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Virtual Simulation Experiment System for Spacecraft Orbital Principle and Its Teaching Application

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Abstract Generally, space is far away from people's daily life. The motion characteristics of objects in space are very different from those of ground objects, which is easy to cause difficulties in understanding. In order to make everyone have an intuitive understanding of the basic principles of spacecraft orbital motion and the space targets distribution, a virtual simulation experiment system for spacecraft orbital principles was designed and developed. The system mainly includes two modules: space situation analysis module and spacecraft orbital principle module. Specifically, the space situation analysis module is supported by the space target database and can be used to perform classified query and multi-dimensional display and analysis of on-orbit space targets such as satellites and space debris. The spacecraft orbital principle module provides an intuitive and dynamic analysis of the satellite orbital operation principle and typical orbital characteristics under the influence of perturbations. To facilitate the application in teaching, the experimental system also comprehensively considers the students' attention to the space situation, and the difficulty of teaching the spacecraft orbital principle, etc. There are also a number of typical teaching cases in the system, through which students can cultivate interest, understand knowledge, train skills and quickly form the ability to use knowledge.

Keywords Virtual simulation · Experiment system · Spacecraft orbital principle

1 Introduction

With the development of human space activities, space has become more and more closely related to our lives. For example, we acquire the topography of the Earth through remote sensing satellites, live television broadcasts via communication satellites, and provide ground navigation services through navigation satellites.

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Many people have been curious about space. What artificial objects are in space? How is the satellite in space flying around the earth? Will the satellite fall to the ground? These questions are both the puzzle of most ordinary people and the initial confusion of those who are preparing to enter the aerospace field for study and work. To answer these questions, it is not enough to explain by theory and principle alone. It is necessary to use certain experimental means to make these abstract knowledge more clearly. However, due to the high cost of space activities and the complexity of the space environment, it is almost impossible to use spacecraft objects or models in classroom teaching to simulate the orbital motion of spacecraft in the real space environment. Therefore, for the experimental needs of aerospace courses, simulation experiments can be said to be the only effective way [1]. With the development of information technology, the application of virtual simulation experiment in teaching is more and more extensive [2]∼[4]. Satellite Tool Kit (or Systems Tool Kit), often referred to by its initials STK, is a physics-based software package from Analytical Graphics Inc. that allows engineers and scientists to perform complex analyses of space situation. With STK, users can customize spacecraft and ground system parameters, including curve tables, 2D and 3D, to support the entire process of aerospace missions. Unfortunately, the operation of the software is slightly complicated, and it requires a certain amount of training to be proficient in operation. Thus, it is not suitable for students who have no aerospace background to understand the operation principle of space and spacecraft.

In response to the above problems, a vivid and easy-to-use virtual simulation experiment teaching aid platform was designed and developed. The developed system consists of two modules, space situation analysis module and spacecraft orbital principle module. By using the system, students first understand the space targets and their distribution characteristics in space, and then learn more about the motion characteristics of these space targets and the differences in the application of various types of orbits.

The rest of the paper is organized as follows. In Section II, we describe the virtual simulation experiment system, including the composition of the system and the functions of each part. Section III introduces the experimental teaching process, which is combined with classroom centralized teaching and independent appointment experiments. Summary and future expansion of the virtual simulation experiment system are made in Section IV.

2 Virtual simulation experiment system

The developed virtual simulation experiment system mainly includes two modules: space situation analysis module and spacecraft orbital principle module. Specifically, the space situation analysis module is supported by the space objects database and can be used to show what is included in the space. The spacecraft orbital principle module provides an intuitive and dynamic analysis of the satellite orbital operation principle and typical orbital characteristics under the influence of perturbations.

