Design and Implementation of 3D Air Traffic Control Integrated Information Platform

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***Abstract*—With the growth of air traffic in China and even in the whole world, the flexibility, efficiency and safety of ATM information system are facing great challenges. The traditional ATM information system has some prominent problems such as dispersion and independence, difficulty in data sharing, weak information expression and low system automation. In order to improve the controller's management level and efficiency and reduce the workload, key technologies such as Google Earth 3D earth interface interaction technology, 3D track tracking technology, 3D flight plan algorithm and traffic statistics algorithm are studied and a prototype system for 3D ATM information integration platform is designed in this paper. Compared with the operation of the traditional 2D ATM system, it proves that the 3D ATM information integration platform can introduce various air traffic surveillance data sources (ADS-B system, multi-point positioning system, secondary radar, flight plan and meteorology), effectively integrate various ATM information and present the information such as track tracking, flight plan, route, sector and airport layout in the way of 3D. The platform helps to improve the operational efficiency of ATM, allows the front-line staff of ATM to intuitively acquire and understand the operational status of ATM, and improves the information sharing and situation awareness of the various departments of ATM.**

Keywords-air traffic control; Google earth; 3D track tracking; 3D flight plan; traffic statistics

I. INTRODUCTION

In order to cope with the economic globalization and the rapid growth of air traffic flow, it is necessary to broaden the concept of ATM to a global scale, and build a networked, informationalized, intelligent and seamlessly connected operation mechanism globally. The International Civil Aviation Organization (ICAO) firstly puts forward the concept of global integrated operation. With the cooperation of various organizations and departments of air traffic, all organizations and departments can enjoy the public infrastructure and seamlessly connected service, so that air traffic can be subject to organic and integrated management more economically, safely and efficiently. With respect to the above concept, America and Europe propose their own concept of next-generation management system, namely NextGen for America and SESAR for Europe. As the pillar supporting the future ATM system, the future air navigation system FANS is provided with CNS, namely communication, navigation and surveillance is used as the supporting technology of ATM. Currently, ATM organizations in many countries are set up according to communication, navigation and surveillance. In 2012, ICAO expanded the core technology supported by ASBU and added information management (IM) and airborne equipment (A) besides CNS. Due to previous insufficient attention to IM, difficulties in internal coordination and information expansion and sharing of the ATM system exist at present. The future development trend on ATM puts higher requirements on informationization, flexibility, safety and efficiency of the system. Informationization construction must be the top priority since it adapts to the future development trend of ATM [1].

However, at present, the information management system of the ATM department has a variety of prominent problems such as wide range, dispersion and independence of system, inconsistent data standards, and information sharing difficulty on data collection and calculation, as well as insufficient expression, complexity and absence of context and situation awareness on data presentation [1-3]. The geographic information system can model the geospatial data, describe the attributive characters of airspace of civil aviation, and support the query, comprehensive analysis and auxiliary decision-making of ATM geographic information such as routes and sectors [4]. The introduction of geographic information system and 3D terrain visualization technology into information management of ATM system can effectively manage the spatial geographic data concerned by air traffic controller, and express the 3D information and comprehensive features of airspace and low altitude more intuitively and truly.

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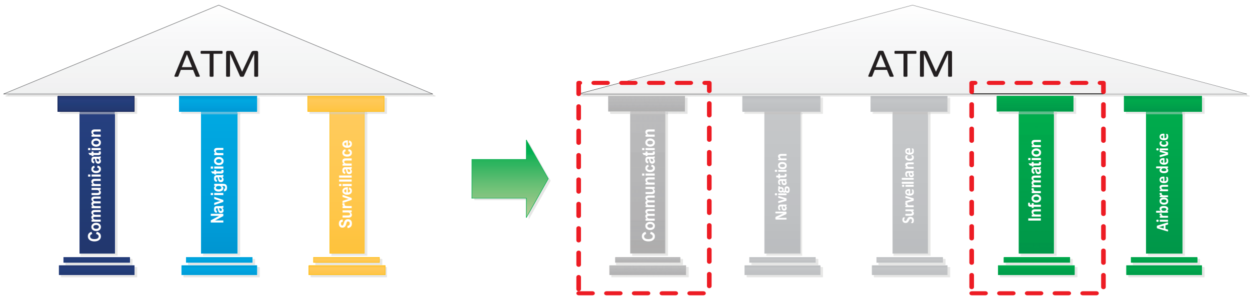

Figure 1. ICAO technology roadmap of ATM.

