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# APPLICATION OF DATA VISUALIZATION INTERACTION TECHNOLOGY IN AEROSPACE DATA PROCESSING

TIANFENG LI *

**Abstract.** In the aerospace sector, efficient data processing is critical to ensuring flight safety and improving operational efficiency. Firstly, an aircraft 3D modeling method based on OpenGL technology is introduced. This method realizes highly realistic aircraft models through accurate geometric rendering and material mapping. At the same time, the Bursa-Wolf method is used for coordinate transformation to ensure the accuracy and consistency of the model from different perspectives. Then, this paper discusses the application of visual interaction technology in aerospace data processing, especially in-flight data visualization systems. The simulation results show that the system can receive and process a lot of flight data in real-time and display the aircraft's attitude, trajectory, and critical parameters through an intuitive graphical interface so that pilots and ground controllers can make decisions quickly. This technology improves the efficiency of data processing and enhances the comprehensibility and usability of data. The stability and reliability of the technology in complex environments are verified by simulating actual flight scenarios.

**Key words:** Aircraft 3D model modeling method; Visual interaction technology; Space data; Flight data visualization system; OpenGL technology; Bursa-Wolf method

**1. Introduction.** Data processing is increasingly required in the aerospace sector to ensure flight safety, improve operational efficiency, and advance scientific innovation. Data visualization interaction technology is crucial as a bridge between raw data and human cognition. Regarding aircraft 3D model modeling methods, early studies mainly rely on manual modeling and simple geometric transformation. Although this method can meet the needs of static display to a certain extent, it is challenging to deal with complex dynamic flight data. With the development of computer graphics, OpenGL technology has gradually become the mainstream tool for aircraft 3D modeling. Literature [1] proposes an aircraft 3D modeling method based on OpenGL, which realizes a highly realistic aircraft model through fine geometric rendering and material mapping and solves the shortcomings of traditional modeling methods in detail presentation and dynamic display. Regarding visual interaction technology, traditional data processing methods are often limited to two-dimensional planes, and it is difficult to show complex spatial relationships and dynamic changes intuitively. Literature [2] applies visual interaction technology to space data processing, realizing real-time tracking and analysis of complex spacecraft motion trajectories and providing powerful decision support for ground controllers.

Regarding flight data visualization systems, a sound system needs to process large amounts of real-time data and be able to present this data intuitively and understandably. The researchers developed flight data visualization systems. For example, the system designed in the literature [3] can receive and process data from aircraft sensors in real-time and display the aircraft's attitude, trajectory, and critical parameters through an intuitive graphical interface. These systems increase data processing automation and reduce the risk of human error. Reference [4] describes in detail the application of the Bursa-Wolf method in aircraft 3D model modeling, which ensures the accuracy and consistency of the model under different perspectives through accurate coordinate conversion. The application of this method makes the establishment of the aircraft model more accurate and provides a solid foundation for the subsequent visual interaction.

Data visualization and interaction technology have broad application prospects and essential practical value in aerospace data processing. This paper will start with the three-dimensional modeling method of aircraft, introduce the application of visual interaction technology in-flight data visualization systems in detail, and discuss its potential to improve data processing efficiency, ensure flight safety and promote scientific research

*NanYang Institute of Technology, Nanyang, Henan, 473004, China (Corresponding author, longyust_001@163.com)

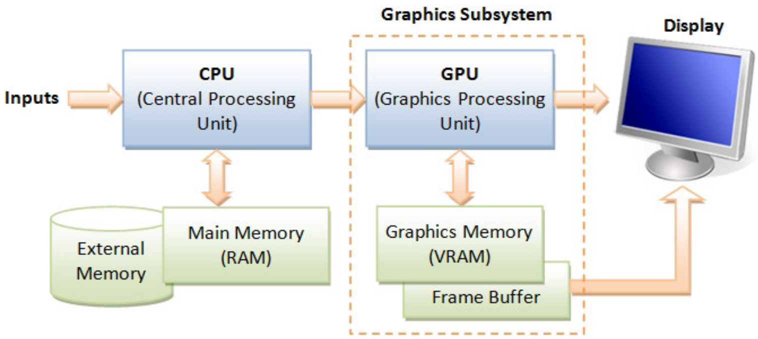


Fig. 2.1: How OpenGL works in a Windows environment.

and innovation [5]. Through system simulation and actual case analysis, this paper will verify the feasibility and superiority of the proposed technology and provide helpful references for future research and practice.

