Simulation System for Airborne Weather Radar Control and Display Based on Virtual Instrument

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Abstract—**A simulation system consisting of display module, control module and process module for the control and display unit(CDU) of airborne weather radar is designed and tested in this paper. Taking advantage of virtual instrument technology as well as practical aeronautical characteristics, the designed system can receive, process and intuitively reflect the meteorological information to fight crews. Adopting the function and algorithm multiplexing, the comprehensive and integrated system is successfully realized with efficiency and fidelity, in which major workings modes of practical weather radar including weather mode, windshear mode, turbulence mode and map mode are provided. The testing results indicate the system performs favorable interactivity, stability and real-time property which meet the requirements of simulation. The system can be widely used for training and teaching and is transplantable to similar simulation systems.**

Index Terms—**airborne weather radar, CDU, virtual instrument, simulation**

I. Introduction

Weather has been considered as a major contributing factor to nearly 25% of aviation and 35% of fatalities[1]. Airborne weather radar is able to collect and dispose weather data and provide visual interface with pilot decision aids, which will greatly help avoid flight accidents[2]. According to aeronautical ARINC Characteristics, practical airborne weather radar system should be viewed as a Transmitter-Receiver(T-R) and Antenna which functions through a standardized electrical interface to the Control and Display Unit.

The CDU of weather radar system is at the core of human-machine interactivity. Since to fulfill the potential of on-board weather radar requires long-term experience and amount of training, it's critical to realize radar processing and human-machine interface of CDU on a simulator or computer. It should provide instructional and chromatic weather image, indicate operational parameters and, most importantly, is the only integrated and directly controllable unit on weather radar. Serving the above purposes, this paper focuses on the virtual realization of CDU which translates data into intuitive and vivid guidance to crews.

The rest of this paper is organized as follows: Section II provides this paper's keynotes comparing to previous work. Section III mainly introduces some relevant concepts and design principles including functions and interface. Section IV particularly describes software implementation and some essential ideas. Section V presents analysis to the results. Finally, Section Ⅵ concludes this paper and provides brief future improvement.

II. Related Work

A. GL Studio

With the development of virtual instrument technology, professional software simulation becomes significant and achievable[3]. GL Studio is a set of system solution, which is provided for instrument simulation software development by the DISTI Corporation[4]. As a platform-independent rapid prototyping tools, GL Studio can be used to create real-time, three-dimensional, interactive graphical interface[5]. GL Studio toolkit is divided into three parts: 2D/3D graphics editor, C++ code generator and relevant plug. The graphics editor allows the user to create the model and to endow it the corresponding behaviors in a convenient way. Code generator automatically transforms the user's results of graphics editing into codes to realize the instrument interior logic simulation[6].

Compared with the conventional Labview[7] and Open GL[8] methods, the virtual instrument developed by means of GL Studio[9] is more accurate, flexible and transplantable[10][11]. With GL Studio, the development of simulation system will also be much easier and quicker[12]. By applying VC++ and GL studio, it is not only able to better simulate and analyze the operation and data exchange process, but also embodies the idea of exploiting radar software for research as well as training.

B. Previous Work

In the past, there has been various simulations and researches focusing on a specific function of airplane cockpit based on GL Studio. [13]-[17] introduce simulation of different flight control panels. Practical flight instruments such as altimeter, level and control

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instruments are widely realized. Emphasis is often put on visual authenticity. In [18]-[20], more developed instruments are integrated to the cockpit scene using GL Studio, focusing on flight operation experience while environmental elements are ignored. Research work [21] concentrates on airborne radar and realizes a static point target detection on radar with dynamic scan line.

Based on the above simulation methods, this paper proposes a comprehensive and integrated dynamic control and display module referring to the practical aeronautical radio standards. In traditional simulation systems, fiddlier real-time property is not considered for priority, while in airborne weather radar CDU design, the dynamic and stable system function responding to high data rate package should be the top concern. In addition, system functional sections are highly multiplexed, that thus equips the system with transplantability and efficiency.

