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Runway Icing Prediction Method and System Development Based on ActiveX Controls

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ABSTRACT Icing on airport runway is an important issue that affecting the operation of the airport. The research on runway icing is of great significance for ensuring the operation and safety of the airport. Firstly, in this paper, the runway temperature and ice thickness were studied by considering the underground temperature. Then combined with industrial configuration software and ActiveX controls, the runway icing prediction system was designed and verified. Through the analysis of the temperature field inside and outside of the runway as well as the studies of the meteorological factors around the surface and the runway heat exchange, the prediction equation of the runway temperature was obtained. Based on the equation, by using the predicted values of temperature and other factors, the BP neural network was trained to predict the ice thickness of the road in future. Furthermore, this paper designed an airport runway icing prediction system which installed with ActiveX controls where embedded with temperature prediction algorithm and neural network training algorithm. The system used multisensor to collect data, and wireless data transmission via GPRS DTU device. The virtual interface software and the configuration software embedded with algorithm were installed on the industrial PC to realize the prediction. By comparing the prediction of ice thickness with or without underground temperature, the average prediction accuracy of ice thickness by considering underground temperature was 13% higher than that without considering underground temperature, which verified the accuracy and feasibility of the ice prediction system.

INDEX TERMS ActiveX controls, airport runway, underground temperature, temperature field, BP neural network, GPRS DTU.

I. INTRODUCTION

With the continuous improvement of national comprehensive strength and people's living standards, air travel, fast and convenient, has gradually become the choice of more people. Airports and airlines have been striving to improve the safety and punctuality of flights in order to guarantee passengers' travel thereby enhancing degree of satisfaction. For example, airlines have invested a lot of energy in flight planning [1]. However, in winter, due to the influence of cold weather, it is very easy to cause icing on airport runway, which means the friction of the airport runway will be greatly reduced and likely to cause an accident. On February 1, 2019, a slipping accident occurred in Narita Airport, Japan, due to the ice on runway when the plane landed. On the other hand, runway icing also have an impact on airport ground operation, resulting in the cancellation, delay and diversion of a large number of flights, increasing the operating costs of airlines and affecting passengers' travel plans. In 2008, a heavy snowfall caused the closure of a large-scale airports in southern China. On February 13, 2019, 5 airports in Xinjiang closed their runways because of icing, where the runway was not up to the standard for takeoff and landing. Therefore, in order to improve the safety margin, ensure the punctuality rate and reduce the impact of ice on the airport, it is very important to develop an icing prediction system for the airport to predict the icing situation in time.

In recent years, prediction of road condition has been studied by scholars in various aspects. Generally speaking, these studies mainly focus on the materials, icing mechanism, detection methods, pavement thermodynamic analysis, icing point prediction and experimental research. Jansson *et al.* [2] established a heat balance model based on the 1-D heat and mass transfer model to estimate the heat flux of asphalt

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surface, which provided a reference for further research on the use of heat flux. Nuijten *et al.* [3] established the runway thermodynamics model of Oslo airport in Norway to realized the temperature prediction, and it had been operating at the airport for a long time. However, the authors had pointed out that they did not take the incoming and outgoing shortwave and longwave radiation from the airport into account, and there is room for improvement. Jonsson and Riehm [4] established a method for nonintrusive temperature measure of pavement by using infrared technology, and explored the feasibility of this method. Riehm *et al.* [5] built passive and active detection systems by means of infrared temperature measurement system. The passive system, providing a method to detect icing, was used to detect the ice of pavement, while the active system was used to detect the icing point temperature of pavement through active cooling. Fujimoto et al. [6] designed the RSF-SV model to calculate the mass of water, ice, salt and other materials on the pavement and the thickness of water film or ice accretion, and verified the feasibility of the model. Bezrukova *et al.* [7] collected the long-term observation data provided by Moscow Road Meteorological Station. And through analysis, the relationship between atmosphere temperature, pavement temperature, dew point and different types of icing was obtained, and the empirical curve was drawn. Based on the curve, the pavement temperature in the future 30 min∼2 h was obtained by inertia prediction. Chen-wei *et al.* [8] used the friction coefficient of pavement as the basis for judging pavement icing, simulated the pavement icing process in southern China by indoor experiments, and established a model for judging pavement icing. However, the current research of these scholars on icing and temperature predictions were mainly around the surface of expressways [9]–[11] and Bridges [12]–[14] which was not aimed at solving the prediction of icing in airports.

In this paper, considering the following characteristics of the airport runway: a) located in the open area with no shelter around, b) the area and intensity of solar radiation during the day are large, the temperature and ice thickness were studied. At the same time, it is found that besides the common factors such as atmospheric and pavement temperature, underground temperature is also an important factor in the study. Moreover, the surface temperature has a crucial effect on icing. Therefore, in order to ensure the prediction accuracy, the underground temperature was introduced into the temperature and ice thickness research. Firstly, the function of temperature field including runway depth and underground temperature was established and the temperature prediction equation was derived. Then, by considering temperature prediction value,underground temperature and other factors, the prediction of ice thickness on airport runway was obtained by using BP neural network. Secondly, aiming at the actual operation of airport runway, an airport icing prediction system was designed which was divided into three layers, two aspects of software and hardware. In terms of hardware, considering the particularity of airport runway and referring to relevant research [15], [16], wireless mode was chosen for data transmission. The data collected by sensors was transmitted via GPRS DTU wireless device in real-time. Compared with the transmission of physical wiring, the stability of system in some aspects were improved. In terms of software, the virtual interface and configuration software were installed in PC. Then referring to research [17]–[21], the technology of ActiveX controls that used in configuration software were studied. Using the MFC class libraries provided by Microsoft, the ActiveX controls of the embedded algorithm were compiled, which greatly expanded the function of the system. After the design and development of the system, data was collected and used for prediction in experimental research. The predicted value of pavement temperature was obtained in the system, and the value was compared with the measured value to verify the feasibility of prediction by adding underground temperature. Then using the data trained by the neural network algorithm, ice thickness was predicted and compared with the prediction without underground temperature and the measured ice thickness in future, the feasibility of the prediction of ice thickness was verified. At the same time, since the embedded algorithm is responsive, the system meets the requirements in terms of long-term operation and algorithm operation efficiency, which proves that it has high feasibility.

II. TEMPERATURE PREDICTION MODEL OF AIRPORT RUNWAY

A. PROCESS OF THE RUNWAY TEMPERATURE PREDICTION

The temperature prediction model mainly followed the idea of energy conservation around the heat transfer of the runway. First, the heat flux balance equation of the runway was established. Then, by solving the temperature field model equation, the runway temperature prediction model was obtained. The process of establishing the runway temperature prediction model is shown in Figure 1.

