ISC: A Comprehensive Low-Latitude Integral Surveillance and Control System

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Abstract—This paper proposes design and implementation of comprehensive ISC for low latitude air traffic management. The design enable the controller to supervise various low-latitude aircrafts, including those aircrafts carrying out complex tasks in remote areas, or those in sensitive border areas. The result is a powerful software. First, this software provides flight plan function, which can enable pilot to obtain better information service. Second, this design provides a hybrid radar-infrared surveillance techniques to identify the flying objects. More specifically, primary radar is used to detect and capture the suspected flying object. Then, infrared camera will start to show the video of suspected flying objects on screen. This is particularly meaningful for national defense. Finally, this software provides a simple yet efficient and robust design of record & replay. This function is useful for accident analysis and newbies training. Various factors are also thoroughly considered when implementing this software, including robustness, simplicity, ease of use and efficiency. This software provides a user-friendly interface and it can run smoothly.

Index Terms—ATM; Low Altitude Surveillance; General Aviation; Infrared Surveillance

I. INTRODUCTION

In general aviation, the pilots usually carry out most flight missions by visual means [1]. Flight station on ground plays a supporting role for general aviation. Air Traffic Management (ATM) system for general aviation, which is located in flight station, will not guarantee the space between in-flight aircrafts [2]. There are only a simple ATM system set in flight station. In this paper, ATM specially refers to the air traffic management for general aviation.

The basic function of ATM is to show on screen the tracks of in-flight aircrafts [3, 4]. The controllers of flight station can exchange information with pilot via its corresponding track on the screen.

Integral Surveillance and Control System (ISC) is a man-machine interactive system, which is a primary part of ATM system. Main functions of ISC is three-fold: 1) to display the supervision data from primary radar, infrared camera or ADS-B; 2) to process the Flight Plan and present it in form of Flight Strip; 3) to exchange information from/to the controller to/from the pilots.

ISC is a part of ATM system which is a distributed computer system used to supervise air traffic. Usually an ATM is primarily composed of Radar Data Fusion System, Conflict and Alarm System, Flight Plan Processing System and ISC. A typical ATM is illustrate in Figure 1.

In an ATM, there may be more than one ISCs which cooperates with each other to complete the task. In Figure 1, two ISCs are employed, i.e., ISC I and ISC II. In addition, it is required that ATM should be highly reliable and available. Hence, double-network structure is usually employed to avoid network failure, as is shown in Figure 1. Certainly, a highly reliable and available system should adopt several fault-tolerance techniques. However, this paper is intended to illustrate the operational principle of ISC but reliability design of ATM.

II. MOTIVATION

If the pilot expect to get better service from flight station, he/she shall submit flight plan to flight station before departure. Whether to submit flight plan to flight station depends on the pilot himself. The advantage of submitting flight plan lies in that the pilot can get helpful suggestions or information along the way from ATM.

In some cases, general aviation should subject to surveillance and control. For example, there will be too much aircrafts in a small region to carry out a task such as disaster relief. Those aircrafts must fly sequentially as coordinated by controllers working in flight station. Safe separation among aircrafts must be guaranteed to avoid confliction. In addition, aircrafts must subject to surveillance in some regions. For example, when a general aviation carry out tasks of pest control on the grasslands, or aerial photography in remote area, such tasks will be performed better if supervised and controlled by controllers on ground. Thus, the monitored information from a primary radar should be introduced to ATM. In some sensitive regions such as border area, the
flying objects should be clearly identified whether they are civil aircrafts or an invasive hostile planes. It is difficult to satisfy this requirement with primary radar only. Additional assistant surveillance techniques should be added to ATM.

To sum up, a full-featured ATM should be designed to meet those targets. It is meaningful to illustrate the design and implementation of a software for meeting special requirements [5, 6]. This paper is intended to illustrate the Integral Surveillance and Control (ISC) system of a “full-featured” ATM.

III. OVERVIEW OF ISC

The main window of ISC is depicted in Figure 2, which can be roughly divided into three fields, i.e., formation field on top toolbar, man-machine interaction field in middle part, and function field at bottom toolbar.