III. Principles And System Design

A. Aims and Functions

The whole system simulation and design is based on ARINC principles which set practical standards for aeronautical equipments. That gives CDU simulation practical value of training as well as education.

In particular, ARINC Characteristic 708A provides detailed regulations for airborne weather radar with forward looking windshear detection capability. It stipulates the physical, electrical and signal characteristic of the radar. The mimetic Control and Display Unit of on-board weather radar is designed mainly in compliance with that principle. It states that the display could consist of a dedicated "Weather Radar Indicator" unit and the controls may be provided by separate units. This concept provides for the independent future upgrading of sensor and its use with other display systems. Table 1 depicts part of the general design criteria and the required radar functions.

TABLE I.
Control And Display Unit Form Factor

Display Control	System Control	Display
Intensity (Brightness)	WX(Weather Mode)	Scan Angle (Scan period less than 4s)
Range	MAP(Map Mode)	Display Color
Hold (Stop update)	TEST(System self-test)	Alert Outputs form
Range/Azimuth Marks	TILT(Adjust antenna position)	Ranges(5, 10, 20, 40, 80, 160, 320nm)
Function	WS(Windshear)	TILT(More than 15 °)

Referring to practical weather radars, the virtual CDU is designed concerning the above functions. Taking advantage of GL Studio, the interface can be designed as real as possible.

B. Precipitation Algorithm

Weather states are distinguished by different form of radar echoes. Z-I relation[22] is one of the methods that connecting radar return and quantitative precipitation value.

Adopting typical radar-based quantitative precipitation estimation(RQPE) algorithm[23], radar hazard factor Z can be obtained from radar meteorological equation as shown in (1).

$$\bar{P}_r = \left\{\frac{\pi^3}{1024\ln 2}\right\}\left\{\frac{P_t h G\theta\phi}{\lambda^2}\right\}\left\{\left|\frac{m^2-1}{m^2+2}\right|^2\right\}\frac{Z}{R^2} \qquad (1)$$

P_t transmit power

$\bar{P}_t$ received power

h radar pulse length

G antenna gain

θ horizonal beam width

φ vertical beam width

λ wavelength

R target distance

Once the radar parameters are set, the value of second brace can be viewed as a constant. While the third brace is related to weather target phase. Dielectric constant $|K|$ is commonly used to denote this term as shown in (2).

$$|K|^2 = \left|\frac{m^2-1}{m^2+2}\right|^2 \qquad (2)$$

When the target particle is in water state, the value of (2) approximately equals to 0.93[24]. Since Z remains the only unknown variable in (1), the value can be obtained. According to classical Z-I relations. Precipitation strength I is induced as shown in (3).

$$Z = 200I^{1.6} \qquad (3)$$

C. Data Exchange

The data words are exchanged through a serial interface between the upper computer and a DSP processor.

- **Type and Structure:** ARINC 708A provides detailed structure of the display and control data. The received weather data of each scan radial is packaged into 1600bits. Each display word includes, among other things, the essential information: antenna tilt angle, system default information, mode and alert flags, range bin data. Meanwhile pilot operation forms two main classes of output control data packages.
- **Coding schemes:** The encoding rules are significant for the dynamic display of weather status. The range bin data comprises the bulk of the 1600 bits. The range bins store the radar reflection data in 3-bit sets. Each range bin is displayed as a colored pixel to indicate the precipitation rate or hazard for that location[25]. Table 2 demonstrates the display color code. Another prime set of coding scheme goes for the tilt angel, scan angel and range. BCD code and BNR format are adopted. In BNR format, the most significant bit(MSB) in the data area represents half the maximum value, while the least significant bit reflects resolution. By this way, the

analog information of tilt angel, scan angel and range is quantized and coded respectively.