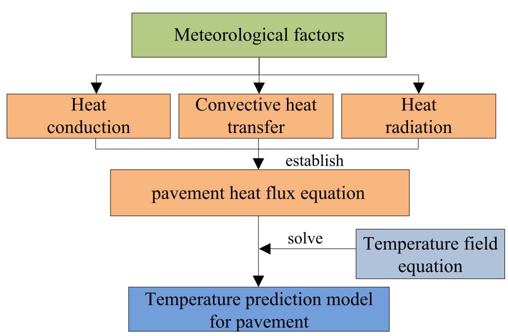


FIGURE 1. The flow chart of temperature prediction model for airport runways.

1) AIRPORT PAVEMENT HEAT FLUX EQUATION

According to the energy conservation law, the heat flux entering the runway is

$$G(t) = Q + L_1 - L_2 - H_E - L_E - R \tag{1}$$

where Q is solar shortwave radiation flux; L_1 and L_2 are atmospheric and pavement long radiation flux; H_E and L_E are sensible heat flux and latent heat flux; R is heat flux between pavement and water film.

(1) The solar shortwave radiation flux is

$$Q = r \cdot a \cdot Q_0 \tag{2}$$

$$a = 1 - (1 - k) \cdot N \tag{3}$$

where Q_0 is the total solar radiation reaching the earth's surface on sunny days. a is the transmittance of solar radiation, r is the absorption of solar radiation on the runway surface, k is the empirical coefficient, and N is the atmospheric transparency.

Derived from the M.E.Berlyand formula [22]

$$Q_0 = \frac{I_0\ sinh_0}{1 + f \cdot m} = \frac{I_0\ sin^2 h_0}{sinh_0 + f} = \frac{I_0(sin\ \varphi\ sin\ \delta + cos\ \varphi\ cos\ \delta\ cos\ \gamma)^2}{sin\ \varphi\ sin\ \delta + cos\ \varphi\ cos\ \delta\ cos\ \gamma + f} \tag{4}$$

where φ is the latitude of the measuring point; δ is the solar declination; h_0 is the solar elevation angle; γ is the time angle; m is the atmospheric optical quality; and f is the weakening coefficient of the atmosphere to solar radiation.

In formula (4), considering that the temperature needs to be deduced is after a certain period of time in the future, the time angle brought into the calculation is chosen here as the time angle of a certain period in the future.

The weakening coefficient of the atmosphere to solar radiation is

$$f = [0.174 + 0.056 \ln (1 + e (T_a))] \cdot \frac{P}{P_0} \tag{5}$$

$$e (T_a) = 1 + H_a \cdot 6.11 \cdot e^{17268 \times \frac{T_a - 35.33}{T_a - 3.556}} \tag{6}$$

where, T_a is the atmospheric temperature; $e(T_a)$ is the vapor pressure at the measuring point when the atmospheric temperature is T_a; P is the atmospheric pressure at the measuring point; H_a is the relative humidity of the air at the measuring point.

(2) Obtained by Stefan-Boltzmann law, atmospheric long radiation flux is

$$L_1 = \sigma T_0^4 \cdot \varepsilon_s \tag{7}$$

pavement long radiation flux is

$$L_2 = \sigma T_a^4 \cdot \varepsilon_a \tag{8}$$

(3) Sensible heat flux is

$$H_E = C_P \rho_a C_H v (T_a - T_o) \tag{9}$$

where v is the wind speed near the pavement.

Latent heat flux is

$$\begin{aligned} LE &= L\rho_a C_E v (H_a - q_s) \\ &= L\rho_a C_E v \left[H_a - \left(\frac{W_s}{W_c} \cdot q_{sat} (T_o) + \left(1 - \frac{W_s}{W_c}\right) \cdot H_a \right) \right] \\ &= L\rho_a C_E v \left[H_a - \left(\frac{W_s}{W_c} \cdot 0.622 \cdot \frac{e(T_o)}{P - 0.378e(T_o)} + \left(1 - \frac{W_s}{W_c}\right) \cdot H_a \right) \right] \end{aligned} \tag{10}$$

where q_s is the pavement specific humidity; $q_{sat}(T_0)$ is saturated specific humidity when pavement temperature is T_0; W_s is the water absorption of the airport runway surface; W_c is the saturated water absorption of the airport pavement.

(4) Heat flux between pavement and water film

$$R = [P_r \cdot (T_0 - T_s) / 3600] \cdot E_r \tag{11}$$

where P_r is the hourly rainfall; T_s is the water film temperature.

2) SOLUTION OF TEMPERATURE FIELD EQUATION

a: TEMPERATURE FIELD MODEL

Considering the airport runway as a semi-infinite object [23], the temperature field of the airport runway can be obtained as shown in Figure 2.

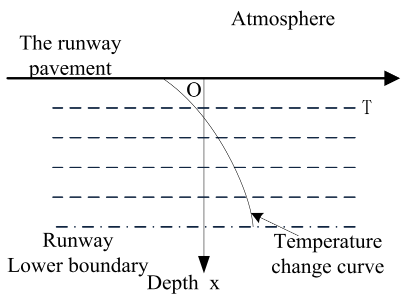


FIGURE 2. **The temperature field of airport runway.**

Then, the temperature field of airport runway can be regarded as a function of time and depth, i.e.

$$T = f (x, t) \tag{12}$$

According to Fourier's law [24], at time t, the heat flux through the airport surface is proportional to the rate of change of depth x, i.e.

$$G(t) = -\lambda \frac{\partial T(0, 1)}{\partial x} \tag{13}$$

where λ is the thermal conductivity of the material for the airport runway.

According to the energy conservation law, the total heat flow of the incoming pavement is equal to the sum of the heat flow of the outflow pavement and the internal energy increment of the runway, i.e.

$$\frac{\partial T}{\partial t} - \frac{\lambda}{\rho c} \frac{\partial T^2}{\partial x^2} = 0 \tag{14}$$

where ρ is the airport runway material density; c is the airport runway material specific heat capacity.

If $a = \frac{\lambda}{\rho c}, b = -\frac{1}{\lambda}$, the temperature field model of the runway can be obtained as

$$\begin{cases} \frac{\partial T}{\partial t} - a\frac{\partial T^2}{\partial x^2} = 0 \\ \frac{\partial T\left(0, t\right)}{\partial x} = bG\left(t\right) \end{cases} \tag{15}$$

b: SOLUTION OF THE PARTIAL DIFFERENTIAL EQUATIONS OF TEMPERATURE FIELD

The finite difference method is used to solve the partial differential equation, and the solution area mesh is constrained to the area enclosed by the time step and the space step, as shown in Figure 3.

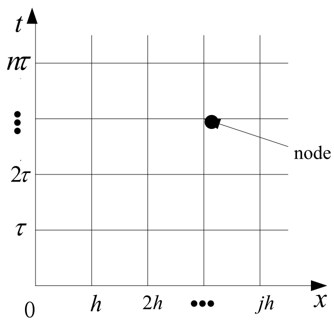


FIGURE 3. Regional gridding.