In order to improve the situation awareness of pilots and controllers on the real-time operation of airspace, improve the control level and efficiency of controllers and reduce the workload, it is urgent to expand the traditional 2D spatial geographic information of airspace and low altitude and flight track of the flight into 3D information and integrate traditional functions of flight plan, traffic statistics and role management into a 3D ATM information integration platform with unified standards.

At present, various ATM information systems generally have prominent problems such as system dispersion, data sharing difficulty, poor data correlation and outdated data presentation way. The 2D ATM system lacks data such as terrain, landforms, low-altitude obstacles, and low/medium/high-altitude meteorological information; the 2D flight plan system and the navigation notification system lack data correlation with the ATM system; the 2D flight supervising and warning system lacks real-time analysis and display of flight altitude [5]. The above problems make the controller repeatedly view multiple terminals during the actual control of the flight operation, find and calculate the real-time flight information from different 2D information and even a single data table, judge the operation situation of airspace based on his/her personal experience, and artificially construct the 3D flight situation of all flights in the control area [6].

Foreign organizations such as NLR, DLR, and American AirNav Systems LLC have successively proposed to integrate ATM surveillance data into 3D map terminal to obtain 3D flight track. In China, there is nearly no the condition that the flight information concerned by the controller is displayed in real time in the way of 3D and the 3D information is integrated into one 3D ATM information integration platform.

II. INTRODUCTION

In this paper, a prototype system of 3D ATM information integration platform is constructed, which centrally manages and presents 3D geographic information such as airport layout, low-altitude terrain and obstacles, airspace routes and sectors, constructs a 3D flight track and further integrates traffic statistics (core function of the traditional ATM information system) on this basis.

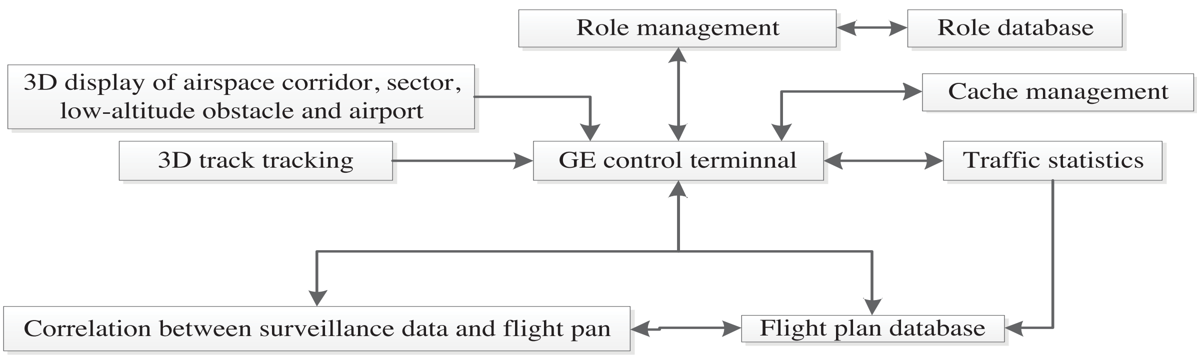

Figure 2. Architecture of prototype system.

Internationally mature GIS software mainly includes open source software and commercial software such as ArcGIS, MapGIS, ERDAS and Google Earth. Considering the universality and expandability of the system, Google Earth is selected in this paper. Google Earth is virtual earth software developed by Google. It is not only a geographic information system, but also provides satellite images, maps, terrains and 3D buildings covering the whole world. Google Earth provides two development interfaces - JavaScript API and COM API for secondary development. JavaScript API is a web-embedded development interface that is a B/S modearchitecture by embedding a full-featured Google Earth and its 3D rendering capability in a WEB browser. COM API can call some functions of Google Earth in an external application, inserting Google Earth as a control into the user application. Due to the safety requirement of ATM system, it must be used offline. COM API provides a caching function of offline geographic information of maximum 2G while the web caching capacity of JavaScript API is only a few hundred megabytes which cannot meet the needs. Therefore, COM API is selected in this paper for secondary development [7].