Just like the STK software, the more powerful the software is, the more difficult it is to learn and operate, thus it is not easy to use in teaching. We comprehensively consider students' concerns and points of interest in space situation, difficult

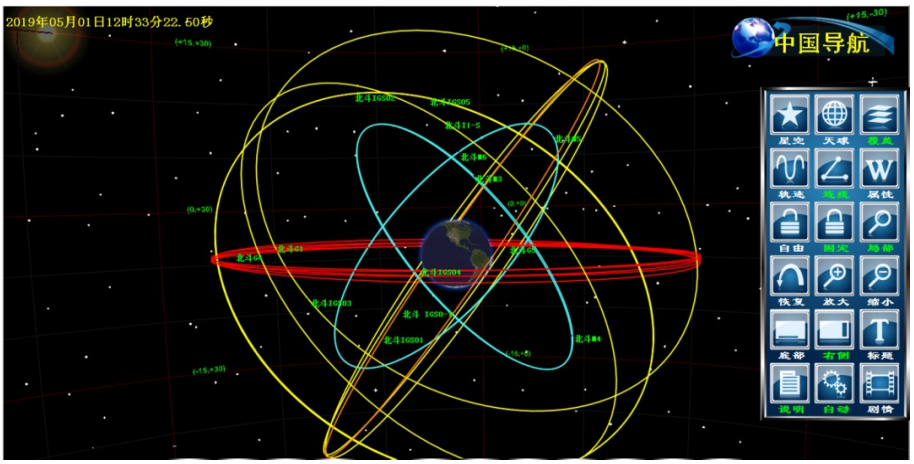

Fig. 1 Space situation analysis module

teaching points in spacecraft mission planning, etc., sort out typical teaching cases, and pre-set several experimental projects in system design. The combination of the project and the typical teaching case enables students to get started quickly in the experiment, open a typical project with simple operation, and learn and understand knowledge in case study. Moreover, for students who have strong learning ability and want to know more about the knowledge, the system reserves the function of self-selection, and students can design experimental projects to expand their learning according to their needs.

2.1 **Space situation analysis module**

With the support of the space objects database and visualization technology, the space situation analysis module can be used to perform classified query and multi-dimensional display and analysis of on-orbit space objects such as satellites and space debris. Based on the space situation analysis module, the three types of experiments, including the overall situation analysis of space objects, the typical satellite constellation operation situation analysis and the satellite constellation design and analysis can be carried out.

Overall situation analysis of space objects

Students can view the distribution and operation status of space objects of global, the United States, Russia, and China through experimental case selection.

Typical satellite constellation operation situation analysis

Through the experimental case selection, students can view the distribution and operation status of China Beidou satellites, US Global Position System, China communication satellites, and US Iridium satellite constellation, and master the characteristics of typical satellite constellations.

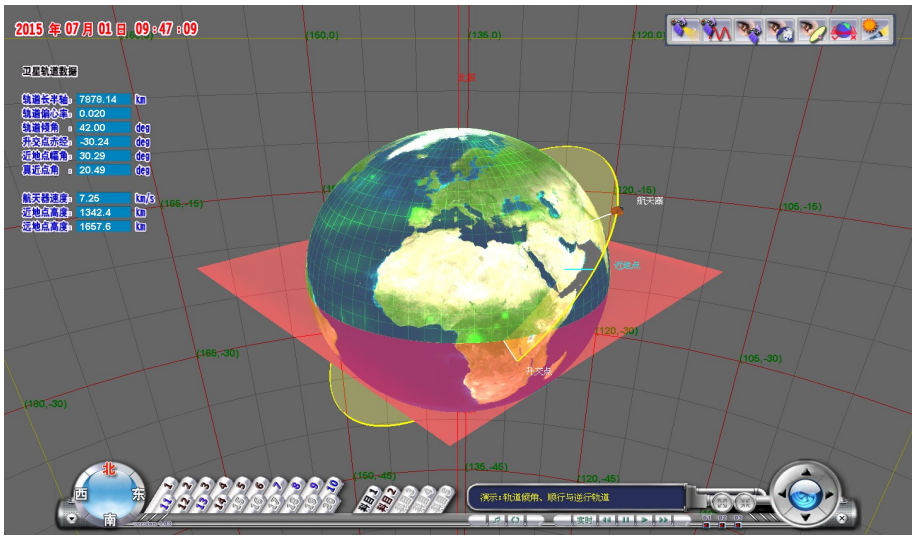

Fig. 2 Space orbital principle module

Satellite constellation design and analysis

Students can independently design the satellite constellation through parameter configuration, and analyze the characteristics of the satellite constellation.