At (xj, tn), it is obtained by Taylor series expansion principle that

$$\frac{T\left(x_j, t_{n+1}\right) - T\left(x_j, t_n\right)}{\tau} = \left[\frac{\partial T}{\partial t}\right]_j^n + O(\tau) \tag{16}$$

$$\frac{T\left(x_{j+1}, t_n\right) - T\left(x_{j-1}, t_n\right)}{2h} = \left[\frac{\partial T}{\partial x}\right]_j^n + O\left(h^2\right) \tag{17}$$

$$\frac{T(x_{j+1}, t_n) - 2T(x_j, t_n) + T(x_{j-1}, t_n)}{h^2} = \left[\frac{\partial^2 T}{\partial x^2}\right]_j^n + O(h^2) \tag{18}$$

where, $[\ ]_j^n$ is the value at the node (x_j, t_n). If an infinitesimal quantity is omitted, the partial differential equation for the temperature field of the airport runway is obtained as follows:

$$\frac{T_j^{n+1} - T_j^n}{\tau} - a\frac{T_{j+1}^n - 2T_j^n + T_{j-1}^n}{h^2} = 0 \tag{19}$$

$$\frac{T_1^n - T_{-1}^n}{2h} = bG_0^n \tag{20}$$

Combine equations (19) and (20) to eliminate T_{-1}^n, prediction model of pavement temperature can be obtained as:

$$T_0^{n+1} = \frac{2\tau a}{h^2}T_1^n + (1 - \frac{2\tau a}{h^2})T_0^n - \frac{2\tau a}{h}bG_0^n \tag{21}$$

where T_0^{n+1} is the temperature of the pavement after τ time. T_0^n is the pavement temperature at the current moment; T_1^n is the temperature at the depth of h at the current moment; G_0^n is the pavement heat flux at the current moment.

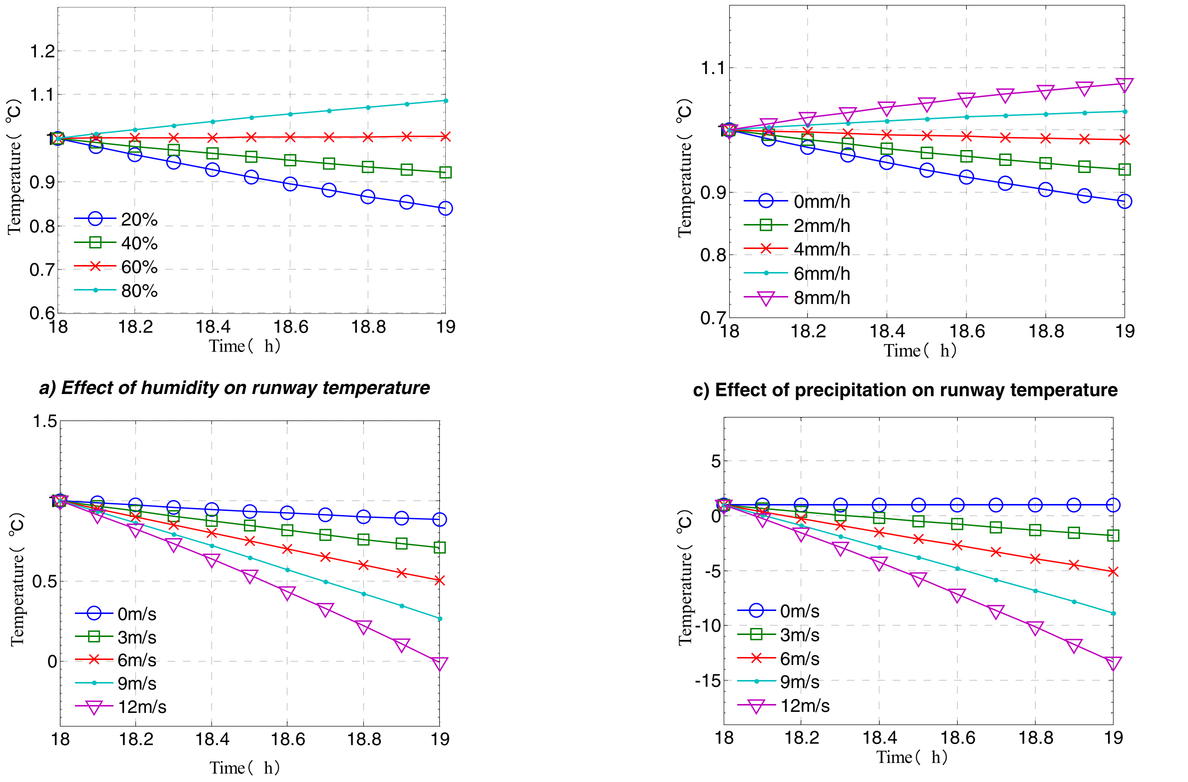
B. SIMULATION OF THE RUNWAY TEMPERATURE PREDICTION MODEL

Referring to the relevant research, the parameters of the pavement temperature prediction model as shown in Table 1 are obtained.

For the later experiments in second half of this paper, taking the time step $\tau = 3600$s, and the space step h=0.15m,

TABLE 1. Runway temperature prediction model parameters.

Parameters	Parameter meaning	Parameter value	Parameters	Parameter meaning	Parameter value
I_0(W/m^2)	Solar constant	1367	C_p(J/(kg•K)	Air specific heat at atmospheric pressure	1005.46
φ(°)	latitude	39.1142	C_H	Sensible heat transmission coefficient	0.00181
c(J/(kg•K)	Specific heat capacity of pavement materials	970	C_E	Water vapor transmission coefficient	0.0015
P_0(kPa)	Standard atmospheric pressure	101.325	L(J/(kg•K)	Latent heat of condensation	2.5×106
r	Surface solar radiation absorptivity	0.7	W_c(kg/m^2)	Saturated water absorption of the pavement	0.5
σ(W/(m^2•K^4)	Boltzmann constant	5.67×10-8	E_r(J/(kg•K)	Specific heat capacity of water	4200
ε_s	Pavement relative emissivity	0.9	λ(W/(m•K))	Thermal conductivity of pavement materials	1.7
ρ_a(kg/m^3)	Air density	1.29	ρ(kg/m^3)	Pavement material density	1930
J	number of days	345	P(kPa)	atmosphere pressure	*102.4*
Ta(℃)	atmosphere temperature	*2*	T1(℃)	runway temperature at the depth of 15cm	*4*
t_0(h)	start time	18			



a) Effect of humidity on runway temperature

b) Effect of wind speed on runway temperature

c) Effect of precipitation on runway temperature

d) Effect of wind on temperature in the presence of precipitation

FIGURE 4. Simulation curves of influence of different parameters on runway temperature.

the formula (22) is obtained for predicting the runway surface temperature after one hour. The parameters are shown in Table 1.

$$T_0^{n+1} = 0.29T_1^n + 0.71T_0^n - 0.0257G_0^n \qquad (22)$$

In the simulation, taking the time step $\tau = 360$s, and the space step h=0.15m, the formula (23) is obtained. Data such as initial conditions and environment parameters are shown in Table 1. Under the conditions of different humidity, wind speed and precipitation, the temperature is predicted every 6 minutes, and the simulation curves of the model are shown in Figure 4.

$$T_0^{n+1} = 0.029T_1^n + 0.971T_0^n - 0.002577G_0^n \qquad (23)$$

Figure 4-a set the weather condition as 0 for both wind speed and precipitation, 20%, 40%, 60% and 80% for air humidity. According to the simulation trend, when humidity were 20% and 40%, the trend of temperature decreased, while when humidity were 60% and 80%, the trend of temperature increased.

