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Research of Multi-Information Integration for the Aircraft Ground Centralized Deicing Monitoring System Based on Wireless Data Transmission

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ABSTRACT In this paper, an aircraft ground centralized deicing monitoring system of multi-information integration is proposed. The multi-information integration system consists of system architecture, database, and monitoring terminal. Among them, the prediction module of ice accumulation calculates ice thickness of the aircraft based on the meteorological data that are collected by the data acquisition module and saved in the database. At the same time, the system uses the methods that GIS is used for making map to locate deicing vehicle precisely, data are transmitted through GPRS, and computer scheduling is adopted, which can ensure the smooth aircraft deicing process and improve the efficiency of the aircraft ground deicing. The practical results show that the proposed monitoring system of aircraft ground centralized deicing increases the efficiency of deicing by 26%. Furthermore, the feasibility and effectiveness of the proposed system are verified.

INDEX TERMS Aircraft ground centralized deicing, information integration, ice accumulation prediction, computer scheduling, GIS and GPRS.

I. INTRODUCTION

With the development of society and the improvement of people's living standards, it becomes more and more popular to travel by plane. In order to meet increasing demand for travelers, it is particularly critical to ensure the flight safety and the punctuality rate. However, there are many factors threatening the safe operation of the aircraft, of which, aircraft icing is easy to cause an airplane crash in winter [1]. So aircraft deicing must be finished quickly before take-off. Furthermore, the efficiency of aircraft deicing will affect the punctuality rate of aircraft directly under ice and snow conditions. According to the data provided by Beijing capital international airport in 2007, it takes about 20 to 30 minutes to deice B737 flight for the mode of non centralized deicing [2]. In real situations, the non centralized deicing takes a long time, causing higher deicing cost. Besides, the existing aircraft deicing system mainly relies on manual scheduling and wired data transmission. And information collected is also basically dispersed for existing aircraft deicing system, which will result in lack of comprehensive analysis of data, difficulty of line maintenance, data transmission and vehicle scheduling lag, and other issues. Hence, in order to ensure the punctuality rate, managerial staffs need to keep abreast of the information including deicing equipment, the allocation of the deicing flat, and so on. At present, energy saving, green and environmental protection have been the common goal pursued by airports and airlines because they are attracted by the form of smart airport. Therefore, it is essential to reduce the use of deicing fluid. To solve these problems, a multi-information integration system based on wireless transmission is designed in this paper. The system can help managerial staffs know the information about the whole process of aircraft ground centralized deicing in time. According to actual real-time situation, managerial staffs can carry out the deicing vehicle scheduling reasonably and efficiently.

For example, the United Parcel Service Company (UPS) designed an airport management system based on Automatic Dependent Surveillance-Broadcast (ADS-B). The system can offer safer, more efficient and environmentally friendly awareness for pilots and reduce more costs at air traffic controllers than other airport management system. The ADS-B data can be recorded and downloaded for post-flight analysis. In addition, ADS-B also provided the inexpensive data support for flight tracking, planning, and dispatching [3]. Moreover, Wang and Wang [4] proposed a method that fuses GPS, GIS, GSM and other wireless communication technologies. GPS and GSM were used to transmit the exact positions of vehicle to the GIS that was operating in monitoring center. Besides, Peng and Lin [5] embedded GIS under VxWorks operating system platform together with his team. This application can monitor aircraft and various vehicles of airport, and process data fusion effectively. Comprehensive analysis of data fused can help staff identify flight number, aircraft type, flight speed and other important information.

In this paper, a set of airport ground deicing system based on GIS and GPRS is designed [6]–[8]. The method of concentrated deicing is adopted by the system. In this way, the deicing system can monitor position of deicing equipment, staff, temperature of deicing fluid and other information. At the same time, the whole process of aircraft ground centralized deicing is dispatched by computer, which will achieve optimal allocation of resources, improve deicing efficiency and avoid to cause a large delay in flight.

II. SYSTEM STRUCTURE AND FUNCTION

The system is divided into hardware and software parts to design. In the hardware design, the acquisition terminal, the prediction terminal and the database are integrated into the system. For software design, the prediction module of ice accumulation is embedded in the system.

A. HAREWARE SYSTEM

In the proposed multi-information integration system, the deicing facilities consist of a variety of monitoring and display terminals. And data communication will be carried out through wireless network based on GPRS. The information in the monitoring and display terminals originates from data collection terminal and icing mechanism prediction unit. The icing mechanism prediction unit is used to act as predicting ice thickness on the surface of aircrafts. Some of data collected serve as the input source for icing mechanism prediction unit, and the other serves for the display terminal. In this way, the hardware system achieves data sharing and interaction through the database server that combines airline resources with airport resources under the same LAN. And GPRS wireless module is added in order to overcome the limitation of airport network communication and reduce expensive costs of remote line laying. Meanwhile, the fixed IP address is used by the airport to overcome the phenomenon of data packet loss. So a process-oriented information service platform, realizing real-time data display under a big data environment, is established, which can help personnel dispatch the whole process of aircraft concentrated deicing and improve the efficiency of the deicing process. The architecture of hardware system is shown in Figure 1.