**2. Open graphics library architecture for Windows.** OpenGL, an open-source 3D drawing tool, can work closely with Visual C++. In this way, the related and drawing operations are completed, ensuring the method's effectiveness and reliability [6]. OpenGL adopts a client /Server approach to implement, which provides a good solution for OpenGL. OpenGL's graphics library is wrapped in OpenGL 32.DLL. When used by the client, all OpenGL functions are processed by OPENGL32.DLL and then sent to the server. The OpenGL instructions are reprocessed and sent directly to the Win32 device driver interface to send the finished image instructions to the image display driver. This process is shown in Figure 2.1.

**3. The architecture development of OpenGL based on MFC.**

**3.1. OpenGL implementation method on MFC.** OpenGL does not support Windows management, performed on a platform-specific system. It is necessary first to connect Windows Visual with OpenGL to realize 3D visual design based on OpenGL language. The 3D image is rendered and processed by OpenGL language [7]. It is necessary to build a simulated aircraft model and then bundle it with a modeled dialog box to realize OpenGL graphics in the MFC environment. OpenGL allows 3D images to be drawn by ”rendering context.”

**3.2. Dual Buffer technology.** The simulation window is constantly updated and rendered to generate an animation. By default, the image will flash. There are two reasons for the flash: one is the background elimination, and the other is the rendering time is too long. The dual cache mechanism is used in OpenGL. Partition the two frame caches. When a 3D surface appears consecutively, the data in one of the frame caches is surface-rendered. In the other frame, the cache is used for image processing [8]. When a video in the background cache needs to be displayed, OpenGL copies it to the front-end cache. The cache continuously reads the information in the cache and outputs it to the screen. Due to dual caching technology, each 3D surface does not appear after the end of rendering, so the viewer can directly view each 3D image.

**4. Three-dimensional modeling of aircraft model..** The 3D modeling of aircraft is an integral part of its visualization process. The structure, materials, positioning and other information of the vehicle are contained in it. Due to OpenGL's lack of advanced 3D modeling instructions, it is challenging to generate a complex aircraft model [9] programmatically. The aircraft was modeled with high precision by 3D modeling software and read by OpenGL. Because of the different 3D modeling documents, their data can be read differently. This makes it more difficult for developers. Therefore, this paper proposes an easy-to-read intermediate format document to realize the conversion between various 3D modeling documents. When modeling OpenGL, the MilkShape3D format was selected. The complexity of modeling and the need for computer hardware should be reduced as much as possible to improve the fluency of rendering. The workflow of actual 3D model construction is shown in Figure 4.1.