Figure 4-b set the weather condition as 0 for wind speed, 40% for humidity, and the wind speed was respectively 0m/s, 3m/s, 6m/s, 9m/s and 12m/s. It can be seen that the decreasing trend of the temperature increased with the increase of wind speed.

Figure 4-c set the weather condition as 0 for wind speed, 40% for humidity, and the precipitation was respectively 0mm/h, 2mm/h, 4mm/h, 6mm/h and 8mm/h. It can be seen that the simulation trend was similar to the trend of humidity. In a small amount of precipitation, the trend of the surface temperature curve decreased, and in the case of more precipitation, the trend of the surface temperature curve increased.

Figure 4-d added the condition of 2mm/h for precipitation on the basis of Figure 4-b. It can be seen that the drop of temperature curve was larger than the drop trend of Figure.4-b. According to the preliminary analysis of the graphs in Figure 4, the temperature prediction method basically accorded with the trend of actual weather. The algorithm would be verified by the actual experiment in the following paper.

III. ICING PREDICTION MODEL OF AIRPORT RUNWAY

A. INTRODUCTION OF THE RUNWAY ICING PREDICTION ALGORITHM

Meteorological factors, such as pavement temperature, wind speed and rainfall, are the most direct and main influencing factors of icing on airport runway. Although the factors are interrelated, the process is complicated. Nonlinear processes can describe the relationship between each other better. In the case of multi-variable and multi-influence conditions, the accuracy of the derived formula algorithm is usually not very ideal. This paper referred to a variety of algorithm research [25], [26]. Through the analysis of factors, the BP neural network, which contains non-linear, self-learning and self-adapting abilities, was used to study these meteorological factors. According to the data collected in advance, the training of the neural network was finished.

Few studies have considered the factor of underground temperature from previous studies. However, in the experiment of icing, it has been found that the underground temperature is another important factor affecting the rate of icing and whether or not icing occurs. Therefore, Considering the influence of underground temperature on the icing of pavement, comparisons were made between the presence and absence of underground temperature in neural network algorithms. This paper chose the main factors affecting the icing of airport pavement as the input of BP neural network, as follows: predicted runway temperature, atmospheric temperature, relative humidity, wind speed, icing point temperature, precipitation, internal runway temperature.

B. FLOW OF ICING PREDICTION ALGORITHM FOR RUNWAY

The three-layer BP neural network as shown in Figure 5 was designed. In order to study the influence of icing prediction model for pavement after adding underground temperature, two BP neural networks were trained at the same time, one did not add underground temperature and the other did. Among them, the input data set contained 6 or 7 influencing factors such as pavement temperature, predicted temperature, air humidity, wind speed and precipitation predicted. According to the empirical formula, the optimal node of hidden layer is

$$H = \sqrt{I + O} + a, \quad a \in [1, 10] \tag{24}$$

where H is the number of hidden layer nodes; I is the number of input layer nodes; O is the number of output layer nodes.

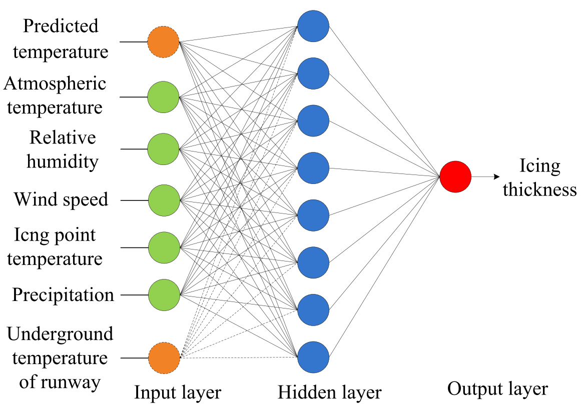


FIGURE 5. BP neural network structure diagram.

When selecting the number of hidden layers, set the number of iterations as 6000, 20000, 50000, 100000, and trained BP network for 3-10 nodes of hidden layers with training data respectively. The results showed that the number of nodes with good error accuracy of the neural network considering the underground temperature was between 7-9, and the training time was the fastest when the number of nodes was 8. So the number of nodes in the hidden layer was selected as 8, $\alpha \approx 5$. The optimal error accuracy point of neural network without considering the underground temperature was 8, so the number of nodes in the hidden layer was also selected as 8, $\alpha \approx 5$. The output layer consisted of only one neuron that output the prediction of the ice thickness of runway.

The mapminmax function in MATLAB was used to normalize the data. The function realizes normalization according to the maximum and minimum values in the data. The normalization formula is shown in formula (25) :

$$y = \frac{(y_{max} - y_{min}) \times (x - x_{min})}{x_{max} - x_{min}} + y_{min} \tag{25}$$

The traingd function was selected as the training algorithm. Compared with other functions, traingd function has the advantage of occupying less memory in operation, but its disadvantage is that it runs slowly. Therefore, the basic traingd function was selected here, and the method of increasing iteration times was used to compensate for the shortcoming of slow running speed. Similarly, for the selection of transfer function, the logsig function which is commonly and basically used was selected in the hidden layer, and the purelin function was selected in the output layer considering the shortcomings of logsig function in maxima and minima.

The flow chart of neural network training is shown in Figure 6.