The features in format field can be illustrated as follows, we can set the System Mode to “NORM MODE: or “REPLAY MODE”. As its name implies, NORM MODE means this ISC is currently used to monitor the air situation, while REPLAY MODE refers to this ISC is used as a terminal to replay the air situation. REPLAY MODE is usually used for accident analysis or newbies training. Measurement Unit provide Imperial Unit or SI. User can select time zone in UTC time field. Alarm clock can be used to remind the controller about important matters at specific time instant. Longitude-latitude field can show the current mouse position.

Man-machine interaction field lies in the middle part of the main application window. This is the main field to show and/or manipulate the tracks, flight trip, and various maps such as section maps, landmark maps, border maps, etc. For example, user can select any flight trip and edit it, or select any track to change the style, or measure the distance between two tracks. In Figure 2, there are many concentric rings. These rings can help the controller to determine the distance between two points.

Track refers to the symbol shown on the screen, which represents the real-world aircraft. It is linked with a piece of string, called track plate. Track plate shows the detailed information about the flying aircraft, such as the altitude, height, position, international registration No., etc. ISC employs different symbols as track to clearly differentiate the data source. The data from radar is shown by symbol “+”, from ADS-B is shown by symbol “Δ”. When manipulating the track, user should select the track first. When the track is selected, a red hexagon is set around it, and the corresponding flight strip is selected meanwhile.

Usually, ISC includes three types of maps, system map, online map and generated map. System maps refers to those relatively static maps, such as airspace map, section map, air line map, guidance station map, airport map, etc. These maps are designed as layers. Thus, user can show anyone number of them arbitrarily. Each layer can be drawn in special color, and each layer can be set to be resizable with other layers or in constant size. If necessary, these maps drawn by controller can be released to other ISC terminals, when there are two or more ISC terminals are employed as shown in Figure 1. For example, temporarily risky area maps are often released to other ISCs.
Function field at the bottom toolbar provide most functions of ISC. When user click any buttons in this field, a window will pop up to provide more details. Click the “map” button, user can display or not each map layer. Click the Flight Plan button, user can set or edit the flight plan in detail. Click the Drawing button, user can select drawing tools to draw maps on screen. This field also provide record & replay function, infrared surveillance function, etc.

In this paper, three parts of ISC will be described, i.e., flight plan module, infrared surveillance module, and record & replay module. These modules are specially designed to meet our targets which described in section 2.

IV. FLIGHT PLAN

If these aircrafts have submitted flight plan, they will get useful information from the ATM system when they are flying, such as meteorology, military-related activity area, ground proximity alarm, etc. [7]. Particularly, the aircrafts flying in commercial route will get beneficial information. Flight plan window is shown in Figure 3.

Flight plan window in ISC provide rich information about the whole flight, mainly including type of aircraft, expected time of departure, expected time of arrival, destination airport, etc. Moreover, if the in-flight aircraft modifies its flight plan, this flight plan window can update the information realtime.

Flight plan correlation means the correspondence between flight plan and the track. It should be noted that, a track plate will not be shown around the track unless the track is correlated with the flight plan. In most cases, controller will frequently observe the flight plan. Thus, a compact version of flight plan called flight strip is created, which is always shown on the screen. The flight strip is illustrated in Figure 4.

It should be noted that all information shown in flight strip can be found in flight plan window. In Figure 4, all fields on flight-plan-related information are arranged by a specified order, which can only be understood by trained controllers.

V. INFRARED SURVEILLANCE

In field of general aviation, ADS-B is the primary communication way between controller and pilot. The advantage of ADS-B is two-fold: 1) it is very economic; 2) it can provide rich and accurate information about the aircraft, such as speed and operating state of the aircraft. Nevertheless, the disadvantage of ADS-B is obvious. The reason lies in that it uses one-way broadcasting technology, and the receiver will not response to the requests from the ADS-B. Hence a hostile flying object carrying ADS-B can disguise itself as a common aircraft by sending fake datagrams. For example, if an invasive fighter send false datagrams to the receiver of ATM, the controller cannot identify this type of invasion. It should be noted that primary radar can only detect but not identify the flying object. More specifically, the primary radar can only get the position and speed of flying object, but we cannot know what the flying object is based on these information.