TABLE
DISPLAY COLOR CODE SCHEME

Color	Precipitation (mm/h)	Windshear Mode	3-bit Range Bin Code
Black	< 0.76	Hazard factor below threshold	0 0 0
Green	0.762~3.81	Low hazard factor	1 0 0
Yellow	3.81~12.7	Moderate hazard factor	0 1 0
Red	2.7~50.8	Alert level hazard factor	1 1 0
Magenta	>50.8	Sever windshear	0 0 1

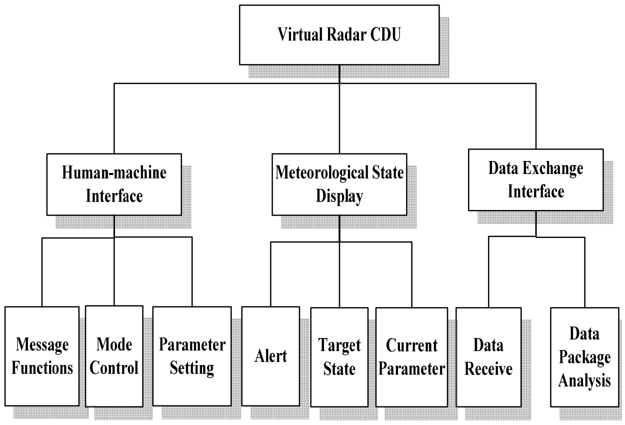


Figure 2. System structure and modules

IV. MODELING AND IMPLEMENTATION

Adopting GL Studio, the system can be realized based on correctness, real-time, fidelity, legibility and transplantability principles[26]. The GL Studio development cycle is shown in Fig. 1.

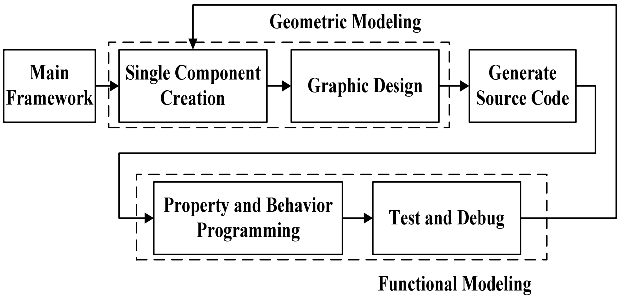


Figure 1. GL studio development flow chart

Taking advantage of GL studio's texture and multi-threading characteristics, the observability and execution efficiency are assured. Geometric modeling with texture mapping provides intuitive and friendly interface. Execution time is evenly allocated among system modules. Exploiting time slice allows more comprehensive and smoother function design.

The framework of virtual CDU is very explicit. The system structure consisting of 3 functional modules is shown in Fig. 2. It is important to make sure modules not only work separately as far as possible but also imply appropriate multiplexing. According to the system structure and GL Studio development cycle, system programming goes through the following process.

A. Geometric Modeling

The Geometric property of CDU originates from ARINC principles and the study of actual radar panels. Since a real human-machine interface contains large amount of irregular geometric modules and complicated functions, accomplishing all such geometric texture mapping will lead to dramatic increase of workload and decline of efficiency, so in the practical process of modeling, geometric structures are reasonably simplified to some extent without missing practical requirements.

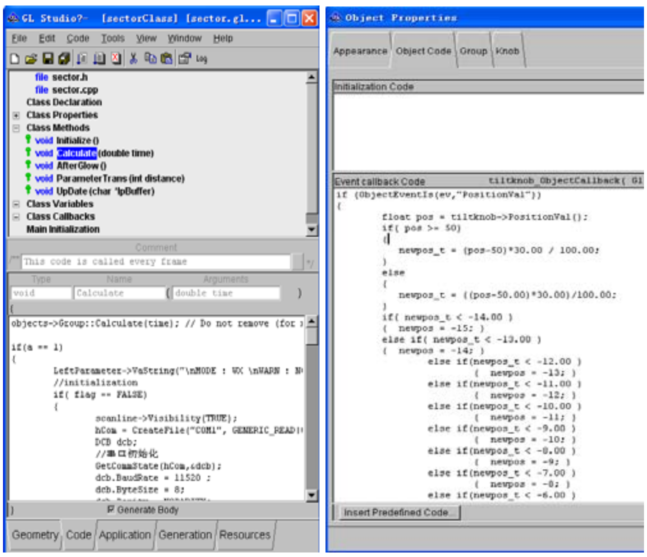
VC++ and GL Studio project can provide a user-friendly edit interface and a framework generation wizard. Intended visual ingredients are added to the main panel frame by means of independent component. Crucial footsteps are as following.