In addition, data acquisition unit, as one of data sources, will collect a variety of data from the airport. Among them,

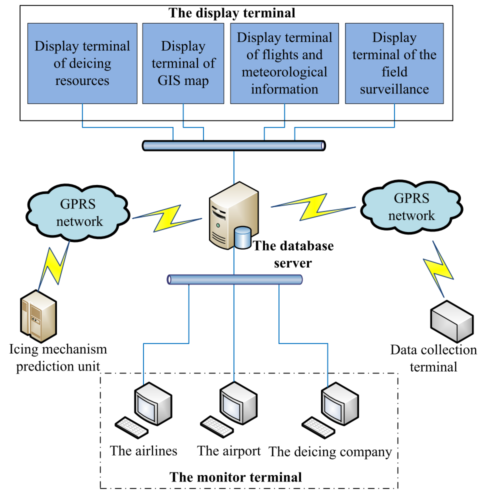

FIGURE 1. The architecture of the hardware system.

the meteorological data will provide icing mechanism prediction unit with forecasting ice thickness on aircraft surface. Furthermore, other data mainly include the position information of deicing equipment, and so on. All of the above information will be transmitted to database server through the GPRS network. Moreover, monitoring terminals of the airlines and airports will display the current flight dynamics and weather information. These data from database server are displayed on the display terminal in real time. So managerial staffs can schedule the deicing resources in time through comprehensive analysis of dynamic information of deicing resources, making the whole deicing process more efficient.

B. SOFTWARE SYSTEM

The real-time information is needed for managerial staffs to allocate deicing resources reasonably, which will be helpful to enhance the efficiency of the whole deicing process and assure the punctuality rate of flight. The data flow of the system is shown in Figure 2.

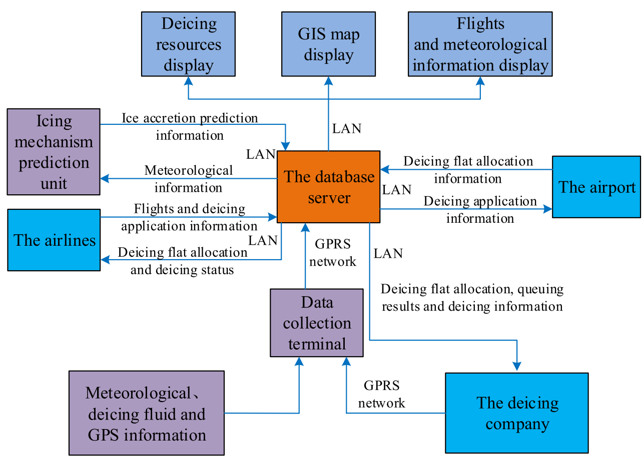

FIGURE 2. The data flow of the system.

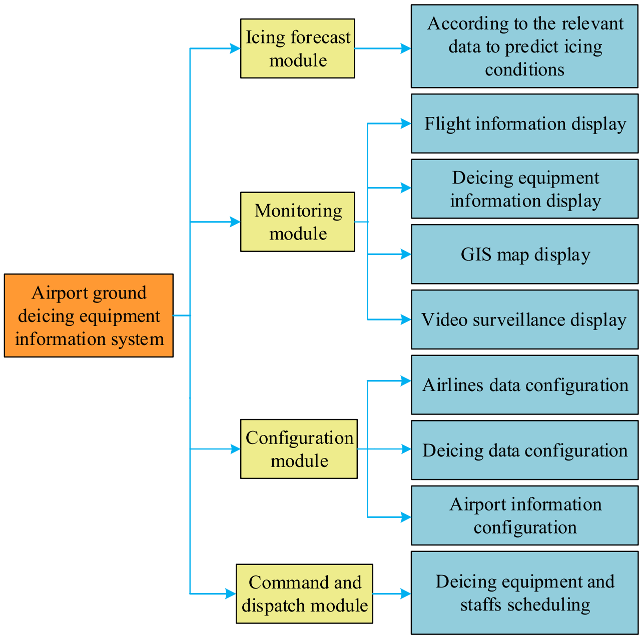

FIGURE 3. System function structure diagram.

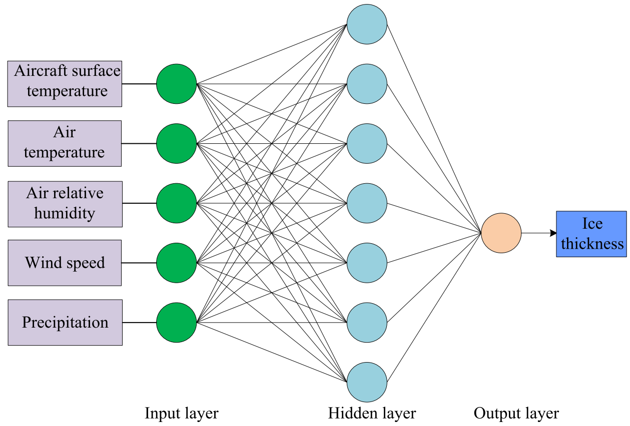

FIGURE 4. BP neural network structure diagram.

TABLE 1. BP neural network parameters.