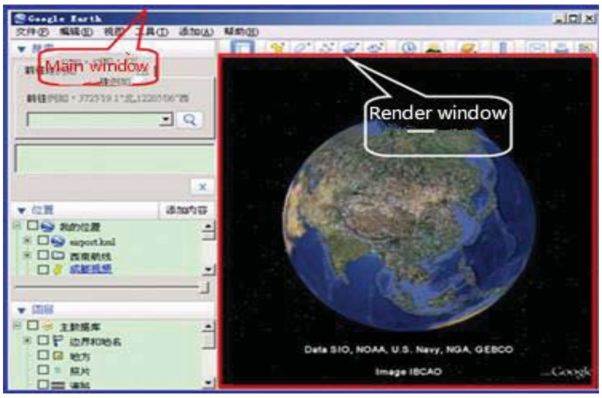

Figure 3. Client of google earth.

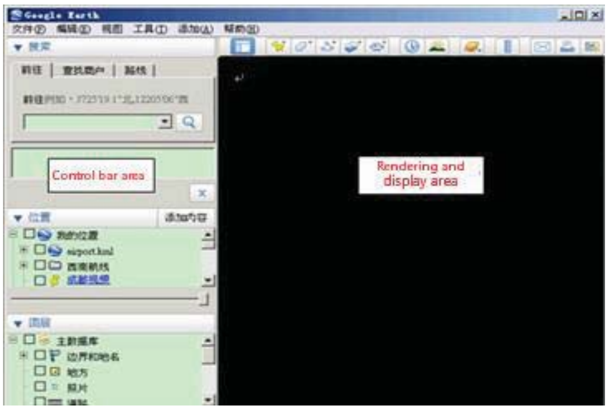

Figure 4. Main window of client of google earth.

For the design of prototype system, Google Earth (GE) is used as a display platform of geographic information. The entire prototype system applies C/S architecture which is shown in figure 2.

The prototype system has eight main functions, including role management, Google Earth (GE) control terminal, cache management, 3D track tracking, 3D flight plan, correlation between surveillance data and flight plan, traffic statistics, and 3D information display of airspace and airport.

ATM controllers can access the system according to different roles and authorities, and control and view the information of route, sector and low-altitude obstacle of airspace and airport layout information according to the management requirements. The 3D track surveillance function uses ADS-B real-time message information, parses the flight call number, address code, time, latitude and longitude and altitude out of the ADS-B message, converts these information into various elements of KML file, and achieves real-time updating and display of 3D track.

The traffic management can filter and screen the flight track individually according to the fixed point of the airspace (waypoint, sector boundary point and airport location point in the control area) and the range of interest, so as to focus on the flight track paid to more attention by different roles.

III. KEY TECHNOLOGY AND ALGORITHM

A. Google Earth 3D Earth Interface Interaction Technology

Google Earth COM API only provides rough software control and function entry; there are no detailed parameter setting, programming example or interaction with the host software, and not all functions of Google Earth are open. At present, many applications cannot get rid of Google Earth itself while developing Google Earth [8].

As a 3D ATM system, it needs to interact with 3D Earth. The functions that are not open to the COM API can only be implemented by intercepting information of WINDOWS with the hook programming technology. Hook is a technology widely used in computer virus design. Hooks can be regarded as backdoor from WINDOWS. Customized hooks are installed in the system to supervise occurrence of specific events in the system and complete functions that are difficult to be implemented by ordinary programs (intercepting inputs of keyboard and mouse, capturing screen words and supervising log).

The client interface of Google Earth includes two parts: main window and render window. It is demonstrated in figure 3. The main window is the parent window of render window. The main window is mainly used to implement various control functions for 3D Earth of the rendering area. The render window implements rendering and display of 3D Earth. Obtain handles of the main window and render window separately by GetMainHwnd() and GetRenderHwnd() of ApplicationGEClass.