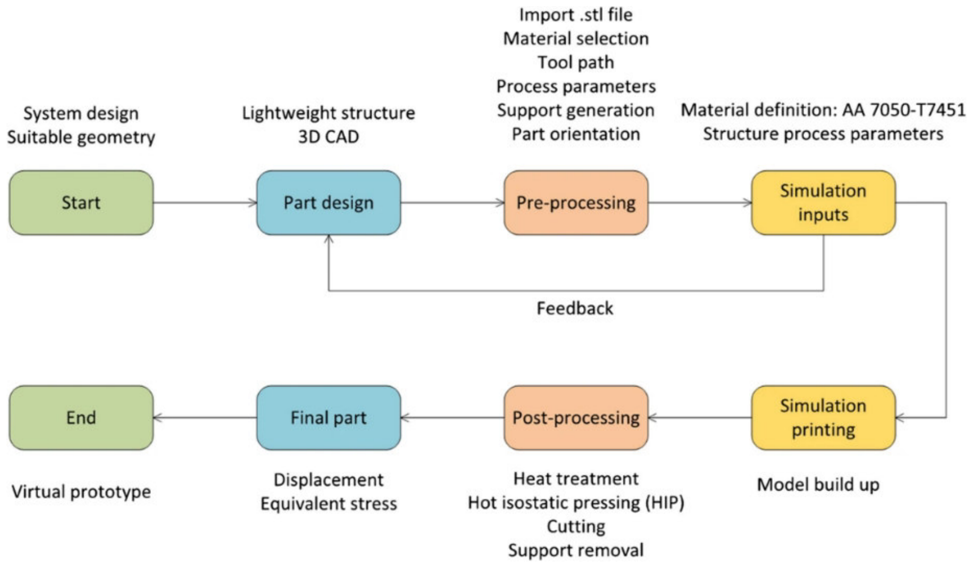


Fig. 4.1: Aircraft 3D model making process.

**4.1. Virtual environment rendering.** The visualization of "flight history" mainly consists of the following aspects: the appearance and texture of the aircraft as an external document. The aircraft model file is automatically matched according to the aircraft type information in the flight measurement data attribute. For example, if there is A "Test Object Name= A" in the aircraft measurement data description file, the AMS3D mode will be automatically found and loaded when the data is replayed. The milk shape Model was used to encapsulate the 3D modeling of the aircraft. Milk shape Model: Model Data () can load the aircraft model from the MS3D file and then convert it into a point, polygon, and material list. Draw () renders the aircraft. Since flight trajectory data display technology focuses on the realistic restoration of aircraft attitude, maneuvering and other motions, the simulation degree of the ground environment is low, so it is transformed into ground texture mapping [10]. The results were excellent based on the spherical dome's diameter, textured with a perfect picture of the clouds. The new wing target model generates a column of smoke of arbitrary length, which is used to identify the target's trajectory.

**4.2. Visualization of flight data based on measured data.** This project uses aircraft attitude simulation as the primary research method to study the relationship between aircraft attitudes. Because some models do not have autonomous navigation and positioning equipment, they must be determined by comprehensive calculation of various parameters in the movement process [11]. The trajectory is solved by integrating the measured aircraft altitude, velocity, Angle of attack, pitch Angle, pitch Angle and yaw Angle. The visualization software of the flight process is designed, and the real-time playback of aircraft measurement parameters is realized. The Flight simulation view starts timing, generating a user zone failure message at a rate of 30 times/second to trigger an upgrade simulation view. The simulation window and the time domain curve frame are loosely coupled by an information-driven method to realize simple and independent programming logic. This project proposes a method based on Windows message queue accumulation information to realize non-synchronous flight data updates. To solve the problem of system response stagnation caused by redrawing due to carrier attitude change [12]. The aircraft trajectory information display system restores the aircraft attitude and the display screen of the aircraft instrument. The tracking view is also known as the wingman view, that is, the tracking view of the posture of the aircraft from the outside of the aircraft. In the process of observation, the moving center of gravity of the aircraft is taken as the starting point of its relative coordinate system, and it is fixed with the relative position of the aircraft [13]. The viewing Angle is always consistent with the vehicle's center of gravity. Its Angle to the X and Z axes and distance to the starting point. Using ordinary input and output devices, the user can adjust the position of the observation point at any Angle to realize the attitude observation of the aircraft.

**5. Six degrees of freedom simulation of aircraft..** The aircraft's motion in the three-dimensional space is a complex action with many degrees of freedom, and its operating state can be obtained through the actual measurement of the aircraft [14]. Data include GPS longitude, latitude, altitude, flight speed, pitch Angle, yaw Angle, etc. In the visual display of the aircraft, it is necessary to consider the change of six parameters, such as the orientation of the center of gravity of the aircraft $(x, y, z)$ and, the pitch angle of the aircraft and the yaw Angle. Here, the yaw Angle $\psi$ is the tilt Angle of the vertical axis of the aircraft in the horizontal plane and the predetermined course, the pitch Angle $\gamma$ is the Angle from the fuselage coordinate system $x$ to the horizontal plane, and the yaw Angle $\theta$ is the Angle from the fuselage coordinate system $y$ to the vertical surface passing through the $z$ axis.