Function	Selection function	Training parameters	Parameter definition	Parameter value
Initialization	Mapmin -max	net.trainParam. epochs	Num. of iterations	30000
Hidden layer	logsig	net.trainParam. goal	Error accuracy	0.0001
Output layer	logsig	net.trainParam. lr	Learning rate	0.3
Training function	traingd			

C. FUNCTION STRUCTURE DIAGRAM

When there are a lot of flights, the aircrafts need to stand in a queue to have ice/frost of their body cleaned by the deicing equipment before they taking off. As deicing equipment and personnel are in different regions, the whole scheduling process usually exists serious lag. So the deicing control and management system is designed to integrate the information of deicing equipment, staffs, weather conditions and flight situation. The modular design is applied in the system so as to satisfy the demand of airport deicing scheduling. The system function structure diagram is shown in Figure 3.

1) CONFIGURATION MODULE

The configuration module includes airlines data configuration, deicing data configuration and airport information configuration. All of these data are provided by deicing companies and airport management agencies. The deicing companies provide the status of equipment and staffs, and airport management agencies provide the information of weather, deicing sequence and distribution of deicing area.

2) MONITORING MODULE

The monitoring module displays data on a large screen, which can provide field information for the dispatch center.

3) ICING FORECAST MODULE

The icing forecast module can forecast ice thickness on aircraft surface based on meteorological data. And the information of ice thickness may be displayed on the screen of ice removal scheduling information in the dispatching center.

As shown in Figure 4, the prediction module is based on the BP neural network to predict ice thickness. TABLE 1 shows the selection of training parameters for the BP neural network. The gradient descent method is used to train the network, and the trained neural network is encapsulated as a control module to predict the ice thickness of the aircraft surface.

4) COMMAND AND DISPATCH MODULE

The goal of command and dispatch module is sure of the safety of deicing flights and maximization of deicing efficiency, which is based on the status of deicing equipment and arrival and departure time of flights for queuing up.

III. SYSTEM DEVELOPMENT

A. GPRS DATA ACQUISITION AND COMMUNICATION

1) MASSIVE STRUCTURE

The data transmission system is comprised of data acquisition terminal, GPRS network, external Internet and monitoring center [9], [10]. Among them, GPRS module transmits data of RS232 protocol through GPRS network, so the device needs

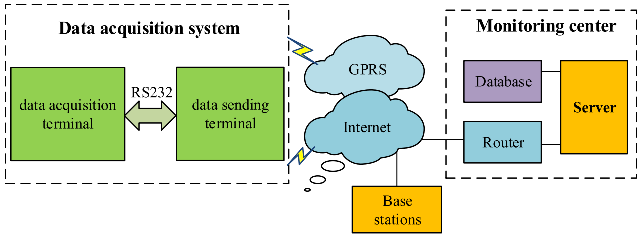

FIGURE 5. GPRS data transmission system structure.

to install SIM card. It achieves communication between field and monitoring center. Figure 5 is the structure of GPRS data transmission system.

2) GPRS COMMUNICATION TECHNOLOGY

The GPRS transmission follows point-to-point protocol. Firstly, data acquisition terminal sends data, which are converted to the RS232 protocol by the RS485 protocol, to data sending terminal, namely, GPRS module. And then, the GPRS module packs IP data up. Finally, IP data packed, which access GPRS network by GPRS module, are sent to server marked destination address through the gateway of router [11], [12].

There are two channels that these data are transmitted to the monitoring center. In the first channel, the GPRS module is used as a middleware between GPRS network and data. And Internet from base stations is used as the accessing path in the second channel. In this paper, the first channel that has mature technologies is adopted, for which can achieve more services.

B. PHYSICAL DATA ACQUISITION STRUCTURE

These physical data are distributed in the airport flying area, and data of different regions have different types and structures. And then, sensors corresponding with these physical data are needed for collecting data. The devices used in the system can be classified as:

1) MOBILE DIGITAL VIDEO RECORDERS (MDVR)

MDVR is used to monitor operating status and parameters of deicing equipment in real time. Meanwhile, it reports the vehicle's information via GPS.

2) METEOROLOGICAL SENSOR

The WXT520, a product of VAISALA company, is used to collect meteorological parameters, such as temperature, wind speed, relative humidity (RH), atmospheric pressure and other parameters.

3) ICE THICKNESS SENSOR

The ice thickness sensor is made by using Fiber Optic Sensor (FOS), Resistance Temperature Detector (RTD) and Micro Control Unit (MCU). The sensor can detect icing thickness and temperature of aircraft wings.

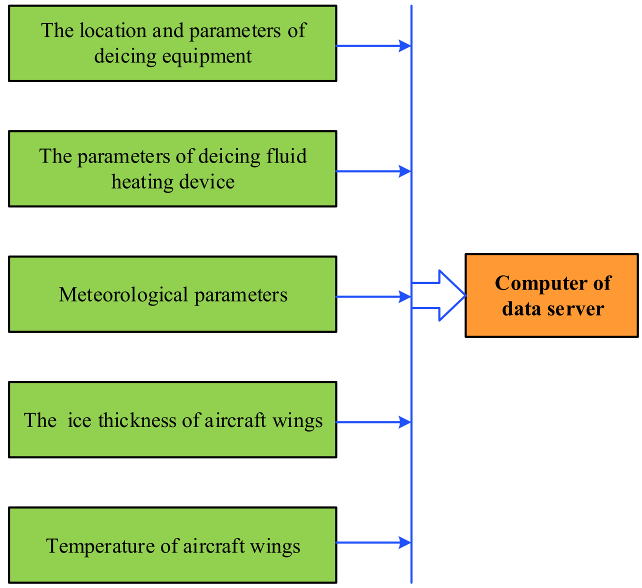

FIGURE 6. Physical data acquisition structure.