The main window consists of two areas: control bar area (including menu, toolbar, sidebar, etc.) and rendering and display area, as revealed in figure 4. All controls for the render window (including keyboard, mouse, size, and zooming) are defined on the main window. The render window is responsible for rendering and display of 3D Earth.

On the 3D ATM information integration platform, 3D Earth of Google Earth needs to be embedded to the main interface by embedding render window or embedding main window. While embedding the main window, you can use all the interaction control functions of the main window, which removes the need of writing control function programs and uses the excellent control functions provided by the main window. However, the menu and control bar displayed on the main window cannot be removed, so that the menu bar of 3D ATM information integration platform and the menu bar of Google Earth will appear simultaneously, as revealed in figure 5.

To solve the above problem, a Panel control is set on the main interface of prototype system for displaying 3D Earth, as displayed in figure 6.

After starting Google Earth, trigger an event to get the handle of main window, set the parent window of main window as Panel, and set the main window as the topmost window. Make the width of MainWindow 1.02 times the width of Panel, and the length of MainWindow 1.2 times the length of Panel. Namely, the size of the main window of Google Earth is slightly larger than that of Panel. In this way, the menu on the main window of Google Earth is just hidden.

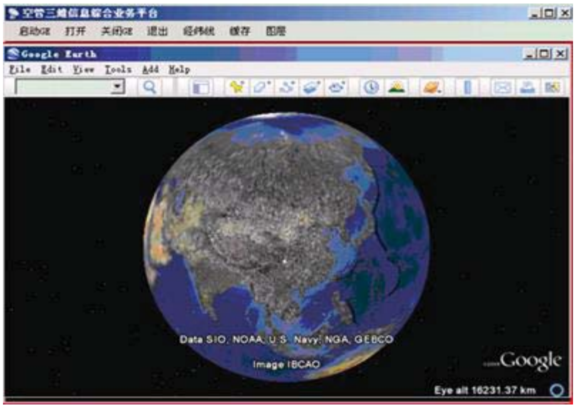

Figure 5. Integration of main window of client of google earth.

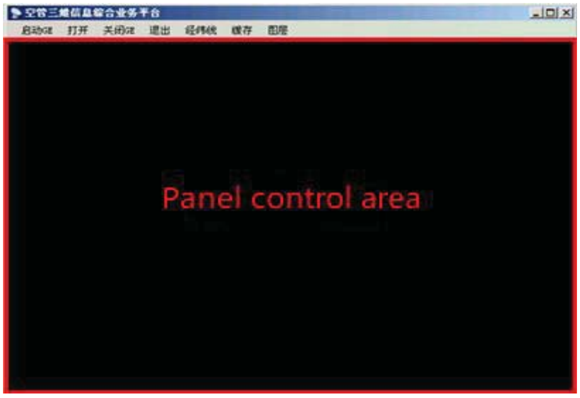

Figure 6. Panel control area of main interface of system.

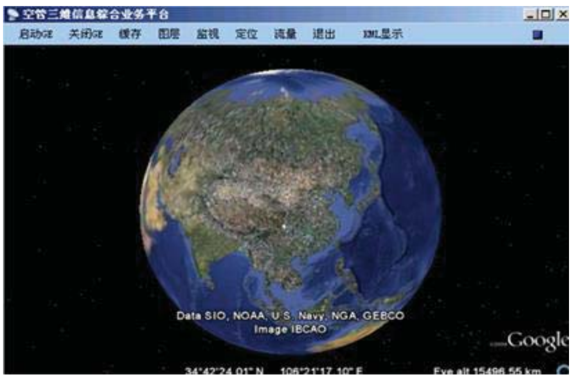

Figure 7. Main interface of 3D ATM information integration platform.

A hook function is hooked into the system. When the mouse is active in the Panel control area, capture scrolling and clicking events of mouse by the hook event processing function. Once the mouse event is captured, immediately place the main window of Google Earth at the top. At any time, only when the main window of Google Earth is the topmost window, can the main window of Google Earth respond to the mouse and keyboard events with its customized processing function, enabling operation interaction with 3D Earth. Figure 7 reveals the effect.