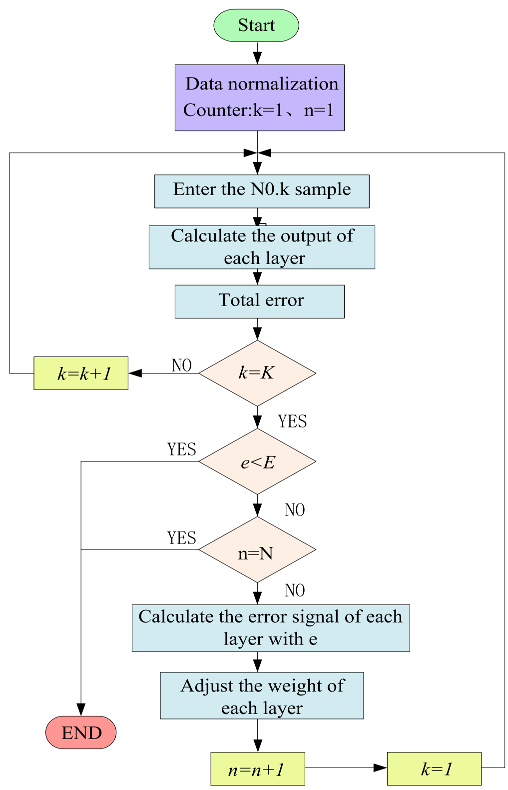


FIGURE 6. BP neural network training flow chart.

TABLE 2. BP neural network parameters.

The name of the function	Function selection	Training parameters	Parameter meaning	Parameter value
Normalization function	mapminmax	net.trainParam.epochs	Iteration times	300000
Hidden layer transfer function	logsig	net.trainParam.goal	Error accuracy	0.05
Output layer transfer function	purelin	net.trainParam.lr	Learning rate	0.3
Training function	traingd	S1	Number of hidden layer nodes	8
		S2	Number of output layer nodes	1

The values of initial weights and thresholds should be given first. The method used here was to set the number of iterations as 100,000 and repeat the training process for several times to get multiple groups of weights and thresholds. The weights and thresholds of the groups with the smallest error in the training were selected as the initial weights and thresholds, and the neural network training continues with 300000 iterations on this basis.

In MATLAB, BP neural network toolbox was used to construct two three-layer networks, one had 7 inputs and predicted the ice thickness by taking into account underground temperature parameter, and the other had 6 inputs without considering underground temperature parameter. The two neural networks above were trained with data respectively. All parameters of the networks were configured in the same way, as shown in Table 2.

253 sets of training sets and 90 sets of testing sets were used in the training of neural networks. Some of the 343 sets of data are shown in Table 3.

IV. DESIGN OF AIRPORT RUNWAY ICING PREDICTION SYSTEM

A. STRUCTURE OF THE RUNWAY ICE PREDICTION SYSTEM

In order to make the airport staff reasonably and accurately give the airport operation instructions and complete the airport service tasks, a system that can timely feedback the real-time information and various environmental data of the airport is very necessary. Based on the research of the runway temperature and ice thickness predictions, the prediction system of temperature and ice thickness was established. This system can make the airport staff know the airport temperature and icing conditions in time, and it also can help the staff to grasp the airport environment situation in real-time, and assist them to make more accurate and efficient operation decisions of the airport.

This system adopted three-layer structure. In the bottom layer, there were various intelligent information sensors of the airport. And equipped with data collection boards to collect various environmental data of the airport, package and process the data, so as to facilitate data transmission in the middle layer. The middle layer mainly adopted the GPRS DTU wireless data transmission module, which was used to transmit the data collected and packaged by the data collection boards. Considering the safety and the particularity of the environment of the airport, it is difficult to realize the data transmission by means of physical wiring. So, wireless communication was a very reasonable choice. The top layer was industrial personal computer (IPC). Configuration software that provided human-computer interaction function and wireless data software to receive data from the middle layer was installed in IPC. Using Visual Studio 2015 (VS2015) platform, ActiveX controls which can be used in configuration software and embedded experimental results algorithm were developed. And the function of configuration software was greatly expanded. The whole system structure is shown in Figure 7 below.

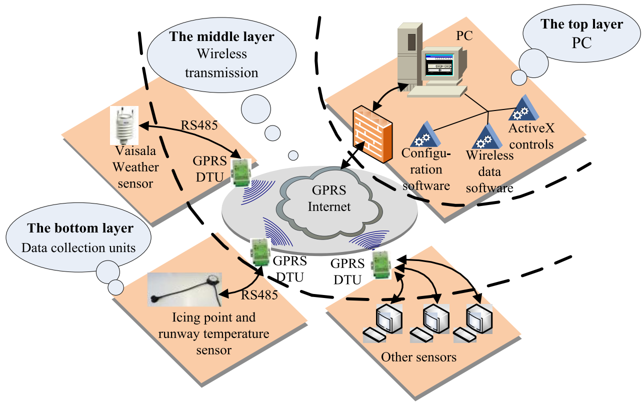


FIGURE 7. Icing prediction system structure.

B. DESIGN OF ActiveX CONTROLS EMBEDDED ALGORITHM MODULE

1) INTRODUCTION TO ActiveX CONTROLS

ActiveX controls are modules that encapsulate specific functions, and its operation depends on the containers. For example, the edit boxes, buttons and combo boxes used in creating software interfaces are controls. These controls expand the

TABLE 3. Data of training set and test set.

	Num	predicted temperature (℃)	atmospheric temperature (/℃)	relative humidity (%)	wind speed (m/s)	icing point temperature ℃	precipitation /mm	underground temperature /℃	(t+30)min ice thickness /mm
training set	1	-1.44	-1.57	38.42	0.5	-0.5	2	2.8	0.34
	…								
	110	-2.97	-4.85	47.77	2.6	-0.5	2	1.95	1.63
	111	-0.29	-1.74	30.39	2.6	-0.5	5	3.64	1.52
	…								
	209	-0.6	-6.01	72.95	2.6	-0.5	5	1.75	4.824
	210	-0.44	-5.12	70.53	2	-0.5	10	-1.06	3.327
	…								
	253	-0.37	-7.19	74.37	3.2	-0.5	10	-0.54	5.6
test set	1	-0.44	-2.27	40.04	0.5	-0.5	2	2.9	1.139
	…								
	37	-2.74	-5.15	45.66	2.6	-0.5	2	2.02	1.336
	38	-0.29	-1.75	29.51	2.6	-0.5	5	3.65	1.552
	…								
	73	-0.52	-5.92	73.46	2.6	-0.5	5	1.81	4.433
	74	-0.29	-5.12	67.26	2	-0.5	10	-1.02	3.87
	…								
	90	-0.44	-7.49	73.22	3.2	-0.5	10	-0.47	5.571

function of the software and have strong stability. In addition, ActiveX control has strong compatibility in various software platforms, and can be easily invoked to achieve the expansion of various functions. VS2015 provides MFC ActiveX Control Wizard based on C++ to create ActiveX controls. This Wizard provides the underlying framework for software development. It can be used to configure project variables, connect external property interfaces and develop control functions directly. After compiling, it generates control files in OCX format. Users can register on other computers and use them.

ActiveX controls mainly consist of three elements: Properties, Methods and Events. The property of the control is the state variable that can be modified by various properties, including environment, extension, inventory and customization. The method of a control is a function in the control that can be called by a container application. The event of the control is a notification message sent to the container to inform the application that it needs to take action on an event. The container controls the control by setting property and calling algorithms, while the control notifies the container through event ignition mechanism to take corresponding measures. The relationship is shown in Figure 8 below.