- **Components Design:** All needed interface contents, including text, graphics, bitmaps, and all the other display elements are presented in components. A certain type of component can be viewed as a class relating to a specific function, such as a designed button. Well designed components reflect the extent of multiplexing. It is convenient to call the class when the same function is required and thus can effectively avoid repetitive programming and reduce the workload.
- **Object Structure:** There is an automatically generated object tree in the graphic editor of GL Studio. The hierarchical structure and logical relationship among objects and sub-objects are intuitively shown in the tree structure . Once a component is added to the main frame, it is linked to the object tree together with its sub-components. By tree structure, geometric edition and programming get twice the result with half the effort.
- **Initial State and Default Value:** The final movement goes for module embellishment and initialization. Designed components are organized and arranged in the main panel. Default values are setted in correspondent components inducing to a system initial waiting state.

B. Functional Modeling

Functional modules shown in Fig .2 are established. GL Studio provides a comprehensive and flexible mechanism to realize complicated system functions. In the main process, each component serves as an independent thread accessible by an automatically generated Calculate() function. It is the main working cycle of the thread in which user defined functions can be called to achieve certain behaviors. Meanwhile, message response mechanism is available to instantly dispose user operations. User messages are captured and handled in correspondent callback functions. Making full use of the those mechanisms can reduce the modeling workload to a large extend. The core realization of system function is illustrated as following.

- **Data Exchange:** Receiving data package correctly and timely is fundamental for CDU functions. To serve that purpose and further enhance efficiency, dynamic display component is considered as a central message pump. Prime CDU data dispose is completed in this component. In the thread cycle, serial port is opened and setted in asynchronous form by which serial read and write event are registered. When the display data is successfully received, the process of package analysis, message delivery among other components is motivated and eventually results in a single scan radial update. It can be seen that the continuous data exchange process is the incentive source of dynamic display and is at the core of functional modeling.
- **Parameter Transmission:** Parameter transmission is mainly referred to two procedures, user input parameter reception and message exchange among components. A certain type of user operation will emit a relevant event message if it is registered in component callback function. The message will bring useful data such as current knob position, button state to the component processing thread. As described above, dynamic display component serves as the central processing unit, therefore parameters received in surrounding components after basic conversion and dispose are delivered to the central component by means of extern variables.
- **Dynamic Display:** Dynamic display includes real-time weather state display and parameter demonstration. The scan line rotates an antenna scan angel, and each scan radial consists of separated pixel object which can be filled with different RGB colors. The range bin data is picked out from the display data package and every 3 bits control the weather state of a pixel object. Current parameters are updated in the thread of independent text components. Thus the fluent real-time display performance is guaranteed.



(a) system function code (b) callback function code

Figure 3. Data exchange

Fig. 3 illustrates two instances of the functions mentioned above. User defined functions and the Calculate() function of a specific class is presented in the category of class method in the editor interface shown in Fig. 3(a). Callback function interfaces responding to user control are already prepared and listed in the objective properties tap. Fig. 3(b) shows the callback function example of the antenna tilt knob message. The integrated programming flow chart is shown in Fig. 4.

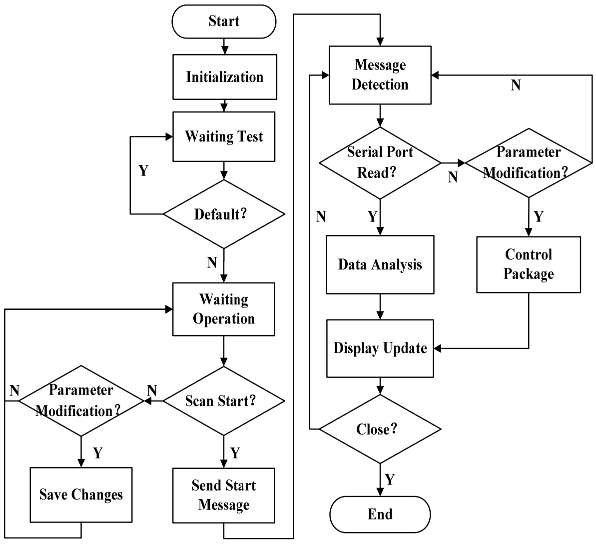


Figure 4. Overall program flow chart

To further increase programming and execution efficiency, modules are settled based on multiplexing. Fig. 5 demonstrates function multiplex among modules.