B. Traffic Statistics Algorithm

Traffic statistics is an important part of ATM service. Usually, the traffic statistics function exists as a single business system. On the 3D ATM platform, we need to integrate the traffic statistics function into the 3D platform to provide users with an intuitive traffic statistics function.

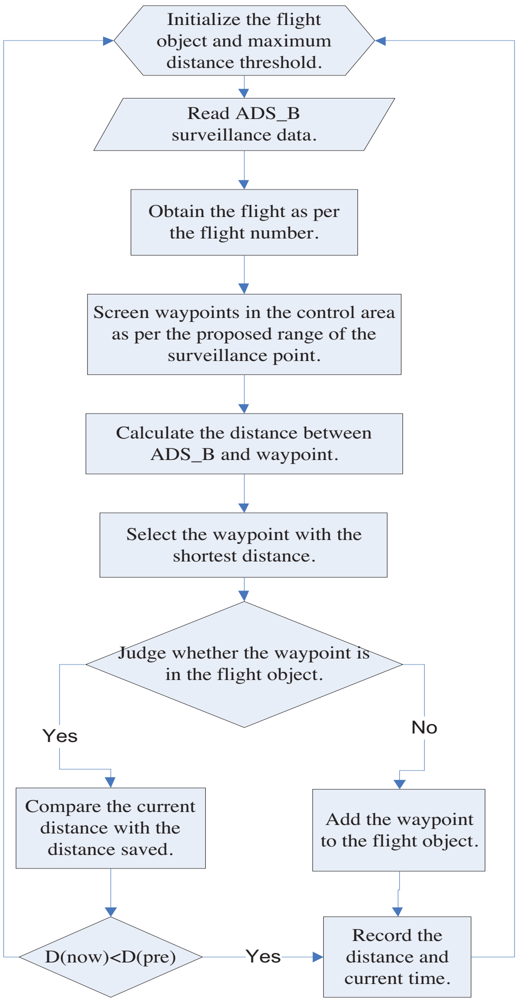

Figure 8. Traffic statistics process.

The traffic statistics mainly refers to establishing a relevant model of information of fixed point in the control area (including waypoint, sector boundary point and airport location point) after receiving surveillance data from network, processing and obtaining information of concerned elements (including passage time of waypoint, time entering and leaving the sector, and departure time and landing time of airport), combining the surveillance data with existing elements for data mining, and getting the historical traffic information of airport, sector and waypoint within a certain period.

Figure 8 indicates the traffic statistics process. Initialize the flight object, read in the information of fixed point (waypoint, sector boundary point and airport location point in the control area), take the flight surveillance data object from the flight data queue from flight data surveillance sensor in order as per the period, primarily screen the result point set from fixed points in the control area using the latitude and longitude of the surveillance data object as the center and the specified distance threshold as the radius, calculate the distance with the surveillance data object, select the fixed points with the shortest distance, judge whether the fixed point exist in the flight object, if not, add the fixed point to the flight object, if so, compare the shortest distance with the distance saved last time, and save the point with smaller distance to the flight object.

The data processing procedure of traffic statistics is demonstrated in figure 9.

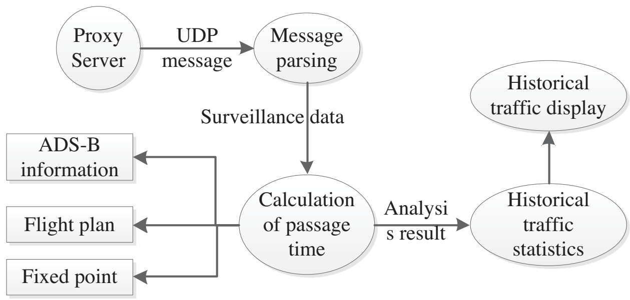

Figure 9. Data processing procedure of traffic statistics.

C. 3D Flight Plan Algorithm

The traditional flight plan mainly contains text information, including various information of departure and landing airport, waypoint, time and aircraft model of the flight. The traditional flight plan is not intuitive enough to display and read. The 3D flight plan turns the flight plan into 3D spatial information, making it intuitive and easy to understand. The scheme is as follows: extract the flight plan from the flight plan database, use the information such as the waypoint and passage time in the flight plan data, calculate the surveillance message data of complete route of the flight simulated, and present the 3D flight plan in the way of 3D surveillance data.