Thus, we need other surveillance techniques to identify the flying objects. Infrared surveillance can show the shape, size, flying altitude, alpha, position, etc. [9]. In those sensitive areas such as border area, infrared surveillance can be used as complementary surveillance technique for ATM.

Infrared surveillance system includes an infrared camera which is usually mounted on the primary radar. Because infrared camera cannot endure long-term working, it is in hot standby state. When the primary radar detect an unidentified object, the infrared camera will start automatically. With the positional information from primary radar, infrared camera can easily capture the flying object.

The rationale behind the integration of primary radar and infrared camera lies in the fact that: first, we use primary radar to detect flying objects and infrared camera to identify them; second, infrared camera cannot locate the flying object at startup state without the assistance of
primary radar; finally, the infrared camera cannot endure long time of working, most of time it is ready but not working. Integration of both can finish the detection and identification better.

When the infrared camera find the flying object, it will capture video. The video stream will be transferred to ISC by network. The dataflow in a typical infrared surveillance is shown in Figure 5.

![Figure 5. Infrared video transmission](image)

Figure 5 illustrate the collection, transmission and display of infrared video stream. There are several coding standards for video coding and compression. More specifically, H.263 is usually used for video meeting, and MPEG-1 and MPED-2 are usually used for multimedia applications. In this paper, we use H.263 coding standard due to its realtime property. The end of infrared video stream is IDC, with which the controller observe and identify the flying object by visual means.

The infrared surveillance windows of ISC is shown in Figure 6, in which a flying aircraft is captured by infrared camera. In figure 6, we can see the shape of flying object clearly.

![Figure 6. Infrared display window](image)

It should be pointed out that, Figure 6 only shows a screenshot of video. In fact, infrared surveillance window can display the video. As mentioned above, when starting, the infrared camera need the help of primary radar to locate the suspected flying object. Once the object is located, the infrared camera can automatically track the flying object by means of some image recognition.

### VI. Record & Replay

Record & replay is a powerful technique to analyze the cause of air accident. Record & replay will record the surveillance data, flight plan and operations of controller, etc. When air accidents occur, we can replay the air situation to analyze the cause and investigate the responsibility of controllers. Also, the feature of record & replay is often used for training newbies [10].

Objectives of record & replay in ISC including: 1) low overhead during recording; 2) interactive operation during replay; 3) low disk usage; 4) sufficiently robust. Low overhead implicates that, the recording process cannot affect the operation of ISC or occupy much computing resources. Interactive operations are required when replaying recorded air situation and operations of controllers. It is meaningful for accident analysis. For example, user can measure the space between two aircrafts when replaying the recorded operations. The recorded files cannot occupy much disk space. Otherwise, long-term recording will exhaust disk space. Recording & replaying process must be implemented by a reliable and robust technology. There are several ways to implement record & replay system as follows:

Screen capture: this method capture the screen in a video file. All operations of the controller and air situation are recorded. This method provide a simple implementation. However, this method has several weaknesses: 1) the recording cost too much computing resource, particularly too much CPU; 2) the recorded video files are too large, so a common PC cannot store enough long time of recorded files as required; 3) when replaying the air situation, the controller cannot intervene the replay. For example, the controller would like to measure the distance between two aircrafts or distance from aircraft to ground when replaying an air accident.

Windows hook: this method take advantage of the message-driven mechanism of Window OS. All the message processed by ISC can be hooked and saved in a file. When replaying the air situation, we can open the file and get the message and its time information, then send the message to ISC. The advantage of this method is obvious. The recorded file is small, and overhead of recording process is relatively small. However, this is a complex and error-prone method. In principle, ISC response to the stored Window message and reexecute the command of controller, and show the recorded track data from radar or ADS-B data. If there is any error in the stored messages or track data, there is inevitable critical failure in ISC. The disadvantage lies in that this is not a robust way to redisplay air situation. In addition, we cannot replay the air situation from arbitrary time instant by using this method. Moreover, this is a platform-specific method.