These data that are collected by above sensors are sent to the computer of data server via Data Transfer Unit (DTU). The physical data acquisition structure is shown in Figure 6.

C. THE DATABASE DESIGN OF THE SYSTEM

The indispensable database is the core of the whole system, which is used for data storage. The performance of database depends on how it transfers data to every part effectively and how to minimize the storage of redundant data [13]–[15].

Based on these requirements, the design of database should be as:

1) STORAGE INFORMATION RELATED TO THE DEICING EQUIPMENT

The information related to deicing equipment includes the number of device, the status of device, operators, deicing fluid temperature and flow in the device, and so on.

2) STORAGE INFORMATION RELATED TO THE FLIGHT

The information related to the flight consists of the number of the flight, aircraft type, deicing time of the flight, deicing status of the flight, and so on.

3) FACILITATE THE WORK OF THE COMMAND AND DISPATCH

The managerial staffs can check the real-time information to make the work of the command and dispatch more reasonable and timely.

As shown in Figure 7, the E-R diagram of database is drawn based on the above requirements. Among them, m represents the number of operator of deicing equipment, and the operator needs to operate m sets of deicing equipment. In addition, n denotes the number of flights to be deiced.

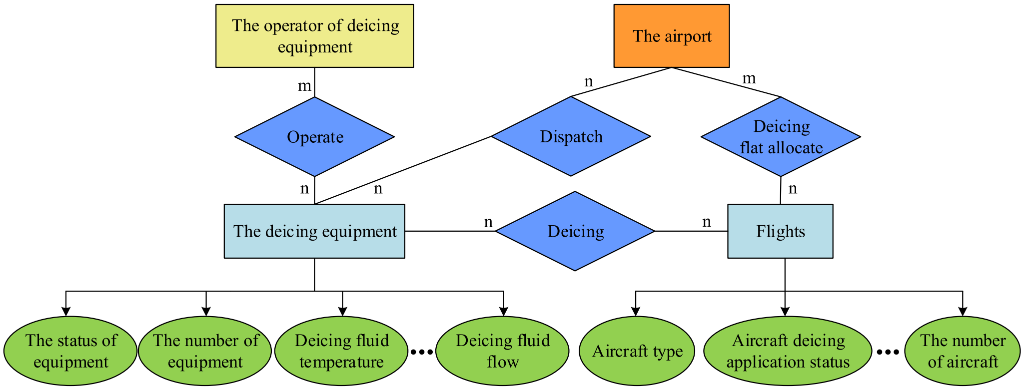

FIGURE 7. The E-R diagram of database.

TABLE 2. The definition of the character in database table.

Character	Definition
Flight_num	The unique identification the flight NO.
Flight_type	The type of flight
Arrival Time	Arrival time of flight
Depart Time	Depart time of flight
Deice_apply	Apply for deicing
Eq_num	The number of deicing equipment
Eq_status	The status of deicing equipment
Operator	The operator of deicing equipment
Fluid_temp	Deicing fluid temperature
Fluid_rem	Deicing fluid flow
Deicing_STime	Initiate time for deicing
Deicing _ETime	End time of deicing
Deicing _sta	The status of deicing
Deicing flat_num	The number of deice flat
Temperature	The temperature of environment
Humidity	The humidity of environment
Win force	The force of wind
Wind Direct	The direct of wind
Atmospheric pressure	The atmospheric pressure
Flight deicing queue	The result of flights queuing
Deicing flat allocation	The result of deicing flat allocation

Then, the information of the E-R diagram of the database is mapped to the table of database shown in Figure 8.

The definition of the character in Figure 8 is shown in Table 2.

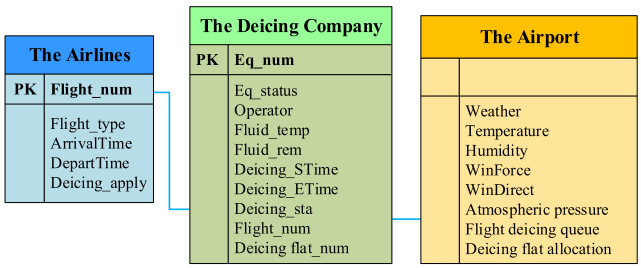

FIGURE 8. The table of database.

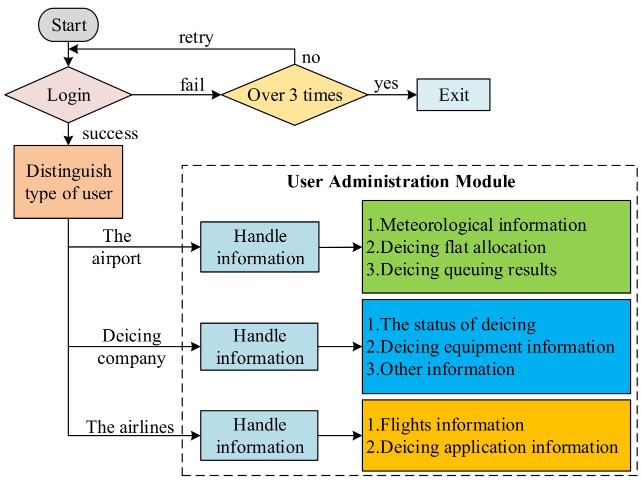

FIGURE 9. The software flow chart of the monitoring terminal.