ActiveX controls provide a series of external interfaces through which an application can trigger various functions

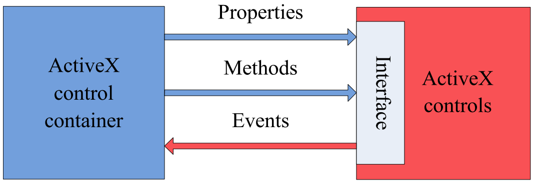


FIGURE 8. Interface relationship of controls.

in the controls. Interfaces can be used to trigger events in the controls or applications, modify property pages of the control or convey control state. When using the ActiveX control wizard, it automatically completes the tedious writing of the basic interface program, so that the developer can focus on the required functions of the controls.

2) FUNCTIONS OF ActiveX CONTROLS

For the prediction of temperature formula derived from the above, the time and depth were 2 variables can be selected according to the situation, and by using BP neural network prediction algorithm of ice thickness, complex result calculation of weights and thresholds requires a number of variables. ActiveX control, where the correlation with configuration system variables can be achieved and complex operations can be embedded, can well realize the results of the two studies. This system used Microsoft MFC ActiveX control technology to embed the forward propagation algorithm of the neural network into it. By connecting the control with the variables of the configuration software, the variables were introduced into the controls for calculation, and the output results were displayed in the configuration software. The process is shown in Figure 9 below.

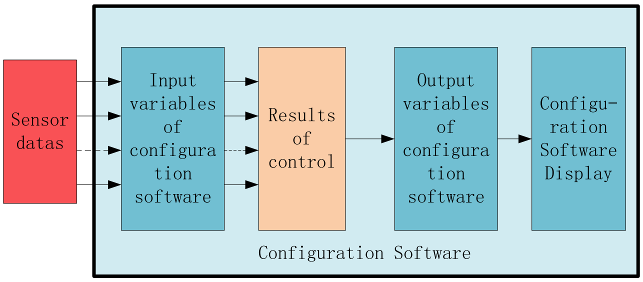


FIGURE 9. Configuration software and control operation process.

3) DEVELOPMENT OF ActiveX CONTROLS FOR ICE THICKNESS ALGORITHMS IN VS2015

ActiveX control development steps:

Step1: Control underlying framework creation

Create a control project named "P_TH" and build the basic framework of the control.

Step2: Add control property variables

Create a callable external property variable interface. Then adding the required "Float" variables and modifying the variable ID in "Ctrl.h".

Step3: Embedded timing and algorithm functions

After the variable connection was completed, the required function is embedded in the control. The timer– OnTimer function controls the function periodically with a preset time of 1 s.

The calculating process of timer embedded algorithm function is shown in Figure 10 below. The variables such as weights and thresholds needed after training were copied into the control and invoked globally.

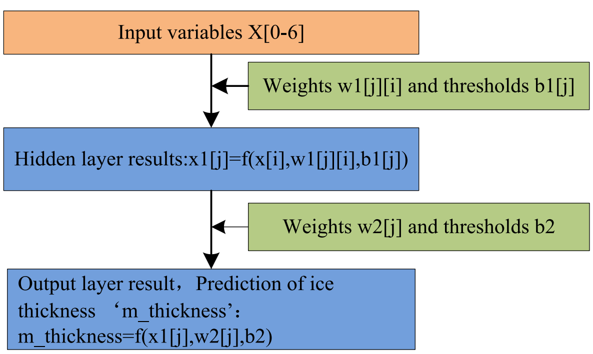


FIGURE 10. Flow chart of algorithm for ActiveX control.

Step4: Compile and register

After setting up and compiling, controls are automatically registered and it can be invoked in the configuration software.

C. DESIGN OF THE WIRELESS COMMUNICATION MODULE

Considering the safety and the environment particularity of the airport, if the data transmission was carried out by physical wiring between the collection point and the display control center, it is not only because laying cables under the ground cause damage to the ground structure of the airport, but also because the inspection and maintenance of cables in the later stage may affect the operation of the airport. Because in the busy operation of the airport, once the lines are damaged, maintenance becomes a difficult task and may cause secondary damage. Therefore, there are some difficulties in the realization of using wire connection. This system used GPRS technology to realize data wireless transmission.

At present, the GPRS public network has covered most of the nation, and its data transmission delay is within the range of seconds. The average delay is about 2s, and the communication rate is between 10kbps-60kbps, which is very sufficient for the data collection of this system. The current GPRS DTU devices have the following characteristics: 1) integrated TCP/IP protocol stack; 2) "transparent conversion" of serial data without changing the original data content; 3) support GPRS users to be online permanently; 4) device configuration parameters are permanently retained.

GPRS DTU logs on the GSM network and dial-up. After successful dialing, GPRS DTU will get an internal IP address randomly assigned by the network. However, its intranet IP address is usually not fixed and varies with each dial. Therefore, DTU equipment is required to actively connect data center with fixed public IP addresses, and then send data from the data center to the interface software installed in PC, and complete data interaction by reading interface software data through configuration software. The process of data wireless transmission is shown in Figure 11 below.

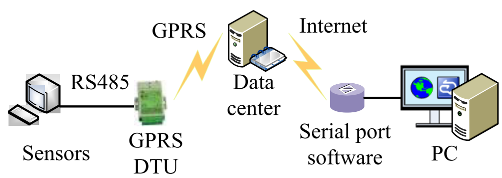


FIGURE 11. Flow chart of data wireless transmission.

D. DEVELOPMENT OF RUNWAY ICING PREDICTION SYSTEM

The three-layer structure of the runway icing prediction system was designed from two aspects of hardware and software respectively. The overall structure of the system was described in Figure 7 above. And the operational data flow chart of the system is shown in Figure 12 .