The 6-dimensional pose change, yaw Angle $\psi$, pitch Angle $\gamma$ and roll Angle $\theta$ of the aircraft can be obtained using the rotation and shift transformation of the solid geometric coordinate system [15]. The goal of the shift transformation in this process is to convert the starting point of the local coordinate system to $(x, y, z)$. That is, without changing the orientation and dimensions of the defined object, the components of each vertex coordinate system in the scene are represented as $x, y$ and $z.\lambda(x, y, z, 1)$ is the uniform coordinate of any point in space, and $S_x, S_y, S_z$ is the amount that moves along the $x, y$, and $z$ axes. The change matrix for this operation is as follows:

$$\lambda'\left(x', y', z', 1\right) = \lambda(x, y, z, 1) \cdot \begin{bmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & y \\ 0 & 0 & 1 & z \\ S_x & S_y & S_z & 1 \end{bmatrix} = R\left(S_x, S_y, S_z\right) \tag{5.1}$$

The three-dimensional rotation transformation is the object's rotation around its axis, and the right-hand rule determines its rotation direction. After rotation, the size and shape of the object itself does not change, but changes its position [16]. If $\lambda(x, y, z, 1)$ is the uniform coordinate of any point in space and $\beta$ is the Angle of rotation around the $x, y$, and $z$ axes, then the equation for rotation around the $x$, $y$, and $z$ axes is:

$$\lambda'\left(x', y', z', 1\right) = \lambda(x, y, z, 1) \cdot \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\beta & \sin\beta & 0 \\ 0 & -\sin\beta & -\cos\beta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = Q_{x(A)} \tag{5.2}$$

$$\lambda'\left(x', y', z', 1\right) = \lambda(x, y, z, 1) \cdot \begin{bmatrix} \cos\beta & \sin\beta & 0 & 0 \\ -\sin\beta & \cos\beta & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = Q_{z(A)} \tag{5.3}$$

$$\lambda'\left(x', y', z', 1\right) = \lambda(x, y, z, 1) \cdot \begin{bmatrix} -\cos\beta & 0 & -\sin\beta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\beta & 0 & \cos\beta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = Q_{r(F)} \tag{5.4}$$

KML uses WGS-84 as the benchmark. The $Z$-axis is the conventional polar CTP direction specified by BIH1984.o. The X -axis is the zero-meridian plane of BIH1984.o intersecting the CTP equator. The $\mathrm{Y}, \mathrm{Z}$ and X axes form a right-handed coordinate system [17]. The actual flight track data adopts the national coordinate system of the NMEA-o183 standard. This article will use the Bursha-Wolf transformation method, which includes 7 parameters:

$$\begin{bmatrix} X_\mu \\ Y_\mu \\ Z_\mu \end{bmatrix} = \begin{bmatrix} 1 & \zeta_Z & -\zeta_Y \\ -\zeta_Z & 1 & \zeta_X \\ -\zeta_Y & -\zeta_X & 1 \end{bmatrix} \begin{bmatrix} X_L \\ Y_L \\ Z_L \end{bmatrix} + (1+\varphi) \times \begin{bmatrix} X_L \\ Y_L \\ Z_L \end{bmatrix} + \begin{bmatrix} \Delta X_0 \\ \Delta Y_0 \\ \Delta Z_0 \end{bmatrix} \tag{5.5}$$