D. THE SOFTWARE DEVELOPMENT OF THE MONITORING TERMINAL

The monitoring terminal can digitalize and graph the deicing process, and it can also present all information of deicing resources to different users in digital and graphical forms, such as deicing companies, airlines and airports. Considering the demands of different users, the multi-information integration system adopts Client/Server (C/S) mode in the whole process of aircraft concentrate deicing. The distinct feature of the mode is that client and server can cooperate with each other, and each of them has its own special functions. For ordinary users, the database of client can meet their query requirements. When the client is unable to meet the users' demand, it will request resource acquisition to the server actively. The C/S mode in the system can not only achieve large amounts of resources querying, but it also can make sure data real-time performance, which can reduce the lag of data acquisition greatly. The software flow diagram of the monitoring terminal is shown in Figure 9 [16], [17].

IV. GIS INFORMATION AND THE APPLICATION

A. THE INTRODUCTION OF GIS

GIS is designed to capture, store, manipulate analysis, and present all types of geographical data. It is the merging of cartography statistical analysis and computer science technology. Figure 10 shows the GIS conceptual framework and composition.

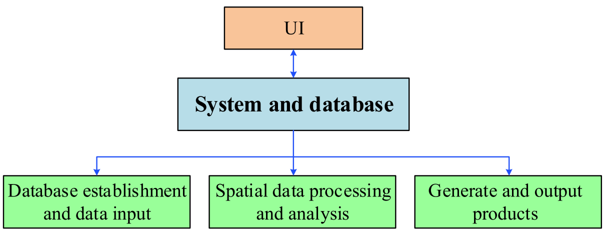

FIGURE 10. GIS conceptual framework and composition.

B. GIS MAP BUILDING

The airport GIS map is composed of vector layers and raster layers.

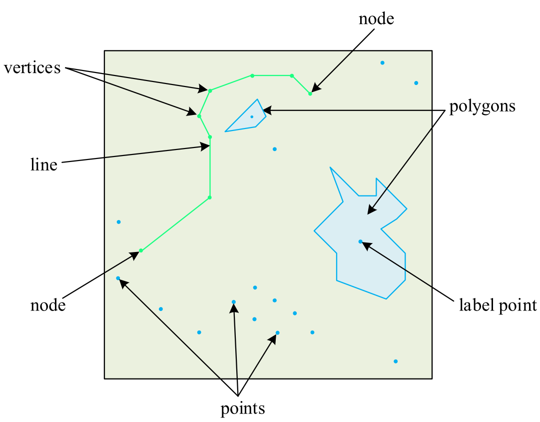

FIGURE 11. GIS map vector layer.

As shown in Figure 11, the vector layers mainly consist of points, lines, and polygons with latitude and longitude information. Of them, points represent the elements in the map, such as the house. A line represents some points connected line with the same attribute, and it can indicate the boundary of the runway or the boundary of the lawn. Furthermore, the curvature of a line shows the degree of curvature at the turning of a road. The polygon is used to represent a block area, such as the deicing flat. And the label point denotes the deicing flight in the deicing flat or deicing vehicle.

Besides, raster image is derived from the airport satellite imagery [18]. By inserting all the raster images of the airport behind the vector layer, images are superimposed with the polygons surrounded by the dots and lines in Figure 11 to correct the latitude and longitude information and crop the redundant image portion. Finally, the GIS map is obtained.

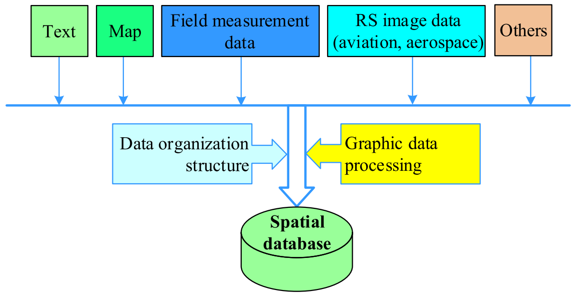

FIGURE 12. Spatial database input management function.

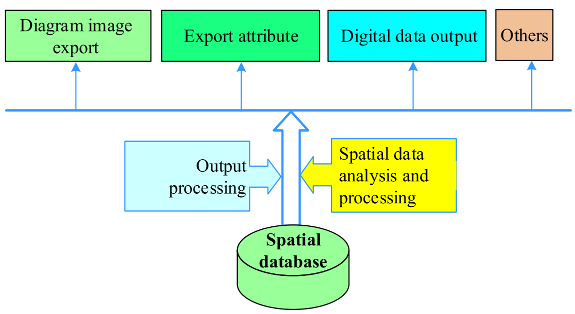

FIGURE 13. Spatial database output management function.

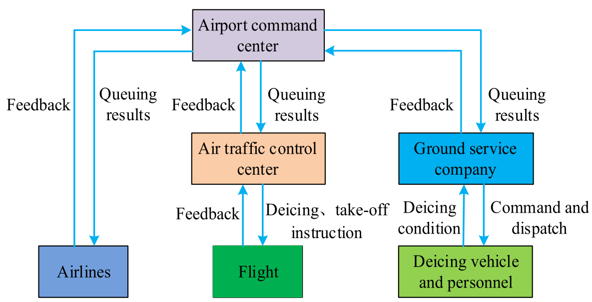

FIGURE 14. Aircraft ground deicing command and dispatch service flow diagram.