1) HARDWARE DEVELOPMENT OF RUNWAY ICING PREDICTION SYSTEM

At the data collection terminal, platinum thermal resistance, weather sensor, humidity sensor, road surface icing point sensor and ice thickness sensor were set to collect various environmental data required by the system. The temperature

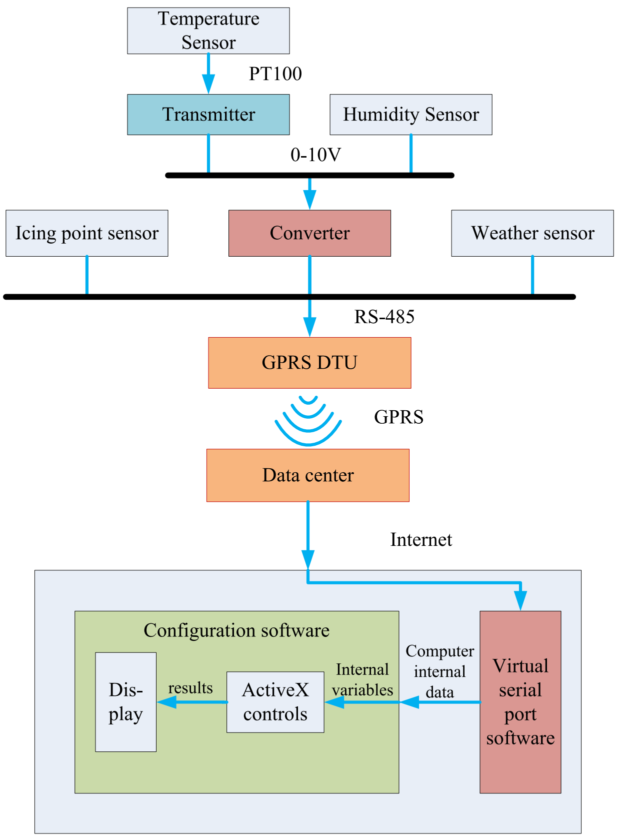


FIGURE 12. Flow chart of system data information transmission.

sensor data was connected to the pt-100 to 0-10v signal transmitter, and the 0-10v signal was connected to the analog input module Adam 4017+ together with the humidity sensor to convert the signal into RS-485 data. Meteorological and icing point sensors used RS-485 bus for data transmission.

The data collection terminal is shown in Figure 13-a. The data was connected to the GPRS DTU wireless transmission device through the RS-485 bus and sent, and the data was received through the software terminal. The physical picture is shown in Figure 13-b.

a) The data collection terminal b) GPRS DTU wireless device

FIGURE 13. Hardware of runway icing prediction system.

The data transmission path of the hardware system is shown in Figure 14.

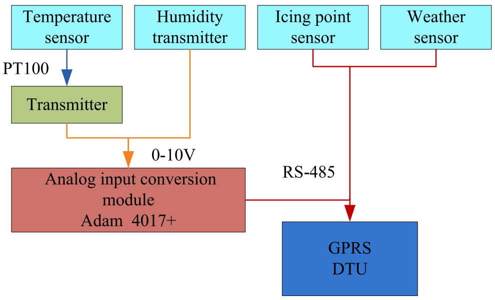


FIGURE 14. Schematic diagram of GPRS DTU data transmission.

In order to ensure the authenticity and accuracy of the pavement temperature prediction method, the GPRS DTU data collection and transmission system for airport pavement prediction was built based on schematic diagram of the airport icing prediction system as shown in Figure 15 by using the sensors of the prediction system.

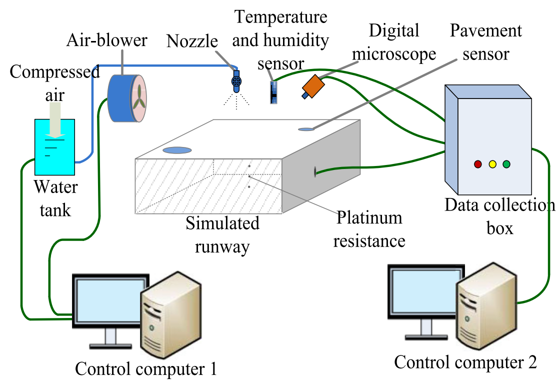


FIGURE 15. Schematic diagram of icing prediction model for airport runway.

2) SOFTWARE DEVELOPMENT OF RUNWAY ICING PREDICTION SYSTEM

According to the whole framework of the runway icing prediction system, the sensors completed data collection, and data transmission was realized through GPRS DTU equipment. Finally, the general control configuration system was developed in industrial PC.

a: DEVELOPMENT OF BASIC SOFTWARE FRAMEWORK

The configuration software used in the system was the "KingView" software developed by WellinTech, Inc. In kingview "device", virtual device serial port was added to read the data transmitted by GPRS DTU device from the wireless data transmission serial port software. In the "Data Dictionary", the type and address of the variable were defined according to the data transmitted by the virtual serial port.

b: INSERTING ActiveX CONTROL IN CONFIGURATION SYSTEM

Create a system interface and add the controls created in the previous section to the interface. Then the ActiveX controls and Kingview were connected through the interface, and the algorithms inside the controls were called to complete the calculation of the prediction results. As shown in Table 4, the variable of controls was connected to the kingview .

TABLE 4. Control variable connection in Kingview.

PROPERTY	TYPE	VARIABLES
airh	FLOAT	<->\\本站点\airh
airt	FLOAT	<->\\本站点\ airt
icet	FLOAT	<->\\本站点\ icet
rain	FLOAT	<->\\本站点\ rain
road3t	FLOAT	<->\\本站点\ road3t
roadt	FLOAT	<->\\本站点\ roadt
thickness	FLOAT	<->\\本站点\ thickness
thtimer	FLOAT	<->\\本站点\ thtimer
windv	FLOAT	<->\\本站点\ windv

c: VIRTUAL INTERFACE SOFTWARE SETTINGS

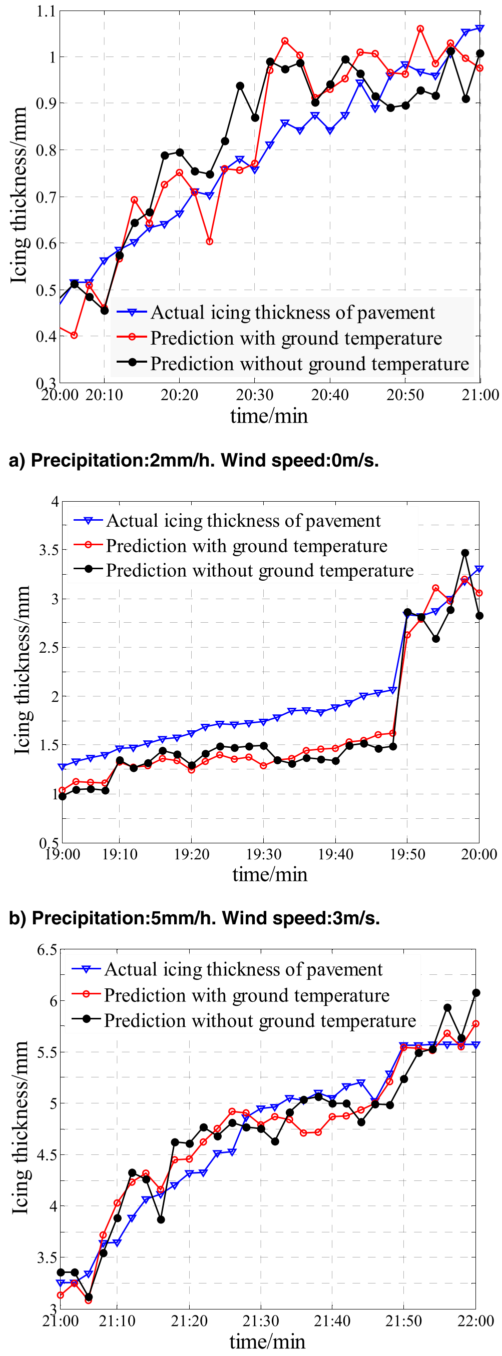
Virtual interface software used dynamic domain name resolution software, commonly known as ''peanut shell''. GPRS devices used dynamic IP addresses. Through address resolution, the data was transmitted into the fixed domain name address of the software, and connected with the configuration software, and the virtual serial port was set in the configuration software to complete data reception.

