2.3 Forecast model

This study randomly selects 60% samples as the training set and 40% samples as the test set. The 4 factors (echo intensity, echo height, echo speed, echo azimuth 1 hour ago) obtained by PCA are input as variables Train in the ELM model with relatively simple parameter settings. The structure of the ELM model is 4-M-1. After many experiments, the parameters of the model are determined as: the number of neurons M=12, and the'sig' function is passed as a hidden layer function.

Through the use of ELM algorithm for modeling, the prediction of the precipitation and precipitation type of the salt source in the next 1 hour will be completed, and it will be displayed in the visualization interface in the form of numerical values and display lights. Among them, according to the documents of the Meteorological Department, the precipitation types (24 hours) are divided as shown in Table 1:

Table 1. Classification of precipitation types

Type	**Precipitation (unit: mm)**
Light rain	0.1~9.9
Light rain to moderate rain	5~16.9
Moderate rain	10~24.9
Moderate rain to heavy rain	17~37.9
Heavy rain	17~37.9

4.2.4 Data storage

While the warning result is displayed, a log file is generated, written into the database, and the warning information is recorded.

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5. System function and application

5.1 Main functions of the system

5.1.1 Login settings

Figure 3. System login

5.1.2 Real-time display

Through the input of real-time parameters, an early warning display of the precipitation type is carried out. The results are displayed by rainfall type (red is the predicted precipitation type) and rainfall value.

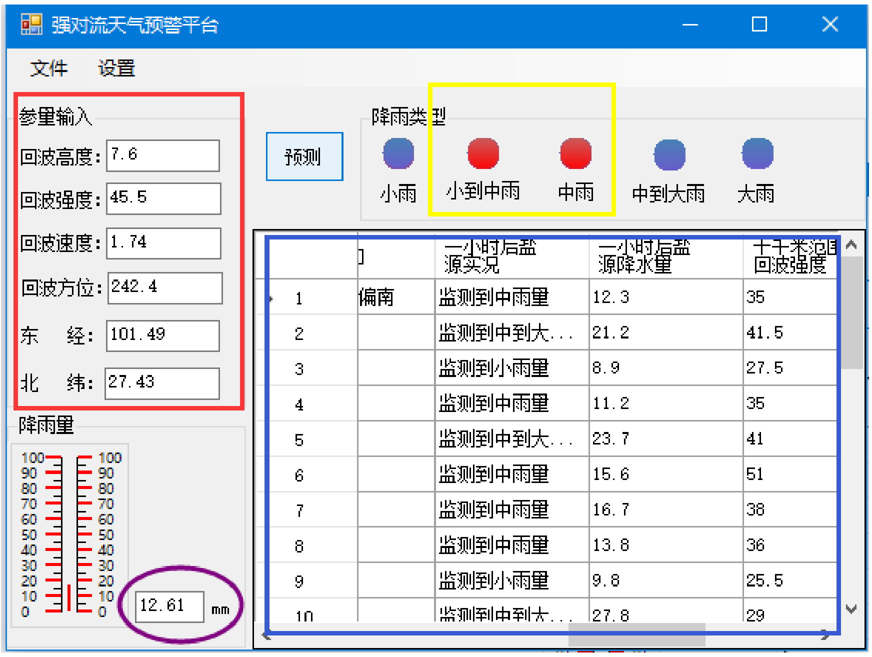

Figure 4. Real-time display

5.1.3 Data storage

After the user operates, the corresponding log file will be generated under the software path to record early warning information (including the current time, input parameters, and predicted precipitation type results).

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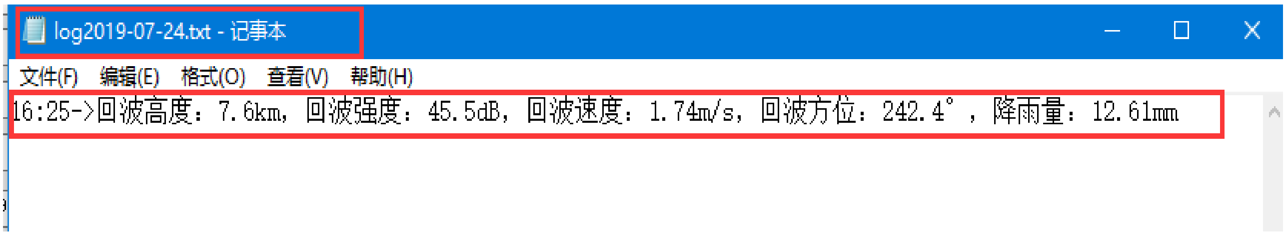

Figure 5. Data storage

5.1.4 Data query

The saved data is a database file with "current date.db", which can be opened and viewed with the software SQLite Expert Personal 3.