The geographic spatial data are sent to GIS in a digital format, and then they can be processed by the computer. The input and output processes are shown in Figure 12 and Figure 13. Afterwards, the analysts generate reports to describe conclusions obtained from the analysis. So it is obvious for command center of the airport that can learn the dynamics of deicing vehicles, security personnel and flights. As shown in Figure 14, command center can coordinate scheduling details with various departments in

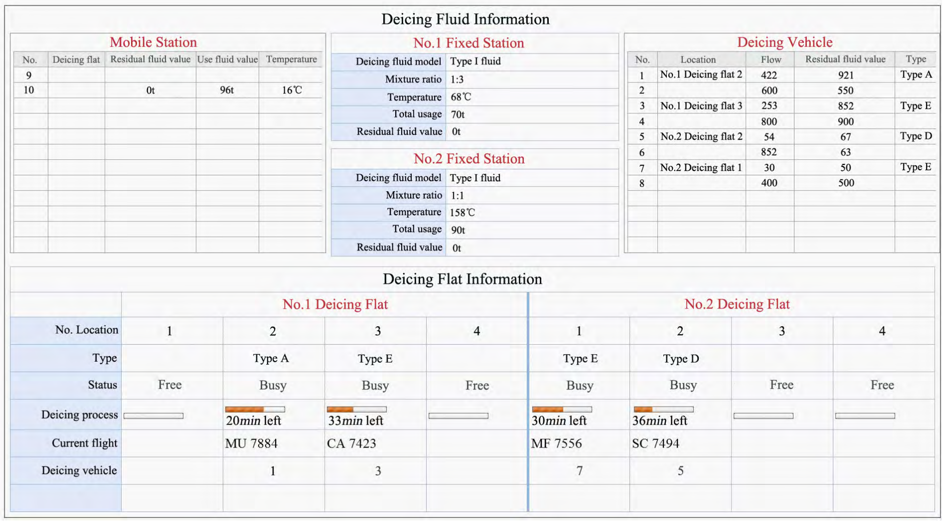

FIGURE 15. The interface of deicing vehicle scheduling module.

time, which makes scheduling instructions more accurate and enhances the efficiency of the entire aircraft ground centralized deicing process.

V. TESTING OF THE SYSTEM AND DATA ANALYSIS

A. THE INTERFACE OF THE DEICING VEHICLE SCHEDULING MODULE

The scheduling resource module is designed to collect and process the information from deicing flat. As shown in Figure 15, the GIS map is employed to monitor the real-time location and dynamic information of deicing vehicles, and to know the usage of deicing fluid and the residual fluid value, so as to facilitate the scheduling of deicing vehicles. Hence deicing resources can be reasonably distributed, time can be saved and the efficiency of the whole centralized deicing process can be improved [19]–[21].

B. THE SYSTEM FIELD TEST AND DEICING PROCESS ORGANIZATION

The system test diagram is shown in Figure 16. As seen from Figure 16, this system is mainly composed of 5 parts, such as field equipment, data transmission terminal, command and control seat, database server and display terminal.

When the system is running, data acquisition, control and transmission are carried out by the field equipment, such as the airport surveillance camera, positioning sensors, weather sensors. And the system data flow of different protocols, using a number of different GPRS transmission terminals, is sent to communication server for temporary storage. Among them, ice prediction computer predicts the possible icing phenomenon based on meteorological parameters collected and ice thickness is transmitted to communication server through the corresponding application of the computer. Then, the service program in the communication server is further responsible for sending the different data flow to the corresponding database of data server for storage through the Local Area Network (LAN). Besides, the command data of five command and control seats, that is, general conductor seat, air traffic control seat, airline company seat, airport seat and ground service seat, are written into the data server. At the same time, the five command and control seats read the relevant data information from data server. Finally, the corresponding data from data server, which are read by the service program on the IPC of display terminal, are displayed on the monitor screen in real time, as shown in Figure 16. The entire deicing dispatch monitoring is shown in Figure 17.

Among them, the computer of general conductor seat communicates with the remaining computers of four seats under the same LAN and can query all the data of the other four seats.

There are two main types of data flow on the ground service seat, one is from the remote liquid supply center, including the temperature of deicing fluid, residual fluid value, used deicing fluid value, and so on. The other is the data of deicing vehicle, such as the number, real-time location and deicing vehicle status, and so on.

Data of airport seat's computer are mainly classified into two categories, one is information of ice accretion, including type of ice accretion, ice thickness, and so on. The other is information of deicing flat, such as the location of deicing flat, spare aircraft positions, and current deicing flights, and so on.

The airline seat mainly has 3 kinds of information, the first is that the flight which is deicing, such as the flight number, the departure time, and the airline name, and so on; the second is that the deiced flight; and the third is that waiting for deicing flights.

The air traffic control seat mainly has deicing scheduling parameters, for example, a secondary deicing request, deicing time, and end time, and so on.