2.2 **Space orbital principle module**

In this module, intuitive dynamic analysis of satellite orbital principles and typical orbital characteristics is carried out in the form of cross-display of multi-dimensional views to help students understand the basic principles of spacecraft motion.

Based on the spacecraft orbit principle simulation module, three types of experiments, including the orbital elements analysis, the track of subsatellite point analysis and the satellite on-orbit acceleration and deceleration principle analysis are carried out.

Orbital elements analysis

By adjusting the orbital elements such as the semi-major axis of the orbit, the eccentricity, the inclination, the longitude of the ascending node, and the argument of periapsis, students observe and analyze the shape and characteristics of satellite orbits, the changes of orbital positions, and understand the difficulties such as orbital precession.

Track of sub-satellite point analysis

By adjusting the orbital elements, students analyze the trajectory changes of subsatellite points and the shape characteristics of the track of subsatellite point for several typical orbits.

Satellite on-orbit acceleration and deceleration principle analysis

Students provide a momentary speed increment (forward or reverse) to the satellite at the current moment through parameter setting, analyze the changes of the satellite's orbit, and consider further research on how to improve satellite orbits and how to make satellites fall back into the Earth's atmosphere.

3 Experimental teaching process

The experimental teaching of the project is combined with classroom centralized teaching and independent appointment experiments. The classroom centralized teaching is carried out in the student computer room in a unified manner, and the experimental instructor guides the students in the classroom. The independent appointment experiments can be completed by logging into the experimental teaching management platform via the Internet.

In the classroom centralized teaching, the teaching is implemented in the way of principle explanation and offline design, practical operation and program verification, review and summary, and knowledge promotion. Before the experiment, the teacher briefly reviewed the relevant knowledge and principles of the experiment, and explained the teaching objectives of the experiment, the main functions of the experimental software, the experimental operation methods and precautions, etc. The students conduct experiments such as satellite constellation and spacecraft orbital parameters design according to the purpose of the experiment. Then, the students complete the experimental tasks and record the experimental results by setting different experimental parameters. The instructor will master the experimental design and implement the necessary guidance. After the experiment, the students summarize the experimental results, self-assess whether the experimental design content is completed, whether the experimental purpose requirements are met, and write the experimental report. Based on the student's classroom performance and experimental report, the teacher summarizes whether or not to achieve the teaching objectives and gives corresponding student experimental grade or experimental improvement suggestions.

In the independent appointment experiments, students can log into the experimental teaching management platform through the Internet according to the requirements of the task and the need for self-learning, and the experiment projects can be completed in sequence according to the experimental operation steps in help document. In the experimental operation, students conduct experiments and record the results by setting different experimental parameters and interactive operations. After the experiment, the students summarize the experimental results and write the experimental reports. The teacher evaluates whether the teaching goal is achieved according to the experimental reports, and gives the corresponding experimental grade or experimental improvement suggestions.

4 Summary

The motion characteristics of objects in space are quite different from those of ground objects, and it is difficult to conduct physical operation experiments. The

developed project makes full use of teaching aid software tools to combine knowledge learning with experimental design and operation, to integrate learning and practicing, to deepen students' understanding of the spacecraft orbit principle, and to improve the application of relevant knowledge. The virtual experiment system can not only visualize the complex space motion characteristics of spacecraft, but also stimulate student's learning and exploration interest through their interactive participation. The networked virtual simulation experiment project breaks the space and time limit of traditional teaching. Students can flexibly arrange their own experimental time through the network platform, and can also flexibly select experimental projects according to their own professions and interests, thus effectively expanding the time and space of traditional teaching.

The current experimental system is still focused on the principle cognitive experiment, and the subsequent comprehensive experimental content can be added on this basis. It is anticipated that the future system will include a number of experiments, such as the coverage of the ground targets, the revisiting cycle, the ground stations, and the space and ground coordination system, etc.

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