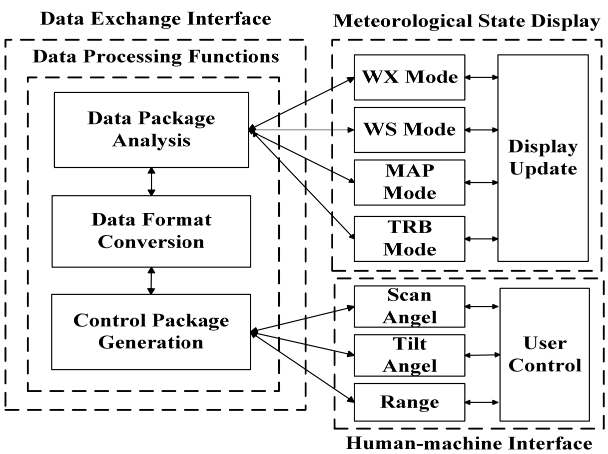


Figure 5. Function multiplexing

In Fig. 5, functions of data analysis and control package generation are repeatedly called in display module and control module respectively. Since ARINC principle sets unified regulations for different working modes and the display word structure is relatively fixed, data analysis function can be recalled in all four display modes. The same principle is adopted for control package forming. Because input parameters share the same coding scheme, they can be disposed calling the same package forming function. In addition, as data requires constant format conversion and exchange, frequently used format conversion functions are packed so that they can be easily called when needed.

V. Testing And Results

The effect of virtual airborne weather radar CDU is ideal and can achieve the desired objectives and multi-function requirements in accordance with practical principles. Simulation is processed due to the four major working modes and relevant parameter setting(Reference to Table 1 and Table 2). Main simulation results are demonstrated in following parts.

A. *Weather Detection(WX Mode)*

WX Mode is used for real-time precipitation rate surveillance. Fig. 6 shows the simulation result of a certain weather state display. It can be seen that the current measure range is 30km. The red part of colored region is the central of the heavy rainfall. The correctness and timeliness of weather target display is testified.

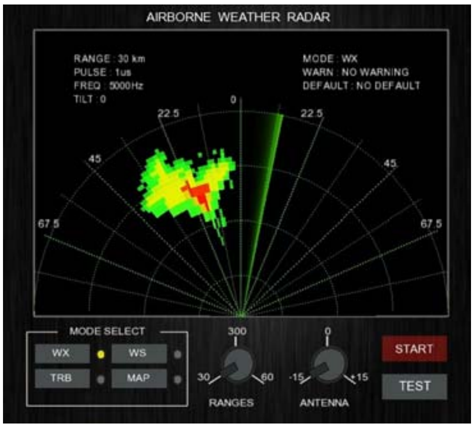


Figure 6. 30km WX display

Fig. 7 verifies the display effect after changing the range to 60km by rotating the knob.

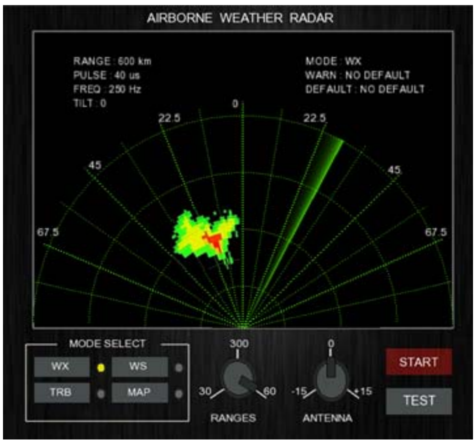


Figure 7. 60km WX display

The detection of weather state is correctly shown on screen in proportion to the selected range. The size of the target area is half of that shown in Fig. 6.