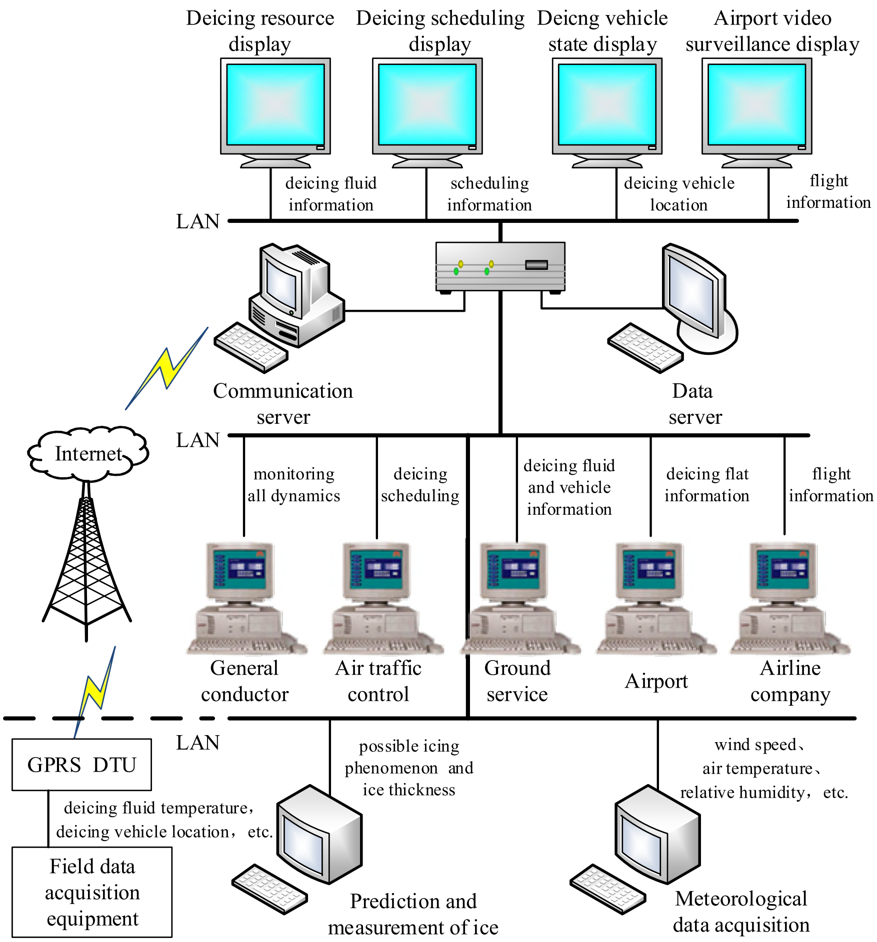

FIGURE 16. The system test diagram.

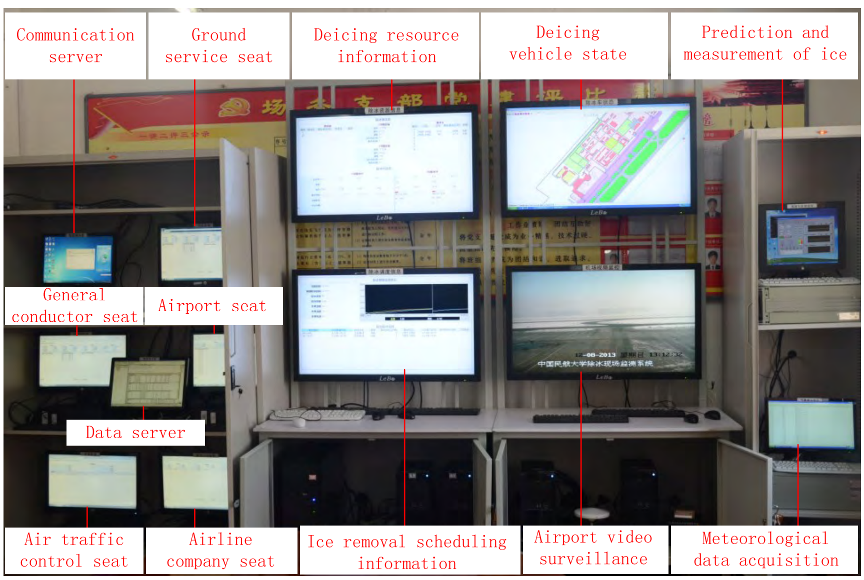

FIGURE 17. The system filed test.

When manual scheduling is used, dispatcher officer firstly receives the deicing instruction from the control center at the airport. Then dispatcher telephones the airport to know each device's status and location, the deicing preparation of deicing companies, and so on. At the same time, the dispatcher asks the airlines about the flight information that

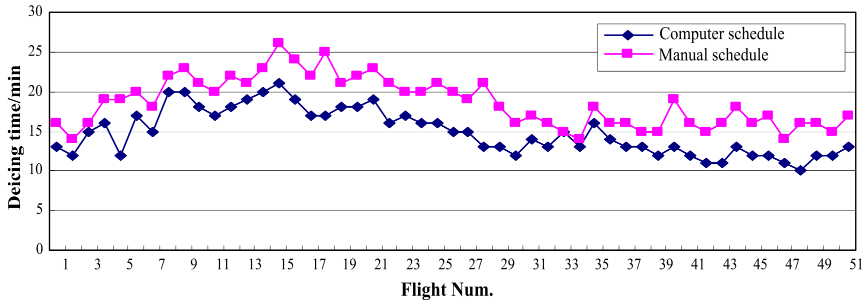

FIGURE 18. Comparison between the two schedule model.

contains flight number, location, departure time, and so on. And then the status of deicing queue, deicing flat and the weather conditions are got from the airport authorities. After that, the dispatcher dispatches the deicing equipment to the designated deicing flat for the flight deicing. Because the dispatcher might not know the deicing equipment's situation in time, the deicing time will be prolonged and the deicing efficiency will be affected.

