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Object-oriented landing gear model in a PC-based flight simulator

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ABSTRACT

Training pilots the skill of maneuvering an aircraft on ground is important for flight safety. This demands a detailed landing gear model running in real-time. We developed the model and verified its validity by contrast with flight test data. It is accurate sufficiently and very suitable for real-time flight simulation to represent complex ground reaction behavior under various conditions and occasions. Based on this model, we realized a landing gear class in a unified flight simulation framework written in C++ and successfully applied the whole simulation codes through S-function in a PC-based experimental flight simulator. Because of the unique features of object-oriented design principles, the software framework presented here is structural, transplantable and convenient to maintain. The constitution and the quality of the simulator reveal that it would have cause to decrease the cost for developing a flight simulator with higher fidelity in future.

1. Introduction

One of the most basic skills of a pilot is the ability to manipulate an airplane landing safely. Landing is the most dangerous phase in a whole flight profile. Numerous accidents occurred while landing [1]. Pilots often exercise landing skills on flight simulators. But landing gear models in typical flight training simulators are usually simple, for a detailed model is challenging to programming technology and computer power in real-time simulation environment. Although a paper [2] and two review papers [3,4] mentioned various studies on landing gear for system analysis and design purpose, these models are difficult for use in flight simulator for their complexity. Even so, it is still difficult for them to simulate landing gear shimmy and brake-induced vibration which can lead to accidents [4]. While models in [5–7] are easy for use in real-time computing, they perform inadequate on ground handling characteristics. Just model is not enough, real-time simulation needs an elaborated design for programming. Though the software framework and realization method for complex landing gear system's real-time simulation are usually more useful to engineers, only a few publications can be found in the open literatures for this purpose. Very few references covered modeling method and software realization method for flight simulator which carries out pilots training for ground handling studies with sufficient details under complex conditions such as malfunctions and various runway surfaces.

Software design needs theory and principle as guidance. Since the first commercial real-time digital computer, Link Mark I computer, was successfully used for flight simulator, software engineers have begun to practice unstructured programming technique and use low level languages for developing simulation software. They often avoided powerful, modern operating systems so that the code would be "closer" to the machine, though this usually made the program difficult on readability and maintenance. With the advent of more and more complex modern aircrafts, the simulation codes are becoming more and more gigantic. One of the most famous companies which provides simulation technologies, CAE, has a product line of

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commercial aircraft flight simulators, for which over 400 engineers develop the simulation codes [8]. It would be time consuming if the unstructured programming technique continues to be used.

There are two flight dynamic model frameworks, JSBSim [9] and LaSRS++ [10], which are popular in engineering field [11,12]. Although the landing gear models [13,14] integrated with them are too simple to be used for pilots training, the whole frameworks of them are all based on object-oriented principles, so they can afford good references for simulation software development.

We have implemented a flight simulator based on PC. Landing gear model was a sub-model of the simulator. We needed it to present landing gear behavior in real-time as accurate as possible, for the simulator was a platform for study. The main objective of the project is to find a low-cost alternative to human in the loop flight simulation while still aiming for a competitive high level of quality. To achieve this goal, we selected some non-flight-certified commercial-off-the-shelf (COTS) components and software development tools such as MathWorks MATLAB, Microsoft Visual Studio.Net, VPI VAPS, MultiGen Vega & Creator, Opal-RT RT-LAB and so on. But how to organize these tools and take advantage of each of them to achieve the goal are important in our work, because the flight simulation program is rather complex for it contains numerous logical calculus and tremendous computation operations. If this simulation application was developed by Simulink alone, the diagram of the Simulink model would be desultory even if the complex logic was expressed all by Stateflow. However, the C++ programming language is ideal for use in flight simulation software in part because of its support of the primary object-oriented concepts: polymorphism, inheritance, encapsulation, and abstraction [15,16]. But if the whole real-time flight simulation program was developed in C++, it would be a huge project and not easy to implement, for it needed to customize and optimize platform specific code to the machine which the real-time application would run on, so that techniques of "control-loading" and "real-time executives" must be taken into account during the code development process. The best solution is to combine each advantage of these two modeling language through S-function, which can be written in C++ and dynamically linked to MATLAB when needed. Then the Real-Time Workshop can compile the Simulink model to real-time application. This could make us concentrate on the algorithms of flight simulation.

In this paper, a sufficiently detailed model of aircraft-runway dynamics suitable for engineering simulation in real-time environment is developed. And then, we present the framework of flight simulation based on object-oriented principles, which is epitomized by landing gear class and provides a generic accessible way to simulate other types of aircraft. Finally, the simulation results versus flight test data are presented and the observed efficacy of the model which has been incorporated into the simulator is verified.

2. Landing gear model

The landing gear is assumed to be a shock strut mounted perpendicularly to the airframe with two tires as in Fig. 1.

The first step in modeling a landing gear system is to define coordinate systems (CS). The five coordinate systems are runway coordinates FR_r, aircraft body coordinates FR_b, strut coordinates FR_s, gear coordinates FR_g, and tire coordinates FR_t. The runway coordinate system is defined with origin at the intersection of the threshold and the centerline of the current reference runway. The x-axis points along the runway and the y-axis points out to the right. The z-axis is perpendicular to the runway plane and points down. Runway coordinates in landing gear model are defined by navigation database. Its origin is indicated by latitude and longitude, and its orientation is relative to the local north, east and down (NED) coordinates. Runway can slope with respect to horizontal plane as in Fig. 1. Though the slope does not affect the structure of aircraft-runway dynamic model if the attitude of airplane is depicted relative to runway frame, it is mentioned here for we may use different runways even flight deck of carriers in flight simulation, when it is necessary to distinguish orientation of runways. Different

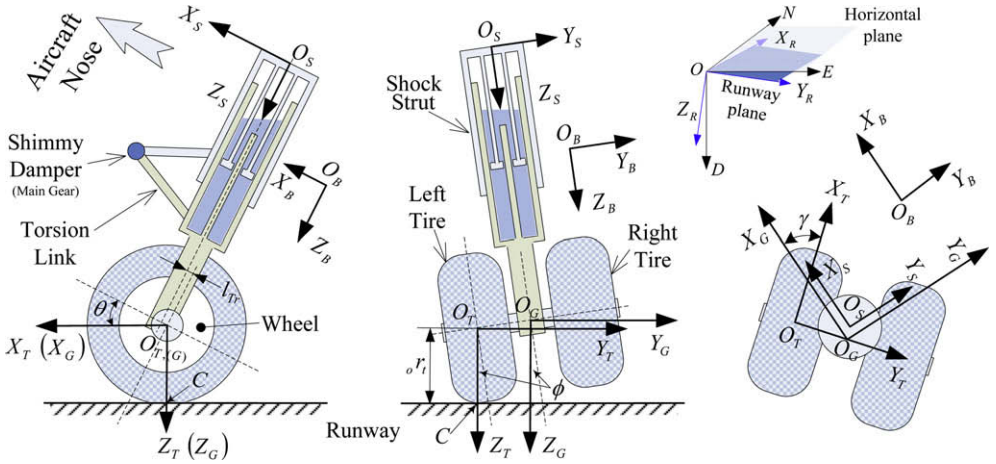

Fig. 1. Coordinate systems used in landing gear model development.