B. *Windshear Alert(WS Mode)*

WS Mode warns the crews with windshear warning alerts. Once the mode is selected, windshear state is informed in addition to fundamental weather detection(WX Mode). In obedience with ARINC principles, 3 levels of windshear warning alerts are setted and achieved. One typical example of the warning alter simulation is depicted in Fig. 8.

Figure 8. WS warning alert

C. *Turbulence Indication(TRB Mode)*

Like WS Mode, it is also based on the WX Mode information. TRB Mode demonstrates the potential turbulence spot under certain weather circumstances. The magenta region refers to the possible sever turbulence area and needs to be avoided when fighting. A display instant is shown in Fig. 9.

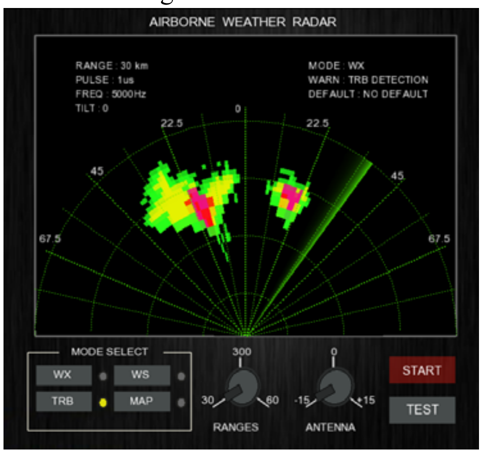


Figure 9. Turbulence indication

D. *Topography(MAP Mode)*

MAP Mode shows fight crews the physical feathers of the earth. Under this mode, colors represent different altitude levels of mountains and hills. The dynamic image can be smoothly and correctly displayed as the example shown in Fig. 10.

E. Additional Functions

Other system controls and display controls are also realized and tested. System self-test, taken as an example indicating certain system defaults, is tested as Fig. 11. Range and antenna tile change are also perfectly achieved. Hold function, which is of less importance, is realized by multiplexing start button.

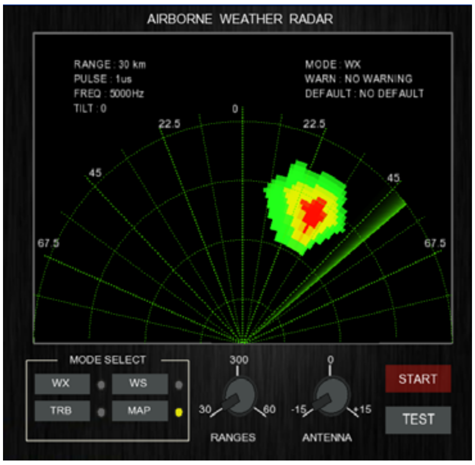


Figure 10. MAP mode instance

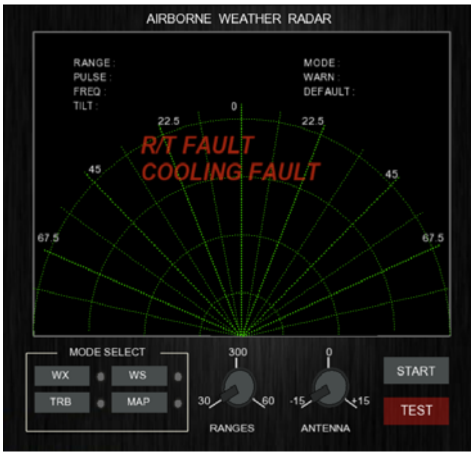


Figure 11. Self-testing fault indication

VI. Conclusions

The simulation system developed in this paper successfully achieves comprehensive and integrated functions of practical CDU in airborne weather radar. Four major working modes, WX, WS, TRB and MAP modes are operational, while many other functions are also realized, tested and integrated to the virtual unit. Intuitive and vivid fight guidance is provided to users. Based on GL studio and VC++, the system efficiency and transplantability are achieved taking advantage of multi-thread and function multiplexing. The simulation methods can further achieve better results when combining with 3D-vision and real input device.

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