When computer scheduling is employed, the dispatcher can know the weather information and predict icing conditions in advance. According to the information of deicing flat, the deicing equipment is arranged to wait for the flight deicing ahead of time. In the process of the deicing, if the equipment breaks down or the queue of deicing flight changes, dispatcher can respond quickly. So the efficiency of flight deicing is improved.

By comparison, deicing equipment and staffs of manual scheduling are arranged based on flight deicing information, while deicing equipment and personnel of computer scheduling can be arranged in the light of the weather forecast and predicted icing conditions. In this way, with the help of computer scheduling, the dispatcher can execute parallel scheduling for deicing equipment and other resources efficiently.

C. DATA ANALYSIS

In order to test effect of the system on airport deicing, the data of computer scheduling and manual scheduling are obtained from Harbin International Airport between 7 and 9 a.m. on December 24 and 25, 2015 when these two days were just two deicing days, as shown in the Table 3. Meanwhile, a total of 51 same flights were deiced using manual scheduling and computer scheduling respectively. And the computer scheduling is performed on the aircraft ground centralized deicing monitoring system, however, manual scheduling is not.

The airport is equipped with 7 sets of deicing vehicles. On the basis of the two sets of data collected, two curves that show the deicing time of manual scheduling and computer scheduling under the same ice conditions can be drawn. The abscissa represents the 51 flights sequence of 7:00 to 9:00 in the morning, and the ordinate indicates the deicing time of every flight.

TABLE 3. Deicing time under two scheduling modes in 2015.

Flight_num	A/min	B/min	Flight_num	A/min	B/min
1	13	16	27	15	19
2	12	14	28	13	21
3	15	16	29	13	18
4	16	19	30	12	16
5	12	19	31	14	17
6	17	20	32	13	16
7	15	18	33	15	15
8	20	22	34	13	14
9	20	23	35	16	18
10	18	21	36	14	16
11	17	20	37	13	16
12	18	22	38	13	15
13	19	21	39	12	15
14	20	23	40	13	19
15	21	26	41	12	16
16	19	24	42	11	15
17	17	22	43	11	16
18	17	25	44	13	18
19	18	21	45	12	16
20	18	22	46	12	17
21	19	23	47	11	14
22	16	21	48	10	16
23	17	20	49	12	16
24	16	20	50	12	15
25	16	21	51	13	17
26	15	20			

As shown in Figure 18, when manual scheduling is applied, it takes about 15 to 28 minutes for the flight deicing. But when the deicing process is under the control of computer scheduling, the deicing time is about 12 to 22 minutes. By substituting the data in Table 3 into (1), it can be obtained that the deicing efficiency is increased by 26%.

$$Eff = \frac{1}{51} \cdot \left(\sum_{i=1}^{51} (B_i - A_i) \right) \times 100\% \quad (1)$$

In (1), Eff denotes the deicing efficiency. B and A indicate deicing time under computer scheduling and manual scheduling, respectively. i refers to the number of flights.

The reason why the efficiency of deicing under computer scheduling is 26% higher than that under manual scheduling, is that computer scheduling system can predict icing situation based on meteorological parameters and know the dynamics of deicing equipment and personnel in a timely manner, which can help dispatch the deicing equipment ahead of time. However, manual scheduling can't dispatch the deicing equipment in time, so it extends the time of the flight deicing. The next step, further research on deicing resources scheduling and optimization will be done to improve the efficiency of aircraft deicing.

VI. CONCLUSION

In this paper, the airport ground centralized deicing monitoring system is constructed, of which data acquisition unit is used to collect data from different sources, including the deicing fluid parameters, device status, vehicles' location and icing forecasting data. Then data are transmitted to database of the monitoring center through the wireless data transmission system for querying, data calculation and predicting ice thickness on aircraft surface. At the same time, the embedded GIS map helps master the dynamics of field personnel and deicing vehicles in real time. And then with the help of computer, scheduling path is planned and the optimal path of deicing vehicles is selected, facilitating cooperative scheduling between airports, airlines and ground service companies.

The main features of the proposed system can be summarized as follows: 1) The system is well integrated with data acquisition module, icing prediction module and scheduling module, and has developed display interface; 2) The SQL and ACCESS database are fused for monitoring center querying and calculating; 3) The embedded GIS map indicates the dynamic scheduling of vehicles and personnel vividly for online path planning and scheduling of computer, which makes vehicle scheduling more timely [22], [23].

Summarily, the aircraft ground centralized deicing monitoring system can reduce the used amount of deicing fluid greatly and increase the deicing efficiency by 26%, saving cost for airports and airlines. Meanwhile, GPRS technology for data communication is also adopted, which not only solves the restriction of communication frequency at the airport, but also gives a perfect solution for remote data communication. The whole aircraft ground centralized deicing system shows the embryonic form of smart airport initially.

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