For the 3D flight plan, extract the data from the flight plan database, calculate the location of flight at present with the uniform linear motion model as per the waypoint and passage time, and generate surveillance data message in the format of CAT21. ASTRIX-CAT021 is a data format specially defined for ADS-B data by Eurocontrol. It contains various surveillance data of the flight such as call number, longitude and latitude, altitude and time. The data collected from the ADS-B receiver is in CAT21 format, so the flight surveillance data in this format needs to be parsed and extracted [9]. The implementation algorithm of 3D flight plan is as follows.

Where two waypoints A (lon1, lat1, alt1, t1) and B (lon2, lat2, alt2, t2) are known, where lon1 and lon2 are longitudes while lat1 and lat2 are latitudes, alt1 and alt2 are altitudes of the flight flying over A and B, and t1 and t2 are the time when the flight flies over A and B. Predict the location point S (lon, lat, alt, t) of flight at any time t (t1<t<t2) between time 1 and time 2 as follows.

According to the principle of coordinate transformation, A and B are transformed into geocentric coordinates, and two corresponding points are obtained as A'(x1, y1, z1) and B'(x2, y2, z2). In addition, assuming that flight is in uniform linear motion between A' and B', then it is also flying in uniform linear motion at three directions of x, y and z. The time difference from time t1 to time t2 is t2-t1 seconds, and the speed at three directions can be calculated through this time difference. The coordinate of point S' at any time t is as follows.

$$x = x_1 + (x_2 - x_1) / (t_2 - t_1) * (t - t_1) \quad (1)$$

$$y = y_1 + (y_2 - y_1) / (t_2 - t_1) * (t - t_1) \quad t_1 < t < t_2 \quad (2)$$

$$z = z_1 + (z_2 - z_1) / (t_2 - t_1) * (t - t_1) \quad (3)$$

According to the principle of coordinate transformation, transform the point S' into a geodetic coordinate S (lon, lat, alt, t), so as to calculate the longitude and latitude and altitude of the flight at the time t.

D. 3D Track Tracking Technology

The 3D supervising module is responsible for receiving decoded surveillance data messages and dynamically generating 3D track KML files. It is a background processing module and is implemented by multithreading technology. The surveillance data is from UDP message. The module classifies the received message first, parses the correct message byte by byte, and extracts information such as flight call number, address code, time, latitude and longitude, and altitude. Use the linked list to manage the received flight, determine whether the received flight message has been registered, add the unregistered flight to the linked list management, and update the corresponding data with the new message data (time, latitude and longitude, and altitude) for the registered flight.

Another important task of the 3D supervising module is to dynamically generate KML files using the surveillance data. KML is the acronym for Keyhole Markup Language, a language that uses XML syntax and format; it is used to describe and save geographic information (such as points, lines, images, polygons, models, etc.) and can be recognized and displayed by Google Earth. Various information form Google Earth is added with different layers. By writing KML files, points, lines, landmarks, images and 3D models can be superimposed on Google Earth. The way of Google Earth browser for processing KML files is similar to that of web browser for HTML and XML files. Like HTML, KML confirms the display way through the tag containing name and attribute. Google Earth can be regarded as KML file browser, and KML files describe all GIS information that can be displayed.

3D track is expressed with location points and lines of space in Google Earth, so that a very realistic 3D track effect can be represented by the rotation and tilting functions of Google Earth, 3D terrain and building model, and a wall generated by connecting the track line to the ground with a vertical line. Therefore, two types of elements (point (Point) and line (LineString)) need to be generated in the KML file. Point represents the current location of the flight, and LineString represents the historical track of the flight. The process of dynamically generating KML files is a process of constantly reading and writing XML files. XML operation-class XmlDocument from .NET can be used. XmlElement is very convenient for operating KML files.

Google Earth re-reads the specified KML file every one second through the NetworkLink link. This KML file can be located on the local hard disk or on the WEB server. If the flight dynamic KML file is located on the WEB server, the system architecture becomes the B/S mode, and all display terminals must be connected to the system architecture. If the flight dynamic KML file is located on the local hard disk, the 3D track function is similar to the ATC system. This way is more flexible without relying on the WEB server. Therefore, the way is used for the system.