Another method is using Xwindow protocol of Unix OS. The recording application uses Xwindow protocol to store the state of application in Xserver. This is a platform-specific method like Windows hook method, and we also cannot replay the air situation from arbitrary time.

Obviously, above schemes cannot meet our objectives. Thus, we do not adopt above methods to implement record & replay module of ISCS in this paper. Instead, we record the original operational data of ISC, including the following four parts: 1) operation time; 2) operation type, including window-related operations, track-related operations and track plate-related operations; 3) target UI object, including the IDs of controls and its parent controls; 4) user’s input; this refers to the results applied to ISC. For example, the input of users in an edit text. A sample of recorded contents are summarized in table 1.
We record the operations of controller in a manner of incremental recording, i.e., if the controller don’t operate within a period of time, there is nothing recorded in files. This method can save disk space greatly.

We conduct four experiments to test the efficiency of our approach against others in our ATM platform. We specially test the disk usage of each solution, because CPU usage test is only required when there is large overload, i.e., too much operations need to be recorded. This occurs rarely in general aviation. In our test, a typical air traffic management process is run on our ATM. Two aircrafts fly from one place to another four rounds. Each round cost about 20 minutes, 40 minutes, 80 minutes and 160 minutes respectively. During the flying, the operations of controller are recorded by each solution, and disk usage is recorded respectively. The test results are shown in Figure 7 and Figure 8.

From Figure 7 and Figure 8 we can see that, disk usage of our solution is greatly less than others. In addition, the curve in Figure 8 shows a flattening trend. This is to say our solution will occupy less disk when flight period increases. This is due to our incremental recording design as mentioned above. This can be interpreted as follows. Any flight will require specific interactions with controller, such as departure report, flight plan manipulation and landing report, etc. Usually, the controller will intervene the flight rarely except for some dangerous conditions occur. As the travelling time increases, idle time of controller will occupy more proportion. The idle time refers to the period when the controller has no operations.

Several fault-tolerance techniques are implemented in record & replay module to improve its robustness. Each recorded file does not exceed 5 minutes. In this way, we will not lose much information even if there is any faults occur at recording or replaying stages. Moreover, we record the “global state” of ISC at the head of each recorded file, including all the state of windows, controls and maps, tracks, etc. The recorded global state can be treated as a savepoint. If any faults occur during replaying process, we can roll back to the savepoint then retry. These measures can enhance the reliability greatly.

Considering the interactive operation during replaying air situation, this method allow the controller intervene the replaying process. For example, the controller can measure the distance between two aircrafts, zoom in/out the screen, etc. These operations can help the controller to make an in-depth investigation of the cause of air accidents.

### VII. Conclusions/Outlook

Several surveillance techniques should be employed for those low-latitude aircrafts carrying out various complex tasks. This paper describes the ISC of a full-featured ATM system for general aviation. Moreover, we illustrate the design and implementation of ISC. ISC provides visualized surveillance for data from ADS-B, radar or infrared camera.

This software is specially designed for a powerful ATM system. It can detect and identify almost all flying objects. Besides the common functions of a flight station, it can provide many new features. First, this software provide a complete flight-plan-related functions. This design has potential to enable the controller to help get the pilot out of trouble. Second, it incorporate a hybrid radar-infrared surveillance technique. This feature can be used for monitoring those aircrafts flying in sensitive areas. Finally, this software provides interactive...
recording & replay function. This function is implemented in a high-efficiency and robust way. Controller can manipulate the ISC during replaying air situation.

The software is intended to be robust and powerful. Almost all features are implemented by defensive programming. In addition, this software is designed considering the portability. The implementation of all features can be easily ported to other Operating Systems.

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REFERENCES


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