RecNo	小时前回波高度	回波强度	回波速度	回波方位	东经	北纬	回波移向	小时后盐源实况	小时后盐源降水量	十千米范围回波强度	回波速度1	回波高度
1	7.87	50	2.91	238.55	101.68	27.46	东西偏南	监测到中雨量	11.6	42.5	2.52	7.3
2	7	27	9.3	243.19	101.3	27.34	东北	监测到小到中雨量	9.9	27	10.27	7.1
3	6.7	26	9.11	244	101.3	27.39	西东	监测到大雨量	12.7	41	8.33	5.7
4	7.2	32.5	2.33	243.08	101.23	27.32	西东偏南	监测到小到中雨量	12.82	44	19.96	4.6
5	6.67	23.5	5.29	226.8	101.5	27.17	正北	监测到小雨量	10.3	27.5	4.07	5.1
6	7.9	27	3.49	241.95	101.68	27.52	东西偏南	监测到中到大雨量	19.9	42	3.68	9.3
7	9.3	40	1.94	238.17	101.54	27.37	正北	监测到中雨量	12.5	48	2.17	9.3
8	8.7	41	16.27	231.95	101.55	27.23	东西偏北	监测到中到大雨量	27	33	7.18	8.8
9	7.68	39	4.65	249.56	101.39	27.51	西东偏南	监测到中雨量	11.4	34	2.33	7.1
10	5.1	38	7.94	253.79	101.37	27.59	西东偏南	监测到中雨量	16.3	37	7.75	6.7
11	6.4	36.5	8.85	251.07	101.38	27.55	西东偏南	监测到中雨量	13.1	31	3.49	6.3
12	8.1	28.5	3.29	236.77	101.54	27.33	正北	监测到中到大雨量	24.1	38.5	4.07	7.98
13	6.7	36.5	3.88	254.01	101.33	27.58	正南	监测到中雨量	12.1	46	6.11	8.99
14	5.1	27	2.71	241.66	101.41	27.38	西东偏北	监测到小雨量	8.9	36.5	5.12	5.53
15	6.9	36	18.21	267.1	101.1	27.8	东南	监测到中雨量	17.6	41.5	8.14	5.9
16	6.7	34	1.36	232.07	101.59	27.38	东西偏北	监测到中雨量	12.1	33	2.91	7.4
17	6.7	44	2.74	230.19	101.7	27.32	东西偏北	监测到小雨量	7.7	32	4.77	5.76
18	10.4	50	17.4	256.18	101.29	27.61	西东偏南	监测到中到大雨量	21.9	45	7.17	8.77
19	4.9	20.5	11.9	242.94	101.29	27.34	西东偏北	监测到小雨量	7.6	24.5	12.59	6.1
20	6.6	33	4.26	247.36	101.43	27.5	西东偏南	监测到中雨量	15.6	38.5	5.22	6.3

Figure 6. Data query

5.2 Accuracy

The prediction model uses ELM algorithm modeling. Each time the parameter is input, the model will automatically find the output of the predicted value that is closest to the standard value, which is random. Therefore, for the same input parameters, each prediction result is not unique and fluctuates within its error range. The error of the prediction model is as follows:

Table 2. Error analysis table

Error index	RMSE(mm)	MAPE	MSPE	R^2
Value	0.45	0.277	0.0685	76%

5.3 Forecast release

In order to issue forecasts more quickly and effectively, the system uses a visual interface with real-time updates and a red light alarm function. When the predicted intensity of strong convective weather reaches a certain value, it will sound an alarm. Early warning signals can be downloaded to the local area through the save operation and viewed in the warning list. The saved and unpublished warning signals can be deleted.

6. Conclusion

(1) Based on the ELM-based strong convective weather early warning system, a visual real-time early warning platform of the radar base data such as echo height, echo intensity, strong echo center position, echo moving speed and other factors and strong convective weather intensity has been established , Used to guide short-term nowcasting operations.

(2) Based on radar-based data, this system can realize the one-hour warning issuance of the future strong convective echo weather in the central and western parts of Liangshan Prefecture, effectively improving the use value of Liangshan Prefecture's weather radar, and improving the efficiency of disaster prevention and mitigation. The forecast service of severe weather in the central, northern, and central-eastern regions also has a very good auxiliary role.

(3) After the early warning system has been verified by actual work, in the future work, continue to study the threshold of strong convective weather in the southwest, south and southeast of Liangshan Prefecture. Finally, the system analyzes the overall weather radar echoes in the entire Liangshan Prefecture. The law of development and the probability of occurrence of severe weather.

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