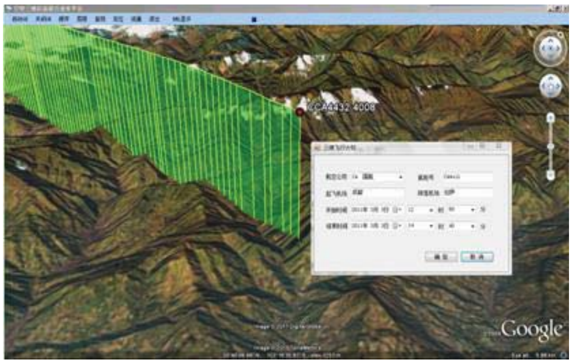

Figure 10. 3D track tracking.

E. *Flight Plan Correlation*

The air traffic controller cares about not only the location of the current flight, but also the flight plan, and these two kinds of information are usually distributed independently in two different systems in the traditional ATM service. The 3D ATM information system not only provides 3D ATM information, but also correlates and integrates various information of ATM.

The flight data only provides location-related information such as call number, time, latitude and longitude, and altitude while the flight plan provides more information, including aircraft model, departure and landing airport and departure and landing time related to the flight task. Displaying the two kinds of information after correlation will undoubtedly improve the control efficiency a lot[10]. There are two ways to implement correlation display. One is to use the bubble pop-up function of Google Earth. When a flight icon is clicked, a bubble display box pops up, and the flight plan information can be added to this display box. The way is advantaged in more flexible display mode. If the bubble is required to be displayed continuously after clicking "Display" (move with the flight), the 3D track KML file must be dynamically generated on the server side by WEB programming. For the way, B/S architecture of WEB programming way must be used. The other way is to use ATC terminal as the 3D display terminal. There is no need to use WEB server. Receive the data directly through UDP port. Since Google Earth provides the conversion function of 3D earth screen coordinates and geographic coordinates, you can use the mouse to drag the associated button to pick up the screen coordinates (x, y) and convert it into geographic coordinates (lon, lat). Compare the geographic coordinate data with the data recorded in the current surveillance data link list, find the nearest flight, find the corresponding flight plan data from the flight plan database, and pop up the correlation information generation box. It is demonstrated in figure 11.

Figure 11. Flight plan correlation.

IV. VERIFICATION

Through verification tests at Chengdu Shuangliu International Airport, it proves that the 3D ATC information integration platform can access surveillance data of various sensors such as ADS-B, MLAT and SSR and flight plan data, and integrate, display and process at the same terminal, so as to improve ATM safety and efficiency. The platform allows the front-line staff of ATM to intuitively acquire and understand the operational status of ATM, so as to improve the communication efficiency of various ATM departments. In addition, the platform has good expandability and can increase the service functions of the platform based on needs as well as personnel training, air disaster search and rescue and emergency exercise as required.

V. CONCLUSION

Compared with various traditional ATM information systems, the 3D ATM information integration platform is more intuitive and efficient and has the following innovation points.

For the traditional ATM system, only the conditions of airport and airspace are marked with vector diagrams. For the airport, only sector contour is provided. Once the aircraft leaves the airport, your can only see the current location and azimuth information, and you will not be aware of the specific geographical situation of the region in which the flight is currently located.

The 3D ATM information integration platform integrates Google Earth as a geographic information system, and provides very intuitive ground-object background reference by various satellite photos, aerial photos, 3D terrains and 3D models of Google Earth, so as to be aware of the current location of the flight. Especially in case of emergency, you can use the geographic information provided by Google Earth to provide immediate rescue service.

In the traditional ATM system, the flight surveillance track information is 2D, and it is impossible to visually express the altitude information of the flight.

Compared with 2D track, 3D track of the 3D ATM information integration platform provides a more intuitive and stereoscopic representation of the flight situation of the flight, especially various flight levels of flights at the same route and cross route.

The traditional flight plan is an independent system and only contains text information. The 3D ATM information integration platform integrates the flight plan into the ATC system and turns the text information into intuitive and stereoscopic 3D analog surveillance information.

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