V. EXPERIMENT AND TEST OF RUNWAY ICING PREDICTION SYSTEM

A. EXPERIMENTS AND RESULTS ANALYSIS OF RUNWAY ICING PREDICTION SYSTEM

The runway environment was simulated on the airport runway icing prediction system, and the experimental data of runway icing was collected by controlling the parameters of wind speed, precipitation and so on. Using the runway icing prediction system, the prediction data of airport runway icing after one hour was collected, and the prediction algorithm of neural network without underground temperature was also used to predict the icing thickness after one hour. The results of the two algorithms were compared with the measured values one hour later, and the comparison between the predicted values and the measured values as shown in Figure 16 was obtained.

It can be seen from Figure 16 that the ice prediction curve of the whole runway has a high degree of agreement with the actual icing condition, and the two icing prediction curves of the models with the underground temperature and without the underground temperature are close to each other. However, the ice thickness predicted by the icing prediction model with considering the underground temperature is more similar to the actual temperature of the pavement, and the fluctuation range is smaller.



a) Precipitation:2mm/h. Wind speed:0m/s.

b) Precipitation:5mm/h. Wind speed:3m/s.

c) Precipitation:10mm/h. Wind speed:5m/s.

FIGURE 16. Comparison of runway icing thickness.

It can be obtained from the analysis of error distribution Table 5 that the ice thickness prediction model of airport runway with considering underground temperature has a higher accuracy, that is, the icing accuracy of runway with underground temperature taken into account is 13% higher than that of the icing prediction model neglecting underground temperature, which verifies the accuracy and feasibility of the icing prediction model of runway with underground temperature taken into account.

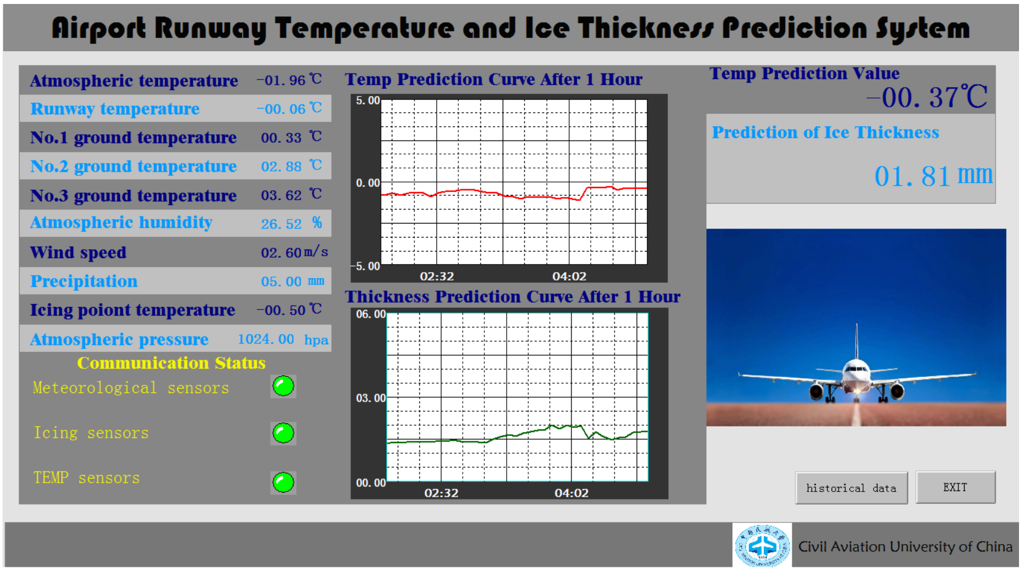


FIGURE 17. System software operating interface.

TABLE 5. Error distribution of icing prediction model.

Meteorological conditions	MSE /mm	
	With underground temperature	Without underground temperature
Precipitation 2mm/h, Wind speed 0m/s	0.1106	0.1288
Precipitation 5mm/h, Wind speed 3m/s	0.2590	0.2857
Precipitation 10mm/h, Wind speed 5m/s	0.2141	0.2555

B. TESTS OF THE WHOLE THE RUNWAY ICING PREDICTION SYSTEM

The stability and data calculation ability of the completed system are important indicators of whether the system can be used efficiently and smoothly in actual working conditions. The data collection and wireless communication system was placed in the outdoor environment, as shown in Figure 13-a. The control box has been covered and protected to prevent damage caused by weather and human factors. The selection of the equipment fully took into account the operating state in cold weather, so the hardware system can fulfill the tasks.

In terms of software operation, the Kingview software used in this system is a very mature industrial configuration software, and there are few downtime phenomena in operation. Even after adding ActiveX controls, because the embedded algorithm controls themselves use very few resources, the impact on the stability of the system operation can be neglected. In terms of the algorithm operation of the control, after the data connected, the calculation of the algorithm can achieve the effect of the second level. The system's problem is data loss caused by sensors or DTU data transmission devices. These problem needs to be solved by choosing more stable and accurate sensors and wireless transmission devices. The actual developed and running system is shown in figure 17 below:

VI. CONCLUSION

Aiming at the problem of icing prediction of airport pavement in winter, this paper proposed an icing prediction method of airport pavement considering underground temperature, and established a prediction model of runway temperature based on energy conservation. By establishing the temperature and ice thickness prediction system, the experimental results were compared with the actual results, and the following conclusions are obtained:

1) Based on the simulation of airport runway, the temperature prediction formula was derived with the consideration of underground temperature, and the prediction of runway temperature basically in line with the actual temperature trend.

2) The average prediction accuracy of ice thickness of airport pavement with underground temperature considered was 13% higher than that without underground temperature, which can be used for the icing prediction of airport pavement in winter, and the feasibility of BP neural network in the prediction problem was verified. However, the prediction of the icing in different regions still needs further study.

3) The system can run for a long time and has a high stability in operation. Considering the special situation of the airport, the wireless data transmission method was adopted, which had a high feasibility. Due to hardware and wireless transmission, there will be occasional packet loss of data, but the impact on system operation was negligible.

4) Using ActiveX control technology, in the future system and experiment, not only the control can be used in a variety

of configuration systems, but also can be embedded with more algorithms that greatly enriching the function of the system.

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