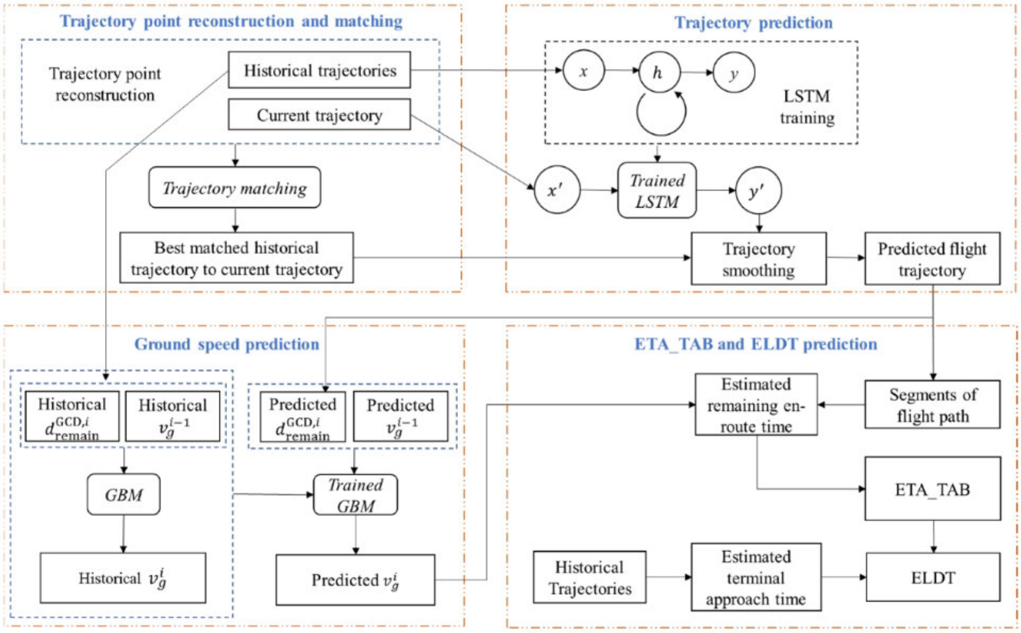


Fig. 5.1: Flight trajectory data preprocessing process.

$\Delta X_0, \Delta Y_0, \Delta Z_0$ represents the translational coefficient, $\zeta_X, \zeta_Y, \zeta_Z$ represents the rotational coefficient, and $\varphi$ represents the proportional coefficient. The formula (5.5) can be further transformed into

$$\begin{bmatrix} X_\mu \\ Y_\mu \\ Z_\mu \end{bmatrix} = \begin{bmatrix} X_L \\ Y_L \\ Z_L \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 & 0 & -Z_L & Y_L & X_L \\ 0 & 1 & 0 & Z_L & 0 & -X_L & Y_L \\ 0 & 0 & 1 & -Y_L & X_L & 0 & Z_L \end{bmatrix} \begin{bmatrix} \Delta X_0 \\ \Delta Y_0 \\ \Delta Z_0 \\ \zeta_X \\ \zeta_Y \\ \zeta_Z \\ \varphi \end{bmatrix} \tag{5.6}$$

Seven parameter values are obtained by using more than 3 known points. Bursa-Wolf equation is used to calculate the position of the point to be measured, and then the coordinates meeting the requirements of KML specification are calculated according to the coordinates of each point to be measured. A trajectory data processing component based on KML is proposed [18]. This project intends to take the observation data of the NMEA-0183 satellite as the research object, use the Bursa-Wolf algorithm to carry out spatial transformation and achieve high-precision transformation from space to KML. This project intends to analyze the space orbit data obtained from the aerial survey in depth. With the expression of high-definition images, such as Google Earth, it is applied to the aerospace field [19]. Visualizing massive abstract data in aerospace lays a solid theoretical and practical foundation for research and application in related fields. The overall preprocessing process of flight trajectory data is shown in Figure 5.1 (the picture is quoted in Aerospace 2023, 10(8), 675).

**6. Implementation and verification of the system.** This paper presents a visualization method of aircraft attitude simulation based on OpenGL and transforms it into KML format. It takes full advantage of Google Earth's high-resolution images to visualize them in 3D. Finally, each function module is embedded in the measurement data management platform system. They use a unified standard system, database structure, data storage and transmission structure to build the measurement data storage, management, query, and later data processing. The software uses B/S and C/S combined architecture to establish an efficient data storage

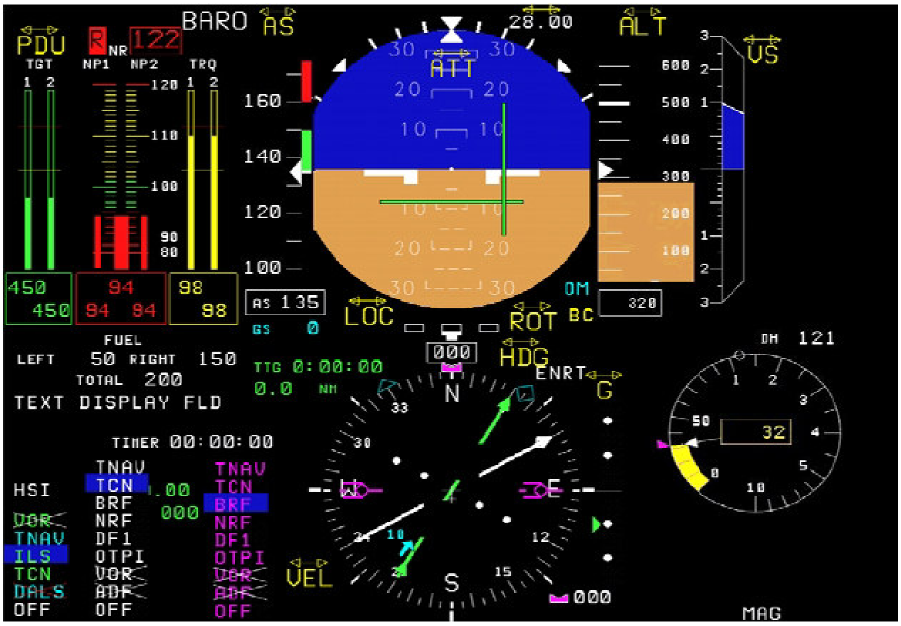


Fig. 6.1: *Visual display of single take-off and landing flight.*

system. At the same time, the 3D visualization and interactive processing of measured data are realized by using the display based on C/S structure. The results are shown in Figure 6.1.

**7. Conclusion.** This paper profoundly studies the application of data visualization and interaction technology in aerospace data processing, focusing on aircraft 3D model modeling methods, visual interaction technology, flight data visualization systems, and related OpenGL technology and the Bursa-Wolf method. The highly realistic aircraft model display is realized through the fine modeling of the aircraft 3D model, combined with OpenGL technology. At the same time, the Bursa-Wolf method is used for accurate coordinate transformation to ensure the consistency and accuracy of the model from different perspectives. The flight data visualization system designed in this paper can receive and process a large amount of flight data in real time and display aircraft attitude, trajectory, and critical parameters through an intuitive graphical interface, significantly improving the efficiency and accuracy of data processing. The simulation results show that the technology can quickly respond to the changes in flight data and effectively assist pilots and ground controllers in making decisions. However, although the existing technology has made significant progress, there are still some challenges and limitations. For example, how to further improve the real-time and interactivity of data visualization to support the dynamic decision-making process better is still a problem worthy of in-depth study. In addition, with the advent of the significant data era, how to effectively process and analyze larger data sets is also an important direction for future research. In future work, this paper looks forward to further optimizing the performance and functionality of data visualization interaction technology by introducing more advanced algorithms and technologies. At the same time, this paper also hopes to better integrate data visualization interaction technology into all aspects of aerospace data processing through interdisciplinary cooperation and research, thereby promoting the development and progress of the entire field. Although the current research has achieved specific results, the application of data visualization interaction technology in aerospace data processing will have more excellent development space and broader application prospects in the future.

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